Features

- High-performance, Low-power AVR® 8-bit Microcontroller
- Advanced RISC Architecture
  - 131 Powerful Instructions – Most Single-clock Cycle Execution
  - 32 x 8 General Purpose Working Registers
  - Fully Static Operation
  - Up to 16 MIPS Throughput at 16 MHz
  - On-chip 2-cycle Multiplier
- Non-volatile Program and Data Memories
  - 16K Bytes of In-System Self-programmable Flash
    Endurance: 10,000 Write/Erase Cycles
  - Optional Boot Code Section with Independent Lock Bits
    In-System Programming by On-chip Boot Program
    True Read-While-Write Operation
  - 512 Bytes EEPROM
    Endurance: 100,000 Write/Erase Cycles
  - 1K Bytes Internal SRAM
  - Up to 64K Bytes Optional External Memory Space
  - Programming Lock for Software Security
- JTAG (IEEE std. 1149.1 Compliant) Interface
  - Boundary-scan Capabilities According to the JTAG Standard
  - Extensive On-chip Debug Support
  - Programming of Flash, EEPROM, Fuses, and Lock Bits through the JTAG Interface
- Peripheral Features
  - Two 8-bit Timer/Counters with Separate Prescalers and Compare Modes
  - Two 16-bit Timer/Counters with Separate Prescalers, Compare Modes, and Capture Modes
  - Real Time Counter with Separate Oscillator
  - Six PWM Channels
  - Dual Programmable Serial USARTs
  - Master/Slave SPI Serial Interface
  - Programmable Watchdog Timer with Separate On-chip Oscillator
  - On-chip Analog Comparator
- Special Microcontroller Features
  - Power-on Reset and Programmable Brown-out Detection
  - Internal Calibrated RC Oscillator
  - External and Internal Interrupt Sources
  - Five Sleep Modes: Idle, Power-save, Power-down, Standby, and Extended Standby
- I/O and Packages
  - 35 Programmable I/O Lines
  - 40-pin PDIP, 44-lead TQFP, and 44-pad MLF
- Operating Voltages
  - 1.8 - 5.5V for ATmega162V
  - 2.7 - 5.5V for ATmega162
- Speed Grades
  - 0 - 8 MHz for ATmega162V (see Figure 113 on page 265)
  - 0 - 16 MHz for ATmega162 (see Figure 114 on page 265)

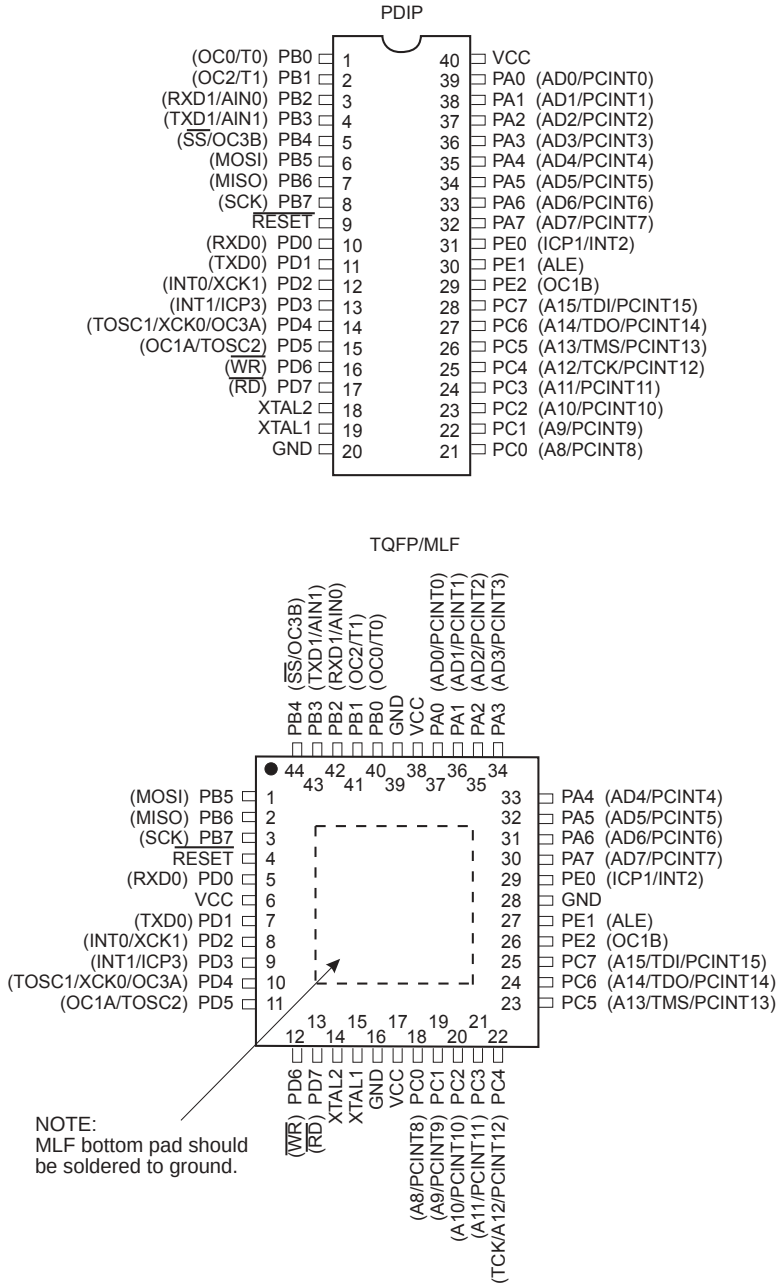
8-bit AVR® Microcontroller with 16K Bytes In-System Programmable Flash

ATmega162
ATmega162V

2513F–AVR–12/03

Pin Configurations

Figure 1. Pinout ATmega162



Disclaimer

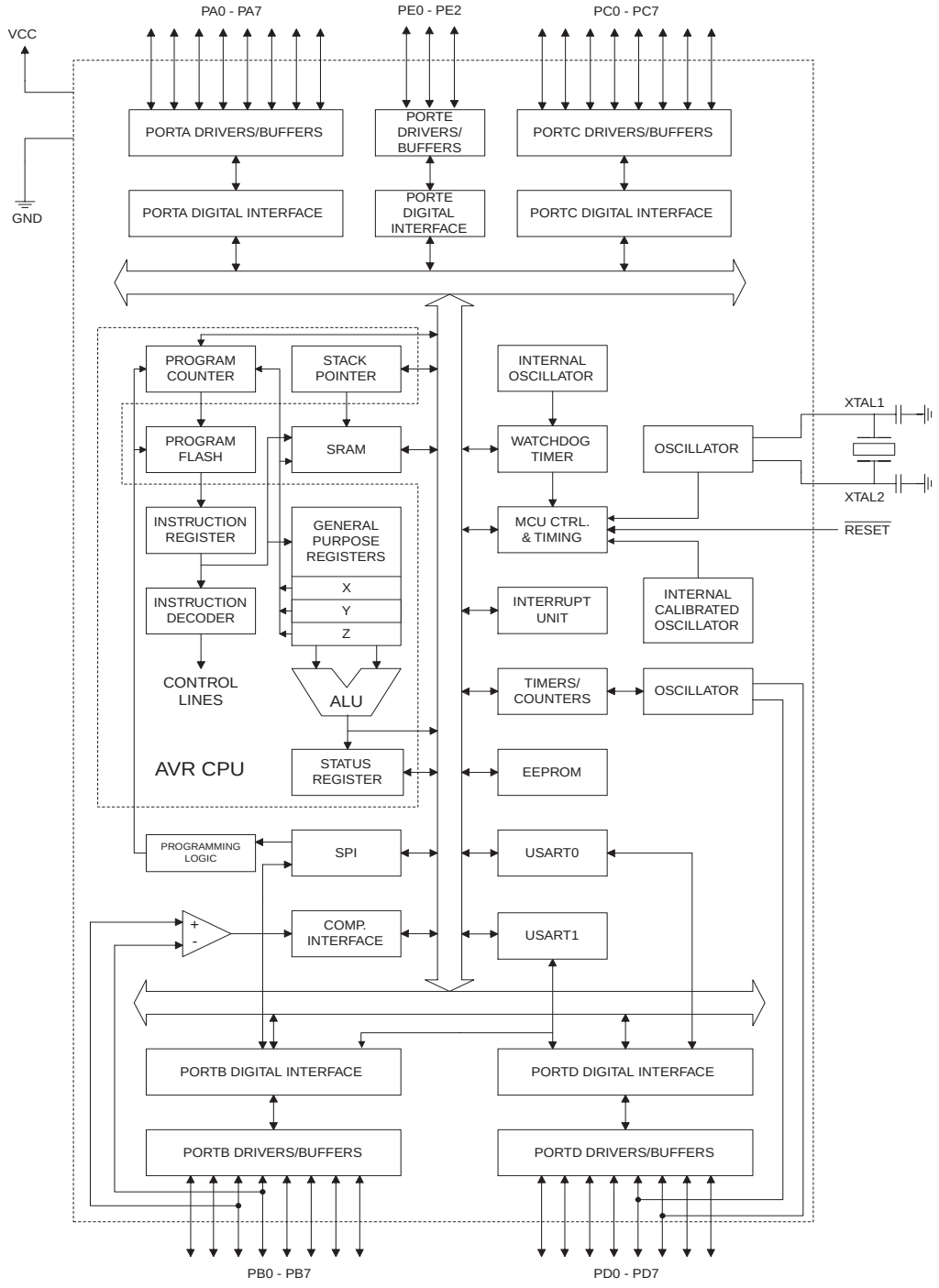
Typical values contained in this datasheet are based on simulations and characterization of other AVR microcontrollers manufactured on the same process technology. Min and Max values will be available after the device is characterized.

Overview

The ATmega162 is a low-power CMOS 8-bit microcontroller based on the AVR enhanced RISC architecture. By executing powerful instructions in a single clock cycle, the ATmega162 achieves throughputs approaching 1 MIPS per MHz allowing the system designer to optimize power consumption versus processing speed.

Block Diagram

Figure 2. Block Diagram



The AVR core combines a rich instruction set with 32 general purpose working registers. All the 32 registers are directly connected to the Arithmetic Logic Unit (ALU), allowing two independent registers to be accessed in one single instruction executed in one clock cycle. The resulting architecture is more code efficient while achieving throughputs up to ten times faster than conventional CISC microcontrollers.

The ATmega162 provides the following features: 16K bytes of In-System Programmable Flash with Read-While-Write capabilities, 512 bytes EEPROM, 1K bytes SRAM, an external memory interface, 35 general purpose I/O lines, 32 general purpose working registers, a JTAG interface for Boundary-scan, On-chip Debugging support and programming, four flexible Timer/Counters with compare modes, internal and external interrupts, two serial programmable USARTs, a programmable Watchdog Timer with Internal Oscillator, an SPI serial port, and five software selectable power saving modes. The Idle mode stops the CPU while allowing the SRAM, Timer/Counters, SPI port, and interrupt system to continue functioning. The Power-down mode saves the register contents but freezes the Oscillator, disabling all other chip functions until the next interrupt or Hardware Reset. In Power-save mode, the Asynchronous Timer continues to run, allowing the user to maintain a timer base while the rest of the device is sleeping. In Standby mode, the crystal/resonator Oscillator is running while the rest of the device is sleeping. This allows very fast start-up combined with low-power consumption. In Extended Standby mode, both the main Oscillator and the Asynchronous Timer continue to run.

The device is manufactured using Atmel's high density non-volatile memory technology. The On-chip ISP Flash allows the program memory to be reprogrammed In-System through an SPI serial interface, by a conventional non-volatile memory programmer, or by an On-chip Boot Program running on the AVR core. The Boot Program can use any interface to download the Application Program in the Application Flash memory. Software in the Boot Flash section will continue to run while the Application Flash section is updated, providing true Read-While-Write operation. By combining an 8-bit RISC CPU with In-System Self-Programmable Flash on a monolithic chip, the Atmel ATmega162 is a powerful microcontroller that provides a highly flexible and cost effective solution to many embedded control applications.

The ATmega162 AVR is supported with a full suite of program and system development tools including: C compilers, macro assemblers, program debugger/simulators, In-Circuit Emulators, and evaluation kits.

ATmega161 and ATmega162 Compatibility

The ATmega162 is a highly complex microcontroller where the number of I/O locations supersedes the 64 I/O locations reserved in the AVR instruction set. To ensure backward compatibility with the ATmega161, all I/O locations present in ATmega161 have the same locations in ATmega162. Some additional I/O locations are added in an Extended I/O space starting from 0x60 to 0xFF, (i.e., in the ATmega162 internal RAM space). These locations can be reached by using LD/LDS/LDD and ST/STS/STD instructions only, not by using IN and OUT instructions. The relocation of the internal RAM space may still be a problem for ATmega161 users. Also, the increased number of Interrupt Vectors might be a problem if the code uses absolute addresses. To solve these problems, an ATmega161 compatibility mode can be selected by programming the fuse M161C. In this mode, none of the functions in the Extended I/O space are in use, so the internal RAM is located as in ATmega161. Also, the Extended Interrupt Vectors are removed. The ATmega162 is 100% pin compatible with ATmega161, and can replace the ATmega161 on current Printed Circuit Boards. However, the location of Fuse bits and the electrical characteristics differs between the two devices.

ATmega161 Compatibility Mode

Programming the M161C will change the following functionality:

- The extended I/O map will be configured as internal RAM once the M161C Fuse is programmed.
- The timed sequence for changing the Watchdog Time-out period is disabled. See “Timed Sequences for Changing the Configuration of the Watchdog Timer” on page 55 for details.
- The double buffering of the USART Receive Registers is disabled. See “AVR USART vs. AVR UART – Compatibility” on page 167 for details.
- Pin change interrupts are not supported (Control Registers are located in Extended I/O).
- One 16 bits Timer/Counter (Timer/Counter1) only. Timer/Counter3 is not accessible.

Note that the shared UBRRHI Register in ATmega161 is split into two separate registers in ATmega162, UBRR0H and UBRR1H. The location of these registers will not be affected by the ATmega161 compatibility fuse.

Pin Descriptions

VCC

Digital supply voltage

GND

Ground

Port A (PA7..PA0)

Port A is an 8-bit bi-directional I/O port with internal pull-up resistors (selected for each bit). The Port A output buffers have symmetrical drive characteristics with both high sink and source capability. When pins PA0 to PA7 are used as inputs and are externally pulled low, they will source current if the internal pull-up resistors are activated. The Port A pins are tri-stated when a reset condition becomes active, even if the clock is not running.

Port A also serves the functions of various special features of the ATmega162 as listed on page 71.

Port B (PB7..PB0)

Port B is an 8-bit bi-directional I/O port with internal pull-up resistors (selected for each bit). The Port B output buffers have symmetrical drive characteristics with both high sink and source capability. As inputs, Port B pins that are externally pulled low will source current if the pull-up resistors are activated. The Port B pins are tri-stated when a reset condition becomes active, even if the clock is not running.

Port B also serves the functions of various special features of the ATmega162 as listed on page 71.

Port C (PC7..PC0)

Port C is an 8-bit bi-directional I/O port with internal pull-up resistors (selected for each bit). The Port C output buffers have symmetrical drive characteristics with both high sink and source capability. As inputs, Port C pins that are externally pulled low will source current if the pull-up resistors are activated. The Port C pins are tri-stated when a reset condition becomes active, even if the clock is not running. If the JTAG interface is enabled, the pull-up resistors on pins PC7(TDI), PC5(TMS) and PC4(TCK) will be activated even if a Reset occurs.

Port C also serves the functions of the JTAG interface and other special features of the ATmega162 as listed on page 74.

Port D (PD7..PD0)

Port D is an 8-bit bi-directional I/O port with internal pull-up resistors (selected for each bit). The Port D output buffers have symmetrical drive characteristics with both high sink and source capability. As inputs, Port D pins that are externally pulled low will source current if the pull-up resistors are activated. The Port D pins are tri-stated when a reset condition becomes active, even if the clock is not running.

Port D also serves the functions of various special features of the ATmega162 as listed on page 77.

Port E(PE2..PE0)

Port E is an 3-bit bi-directional I/O port with internal pull-up resistors (selected for each bit). The Port E output buffers have symmetrical drive characteristics with both high sink and source capability. As inputs, Port E pins that are externally pulled low will source current if the pull-up resistors are activated. The Port E pins are tri-stated when a reset condition becomes active, even if the clock is not running.

Port E also serves the functions of various special features of the ATmega162 as listed on page 80.

$\overline{\text{RESET}}$

Reset input. A low level on this pin for longer than the minimum pulse length will generate a Reset, even if the clock is not running. The minimum pulse length is given in Table 18 on page 47. Shorter pulses are not guaranteed to generate a reset.

XTAL1

Input to the Inverting Oscillator amplifier and input to the internal clock operating circuit.

XTAL2

Output from the Inverting Oscillator amplifier.

About Code Examples

This documentation contains simple code examples that briefly show how to use various parts of the device. These code examples assume that the part specific header file is included before compilation. Be aware that not all C compiler vendors include bit definitions in the header files and interrupt handling in C is compiler dependent. Please confirm with the C compiler documentation for more details.

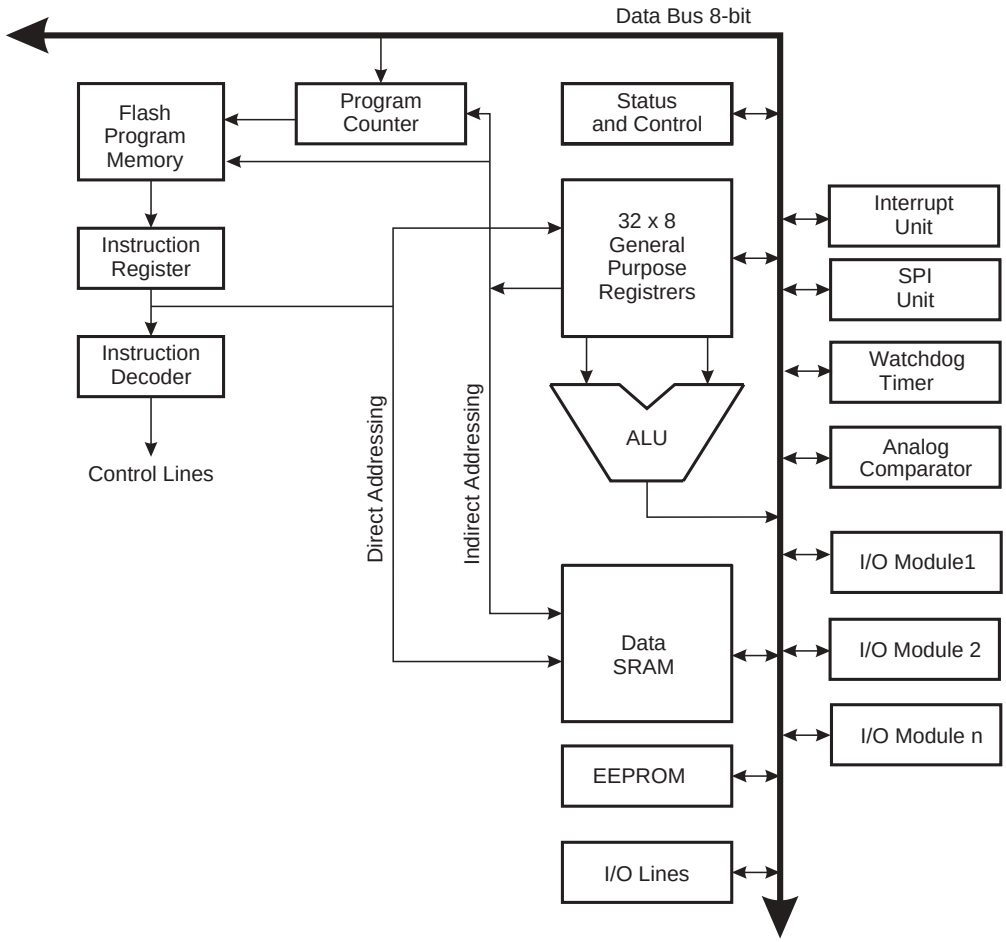
AVR CPU Core

Introduction

This section discusses the AVR core architecture in general. The main function of the CPU core is to ensure correct program execution. The CPU must therefore be able to access memories, perform calculations, control peripherals, and handle interrupts.

Architectural Overview

Figure 3. Block Diagram of the AVR Architecture



In order to maximize performance and parallelism, the AVR uses a Harvard architecture – with separate memories and buses for program and data. Instructions in the program memory are executed with a single level pipelining. While one instruction is being executed, the next instruction is pre-fetched from the program memory. This concept enables instructions to be executed in every clock cycle. The program memory is In-System Reprogrammable Flash memory.

The fast-access Register File contains 32 x 8-bit general purpose working registers with a single clock cycle access time. This allows single-cycle Arithmetic Logic Unit (ALU) operation. In a typical ALU operation, two operands are output from the Register File, the operation is executed, and the result is stored back in the Register File – in one clock cycle.

Six of the 32 registers can be used as three 16-bit indirect address register pointers for Data Space addressing – enabling efficient address calculations. One of the these address pointers can also be used as an address pointer for look up tables in Flash Program memory. These added function registers are the 16-bit X-, Y-, and Z-register, described later in this section.

The ALU supports arithmetic and logic operations between registers or between a constant and a register. Single register operations can also be executed in the ALU. After an arithmetic operation, the Status Register is updated to reflect information about the result of the operation.

Program flow is provided by conditional and unconditional jump and call instructions, able to directly address the whole address space. Most AVR instructions have a single 16-bit word format. Every program memory address contains a 16- or 32-bit instruction.

Program Flash memory space is divided in two sections, the Boot Program section and the Application Program section. Both sections have dedicated Lock bits for write and read/write protection. The SPM instruction that writes into the Application Flash memory section must reside in the Boot Program section.

During interrupts and subroutine calls, the return address Program Counter (PC) is stored on the Stack. The Stack is effectively allocated in the general data SRAM, and consequently the Stack size is only limited by the total SRAM size and the usage of the SRAM. All user programs must initialize the SP in the reset routine (before subroutines or interrupts are executed). The Stack Pointer SP is read/write accessible in the I/O space. The data SRAM can easily be accessed through the five different addressing modes supported in the AVR architecture.

The memory spaces in the AVR architecture are all linear and regular memory maps.

A flexible interrupt module has its control registers in the I/O space with an additional Global Interrupt Enable bit in the Status Register. All interrupts have a separate Interrupt Vector in the Interrupt Vector table. The interrupts have priority in accordance with their Interrupt Vector position. The lower the Interrupt Vector address, the higher the priority.

The I/O memory space contains 64 addresses for CPU peripheral functions as Control Registers, SPI, and other I/O functions. The I/O memory can be accessed directly, or as the Data Space locations following those of the Register File, 0x20 - 0x5F.

ALU – Arithmetic Logic Unit

The high-performance AVR ALU operates in direct connection with all the 32 general purpose working registers. Within a single clock cycle, arithmetic operations between general purpose registers or between a register and an immediate are executed. The ALU operations are divided into three main categories – arithmetic, logical, and bit-functions. Some implementations of the architecture also provide a powerful multiplier supporting both signed/unsigned multiplication and fractional format. See the “Instruction Set” section for a detailed description.

Status Register

The Status Register contains information about the result of the most recently executed arithmetic instruction. This information can be used for altering program flow in order to perform conditional operations. Note that the Status Register is updated after all ALU operations, as specified in the Instruction Set Reference. This will in many cases remove the need for using the dedicated compare instructions, resulting in faster and more compact code.

The Status Register is not automatically stored when entering an interrupt routine and restored when returning from an interrupt. This must be handled by software.

The AVR Status Register – SREG – is defined as:

Bit	7	6	5	4	3	2	1	0	
	I	T	H	S	V	N	Z	C	SREG
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

- **Bit 7 – I: Global Interrupt Enable**

The Global Interrupt Enable bit must be set for the interrupts to be enabled. The individual interrupt enable control is then performed in separate control registers. If the Global Interrupt Enable Register is cleared, none of the interrupts are enabled independent of the individual interrupt enable settings. The I-bit is cleared by hardware after an interrupt has occurred, and is set by the RETI instruction to enable subsequent interrupts. The I-bit can also be set and cleared by the application with the SEI and CLI instructions, as described in the instruction set reference.

- **Bit 6 – T: Bit Copy Storage**

The Bit Copy instructions BLD (Bit LoaD) and BST (Bit STore) use the T bit as source or destination for the operated bit. A bit from a register in the Register File can be copied into T by the BST instruction, and a bit in T can be copied into a bit in a register in the Register File by the BLD instruction.

- **Bit 5 – H: Half Carry Flag**

The Half Carry Flag H indicates a half carry in some arithmetic operations. Half Carry is useful in BCD arithmetic. See the “Instruction Set Description” for detailed information.

- **Bit 4 – S: Sign Bit, S = N ⊕ V**

The S-bit is always an exclusive or between the Negative Flag N and the Two’s Complement Overflow Flag V. See the “Instruction Set Description” for detailed information.

- **Bit 3 – V: Two’s Complement Overflow Flag**

The Two’s Complement Overflow Flag V supports two’s complement arithmetics. See the “Instruction Set Description” for detailed information.

- **Bit 2 – N: Negative Flag**

The Negative Flag N indicates a negative result in an arithmetic or logic operation. See the “Instruction Set Description” for detailed information.

- **Bit 1 – Z: Zero Flag**

The Zero Flag Z indicates a zero result in an arithmetic or logic operation. See the “Instruction Set Description” for detailed information.

- **Bit 0 – C: Carry Flag**

The Carry Flag C indicates a carry in an arithmetic or logic operation. See the “Instruction Set Description” for detailed information.

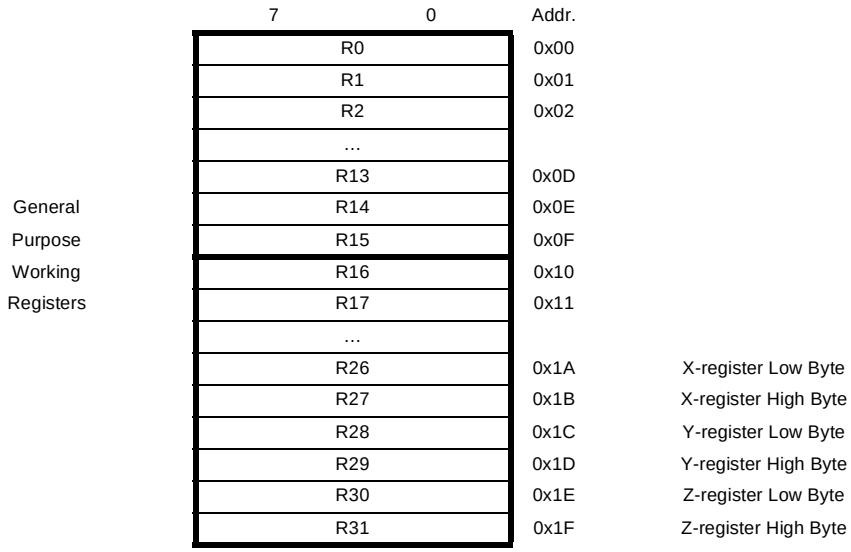
General Purpose Register File

The Register File is optimized for the AVR Enhanced RISC instruction set. In order to achieve the required performance and flexibility, the following input/output schemes are supported by the Register File:

- One 8-bit output operand and one 8-bit result input
- Two 8-bit output operands and one 8-bit result input
- Two 8-bit output operands and one 16-bit result input
- One 16-bit output operand and one 16-bit result input

Figure 4 shows the structure of the 32 general purpose working registers in the CPU.

Figure 4. AVR CPU General Purpose Working Registers



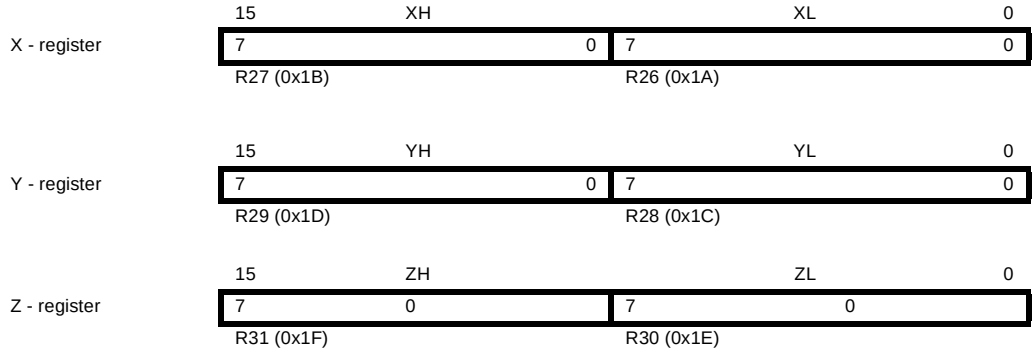
Most of the instructions operating on the Register File have direct access to all registers, and most of them are single cycle instructions.

As shown in Figure 4, each register is also assigned a data memory address, mapping them directly into the first 32 locations of the user Data Space. Although not being physically implemented as SRAM locations, this memory organization provides great flexibility in access of the registers, as the X-, Y-, and Z-pointer registers can be set to index any register in the file.

The X-register, Y-register, and Z-register

The registers R26..R31 have some added functions to their general purpose usage. These registers are 16-bit address pointers for indirect addressing of the Data Space. The three indirect address registers X, Y, and Z are defined as described in Figure 5.

Figure 5. The X-, Y-, and Z-registers



In the different addressing modes these address registers have functions as fixed displacement, automatic increment, and automatic decrement (see the instruction set reference for details).

Stack Pointer

The Stack is mainly used for storing temporary data, for storing local variables and for storing return addresses after interrupts and subroutine calls. The Stack Pointer Register always points to the top of the Stack. Note that the Stack is implemented as growing from higher memory locations to lower memory locations. This implies that a Stack PUSH command decreases the Stack Pointer.

The Stack Pointer points to the data SRAM Stack area where the Subroutine and Interrupt Stacks are located. This Stack space in the data SRAM must be defined by the program before any subroutine calls are executed or interrupts are enabled. The Stack Pointer must be set to point above 0x60. The Stack Pointer is decremented by one when data is pushed onto the Stack with the PUSH instruction, and it is decremented by two when the return address is pushed onto the Stack with subroutine call or interrupt. The Stack Pointer is incremented by one when data is popped from the Stack with the POP instruction, and it is incremented by two when data is popped from the Stack with return from subroutine RET or return from interrupt RETI.

The AVR Stack Pointer is implemented as two 8-bit registers in the I/O space. The number of bits actually used is implementation dependent. Note that the data space in some implementations of the AVR architecture is so small that only SPL is needed. In this case, the SPH Register will not be present.

Bit	15	14	13	12	11	10	9	8	
	SP15	**SP14**	**SP13**	**SP12**	**SP11**	**SP10**	**SP9**	**SP8**	**SPH**
	SP7	**SP6**	**SP5**	**SP4**	**SP3**	**SP2**	**SP1**	**SP0**	**SPL**
	7	6	5	4	3	2	1	0	
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	
	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	
	0	0	0	0	0	0	0	0	

Instruction Execution Timing

This section describes the general access timing concepts for instruction execution. The AVR CPU is driven by the CPU clock clk_{CPU}, directly generated from the selected clock source for the chip. No internal clock division is used.

Figure 6 shows the parallel instruction fetches and instruction executions enabled by the Harvard architecture and the fast-access Register File concept. This is the basic pipelining concept to obtain up to 1 MIPS per MHz with the corresponding unique results for functions per cost, functions per clocks, and functions per power-unit.

Figure 6. The Parallel Instruction Fetches and Instruction Executions

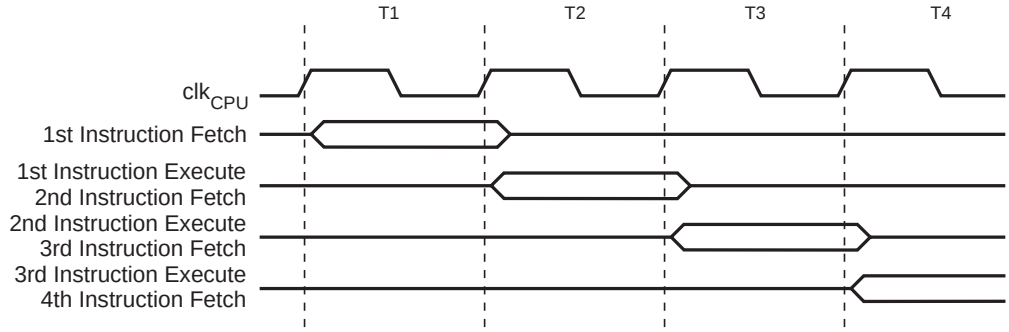
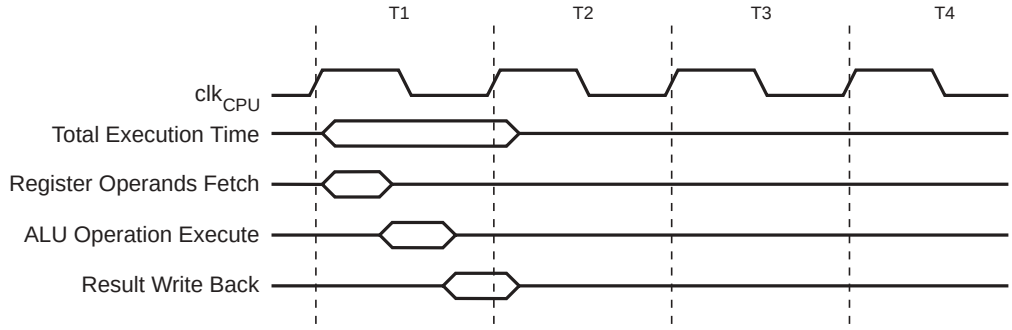


Figure 7 shows the internal timing concept for the Register File. In a single clock cycle an ALU operation using two register operands is executed, and the result is stored back to the destination register.

Figure 7. Single Cycle ALU Operation



Reset and Interrupt Handling

The AVR provides several different interrupt sources. These interrupts and the separate Reset Vector each have a separate program vector in the program memory space. All interrupts are assigned individual enable bits which must be written logic one together with the Global Interrupt Enable bit in the Status Register in order to enable the interrupt. Depending on the Program Counter value, interrupts may be automatically disabled when Boot Lock bits BLB02 or BLB12 are programmed. This feature improves software security. See the section “Memory Programming” on page 230 for details.

The lowest addresses in the program memory space are by default defined as the Reset and Interrupt Vectors. The complete list of vectors is shown in “Interrupts” on page 56. The list also determines the priority levels of the different interrupts. The lower the address the higher is the priority level. RESET has the highest priority, and next is INT0 – the External Interrupt Request 0. The Interrupt Vectors can be moved to the start of the Boot Flash section by setting the IVSEL bit in the General Interrupt Control Register (GICR). Refer to “Interrupts” on page 56 for more information. The Reset Vector can

also be moved to the start of the Boot Flash section by programming the BOOTRST Fuse, see “Boot Loader Support – Read-While-Write Self-programming” on page 216.

When an interrupt occurs, the Global Interrupt Enable I-bit is cleared and all interrupts are disabled. The user software can write logic one to the I-bit to enable nested interrupts. All enabled interrupts can then interrupt the current interrupt routine. The I-bit is automatically set when a Return from Interrupt instruction – RETI – is executed.

There are basically two types of interrupts. The first type is triggered by an event that sets the Interrupt Flag. For these interrupts, the Program Counter is vectored to the actual Interrupt Vector in order to execute the interrupt handling routine, and hardware clears the corresponding Interrupt Flag. Interrupt Flags can also be cleared by writing a logic one to the flag bit position(s) to be cleared. If an interrupt condition occurs while the corresponding interrupt enable bit is cleared, the Interrupt Flag will be set and remembered until the interrupt is enabled, or the flag is cleared by software. Similarly, if one or more interrupt conditions occur while the global interrupt enable bit is cleared, the corresponding Interrupt Flag(s) will be set and remembered until the Global Interrupt Enable bit is set, and will then be executed by order of priority.

The second type of interrupts will trigger as long as the interrupt condition is present. These interrupts do not necessarily have Interrupt Flags. If the interrupt condition disappears before the interrupt is enabled, the interrupt will not be triggered.

When the AVR exits from an interrupt, it will always return to the main program and execute one more instruction before any pending interrupt is served.

Note that the Status Register is not automatically stored when entering an interrupt routine, nor restored when returning from an interrupt routine. This must be handled by software.

When using the CLI instruction to disable interrupts, the interrupts will be immediately disabled. No interrupt will be executed after the CLI instruction, even if it occurs simultaneously with the CLI instruction. The following example shows how this can be used to avoid interrupts during the timed EEPROM write sequence.

Assembly Code Example

```
in  r16, SREG      ; store SREG value
cli     ; disable interrupts during timed sequence
sbi EECR, EEMWE    ; start EEPROM write
sbi EECR, EEWE
out SREG, r16      ; restore SREG value (I-bit)
```

C Code Example

```
char cSREG;
cSREG = SREG;  /* store SREG value */
/* disable interrupts during timed sequence */
_CLI();
EECR |= (1<<EEMWE); /* start EEPROM write */
EECR |= (1<<EEWE);
SREG = cSREG; /* restore SREG value (I-bit) */
```

When using the SEI instruction to enable interrupts, the instruction following SEI will be executed before any pending interrupts, as shown in this example.

Assembly Code Example

```
sei   ; set global interrupt enable
sleep ; enter sleep, waiting for interrupt
; note: will enter sleep before any pending
; interrupt(s)
```

C Code Example

```
_SEI(); /* set global interrupt enable */
_SLEEP(); /* enter sleep, waiting for interrupt */
/* note: will enter sleep before any pending interrupt(s) */
```

Interrupt Response Time

The interrupt execution response for all the enabled AVR interrupts is four clock cycles minimum. After four clock cycles the program vector address for the actual interrupt handling routine is executed. During this four clock cycle period, the Program Counter is pushed onto the Stack. The vector is normally a jump to the interrupt routine, and this jump takes three clock cycles. If an interrupt occurs during execution of a multi-cycle instruction, this instruction is completed before the interrupt is served. If an interrupt occurs when the MCU is in sleep mode, the interrupt execution response time is increased by four clock cycles. This increase comes in addition to the start-up time from the selected sleep mode.

A return from an interrupt handling routine takes four clock cycles. During these four clock cycles, the Program Counter (two bytes) is popped back from the Stack, the Stack Pointer is incremented by two, and the I-bit in SREG is set.

AVR ATmega162 Memories

This section describes the different memories in the ATmega162. The AVR architecture has two main memory spaces, the Data Memory and the Program Memory space. In addition, the ATmega162 features an EEPROM Memory for data storage. All three memory spaces are linear and regular.

In-System Reprogrammable Flash Program Memory

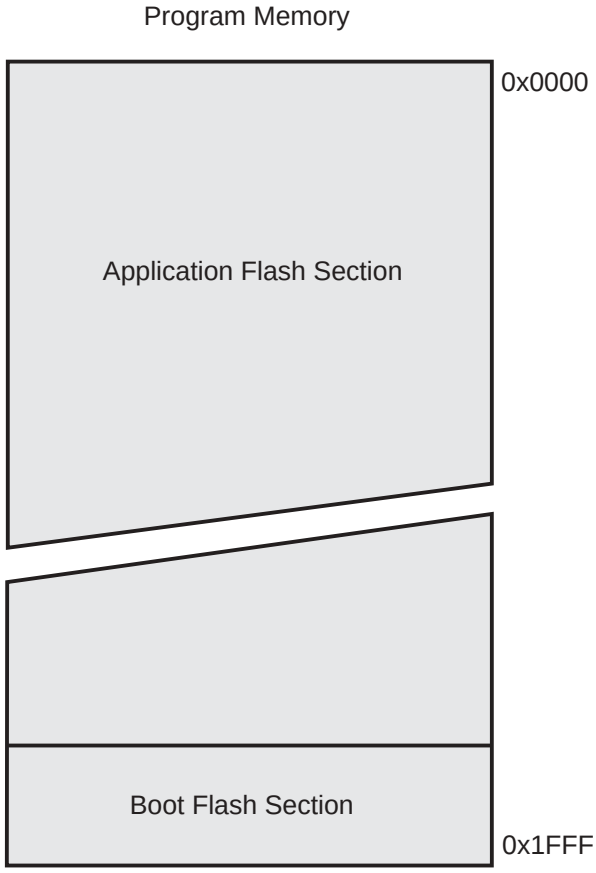
The ATmega162 contains 16K bytes On-chip In-System Reprogrammable Flash memory for program storage. Since all AVR instructions are 16 or 32 bits wide, the Flash is organized as 8K x 16. For software security, the Flash Program memory space is divided into two sections, Boot Program section and Application Program section.

The Flash memory has an endurance of at least 10,000 write/erase cycles. The ATmega162 Program Counter (PC) is 13 bits wide, thus addressing the 8K program memory locations. The operation of Boot Program section and associated Boot Lock bits for software protection are described in detail in “Boot Loader Support – Read-While-Write Self-programming” on page 216. “Memory Programming” on page 230 contains a detailed description on Flash data serial downloading using the SPI pins or the JTAG interface.

Constant tables can be allocated within the entire program memory address space (see the LPM – Load Program Memory instruction description).

Timing diagrams for instruction fetch and execution are presented in “Instruction Execution Timing” on page 12.

Figure 8. Program Memory Map[1]



Note: 1. The address reflects word addresses.

SRAM Data Memory

Figure 9 shows how the ATmega162 SRAM Memory is organized. Memory configuration B refers to the ATmega161 compatibility mode, configuration A to the non-compatible mode.

The ATmega162 is a complex microcontroller with more peripheral units than can be supported within the 64 location reserved in the Opcode for the IN and OUT instructions. For the Extended I/O space from 0x60 - 0xFF in SRAM, only the ST/STS/STD and LD/LDS/LDD instructions can be used. The Extended I/O space does not exist when the ATmega162 is in the ATmega161 compatibility mode.

In Normal mode, the first 1280 Data Memory locations address both the Register File, the I/O Memory, Extended I/O Memory, and the internal data SRAM. The first 32 locations address the Register File, the next 64 location the standard I/O memory, then 160 locations of Extended I/O memory, and the next 1024 locations address the internal data SRAM.

In ATmega161 compatibility mode, the lower 1120 Data Memory locations address the Register File, the I/O Memory, and the internal data SRAM. The first 96 locations address the Register File and I/O Memory, and the next 1024 locations address the internal data SRAM.

An optional external data SRAM can be used with the ATmega162. This SRAM will occupy an area in the remaining address locations in the 64K address space. This area starts at the address following the internal SRAM. The Register File, I/O, Extended I/O and Internal SRAM uses the occupies the lowest 1280 bytes in Normal mode, and the lowest 1120 bytes in the ATmega161 compatibility mode (Extended I/O not present), so when using 64KB (65,536 bytes) of External Memory, 64,256 Bytes of External Memory are available in Normal mode, and 64,416 Bytes in ATmega161 compatibility mode. See “External Memory Interface” on page 24 for details on how to take advantage of the external memory map.

When the addresses accessing the SRAM memory space exceeds the internal data memory locations, the external data SRAM is accessed using the same instructions as for the internal data memory access. When the internal data memories are accessed, the read and write strobe pins (PD7 and PD6) are inactive during the whole access cycle. External SRAM operation is enabled by setting the SRE bit in the MCUCR Register.

Accessing external SRAM takes one additional clock cycle per byte compared to access of the internal SRAM. This means that the commands LD, ST, LDS, STS, LDD, STD, PUSH, and POP take one additional clock cycle. If the Stack is placed in external SRAM, interrupts, subroutine calls and returns take three clock cycles extra because the 2-byte Program Counter is pushed and popped, and external memory access does not take advantage of the internal pipeline memory access. When external SRAM interface is used with wait-state, one-byte external access takes two, three, or four additional clock cycles for one, two, and three wait-states respectively. Interrupt, subroutine calls and returns will need five, seven, or nine clock cycles more than specified in the instruction set manual for one, two, and three wait-states.

The five different addressing modes for the data memory cover: Direct, Indirect with Displacement, Indirect, Indirect with Pre-decrement, and Indirect with Post-increment. In the Register File, registers R26 to R31 feature the indirect addressing pointer registers.

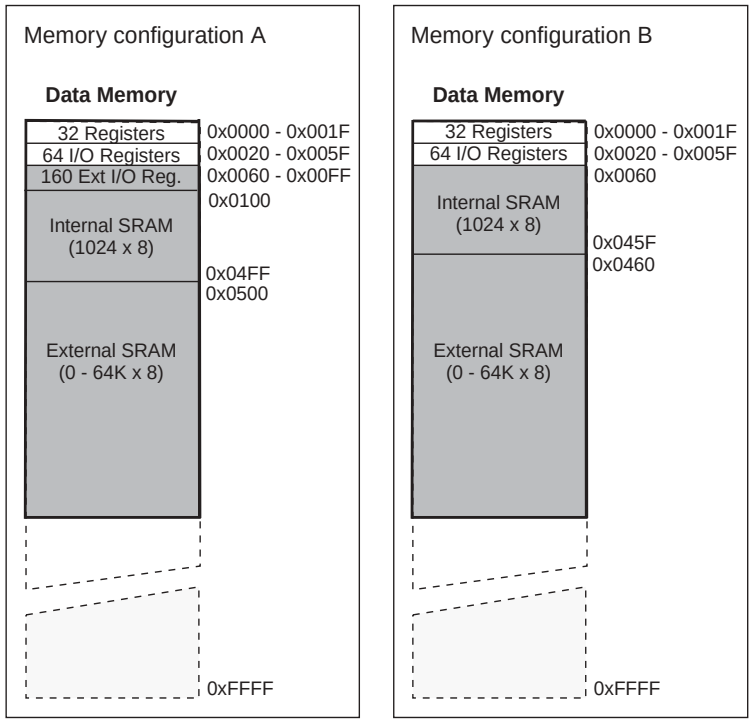
The direct addressing reaches the entire data space.

The Indirect with Displacement mode reaches 63 address locations from the base address given by the Y- or Z-register.

When using register indirect addressing modes with automatic pre-decrement and post-increment, the address registers X, Y, and Z are decremented or incremented.

The 32 general purpose working registers, 64 (+160) I/O Registers, and the 1024 bytes of internal data SRAM in the ATmega162 are all accessible through all these addressing modes. The Register File is described in “General Purpose Register File” on page 10.

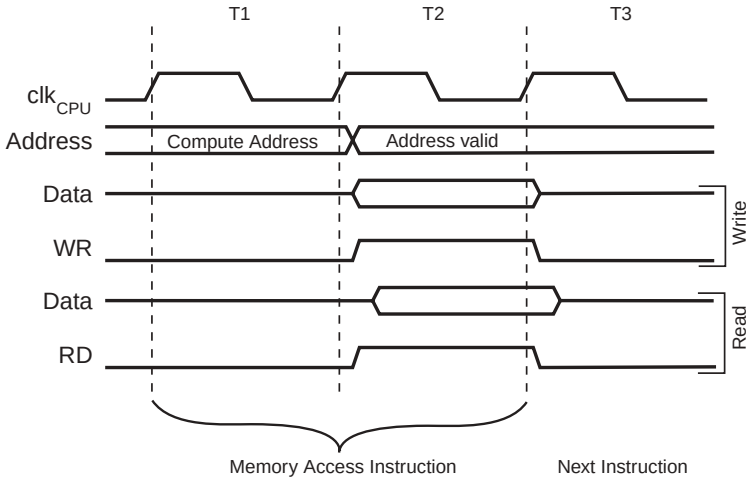
Figure 9. Data Memory Map



Data Memory Access Times

This section describes the general access timing concepts for internal memory access. The internal data SRAM access is performed in two clk_{CPU} cycles as described in Figure 10.

Figure 10. On-chip Data SRAM Access Cycles



EEPROM Data Memory

The ATmega162 contains 512 bytes of data EEPROM memory. It is organized as a separate data space, in which single bytes can be read and written. The EEPROM has an endurance of at least 100,000 write/erase cycles. The access between the EEPROM and the CPU is described in the following, specifying the EEPROM Address Registers, the EEPROM Data Register, and the EEPROM Control Register.

"Memory Programming" on page 230 contains a detailed description on EEPROM Programming in SPI, JTAG, or Parallel Programming mode.

EEPROM Read/Write Access

The EEPROM Access Registers are accessible in the I/O space.

The write access time for the EEPROM is given in Table 1. A selftiming function, however, lets the user software detect when the next byte can be written. If the user code contains instructions that write the EEPROM, some precautions must be taken. In heavily filtered power supplies, V_{CC} is likely to rise or fall slowly on Power-up/down. This causes the device for some period of time to run at a voltage lower than specified as minimum for the clock frequency used. See "Preventing EEPROM Corruption" on page 22 for details on how to avoid problems in these situations.

In order to prevent unintentional EEPROM writes, a specific write procedure must be followed. Refer to the description of the EEPROM Control Register for details on this.

When the EEPROM is read, the CPU is halted for four clock cycles before the next instruction is executed. When the EEPROM is written, the CPU is halted for two clock cycles before the next instruction is executed.

The EEPROM Address Register – EEARH and EEARL

Bit	15	14	13	12	11	10	9	8	
	–	–	–	–	–	–	–	**EEAR8**	**EEARH**
	EEAR7	**EEAR6**	**EEAR5**	**EEAR4**	**EEAR3**	**EEAR2**	**EEAR1**	**EEAR0**	**EEARL**
	7	6	5	4	3	2	1	0	
Read/Write	R	R	R	R	R	R	R	R/W	
	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	X	
	X	X	X	X	X	X	X	X	

- **Bits 15..9 – Res: Reserved Bits**

These bits are reserved bits in the ATmega162 and will always read as zero.

- **Bits 8..0 – EEAR8..0: EEPROM Address**

The EEPROM Address Registers – EEARH and EEARL specify the EEPROM address in the 512 bytes EEPROM space. The EEPROM data bytes are addressed linearly between 0 and 511. The initial value of EEAR is undefined. A proper value must be written before the EEPROM may be accessed.

The EEPROM Data Register – EEDR

Bit	7	6	5	4	3	2	1	0	
	MSB							LSB	EEDR
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

- **Bits 7..0 – EEDR7.0: EEPROM Data**

For the EEPROM write operation, the EEDR Register contains the data to be written to the EEPROM in the address given by the EEAR Register. For the EEPROM read operation, the EEDR contains the data read out from the EEPROM at the address given by EEAR.

The EEPROM Control Register – EECR

Bit	7	6	5	4	3	2	1	0	
	–	–	–	–	EERIE	EEMWE	EEWE	EERE	EECR
Read/Write	R	R	R	R	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	X	0	

- **Bits 7..4 – Res: Reserved Bits**

These bits are reserved bits in the ATmega162 and will always read as zero.

- **Bit 3 – EERIE: EEPROM Ready Interrupt Enable**

Writing EERIE to one enables the EEPROM Ready Interrupt if the I bit in SREG is set. Writing EERIE to zero disables the interrupt. The EEPROM Ready interrupt generates a constant interrupt when EEWE is cleared.

- **Bit 2 – EEMWE: EEPROM Master Write Enable**

The EEMWE bit determines whether setting EEWE to one causes the EEPROM to be written. When EEMWE is set, setting EEWE within four clock cycles will write data to the EEPROM at the selected address. If EEMWE is zero, setting EEWE will have no effect. When EEMWE has been written to one by software, hardware clears the bit to zero after four clock cycles. See the description of the EEWE bit for an EEPROM write procedure.

- **Bit 1 – EEWE: EEPROM Write Enable**

The EEPROM Write Enable signal EEWE is the write strobe to the EEPROM. When address and data are correctly set up, the EEWE bit must be written to one to write the value into the EEPROM. The EEMWE bit must be written to one before a logical one is written to EEWE, otherwise no EEPROM write takes place. The following procedure should be followed when writing the EEPROM (the order of steps 3 and 4 is not essential):

1. Wait until EEWE becomes zero.
2. Wait until SPMEN in SPMCR becomes zero.
3. Write new EEPROM address to EEAR (optional).
4. Write new EEPROM data to EEDR (optional).
5. Write a logical one to the EEMWE bit while writing a zero to EEWE in EECR.
6. Within four clock cycles after setting EEMWE, write a logical one to EEWE.

The EEPROM can not be programmed during a CPU write to the Flash memory. The software must check that the Flash programming is completed before initiating a new EEPROM write. Step 2 is only relevant if the software contains a Boot Loader allowing the CPU to program the Flash. If the Flash is never being updated by the CPU, step 2

can be omitted. See “Boot Loader Support – Read-While-Write Self-programming” on page 216 for details about boot programming.

Caution: An interrupt between step 5 and step 6 will make the write cycle fail, since the EEPROM Master Write Enable will time-out. If an interrupt routine accessing the EEPROM is interrupting another EEPROM access, the EEAR or EEDR Register will be modified, causing the interrupted EEPROM access to fail. It is recommended to have the Global Interrupt Flag cleared during all the steps to avoid these problems.

When the write access time has elapsed, the EEWE bit is cleared by hardware. The user software can poll this bit and wait for a zero before writing the next byte. When EEWE has been set, the CPU is halted for two cycles before the next instruction is executed.

- **Bit 0 – EERE: EEPROM Read Enable**

The EEPROM Read Enable Signal EERE is the read strobe to the EEPROM. When the correct address is set up in the EEAR Register, the EERE bit must be written to a logic one to trigger the EEPROM read. The EEPROM read access takes one instruction, and the requested data is available immediately. When the EEPROM is read, the CPU is halted for four cycles before the next instruction is executed.

The user should poll the EEWE bit before starting the read operation. If a write operation is in progress, it is neither possible to read the EEPROM, nor to change the EEAR Register.

The calibrated Oscillator is used to time the EEPROM accesses. Table 1 lists the typical programming time for EEPROM access from the CPU.

Table 1. EEPROM Programming Time

Symbol	Number of Calibrated RC Oscillator Cycles(1)	Typ Programming Time
EEPROM write (from CPU)	8448	8.5 ms

Note: 1. Uses 1 MHz clock, independent of CKSEL Fuse settings

The following code examples show one assembly and one C function for writing to the EEPROM. The examples assume that interrupts are controlled (e.g., by disabling interrupts globally) so that no interrupts will occur during execution of these functions. The examples also assume that no Flash Boot Loader is present in the software. If such code is present, the EEPROM write function must also wait for any ongoing SPM command to finish.

Assembly Code Example

```
EEPROM_write:
  ; Wait for completion of previous write
  sbic EECR,EEWE
  rjmp EEPROM_write
  ; Set up address (r18:r17) in address register
  out  EEARH, r18
  out  EEARL, r17
  ; Write data (r16) to data register
  out  EEDR,r16
  ; Write logical one to EEMWE
  sbi  EECR,EEMWE
  ; Start eeprom write by setting EEWE
  sbi  EECR,EEWE
  ret
```

C Code Example

```
void EEPROM_write(unsigned int uiAddress, unsigned char ucData)
{
  /* Wait for completion of previous write */
  while(EECR & (1<<EEWE))
    ;
  /* Set up address and data registers */
  EEAR = uiAddress;
  EEDR = ucData;
  /* Write logical one to EEMWE */
  EECR |= (1<<EEMWE);
  /* Start eeprom write by setting EEWE */
  EECR |= (1<<EEWE);
}
```

The next code examples show assembly and C functions for reading the EEPROM. The examples assume that interrupts are controlled so that no interrupts will occur during execution of these functions.

Assembly Code Example

```
EEPROM_read:
  ; Wait for completion of previous write
  sbic EECR,EEWE
  rjmp EEPROM_read
  ; Set up address (r18:r17) in address register
  out  EEARH, r18
  out  EEARL, r17
  ; Start eeprom read by writing EERE
  sbi  EECR,EERE
  ; Read data from data register
  in   r16,EEDR
  ret
```

C Code Example

```
unsigned char EEPROM_read(unsigned int uiAddress)
{
  /* Wait for completion of previous write */
  while(EECR & (1<<EEWE))
    ;
  /* Set up address register */
  EEAR = uiAddress;
  /* Start eeprom read by writing EERE */
  EECR |= (1<<EERE);
  /* Return data from data register */
  return EEDR;
}
```

EEPROM Write During Power-down Sleep Mode

When entering Power-down sleep mode while an EEPROM write operation is active, the EEPROM write operation will continue, and will complete before the write access time has passed. However, when the write operation is complete, the Oscillator continues running, and as a consequence, the device does not enter Power-down entirely. It is therefore recommended to verify that the EEPROM write operation is completed before entering Power-down.

Preventing EEPROM Corruption

During periods of low $V_{CC,}$ the EEPROM data can be corrupted because the supply voltage is too low for the CPU and the EEPROM to operate properly. These issues are the same as for board level systems using EEPROM, and the same design solutions should be applied.

An EEPROM data corruption can be caused by two situations when the voltage is too low. First, a regular write sequence to the EEPROM requires a minimum voltage to operate correctly. Secondly, the CPU itself can execute instructions incorrectly, if the supply voltage is too low.

EEPROM data corruption can easily be avoided by following this design recommendation:

Keep the AVR RESET active (low) during periods of insufficient power supply voltage. This can be done by enabling the internal Brown-out Detector (BOD). If the detection level of the internal BOD does not match the needed detection level, an external low V_{CC} Reset Protection circuit can be used. If a Reset occurs while a write operation is in progress, the write operation will be completed provided that the power supply voltage is sufficient.

I/O Memory

The I/O space definition of the ATmega162 is shown in “Register Summary” on page 303.

All ATmega162 I/Os and peripherals are placed in the I/O space. All I/O locations may be accessed by the LD/LDS/LDD and ST/STS/STD instructions, transferring data between the 32 general purpose working registers and the I/O space. I/O Registers within the address range 0x00 - 0x1F are directly bit-accessible using the SBI and CBI instructions. In these registers, the value of single bits can be checked by using the SBIS and SBIC instructions. Refer to the instruction set section for more details. When using the I/O specific commands IN and OUT, the I/O addresses 0x00 - 0x3F must be used. When addressing I/O Registers as data space using LD and ST instructions, 0x20 must be added to these addresses. The ATmega162 is a complex microcontroller with more peripheral units than can be supported within the 64 location reserved in Opcode for the IN and OUT instructions. For the Extended I/O space from 0x60 - 0xFF in SRAM, only the ST/STS/STD and LD/LDS/LDD instructions can be used. The Extended I/O space is replaced with SRAM locations when the ATmega162 is in the ATmega161 compatibility mode.

For compatibility with future devices, reserved bits should be written to zero if accessed. Reserved I/O memory addresses should never be written.

Some of the Status Flags are cleared by writing a logical one to them. Note that the CBI and SBI instructions will operate on all bits in the I/O Register, writing a one back into any flag read as set, thus clearing the flag. The CBI and SBI instructions work with registers 0x00 to 0x1F only.

The I/O and peripherals control registers are explained in later sections.

External Memory Interface

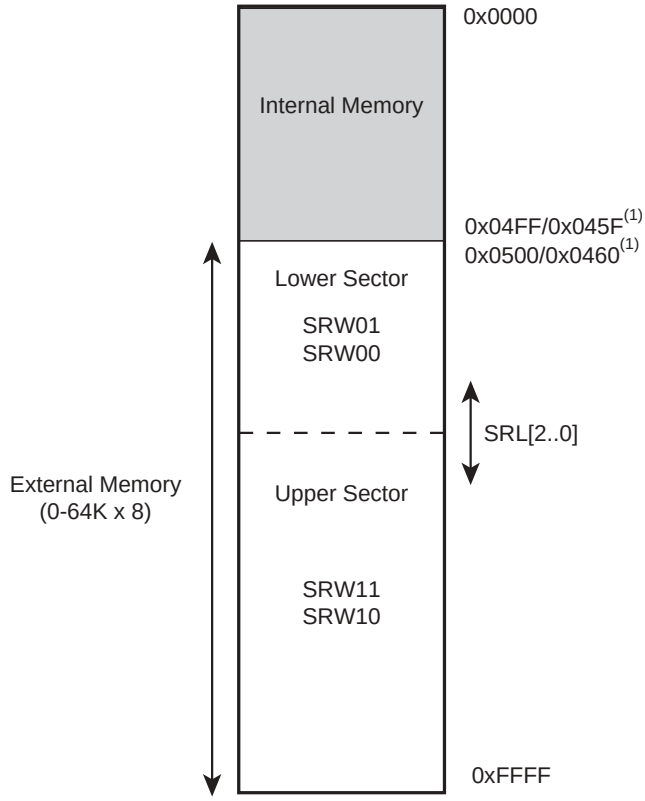
With all the features the External Memory Interface provides, it is well suited to operate as an interface to memory devices such as external SRAM and FLASH, and peripherals such as LCD-display, A/D, and D/A. The main features are:

- **Four Different Wait-state Settings (Including No Wait-state)**
- **Independent Wait-state Setting for Different External Memory Sectors (Configurable Sector Size)**
- **The Number of Bits Dedicated to Address High Byte is Selectable**
- **Bus Keepers on Data Lines to Minimize Current Consumption (Optional)**

Overview

When the eXternal MEMory (XMEM) is enabled, address space outside the internal SRAM becomes available using the dedicated external memory pins (see Figure 1 on page 2, Table 29 on page 69, Table 35 on page 74, and Table 41 on page 80). The memory configuration is shown in Figure 11.

Figure 11. External Memory with Sector Select



Note: 1. Address depends on the ATmega161 compatibility Fuse. See “SRAM Data Memory” on page 16 and Figure 9 on page 17 for details.

Using the External Memory Interface

The interface consists of:

- AD7:0: Multiplexed low-order address bus and data bus
- A15:8: High-order address bus (configurable number of bits)
- ALE: Address latch enable
- $\overline{RD}$: Read strobe.
- $\overline{WR}$: Write strobe.

The control bits for the External Memory Interface are located in three registers, the MCU Control Register – MCUCR, the Extended MCU Control Register – EMCUCR, and the Special Function IO Register – SFIOR.

When the XMEM interface is enabled, it will override the settings in the Data Direction registers corresponding to the ports dedicated to the interface. For details about this port override, see the alternate functions in section “I/O-Ports” on page 62. The XMEM interface will autodetect whether an access is internal or external. If the access is external, the XMEM interface will output address, data, and the control signals on the ports according to Figure 13 (this figure shows the wave forms without wait-states). When ALE goes from high to low, there is a valid address on AD7:0. ALE is low during a data transfer. When the XMEM interface is enabled, also an internal access will cause activity on address-, data- and ALE ports, but the $\overline{RD}$ and $\overline{WR}$ strobes will not toggle during internal access. When the External Memory Interface is disabled, the normal pin and data direction settings are used. Note that when the XMEM interface is disabled, the address space above the internal SRAM boundary is not mapped into the internal SRAM. Figure 12 illustrates how to connect an external SRAM to the AVR using an octal latch (typically “74x573” or equivalent) which is transparent when G is high.

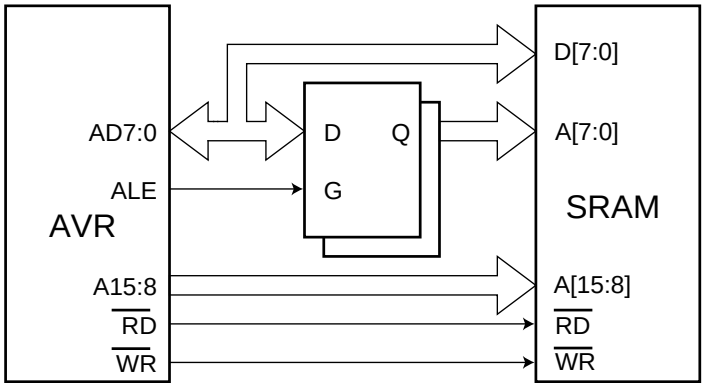
Address Latch Requirements

Due to the high-speed operation of the XRAM interface, the address latch must be selected with care for system frequencies above 8 MHz @ 4V and 4 MHz @ 2.7V. When operating at conditions above these frequencies, the typical old style 74HC series latch becomes inadequate. The external memory interface is designed in compliance to the 74AHC series latch. However, most latches can be used as long they comply with the main timing parameters. The main parameters for the address latch are:

- D to Q propagation delay (t_{pd}).
- Data setup time before G low (t_{su}).
- Data (address) hold time after G low ($_{th}$).

The external memory interface is designed to guaranty minimum address hold time after G is asserted low of t_h = 5 ns (refer to t_{LAXX_LD}/t_{LLAXX_ST} in Table 115 to Table 122 on page 271). The D to Q propagation delay (t_{pd}) must be taken into consideration when calculating the access time requirement of the external component. The data setup time before G low (t_{su}) must not exceed address valid to ALE low (t_{AVLLC}) minus PCB wiring delay (dependent on the capacitive load).

Figure 12. External SRAM Connected to the AVR



Pull-up and Bus Keeper

The pull-up resistors on the AD7:0 ports may be activated if the corresponding Port register is written to one. To reduce power consumption in sleep mode, it is recommended to disable the pull-ups by writing the Port register to zero before entering sleep.

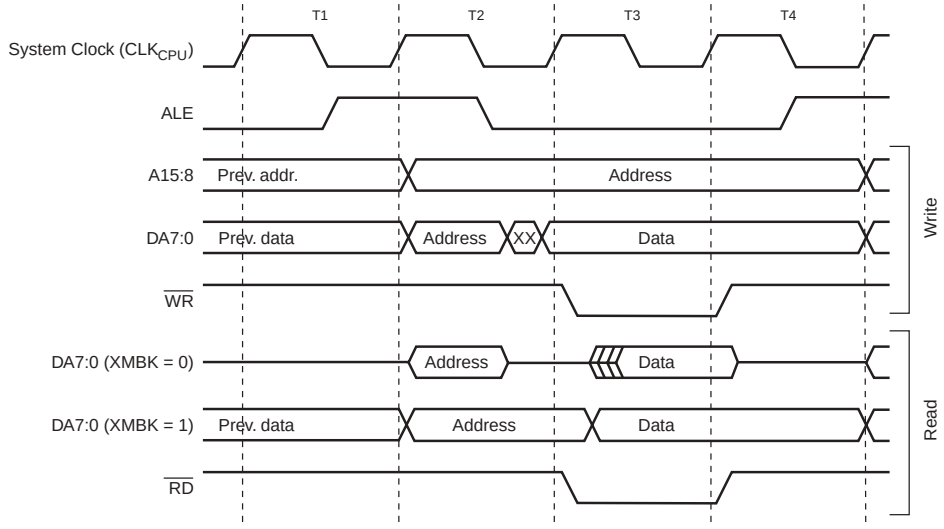
The XMEM interface also provides a bus keeper on the AD7:0 lines. The Bus Keeper can be disabled and enabled in software as described in "Special Function IO Register – SFIOR" on page 30. When enabled, the Bus Keeper will keep the previous value on the AD7:0 bus while these lines are tri-stated by the XMEM interface.

Timing

External memory devices have various timing requirements. To meet these requirements, the ATmega162 XMEM interface provides four different wait-states as shown in Table 3. It is important to consider the timing specification of the external memory device before selecting the wait-state. The most important parameters are the access time for the external memory in conjunction with the set-up requirement of the ATmega162. The access time for the external memory is defined to be the time from receiving the chip select/address until the data of this address actually is driven on the bus. The access time cannot exceed the time from the ALE pulse is asserted low until data must be stable during a read sequence (t_{LLRL}+ t_{RLRH} - t_{DVRH} in Table 115 to Table 122 on page 271). The different wait-states are set up in software. As an additional feature, it is possible to divide the external memory space in two sectors with individual wait-state settings. This makes it possible to connect two different memory devices with different timing requirements to the same XMEM interface. For XMEM interface timing details, please refer to Figure 118 to Figure 121, and Table 115 to Table 122.

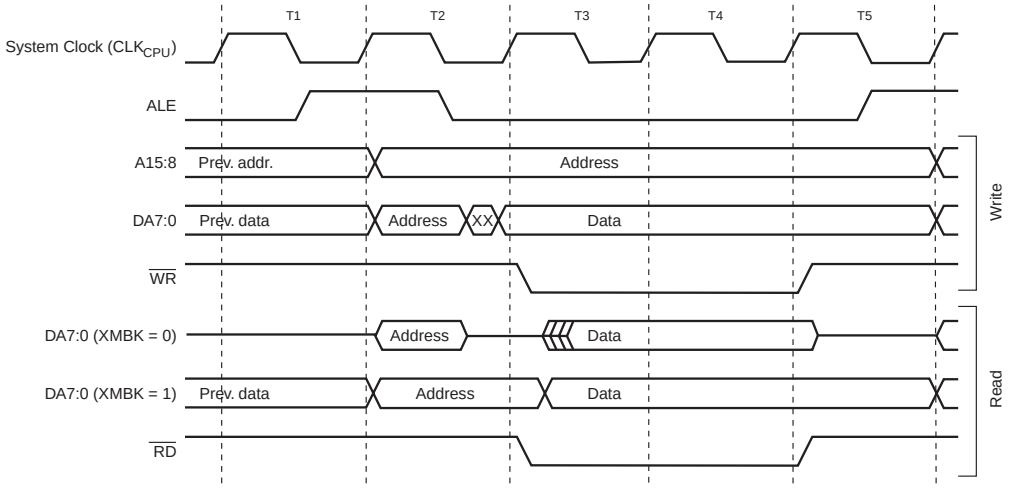
Note that the XMEM interface is asynchronous and that the waveforms in the figures below are related to the internal system clock. The skew between the internal and external clock (XTAL1) is not guaranteed (it varies between devices, temperature, and supply voltage). Consequently, the XMEM interface is not suited for synchronous operation.

Figure 13. External Data Memory Cycles without Wait-state (SRWn1 = 0 and SRWn0 =0)[1]



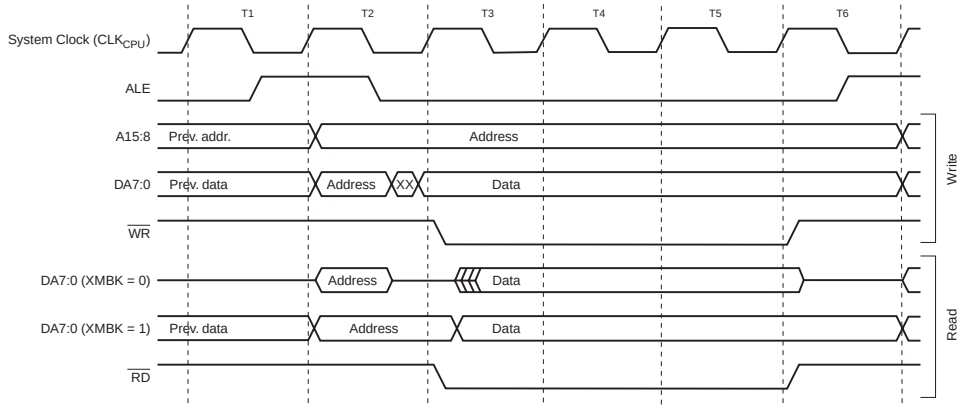
Note: 1. SRWn1 = SRW11 (upper sector) or SRW01 (lower sector), SRWn0 = SRW10 (upper sector) or SRW00 (lower sector).
The ALE pulse in period T4 is only present if the next instruction accesses the RAM (internal or external).

Figure 14. External Data Memory Cycles with SRWn1 = 0 and SRWn0 = 1[1]



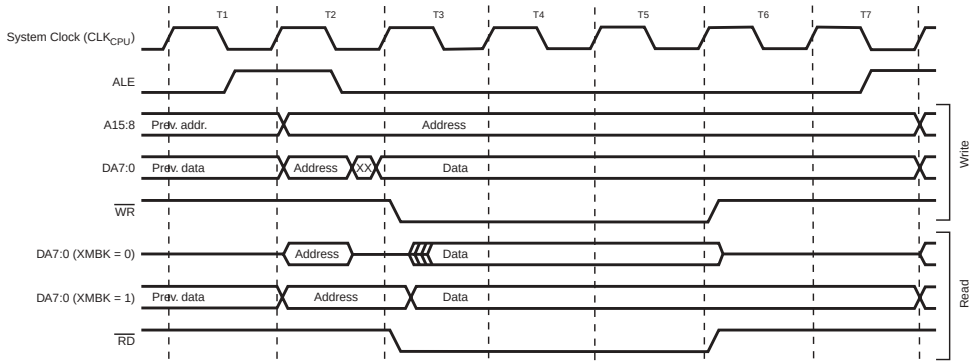
Note: 1. SRWn1 = SRW11 (upper sector) or SRW01 (lower sector), SRWn0 = SRW10 (upper sector) or SRW00 (lower sector)
The ALE pulse in period T5 is only present if the next instruction accesses the RAM (internal or external).

Figure 15. External Data Memory Cycles with SRWn1 = 1 and SRWn0 = 0[1]



Note: 1. SRWn1 = SRW11 (upper sector) or SRW01 (lower sector), SRWn0 = SRW10 (upper sector) or SRW00 (lower sector).
The ALE pulse in period T6 is only present if the next instruction accesses the RAM (internal or external).

Figure 16. External Data Memory Cycles with SRWn1 = 1 and SRWn0 = 1[1]



Note: 1. SRWn1 = SRW11 (upper sector) or SRW01 (lower sector), SRWn0 = SRW10 (upper sector) or SRW00 (lower sector).
The ALE pulse in period T7 is only present if the next instruction accesses the RAM (internal or external).

XMEM Register Description

MCU Control Register – MCUCR

Bit	7	6	5	4	3	2	1	0	
	SRE	**SRW10**	**SE**	**SM1**	**ISC11**	**ISC10**	**ISC01**	**ISC00**	**MCUCR**
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

- **Bit 7 – SRE: External SRAM/XMEM Enable**

Writing SRE to one enables the External Memory Interface.The pin functions AD7:0, A15:8, ALE, $\overline{WR}$, and $\overline{RD}$ are activated as the alternate pin functions. The SRE bit overrides any pin direction settings in the respective Data Direction Registers. Writing SRE to zero, disables the External Memory Interface and the normal pin and data direction settings are used.

- **Bit 6 – SRW10: Wait State Select Bit**

For a detailed description, see common description for the SRWn bits below (EMCUCR description).

Extended MCU Control Register – EMCUCR

Bit	7	6	5	4	3	2	1	0	
	SM0	**SRL2**	**SRL1**	**SRL0**	**SRW01**	**SRW00**	**SRW11**	**ISC2**	**EMCUCR**
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

- **Bit 6..4 – SRL2, SRL1, SRL0: Wait State Sector Limit**

It is possible to configure different wait-states for different external memory addresses. The external memory address space can be divided in two sectors that have separate wait-state bits. The SRL2, SRL1, and SRL0 bits select the splitting of these sectors, see Table 2 and Figure 11. By default, the SRL2, SRL1, and SRL0 bits are set to zero and the entire external memory address space is treated as one sector. When the entire

SRAM address space is configured as one sector, the wait-states are configured by the SRW11 and SRW10 bits.

Table 2. Sector Limits with Different Settings of SRL2..0

SRL2	SRL1	SRL0	Sector Limits
0	0	0	Lower sector = N/A Upper sector = 0x1100 - 0xFFFF
0	0	1	Lower sector = 0x1100 - 0x1FFF Upper sector = 0x2000 - 0xFFFF
0	1	0	Lower sector = 0x1100 - 0x3FFF Upper sector = 0x4000 - 0xFFFF
0	1	1	Lower sector = 0x1100 - 0x5FFF Upper sector = 0x6000 - 0xFFFF
1	0	0	Lower sector = 0x1100 - 0x7FFF Upper sector = 0x8000 - 0xFFFF
1	0	1	Lower sector = 0x1100 - 0x9FFF Upper sector = 0xA000 - 0xFFFF
1	1	0	Lower sector = 0x1100 - 0xBFFF Upper sector = 0xC000 - 0xFFFF
1	1	1	Lower sector = 0x1100 - 0xDFFF Upper sector = 0xE000 - 0xFFFF

- **Bit 1 and Bit 6 MCUCR – SRW11, SRW10: Wait-state Select Bits for Upper Sector**

The SRW11 and SRW10 bits control the number of wait-states for the upper sector of the external memory address space, see Table 3.

- **Bit 3..2 – SRW01, SRW00: Wait-state Select Bits for Lower Sector**

The SRW01 and SRW00 bits control the number of wait-states for the lower sector of the external memory address space, see Table 3.

Table 3. Wait-states(1)

SRWn1	SRWn0	Wait-states
0	0	No wait-states
0	1	Wait one cycle during read/write strobe
1	0	Wait two cycles during read/write strobe
1	1	Wait two cycles during read/write and wait one cycle before driving out new address

Note: 1. n = 0 or 1 (lower/upper sector).
For further details of the timing and wait-states of the External Memory Interface, see Figure 13 to Figure 16 how the setting of the SRW bits affects the timing.

Special Function IO Register – SFIOR

Bit	7	6	5	4	3	2	1	0	
	TSM	XMBK	XMM2	XMM1	XMM0	PUD	PSR2	PSR310	SFIOR
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

- **Bit 6 – XMBK: External Memory Bus Keeper Enable**

Writing XMBK to one enables the Bus Keeper on the AD7:0 lines. When the Bus Keeper is enabled, AD7:0 will keep the last driven value on the lines even if the XMEM interface has tri-stated the lines. Writing XMBK to zero disables the Bus Keeper. XMBK is not qualified with SRE, so even if the XMEM interface is disabled, the bus keepers are still activated as long as XMBK is one.

- **Bit 6..3 – XMM2, XMM1, XMM0: External Memory High Mask**

When the External Memory is enabled, all Port C pins are used for the high address byte by default. If the full 60KB address space is not required to access the external memory, some, or all, Port C pins can be released for normal Port Pin function as described in Table 4. As described in “Using all 64KB Locations of External Memory” on page 32, it is possible to use the XMMn bits to access all 64KB locations of the external memory.

Table 4. Port C Pins Released as Normal Port Pins when the External Memory is Enabled

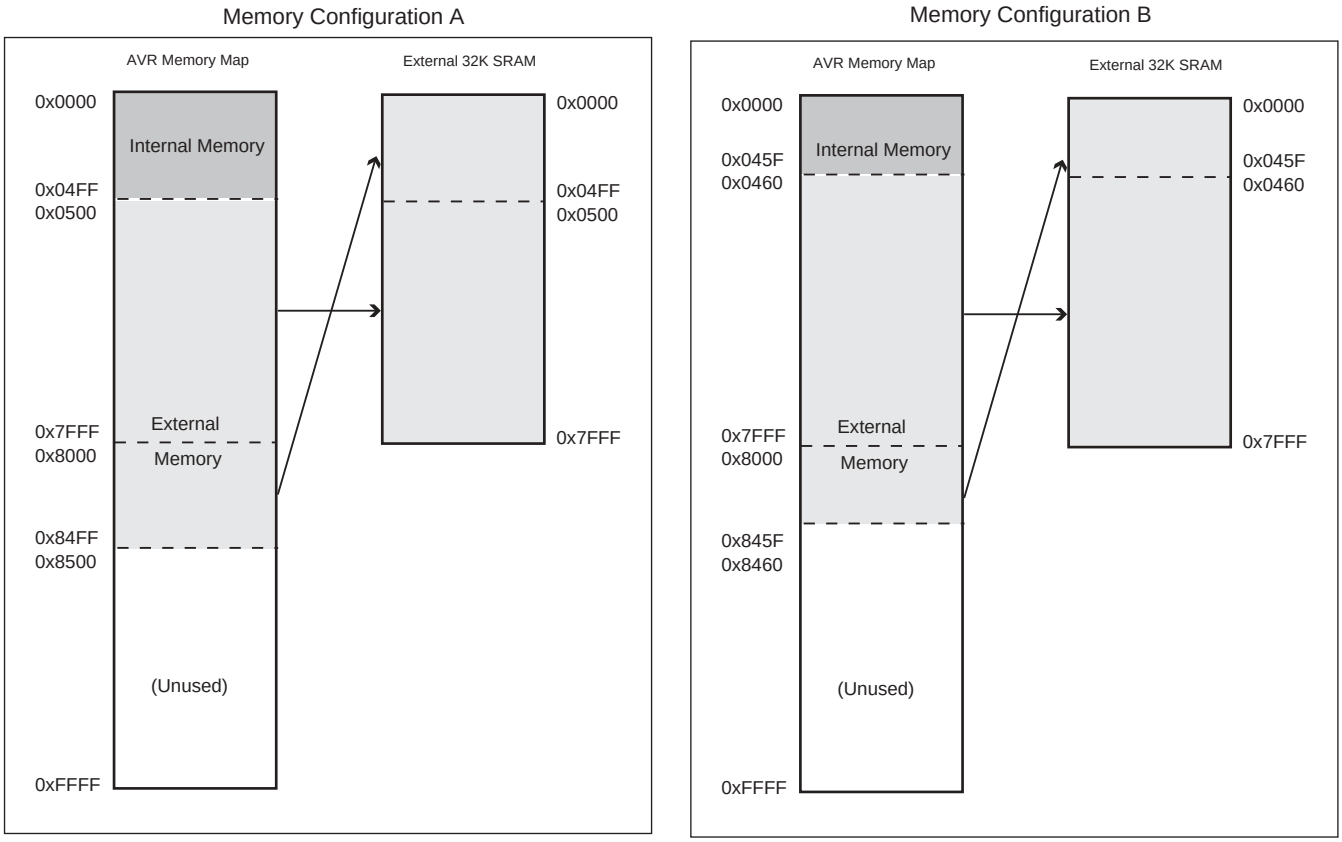
XMM2	XMM1	XMM0	# Bits for External Memory Address	Released Port Pins
0	0	0	8 (Full 60 KB space)	None
0	0	1	7	PC7
0	1	0	6	PC7 - PC6
0	1	1	5	PC7 - PC5
1	0	0	4	PC7 - PC4
1	0	1	3	PC7 - PC3
1	1	0	2	PC7 - PC2
1	1	1	No Address high bits	Full Port C

Using all Locations of External Memory Smaller than 64 KB

Since the external memory is mapped after the internal memory as shown in Figure 11, the external memory is not addressed when addressing the first 1,280 bytes of data space. It may appear that the first 1,280 bytes of the external memory are inaccessible (external memory addresses 0x0000 to 0x04FF). However, when connecting an external memory smaller than 64 KB, for example 32 KB, these locations are easily accessed simply by addressing from address 0x8000 to 0x84FF. Since the External Memory Address bit A15 is not connected to the external memory, addresses 0x8000 to 0x84FF will appear as addresses 0x0000 to 0x04FF for the external memory. Addressing above address 0x84FF is not recommended, since this will address an external memory location that is already accessed by another (lower) address. To the Application software, the external 32 KB memory will appear as one linear 32 KB address space from 0x0500 to 0x84FF. This is illustrated in Figure 17. Memory configuration B refers to the ATmega161 compatibility mode, configuration A to the non-compatible mode.

When the device is set in ATmega161 compatibility mode, the internal address space is 1,120 bytes. This implies that the first 1,120 bytes of the external memory can be accessed at addresses 0x8000 to 0x845F. To the Application software, the external 32 KB memory will appear as one linear 32 KB address space from 0x0460 to 0x845F.

Figure 17. Address Map with 32 KB External Memory



Using all 64KB Locations of External Memory

Since the external memory is mapped after the internal memory as shown in Figure 11, only 64,256 Bytes of external memory are available by default (address space 0x0000 to 0x05FF is reserved for internal memory). However, it is possible to take advantage of the entire external memory by masking the higher address bits to zero. This can be done by using the XMMn bits and control by software the most significant bits of the address. By setting Port C to output 0x00, and releasing the most significant bits for normal Port Pin operation, the Memory Interface will address 0x0000 - 0x1FFF. See code example below.

Assembly Code Example[1]

```
; OFFSET is defined to 0x2000 to ensure
; external memory access
; Configure Port C (address high byte) to
; output 0x00 when the pins are released
; for normal Port Pin operation
ldi   r16, 0xFF
out   DDRC, r16
ldi   r16, 0x00
out   PORTC, r16
; release PC7:5
ldi   r16, (1<<XMM1)|(1<<XMM0)
out   SFIOR, r16
; write 0xAA to address 0x0001 of external
; memory
ldi   r16, 0xaa
sts   0x0001+OFFSET, r16
; re-enable PC7:5 for external memory
ldi   r16, (0<<XMM1)|(0<<XMM0)
out   SFIOR, r16
; store 0x55 to address (OFFSET + 1) of
; external memory
ldi   r16, 0x55
sts   0x0001+OFFSET, r16
```

C Code Example[1]

```
#define OFFSET 0x2000

void XRAM_example(void)
{
unsigned char *p = (unsigned char *) (OFFSET + 1);

DDRC = 0xFF;
PORTC = 0x00;

SFIOR = (1<<XMM1) | (1<<XMM0);

*p = 0xaa;

SFIOR = 0x00;

*p = 0x55;
}
```

Note: 1. The example code assumes that the part specific header file is included.

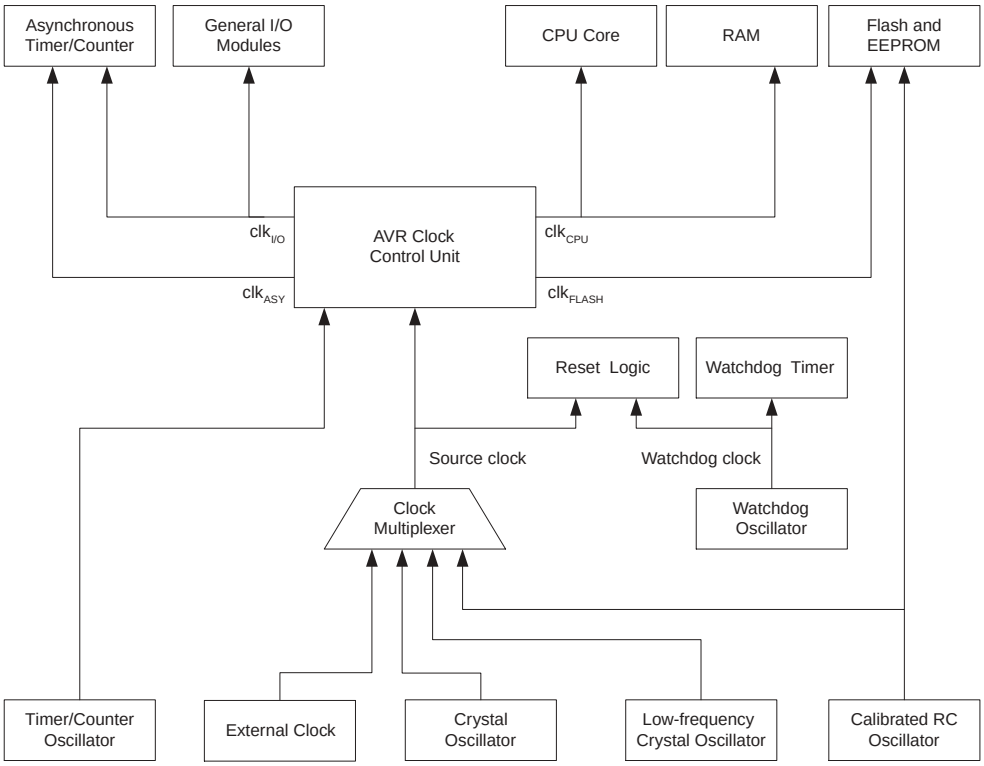
Care must be exercised using this option as most of the memory is masked away.

System Clock and Clock Options

Clock Systems and their Distribution

Figure 18 presents the principal clock systems in the AVR and their distribution. All of the clocks need not be active at a given time. In order to reduce power consumption, the clocks to modules not being used can be halted by using different sleep modes, as described in “Power Management and Sleep Modes” on page 41. The clock systems are detailed below.

Figure 18. Clock Distribution



CPU clock – clk_{CPU}

The CPU clock is routed to parts of the system concerned with operation of the AVR core. Examples of such modules are the General Purpose Register File, the Status Register and the data memory holding the Stack Pointer. Halting the CPU clock inhibits the core from performing general operations and calculations.

I/O clock – $clk_{I/O}$

The I/O clock is used by the majority of the I/O modules, like Timer/Counters, SPI, and USART. The I/O clock is also used by the External Interrupt module, but note that some external interrupts are detected by asynchronous logic, allowing such interrupts to be detected even if the I/O clock is halted.

Flash clock – clk_{FLASH}

The Flash clock controls operation of the Flash interface. The Flash clock is usually active simultaneously with the CPU clock.

Asynchronous Timer clock – clk_{ASY}

The Asynchronous Timer clock allows the Asynchronous Timer/Counter to be clocked directly from an external 32 kHz clock crystal. The dedicated clock domain allows using this Timer/Counter as a realtime counter even when the device is in sleep mode.

Clock Sources

The device has the following clock source options, selectable by Flash Fuse bits as shown below. The clock from the selected source is input to the AVR clock generator, and routed to the appropriate modules.

Table 5. Device Clocking Options Select

Device Clocking Option	CKSEL3..0
External Crystal/Ceramic Resonator	1111 - 1000
External Low-frequency Crystal	0111 - 0100
Calibrated Internal RC Oscillator	0010
External Clock	0000
Reserved	0011, 0001

Note: For all fuses “1” means unprogrammed while “0” means programmed.

The various choices for each clocking option is given in the following sections. When the CPU wakes up from Power-down or Power-save, the selected clock source is used to time the start-up, ensuring stable Oscillator operation before instruction execution starts. When the CPU starts from Reset, there is an additional delay allowing the power to reach a stable level before commencing normal operation. The Watchdog Oscillator is used for timing this realtime part of the start-up time. The number of WDT Oscillator cycles used for each Time-out is shown in Table 6. The frequency of the Watchdog Oscillator is voltage dependent as shown in “ATmega162 Typical Characteristics” on page 274.

Table 6. Number of Watchdog Oscillator Cycles

Typ Time-out (V_{CC} = 5.0V)	Typ Time-out (V_{CC} = 3.0V)	Number of Cycles
4.1 ms	4.3 ms	4K (4,096)
65 ms	69 ms	64K (65,536)

Default Clock Source

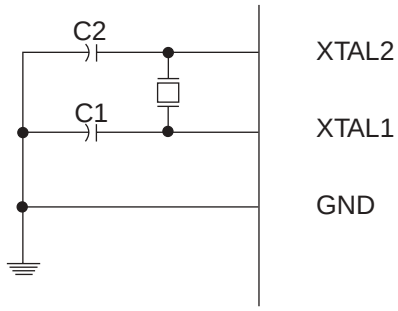
The device is shipped with CKSEL = “0010”, SUT = “10” and CKDIV8 programmed. The default clock source setting is therefore the Internal RC Oscillator with longest startup time and an initial system clock prescaling of 8. This default setting ensures that all users can make their desired clock source setting using an In-System or Parallel programmer.

Crystal Oscillator

XTAL1 and XTAL2 are input and output, respectively, of an inverting amplifier which can be configured for use as an On-chip Oscillator, as shown in Figure 19. Either a quartz crystal or a ceramic resonator may be used.

C1 and C2 should always be equal for both crystals and resonators. The optimal value of the capacitors depends on the crystal or resonator in use, the amount of stray capacitance, and the electromagnetic noise of the environment. Some initial guidelines for choosing capacitors for use with crystals are given in Table 7. For ceramic resonators, the capacitor values given by the manufacturer should be used.

Figure 19. Crystal Oscillator Connections



The Oscillator can operate in four different modes, each optimized for a specific frequency range. The operating mode is selected by the fuses CKSEL3:1 as shown in Table 7.

Table 7. Crystal Oscillator Operating Modes

CKSEL3:1	Frequency Range (MHz)	Recommended Range for Capacitors C1 and C2 for Use with Crystals (pF)
100[1]	0.4 - 0.9	–
101	0.9 - 3.0	12 - 22
110	3.0 - 8.0	12 - 22
111	8.0 -	12 - 22

Note: 1. This option should not be used with crystals, only with ceramic resonators.

The CKSEL0 Fuse together with the SUT1..0 Fuses select the start-up times as shown in Table 8.

Table 8. Start-up Times for the Crystal Oscillator Clock Selection

CKSEL0	SUT1:0	Start-up Time from Power-down and Power-save	Additional Delay from Reset (V_{CC} = 5.0V)	Recommended Usage
0	00	258 CK[1]	4.1 ms	Ceramic resonator, fast rising power
0	01	258 CK[1]	65 ms	Ceramic resonator, slowly rising power
0	10	1K CK[2]	–	Ceramic resonator, BOD enabled
0	11	1K CK[2]	4.1 ms	Ceramic resonator, fast rising power
1	00	1K CK[2]	65 ms	Ceramic resonator, slowly rising power
1	01	16K CK	–	Crystal Oscillator, BOD enabled
1	10	16K CK	4.1 ms	Crystal Oscillator, fast rising power
1	11	16K CK	65 ms	Crystal Oscillator, slowly rising power

Notes: 1. These options should only be used when not operating close to the maximum frequency of the device, and only if frequency stability at start-up is not important for the application. These options are not suitable for crystals.
2. These options are intended for use with ceramic resonators and will ensure frequency stability at start-up. They can also be used with crystals when not operating close to the maximum frequency of the device, and if frequency stability at start-up is not important for the application.

Low-frequency Crystal Oscillator

To use a 32.768 kHz watch crystal as the clock source for the device, the Low-frequency Crystal Oscillator must be selected by setting the CKSEL Fuses to “0100”, “0101”, “0110” or “0111”. The crystal should be connected as shown in Figure 19. If CKSEL equals “0110” or “0111”, the internal capacitors on XTAL1 and XTAL2 are enabled, thereby removing the need for external capacitors. The internal capacitors have a nominal value of 10 pF.

When this Oscillator is selected, start-up times are determined by the SUT Fuses (real time-out from Reset) and CKSEL0 (number of clock cycles) as shown in Table 9 and Table 10.

Table 9. Start-up Delay from Reset when Low-frequency Crystal Oscillator is Selected

SUT1:0	Additional Delay from Reset (V_{CC} = 5.0V)	Recommended Usage
00	0 ms	Fast rising power or BOD enabled
01	4.1 ms	Fast rising power or BOD enabled
10	65 ms	Slowly rising power
11	Reserved	

Table 10. Start-up Times for the Low-frequency Crystal Oscillator Clock Selection

CKSEL1:0	Internal Capacitors Enabled?	Start-up Time from Power-down and Power-save	Recommended Usage
00(1)	No	1K CK	
01	No	32K CK	Stable Frequency at start-up
10(1)	Yes	1K CK	
11	Yes	32K CK	Stable Frequency at start-up

Note: 1. These options should only be used if frequency stability at start-up is not important for the application.

Calibrated Internal RC Oscillator

The calibrated internal RC Oscillator provides a fixed 8.0 MHz clock. The frequency is nominal value at 3V and 25°C. If 8.0 MHz frequency exceed the specification of the device (depends on V_{CC}), the CKDIV8 Fuse must be programmed in order to divide the internal frequency by 8 during start-up. See “System Clock Prescaler” on page 39 for more details. This clock may be selected as the system clock by programming the CKSEL Fuses as shown in Table 11. If selected, it will operate with no external components. During Reset, hardware loads the calibration byte into the OSCCAL Register and thereby automatically calibrates the RC Oscillator. At 3V and 25°C, this calibration gives a frequency within ± 10% of the nominal frequency. Using run-time calibration methods as described in application notes available at www.atmel.com/avr it is possible to achieve ± 2% accuracy at any given V_{CC} and Temperature. When this Oscillator is used as the chip clock, the Watchdog Oscillator will still be used for the Watchdog Timer and

for the Reset Time-out. For more information on the pre-programmed calibration value, see the section “Calibration Byte” on page 233.

Table 11. Internal Calibrated RC Oscillator Operating Modes

CKSEL3:0	Nominal Frequency
0010(1)	8.0 MHz

Note: 1. The device is shipped with this option selected.

When this Oscillator is selected, start-up times are determined by the SUT Fuses as shown in Table 12. XTAL1 and XTAL2 should be left unconnected (NC).

Table 12. Start-up Times for the Internal Calibrated RC Oscillator Clock Selection

SUT1:0	Start-up Time from Power-down and Power-save	Additional Delay from Reset (V_{CC} = 5.0V)	Recommended Usage
00	6 CK	–	BOD enabled
01	6 CK	4.1 ms	Fast rising power
10(1)	6 CK	65 ms	Slowly rising power
11	Reserved		

Note: 1. The device is shipped with this option selected.

Oscillator Calibration Register – OSCCAL

Bit	7	6	5	4	3	2	1	0	
	–	CAL6	CAL5	CAL4	CAL3	CAL2	CAL1	CAL0	OSCCAL
Read/Write	R	R/W	R/W	R/W	R/W	R/W	R/W	R/W	
Initial Value	0	Device Specific Calibration Value							

- **Bit 7 – Res: Reserved Bit**

This bit is reserved bit in the ATmega162, and will always read as zero.

- **Bits 6..0 – CAL6..0: Oscillator Calibration Value**

Writing the calibration byte to this address will trim the Internal Oscillator to remove process variations from the Oscillator frequency. This is done automatically during Chip Reset. When OSCCAL is zero, the lowest available frequency is chosen. Writing non-zero values to this register will increase the frequency of the Internal Oscillator. Writing 0x7F to the register gives the highest available frequency. The calibrated Oscillator is used to time EEPROM and Flash access. If EEPROM or Flash is written, do not calibrate to more than 10% above the nominal frequency. Otherwise, the EEPROM or Flash write may fail.

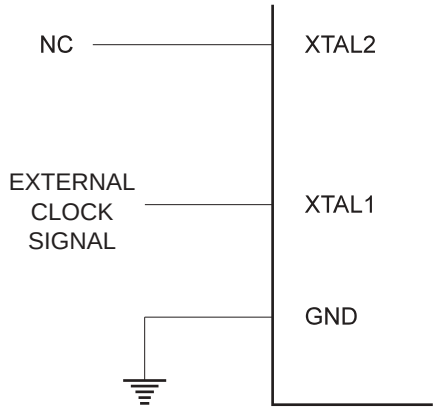
Table 13. Internal RC Oscillator Frequency Range.

OSCCAL Value	Min Frequency in Percentage of Nominal Frequency	Max Frequency in Percentage of Nominal Frequency
0x00	50%	100%
0x3F	75%	150%
0x7F	100%	200%

External Clock

To drive the device from an external clock source, XTAL1 should be driven as shown in Figure 20. To run the device on an external clock, the CKSEL Fuses must be programmed to “0000”.

Figure 20. External Clock Drive Configuration



When this clock source is selected, start-up times are determined by the SUT Fuses as shown in Table 14.

Table 14. Start-up Times for the External Clock Selection

SUT1..0	Start-up Time from Power-down and Power-save	Additional Delay from Reset (V_{CC} = 5.0V)	Recommended Usage
00	6 CK	–	BOD enabled
01	6 CK	4.1 ms	Fast rising power
10	6 CK	65 ms	Slowly rising power
11	Reserved		

When applying an external clock, it is required to avoid sudden changes in the applied clock frequency to ensure stable operation of the MCU. A variation in frequency of more than 2% from one clock cycle to the next can lead to unpredictable behavior. It is required to ensure that the MCU is kept in reset during such changes in the clock frequency.

Note that the System Clock Prescaler can be used to implement run-time changes of the internal clock frequency while still ensuring stable operation. Refer to “System Clock Prescaler” on page 39 for details.

Clock output buffer

When the CKOUT Fuse is programmed, the system clock will be output on PortB 0. This mode is suitable when chip clock is used to drive other circuits on the system. The clock

will be output also during Reset and the normal operation of PortB will be overridden when the fuse is programmed. Any clock sources, including Internal RC Oscillator, can be selected when PortB 0 serves as clock output.

If the system clock prescaler is used, it is the divided system clock that is output when the CKOUT Fuse is programmed. See “System Clock Prescaler” on page 39. for a description of the system clock prescaler.

Timer/Counter Oscillator

For AVR microcontrollers with Timer/Counter Oscillator pins (TOSC1 and TOSC2), the crystal is connected directly between the pins. The Oscillator provides internal capacitors on TOSC1 and TOSC2, thereby removing the need for external capacitors. The internal capacitors have a nominal value of 10 pF. The Oscillator is optimized for use with a 32.768 kHz watch crystal. Applying an external clock source to TOSC1 is not recommended.

System Clock Prescaler

The ATmega162 system clock can be divided by setting the Clock Prescale Register – CLKPR. This feature can be used to decrease power consumption when the requirement for processing power is low. This can be used with all clock source options, and it will affect the clock frequency of the CPU and all synchronous peripherals. $clk_{I/O}$, clk_{CPU}, and clk_{FLASH} are divided by a factor as shown in Table 15. Note that the clock frequency of clk_{ASY} (asynchronously Timer/Counter) only will be scaled if the Timer/Counter is clocked synchronously.

Clock Prescale Register – CLKPR

Bit	7	6	5	4	3	2	1	0	
	CLKPCE	–	–	–	CLKPS3	CLKPS2	CLKPS1	CLKPS0	CLKPR
Read/Write	R/W	R	R	R	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	0	See Bit Description				

- **Bit 7 – CLKPCE: Clock Prescaler Change Enable**

The CLKPCE bit must be written to logic one to enable change of the CLKPS bits. CLKPCE is cleared by hardware four cycles after it is written or when CLKPS is written. Setting the CLKPCE bit will disable interrupts, as explained in the CLKPS description below.

- **Bits 3..0 – CLKPS3..0: Clock Prescaler Select Bits 3 - 0**

These bits define the division factor between the selected clock source and the internal system clock. These bits can be written run-time to vary the clock frequency to suit the application requirements. As the divider divides the master clock input to the MCU, the speed of all synchronous peripherals is reduced when a division factor is used. The division factors are given in Table 15.

To avoid unintentional changes of clock frequency, a special write procedure must be followed to change the CLKPS bits:

1. Write the Clock Prescaler Change Enable (CLKPCE) bit to one and all other bits in CLKPR to zero.
2. Within four cycles, write the desired value to CLKPS while writing a zero to CLKPCE.

Caution: An interrupt between step 1 and step 2 will make the timed sequence fail. It is recommended to have the Global Interrupt Flag cleared during these steps to avoid this problem.

The CKDIV8 Fuse determines the initial value of the CLKPS bits. If CKDIV8 is unprogrammed, the CLKPS bits will be reset to “0000”. If CKDIV8 is programmed, CLKPS bits are reset to “0011”, giving a division factor of 8 at start up. This feature should be used if the selected clock source has a higher frequency than the maximum frequency of the device at the present operating conditions. Note that any value can be written to the CLKPS bits regardless of the CKDIV8 Fuse setting. The Application software must ensure that a sufficient division factor is chosen if the selected clock source has a higher frequency than the maximum frequency of the device at the present operating conditions. The device is shipped with the CKDIV8 Fuse programmed.

Table 15. Clock Prescaler Select

CLKPS3	CLKPS2	CLKPS1	CLKPS0	Clock Division Factor
0	0	0	0	1
0	0	0	1	2
0	0	1	0	4
0	0	1	1	8
0	1	0	0	16
0	1	0	1	32
0	1	1	0	64
0	1	1	1	128
1	0	0	0	256
1	0	0	1	Reserved
1	0	1	0	Reserved
1	0	1	1	Reserved
1	1	0	0	Reserved
1	1	0	1	Reserved
1	1	1	0	Reserved
1	1	1	1	Reserved

Power Management and Sleep Modes

Sleep modes enable the application to shut down unused modules in the MCU, thereby saving power. The AVR provides various sleep modes allowing the user to tailor the power consumption to the application's requirements.

To enter any of the five sleep modes, the SE bit in MCUCR must be written to logic one and a SLEEP instruction must be executed. The SM2 bit in MCUCSR, the SM1 bit in MCUCR, and the SM0 bit in the EMCUCR Register select which sleep mode (Idle, Power-down, Power-save, Standby, or Extended Standby) will be activated by the SLEEP instruction. See Table 16 for a summary. If an enabled interrupt occurs while the MCU is in a sleep mode, the MCU wakes up. The MCU is then halted for four cycles in addition to the start-up time, executes the interrupt routine, and resumes execution from the instruction following SLEEP. The contents of the Register File and SRAM are unaltered when the device wakes up from sleep. If a Reset occurs during sleep mode, the MCU wakes up and executes from the Reset Vector.

Figure 18 on page 33 presents the different clock systems in the ATmega162, and their distribution. The figure is helpful in selecting an appropriate sleep mode.

MCU Control Register – MCUCR

Bit	7	6	5	4	3	2	1	0	
	SRE	SRW10	SE	SM1	ISC11	ISC10	ISC01	ISC00	MCUCR
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

- **Bit 5 – SE: Sleep Enable**

The SE bit must be written to logic one to make the MCU enter the sleep mode when the SLEEP instruction is executed. To avoid the MCU entering the sleep mode unless it is the programmer's purpose, it is recommended to write the Sleep Enable (SE) bit to one just before the execution of the SLEEP instruction and to clear it immediately after waking up.

- **Bit 4 – SM1: Sleep Mode Select Bit 1**

The Sleep Mode Select bits select between the five available sleep modes as shown in Table 16.

MCU Control and Status Register – MCUCSR

Bit	7	6	5	4	3	2	1	0	
	JTD	–	SM2	JTRF	WDRF	BORF	EXTRF	PORF	MCUCSR
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

- **Bit 5 – SM2: Sleep Mode Select Bit 2**

The Sleep Mode Select bits select between the five available sleep modes as shown in Table 16.

Extended MCU Control Register – EMCUCR

Bit	7	6	5	4	3	2	1	0	
	SM0	SRL2	SRL1	SRL0	SRW01	SRW00	SRW11	ISC2	EMCUCR
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

- **Bit 7 – SM0: Sleep Mode Select Bit 0**

The Sleep Mode Select bits select between the five available sleep modes as shown in Table 16.

Table 16. Sleep Mode Select

SM2	SM1	SM0	Sleep Mode
0	0	0	Idle
0	0	1	Reserved
0	1	0	Power-down
0	1	1	Power-save
1	0	0	Reserved
1	0	1	Reserved
1	1	0	Standby(1)
1	1	1	Extended Standby(1)

Note: 1. Standby mode and Extended Standby mode are only available with external crystals or resonators.

Idle Mode

When the SM2..0 bits are written to 000, the SLEEP instruction makes the MCU enter Idle mode, stopping the CPU but allowing the SPI, USART, Analog Comparator, Timer/Counters, Watchdog, and the interrupt system to continue operating. This sleep mode basically halts clk_{CPU} and clk_{FLASH}, while allowing the other clocks to run.

Idle mode enables the MCU to wake up from external triggered interrupts as well as internal ones like the Timer Overflow and USART Transmit Complete interrupts. If wake-up from the Analog Comparator interrupt is not required, the Analog Comparator can be powered down by setting the ACD bit in the Analog Comparator Control and Status Register – ACSR. This will reduce power consumption in Idle mode.

Power-down Mode

When the SM2..0 bits are written to 010, the SLEEP instruction makes the MCU enter Power-down mode. In this mode, the external Oscillator is stopped, while the external interrupts and the Watchdog continue operating (if enabled). Only an External Reset, a Watchdog Reset, a Brown-out Reset, an External Level Interrupt on INT0 or INT1, an external interrupt on INT2, or a pin change interrupt can wake up the MCU. This sleep mode basically halts all generated clocks, allowing operation of asynchronous modules only.

Note that if a level triggered interrupt is used for wake-up from Power-down mode, the changed level must be held for some time to wake up the MCU. Refer to “External Interrupts” on page 83 for details.

When waking up from Power-down mode, there is a delay from the wake-up condition occurs until the wake-up becomes effective. This allows the clock to restart and become stable after having been stopped. The wake-up period is defined by the same CKSEL Fuses that define the Reset Time-out period, as described in “Clock Sources” on page 34.

Power-save Mode

When the SM2..0 bits are written to 011, the SLEEP instruction makes the MCU enter Power-save mode. This mode is identical to Power-down, with one exception:

If Timer/Counter2 is clocked asynchronously, i.e., the AS2 bit in ASSR is set, Timer/Counter2 will run during sleep. The device can wake up from either Timer Overflow or Output Compare event from Timer/Counter2 if the corresponding Timer/Counter2 interrupt enable bits are set in TIMSK, and the Global Interrupt Enable bit in SREG is set.

If the Asynchronous Timer is NOT clocked asynchronously, Power-down mode is recommended instead of Power-save mode because the contents of the registers in the Asynchronous Timer should be considered undefined after wake-up in Power-save mode if AS2 is 0.

This sleep mode basically halts all clocks except clk_{ASY}, allowing operation only of asynchronous modules, including Timer/Counter 2 if clocked asynchronously.

Standby Mode

When the SM2..0 bits are 110 and an external crystal/resonator clock option is selected, the SLEEP instruction makes the MCU enter Standby mode. This mode is identical to Power-down with the exception that the main Oscillator is kept running. From Standby mode, the device wakes up in six clock cycles.

Extended Standby Mode

When the SM2..0 bits are 111 and an external crystal/resonator clock option is selected, the SLEEP instruction makes the MCU enter Extended Standby mode. This mode is identical to Power-save mode with the exception that the main Oscillator is kept running. From Extended Standby mode, the device wakes up in six clock cycles.

Table 17. Active Clock domains and Wake up sources in the different sleep modes

	Active Clock domains				Oscillators		Wake-up Sources			
Sleep Mode	clk_{CPU}	clk_{FLASH}	clk_{IO}	clk_{ASY}	Main Clock Source Enabled	Timer Osc Enabled	INT2 INT1 INT0 and Pin Change	Timer2	SPM/ EEPROM Ready	Other I/O
Idle			X	X	X	X(2)	X	X	X	X
Power-down							X(3)			
Power-save				X(2)		X(2)	X(3)	X(2)		
Standby(1)					X		X(3)			
Extended Standby(1)				X(2)	X	X(2)	X(3)	X(2)		

Notes: 1. External Crystal or resonator selected as clock source
2. If AS2 bit in ASSR is set
3. For INT1 and INT0, only level interrupt

Minimizing Power Consumption

There are several issues to consider when trying to minimize the power consumption in an AVR controlled system. In general, sleep modes should be used as much as possible, and the sleep mode should be selected so that as few as possible of the device's functions are operating. All functions not needed should be disabled. In particular, the following modules may need special consideration when trying to achieve the lowest possible power consumption.

Analog Comparator

When entering Idle mode, the Analog Comparator should be disabled if not needed. In the other sleep modes, the Analog Comparator is automatically disabled. However, if the Analog Comparator is set up to use the Internal Voltage Reference as input, the Analog Comparator should be disabled in all sleep modes. Otherwise, the Internal Voltage Reference will be enabled, independent of sleep mode. Refer to "Analog Comparator" on page 194 for details on how to configure the Analog Comparator.

Brown-out Detector

If the Brown-out Detector is not needed in the application, this module should be turned off. If the Brown-out Detector is enabled by the BODLEVEL Fuses, it will be enabled in all sleep modes, and hence, always consume power. In the deeper sleep modes, this will contribute significantly to the total current consumption. Refer to "Brown-out Detection" on page 49 for details on how to configure the Brown-out Detector.

Internal Voltage Reference

The Internal Voltage Reference will be enabled when needed by the Brown-out Detector or the Analog Comparator. If these modules are disabled as described in the sections above, the internal voltage reference will be disabled and it will not be consuming power. When turned on again, the user must allow the reference to start up before the output is used. If the reference is kept on in sleep mode, the output can be used immediately. Refer to "Internal Voltage Reference" on page 51 for details on the start-up time.

Watchdog Timer

If the Watchdog Timer is not needed in the application, this module should be turned off. If the Watchdog Timer is enabled, it will be enabled in all sleep modes, and hence, always consume power. In the deeper sleep modes, this will contribute significantly to the total current consumption. Refer to "Watchdog Timer" on page 51 for details on how to configure the Watchdog Timer.

Port Pins

When entering a sleep mode, all port pins should be configured to use minimum power. The most important thing is to ensure that no pins drive resistive loads. In sleep modes where the I/O clock ($clk_{I/O}$) is stopped, the input buffers of the device will be disabled. This ensures that no power is consumed by the input logic when not needed. In some cases, the input logic is needed for detecting wake-up conditions, and it will then be enabled. Refer to the section "Digital Input Enable and Sleep Modes" on page 66 for details on which pins are enabled. If the input buffer is enabled and the input signal is left floating or have an analog signal level close to $V_{CC}/2$, the input buffer will use excessive power.

JTAG Interface and On-chip Debug System

If the On-chip debug system is enabled by the OCDEN Fuse and the chip enter Power down or Power save sleep mode, the main clock source remains enabled. In these sleep modes, this will contribute significantly to the total current consumption. There are three alternative ways to avoid this:

- Disable OCDEN Fuse.
- Disable JTAGEN Fuse.
- Write one to the JTD bit in MCUCSR.

The TDO pin is left floating when the JTAG interface is enabled while the JTAG TAP controller is not shifting data. If the hardware connected to the TDO pin does not pull up

the logic level, power consumption will increase. Note that the TDI pin for the next device in the scan chain contains a pull-up that avoids this problem. Writing the JTD bit in the MCUCSR register to one or leaving the JTAG fuse unprogrammed disables the JTAG interface.

System Control and Reset

Resetting the AVR

During Reset, all I/O Registers are set to their initial values, and the program starts execution from the Reset Vector. The instruction placed at the Reset Vector must be a JMP – Absolute Jump – instruction to the reset handling routine. If the program never enables an interrupt source, the Interrupt Vectors are not used, and regular program code can be placed at these locations. This is also the case if the Reset Vector is in the Application section while the Interrupt Vectors are in the Boot section or vice versa. The circuit diagram in Figure 21 shows the Reset Logic. Table 18 defines the electrical parameters of the reset circuitry.

The I/O ports of the AVR are immediately reset to their initial state when a reset source goes active. This does not require any clock source to be running.

After all reset sources have gone inactive, a delay counter is invoked, stretching the Internal Reset. This allows the power to reach a stable level before normal operation starts. The Time-out period of the delay counter is defined by the user through the CKSEL Fuses. The different selections for the delay period are presented in “Clock Sources” on page 34.

Reset Sources

The ATmega162 has five sources of reset:

- Power-on Reset. The MCU is reset when the supply voltage is below the Power-on Reset threshold (V_{POT}).
- External Reset. The MCU is reset when a low level is present on the $\overline{\text{RESET}}$ pin for longer than the minimum pulse length.
- Watchdog Reset. The MCU is reset when the Watchdog Timer period expires and the Watchdog is enabled.
- Brown-out Reset. The MCU is reset when the supply voltage V_{CC} is below the Brown-out Reset threshold (V_{BOT}) and the Brown-out Detector is enabled. The device is guaranteed to operate at maximum frequency for the V_{CC} voltage down to V_{BOT}. V_{BOT} must be set to the corresponding minimum voltage of the device (i.e., minimum V_{BOT} for ATmega162V is 1.8V).
- JTAG AVR Reset. The MCU is reset as long as there is a logic one in the Reset Register, one of the scan chains of the JTAG system. Refer to the section “IEEE 1149.1 (JTAG) Boundary-scan” on page 203 for details.

Figure 21. Reset Logic

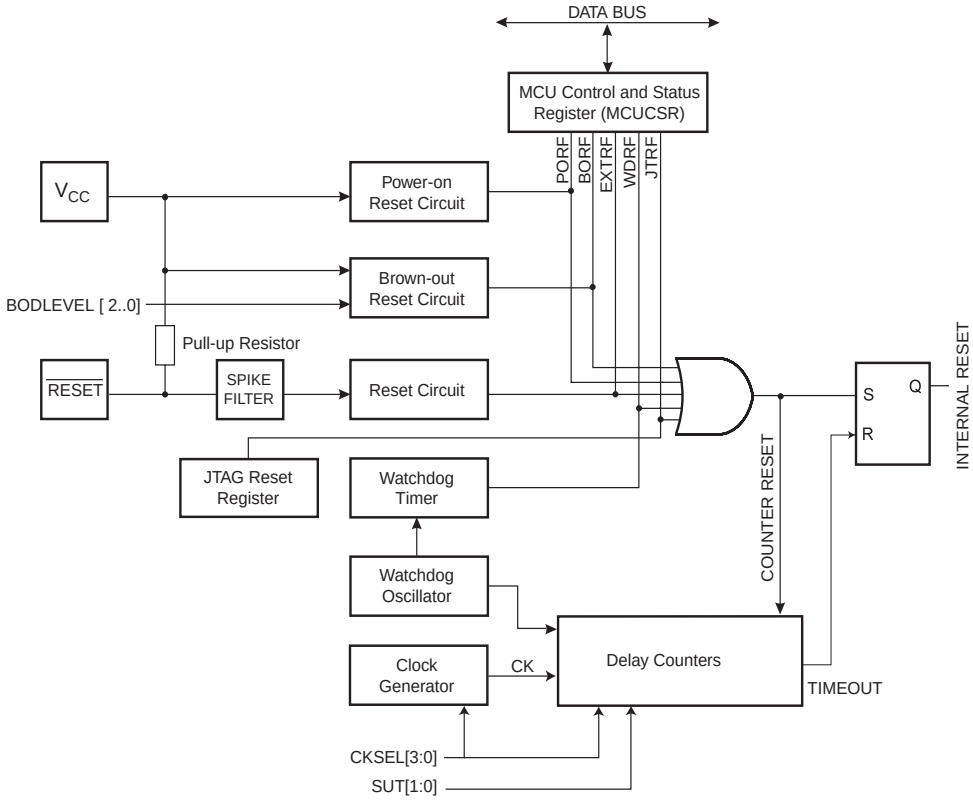


Table 18. Reset Characteristics

Symbol	Parameter	Condition	Min.	Typ.	Max.	Units
V_{POT}	Power-on Reset Threshold Voltage (rising)	T_A = -40 - 85°C	0.7	1.0	1.4	V
	Power-on Reset Threshold Voltage (falling)(1)	T_A = -40 - 85°C	0.6	0.9	1.3	V
V_{RST}	$\overline{\text{RESET}}$ Pin Threshold Voltage	V_{CC} = 3V	0.1 V_{CC}		0.9 V_{CC}	V
t_{RST}	Minimum pulse width on $\overline{\text{RESET}}$ Pin	V_{CC} = 3V			2.5	µs

Note: 1. The Power-on Reset will not work unless the supply voltage has been below V_{POT} (falling)

Power-on Reset

A Power-on Reset (POR) pulse is generated by an On-chip detection circuit. The detection level is defined in Table 18. The POR is activated whenever V_{CC} is below the detection level. The POR circuit can be used to trigger the Start-up Reset, as well as to detect a failure in supply voltage.

A Power-on Reset (POR) circuit ensures that the device is Reset from Power-on. Reaching the Power-on Reset threshold voltage invokes the delay counter, which determines how long the device is kept in RESET after V_{CC} rise. The RESET signal is activated again, without any delay, when V_{CC} decreases below the detection level.

Figure 22. MCU Start-up, $\overline{\text{RESET}}$ Tied to V_{CC}.

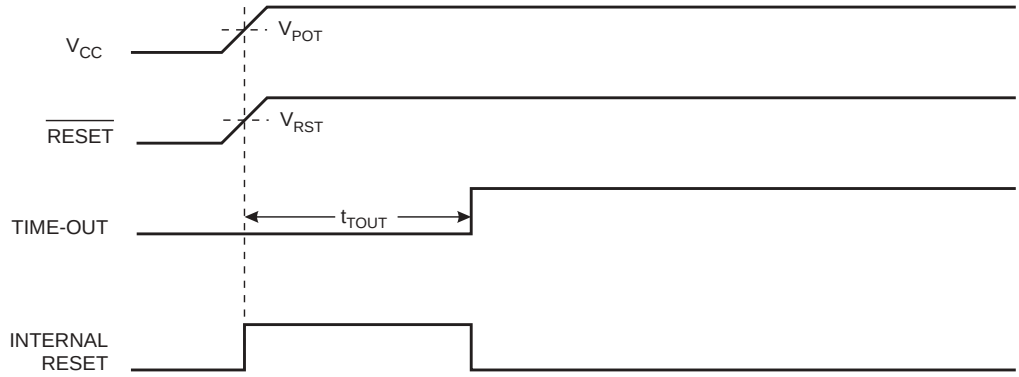
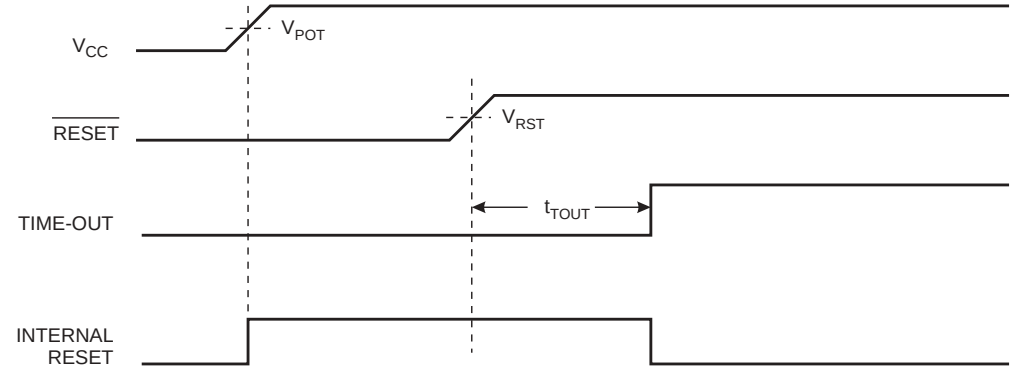


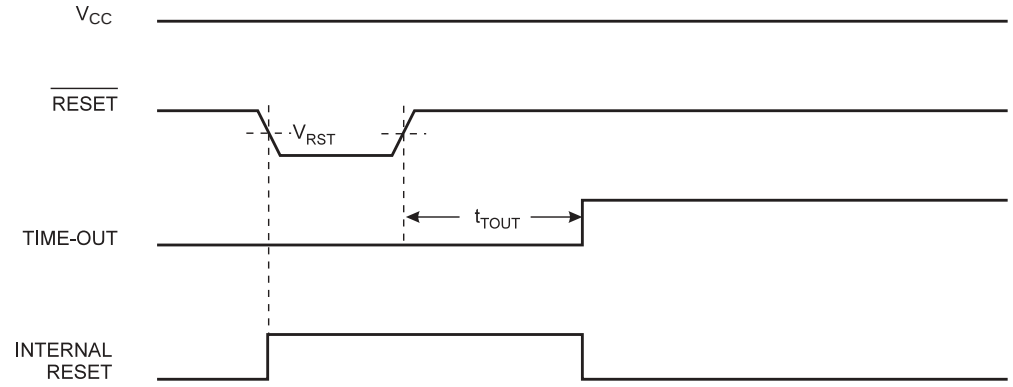
Figure 23. MCU Start-up, $\overline{\text{RESET}}$ Extended Externally



External Reset

An External Reset is generated by a low level on the $\overline{\text{RESET}}$ pin. Reset pulses longer than the minimum pulse width (see Table 18) will generate a Reset, even if the clock is not running. Shorter pulses are not guaranteed to generate a Reset. When the applied signal reaches the Reset Threshold Voltage – V_{RST} on its positive edge, the delay counter starts the MCU after the Time-out period t_{TOUT} has expired.

Figure 24. External Reset During Operation



Brown-out Detection

ATmega162 has an On-chip Brown-out Detection (BOD) circuit for monitoring the V_{CC} level during operation by comparing it to a fixed trigger level. The trigger level for the BOD can be selected by the BODLEVEL Fuses. The trigger level has a hysteresis to ensure spike free Brown-out Detection. The hysteresis on the detection level should be interpreted as $V_{BOT+} = V_{BOT} + V_{HYST}/2$ and $V_{BOT-} = V_{BOT} - V_{HYST}/2$.

Table 19. BODLEVEL Fuse Coding

BODLEVEL Fuses [2:0]	Min. V_{BOT} (1)	Typ. V_{BOT}	Max. V_{BOT}	Units
111	BOD Disabled			
110 (2)	1.7	1.8	2.0	V
101	2.5	2.7	2.9	
100	4.1	4.3	4.5	
011 (2)	2.1	2.3	2.5	
010	Reserved			
001				
000				

Notes: 1. V_{BOT} may be below nominal minimum operating voltage for some devices. For devices where this is the case, the device is tested down to $V_{CC} = V_{BOT}$ during the production test. This guarantees that a Brown-out Reset will occur before V_{CC} drops to a voltage where correct operation of the microcontroller is no longer guaranteed. This test is performed using BODLEVEL = 110 for ATmega162V, BODLEVEL = 101 for ATmega162L, and BODLEVEL = 100 for ATmega162.

2. For ATmega162V. Otherwise reserved.

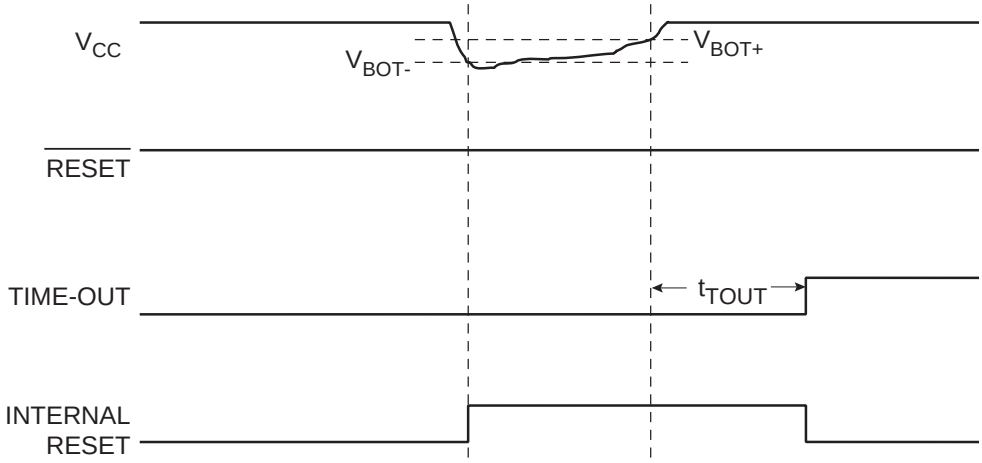
Table 20. Brown-out Hysteresis

Symbol	Parameter	Min.	Typ.	Max.	Units
V_{HYST}	Brown-out Detector hysteresis		50		mV
t_{BOD}	Min Pulse Width on Brown-out Reset		2		µs

When the BOD is enabled and V_{CC} decreases to a value below the trigger level (V_{BOT-} in Figure 25), the Brown-out Reset is immediately activated. When V_{CC} increases above the trigger level (V_{BOT+} in Figure 25), the delay counter starts the MCU after the Time-out period t_{TOUT} has expired.

The BOD circuit will only detect a drop in V_{CC} if the voltage stays below the trigger level for longer than t_{BOD} given in Table 18.

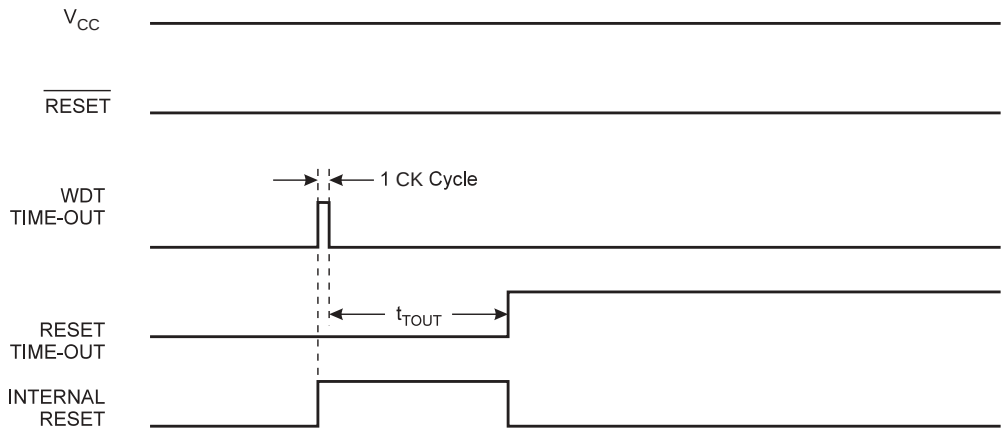
Figure 25. Brown-out Reset During Operation



Watchdog Reset

When the Watchdog times out, it will generate a short reset pulse of one CK cycle duration. On the falling edge of this pulse, the delay timer starts counting the Time-out period t_{TOUT}. Refer to page 51 for details on operation of the Watchdog Timer.

Figure 26. Watchdog Reset During Operation



MCU Control and Status Register – MCUCSR

The MCU Control and Status Register provides information on which reset source caused an MCU Reset.

Bit	7	6	5	4	3	2	1	0	
	JTD	–	SM2	JTRF	WDRF	BORF	EXTRF	PORF	MCUCSR
Read/Write	R/W	R/W	R	R/W	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	See Bit Description					

- **Bit 4 – JTRF: JTAG Reset Flag**

This bit is set if a reset is being caused by a logic one in the JTAG Reset Register selected by the JTAG instruction AVR_RESET. This bit is reset by a Power-on Reset, or by writing a logic zero to the flag.

- **Bit 3 – WDRF: Watchdog Reset Flag**

This bit is set if a Watchdog Reset occurs. The bit is reset by a Power-on Reset, or by writing a logic zero to the flag.

- **Bit 2 – BORF: Brown-out Reset Flag**

This bit is set if a Brown-out Reset occurs. The bit is reset by a Power-on Reset, or by writing a logic zero to the flag.

- **Bit 1 – EXTRF: External Reset Flag**

This bit is set if an External Reset occurs. The bit is reset by a Power-on Reset, or by writing a logic zero to the flag.

- **Bit 0 – PORF: Power-on Reset Flag**

This bit is set if a Power-on Reset occurs. The bit is reset only by writing a logic zero to the flag.

To make use of the Reset Flags to identify a reset condition, the user should read and then Reset the MCUCSR as early as possible in the program. If the register is cleared before another reset occurs, the source of the Reset can be found by examining the Reset Flags.

Internal Voltage Reference

ATmega162 features an internal bandgap reference. This reference is used for Brown-out Detection, and it can be used as an input to the Analog Comparator.

Voltage Reference Enable Signals and Start-up Time

The voltage reference has a start-up time that may influence the way it should be used. The start-up time is given in Table 21. To save power, the reference is not always turned on. The reference is on during the following situations:

1. When the BOD is enabled (by programming the BODLEVEL Fuses).
2. When the bandgap reference is connected to the Analog Comparator (by setting the ACBG bit in ACSR).

Thus, when the BOD is not enabled, after setting the ACBG bit, the user must always allow the reference to start up before the output from the Analog Comparator is used. To reduce power consumption in Power-down mode, the user can avoid the two conditions above to ensure that the reference is turned off before entering Power-down mode.

Table 21. Internal Voltage Reference Characteristics

Symbol	Parameter	Min.	Typ.	Max.	Units
V_{BG}	Bandgap reference voltage	1.05	1.10	1.15	V
t_{BG}	Bandgap reference start-up time		40	70	µs
I_{BG}	Bandgap reference current consumption		10		µA

Watchdog Timer

The Watchdog Timer is clocked from a separate On-chip Oscillator which runs at 1 MHz. This is the typical frequency at V_{CC} = 5V. See characterization data for typical values at other V_{CC} levels. By controlling the Watchdog Timer prescaler, the Watchdog Reset interval can be adjusted as shown in Table 23 on page 53. The WDR – Watchdog Reset – instruction resets the Watchdog Timer. The Watchdog Timer is also reset when it is disabled and when a Chip Reset occurs. Eight different clock cycle periods can be selected to determine the reset period. If the reset period expires without another Watchdog Reset, the ATmega162 resets and executes from the Reset Vector. For timing details on the Watchdog Reset, refer to page 53.

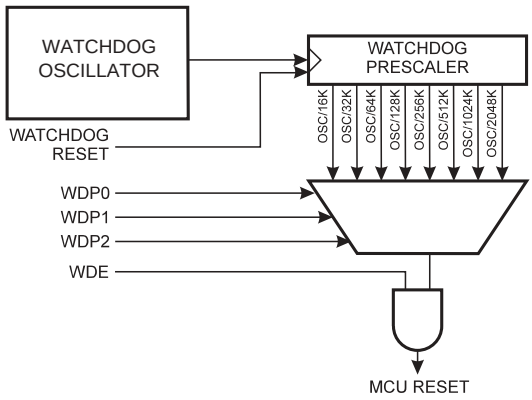
To prevent unintentional disabling of the Watchdog or unintentional change of time-out period, 3 different safety levels are selected by the Fuses M161C and WDTON as

shown in Table 22. Safety level 0 corresponds to the setting in ATmega161. There is no restriction on enabling the WDT in any of the safety levels. Refer to “Timed Sequences for Changing the Configuration of the Watchdog Timer” on page 55 for details.

Table 22. WDT Configuration as a Function of the Fuse Settings of M161C and WDTON.

M161C	WDTON	Safety Level	WDT Initial State	How to Disable the WDT	How to Change Time-out
Unprogrammed	Unprogrammed	1	Disabled	Timed sequence	Timed sequence
Unprogrammed	Programmed	2	Enabled	Always enabled	Timed sequence
Programmed	Unprogrammed	0	Disabled	Timed sequence	No restriction
Programmed	Programmed	2	Enabled	Always enabled	Timed sequence

Figure 27. Watchdog Timer



Watchdog Timer Control Register – WDTCR

Bit	7	6	5	4	3	2	1	0	
	–	–	–	WDCE	WDE	WDP2	WDP1	WDP0	WDTCR
Read/Write	R	R	R	R/W	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

- **Bits 7..5 – Res: Reserved Bits**

These bits are reserved bits in the ATmega162 and will always read as zero.

- **Bit 4 – WDCE: Watchdog Change Enable**

This bit must be set when the WDE bit is written to logic zero. Otherwise, the Watchdog will not be disabled. Once written to one, hardware will clear this bit after four clock cycles. Refer to the description of the WDE bit for a Watchdog disable procedure. In Safety Levels 1 and 2, this bit must also be set when changing the prescaler bits. See “Timed Sequences for Changing the Configuration of the Watchdog Timer” on page 55.

- **Bit 3 – WDE: Watchdog Enable**

When the WDE is written to logic one, the Watchdog Timer is enabled, and if the WDE is written to logic zero, the Watchdog Timer function is disabled. WDE can only be cleared

if the WDCE bit has logic level one. To disable an enabled Watchdog Timer, the following procedure must be followed:

1. In the same operation, write a logic one to WDCE and WDE. A logic one must be written to WDE even though it is set to one before the disable operation starts.
2. Within the next four clock cycles, write a logic 0 to WDE. This disables the Watchdog.

In safety level 2, it is not possible to disable the Watchdog Timer, even with the algorithm described above. See “Timed Sequences for Changing the Configuration of the Watchdog Timer” on page 55.

- **Bits 2..0 – WDP2, WDP1, WDP0: Watchdog Timer Prescaler 2, 1, and 0**

The WDP2, WDP1, and WDP0 bits determine the Watchdog Timer prescaling when the Watchdog Timer is enabled. The different prescaling values and their corresponding Timeout Periods are shown in Table 23.

Table 23. Watchdog Timer Prescale Select

WDP2	WDP1	WDP0	Number of WDT Oscillator Cycles	Typical Time-out at V_{CC} = 3.0V	Typical Time-out at V_{CC} = 5.0V
0	0	0	16K (16,384)	17 ms	16 ms
0	0	1	32K (32,768)	34 ms	33 ms
0	1	0	65K (65,536)	69 ms	65 ms
0	1	1	128K (131,072)	0.14 s	0.13 s
1	0	0	256K (262,144)	0.27 s	0.26 s
1	0	1	512K (524,288)	0.55 s	0.52 s
1	1	0	1,024K (1,048,576)	1.1 s	1.0 s
1	1	1	2,048K (2,097,152)	2.2 s	2.1 s

The following code example shows one assembly and one C function for turning off the WDT. The example assumes that interrupts are controlled (e.g., by disabling interrupts globally) so that no interrupts will occur during execution of these functions.

Assembly Code Example

```
WDT_off:
  ; Reset WDT
  WDR
  ; Write logical one to WDCE and WDE
  in   r16, WDTCR
  ori  r16, (1<<WDCE)|(1<<WDE)
  out  WDTCR, r16
  ; Turn off WDT
  ldi  r16, (0<<WDE)
  out  WDTCR, r16
  ret
```

C Code Example

```
void WDT_off(void)
{
  /* Reset WDT*/
  _WDR()
  /* Write logical one to WDCE and WDE */
  WDTCR |= (1<<WDCE) | (1<<WDE);
  /* Turn off WDT */
  WDTCR = 0x00;
}
```

Timed Sequences for Changing the Configuration of the Watchdog Timer

The sequence for changing configuration differs slightly between the three safety levels. Separate procedures are described for each level.

Safety Level 0

This mode is compatible with the Watchdog operation found in ATmega161. The Watchdog Timer is initially disabled, but can be enabled by writing the WDE bit to one without any restriction. The Time-out period can be changed at any time without restriction. To disable an enabled Watchdog Timer, the procedure described on page 52 (WDE bit description) must be followed.

Safety Level 1

In this mode, the Watchdog Timer is initially disabled, but can be enabled by writing the WDE bit to one without any restriction. A timed sequence is needed when changing the Watchdog Time-out period or disabling an enabled Watchdog Timer. To disable an enabled Watchdog Timer, and/or changing the Watchdog Time-out, the following procedure must be followed:

1. In the same operation, write a logic one to WDCE and WDE. A logic one must be written to WDE regardless of the previous value of the WDE bit.
2. Within the next four clock cycles, in the same operation, write the WDE and WDP bits as desired, but with the WDCE bit cleared.

Safety Level 2

In this mode, the Watchdog Timer is always enabled, and the WDE bit will always read as one. A timed sequence is needed when changing the Watchdog Time-out period. To change the Watchdog Time-out, the following procedure must be followed:

1. In the same operation, write a logical one to WDCE and WDE. Even though the WDE always is set, the WDE must be written to one to start the timed sequence.
2. Within the next four clock cycles, in the same operation, write the WDP bits as desired, but with the WDCE bit cleared. The value written to the WDE bit is irrelevant.

Interrupts

This section describes the specifics of the interrupt handling as performed in ATmega162. For a general explanation of the AVR interrupt handling, refer to “Reset and Interrupt Handling” on page 12. Table 24 shows the interrupt table when the compatibility fuse (M161C) is unprogrammed, while Table 25 shows the interrupt table when M161C Fuse is programmed. All assembly code examples in this sections are using the interrupt table when the M161C Fuse is unprogrammed.

Interrupt Vectors in ATmega162

Table 24. Reset and Interrupt Vectors if M161C is unprogrammed

Vector No.	Program Address(2)	Source	Interrupt Definition
1	0x000(1)	RESET	External Pin, Power-on Reset, Brown-out Reset, Watchdog Reset, and JTAG AVR Reset
2	0x002	INT0	External Interrupt Request 0
3	0x004	INT1	External Interrupt Request 1
4	0x006	INT2	External Interrupt Request 2
5	0x008	PCINT0	Pin Change Interrupt Request 0
6	0x00A	PCINT1	Pin Change Interrupt Request 1
7	0x00C	TIMER3 CAPT	Timer/Counter3 Capture Event
8	0x00E	TIMER3 COMPA	Timer/Counter3 Compare Match A
9	0x010	TIMER3 COMPB	Timer/Counter3 Compare Match B
10	0x012	TIMER3 OVF	Timer/Counter3 Overflow
11	0x014	TIMER2 COMP	Timer/Counter2 Compare Match
12	0x016	TIMER2 OVF	Timer/Counter2 Overflow
13	0x018	TIMER1 CAPT	Timer/Counter1 Capture Event
14	0x01A	TIMER1 COMPA	Timer/Counter1 Compare Match A
15	0x01C	TIMER1 COMPB	Timer/Counter1 Compare Match B
16	0x01E	TIMER1 OVF	Timer/Counter1 Overflow
17	0x020	TIMER0 COMP	Timer/Counter0 Compare Match
18	0x022	TIMER0 OVF	Timer/Counter0 Overflow
19	0x024	SPI, STC	Serial Transfer Complete
20	0x026	USART0, RXC	USART0, Rx Complete
21	0x028	USART1, RXC	USART1, Rx Complete
22	0x02A	USART0, UDRE	USART0 Data Register Empty
23	0x02C	USART1, UDRE	USART1 Data Register Empty
24	0x02E	USART0, TXC	USART0, Tx Complete
25	0x030	USART1, TXC	USART1, Tx Complete
26	0x032	EE_RDY	EEPROM Ready
27	0x034	ANA_COMP	Analog Comparator
28	0x036	SPM_RDY	Store Program Memory Ready

Notes: 1. When the BOOTRST Fuse is programmed, the device will jump to the Boot Loader address at reset, see “Boot Loader Support – Read-While-Write Self-programming” on page 216.
2. When the IVSEL bit in GICR is set, Interrupt Vectors will be moved to the start of the Boot Flash section. The address of each Interrupt Vector will then be the address in this table added to the start address of the Boot Flash section.

Table 25. Reset and Interrupt Vectors if M161C is programmed

Vector No.	Program Address(2)	Source	Interrupt Definition
1	0x000(1)	RESET	External Pin, Power-on Reset, Brown-out Reset, Watchdog Reset, and JTAG AVR Reset
2	0x002	INT0	External Interrupt Request 0
3	0x004	INT1	External Interrupt Request 1
4	0x006	INT2	External Interrupt Request 2
5	0x008	TIMER2 COMP	Timer/Counter2 Compare Match
6	0x00A	TIMER2 OVF	Timer/Counter2 Overflow
7	0x00C	TIMER1 CAPT	Timer/Counter1 Capture Event
8	0x00E	TIMER1 COMPA	Timer/Counter1 Compare Match A
9	0x010	TIMER1 COMPB	Timer/Counter1 Compare Match B
10	0x012	TIMER1 OVF	Timer/Counter1 Overflow
11	0x014	TIMER0 COMP	Timer/Counter0 Compare Match
12	0x016	TIMER0 OVF	Timer/Counter0 Overflow
13	0x018	SPI, STC	Serial Transfer Complete
14	0x01A	USART0, RXC	USART0, Rx Complete
15	0x01C	USART1, RXC	USART1, Rx Complete
16	0x01E	USART0, UDRE	USART0 Data Register Empty
17	0x020	USART1, UDRE	USART1 Data Register Empty
18	0x022	USART0, TXC	USART0, Tx Complete
19	0x024	USART1, TXC	USART1, Tx Complete
20	0x026	EE_RDY	EEPROM Ready
21	0x028	ANA_COMP	Analog Comparator
22	0x02A	SPM_RDY	Store Program Memory Ready

Notes: 1. When the BOOTRST Fuse is programmed, the device will jump to the Boot Loader address at reset, see “Boot Loader Support – Read-While-Write Self-programming” on page 216.
2. When the IVSEL bit in GICR is set, Interrupt Vectors will be moved to the start of the Boot Flash section. The address of each Interrupt Vector will then be the address in this table added to the start address of the Boot Flash section.

Table 26 shows Reset and Interrupt Vectors placement for the various combinations of BOOTRST and IVSEL settings. If the program never enables an interrupt source, the Interrupt Vectors are not used, and regular program code can be placed at these locations. This is also the case if the Reset Vector is in the Application section while the Interrupt Vectors are in the Boot section or vice versa.

Table 26. Reset and Interrupt Vectors Placement(1)

BOOTRST	IVSEL	Reset address	Interrupt Vectors Start Address
1	0	0x0000	0x0002
1	1	0x0000	Boot Reset Address + 0x0002
0	0	Boot Reset Address	0x0002
0	1	Boot Reset Address	Boot Reset Address + 0x0002

Note: 1. The Boot Reset Address is shown in Table 94 on page 228. For the BOOTRST Fuse "1" means unprogrammed while "0" means programmed.

The most typical and general program setup for the Reset and Interrupt Vector Addresses in ATmega162 is:

```
Address   Labels   Code                 Comments
0x000              jmp   RESET          ; Reset Handler
0x002              jmp   EXT_INT0       ; IRQ0 Handler
0x004              jmp   EXT_INT1       ; IRQ1 Handler
0x006              jmp   EXT_INT2       ; IRQ2 Handler
0x008              jmp   PCINT0         ; PCINT0 Handler
0x00A              jmp   PCINT1         ; PCINT1 Handler
0x00C              jmp   TIM3_CAPT      ; Timer3 Capture Handler
0x00E              jmp   TIM3_COMPA     ; Timer3 CompareA Handler
0x010              jmp   TIM3_COMPB     ; Timer3 CompareB Handler
0x012              jmp   TIM3_OVF       ; Timer3 Overflow Handler
0x014              jmp   TIM2_COMP      ; Timer2 Compare Handler
0x016              jmp   TIM2_OVF       ; Timer2 Overflow Handler
0x018              jmp   TIM1_CAPT      ; Timer1 Capture Handler
0x01A              jmp   TIM1_COMPA     ; Timer1 CompareA Handler
0x01C              jmp   TIM1_COMPB     ; Timer1 CompareB Handler
0x01E              jmp   TIM1_OVF       ; Timer1 Overflow Handler
0x020              jmp   TIM0_COMP      ; Timer0 Compare Handler
0x022              jmp   TIM0_OVF       ; Timer0 Overflow Handler
0x024              jmp   SPI_STC        ; SPI Transfer Complete Handler
0x026              jmp   USART0_RXC     ; USART0 RX Complete Handler
0x028              jmp   USART1_RXC     ; USART1 RX Complete Handler
0x02A              jmp   USART0_UDRE    ; UDR0 Empty Handler
0x02C              jmp   USART1_UDRE    ; UDR1 Empty Handler
0x02E              jmp   USART0_TXC     ; USART0 TX Complete Handler
0x030              jmp   USART1_TXC     ; USART1 TX Complete Handler
0x032              jmp   EE_RDY         ; EEPROM Ready Handler
0x034              jmp   ANA_COMP       ; Analog Comparator Handler
0x036              jmp   SPM_RDY        ; Store Program Memory Ready Handler
;
0x038 RESET:       ldi   r16,high(RAMEND) ; Main program start
0x039              out   SPH,r16        ; Set Stack Pointer to top of RAM
```

```
0x03A             ldi   r16,low(RAMEND)
0x03B             out   SPL,r16
0x03C             sei                   ; Enable interrupts
0x03D             <instr>  xxx
...      ...      ...
```

When the BOOTRST Fuse is unprogrammed, the boot section size set to 2K bytes and the IVSEL bit in the GICR Register is set before any interrupts are enabled, the most typical and general program setup for the Reset and Interrupt Vector Addresses is:

```
Address   Labels   Code                 Comments
0x000     RESET:   ldi   r16,high(RAMEND) ; Main program start
0x001              out   SPH,r16          ; Set Stack Pointer to top of RAM
0x002              ldi   r16,low(RAMEND)
0x003              out   SPL,r16
0x004              sei                   ; Enable interrupts
0x005              <instr>  xxx
;
.org 0x1C02
0x1C02             jmp   EXT_INT0        ; IRQ0 Handler
0x1C04             jmp   EXT_INT1        ; IRQ1 Handler
...       ....     ..                    ;
0x1C36             jmp   SPM_RDY         ; Store Program Memory Ready Handler
```

When the BOOTRST Fuse is programmed and the boot section size set to 2K bytes, the most typical and general program setup for the Reset and Interrupt Vector Addresses is:

```
Address   Labels     Code                  Comments
.org 0x002
0x002              jmp   EXT_INT0        ; IRQ0 Handler
0x004              jmp   EXT_INT1        ; IRQ1 Handler
...       ....     ..                    ;
0x036              jmp   SPM_RDY         ; Store Program Memory Ready Handler
;
.org 0x1C00
0x1C00    RESET:   ldi   r16,high(RAMEND) ; Main program start
0x1C01             out   SPH,r16          ; Set Stack Pointer to top of RAM
0x1C02             ldi   r16,low(RAMEND)
0x1C03             out   SPL,r16
0x1C04             sei                   ; Enable interrupts
0x1C05             <instr>  xxx
```

When the BOOTRST Fuse is programmed, the boot section size set to 2K bytes and the IVSEL bit in the GICR Register is set before any interrupts are enabled, the most typical and general program setup for the Reset and Interrupt Vector Addresses is:

```
Address   Labels   Code                 Comments

.org 0x1C00
0x1C00             jmp   RESET          ; Reset handler
0x1C02             jmp   EXT_INT0       ; IRQ0 Handler
0x1C04             jmp   EXT_INT1       ; IRQ1 Handler
...       ....     ..                   ;
0x1C36             jmp   SPM_RDY        ; Store Program Memory Ready Handler
;
0x1C38    RESET:   ldi   r16,high(RAMEND) ; Main program start
0x1C39             out   SPH,r16        ; Set Stack Pointer to top of RAM
0x1C3A             ldi   r16,low(RAMEND)
0x1C3B             out   SPL,r16
0x1C3C             sei                  ; Enable interrupts
0x1C3D             <instr>  xxx
```

Moving Interrupts Between Application and Boot Space

The General Interrupt Control Register controls the placement of the Interrupt Vector table.

General Interrupt Control Register – GICR

Bit	7	6	5	4	3	2	1	0	
	INT1	INT0	INT2	PCIE1	PCIE0	–	IVSEL	IVCE	GICR
Read/Write	R/W	R/W	R/W	R/W	R/W	R	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

- **Bit 1 – IVSEL: Interrupt Vector Select**

When the IVSEL bit is cleared (zero), the Interrupt Vectors are placed at the start of the Flash memory. When this bit is set (one), the Interrupt Vectors are moved to the beginning of the Boot Loader section of the Flash. The actual address of the start of the Boot Flash section is determined by the BOOTSZ Fuses. Refer to the section “Boot Loader Support – Read-While-Write Self-programming” on page 216 for details. To avoid unintentional changes of Interrupt Vector tables, a special write procedure must be followed to change the IVSEL bit:

1. Write the Interrupt Vector Change Enable (IVCE) bit to one.
2. Within four cycles, write the desired value to IVSEL while writing a zero to IVCE.

Interrupts will automatically be disabled while this sequence is executed. Interrupts are disabled in the cycle IVCE is set, and they remain disabled until after the instruction following the write to IVSEL. If IVSEL is not written, interrupts remain disabled for four cycles. The I-bit in the Status Register is unaffected by the automatic disabling.

Note: If Interrupt Vectors are placed in the Boot Loader section and Boot Lock bit BLB02 is programmed, interrupts are disabled while executing from the Application section. If Interrupt Vectors are placed in the Application section and Boot Lock bit BLB12 is programed, interrupts are disabled while executing from the Boot Loader section. Refer to the section “Boot Loader Support – Read-While-Write Self-programming” on page 216 for details on Boot Lock bits.

- **Bit 0 – IVCE: Interrupt Vector Change Enable**

The IVCE bit must be written to logic one to enable change of the IVSEL bit. IVCE is cleared by hardware four cycles after it is written or when IVSEL is written. Setting the

IVCE bit will disable interrupts, as explained in the IVSEL description above. See Code Example below.

Assembly Code Example

```
Move_interrupts:
  ; Enable change of Interrupt Vectors
  ldi  r16, (1<<IVCE)
  out  GICR, r16
  ; Move interrupts to Boot Flash section
  ldi  r16, (1<<IVSEL)
  out  GICR, r16
  ret
```

C Code Example

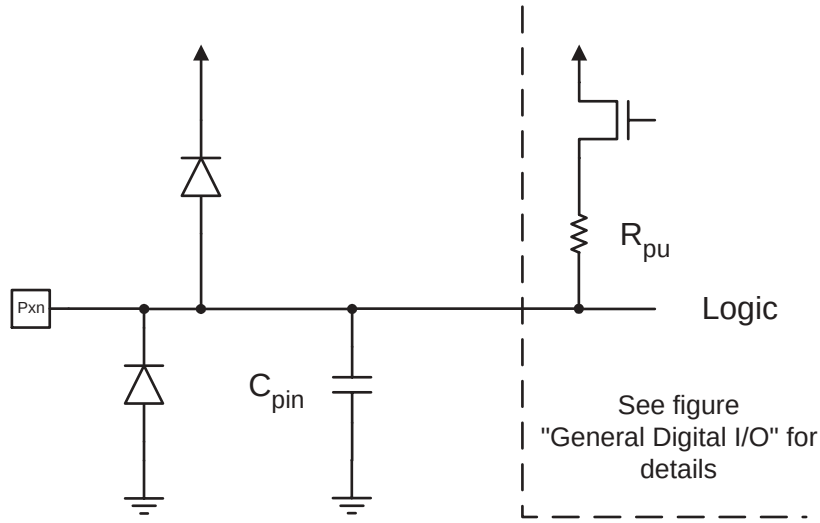
```
void Move_interrupts(void)
{
  /* Enable change of Interrupt Vectors */
  GICR = (1<<IVCE);
  /* Move interrupts to Boot Flash section */
  GICR = (1<<IVSEL);
}
```

I/O-Ports

Introduction

All AVR ports have true Read-Modify-Write functionality when used as general digital I/O ports. This means that the direction of one port pin can be changed without unintentionally changing the direction of any other pin with the SBI and CBI instructions. The same applies when changing drive value (if configured as output) or enabling/disabling of pull-up resistors (if configured as input). Each output buffer has symmetrical drive characteristics with both high sink and source capability. The pin driver is strong enough to drive LED displays directly. All port pins have individually selectable pull-up resistors with a supply-voltage invariant resistance. All I/O pins have protection diodes to both V_{CC} and Ground as indicated in Figure 28. Refer to “Electrical Characteristics” on page 263 for a complete list of parameters.

Figure 28. I/O Pin Equivalent Schematic



All registers and bit references in this section are written in general form. A lower case “x” represents the numbering letter for the port, and a lower case “n” represents the bit number. However, when using the register or bit defines in a program, the precise form must be used. For example, PORTB3 for bit no. 3 in Port B, here documented generally as PORTxn. The physical I/O Registers and bit locations are listed in “Register Description for I/O-Ports” on page 81.

Three I/O memory address locations are allocated for each port, one each for the Data Register – PORTx, Data Direction Register – DDRx, and the Port Input Pins – PINx. The Port Input Pins I/O location is read only, while the Data Register and the Data Direction Register are read/write. In addition, the Pull-up Disable – PUD bit in SFIOR disables the pull-up function for all pins in all ports when set.

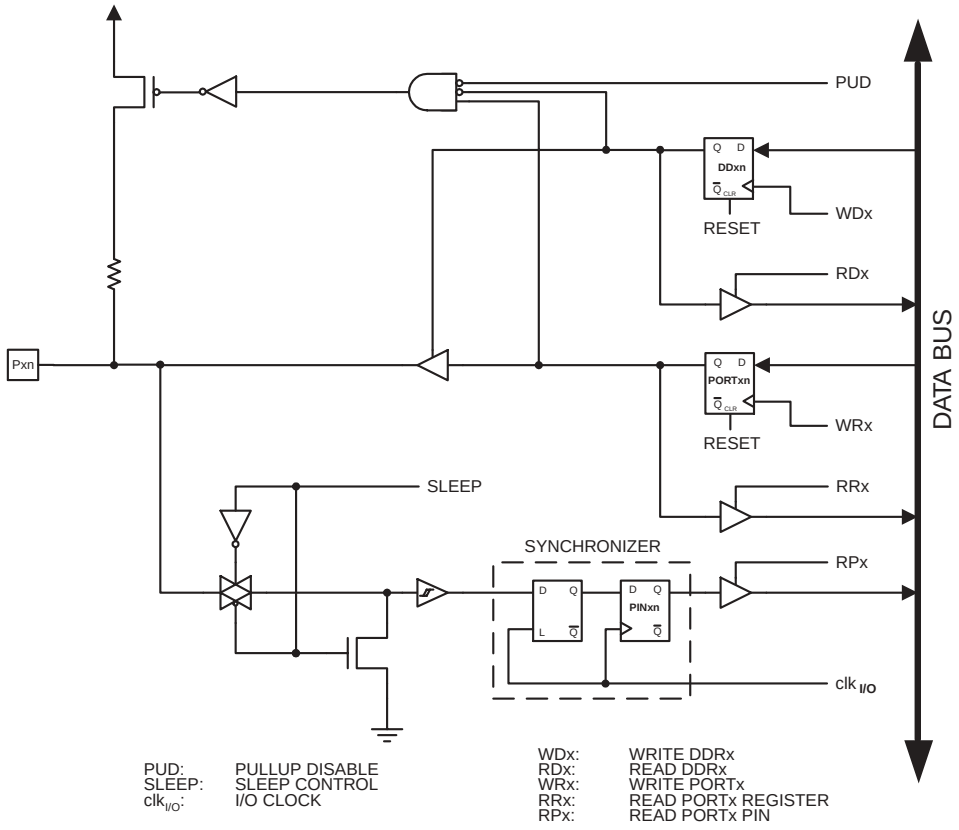
Using the I/O port as General Digital I/O is described in “Ports as General Digital I/O” on page 63. Most port pins are multiplexed with alternate functions for the peripheral features on the device. How each alternate function interferes with the port pin is described in “Alternate Port Functions” on page 67. Refer to the individual module sections for a full description of the alternate functions.

Note that enabling the alternate function of some of the port pins does not affect the use of the other pins in the port as general digital I/O.

Ports as General Digital I/O

The ports are bi-directional I/O ports with optional internal pull-ups. Figure 29 shows a functional description of one I/O-port pin, here generically called Pxn.

Figure 29. General Digital I/O(1)



Note: 1. WPx, WDx, RRx, RPx, and RDx are common to all pins within the same port. $clk_{I/O}$, SLEEP, and PUD are common to all ports.

Configuring the Pin

Each port pin consists of three register bits: DDxn, PORTxn, and PINxn. As shown in "Register Description for I/O-Ports" on page 81, the DDxn bits are accessed at the DDRx I/O address, the PORTxn bits at the PORTx I/O address, and the PINxn bits at the PINx I/O address.

The DDxn bit in the DDRx Register selects the direction of this pin. If DDxn is written logic one, Pxn is configured as an output pin. If DDxn is written logic zero, Pxn is configured as an input pin.

If PORTxn is written logic one when the pin is configured as an input pin, the pull-up resistor is activated. To switch the pull-up resistor off, PORTxn has to be written logic zero or the pin has to be configured as an output pin. The port pins are tri-stated when a reset condition becomes active, even if no clocks are running.

If PORTxn is written logic one when the pin is configured as an output pin, the port pin is driven high (one). If PORTxn is written logic zero when the pin is configured as an output pin, the port pin is driven low (zero).

When switching between tri-state ({DDxn, PORTxn} = 0b00) and output high ({DDxn, PORTxn} = 0b11), an intermediate state with either pull-up enabled ({DDxn, PORTxn} = 0b01) or output low ({DDxn, PORTxn} = 0b10) must occur. Normally, the pull-up

enabled state is fully acceptable, as a high-impedant environment will not notice the difference between a strong high driver and a pull-up. If this is not the case, the PUD bit in the SFIOR Register can be set to disable all pull-ups in all ports.

Switching between input with pull-up and output low generates the same problem. The user must use either the tri-state ({DDxn, PORTxn} = 0b00) or the output high state ({DDxn, PORTxn} = 0b11) as an intermediate step.

Table 27 summarizes the control signals for the pin value.

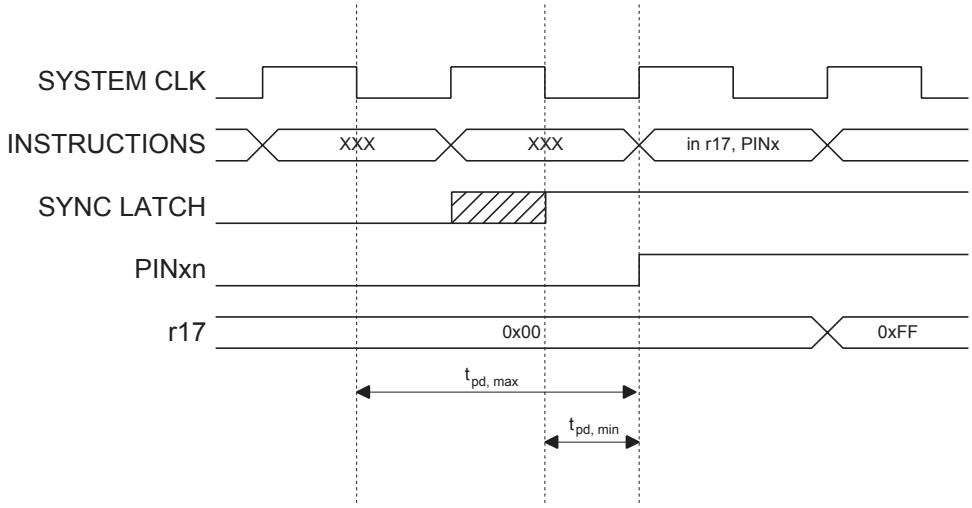
Table 27. Port Pin Configurations

DDxn	PORTxn	PUD (in SFIOR)	I/O	Pull-up	Comment
0	0	X	Input	No	Tri-state (Hi-Z)
0	1	0	Input	Yes	Pxn will source current if ext. pulled low.
0	1	1	Input	No	Tri-state (Hi-Z)
1	0	X	Output	No	Output Low (Sink)
1	1	X	Output	No	Output High (Source)

Reading the Pin Value

Independent of the setting of Data Direction bit DDxn, the port pin can be read through the PINxn Register bit. As shown in Figure 29, the PINxn Register bit and the preceding latch constitute a synchronizer. This is needed to avoid metastability if the physical pin changes value near the edge of the internal clock, but it also introduces a delay. Figure 30 shows a timing diagram of the synchronization when reading an externally applied pin value. The maximum and minimum propagation delays are denoted $t_{pd,max}$ and $t_{pd,min}$ respectively.

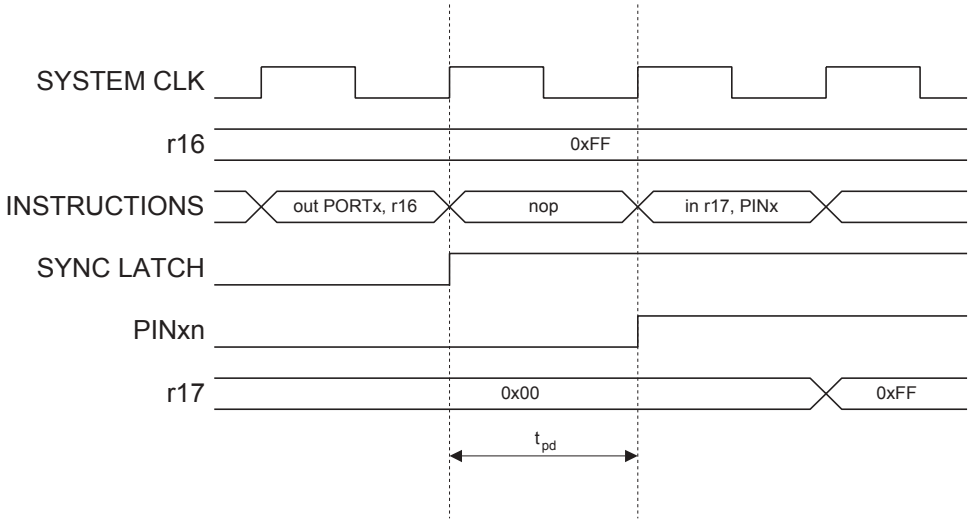
Figure 30. Synchronization when Reading an Externally Applied Pin Value



Consider the clock period starting shortly *after* the first falling edge of the system clock. The latch is closed when the clock is low, and goes transparent when the clock is high, as indicated by the shaded region of the “SYNC LATCH” signal. The signal value is latched when the system clock goes low. It is clocked into the PINxn Register at the succeeding positive clock edge. As indicated by the two arrows $t_{pd,max}$ and $t_{pd,min}$, a single signal transition on the pin will be delayed between ½ and 1½ system clock period depending upon the time of assertion.

When reading back a software assigned pin value, a *nop* instruction must be inserted as indicated in Figure 31. The *out* instruction sets the “SYNC LATCH” signal at the positive edge of the clock. In this case, the delay t_{pd} through the synchronizer is one system clock period.

Figure 31. Synchronization when Reading a Software Assigned Pin Value



The following code example shows how to set port B pins 0 and 1 high, 2 and 3 low, and define the port pins from 4 to 7 as input with pull-ups assigned to port pins 6 and 7. The resulting pin values are read back again, but as previously discussed, a *nop* instruction is included to be able to read back the value recently assigned to some of the pins.

Assembly Code Example[1]

```
...
; Define pull-ups and set outputs high
; Define directions for port pins
ldi   r16,(1<<PB7)|(1<<PB6)|(1<<PB1)|(1<<PB0)
ldi   r17,(1<<DDB3)|(1<<DDB2)|(1<<DDB1)|(1<<DDB0)
out   PORTB,r16
out   DDRB,r17
; Insert nop for synchronization
nop
; Read port pins
in    r16,PINB
...
```

C Code Example[1]

```
unsigned char i;
...
/* Define pull-ups and set outputs high */
/* Define directions for port pins */
PORTB = (1<<PB7)|(1<<PB6)|(1<<PB1)|(1<<PB0);
DDRB = (1<<DDB3)|(1<<DDB2)|(1<<DDB1)|(1<<DDB0);
/* Insert nop for synchronization*/
_NOP();
/* Read port pins */
i = PINB;
...
```

Note: 1. For the assembly program, two temporary registers are used to minimize the time from pull-ups are set on pins 0, 1, 6, and 7, until the direction bits are correctly set, defining bit 2 and 3 as low and redefining bits 0 and 1 as strong high drivers.

Digital Input Enable and Sleep Modes

As shown in Figure 29, the digital input signal can be clamped to ground at the input of the Schmitt Trigger. The signal denoted SLEEP in the figure, is set by the MCU Sleep Controller in Power-down mode, Power-save mode, Standby mode, and Extended Standby mode to avoid high power consumption if some input signals are left floating, or have an analog signal level close to $V_{CC}/2$.

SLEEP is overridden for port pins enabled as External Interrupt pins. If the External Interrupt Request is not enabled, SLEEP is active also for these pins. SLEEP is also overridden by various other alternate functions as described in “Alternate Port Functions” on page 67.

If a logic high level (“one”) is present on an Asynchronous External Interrupt pin configured as “Interrupt on Rising Edge, Falling Edge, or Any Logic Change on Pin” while the external interrupt is *not* enabled, the corresponding External Interrupt Flag will be set when resuming from the above mentioned sleep modes, as the clamping in these sleep modes produces the requested logic change.

Unconnected pins

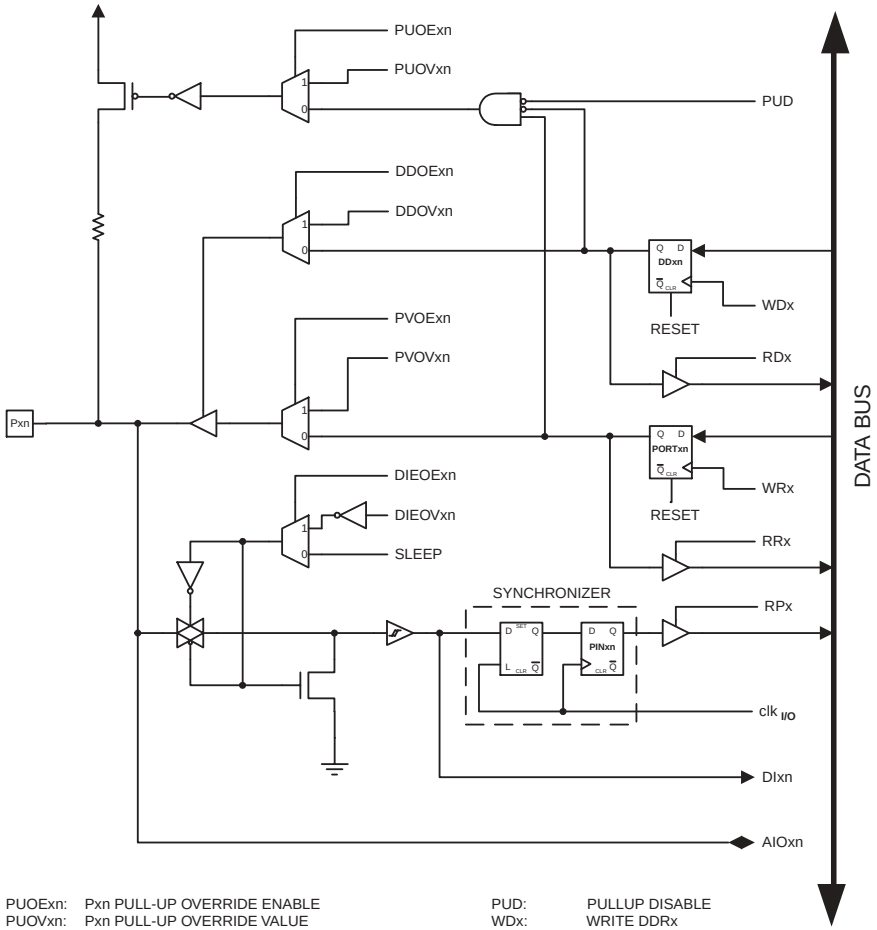
If some pins are unused, it is recommended to ensure that these pins have a defined level. Even though most of the digital inputs are disabled in the deep sleep modes as described above, floating inputs should be avoided to reduce current consumption in all other modes where the digital inputs are enabled (Reset, Active mode and Idle mode).

The simplest method to ensure a defined level of an unused pin, is to enable the internal pull-up. In this case, the pull-up will be disabled during reset. If low power consumption during reset is important, it is recommended to use an external pull-up or pull-down. Connecting unused pins directly to V_{CC} or GND is not recommended, since this may cause excessive currents if the pin is accidentally configured as an output.

Alternate Port Functions

Most port pins have alternate functions in addition to being general digital I/Os. Figure 32 shows how the port pin control signals from the simplified Figure 29 can be overridden by alternate functions. The overriding signals may not be present in all port pins, but the figure serves as a generic description applicable to all port pins in the AVR microcontroller family.

Figure 32. Alternate Port Functions(1)



PUOExn:	Pxn PULL-UP OVERRIDE ENABLE	PUD:	PULLUP DISABLE
PUOVxn:	Pxn PULL-UP OVERRIDE VALUE	WDx:	WRITE DDRx
DDOExn:	Pxn DATA DIRECTION OVERRIDE ENABLE	RDx:	READ DDRx
DDOVxn:	Pxn DATA DIRECTION OVERRIDE VALUE	RRx:	READ PORTx REGISTER
PVOExn:	Pxn PORT VALUE OVERRIDE ENABLE	WRx:	WRITE PORTx
PVOVxn:	Pxn PORT VALUE OVERRIDE VALUE	RPx:	READ PORTx PIN
DIEOExn:	Pxn DIGITAL INPUT-ENABLE OVERRIDE ENABLE	$clk_{I/O}$:	I/O CLOCK
DIEOVxn:	Pxn DIGITAL INPUT-ENABLE OVERRIDE VALUE	DIxn:	DIGITAL INPUT PIN n ON PORTx
SLEEP:	SLEEP CONTROL	AIOxn:	ANALOG INPUT/OUTPUT PIN n ON PORTx

Note: 1. WPx, WDx, RRx, RPx, and RDx are common to all pins within the same port. $clk_{I/O}$, SLEEP, and PUD are common to all ports. All other signals are unique for each pin.

Table 28 summarizes the function of the overriding signals. The pin and port indexes from Figure 32 are not shown in the succeeding tables. The overriding signals are generated internally in the modules having the alternate function.

Table 28. Generic Description of Overriding Signals for Alternate Functions.

Signal Name	Full Name	Description
PUOE	Pull-up Override Enable	If this signal is set, the pull-up enable is controlled by the PUOV signal. If this signal is cleared, the pull-up is enabled when {DDxn, PORTxn, PUD} = 0b010.
PUOV	Pull-up Override Value	If PUOE is set, the pull-up is enabled/disabled when PUOV is set/cleared, regardless of the setting of the DDxn, PORTxn, and PUD Register bits.
DDOE	Data Direction Override Enable	If this signal is set, the Output Driver Enable is controlled by the DDOV signal. If this signal is cleared, the Output driver is enabled by the DDxn Register bit.
DDOV	Data Direction Override Value	If DDOE is set, the Output Driver is enabled/disabled when DDOV is set/cleared, regardless of the setting of the DDxn Register bit.
PVOE	Port Value Override Enable	If this signal is set and the Output Driver is enabled, the port value is controlled by the PVOV signal. If PVOE is cleared, and the Output Driver is enabled, the port Value is controlled by the PORTxn Register bit.
PVOV	Port Value Override Value	If PVOE is set, the port value is set to PVOV, regardless of the setting of the PORTxn Register bit.
DIEOE	Digital Input Enable Override Enable	If this bit is set, the Digital Input Enable is controlled by the DIEOV signal. If this signal is cleared, the Digital Input Enable is determined by MCU state (Normal Mode, Sleep Modes).
DIEOV	Digital Input Enable Override Value	If DIEOE is set, the Digital Input is enabled/disabled when DIEOV is set/cleared, regardless of the MCU state (Normal Mode, Sleep Modes).
DI	Digital Input	This is the Digital Input to alternate functions. In the figure, the signal is connected to the output of the schmitt trigger but before the synchronizer. Unless the Digital Input is used as a clock source, the module with the alternate function will use its own synchronizer.
AIO	Analog Input/output	This is the Analog Input/output to/from alternate functions. The signal is connected directly to the pad, and can be used bi-directionally.

The following subsections shortly describe the alternate functions for each port, and relate the overriding signals to the alternate function. Refer to the alternate function description for further details.

Special Function IO Register – SFIOR

Bit	7	6	5	4	3	2	1	0	
	TSM	XMBK	XMM2	XMM1	XMM0	PUD	PSR2	PSR310	SFIOR
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

- **Bit 2 – PUD: Pull-up Disable**

When this bit is written to one, the pull-ups in the I/O ports are disabled even if the DDxn and PORTxn Registers are configured to enable the pull-ups ({DDxn, PORTxn} = 0b01). See “Configuring the Pin” on page 63 for more details about this feature.

Alternate Functions of Port A

Port A has an alternate function as the address low byte and data lines for the External Memory Interface and as Pin Change Interrupt.

Table 29. Port A Pins Alternate Functions

Port Pin	Alternate Function
PA7	AD7 (External memory interface address and data bit 7) PCINT7 (Pin Change INTerrupt 7)
PA6	AD6 (External memory interface address and data bit 6) PCINT6 (Pin Change INTerrupt 6)
PA5	AD5 (External memory interface address and data bit 5) PCINT5 (Pin Change INTerrupt 5)
PA4	AD4 (External memory interface address and data bit 4) PCINT4 (Pin Change INTerrupt 4)
PA3	AD3 (External memory interface address and data bit 3) PCINT3 (Pin Change INTerrupt 3)
PA2	AD2 (External memory interface address and data bit 2) PCINT2 (Pin Change INTerrupt 2)
PA1	AD1 (External memory interface address and data bit 1) PCINT1 (Pin Change INTerrupt 1)
PA0	AD0 (External memory interface address and data bit 0) PCINT0 (Pin Change INTerrupt 0)

Table 30 and Table 31 relate the alternate functions of Port A to the overriding signals shown in Figure 32 on page 67.

Table 30. Overriding Signals for Alternate Functions in PA7..PA4

Signal Name	PA7/AD7/ PCINT7	PA6/AD6/PCINT6	PA5/AD5/PCINT5	PA4/AD4/PCINT4
PUOE	SRE	SRE	SRE	SRE
PUOV	~($\overline{WR}$ + ADA[1]) • PORTA7	~($\overline{WR}$ + ADA) • PORTA6	~($\overline{WR}$ + ADA) • PORTA5	~($\overline{WR}$ + ADA) • PORTA4
DDOE	SRE	SRE	SRE	SRE
DDOV	$\overline{WR}$ + ADA	$\overline{WR}$ + ADA	$\overline{WR}$ + ADA	$\overline{WR}$ + ADA
PVOE	SRE	SRE	SRE	SRE
PVOV	if (ADA) then A7 else D7 OUTPUT • $\overline{WR}$	if (ADA) then A6 else D6 OUTPUT • $\overline{WR}$	if (ADA) then A5 else D5 OUTPUT • $\overline{WR}$	if (ADA) then A4 else D4 OUTPUT • $\overline{WR}$
DIEOE[2]	PCIE0 • PCINT7	PCIE0 • PCINT6	PCIE0 • PCINT5	PCIE0 • PCINT4
DIEOV	1	1	1	1
DI[3]	D7 INPUT/ PCINT7	D6 INPUT/ PCINT6	D5 INPUT/ PCINT5	D4 INPUT/ PCINT4
AIO	–	–	–	–

Notes: 1. ADA is short for ADdress Active and represents the time when address is output. See “External Memory Interface” on page 24.
2. PCINTn is Pin Change Interrupt Enable bit n.
3. PCINTn is Pin Change Interrupt input n.

Table 31. Overriding Signals for Alternate Functions in PA3..PA0

Signal Name	PA3/AD3/ PCINT3	PA2/AD2/ PCINT2	PA1/AD1/ PCINT1	PA0/AD0/ PCINT0
PUOE	SRE	SRE	SRE	SRE
PUOV	~($\overline{WR}$ + ADA) • PORTA3	~($\overline{WR}$ + ADA) • PORTA2	~($\overline{WR}$ + ADA) • PORTA1	~($\overline{WR}$ + ADA) • PORTA0
DDOE	SRE	SRE	SRE	SRE
DDOV	$\overline{WR}$ + ADA	$\overline{WR}$ + ADA	$\overline{WR}$ + ADA	$\overline{WR}$ + ADA
PVOE	SRE	SRE	SRE	SRE
PVOV	if (ADA) then A3 else D3 OUTPUT • $\overline{WR}$	if (ADA) then A2 else D2 OUTPUT • $\overline{WR}$	if (ADA) then A1 else D1 OUTPUT • $\overline{WR}$	if (ADA) then A0 else D0 OUTPUT • $\overline{WR}$
DIEOE[1]	PCIE0 • PCINT3	PCIE0 • PCINT2	PCIE0 • PCINT1	PCIE0 • PCINT0
DIEOV	1	1	1	1
DI[2]	D3 INPUT /PCINT3	D2 INPUT /PCINT2	D1 INPUT /PCINT1	D0 INPUT /PCINT0
AIO	–	–	–	–

Notes: 1. PCINT is Pin Change Interrupt Enable bit n.
2. PCINT is Pin Change Interrupt input n.

Alternate Functions Of Port B

The Port B pins with alternate functions are shown in Table 32.

Table 32. Port B Pins Alternate Functions

Port Pin	Alternate Functions
PB7	SCK (SPI Bus Serial Clock)
PB6	MISO (SPI Bus Master Input/Slave Output)
PB5	MOSI (SPI Bus Master Output/Slave Input)
PB4	$\overline{SS}$ (SPI Slave Select Input) OC3B (Timer/Counter3 Output Compare Match Output)
PB3	AIN1 (Analog Comparator Negative Input) TXD1 (USART1 Output Pin)
PB2	AIN0 (Analog Comparator Positive Input) RXD1 (USART1 Input Pin)
PB1	T1 (Timer/Counter1 External Counter Input) OC2 (Timer/Counter2 Output Compare Match Output)
PB0	T0 (Timer/Counter0 External Counter Input) OC0 (Timer/Counter0 Output Compare Match Output) $clk_{I/O}$ (Divided System Clock)

The alternate pin configuration is as follows:

- **SCK – Port B, Bit 7**

SCK: Master Clock output, Slave Clock input pin for SPI channel. When the SPI is enabled as a Slave, this pin is configured as an input regardless of the setting of DDB7. When the SPI is enabled as a Master, the data direction of this pin is controlled by DDB7. When the pin is forced by the SPI to be an input, the pull-up can still be controlled by the PORTB7 bit.

- **MISO – Port B, Bit 6**

MISO: Master Data input, Slave Data output pin for SPI channel. When the SPI is enabled as a Master, this pin is configured as an input regardless of the setting of DDB6. When the SPI is enabled as a Slave, the data direction of this pin is controlled by DDB6. When the pin is forced by the SPI to be an input, the pull-up can still be controlled by the PORTB6 bit.

- **MOSI – Port B, Bit 5**

MOSI: SPI Master Data output, Slave Data input for SPI channel. When the SPI is enabled as a Slave, this pin is configured as an input regardless of the setting of DDB5. When the SPI is enabled as a Master, the data direction of this pin is controlled by DDB5. When the pin is forced by the SPI to be an input, the pull-up can still be controlled by the PORTB5 bit.

- **$\overline{SS}$/OC3B – Port B, Bit 4**

$\overline{SS}$: Slave Select input. When the SPI is enabled as a slave, this pin is configured as an input regardless of the setting of DDB4. As a Slave, the SPI is activated when this pin is driven low. When the SPI is enabled as a Master, the data direction of this pin is controlled by DDB4. When the pin is forced by the SPI to be an input, the pull-up can still be controlled by the PORTB4 bit.

OC3B, Output Compare Match B output: The PB4 pin can serve as an external output for the Timer/Counter3 Output Compare B. The pin has to be configured as an output (DDB4 set (one)) to serve this function. The OC3B pin is also the output pin for the PWM mode timer function.

- **AIN1/TXD1 – Port B, Bit 3**

AIN1, Analog Comparator Negative input. Configure the port pin as input with the internal pull-up switched off to avoid the digital port function from interfering with the function of the Analog Comparator.

TXD1, Transmit Data (Data output pin for USART1). When the USART1 Transmitter is enabled, this pin is configured as an output regardless of the value of DDB3.

- **AIN0/RXD1 – Port B, Bit 2**

AIN0, Analog Comparator Positive Input. Configure the port pin as input with the internal pull-up switched off to avoid the digital port function from interfering with the function of the Analog Comparator.

RXD1, Receive Data (Data input pin for USART1). When the USART1 Receiver is enabled this pin is configured as an input regardless of the value of DDB2. When the USART1 forces this pin to be an input, the pull-up can still be controlled by the PORTB2 bit.

- **T1/OC2 – Port B, Bit 1**

T1, Timer/Counter1 Counter Source.

OC2, Output Compare Match output: The PB1 pin can serve as an external output for the Timer/Counter2 Compare Match. The PB1 pin has to be configured as an output (DDB1 set (one)) to serve this function. The OC2 pin is also the output pin for the PWM mode timer function.

- **T0/OC0 – Port B, Bit 0**

T0, Timer/Counter0 counter source.

OC0, Output Compare Match output: The PB0 pin can serve as an external output for the Timer/Counter0 Compare Match. The PB0 pin has to be configured as an output (DDB0 set (one)) to serve this function. The OC0 pin is also the output pin for the PWM mode timer function.

$clk_{I/O}$, Divided System Clock: The divided system clock can be output on the PB0 pin. The divided system clock will be output if the CKOUT Fuse is programmed, regardless of the PORTB0 and DDB0 settings. It will also be output during reset.

Table 33 and Table 34 relate the alternate functions of Port B to the overriding signals shown in Figure 32 on page 67. SPI MSTR INPUT and SPI SLAVE OUTPUT constitute the MISO signal, while MOSI is divided into SPI MSTR OUTPUT and SPI SLAVE INPUT.

Table 33. Overriding Signals for Alternate Functions in PB7..PB4

Signal Name	PB7/SCK	PB6/MISO	PB5/MOSI	PB4/$\overline{SS}$/OC3B
PUOE	SPE • $\overline{MSTR}$	SPE • MSTR	SPE • $\overline{MSTR}$	SPE • $\overline{MSTR}$
PUOV	PORTB7 • $\overline{PUD}$	PORTB6 • $\overline{PUD}$	PORTB5 • $\overline{PUD}$	PORTB4 • $\overline{PUD}$
DDOE	SPE • $\overline{MSTR}$	SPE • MSTR	SPE • $\overline{MSTR}$	SPE • $\overline{MSTR}$
DDOV	0	0	0	0
PVOE	SPE • MSTR	SPE • $\overline{MSTR}$	SPE • MSTR	OC3B ENABLE
PVOV	SCK OUTPUT	SPI SLAVE OUTPUT	SPI MSTR OUTPUT	OC3B
DIEOE	0	0	0	0
DIEOV	0	0	0	0
DI	SCK INPUT	SPI MSTR INPUT	SPI SLAVE INPUT	SPI $\overline{SS}$
AIO	–	–	–	–

Table 34. Overriding Signals for Alternate Functions in PB3..PB0

Signal Name	PB3/AIN1/TXD1	PB2/AIN0/RXD1	PB1/T1/OC2	PB0/T0/OC0
PUOE	TXEN1	RXEN1	0	0
PUOV	0	PORTB2• PUD	0	0
DDOE	TXEN1	RXEN1	0	CKOUT(1)
DDOV	1	0	0	1
PVOE	TXEN1	0	OC2 ENABLE	CKOUT + OC0 ENABLE

PVOV	TXD1	0	OC2	if (CKOUT) then $clk_{I/O}$(2)
				else
				OC0

DIEOE	0	0	0	0
DIEOV	0	0	0	0
DI	–	RXD1	T1 INPUT	T0 INPUT
AIO	AIN1 INPUT	AIN0 INPUT	–	–

Notes: 1. CKOUT is one if the CKOUT Fuse is programmed.
2. $clk_{I/O}$ is the divided system clock.

Alternate Functions of Port C

The Port C pins with alternate functions are shown in Table 35. If the JTAG interface is enabled, the pull-up resistors on pins PC7(TDI), PC5(TMS) and PC4(TCK) will be activated even if a reset occurs.

Table 35. Port C Pins Alternate Functions

Port Pin	Alternate Function
PC7	A15 (External memory interface address bit 15) TDI (JTAG Test Data Input) PCINT15 (Pin Change INTerrupt 15)
PC6	A14 (External memory interface address bit 14) TDO (JTAG Test Data Output) PCINT14 (Pin Change INTerrupt 14)
PC5	A13 (External memory interface address bit 13) TMS (JTAG Test Mode Select) PCINT13 (Pin Change INTerrupt 13)
PC4	A12 (External memory interface address bit 12) TCK (JTAG Test Clock) PCINT12 (Pin Change INTerrupt 12)
PC3	A11 (External memory interface address bit 11) PCINT11 (Pin Change INTerrupt 11)
PC2	A10 (External memory interface address bit 10) PCINT10 (Pin Change INTerrupt 10)
PC1	A9 (External memory interface address bit 9) PCINT9 (Pin Change INTerrupt 9)
PC0	A8 (External memory interface address bit 8) PCINT8 (Pin Change INTerrupt 8)

- **A15/TDI/PCINT15 – Port C, Bit 7**

A15, External memory interface address bit 15.

TDI, JTAG Test Data In: Serial input data to be shifted into the Instruction Register or Data Register (scan chains). When the JTAG interface is enabled, this pin can not be used as an I/O pin.

PCINT15: The pin can also serve as a pin change interrupt.

- **A14/TDO/PCINT14 – Port C, Bit 6**

A14, External memory interface address bit 14.

TDO, JTAG Test Data Out: Serial output data from Instruction Register or Data Register. When the JTAG interface is enabled, this pin can not be used as an I/O pin. In TAP states that shift out data, the TD0 pin drives actively. In other states the pin is pulled high.

PCINT14: The pin can also serve as a pin change interrupt.

- **A13/TMS/PCINT13 – Port C, Bit 5**

A13, External memory interface address bit 13.

TMS, JTAG Test Mode Select: This pin is used for navigating through the TAP-controller state machine. When the JTAG interface is enabled, this pin can not be used as an I/O pin.

PCINT13: The pin can also serve as a pin change interrupt.

- **A12/TCK/PCINT12 – Port C, Bit 4**

A12, External memory interface address bit 12.

TCK, JTAG Test Clock: JTAG operation is synchronous to TCK. When the JTAG interface is enabled, this pin can not be used as an I/O pin.

PCINT12: The pin can also serve as a pin change interrupt.

- **A11/PCINT11 – Port C, Bit 3**

A11, External memory interface address bit 11.

PCINT11: The pin can also serve as a pin change interrupt.

- **A10/PCINT10 – Port C, Bit 2**

A10, External memory interface address bit 10.

PCINT11: The pin can also serve as a pin change interrupt.

- **A9/PCINT9 – Port C, Bit 1**

A9, External memory interface address bit 9.

PCINT9: The pin can also serve as a pin change interrupt.

- **A8/PCINT8 – Port C, Bit 0**

A8, External memory interface address bit 8.

PCINT8: The pin can also serve as a pin change interrupt.

Table 36 and Table 37 relate the alternate functions of Port C to the overriding signals shown in Figure 32 on page 67.

Table 36. Overriding Signals for Alternate Functions in PC7..PC4

Signal Name	PC7/A15/TDI /PCINT15	PC6/A14/TDO /PCINT14	PC5/A13/TMS /PCINT13	PC4/A12/TCK /PCINT12
PUOE	(XMM < 1) • SRE + JTAGEN	(XMM < 2) • SRE +JTAGEN	(XMM < 3) • SRE + JTAGEN	(XMM < 4) • SRE + JTAGEN
PUOV	JTAGEN	JTAGEN	JTAGEN	JTAGEN
DDOE	SRE • (XMM<1) + JTAGEN	SRE • (XMM<2) + JTAGEN	SRE • (XMM<3) + JTAGEN	SRE • (XMM<4) + JTAGEN
DDOV	$\overline{\text{JTAGEN}}$	$\overline{\text{JTAGEN}}$ + JTAGEN • (SHIFT_IR | SHIFT_DR)	$\overline{\text{JTAGEN}}$	$\overline{\text{JTAGEN}}$
PVOE	SRE • (XMM<1)	SRE • (XMM<2) + JTAGEN	SRE • (XMM<3)	SRE • (XMM<4)
PVOV	A15	if (JTAGEN) then TDO else A14	A13	A12
DIEOE(1)	JTAGEN | PCIE1 • PCINT15	JTAGEN | PCIE1 • PCINT14	JTAGEN | PCIE1 • PCINT13	JTAGEN | PCIE1 • PCINT12
DIEOV	$\overline{\text{JTAGEN}}$	$\overline{\text{JTAGEN}}$	$\overline{\text{JTAGEN}}$	$\overline{\text{JTAGEN}}$
DI(2)	PCINT15	PCINT14	PCINT13	PCINT12
AIO	TDI	–	TMS	TCK

Notes: 1. PCINTn is Pin Change Interrupt Enable bit n.
2. PCINTn is Pin Change Interrupt input n.

Table 37. Overriding Signals for Alternate Functions in PC3..PC0

Signal Name	PC3/A11/ PCINT11	PC2/A10/ PCINT10	PC1/A9/PCINT9	PC0/A8/PCINT8
PUOE	SRE • (XMM<5)	SRE • (XMM<6)	SRE • (XMM<7)	SRE • (XMM<7)
PUOV	0	0	0	0
DDOE	SRE • (XMM<5)	SRE • (XMM<6)	SRE • (XMM<7)	SRE • (XMM<7)
DDOV	1	1	1	1
PVOE	SRE • (XMM<5)	SRE • (XMM<6)	SRE • (XMM<7)	SRE • (XMM<7)
PVOV	A11	A10	A9	A8
DIEOE(1)	PCIE1 • PCINT11	PCIE1 • PCINT10	PCIE1 • PCINT9	PCIE1 • PCINT8
DIEOV	1	1	1	1
DI(2)	PCINT11	PCINT10	PCINT9	PCINT8
AIO	–	–	–	–

Notes: 1. PCINTn is Pin Change Interrupt Enable bit n.
2. PCINTn is Pin Change Interrupt input n.

Alternate Functions of Port D

The Port D pins with alternate functions are shown in Table 38.

Table 38. Port D Pins Alternate Functions

Port Pin	Alternate Function
PD7	$\overline{RD}$ (Read strobe to external memory)
PD6	$\overline{WR}$ (Write strobe to external memory)
PD5	TOSC2 (Timer Oscillator Pin 2) OC1A (Timer/Counter1 Output Compare A Match Output)
PD4	TOSC1 (Timer Oscillator Pin 1) XCK0 (USART0 External Clock Input/Output) OC3A (Timer/Counter3 Output Compare A Match Output)
PD3	INT1 (External Interrupt 1 Input) ICP3 (Timer/Counter3 Input Capture Pin)
PD2	INT0 (External Interrupt 0 Input) XCK1 (USART1 External Clock Input/Output)
PD1	TXD0 (USART0 Output Pin)
PD0	RXD0 (USART0 Input Pin)

The alternate pin configuration is as follows:

- **$\overline{RD}$ – Port D, Bit 7**

$\overline{RD}$ is the external data memory read control strobe.

- **$\overline{WR}$ – Port D, Bit 6**

$\overline{WR}$ is the external data memory write control strobe.

- **TOSC2/OC1A – Port D, Bit 5**

TOSC2, Timer Oscillator pin 2: When the AS2 bit in ASSR is set (one) to enable asynchronous clocking of Timer/Counter2, pin PD5 is disconnected from the port, and becomes the inverting output of the Oscillator amplifier. In this mode, a crystal Oscillator is connected to this pin, and the pin can not be used as an I/O pin.

OC1A, Output Compare Match A output: The PD5 pin can serve as an external output for the Timer/Counter1 Output Compare A. The pin has to be configured as an output (DDD5 set (one)) to serve this function. The OC1A pin is also the output pin for the PWM mode timer function.

- **TOSC1/XCK0/OC3A – Port D, Bit 4**

TOSC1, Timer Oscillator pin 1: When the AS2 bit in ASSR is set (one) to enable asynchronous clocking of Timer/Counter2, pin PD4 is disconnected from the port, and becomes the input of the inverting Oscillator Amplifier. In this mode, a crystal Oscillator is connected to this pin, and the pin can not be used as an I/O pin.

XCK0, USART0 External Clock: The Data Direction Register (DDD4) controls whether the clock is output (DDD4 set (one)) or input (DDD4 cleared (zero)). The XCK0 pin is active only when USART0 operates in Synchronous mode.

OC3A, Output Compare Match A output: The PD4 pin can serve as an external output for the Timer/Counter1 Output Compare A. The pin has to be configured as an output (DDD4 set (one)) to serve this function. The OC4A pin is also the output pin for the PWM mode timer function.

- **INT1/ICP3 – Port D, Bit 3**

INT1, External Interrupt Source 1: The PD3 pin can serve as an external interrupt source.

ICP3, Input Capture Pin: The PD3 pin can act as an Input Capture pin for Timer/Counter3.

- **INT0/XCK1 – Port D, Bit 2**

INT0, External Interrupt Source 0: The PD2 pin can serve as an external interrupt source.

XCK1, USART1 External Clock: The Data Direction Register (DDD2) controls whether the clock is output (DDD2 set (one)) or input (DDD2 cleared (zero)). The XCK1 pin is active only when USART1 operates in Synchronous mode.

- **TXD0 – Port D, Bit 1**

TXD0, Transmit Data (Data output pin for USART0). When the USART0 Transmitter is enabled, this pin is configured as an output regardless of the value of DDD1.

- **RXD0 – Port D, Bit 0**

RXD0, Receive Data (Data input pin for USART0). When the USART0 Receiver is enabled this pin is configured as an input regardless of the value of DDD0. When USART0 forces this pin to be an input, the pull-up can still be controlled by the PORTD0 bit.

Table 39 and Table 40 relate the alternate functions of Port D to the overriding signals shown in Figure 32 on page 67.

Table 39. Overriding Signals for Alternate Functions PD7..PD4

Signal Name	PD7/$\overline{RD}$	PD6/$\overline{WR}$	PD5/TOSC2/OC1A	PD4/TOSC1/XCK0/OC3A
PUOE	SRE	SRE	AS2	AS2
PUOV	0	0	0	0
DDOE	SRE	SRE	AS2	AS2
DDOV	1	1	0	0
PVOE	SRE	SRE	OC1A ENABLE	XCK0 OUTPUT ENABLE | OC3A ENABLE
PVOV	$\overline{RD}$	$\overline{WR}$	OC1A	if (XCK0 OUTPUT ENABLE) then XCK0 OUTPUT else OC3A
DIEOE	0	0	AS2	AS2
DIEOV	0	0	0	0
DI	–	–	–	XCK0 INPUT
AIO	–	–	T/C2 OSC OUTPUT	T/C2 OSC INPUT

Table 40. Overriding Signals for Alternate Functions in PD3..PD0

Signal Name	PD3/INT1	PD2/INT0/XCK1	PD1/TXD0	PD0/RXD0
PUOE	0	0	TXEN0	RXEN0
PUOV	0	0	0	PORTD0 • $\overline{PUD}$
DDOE	0	0	TXEN0	RXEN0
DDOV	0	0	1	0
PVOE	0	XCK1 OUTPUT ENABLE	TXEN0	0
PVOV	0	XCK1	TXD0	0
DIEOE	INT1 ENABLE	INT0 ENABLE	0	0
DIEOV	1	1	0	0
DI	INT1 INPUT/ ICP1 INPUT	INT0 INPUT/XCK1 INPUT	–	RXD0
AIO	–	–	–	–

Alternate Functions of Port E

The Port E pins with alternate functions are shown in Table 41.

Table 41. Port E Pins Alternate Functions

Port Pin	Alternate Function
PE2	OC1B (Timer/Counter1 Output CompareB Match Output)
PE1	ALE (Address Latch Enable to external memory)
PE0	ICP1 (Timer/Counter1 Input Capture Pin) INT2 (External Interrupt 2 Input)

The alternate pin configuration is as follows:

- **OC1B – Port E, Bit 2**

OC1B, Output Compare Match B output: The PE2 pin can serve as an external output for the Timer/Counter1 Output Compare B. The pin has to be configured as an output (DDE0 set (one)) to serve this function. The OC1B pin is also the output pin for the PWM mode timer function.

Table 42 relate the alternate functions of Port E to the overriding signals shown in Figure 32 on page 67.

- **ALE – Port E, Bit 1**

ALE is the external data memory Address Latch Enable signal.

- **ICP1/INT2 – Port E, Bit 0**

ICP1, Input Capture Pin: The PE0 pin can act as an Input Capture pin for Timer/Counter1.

INT2, External Interrupt Source 2: The PE0 pin can serve as an external interrupt source.

Table 42. Overriding Signals for Alternate Functions PE2..PE0

Signal Name	PE2	PE1	PE0
PUOE	0	SRE	0
PUOV	0	0	0
DDOE	0	SRE	0
DDOV	0	1	0
PVOE	OC1B ENABLE	SRE	0
PVOV	OC1B	ALE	0
DIEOE	0	0	INT2 ENABLED
DIEOV	0	0	1
DI	0	0	INT2 INPUT/ ICP1 INPUT
AIO	–	–	–

Register Description for I/O-Ports

Port A Data Register – PORTA

Bit	7	6	5	4	3	2	1	0	
	PORTA7	PORTA6	PORTA5	PORTA4	PORTA3	PORTA2	PORTA1	PORTA0	PORTA
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

Port A Data Direction Register – DDRA

Bit	7	6	5	4	3	2	1	0	
	DDA7	DDA6	DDA5	DDA4	DDA3	DDA2	DDA1	DDA0	DDRA
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

Port A Input Pins Address – PINA

Bit	7	6	5	4	3	2	1	0	
	PINA7	PINA6	PINA5	PINA4	PINA3	PINA2	PINA1	PINA0	PINA
Read/Write	R	R	R	R	R	R	R	R	
Initial Value	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	

Port B Data Register – PORTB

Bit	7	6	5	4	3	2	1	0	
	PORTB7	PORTB6	PORTB5	PORTB4	PORTB3	PORTB2	PORTB1	PORTB0	PORTB
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

Port B Data Direction Register – DDRB

Bit	7	6	5	4	3	2	1	0	
	DDB7	DDB6	DDB5	DDB4	DDB3	DDB2	DDB1	DDB0	DDRB
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

Port B Input Pins Address – PINB

Bit	7	6	5	4	3	2	1	0	
	PINB7	PINB6	PINB5	PINB4	PINB3	PINB2	PINB1	PINB0	PINB
Read/Write	R	R	R	R	R	R	R	R	
Initial Value	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	

Port C Data Register – PORTC

Bit	7	6	5	4	3	2	1	0	
	PORTC7	PORTC6	PORTC5	PORTC4	PORTC3	PORTC2	PORTC1	PORTC0	PORTC
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

Port C Data Direction Register – DDRC

Bit	7	6	5	4	3	2	1	0	
	DDC7	DDC6	DDC5	DDC4	DDC3	DDC2	DDC1	DDC0	DDRC
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

Port C Input Pins Address – PINC

Bit	7	6	5	4	3	2	1	0	
	PINC7	PINC6	PINC5	PINC4	PINC3	PINC2	PINC1	PINC0	PINC
Read/Write	R	R	R	R	R	R	R	R	
Initial Value	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	

Port D Data Register – PORTD

Bit	7	6	5	4	3	2	1	0	
	PORTD7	PORTD6	PORTD5	PORTD4	PORTD3	PORTD2	PORTD1	PORTD0	PORTD
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

Port D Data Direction Register – DDRD

Bit	7	6	5	4	3	2	1	0	
	DDD7	DDD6	DDD5	DDD4	DDD3	DDD2	DDD1	DDD0	DDRD
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

Port D Input Pins Address – PIND

Bit	7	6	5	4	3	2	1	0	
	PIND7	PIND6	PIND5	PIND4	PIND3	PIND2	PIND1	PIND0	PIND
Read/Write	R	R	R	R	R	R	R	R	
Initial Value	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	

Port E Data Register – PORTE

Bit	7	6	5	4	3	2	1	0	
	–	–	–	–	–	PORTE2	PORTE1	PORTE0	PORTE
Read/Write	R	R	R	R	R	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

Port E Data Direction Register – DDRE

Bit	7	6	5	4	3	2	1	0	
	–	–	–	–	–	DDE2	DDE1	DDE0	DDRE
Read/Write	R	R	R	R	R	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

Port E Input Pins Address – PINE

Bit	7	6	5	4	3	2	1	0	
	–	–	–	–	–	PINE2	PINE1	PINE0	PINE
Read/Write	R	R	R	R	R	R	R	R	
Initial Value	0	0	0	0	0	N/A	N/A	N/A	

External Interrupts

The External Interrupts are triggered by the INT0, INT1, INT2 pin, or any of the PCINT15..0 pins. Observe that, if enabled, the interrupts will trigger even if the INT2..0 or PCINT15..0 pins are configured as outputs. This feature provides a way of generating a software interrupt. The External Interrupts can be triggered by a falling or rising edge or a low level (INT2 is only an edge triggered interrupt). This is set up as indicated in the specification for the MCU Control Register – MCUCR and Extended MCU Control Register – EMCUCR. When the external interrupt is enabled and is configured as level triggered (only INT0/INT1), the interrupt will trigger as long as the pin is held low. The pin change interrupt PCI1 will trigger if any enabled PCINT15..8 pin toggles. Pin change interrupts PCI0 will trigger if any enabled PCINT7..0 pin toggles. The PCMSK1 and PCMSK0 Registers control which pins contribute to the pin change interrupts. Note that recognition of falling or rising edge interrupts on INT0 and INT1 requires the presence of an I/O clock, described in “Clock Systems and their Distribution” on page 33. Low level interrupts on INT0/INT1, the edge interrupt on INT2, and Pin change interrupts on PCINT15..0 are detected asynchronously. This implies that these interrupts can be used for waking the part also from sleep modes other than Idle mode. The I/O clock is halted in all sleep modes except Idle mode.

Note that if a level triggered interrupt is used for wake-up from Power-down mode, the changed level must be held for some time to wake up the MCU. This makes the MCU less sensitive to noise. The changed level is sampled twice by the Watchdog Oscillator clock. The period of the Watchdog Oscillator is 1 µs (nominal) at 5.0V and 25°C. The frequency of the Watchdog Oscillator is voltage dependent as shown in “Electrical Characteristics” on page 263. The MCU will wake up if the input has the required level during this sampling or if it is held until the end of the start-up time. The start-up time is defined by the SUT Fuses as described in “System Clock and Clock Options” on page 33. If the level is sampled twice by the Watchdog Oscillator clock but disappears before the end of the start-up time, the MCU will still wake up, but no interrupt will be generated. The required level must be held long enough for the MCU to complete the wake up to trigger the level interrupt.

MCU Control Register – MCUCR

The MCU Control Register contains control bits for interrupt sense control and general MCU functions.

Bit	7	6	5	4	3	2	1	0	
	SRE	SRW10	SE	SM1	ISC11	ISC10	ISC01	ISC00	MCUCR
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

- **Bit 3, 2 – ISC11, ISC10: Interrupt Sense Control 1 Bit 1 and Bit 0**

The External Interrupt 1 is activated by the external pin INT1 if the SREG I-bit and the corresponding interrupt mask in the GICR are set. The level and edges on the external INT1 pin that activate the interrupt are defined in Table 43. The value on the INT1 pin is sampled before detecting edges. If edge or toggle interrupt is selected, pulses that last longer than one clock period will generate an interrupt. Shorter pulses are not guaranteed to generate an interrupt. If low level interrupt is selected, the low level must be held until the completion of the currently executing instruction to generate an interrupt.

Table 43. Interrupt 1 Sense Control

ISC11	ISC10	Description
0	0	The low level of INT1 generates an interrupt request.
0	1	Any logical change on INT1 generates an interrupt request.
1	0	The falling edge of INT1 generates an interrupt request.
1	1	The rising edge of INT1 generates an interrupt request.

- **Bit 1, 0 – ISC01, ISC00: Interrupt Sense Control 0 Bit 1 and Bit 0**

The External Interrupt 0 is activated by the external pin INT0 if the SREG I-flag and the corresponding interrupt mask are set. The level and edges on the external INT0 pin that activate the interrupt are defined in Table 44. The value on the INT0 pin is sampled before detecting edges. If edge or toggle interrupt is selected, pulses that last longer than one clock period will generate an interrupt. Shorter pulses are not guaranteed to generate an interrupt. If low level interrupt is selected, the low level must be held until the completion of the currently executing instruction to generate an interrupt.

Table 44. Interrupt 0 Sense Control

ISC01	ISC00	Description
0	0	The low level of INT0 generates an interrupt request.
0	1	Any logical change on INT0 generates an interrupt request.
1	0	The falling edge of INT0 generates an interrupt request.
1	1	The rising edge of INT0 generates an interrupt request.

Extended MCU Control Register – EMCUCR

Bit	7	6	5	4	3	2	1	0	
	SM0	SRL2	SRL1	SRL0	SRW01	SRW00	SRW11	ISC2	EMCUCR
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

- **Bit 0 – ISC2: Interrupt Sense Control 2**

The asynchronous External Interrupt 2 is activated by the external pin INT2 if the SREG I-bit and the corresponding interrupt mask in GICR are set. If ISC2 is cleared (zero), a falling edge on INT2 activates the interrupt. If ISC2 is set (one), a rising edge on INT2 activates the interrupt. Edges on INT2 are registered asynchronously. Pulses on INT2 wider than the minimum pulse width given in Table 45 will generate an interrupt. Shorter pulses are not guaranteed to generate an interrupt. When changing the ISC2 bit, an interrupt can occur. Therefore, it is recommended to first disable INT2 by clearing its Interrupt Enable bit in the GICR Register. Then, the ISC2 bit can be changed. Finally, the INT2 Interrupt Flag should be cleared by writing a logical one to its Interrupt Flag bit (INTF2) in the GIFR Register before the interrupt is re-enabled.

Table 45. Asynchronous External Interrupt Characteristics

Symbol	Parameter	Condition	Min.	Typ.	Max.	Units
t_{INT}	Minimum pulse width for asynchronous external interrupt			50		ns

General Interrupt Control Register – GICR

Bit	7	6	5	4	3	2	1	0	
	INT1	INT0	INT2	PCIE1	PCIE0	–	IVSEL	IVCE	GICR
Read/Write	R/W	R/W	R/W	R/W	R/W	R	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

- **Bit 7 – INT1: External Interrupt Request 1 Enable**

When the INT1 bit is set (one) and the I-bit in the Status Register (SREG) is set (one), the external pin interrupt is enabled. The Interrupt Sense Control1 bits 1/0 (ISC11 and ISC10) in the MCU general Control Register (MCUCR) define whether the external interrupt is activated on rising and/or falling edge of the INT1 pin or level sensed. Activity on the pin will cause an interrupt request even if INT1 is configured as an output. The corresponding interrupt of External Interrupt Request 1 is executed from the INT1 Interrupt Vector.

- **Bit 6 – INT0: External Interrupt Request 0 Enable**

When the INT0 bit is set (one) and the I-bit in the Status Register (SREG) is set (one), the external pin interrupt is enabled. The Interrupt Sense Control0 bits 1/0 (ISC01 and ISC00) in the MCU general Control Register (MCUCR) define whether the external interrupt is activated on rising and/or falling edge of the INT0 pin or level sensed. Activity on the pin will cause an interrupt request even if INT0 is configured as an output. The corresponding interrupt of External Interrupt Request 0 is executed from the INT0 Interrupt Vector.

- **Bit 5 – INT2: External Interrupt Request 2 Enable**

When the INT2 bit is set (one) and the I-bit in the Status Register (SREG) is set (one), the external pin interrupt is enabled. The Interrupt Sense Control2 bit (ISC2) in the Extended MCU Control Register (EMCUCR) defines whether the external interrupt is activated on rising or falling edge of the INT2 pin. Activity on the pin will cause an interrupt request even if INT2 is configured as an output. The corresponding interrupt of External Interrupt Request 2 is executed from the INT2 Interrupt Vector.

- **Bit 4 – PCIE1: Pin Change Interrupt Enable 1**

When the PCIE1 bit is set (one) and the I-bit in the Status Register (SREG) is set (one), pin change interrupt 1 is enabled. Any change on any enabled PCINT15..8 pin will cause an interrupt. The corresponding interrupt of Pin Change Interrupt Request is executed from the PCI1 Interrupt Vector. PCINT15..8 pins are enabled individually by the PCMSK1 Register.

- **Bit 3 – PCIE0: Pin Change Interrupt Enable 0**

When the PCIE0 bit is set (one) and the I-bit in the Status Register (SREG) is set (one), pin change interrupt 0 is enabled. Any change on any enabled PCINT7..0 pin will cause an interrupt. The corresponding interrupt of Pin Change Interrupt Request is executed from the PCI0 Interrupt Vector. PCINT7..0 pins are enabled individually by the PCMSK0 Register.

General Interrupt Flag Register – GIFR

Bit	7	6	5	4	3	2	1	0	
	INTF1	INTF0	INTF2	PCIF1	PCIF0	–	–	–	GIFR
Read/Write	R/W	R/W	R/W	R/W	R/W	R	R	R	
Initial Value	0	0	0	0	0	0	0	0	

- **Bit 7 – INTF1: External Interrupt Flag 1**

When an edge or logic change on the INT1 pin triggers an interrupt request, INTF1 becomes set (one). If the I-bit in SREG and the INT1 bit in GICR are set (one), the MCU will jump to the corresponding Interrupt Vector. The flag is cleared when the interrupt routine is executed. Alternatively, the flag can be cleared by writing a logical one to it. This flag is always cleared when INT1 is configured as a level interrupt.

- **Bit 6 – INTF0: External Interrupt Flag 0**

When an edge or logic change on the INT0 pin triggers an interrupt request, INTF0 becomes set (one). If the I-bit in SREG and the INT0 bit in GICR are set (one), the MCU will jump to the corresponding Interrupt Vector. The flag is cleared when the interrupt routine is executed. Alternatively, the flag can be cleared by writing a logical one to it. This flag is always cleared when INT0 is configured as a level interrupt.

- **Bit 5 – INTF2: External Interrupt Flag 2**

When an event on the INT2 pin triggers an interrupt request, INTF2 becomes set (one). If the I-bit in SREG and the INT2 bit in GICR are set (one), the MCU will jump to the corresponding Interrupt Vector. The flag is cleared when the interrupt routine is executed. Alternatively, the flag can be cleared by writing a logical one to it. Note that when entering some sleep modes with the INT2 interrupt disabled, the input buffer on this pin will be disabled. This may cause a logic change in internal signals which will set the INTF2 flag. See “Digital Input Enable and Sleep Modes” on page 66 for more information.

- **Bit 4 – PCIF1: Pin Change Interrupt Flag 1**

When a logic change on any PCINT15..8 pin triggers an interrupt request, PCIF1 becomes set (one). If the I-bit in SREG and the PCIE1 bit in GICR are set (one), the MCU will jump to the corresponding Interrupt Vector. The flag is cleared when the interrupt routine is executed. Alternatively, the flag can be cleared by writing a logical one to it.

- **Bit 3 – PCIF0: Pin Change Interrupt Flag 0**

When a logic change on any PCINT7..0 pin triggers an interrupt request, PCIF0 becomes set (one). If the I-bit in SREG and the PCIE0 bit in GICR are set (one), the MCU will jump to the corresponding Interrupt Vector. The flag is cleared when the interrupt routine is executed. Alternatively, the flag can be cleared by writing a logical one to it.

Pin Change Mask Register 1 – PCMSK1

Bit	7	6	5	4	3	2	1	0	
	PCINT15	PCINT14	PCINT13	PCINT12	PCINT11	PCINT10	PCINT9	PCINT9	PCMSK1
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

- **Bit 7..0 – PCINT15..8: Pin Change Enable Mask 15..8**

Each PCINT15..8 bit selects whether pin change interrupt is enabled on the corresponding I/O pin. If PCINT15..8 is set and the PCIE1 bit in GICR is set, pin change interrupt is enabled on the corresponding I/O pin. If PCINT15..8 is cleared, pin change interrupt on the corresponding I/O pin is disabled.

Pin Change Mask Register 0 – PCMSK0

Bit	7	6	5	4	3	2	1	0	
	PCINT7	PCINT6	PCINT5	PCINT4	PCINT3	PCINT2	PCINT1	PCINT0	PCMSK0
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

- **Bit 7..0 – PCINT7..0: Pin Change Enable Mask 7..0**

Each PCINT7..0 bit selects whether pin change interrupt is enabled on the corresponding I/O pin. If PCINT7..0 is set and the PCIE0 bit in GICR is set, pin change interrupt is enabled on the corresponding I/O pin. If PCINT7..0 is cleared, pin change interrupt on the corresponding I/O pin is disabled.

The mapping between I/O pins and PCINT bits can be found in Figure 1 on page 2. Note that the Pin Change Mask Register are located in Extended I/O. Thus, the pin change interrupts are not supported in ATmega161 compatibility mode.

8-bit Timer/Counter0 with PWM

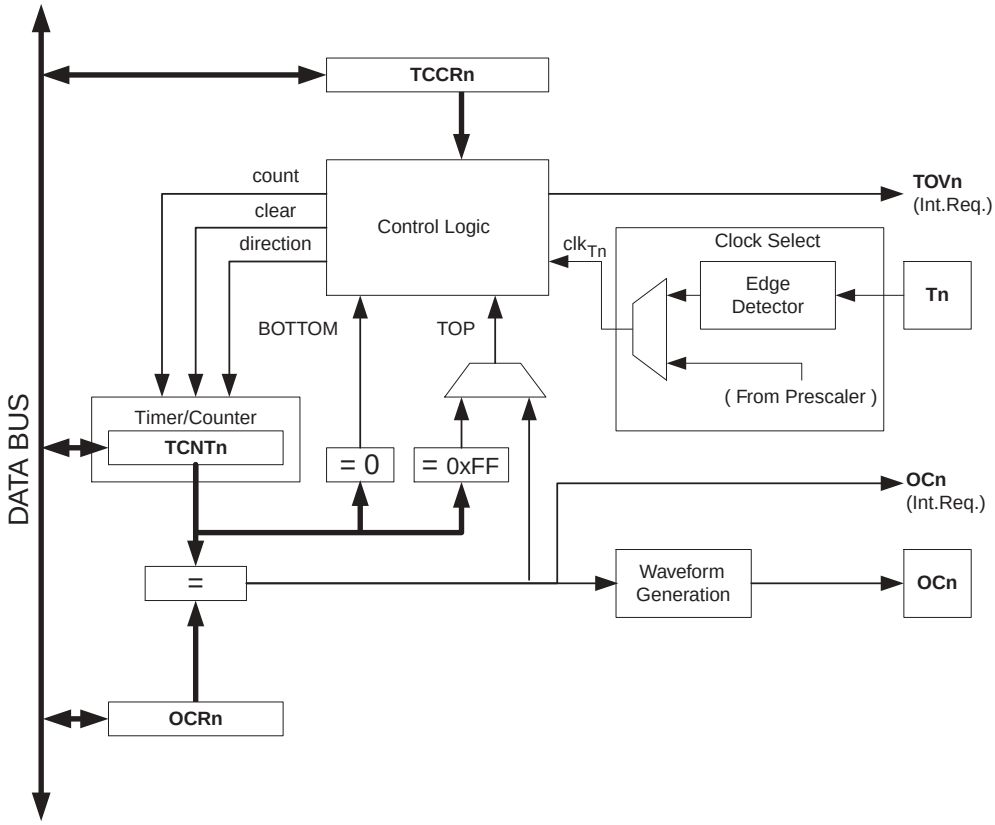
Timer/Counter0 is a general purpose, single channel, 8-bit Timer/Counter module. The main features are:

- **Single Channel Counter**
- **Clear Timer on Compare Match (Auto Reload)**
- **Glitch-free, Phase Correct Pulse Width Modulator (PWM)**
- **Frequency Generator**
- **External Event Counter**
- **10-bit Clock Prescaler**
- **Overflow and Compare Match Interrupt Sources (TOV0 and OCF0)**

Overview

A simplified block diagram of the 8-bit Timer/Counter is shown in Figure 33. For the actual placement of I/O pins, refer to “Pinout ATmega162” on page 2. CPU accessible I/O Registers, including I/O bits and I/O pins, are shown in bold. The device-specific I/O Register and bit locations are listed in the “8-bit Timer/Counter Register Description” on page 99.

Figure 33. 8-bit Timer/Counter Block Diagram



Registers

The Timer/Counter (TCNT0) and Output Compare Register (OCR0) are 8-bit registers. Interrupt request (abbreviated to Int.Req. in the figure) signals are all visible in the Timer Interrupt Flag Register (TIFR). All interrupts are individually masked with the Timer Interrupt Mask Register (TIMSK). TIFR and TIMSK are not shown in the figure since these registers are shared by other timer units.

The Timer/Counter can be clocked internally, via the prescaler, or by an external clock source on the T0 pin. The Clock Select logic block controls which clock source and edge the Timer/Counter uses to increment (or decrement) its value. The Timer/Counter is

inactive when no clock source is selected. The output from the clock select logic is referred to as the timer clock (clk_T0).

The double buffered Output Compare Register (OCR0) is compared with the Timer/Counter value at all times. The result of the compare can be used by the Waveform Generator to generate a PWM or variable frequency output on the Output Compare pin (OC0). See “Output Compare Unit” on page 90. for details. The Compare Match event will also set the Compare Flag (OCF0) which can be used to generate an output compare interrupt request.

Definitions

Many register and bit references in this section are written in general form. A lower case “n” replaces the Timer/Counter number, in this case 0. However, when using the register or bit defines in a program, the precise form must be used i.e., TCNT0 for accessing Timer/Counter0 counter value and so on.

The definitions in Table 46 are also used extensively throughout the document.

Table 46. Definitions

BOTTOM	The counter reaches the BOTTOM when it becomes 0x00.
MAX	The counter reaches its MAXimum when it becomes 0xFF (decimal 255).
TOP	The counter reaches the TOP when it becomes equal to the highest value in the count sequence. The TOP value can be assigned to be the fixed value 0xFF (MAX) or the value stored in the OCR0 Register. The assignment is dependent on the mode of operation.

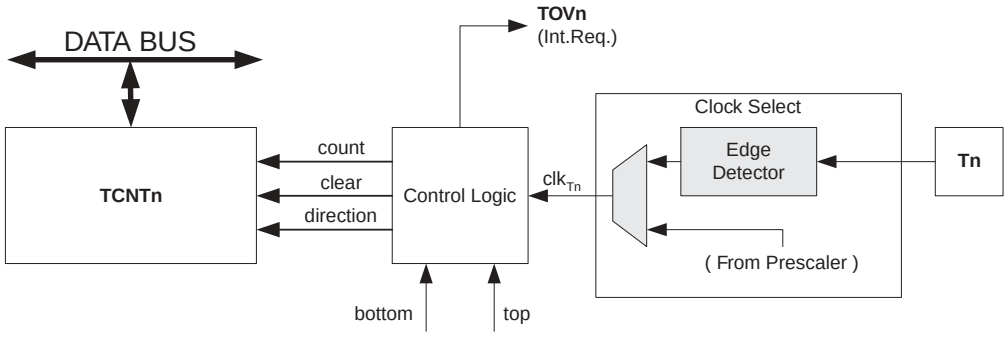
Timer/Counter Clock Sources

The Timer/Counter can be clocked by an internal or an external clock source. The clock source is selected by the Clock Select logic which is controlled by the Clock Select (CS02:0) bits located in the Timer/Counter Control Register (TCCR0). For details on clock sources and prescaler, see “Timer/Counter0, Timer/Counter1, and Timer/Counter3 Prescalers” on page 103.

Counter Unit

The main part of the 8-bit Timer/Counter is the programmable bi-directional counter unit. Figure 34 shows a block diagram of the counter and its surroundings.

Figure 34. Counter Unit Block Diagram



Signal description (internal signals):

count	Increment or decrement TCNT0 by 1.
direction	Select between increment and decrement.
clear	Clear TCNT0 (set all bits to zero).
clk_{Tn}	Timer/Counter clock, referred to as clk_{T0} in the following.
top	Signalize that TCNT0 has reached maximum value.
bottom	Signalize that TCNT0 has reached minimum value (zero).

Depending of the mode of operation used, the counter is cleared, incremented, or decremented at each timer clock (clk_T0). clk_T0 can be generated from an external or internal clock source, selected by the clock select bits (CS02:0). When no clock source is selected (CS02:0 = 0) the timer is stopped. However, the TCNT0 value can be accessed by the CPU, regardless of whether clk_T0 is present or not. A CPU write overrides (has priority over) all counter clear or count operations.

The counting sequence is determined by the setting of the WGM01 and WGM00 bits located in the Timer/Counter Control Register (TCCR0). There are close connections between how the counter behaves (counts) and how waveforms are generated on the output Compare Output OC0. For more details about advanced counting sequences and waveform generation, see “Modes of Operation” on page 93.

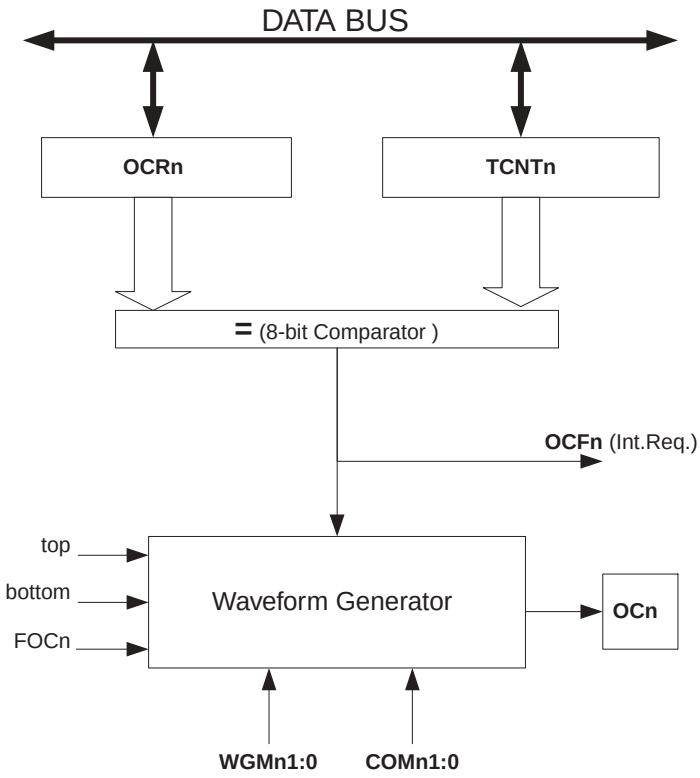
The Timer/Counter Overflow (TOV0) Flag is set according to the mode of operation selected by the WGM01:0 bits. TOV0 can be used for generating a CPU interrupt.

Output Compare Unit

The 8-bit comparator continuously compares TCNT0 with the Output Compare Register (OCR0). Whenever TCNT0 equals OCR0, the comparator signals a match. A match will set the Output Compare Flag (OCF0) at the next timer clock cycle. If enabled (OCIE0 = 1 and Global Interrupt Flag in SREG is set), the Output Compare Flag generates an output compare interrupt. The OCF0 Flag is automatically cleared when the interrupt is executed. Alternatively, the OCF0 Flag can be cleared by software by writing a logical one to its I/O bit location. The waveform generator uses the match signal to generate an output according to operating mode set by the WGM01:0 bits and Compare Output mode (COM01:0) bits. The max and bottom signals are used by the waveform generator for handling the special cases of the extreme values in some modes of operation (See “Modes of Operation” on page 93.).

Figure 35 shows a block diagram of the output compare unit.

Figure 35. Output Compare Unit, Block Diagram



The OCR0 Register is double buffered when using any of the Pulse Width Modulation (PWM) modes. For the Normal and Clear Timer on Compare (CTC) modes of operation, the double buffering is disabled. The double buffering synchronizes the update of the OCR0 Compare Register to either top or bottom of the counting sequence. The synchronization prevents the occurrence of odd-length, non-symmetrical PWM pulses, thereby making the output glitch-free.

The OCR0 Register access may seem complex, but this is not case. When the double buffering is enabled, the CPU has access to the OCR0 Buffer Register, and if double buffering is disabled the CPU will access the OCR0 directly.

Force Output Compare

In non-PWM waveform generation modes, the match output of the comparator can be forced by writing a one to the Force Output Compare (FOC0) bit. Forcing Compare Match will not set the OCF0 Flag or reload/clear the Timer, but the OC0 pin will be updated as if a real Compare Match had occurred (the COM01:0 bits settings define whether the OC0 pin is set, cleared or toggled).

Compare Match Blocking by TCNT0 Write

All CPU write operations to the TCNT0 Register will block any Compare Match that occur in the next timer clock cycle, even when the timer is stopped. This feature allows OCR0 to be initialized to the same value as TCNT0 without triggering an interrupt when the Timer/Counter clock is enabled.

Using the Output Compare Unit

Since writing TCNT0 in any mode of operation will block all compare matches for one timer clock cycle, there are risks involved when changing TCNT0 when using the output compare channel, independently of whether the Timer/Counter is running or not. If the value written to TCNT0 equals the OCR0 value, the Compare Match will be missed, resulting in incorrect waveform generation. Similarly, do not write the TCNT0 value equal to BOTTOM when the counter is down-counting.

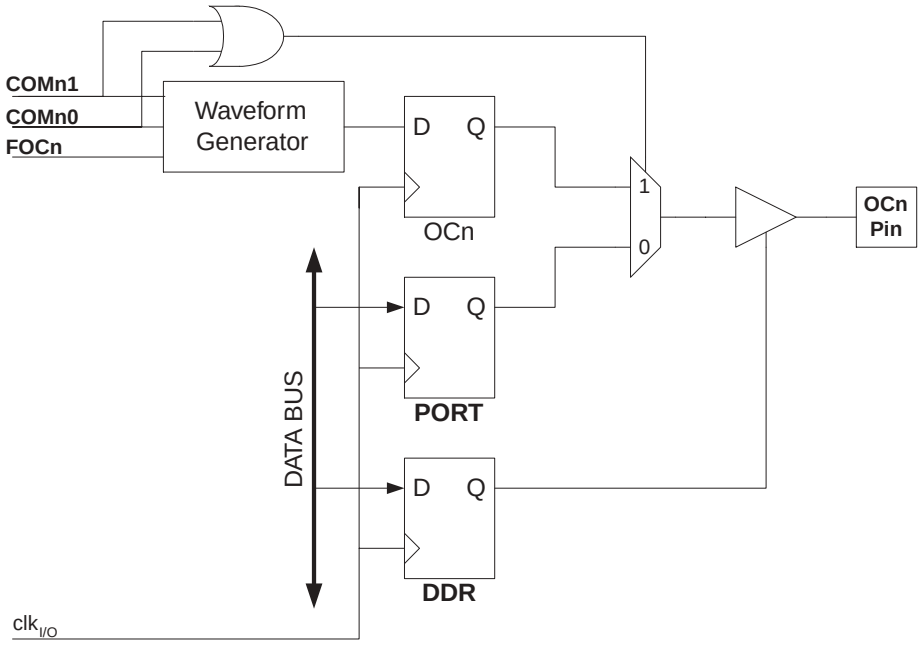
The setup of the OC0 should be performed before setting the Data Direction Register for the port pin to output. The easiest way of setting the OC0 value is to use the Force Output Compare (FOC0) strobe bits in Normal mode. The OC0 Register keeps its value even when changing between Waveform Generation modes.

Be aware that the COM01:0 bits are not double buffered together with the compare value. Changing the COM01:0 bits will take effect immediately.

Compare Match Output Unit

The Compare Output mode (COM01:0) bits have two functions. The Waveform Generator uses the COM01:0 bits for defining the Output Compare (OC0) state at the next Compare Match. Also, the COM01:0 bits control the OC0 pin output source. Figure 36 shows a simplified schematic of the logic affected by the COM01:0 bit setting. The I/O Registers, I/O bits, and I/O pins in the figure are shown in bold. Only the parts of the general I/O Port Control Registers (DDR and PORT) that are affected by the COM01:0 bits are shown. When referring to the OC0 state, the reference is for the internal OC0 Register, not the OC0 pin. If a System Reset occur, the OC0 Register is reset to “0”.

Figure 36. Compare Match Output Unit, Schematics



The general I/O port function is overridden by the Output Compare (OC0) from the waveform generator if either of the COM01:0 bits are set. However, the OC0 pin direction (input or output) is still controlled by the Data Direction Register (DDR) for the port pin. The Data Direction Register bit for the OC0 pin (DDR_OC0) must be set as output before the OC0 value is visible on the pin. The port override function is independent of the Waveform Generation mode.

The design of the output compare pin logic allows initialization of the OC0 state before the output is enabled. Note that some COM01:0 bit settings are reserved for certain modes of operation. See “8-bit Timer/Counter Register Description” on page 99.

Compare Output Mode and Waveform Generation

The Waveform Generator uses the COM01:0 bits differently in Normal, CTC, and PWM modes. For all modes, setting the COM01:0 = 0 tells the Waveform Generator that no action on the OC0 Register is to be performed on the next Compare Match. For Compare Output actions in the non-PWM modes refer to Table 48 on page 100. For fast PWM mode, refer to Table 49 on page 100, and for phase correct PWM refer to Table 50 on page 100.

A change of the COM01:0 bits state will have effect at the first Compare Match after the bits are written. For non-PWM modes, the action can be forced to have immediate effect by using the FOC0 strobe bits.

Modes of Operation

The mode of operation, i.e., the behavior of the Timer/Counter and the Output Compare pins, is defined by the combination of the Waveform Generation mode (WGM01:0) and Compare Output mode (COM01:0) bits. The Compare Output mode bits do not affect the counting sequence, while the Waveform Generation mode bits do. The COM01:0 bits control whether the PWM output generated should be inverted or not (inverted or non-inverted PWM). For non-PWM modes the COM01:0 bits control whether the output should be set, cleared, or toggled at a Compare Match (See “Compare Match Output Unit” on page 92.).

For detailed timing information refer to Figure 40, Figure 41, Figure 42 and Figure 43 in “Timer/Counter Timing Diagrams” on page 97.

Normal Mode

The simplest mode of operation is the Normal mode (WGM01:0 = 0). In this mode the counting direction is always up (incrementing), and no counter clear is performed. The counter simply overruns when it passes its maximum 8-bit value (TOP = 0xFF) and then restarts from the bottom (0x00). In normal operation the Timer/Counter Overflow Flag (TOV0) will be set in the same timer clock cycle as the TCNT0 becomes zero. The TOV0 Flag in this case behaves like a ninth bit, except that it is only set, not cleared. However, combined with the timer overflow interrupt that automatically clears the TOV0 Flag, the timer resolution can be increased by software. There are no special cases to consider in the Normal mode, a new counter value can be written anytime.

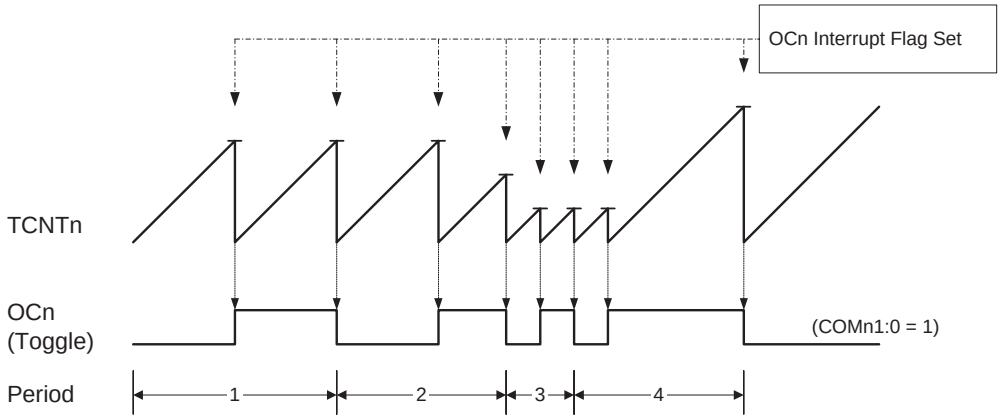
The output compare unit can be used to generate interrupts at some given time. Using the output compare to generate waveforms in Normal mode is not recommended, since this will occupy too much of the CPU time.

Clear Timer on Compare Match (CTC) Mode

In Clear Timer on Compare or CTC mode (WGM01:0 = 2), the OCR0 Register is used to manipulate the counter resolution. In CTC mode the counter is cleared to zero when the counter value (TCNT0) matches the OCR0. The OCR0 defines the top value for the counter, hence also its resolution. This mode allows greater control of the Compare Match output frequency. It also simplifies the operation of counting external events.

The timing diagram for the CTC mode is shown in Figure 37. The counter value (TCNT0) increases until a Compare Match occurs between TCNT0 and OCR0, and then counter (TCNT0) is cleared.

Figure 37. CTC Mode, Timing Diagram



An interrupt can be generated each time the counter value reaches the TOP value by using the OCF0 Flag. If the interrupt is enabled, the interrupt handler routine can be used for updating the TOP value. However, changing TOP to a value close to BOTTOM when the counter is running with none or a low prescaler value must be done with care since the CTC mode does not have the double buffering feature. If the new value written to OCR0 is lower than the current value of TCNT0, the counter will miss the Compare Match. The counter will then have to count to its maximum value (0xFF) and wrap around starting at 0x00 before the Compare Match can occur.

For generating a waveform output in CTC mode, the OC0 output can be set to toggle its logical level on each Compare Match by setting the Compare Output mode bits to toggle bitmode (COM01:0 = 1). The OC0 value will not be visible on the port pin unless the data direction for the pin is set to output. The waveform generated will have a maximum frequency of $f_{OC}0 = f_{clk\_I/O}/2$ when OCR0 is set to zero (0x00). The waveform frequency is defined by the following equation:

$$f_{OCn} = \frac{f_{clk\_I/O}}{2 \cdot N \cdot (1 + OCRn)}$$

The N variable represents the prescale factor (1, 8, 64, 256, or 1024).

As for the Normal mode of operation, the TOV0 Flag is set in the same timer clock cycle that the counter counts from MAX to 0x00.

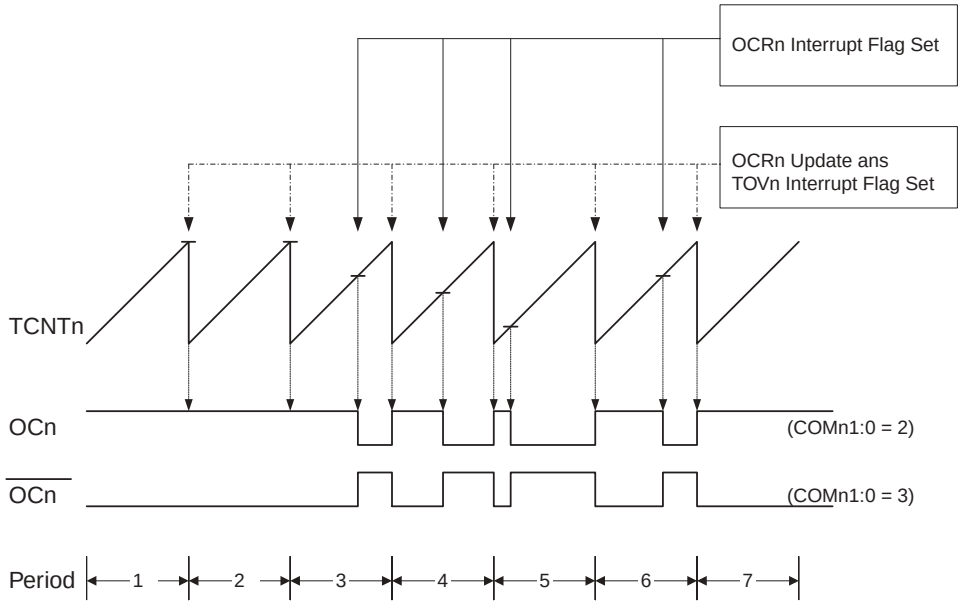
Fast PWM Mode

The fast Pulse Width Modulation or fast PWM mode (WGM01:0 = 3) provides a high frequency PWM waveform generation option. The fast PWM differs from the other PWM option by its single-slope operation. The counter counts from BOTTOM to MAX then restarts from BOTTOM. In non-inverting Compare Output mode, the Output Compare (OC0) is cleared on the Compare Match between TCNT0 and OCR0, and set at BOTTOM. In inverting Compare Output mode, the output is set on Compare Match and cleared at BOTTOM. Due to the single-slope operation, the operating frequency of the fast PWM mode can be twice as high as the phase correct PWM mode that use dual-slope operation. This high frequency makes the fast PWM mode well suited for power regulation, rectification, and DAC applications. High frequency allows physically small sized external components (coils, capacitors), and therefore reduces total system cost.

In fast PWM mode, the counter is incremented until the counter value matches the MAX value. The counter is then cleared at the following timer clock cycle. The timing diagram for the fast PWM mode is shown in Figure 38. The TCNT0 value is in the timing diagram shown as a histogram for illustrating the single-slope operation. The diagram includes

non-inverted and inverted PWM outputs. The small horizontal line marks on the TCNT0 slopes represent compare matches between OCR0 and TCNT0.

Figure 38. Fast PWM Mode, Timing Diagram



The Timer/Counter Overflow Flag (TOV0) is set each time the counter reaches MAX. If the interrupt is enabled, the interrupt handler routine can be used for updating the compare value.

In fast PWM mode, the compare unit allows generation of PWM waveforms on the OC0 pin. Setting the COM01:0 bits to two will produce a non-inverted PWM and an inverted PWM output can be generated by setting the COM01:0 to three (See Table 49 on page 100). The actual OC0 value will only be visible on the port pin if the data direction for the port pin is set as output. The PWM waveform is generated by setting (or clearing) the OC0 Register at the Compare Match between OCR0 and TCNT0, and clearing (or setting) the OC0 Register at the timer clock cycle the counter is cleared (changes from MAX to BOTTOM).

The PWM frequency for the output can be calculated by the following equation:

$$f_{OCnPWM} = \frac{f_{clk\_I/O}}{N \cdot 256}$$

The N variable represents the prescale factor (1, 8, 64, 256, or 1024).

The extreme values for the OCR0 Register represents special cases when generating a PWM waveform output in the fast PWM mode. If the OCR0 is set equal to BOTTOM, the output will be a narrow spike for each MAX+1 timer clock cycle. Setting the OCR0 equal to MAX will result in a constantly high or low output (depending on the polarity of the output set by the COM01:0 bits.)

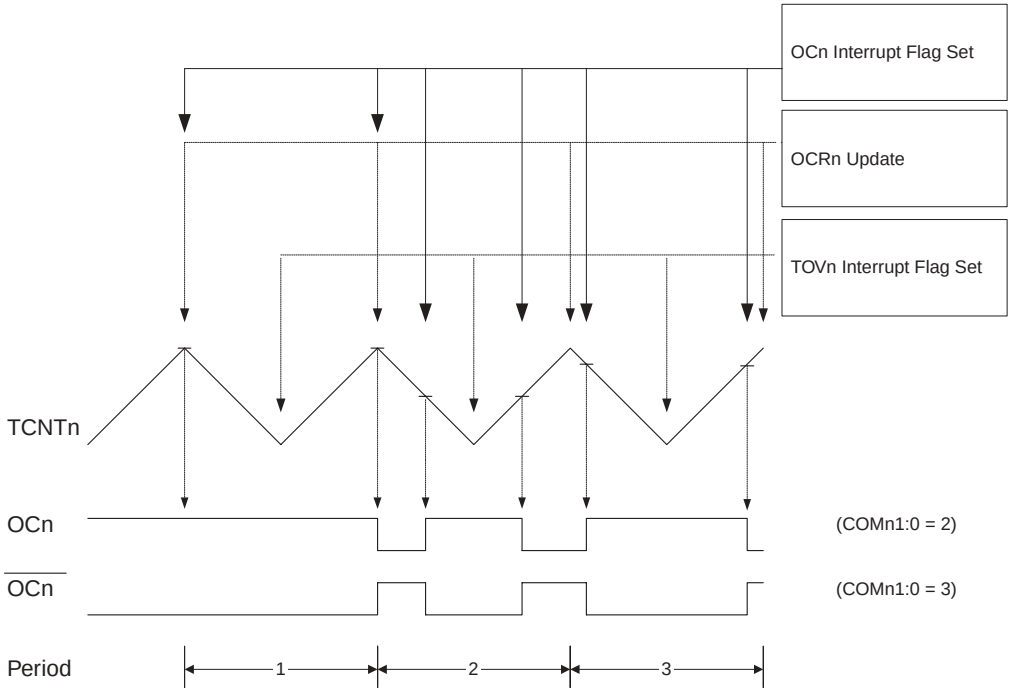
A frequency (with 50% duty cycle) waveform output in fast PWM mode can be achieved by setting OC0 to toggle its logical level on each Compare Match (COM01:0 = 1). The waveform generated will have a maximum frequency of $f_{OC}0 = f_{clk\_I/O}/2$ when OCR0 is set to zero. This feature is similar to the OC0 toggle in CTC mode, except the double buffer feature of the output compare unit is enabled in the fast PWM mode.

Phase Correct PWM Mode

The phase correct PWM mode (WGM01:0 = 1) provides a high resolution phase correct PWM waveform generation option. The phase correct PWM mode is based on a dual-slope operation. The counter counts repeatedly from BOTTOM to MAX and then from MAX to BOTTOM. In non-inverting Compare Output mode, the Output Compare (OC0) is cleared on the Compare Match between TCNT0 and OCR0 while up-counting, and set on the Compare Match while down-counting. In inverting Output Compare mode, the operation is inverted. The dual-slope operation has lower maximum operation frequency than single slope operation. However, due to the symmetric feature of the dual-slope PWM modes, these modes are preferred for motor control applications.

The PWM resolution for the phase correct PWM mode is fixed to eight bits. In phase correct PWM mode the counter is incremented until the counter value matches MAX. When the counter reaches MAX, it changes the count direction. The TCNT0 value will be equal to MAX for one timer clock cycle. The timing diagram for the phase correct PWM mode is shown on Figure 39. The TCNT0 value is in the timing diagram shown as a histogram for illustrating the dual-slope operation. The diagram includes non-inverted and inverted PWM outputs. The small horizontal line marks on the TCNT0 slopes represent compare matches between OCR0 and TCNT0.

Figure 39. Phase Correct PWM Mode, Timing Diagram



The Timer/Counter Overflow Flag (TOV0) is set each time the counter reaches BOTTOM. The Interrupt Flag can be used to generate an interrupt each time the counter reaches the BOTTOM value.

In phase correct PWM mode, the compare unit allows generation of PWM waveforms on the OC0 pin. Setting the COM01:0 bits to two will produce a non-inverted PWM. An inverted PWM output can be generated by setting the COM01:0 to three (See Table 50 on page 100). The actual OC0 value will only be visible on the port pin if the data direction for the port pin is set as output. The PWM waveform is generated by clearing (or setting) the OC0 Register at the Compare Match between OCR0 and TCNT0 when the counter increments, and setting (or clearing) the OC0 Register at Compare Match

between OCR0 and TCNT0 when the counter decrements. The PWM frequency for the output when using phase correct PWM can be calculated by the following equation:

$$f_{OCnPCPWM} = \frac{f_{clk\_I/O}}{N \cdot 510}$$

The N variable represents the prescale factor (1, 8, 64, 256, or 1024).

The extreme values for the OCR0 Register represent special cases when generating a PWM waveform output in the phase correct PWM mode. If the OCR0 is set equal to BOTTOM, the output will be continuously low and if set equal to MAX the output will be continuously high for non-inverted PWM mode. For inverted PWM the output will have the opposite logic values.

At the very start of period 2 in Figure 39 OCn has a transition from high to low even though there is no Compare Match. The point of this transition is to guarantee symmetry around BOTTOM. There are two cases that give a transition without Compare Match.

- OCR0 changes its value from MAX, like in Figure 39. When the OCR0 value is MAX the OCn pin value is the same as the result of a down-counting Compare Match. To ensure symmetry around BOTTOM the OCn value at MAX must correspond to the result of an up-counting Compare Match.
- The timer starts counting from a value higher than the one in OCR0, and for that reason misses the Compare Match and hence the OCn change that would have happened on the way up.

Timer/Counter Timing Diagrams

The Timer/Counter is a synchronous design and the timer clock (clk_T0) is therefore shown as a clock enable signal in the following figures. The figures include information on when Interrupt Flags are set. Figure 40 contains timing data for basic Timer/Counter operation. The figure shows the count sequence close to the MAX value in all modes other than phase correct PWM mode.

Figure 40. Timer/Counter Timing Diagram, no Prescaling

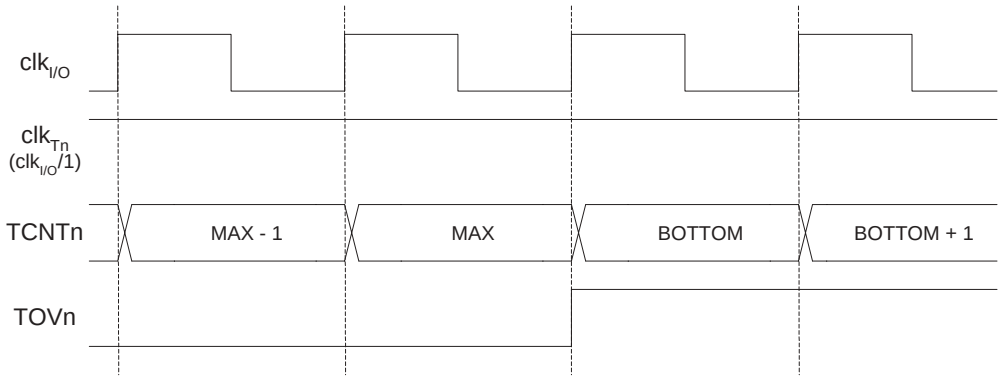


Figure 41 shows the same timing data, but with the prescaler enabled.

Figure 41. Timer/Counter Timing Diagram, with Prescaler ($f_{clk\_I/O}/8$)

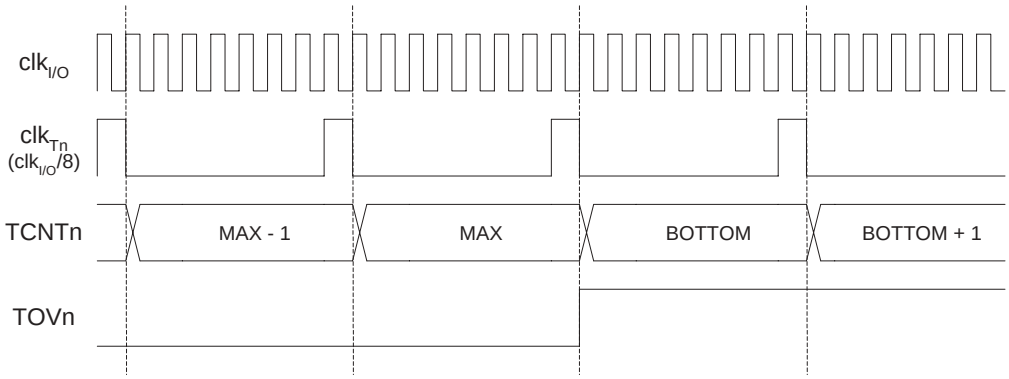


Figure 42 shows the setting of OCF0 in all modes except CTC mode.

Figure 42. Timer/Counter Timing Diagram, Setting of OCF0, with Prescaler ($f_{clk\_I/O}/8$)

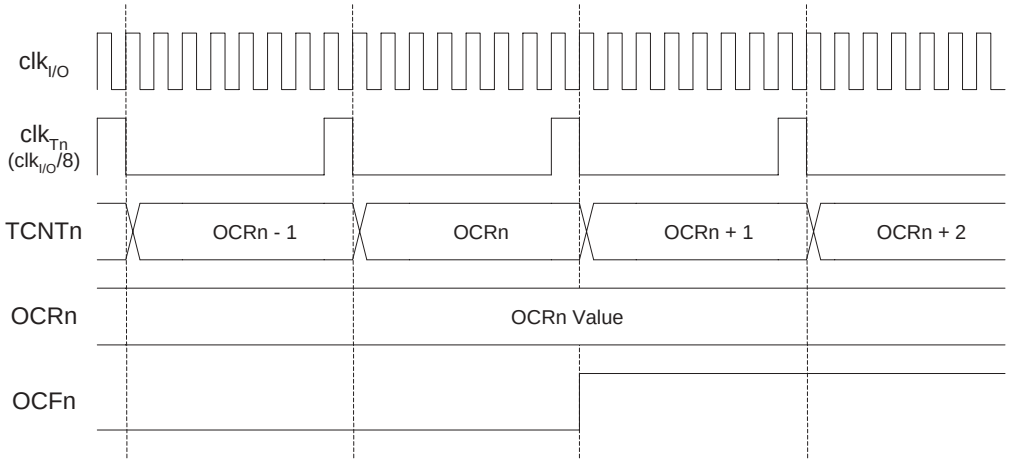
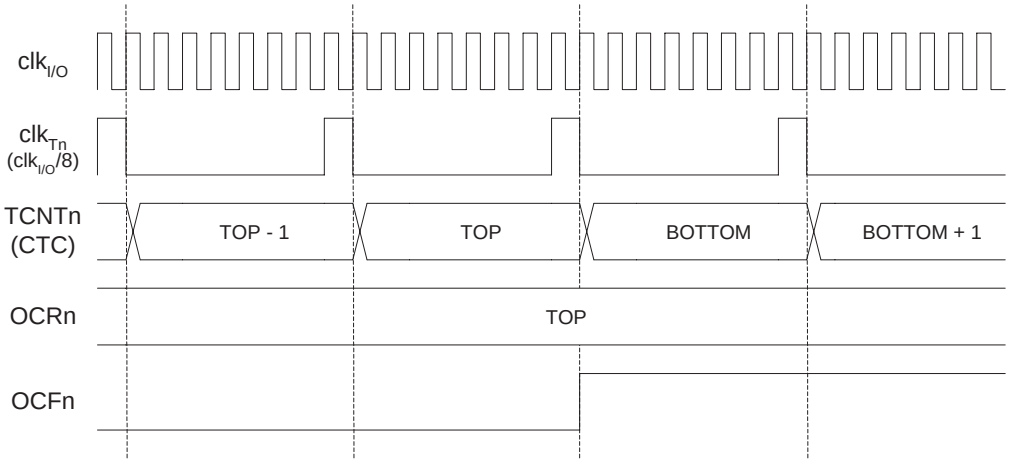


Figure 43 shows the setting of OCF0 and the clearing of TCNT0 in CTC mode.

Figure 43. Timer/Counter Timing Diagram, Clear Timer on Compare Match Mode, with Prescaler ($f_{clk\_I/O}/8$)



8-bit Timer/Counter Register Description

Timer/Counter Control Register – TCCR0

Bit	7	6	5	4	3	2	1	0	
	FOC0	WGM00	COM01	COM00	WGM01	CS02	CS01	CS00	TCCR0
Read/Write	W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

- **Bit 7 – FOC0: Force Output Compare**

The FOC0 bit is only active when the WGM00 bit specifies a non-PWM mode. However, for ensuring compatibility with future devices, this bit must be set to zero when TCCR0 is written when operating in PWM mode. When writing a logical one to the FOC0 bit, an immediate Compare Match is forced on the Waveform Generation unit. The OC0 output is changed according to its COM01:0 bits setting. Note that the FOC0 bit is implemented as a strobe. Therefore it is the value present in the COM01:0 bits that determines the effect of the forced compare.

A FOC0 strobe will not generate any interrupt, nor will it clear the timer in CTC mode using OCR0 as TOP.

The FOC0 bit is always read as zero.

- **Bit 6, 3 – WGM01:0: Waveform Generation Mode**

These bits control the counting sequence of the counter, the source for the maximum (TOP) counter value, and what type of waveform generation to be used. Modes of operation supported by the Timer/Counter unit are: Normal mode, Clear Timer on Compare match (CTC) mode, and two types of Pulse Width Modulation (PWM) modes. See Table 47 and “Modes of Operation” on page 93.

Table 47. Waveform Generation Mode Bit Description[1]

Mode	WGM01 (CTC0)	WGM00 (PWM0)	Timer/Counter Mode of Operation	TOP	Update of OCR0 at	TOV0 Flag Set on
0	0	0	Normal	0xFF	Immediate	MAX
1	0	1	PWM, Phase Correct	0xFF	TOP	BOTTOM
2	1	0	CTC	OCR0	Immediate	MAX
3	1	1	Fast PWM	0xFF	TOP	MAX

Note: 1. The CTC0 and PWM0 bit definition names are now obsolete. Use the WGM01:0 definitions. However, the functionality and location of these bits are compatible with previous versions of the timer.

- **Bit 5:4 – COM01:0: Compare Match Output Mode**

These bits control the output compare pin (OC0) behavior. If one or both of the COM01:0 bits are set, the OC0 output overrides the normal port functionality of the I/O pin it is connected to. However, note that the Data Direction Register (DDR) bit corresponding to the OC0 pin must be set in order to enable the output driver.

When OC0 is connected to the pin, the function of the COM01:0 bits depends on the WGM01:0 bit setting. Table 48 shows the COM01:0 bit functionality when the WGM01:0 bits are set to a Normal or CTC mode (non-PWM).

Table 48. Compare Output Mode, non-PWM Mode

COM01	COM00	Description
0	0	Normal port operation, OC0 disconnected.
0	1	Toggle OC0 on Compare Match.
1	0	Clear OC0 on Compare Match.
1	1	Set OC0 on Compare Match.

Table 49 shows the COM01:0 bit functionality when the WGM01:0 bits are set to fast PWM mode.

Table 49. Compare Output Mode, fast PWM Mode(1)

COM01	COM00	Description
0	0	Normal port operation, OC0 disconnected.
0	1	Reserved
1	0	Clear OC0 on Compare Match, set OC0 at TOP.
1	1	Set OC0 on Compare Match, clear OC0 at TOP.

Note: 1. A special case occurs when OCR0 equals TOP and COM01 is set. In this case, the Compare Match is ignored, but the set or clear is done at TOP. See “Fast PWM Mode” on page 94 for more details.

Table 50 shows the COM01:0 bit functionality when the WGM01:0 bits are set to phase correct PWM mode.

Table 50. Compare Output Mode, Phase Correct PWM Mode(1)

COM01	COM00	Description
0	0	Normal port operation, OC0 disconnected.
0	1	Reserved
1	0	Clear OC0 on Compare Match when up-counting. Set OC0 on Compare Match when down-counting.
1	1	Set OC0 on Compare Match when up-counting. Clear OC0 on Compare Match when down-counting.

Note: 1. A special case occurs when OCR0 equals TOP and COM01 is set. In this case, the Compare Match is ignored, but the set or clear is done at TOP. See “Phase Correct PWM Mode” on page 96 for more details.

- **Bit 2:0 – CS02:0: Clock Select**

The three Clock Select bits select the clock source to be used by the Timer/Counter.

Table 51. Clock Select Bit Description

CS02	CS01	CS00	Description
0	0	0	No clock source (Timer/Counter stopped).
0	0	1	$clk_{I/O}$/(No prescaling)
0	1	0	$clk_{I/O}$/8 (From prescaler)
0	1	1	$clk_{I/O}$/64 (From prescaler)
1	0	0	$clk_{I/O}$/256 (From prescaler)
1	0	1	$clk_{I/O}$/1024 (From prescaler)
1	1	0	External clock source on T0 pin. Clock on falling edge.
1	1	1	External clock source on T0 pin. Clock on rising edge.

If external pin modes are used for the Timer/Counter0, transitions on the T0 pin will clock the counter even if the pin is configured as an output. This feature allows software control of the counting.

Timer/Counter Register – TCNT0

Bit	7	6	5	4	3	2	1	0	
	TCNT0[7:0]								TCNT0
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

The Timer/Counter Register gives direct access, both for read and write operations, to the Timer/Counter unit 8-bit counter. Writing to the TCNT0 Register blocks (removes) the Compare Match on the following timer clock. Modifying the counter (TCNT0) while the counter is running, introduces a risk of missing a Compare Match between TCNT0 and the OCR0 Register.

Output Compare Register – OCR0

Bit	7	6	5	4	3	2	1	0	
	OCR0[7:0]								OCR0
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

The Output Compare Register contains an 8-bit value that is continuously compared with the counter value (TCNT0). A match can be used to generate an output compare interrupt, or to generate a waveform output on the OC0 pin.

Timer/Counter Interrupt Mask Register – TIMSK

Bit	7	6	5	4	3	2	1	0	
	TOIE1	OCIE1A	OCIE1B	OCIE2	TICIE1	TOIE2	TOIE0	OCIE0	TIMSK
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

- **Bit 1 – TOIE0: Timer/Counter0 Overflow Interrupt Enable**

When the TOIE0 bit is written to one, and the I-bit in the Status Register is set (one), the Timer/Counter0 Overflow interrupt is enabled. The corresponding interrupt is executed if an overflow in Timer/Counter0 occurs, i.e., when the TOV0 bit is set in the Timer/Counter Interrupt Flag Register – TIFR.

- **Bit 0 – OCIE0: Timer/Counter0 Output Compare Match Interrupt Enable**

When the OCIE0 bit is written to one, and the I-bit in the Status Register is set (one), the Timer/Counter0 Compare Match interrupt is enabled. The corresponding interrupt is executed if a Compare Match in Timer/Counter0 occurs, i.e., when the OCF0 bit is set in the Timer/Counter Interrupt Flag Register – TIFR.

Timer/Counter Interrupt Flag Register – TIFR

Bit	7	6	5	4	3	2	1	0	
	TOV1	OCF1A	OCF1B	OCF2	ICF1	TOV2	TOV0	OCF0	TIFR
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

- **Bit 1 – TOV0: Timer/Counter0 Overflow Flag**

The bit TOV0 is set (one) when an overflow occurs in Timer/Counter0. TOV0 is cleared by hardware when executing the corresponding interrupt handling vector. Alternatively, TOV0 is cleared by writing a logic one to the flag. When the SREG I-bit, TOIE0 (Timer/Counter0 Overflow Interrupt Enable), and TOV0 are set (one), the Timer/Counter0 Overflow interrupt is executed. In phase correct PWM mode, this bit is set when Timer/Counter0 changes counting direction at 0x00.

- **Bit 0 – OCF0: Output Compare Flag 0**

The OCF0 bit is set (one) when a Compare Match occurs between the Timer/Counter0 and the data in OCR0 – Output Compare Register0. OCF0 is cleared by hardware when executing the corresponding interrupt handling vector. Alternatively, OCF0 is cleared by writing a logic one to the flag. When the I-bit in SREG, OCIE0 (Timer/Counter0 Compare match Interrupt Enable), and OCF0 are set (one), the Timer/Counter0 Compare Match Interrupt is executed.

Timer/Counter0, Timer/Counter1, and Timer/Counter3 Prescalers

Timer/Counter3, Timer/Counter1, and Timer/Counter0 share the same prescaler module, but the Timer/Counters can have different prescaler settings. The description below applies to Timer/Counter3, Timer/Counter1, and Timer/Counter0.

Internal Clock Source

The Timer/Counter can be clocked directly by the system clock (by setting the CSn2:0 = 1). This provides the fastest operation, with a maximum Timer/Counter clock frequency equal to system clock frequency ($f_{CLK\_I/O}$). Alternatively, one of four taps from the prescaler can be used as a clock source. The prescaled clock has a frequency of either $f_{CLK\_I/O}/8$, $f_{CLK\_I/O}/64$, $f_{CLK\_I/O}/256$, or $f_{CLK\_I/O}/1024$. In addition, Timer/Counter3 has the option of choosing $f_{CLK\_I/O}/16$ and $f_{CLK\_I/O}/32$.

Prescaler Reset

The prescaler is free running, i.e., operates independently of the clock select logic of the Timer/Counter, and it is shared by Timer/Counter3, Timer/Counter1, and Timer/Counter0. Since the prescaler is not affected by the Timer/Counter's clock select, the state of the prescaler will have implications for situations where a prescaled clock is used. One example of prescaling artifacts occurs when the Timer is enabled and clocked by the prescaler (6 > CSn2:0 > 1). The number of system clock cycles from when the Timer is enabled to the first count occurs can be from 1 to N+1 system clock cycles, where N equals the prescaler divisor (8, 64, 256, or 1024, additional selections for Timer/Counter3: 32 and 64).

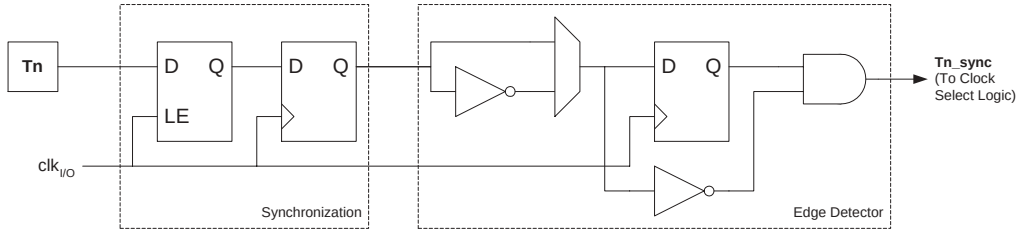
It is possible to use the Prescaler Reset for synchronizing the Timer/Counter to program execution. However, care must be taken if the other Timer/Counter that shares the same prescaler also uses prescaling. A Prescaler Reset will affect the prescaler period for all Timer/Counters it is connected to.

External Clock Source

An external clock source applied to the Tn/T0 pin can be used as Timer/Counter clock (clk_{T1}/clk_T0) for Timer/Counter1 and Timer/Counter0. The Tn/T0 pin is sampled once every system clock cycle by the pin synchronization logic. The synchronized (sampled) signal is then passed through the edge detector. Figure 44 shows a functional equivalent block diagram of the Tn/T0 synchronization and edge detector logic. The registers are clocked at the positive edge of the internal system clock ($clk_{I/O}$). The latch is transparent in the high period of the internal system clock.

The edge detector generates one clk_{T1}/clk_{T0} pulse for each positive (CSn2:0 = 7) or negative (CSn2:0 = 6) edge it detects.

Figure 44. Tn/T0 Pin Sampling



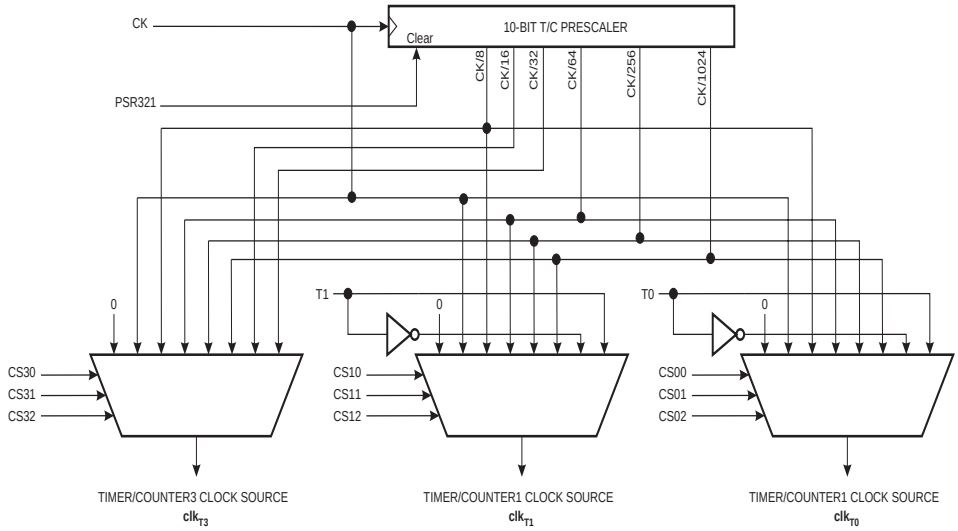
The synchronization and edge detector logic introduces a delay of 2.5 to 3.5 system clock cycles from an edge has been applied to the Tn/T0 pin to the counter is updated.

Enabling and disabling of the clock input must be done when Tn/T0 has been stable for at least one system clock cycle, otherwise it is a risk that a false Timer/Counter clock pulse is generated.

Each half period of the external clock applied must be longer than one system clock cycle to ensure correct sampling. The external clock must be guaranteed to have less than half the system clock frequency ($f_{ExtClk} < f_{clk\_I/O}/2$) given a 50/50% duty cycle. Since the edge detector uses sampling, the maximum frequency of an external clock it can detect is half the sampling frequency (Nyquist sampling theorem). However, due to variation of the system clock frequency and duty cycle caused by Oscillator source (crystal, resonator, and capacitors) tolerances, it is recommended that maximum frequency of an external clock source is less than $f_{clk\_I/O}/2.5$.

An external clock source can not be prescaled.

Figure 45. Prescaler for Timer/Counter0, Timer/Counter1, and Timer/Counter3[1]



Note: 1. The synchronization logic on the input pins (Tn/T0) is shown in Figure 44.

Special Function IO Register – SFIOR

Bit	7	6	5	4	3	2	1	0	
	TSM	XMBK	XMM2	XMM1	XMM0	PUD	PSR2	PSR310	SFIOR
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

- **Bit 7 – TSM: Timer/Counter Synchronization Mode**

Writing the TSM bit to one activates the Timer/Counter Synchronization mode. In this mode, the value that is written to the PSR2 and PSR310 bits is kept, hence keeping the corresponding prescaler reset signals asserted. This ensures that the corresponding Timer/Counters are halted and can be configured to the same value without the risk of one of them advancing during configuration. When the TSM bit is written to zero, the PSR2 and PSR310 bits are cleared by hardware, and the Timer/Counters start counting simultaneously.

- **Bit 0 – PSR310: Prescaler Reset Timer/Counter3, Timer/Counter1, and Timer/Counter0**

When this bit is one, the Timer/Counter3, Timer/Counter1, and Timer/Counter0 prescaler will be reset. This bit is normally cleared immediately by hardware, except if the TSM bit is set. Note that Timer/Counter3, Timer/Counter1, and Timer/Counter0 share the same prescaler and a reset of this prescaler will affect all three timers.

16-bit Timer/Counter (Timer/Counter1 and Timer/Counter3)

The 16-bit Timer/Counter unit allows accurate program execution timing (event management), wave generation, and signal timing measurement. The main features are:

- **True 16-bit Design (i.e., allows 16-bit PWM)**
- **Two Independent Output Compare Units**
- **Double Buffered Output Compare Registers**
- **One Input Capture Unit**
- **Input Capture Noise Canceler**
- **Clear Timer on Compare Match (Auto Reload)**
- **Glitch-free, Phase Correct Pulse Width Modulator (PWM)**
- **Variable PWM Period**
- **Frequency Generator**
- **External Event Counter**
- **Eight Independent Interrupt Sources (TOV1, OCF1A, OCF1B, ICF1, TOV3, OCF3A, OCF3B, and ICF3)**

Restriction in ATmega161 Compatibility Mode

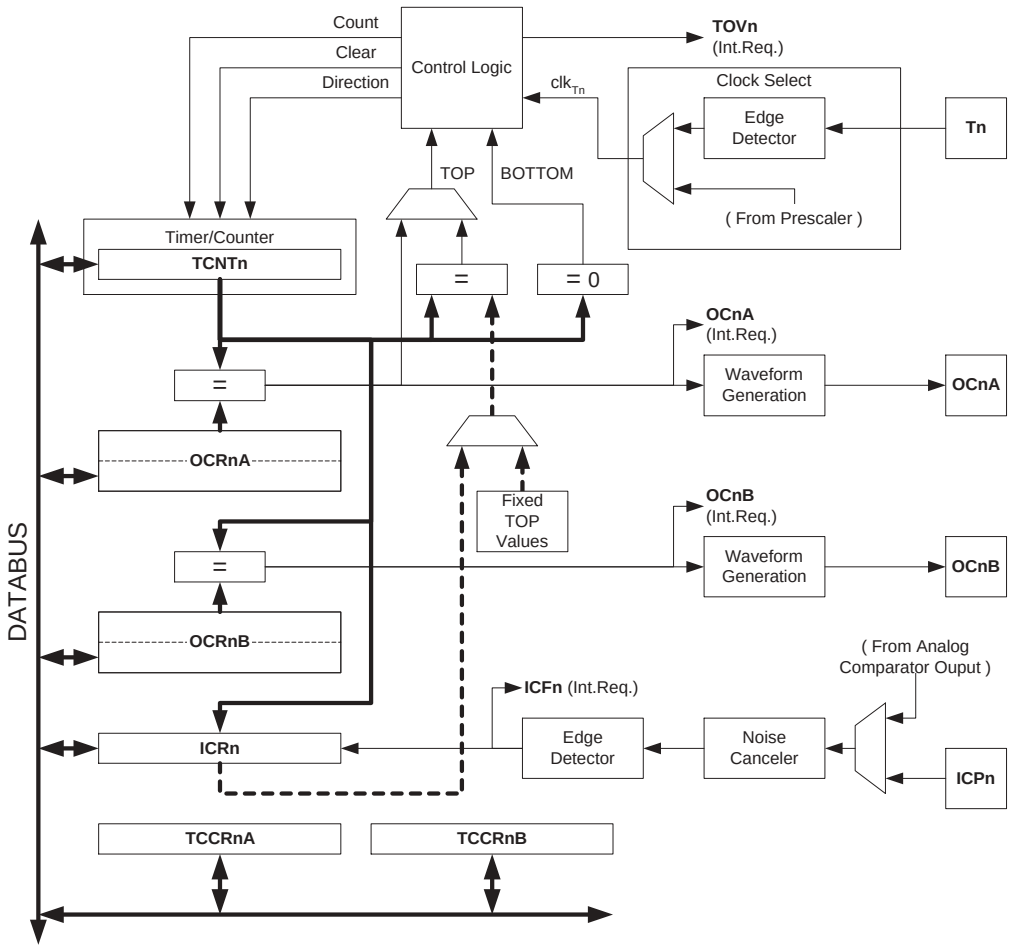
Note that in ATmega161 compatibility mode, only one 16-bits Timer/Counter is available (Timer/Counter1).

Overview

Most register and bit references in this section are written in general form. A lower case “n” replaces the Timer/Counter number, and a lower case “x” replaces the Output Compare unit channel. However, when using the register or bit defines in a program, the precise form must be used i.e., TCNT1 for accessing Timer/Counter1 counter value and so on.

A simplified block diagram of the 16-bit Timer/Counter is shown in Figure 46. For the actual placement of I/O pins, refer to “Pinout ATmega162” on page 2. CPU accessible I/O Registers, including I/O bits and I/O pins, are shown in bold. The device-specific I/O Register and bit locations are listed in the “16-bit Timer/Counter Register Description” on page 127.

Figure 46. 16-bit Timer/Counter Block Diagram[1]



Note: 1. Refer to Figure 1 on page 2, Table 32 on page 71, and Table 38 on page 77 for Timer/Counter1 pin placement and description.

Registers

The *Timer/Counter* (TCNTn), *Output Compare Registers* (OCRnA/B), and *Input Capture Register* (ICRn) are all 16-bit registers. Special procedures must be followed when accessing the 16-bit registers. These procedures are described in the section “Accessing 16-bit Registers” on page 108. The *Timer/Counter Control Registers* (TCCRnA/B) are 8-bit registers and have no CPU access restrictions. Interrupt requests (abbreviated to Int.Req. in the figure) signals are all visible in the *Timer Interrupt Flag Register* (TIFR) and *Extended Timer Interrupt Flag Register* (ETIFR). All interrupts are individually masked with the *Timer Interrupt Mask Register* (TIMSK) and *Extended Timer Interrupt Mask Register* (ETIMSK). (E)TIFR and (E)TIMSK are not shown in the figure since these registers are shared by other Timer units.

The Timer/Counter can be clocked internally, via the prescaler, or by an external clock source on the T1 pin. The Clock Select logic block controls which clock source and edge the Timer/Counter uses to increment (or decrement) its value. The Timer/Counter is inactive when no clock source is selected. The output from the Clock Select logic is referred to as the Timer Clock (clk_Tn).

The double buffered Output Compare Registers (OCRnA/B) are compared with the Timer/Counter value at all time. The result of the compare can be used by the waveform generator to generate a PWM or variable frequency output on the Output Compare pin

(OCnA/B). See “Output Compare Units” on page 114. The Compare Match event will also set the Compare Match Flag (OCFnA/B) which can be used to generate an output compare interrupt request.

The Input Capture Register can capture the Timer/Counter value at a given external (edge triggered) event on either the Input Capture pin (ICPn) or on the Analog Comparator pins (See “Analog Comparator” on page 194.) The Input Capture unit includes a digital filtering unit (Noise Canceler) for reducing the chance of capturing noise spikes.

The TOP value, or maximum Timer/Counter value, can in some modes of operation be defined by either the OCRnA Register, the ICRn Register, or by a set of fixed values. When using OCRnA as TOP value in a PWM mode, the OCRnA Register can not be used for generating a PWM output. However, the TOP value will in this case be double buffered allowing the TOP value to be changed in run time. If a fixed TOP value is required, the ICRn Register can be used as an alternative, freeing the OCRnA to be used as PWM output.

Definitions

The following definitions are used extensively throughout the section:

Table 52. Definitions

BOTTOM	The counter reaches the *BOTTOM* when it becomes 0x0000.
MAX	The counter reaches its *MAX*imum when it becomes 0xFFFF (decimal 65535).
TOP	The counter reaches the *TOP* when it becomes equal to the highest value in the count sequence. The TOP value can be assigned to be one of the fixed values: 0x00FF, 0x01FF, or 0x03FF, or to the value stored in the OCRnA or ICRn Register. The assignment is dependent of the mode of operation.

Compatibility

The 16-bit Timer/Counter has been updated and improved from previous versions of the 16-bit AVR Timer/Counter. This 16-bit Timer/Counter is fully compatible with the earlier version regarding:

- All 16-bit Timer/Counter related I/O Register address locations, including Timer Interrupt Registers.
- Bit locations inside all 16-bit Timer/Counter Registers, including Timer Interrupt Registers.
- Interrupt Vectors.

The following control bits have changed name, but have same functionality and register location:

- PWMn0 is changed to WGMn0.
- PWMn1 is changed to WGMn1.
- CTCn is changed to WGMn2.

The following bits are added to the 16-bit Timer/Counter Control Registers:

- FOCnA and FOCnB are added to TCCRnA.
- WGMn3 is added to TCCRnB.

The 16-bit Timer/Counter has improvements that will affect the compatibility in some special cases.

Accessing 16-bit Registers

The TCNTn, OCRnA/B, and ICRn are 16-bit registers that can be accessed by the AVR CPU via the 8-bit data bus. The 16-bit register must be byte accessed using two read or write operations. Each 16-bit timer has a single 8-bit register for temporary storing of the high byte of the 16-bit access. The same Temporary Register is shared between all 16-bit registers within each 16-bit timer. Accessing the low byte triggers the 16-bit read or write operation. When the low byte of a 16-bit register is written by the CPU, the high byte stored in the temporary register, and the low byte written are both copied into the 16-bit register in the same clock cycle. When the low byte of a 16-bit register is read by the CPU, the high byte of the 16-bit register is copied into the temporary register in the same clock cycle as the low byte is read.

Not all 16-bit accesses uses the temporary register for the high byte. Reading the OCRnA/B 16-bit registers does not involve using the temporary register.

To do a 16-bit write, *the high byte must be written before the low byte*. For a 16-bit read, *the low byte must be read before the high byte*.

The following code examples show how to access the 16-bit Timer Registers assuming that no interrupts updates the temporary register. The same principle can be used directly for accessing the OCRnA/B and ICRn Registers. Note that when using “C”, the compiler handles the 16-bit access.

Assembly Code Examples[1]

```
...
; Set TCNTn to 0x01FF
ldi r17,0x01
ldi r16,0xFF
out TCNTnH,r17
out TCNTnL,r16
; Read TCNTn into r17:r16
in  r16,TCNTnL
in  r17,TCNTnH
...
```

C Code Examples[1]

```
unsigned int i;
...
/* Set TCNTn to 0x01FF */
TCNTn = 0x1FF;
/* Read TCNTn into i */
i = TCNTn;
...
```

Note: 1. The example code assumes that the part specific header file is included.
For I/O Registers located in extended I/O map, “IN”, “OUT”, “SBIS”, “SBIC”, “CBI”, and “SBI” instructions must be replaced with instructions that allow access to extended I/O. Typically “LDS” and “STS” combined with “SBRS”, “SBRC”, “SBR”, and “CBR”.

The assembly code example returns the TCNTn value in the r17:r16 register pair.

It is important to notice that accessing 16-bit registers are atomic operations. If an interrupt occurs between the two instructions accessing the 16-bit register, and the interrupt code updates the temporary register by accessing the same or any other of the 16-bit Timer Registers, then the result of the access outside the interrupt will be corrupted.

Therefore, when both the main code and the interrupt code update the temporary register, the main code must disable the interrupts during the 16-bit access.

The following code examples show how to do an atomic read of the TCNTn Register contents. Reading any of the OCRnA/B or ICRn Registers can be done by using the same principle.

Assembly Code Example[1]

```
TIM16_ReadTCNTn:
  ; Save Global Interrupt Flag
  in  r18,SREG
  ; Disable interrupts
  cli
  ; Read TCNTn into r17:r16
  in  r16,TCNTnL
  in  r17,TCNTnH
  ; Restore Global Interrupt Flag
  out SREG,r18
  ret
```

C Code Example[1]

```
unsigned int TIM16_ReadTCNTn( void )
{
  unsigned char sreg;
  unsigned int i;
  /* Save Global Interrupt Flag */
  sreg = SREG;
  /* Disable interrupts */
  _CLI();
  /* Read TCNTn into i */
  i = TCNTn;
  /* Restore Global Interrupt Flag */
  SREG = sreg;
  return i;
}
```

Note: 1. The example code assumes that the part specific header file is included.
For I/O Registers located in extended I/O map, “IN”, “OUT”, “SBIS”, “SBIC”, “CBI”, and “SBI” instructions must be replaced with instructions that allow access to extended I/O. Typically “LDS” and “STS” combined with “SBRS”, “SBRC”, “SBR”, and “CBR”.

The assembly code example returns the TCNTn value in the r17:r16 register pair.

The following code examples show how to do an atomic write of the TCNTn Register contents. Writing any of the OCRnA/B or ICRn Registers can be done by using the same principle.

Assembly Code Example[1]

```
TIM16_WriteTCNTn:
  ; Save Global Interrupt Flag
  in  r18,SREG
  ; Disable interrupts
  cli
  ; Set TCNTn to r17:r16
  out TCNTnH,r17
  out TCNTnL,r16
  ; Restore Global Interrupt Flag
  out SREG,r18
  ret
```

C Code Example[1]

```
void TIM16_WriteTCNTn( unsigned int i )
{
  unsigned char sreg;
  unsigned int i;
  /* Save Global Interrupt Flag */
  sreg = SREG;
  /* Disable interrupts */
  _CLI();
  /* Set TCNTn to i */
  TCNTn = i;
  /* Restore Global Interrupt Flag */
  SREG = sreg;
}
```

Note: 1. The example code assumes that the part specific header file is included.
For I/O Registers located in extended I/O map, “IN”, “OUT”, “SBIS”, “SBIC”, “CBI”, and “SBI” instructions must be replaced with instructions that allow access to extended I/O. Typically “LDS” and “STS” combined with “SBRS”, “SBRC”, “SBR”, and “CBR”.

The assembly code example requires that the r17:r16 register pair contains the value to be written to TCNTn.

Reusing the Temporary High Byte Register

If writing to more than one 16-bit register where the high byte is the same for all registers written, then the high byte only needs to be written once. However, note that the same rule of atomic operation described previously also applies in this case.

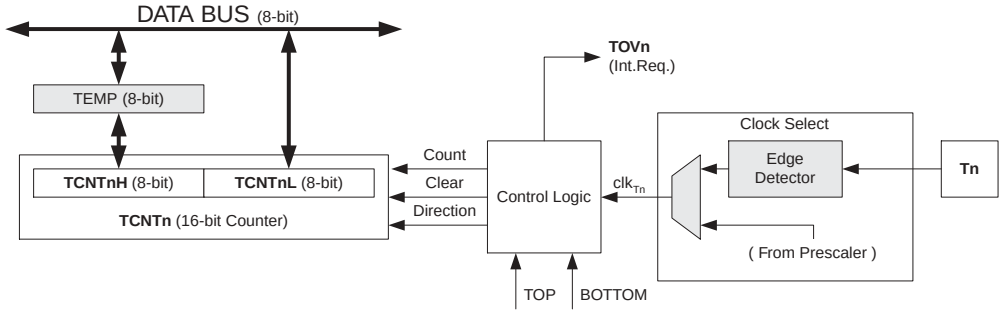
Timer/Counter Clock Sources

The Timer/Counter can be clocked by an internal or an external clock source. The clock source is selected by the clock select logic which is controlled by the *Clock Select* (CSn2:0) bits located in the *Timer/Counter Control Register B* (TCCRnB). For details on clock sources and prescaler, see “Timer/Counter0, Timer/Counter1, and Timer/Counter3 Prescalers” on page 103.

Counter Unit

The main part of the 16-bit Timer/Counter is the programmable 16-bit bi-directional counter unit. Figure 47 shows a block diagram of the counter and its surroundings.

Figure 47. Counter Unit Block Diagram



Signal description (internal signals):

Count Increment or decrement TCNTn by 1.

Direction Select between increment and decrement.

Clear Clear TCNTn (set all bits to zero).

clk_Tn Timer/Counter clock.

TOP Signalize that TCNTn has reached maximum value.

BOTTOM Signalize that TCNTn has reached minimum value (zero).

The 16-bit counter is mapped into two 8-bit I/O memory locations: *Counter High* (TCNTnH) containing the upper eight bits of the counter, and *Counter Low* (TCNTnL) containing the lower eight bits. The TCNTnH Register can only be indirectly accessed by the CPU. When the CPU does an access to the TCNTnH I/O location, the CPU accesses the high byte temporary register (TEMP). The temporary register is updated with the TCNTnH value when the TCNTnL is read, and TCNTnH is updated with the temporary register value when TCNTnL is written. This allows the CPU to read or write the entire 16-bit counter value within one clock cycle via the 8-bit data bus. It is important to notice that there are special cases of writing to the TCNTn Register when the counter is counting that will give unpredictable results. The special cases are described in the sections where they are of importance.

Depending on the mode of operation used, the counter is cleared, incremented, or decremented at each *Timer Clock* (clk_Tn). The clk_Tn can be generated from an external or internal clock source, selected by the *Clock Select* bits (CSn2:0). When no clock source is selected (CSn2:0 = 0) the Timer is stopped. However, the TCNTn value can be accessed by the CPU, independent of whether clk_Tn is present or not. A CPU write overrides (has priority over) all counter clear or count operations.

The counting sequence is determined by the setting of the *Waveform Generation mode* bits (WGMn3:0) located in the *Timer/Counter Control Registers* A and B (TCCRnA and TCCRnB). There are close connections between how the counter behaves (counts) and

how waveforms are generated on the Output Compare outputs OCnx. For more details about advanced counting sequences and waveform generation, see “Modes of Operation” on page 117.

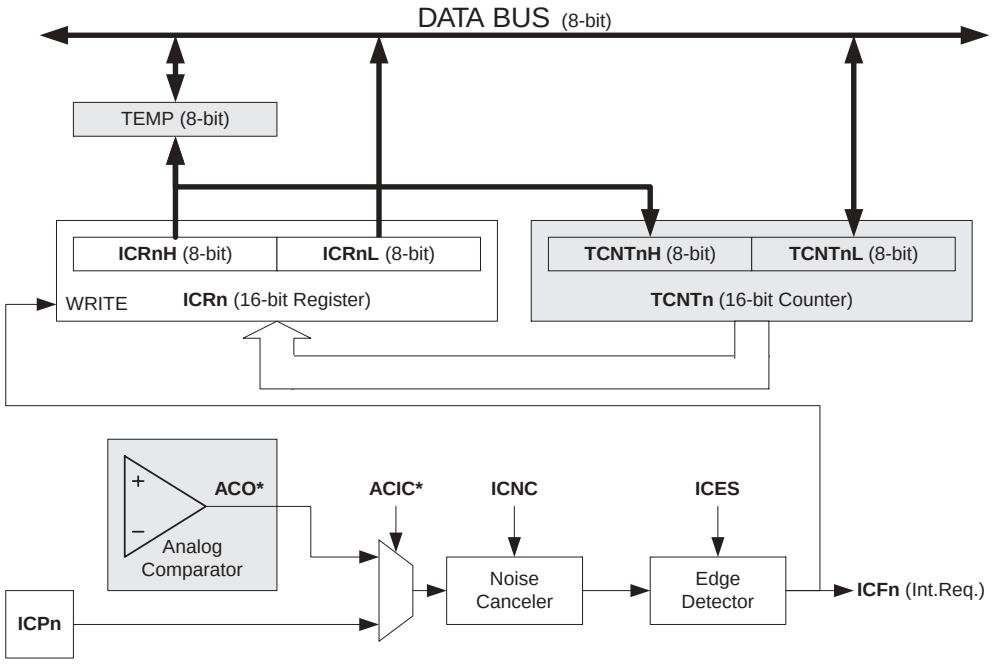
The *Timer/Counter Overflow* Flag (TOVn) is set according to the mode of operation selected by the WGMn3:0 bits. TOVn can be used for generating a CPU interrupt.

Input Capture Unit

The Timer/Counter incorporates an Input Capture unit that can capture external events and give them a time-stamp indicating time of occurrence. The external signal indicating an event, or multiple events, can be applied via the ICPn pin or alternatively, via the Analog Comparator unit. The time-stamps can then be used to calculate frequency, duty-cycle, and other features of the signal applied. Alternatively the time-stamps can be used for creating a log of the events.

The Input Capture unit is illustrated by the block diagram shown in Figure 48. The elements of the block diagram that are not directly a part of the Input Capture unit are gray shaded. The small “n” in register and bit names indicates the Timer/Counter number.

Figure 48. Input Capture Unit Block Diagram(1)



Note: 1. The Analog Comparator Output (ACO) can only trigger the Timer/Counter1 ICP – not Timer/Counter3.

When a change of the logic level (an event) occurs on the *Input Capture pin* (ICPn), alternatively on the *Analog Comparator output* (ACO), and this change confirms to the setting of the edge detector, a capture will be triggered. When a capture is triggered, the 16-bit value of the counter (TCNTn) is written to the *Input Capture Register* (ICRn). The *Input Capture Flag* (ICFn) is set at the same system clock as the TCNTn value is copied into ICRn Register. If enabled (TICIEn = 1), the Input Capture Flag generates an Input Capture interrupt. The ICFn Flag is automatically cleared when the interrupt is executed. Alternatively the ICFn Flag can be cleared by software by writing a logical one to its I/O bit location.

Reading the 16-bit value in the *Input Capture Register* (ICRn) is done by first reading the low byte (ICRnL) and then the high byte (ICRnH). When the low byte is read the high byte is copied into the high byte temporary register (TEMP). When the CPU reads the ICRnH I/O location it will access the TEMP Register.

The ICRn Register can only be written when using a Waveform Generation mode that utilizes the ICRn Register for defining the counter's TOP value. In these cases the *Waveform Generation mode* (WGMn3:0) bits must be set before the TOP value can be written to the ICRn Register. When writing the ICRn Register the high byte must be written to the ICRnH I/O location before the low byte is written to ICRnL.

For more information on how to access the 16-bit registers refer to "Accessing 16-bit Registers" on page 108.

Input Capture Trigger Source

The main trigger source for the Input Capture unit is the *Input Capture pin* (ICPn). Timer/Counter1 can alternatively use the Analog Comparator output as trigger source for the Input Capture unit. The Analog Comparator is selected as trigger source by setting the *Analog Comparator Input Capture* (ACIC) bit in the *Analog Comparator Control and Status Register* (ACSR). Be aware that changing trigger source can trigger a capture. The Input Capture Flag must therefore be cleared after the change.

Both the *Input Capture pin* (ICPn) and the *Analog Comparator output* (ACO) inputs are sampled using the same technique as for the Tn pin (Figure 44 on page 103). The edge detector is also identical. However, when the noise canceler is enabled, additional logic is inserted before the edge detector, which increases the delay by four system clock cycles. Note that the input of the noise canceler and edge detector is always enabled unless the Timer/Counter is set in a Waveform Generation mode that uses ICRn to define TOP.

An Input Capture can be triggered by software by controlling the port of the ICPn pin.

Noise Canceler

The Noise Canceler improves noise immunity by using a simple digital filtering scheme. The Noise Canceler input is monitored over four samples, and all four must be equal for changing the output that in turn is used by the edge detector.

The Noise Canceler is enabled by setting the *Input Capture Noise Canceler* (ICNCn) bit in *Timer/Counter Control Register B* (TCCRnB). When enabled the noise canceler introduces additional four system clock cycles of delay from a change applied to the input, to the update of the ICRn Register. The noise canceler uses the system clock and is therefore not affected by the prescaler.

Using the Input Capture Unit

The main challenge when using the Input Capture unit is to assign enough processor capacity for handling the incoming events. The time between two events is critical. If the processor has not read the captured value in the ICRn Register before the next event occurs, the ICRn will be overwritten with a new value. In this case the result of the capture will be incorrect.

When using the Input Capture interrupt, the ICRn Register should be read as early in the interrupt handler routine as possible. Even though the Input Capture interrupt has relatively high priority, the maximum interrupt response time is dependent on the maximum number of clock cycles it takes to handle any of the other interrupt requests.

Using the Input Capture unit in any mode of operation when the TOP value (resolution) is actively changed during operation, is not recommended.

Measurement of an external signal's duty cycle requires that the trigger edge is changed after each capture. Changing the edge sensing must be done as early as possible after the ICRn Register has been read. After a change of the edge, the Input Capture Flag

(ICFn) must be cleared by software (writing a logical one to the I/O bit location). For measuring frequency only, the clearing of the ICFn Flag is not required (if an interrupt handler is used).

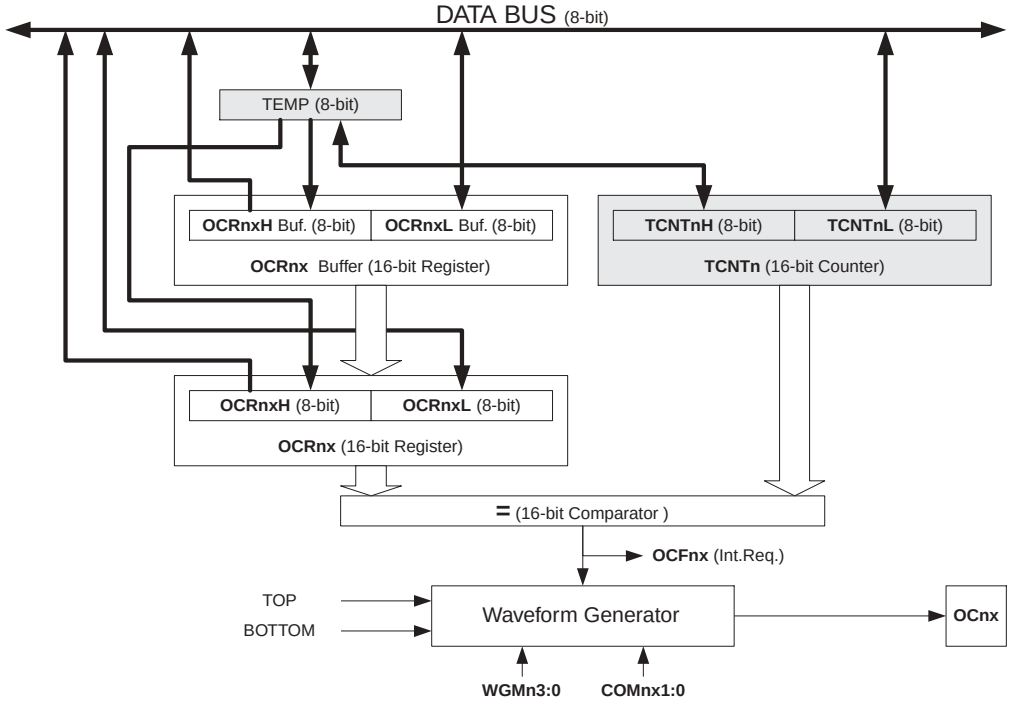
Output Compare Units

The 16-bit comparator continuously compares TCNTn with the *Output Compare Register* (OCRnx). If TCNT equals OCRnx the comparator signals a match. A match will set the *Output Compare Flag* (OCFnx) at the next timer clock cycle. If enabled (OCIEnx = 1), the Output Compare Flag generates an output compare interrupt. The OCFnx Flag is automatically cleared when the interrupt is executed. Alternatively the OCFnx Flag can be cleared by software by writing a logical one to its I/O bit location. The Waveform Generator uses the match signal to generate an output according to operating mode set by the *Waveform Generation mode* (WGMn3:0) bits and *Compare Output mode* (COMnx1:0) bits. The TOP and BOTTOM signals are used by the Waveform Generator for handling the special cases of the extreme values in some modes of operation (See “Modes of Operation” on page 117.)

A special feature of output compare unit A allows it to define the Timer/Counter TOP value (i.e., counter resolution). In addition to the counter resolution, the TOP value defines the period time for waveforms generated by the Waveform Generator.

Figure 49 shows a block diagram of the output compare unit. The small “n” in the register and bit names indicates the device number (n = n for Timer/Counter n), and the “x” indicates output compare unit (A/B). The elements of the block diagram that are not directly a part of the output compare unit are gray shaded.

Figure 49. Output Compare Unit, Block Diagram



The OCRnx Register is double buffered when using any of the twelve *Pulse Width Modulation* (PWM) modes. For the normal and *Clear Timer on Compare* (CTC) modes of operation, the double buffering is disabled. The double buffering synchronizes the update of the OCRnx Compare Register to either TOP or BOTTOM of the counting

sequence. The synchronization prevents the occurrence of odd-length, non-symmetrical PWM pulses, thereby making the output glitch-free.

The OCRnx Register access may seem complex, but this is not case. When the double buffering is enabled, the CPU has access to the OCRnx Buffer Register, and if double buffering is disabled the CPU will access the OCRnx directly. The content of the OCR1x (Buffer or Compare) Register is only changed by a write operation (the Timer/Counter does not update this register automatically as the TCNT1 and ICR1 Register). Therefore OCR1x is not read via the high byte temporary register (TEMP). However, it is a good practice to read the low byte first as when accessing other 16-bit registers. Writing the OCRnx Registers must be done via the TEMP Register since the compare of all 16 bits is done continuously. The high byte (OCRnxH) has to be written first. When the high byte I/O location is written by the CPU, the TEMP Register will be updated by the value written. Then when the low byte (OCRnxL) is written to the lower eight bits, the high byte will be copied into the upper eight bits of either the OCRnx buffer or OCRnx Compare Register in the same system clock cycle.

For more information of how to access the 16-bit registers refer to “Accessing 16-bit Registers” on page 108.

Force Output Compare

In non-PWM waveform generation modes, the match output of the comparator can be forced by writing a one to the *Force Output Compare* (FOCnx) bit. Forcing Compare Match will not set the OCFnx Flag or reload/clear the timer, but the OCnx pin will be updated as if a real Compare Match had occurred (the COMn1:0 bits settings define whether the OCnx pin is set, cleared or toggled).

Compare Match Blocking by TCNTn Write

All CPU writes to the TCNTn Register will block any Compare Match that occurs in the next timer clock cycle, even when the timer is stopped. This feature allows OCRnx to be initialized to the same value as TCNTn without triggering an interrupt when the Timer/Counter clock is enabled.

Using the Output Compare Unit

Since writing TCNTn in any mode of operation will block all compare matches for one timer clock cycle, there are risks involved when changing TCNTn when using any of the output compare channels, independent of whether the Timer/Counter is running or not. If the value written to TCNTn equals the OCRnx value, the Compare Match will be missed, resulting in incorrect waveform generation. Do not write the TCNTn equal to TOP in PWM modes with variable TOP values. The Compare Match for the TOP will be ignored and the counter will continue to 0xFFFF. Similarly, do not write the TCNTn value equal to BOTTOM when the counter is down-counting.

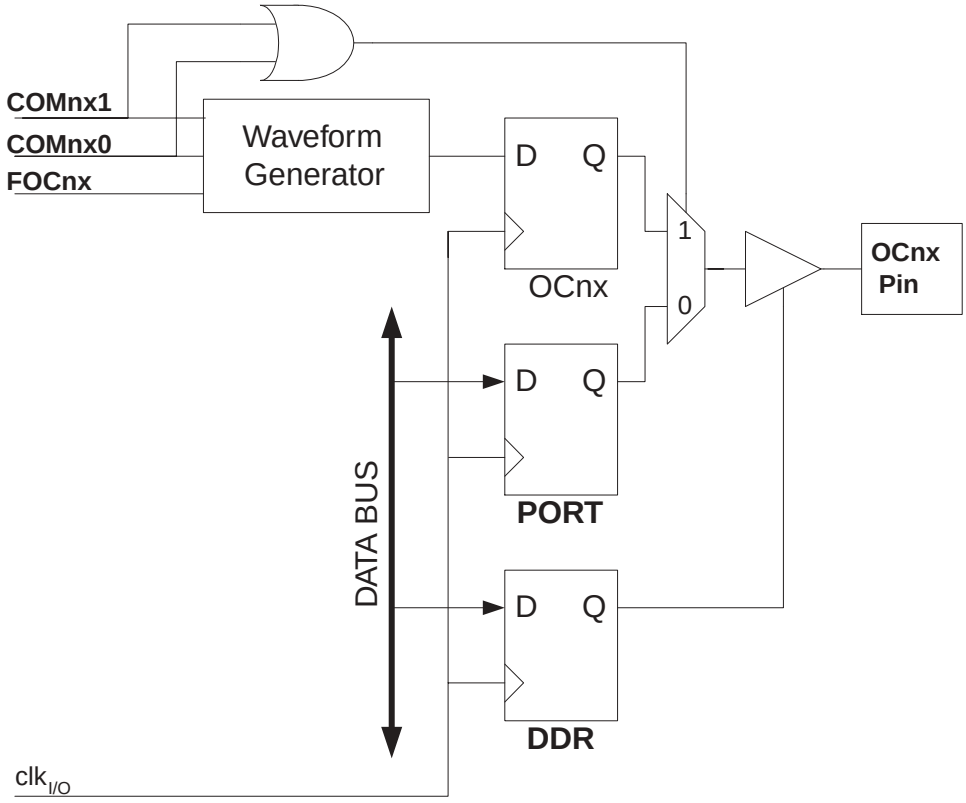
The setup of the OCnx should be performed before setting the Data Direction Register for the port pin to output. The easiest way of setting the OCnx value is to use the Force Output Compare (FOCnx) strobe bits in Normal mode. The OCnx Register keeps its value even when changing between Waveform Generation modes.

Be aware that the COMnx1:0 bits are not double buffered together with the compare value. Changing the COMnx1:0 bits will take effect immediately.

Compare Match Output Unit

The *Compare Output mode* (COMnx1:0) bits have two functions. The waveform generator uses the COMnx1:0 bits for defining the output compare (OCnx) state at the next Compare Match. Secondly the COMnx1:0 bits control the OCnx pin output source. Figure 50 shows a simplified schematic of the logic affected by the COMnx1:0 bit setting. The I/O Registers, I/O bits, and I/O pins in the figure are shown in bold. Only the parts of the general I/O Port Control Registers (DDR and PORT) that are affected by the COMnx1:0 bits are shown. When referring to the OCnx state, the reference is for the internal OCnx Register, not the OCnx pin. If a System Reset occur, the OCnx Register is reset to “0”.

Figure 50. Compare Match Output Unit, Schematic



The general I/O port function is overridden by the output compare (OCnx) from the Waveform Generator if either of the COMnx1:0 bits are set. However, the OCnx pin direction (input or output) is still controlled by the *Data Direction Register* (DDR) for the port pin. The Data Direction Register bit for the OCnx pin (DDR_OCnx) must be set as output before the OCnx value is visible on the pin. The port override function is generally independent of the Waveform Generation mode, but there are some exceptions. Refer to Table 53, Table 54 and Table 55 for details.

The design of the output compare pin logic allows initialization of the OCnx state before the output is enabled. Note that some COMnx1:0 bit settings are reserved for certain modes of operation. See “16-bit Timer/Counter Register Description” on page 127.

The COMnx1:0 bits have no effect on the Input Capture unit.

Compare Output Mode and Waveform Generation

The Waveform Generator uses the COMnx1:0 bits differently in normal, CTC, and PWM modes. For all modes, setting the COMnx1:0 = 0 tells the Waveform Generator that no action on the OCnx Register is to be performed on the next Compare Match. For Compare Output actions in the non-PWM modes refer to Table 53 on page 127. For fast PWM mode refer to Table 54 on page 128, and for phase correct and phase and frequency correct PWM refer to Table 55 on page 128.

A change of the COMnx1:0 bits state will have effect at the first Compare Match after the bits are written. For non-PWM modes, the action can be forced to have immediate effect by using the FOCnx strobe bits.

Modes of Operation

The mode of operation, i.e., the behavior of the Timer/Counter and the Output Compare pins, is defined by the combination of the *Waveform Generation mode* (WGMn3:0) and *Compare Output mode* (COMnx1:0) bits. The Compare Output mode bits do not affect the counting sequence, while the Waveform Generation mode bits do. The COMnx1:0 bits control whether the PWM output generated should be inverted or not (inverted or non-inverted PWM). For non-PWM modes the COMnx1:0 bits control whether the output should be set, cleared or toggle at a Compare Match (See “Compare Match Output Unit” on page 116.)

For detailed timing information refer to “Timer/Counter Timing Diagrams” on page 125.

Normal Mode

The simplest mode of operation is the *Normal* mode (WGMn3:0 = 0). In this mode the counting direction is always up (incrementing), and no counter clear is performed. The counter simply overruns when it passes its maximum 16-bit value (MAX = 0xFFFF) and then restarts from the BOTTOM (0x0000). In normal operation the *Timer/Counter Overflow Flag* (TOVn) will be set in the same timer clock cycle as the TCNTn becomes zero. The TOVn Flag in this case behaves like a 17th bit, except that it is only set, not cleared. However, combined with the timer overflow interrupt that automatically clears the TOVn Flag, the timer resolution can be increased by software. There are no special cases to consider in the normal mode, a new counter value can be written anytime.

The Input Capture unit is easy to use in Normal mode. However, observe that the maximum interval between the external events must not exceed the resolution of the counter. If the interval between events are too long, the timer overflow interrupt or the prescaler must be used to extend the resolution for the capture unit.

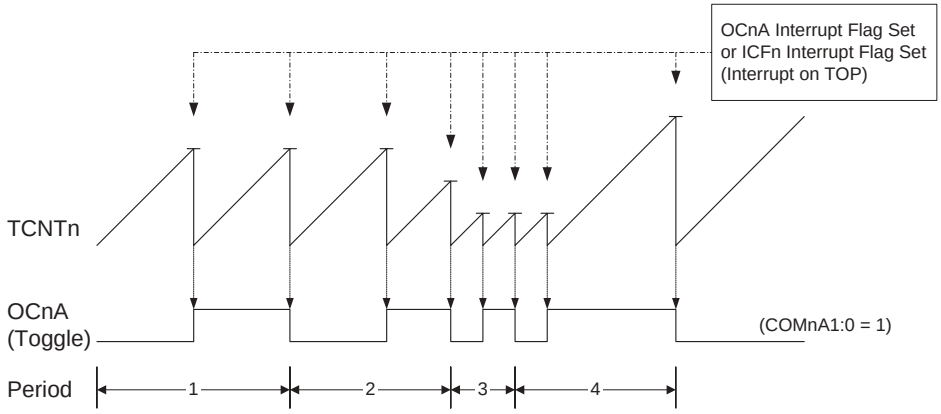
The Output Compare units can be used to generate interrupts at some given time. Using the Output Compare to generate waveforms in Normal mode is not recommended, since this will occupy too much of the CPU time.

Clear Timer on Compare Match (CTC) Mode

In *Clear Timer on Compare* or CTC mode (WGMn3:0 = 4 or 12), the OCRnA or ICRn Register are used to manipulate the counter resolution. In CTC mode the counter is cleared to zero when the counter value (TCNTn) matches either the OCRnA (WGMn3:0 = 4) or the ICRn (WGMn3:0 = 12). The OCRnA or ICRn define the top value for the counter, hence also its resolution. This mode allows greater control of the Compare Match output frequency. It also simplifies the operation of counting external events.

The timing diagram for the CTC mode is shown in Figure 51. The counter value (TCNTn) increases until a Compare Match occurs with either OCRnA or ICRn, and then counter (TCNTn) is cleared.

Figure 51. CTC Mode, Timing Diagram



An interrupt can be generated at each time the counter value reaches the TOP value by either using the OCFnA or ICFn Flag according to the register used to define the TOP value. If the interrupt is enabled, the interrupt handler routine can be used for updating the TOP value. However, changing the TOP to a value close to BOTTOM when the counter is running with none or a low prescaler value must be done with care since the CTC mode does not have the double buffering feature. If the new value written to OCRnA or ICRn is lower than the current value of TCNTn, the counter will miss the Compare Match. The counter will then have to count to its maximum value (0xFFFF) and wrap around starting at 0x0000 before the Compare Match can occur. In many cases this feature is not desirable. An alternative will then be to use the fast PWM mode using OCRnA for defining TOP (WGMn3:0 = 15) since the OCRnA then will be double buffered.

For generating a waveform output in CTC mode, the OCnA output can be set to toggle its logical level on each Compare Match by setting the Compare Output mode bits to toggle mode (COMnA1:0 = 1). The OCnA value will not be visible on the port pin unless the data direction for the pin is set to output (DDR_OCnA = 1). The waveform generated will have a maximum frequency of $f_{OC}n_A = f_{clk\_I/O}/2$ when OCRnA is set to zero (0x0000). The waveform frequency is defined by the following equation:

$$f_{OCnA} = \frac{f_{clk\_I/O}}{2 \cdot N \cdot (1 + OCRnA)}$$

The N variable represents the prescaler factor (1, 8, 64, 256, or 1024). For Timer/Counter3 also prescaler factors 16 and 32 are available.

As for the Normal mode of operation, the TOVn Flag is set in the same timer clock cycle that the counter counts from MAX to 0x0000.

Fast PWM Mode

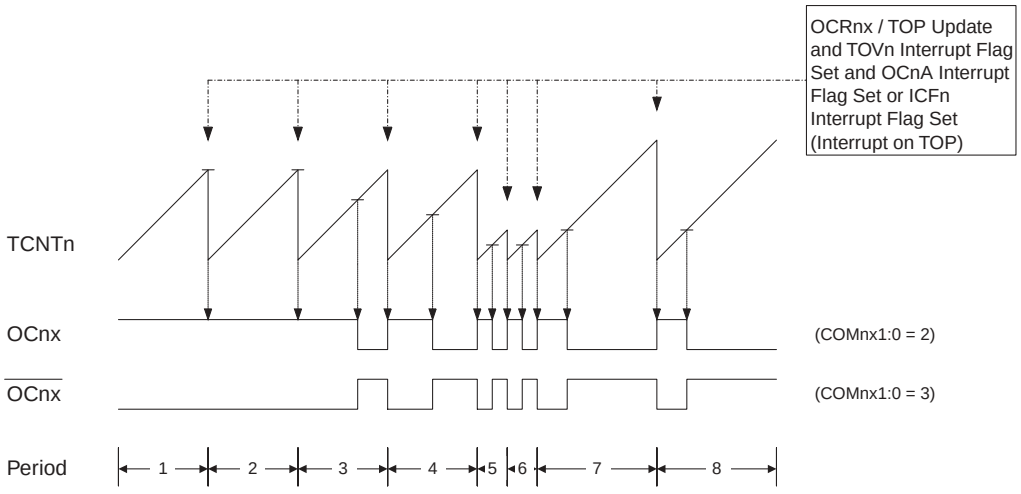
The *fast Pulse Width Modulation* or fast PWM mode (WGMn3:0 = 5,6,7,14, or 15) provides a high frequency PWM waveform generation option. The fast PWM differs from the other PWM options by its single-slope operation. The counter counts from BOTTOM to TOP then restarts from BOTTOM. In non-inverting Compare Output mode, the Output Compare (OCnx) is set on the Compare Match between TCNTn and OCRnx, and cleared at TOP. In inverting Compare Output mode output is cleared on Compare Match and set at TOP. Due to the single-slope operation, the operating frequency of the fast PWM mode can be twice as high as the phase correct and phase and frequency correct PWM modes that use dual-slope operation. This high frequency makes the fast PWM mode well suited for power regulation, rectification, and DAC applications. High frequency allows physically small sized external components (coils, capacitors), hence reduces total system cost.

The PWM resolution for fast PWM can be fixed to 8-, 9-, or 10-bit, or defined by either ICRn or OCRnA. The minimum resolution allowed is 2-bit (ICRn or OCRnA set to 0x0003), and the maximum resolution is 16-bit (ICRn or OCRnA set to MAX). The PWM resolution in bits can be calculated by using the following equation:

$$R_{FPWM} = \frac{\log(TOP + 1)}{\log(2)}$$

In fast PWM mode the counter is incremented until the counter value matches either one of the fixed values 0x00FF, 0x01FF, or 0x03FF (WGMn3:0 = 5, 6, or 7), the value in ICRn (WGMn3:0 = 14), or the value in OCRnA (WGMn3:0 = 15). The counter is then cleared at the following timer clock cycle. The timing diagram for the fast PWM mode is shown in Figure 52. The figure shows fast PWM mode when OCRnA or ICRn is used to define TOP. The TCNTn value is in the timing diagram shown as a histogram for illustrating the single-slope operation. The diagram includes non-inverted and inverted PWM outputs. The small horizontal line marks on the TCNTn slopes represent compare matches between OCRnx and TCNTn. The OCnx Interrupt Flag will be set when a Compare Match occurs.

Figure 52. Fast PWM Mode, Timing Diagram



The Timer/Counter Overflow Flag (TOVn) is set each time the counter reaches TOP. In addition the OCnA or ICFn Flag is set at the same timer clock cycle as TOVn is set when either OCRnA or ICRn is used for defining the TOP value. If one of the interrupts are enabled, the interrupt handler routine can be used for updating the TOP and compare values.

When changing the TOP value the program must ensure that the new TOP value is higher or equal to the value of all of the compare registers. If the TOP value is lower than any of the compare registers, a Compare Match will never occur between the TCNTn and the OCRnx. Note that when using fixed TOP values the unused bits are masked to zero when any of the OCRnx Registers are written.

The procedure for updating ICRn differs from updating OCRnA when used for defining the TOP value. The ICRn Register is not double buffered. This means that if ICRn is changed to a low value when the counter is running with none or a low prescaler value, there is a risk that the new ICRn value written is lower than the current value of TCNTn. The result will then be that the counter will miss the Compare Match at the TOP value. The counter will then have to count to the MAX value (0xFFFF) and wrap around starting at 0x0000 before the Compare Match can occur. The OCRnA Register however, is double buffered. This feature allows the OCRnA I/O location to be written anytime. When the OCRnA I/O location is written the value written will be put into the OCRnA Buffer Register. The OCRnA Compare Register will then be updated with the value in the Buffer Register at the next timer clock cycle the TCNTn matches TOP. The update is done at the same timer clock cycle as the TCNTn is cleared and the TOVn Flag is set.

Using the ICRn Register for defining TOP works well when using fixed TOP values. By using ICRn, the OCRnA Register is free to be used for generating a PWM output on OCnA. However, if the base PWM frequency is actively changed (by changing the TOP value), using the OCRnA as TOP is clearly a better choice due to its double buffer feature.

In fast PWM mode, the compare units allow generation of PWM waveforms on the OCnx pins. Setting the COMnx1:0 bits to two will produce a non-inverted PWM and an inverted PWM output can be generated by setting the COMnx1:0 to three (See Table on page 128). The actual OCnx value will only be visible on the port pin if the data direction for the port pin is set as output (DDR_OCnx). The PWM waveform is generated by setting (or clearing) the OCnx Register at the Compare Match between OCRnx and TCNTn, and clearing (or setting) the OCnx Register at the timer clock cycle the counter is cleared (changes from TOP to BOTTOM).

The PWM frequency for the output can be calculated by the following equation:

$$f_{OCnxPWM} = \frac{f_{clk\_I/O}}{N \cdot (1 + TOP)}$$

The N variable represents the prescaler divider (1, 8, 64, 256, or 1024). For Timer/Counter3 also prescaler factors 16 and 32 are available.

The extreme values for the OCRnx Register represents special cases when generating a PWM waveform output in the fast PWM mode. If the OCRnx is set equal to BOTTOM (0x0000) the output will be a narrow spike for each TOP+1 timer clock cycle. Setting the OCRnx equal to TOP will result in a constant high or low output (depending on the polarity of the output set by the COMnx1:0 bits.)

A frequency (with 50% duty cycle) waveform output in fast PWM mode can be achieved by setting OCnA to toggle its logical level on each Compare Match (COMnA1:0 = 1). This applies only if OCRnA is used to define the TOP value (WGMn3:0 = 15). The waveform generated will have a maximum frequency of $f_{OC}n_A = f_{clk\_I/O}/2$ when OCRnA is set to zero (0x0000). This feature is similar to the OCnA toggle in CTC mode, except the double buffer feature of the output compare unit is enabled in the fast PWM mode.

Phase Correct PWM Mode

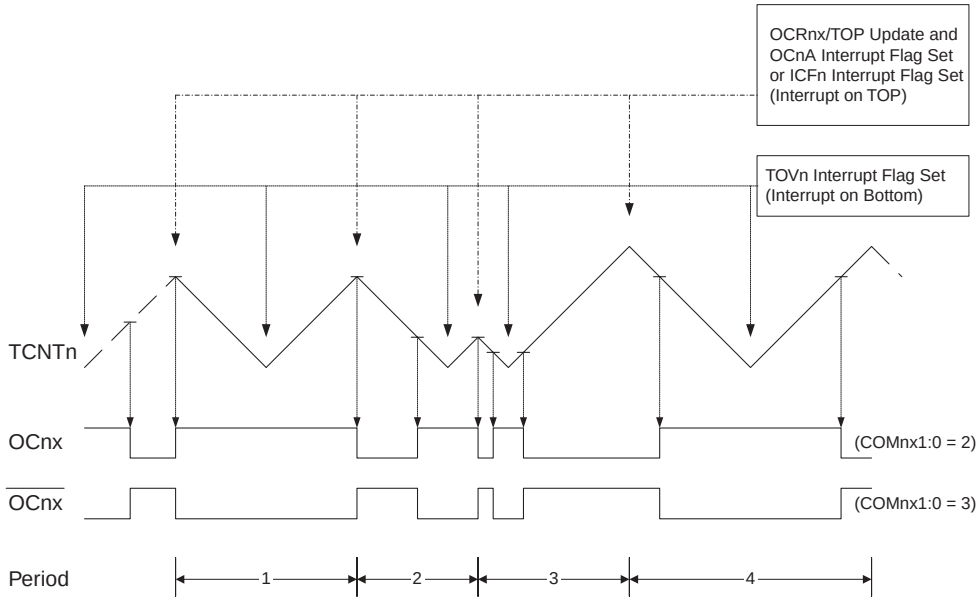
The *phase correct Pulse Width Modulation* or phase correct PWM mode (WGMn3:0 = 1, 2, 3, 10, or 11) provides a high resolution phase correct PWM waveform generation option. The phase correct PWM mode is, like the phase and frequency correct PWM mode, based on a dual-slope operation. The counter counts repeatedly from BOTTOM (0x0000) to TOP and then from TOP to BOTTOM. In non-inverting Compare Output mode, the Output Compare (OCnx) is cleared on the Compare Match between TCNTn and OCRnx while up-counting, and set on the Compare Match while down-counting. In inverting Output Compare mode, the operation is inverted. The dual-slope operation has lower maximum operation frequency than single slope operation. However, due to the symmetric feature of the dual-slope PWM modes, these modes are preferred for motor control applications.

The PWM resolution for the phase correct PWM mode can be fixed to 8-, 9-, or 10-bit, or defined by either ICRn or OCRnA. The minimum resolution allowed is 2-bit (ICRn or OCRnA set to 0x0003), and the maximum resolution is 16-bit (ICRn or OCRnA set to MAX). The PWM resolution in bits can be calculated by using the following equation:

$$R_{PCPWM} = \frac{\log(TOP+1)}{\log(2)}$$

In phase correct PWM mode the counter is incremented until the counter value matches either one of the fixed values 0x00FF, 0x01FF, or 0x03FF (WGMn3:0 = 1, 2, or 3), the value in ICRn (WGMn3:0 = 10), or the value in OCRnA (WGMn3:0 = 11). The counter has then reached the TOP and changes the count direction. The TCNTn value will be equal to TOP for one timer clock cycle. The timing diagram for the phase correct PWM mode is shown on Figure 53. The figure shows phase correct PWM mode when OCRnA or ICRn is used to define TOP. The TCNTn value is in the timing diagram shown as a histogram for illustrating the dual-slope operation. The diagram includes non-inverted and inverted PWM outputs. The small horizontal line marks on the TCNTn slopes represent compare matches between OCRnx and TCNTn. The OCnx Interrupt Flag will be set when a Compare Match occurs.

Figure 53. Phase Correct PWM Mode, Timing Diagram



The Timer/Counter Overflow Flag (TOVn) is set each time the counter reaches BOTTOM. When either OCRnA or ICRn is used for defining the TOP value, the OCnA or

ICFn Flag is set accordingly at the same timer clock cycle as the OCRnx Registers are updated with the double buffer value (at TOP). The Interrupt Flags can be used to generate an interrupt each time the counter reaches the TOP or BOTTOM value.

When changing the TOP value the program must ensure that the new TOP value is higher or equal to the value of all of the compare registers. If the TOP value is lower than any of the compare registers, a Compare Match will never occur between the TCNTn and the OCRnx. Note that when using fixed TOP values, the unused bits are masked to zero when any of the OCRnx Registers are written. As the third period shown in Figure 53 illustrates, changing the TOP actively while the Timer/Counter is running in the phase correct mode can result in an unsymmetrical output. The reason for this can be found in the time of update of the OCRnx Register. Since the OCRnx update occurs at TOP, the PWM period starts and ends at TOP. This implies that the length of the falling slope is determined by the previous TOP value, while the length of the rising slope is determined by the new TOP value. When these two values differ the two slopes of the period will differ in length. The difference in length gives the unsymmetrical result on the output.

It is recommended to use the phase and frequency correct mode instead of the phase correct mode when changing the TOP value while the Timer/Counter is running. When using a static TOP value there are practically no differences between the two modes of operation.

In phase correct PWM mode, the compare units allow generation of PWM waveforms on the OCnx pins. Setting the COMnx1:0 bits to two will produce a non-inverted PWM and an inverted PWM output can be generated by setting the COMnx1:0 to three (See Table 55 on page 128). The actual OCnx value will only be visible on the port pin if the data direction for the port pin is set as output (DDR_OCnx). The PWM waveform is generated by setting (or clearing) the OCnx Register at the Compare Match between OCRnx and TCNTn when the counter increments, and clearing (or setting) the OCnx Register at Compare Match between OCRnx and TCNTn when the counter decrements. The PWM frequency for the output when using phase correct PWM can be calculated by the following equation:

$$f_{OCnxPCPWM} = \frac{f_{clk\_I/O}}{2 \cdot N \cdot TOP}$$

The N variable represents the prescaler divider (1, 8, 64, 256, or 1024). For Timer/Counter3 also prescaler factors 16 and 32 are available.

The extreme values for the OCRnx Register represent special cases when generating a PWM waveform output in the phase correct PWM mode. If the OCRnx is set equal to BOTTOM the output will be continuously low and if set equal to TOP the output will be continuously high for non-inverted PWM mode. For inverted PWM the output will have the opposite logic values. If OCRnA is used to define the TOP value (WGMn3:0 = 11) and COMnA1:0 = 1, the OCnA output will toggle with a 50% duty cycle.

Phase and Frequency Correct PWM Mode

The *phase and frequency correct Pulse Width Modulation,* or phase and frequency correct PWM mode (WGMn3:0 = 8 or 9) provides a high resolution phase and frequency correct PWM waveform generation option. The phase and frequency correct PWM mode is, like the phase correct PWM mode, based on a dual-slope operation. The counter counts repeatedly from BOTTOM (0x0000) to TOP and then from TOP to BOTTOM. In non-inverting Compare Output mode, the Output Compare (OCnx) is cleared on the Compare Match between TCNTn and OCRnx while up-counting, and set on the Compare Match while down-counting. In inverting Compare Output mode, the operation is inverted. The dual-slope operation gives a lower maximum operation frequency com-

pared to the single-slope operation. However, due to the symmetric feature of the dual-slope PWM modes, these modes are preferred for motor control applications.

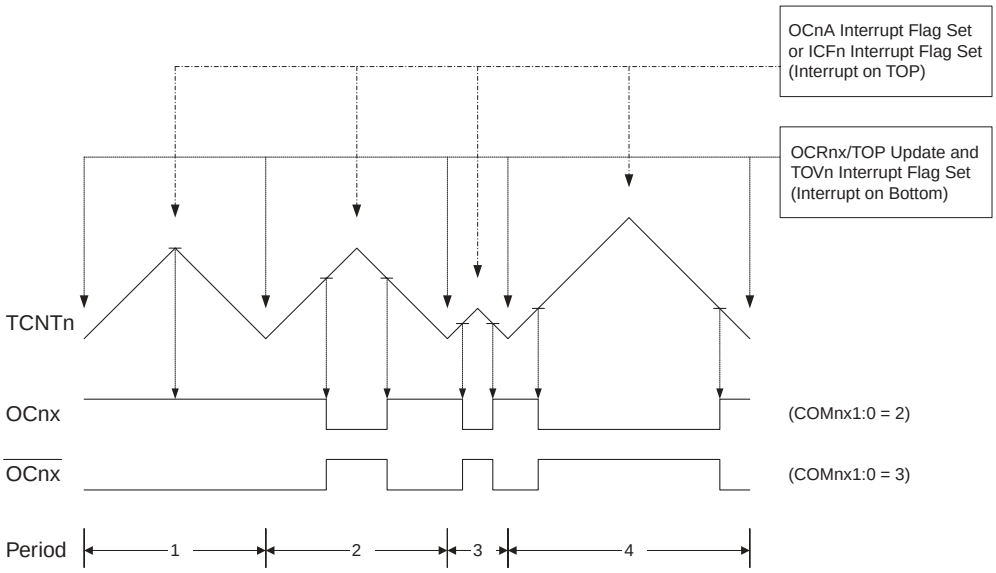
The main difference between the phase correct, and the phase and frequency correct PWM mode is the time the OCRnx Register is updated by the OCRnx Buffer Register, (see Figure 53 and Figure 54).

The PWM resolution for the phase and frequency correct PWM mode can be defined by either ICRn or OCRnA. The minimum resolution allowed is 2-bit (ICRn or OCRnA set to 0x0003), and the maximum resolution is 16-bit (ICRn or OCRnA set to MAX). The PWM resolution in bits can be calculated using the following equation:

$$R_{PFCPWM} = \frac{\log(TOP + 1)}{\log(2)}$$

In phase and frequency correct PWM mode the counter is incremented until the counter value matches either the value in ICRn (WGMn3:0 = 8), or the value in OCRnA (WGMn3:0 = 9). The counter has then reached the TOP and changes the count direction. The TCNTn value will be equal to TOP for one timer clock cycle. The timing diagram for the phase correct and frequency correct PWM mode is shown on Figure 54. The figure shows phase and frequency correct PWM mode when OCRnA or ICRn is used to define TOP. The TCNTn value is in the timing diagram shown as a histogram for illustrating the dual-slope operation. The diagram includes non-inverted and inverted PWM outputs. The small horizontal line marks on the TCNTn slopes represent compare matches between OCRnx and TCNTn. The OCnx Interrupt Flag will be set when a Compare Match occurs.

Figure 54. Phase and Frequency Correct PWM Mode, Timing Diagram



The Timer/Counter Overflow Flag (TOVn) is set at the same timer clock cycle as the OCRnx Registers are updated with the double buffer value (at BOTTOM). When either OCRnA or ICRn is used for defining the TOP value, the OCnA or ICFn Flag set when TCNTn has reached TOP. The Interrupt Flags can then be used to generate an interrupt each time the counter reaches the TOP or BOTTOM value.

When changing the TOP value the program must ensure that the new TOP value is higher or equal to the value of all of the compare registers. If the TOP value is lower

than any of the compare registers, a Compare Match will never occur between the TCNTn and the OCRnx.

As Figure 54 shows the output generated is, in contrast to the phase correct mode, symmetrical in all periods. Since the OCRnx Registers are updated at BOTTOM, the length of the rising and the falling slopes will always be equal. This gives symmetrical output pulses and is therefore frequency correct.

Using the ICRn Register for defining TOP works well when using fixed TOP values. By using ICRn, the OCRnA Register is free to be used for generating a PWM output on OCnA. However, if the base PWM frequency is actively changed by changing the TOP value, using the OCRnA as TOP is clearly a better choice due to its double buffer feature.

In phase and frequency correct PWM mode, the compare units allow generation of PWM waveforms on the OCnx pins. Setting the COMnx1:0 bits to two will produce a non-inverted PWM and an inverted PWM output can be generated by setting the COMnx1:0 to three (See Table 55 on page 128). The actual OCnx value will only be visible on the port pin if the data direction for the port pin is set as output (DDR_OCnx). The PWM waveform is generated by setting (or clearing) the OCnx Register at the Compare Match between OCRnx and TCNTn when the counter increments, and clearing (or setting) the OCnx Register at Compare Match between OCRnx and TCNTn when the counter decrements. The PWM frequency for the output when using phase and frequency correct PWM can be calculated by the following equation:

$$f_{OCnxPFCPWM} = \frac{f_{clk\_I/O}}{2 \cdot N \cdot TOP}$$

The N variable represents the prescaler divider (1, 8, 64, 256, or 1024). For Timer/Counter3 also prescaler factors 16 and 32 are available.

The extreme values for the OCRnx Register represents special cases when generating a PWM waveform output in the phase correct PWM mode. If the OCRnx is set equal to BOTTOM the output will be continuously low and if set equal to TOP the output will be set to high for non-inverted PWM mode. For inverted PWM the output will have the opposite logic values. If OCRnA is used to define the TOP value (WGMn3:0 = 9) and COMnA1:0 = 1, the OCnA output will toggle with a 50% duty cycle.

Timer/Counter Timing Diagrams

The Timer/Counter is a synchronous design and the timer clock ($clk_T n$) is therefore shown as a clock enable signal in the following figures. The figures include information on when Interrupt Flags are set, and when the OCRnx Register is updated with the OCRnx buffer value (only for modes utilizing double buffering). Figure 55 shows a timing diagram for the setting of OCFnx.

Figure 55. Timer/Counter Timing Diagram, Setting of OCFnx, no Prescaling

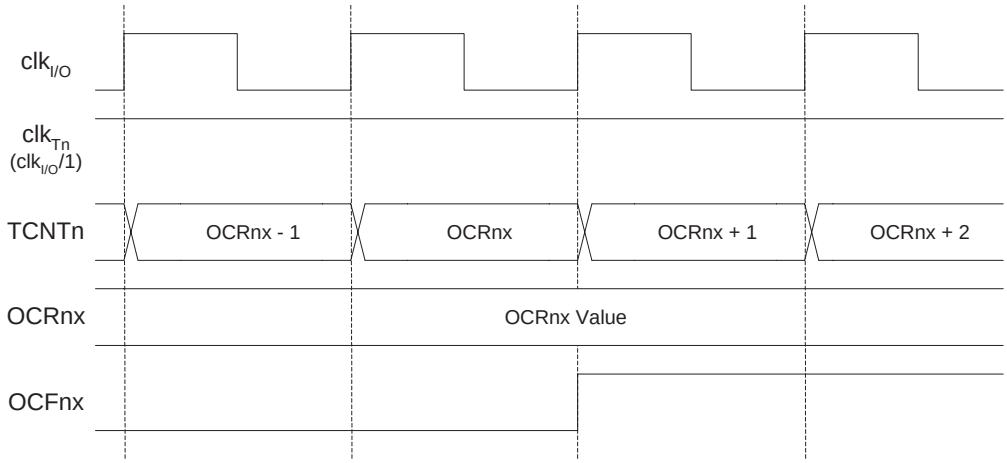


Figure 56 shows the same timing data, but with the prescaler enabled.

Figure 56. Timer/Counter Timing Diagram, Setting of OCFnx, with Prescaler ($f_{clk\_I/O}/8$)

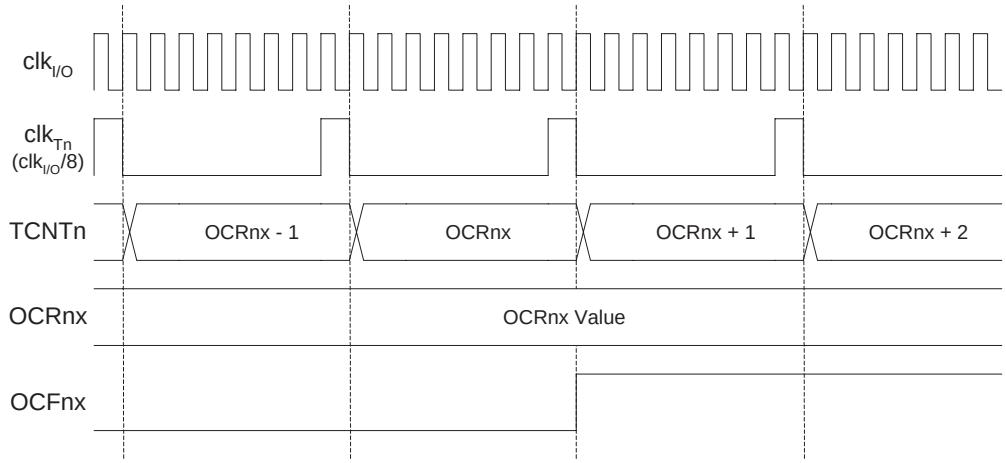


Figure 57 shows the count sequence close to TOP in various modes. When using phase and frequency correct PWM mode the OCRnx Register is updated at BOTTOM. The timing diagrams will be the same, but TOP should be replaced by BOTTOM, TOP-1 by BOTTOM+1 and so on. The same renaming applies for modes that set the TOVn Flag at BOTTOM.

Figure 57. Timer/Counter Timing Diagram, no Prescaling

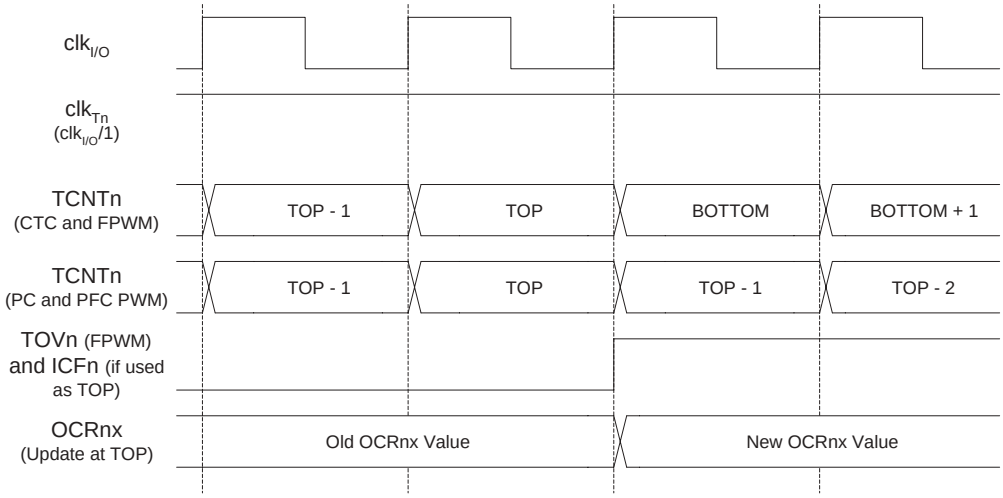
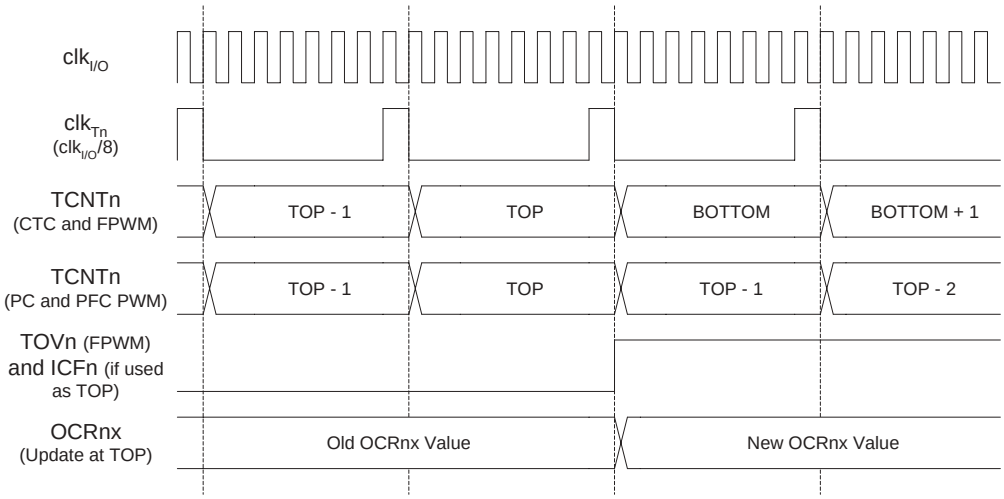


Figure 58 shows the same timing data, but with the prescaler enabled.

Figure 58. Timer/Counter Timing Diagram, with Prescaler ($f_{clk\_I/O}/8$)



16-bit Timer/Counter Register Description

Timer/Counter1 Control Register A – TCCR1A

Bit	7	6	5	4	3	2	1	0	
	COM1A1	COM1A0	COM1B1	COM1B0	FOC1A	FOC1B	WGM11	WGM10	TCCR1A
Read/Write	R/W	R/W	R/W	R/W	W	W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

Timer/Counter3 Control Register A – TCCR3A

Bit	7	6	5	4	3	2	1	0	
	COM3A1	COM3A0	COM3B1	COM3B0	FOC3A	FOC3B	WGM31	WGM30	TCCR3A
Read/Write	R/W	R/W	R/W	R/W	W	W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

- **Bit 7:6 – COMnA1:0: Compare Output Mode for channel A**

- **Bit 5:4 – COMnB1:0: Compare Output Mode for channel B**

The COMnA1:0 and COMnB1:0 control the Output Compare pins (OCnA and OCnB respectively) behavior. If one or both of the COMnA1:0 bits are written to one, the OCnA output overrides the normal port functionality of the I/O pin it is connected to. If one or both of the COMnB1:0 bit are written to one, the OCnB output overrides the normal port functionality of the I/O pin it is connected to. However, note that the *Data Direction Register* (DDR) bit corresponding to the OCnA or OCnB pin must be set in order to enable the output driver.

When the OCnA or OCnB is connected to the pin, the function of the COMnx1:0 bits is dependent of the WGMn3:0 bits setting. Table 53 shows the COMnx1:0 bit functionality when the WGMn3:0 bits are set to a normal or a CTC mode (non-PWM).

Table 53. Compare Output Mode, non-PWM

COMnA1/ COMnB1	COMnA0/ COMnB0	Description
0	0	Normal port operation, OCnA/OCnB disconnected.
0	1	Toggle OCnA/OCnB on Compare Match.
1	0	Clear OCnA/OCnB on Compare Match (Set output to low level).
1	1	Set OCnA/OCnB on Compare Match (Set output to high level).

Table 54 shows the COMnx1:0 bit functionality when the WGMn3:0 bits are set to the fast PWM mode.

Table 54. Compare Output Mode, Fast PWM(1)

COMnA1/ COMnB1	COMnA0/ COMnB0	Description
0	0	Normal port operation, OCnA/OCnB disconnected.
0	1	WGMn3:0 = 15: Toggle OCnA on Compare Match, OCnB disconnected (normal port operation). For all other WGMn settings, normal port operation, OCnA/OCnB disconnected.
1	0	Clear OCnA/OCnB on Compare Match, set OCnA/OCnB at TOP.
1	1	Set OCnA/OCnB on Compare Match, clear OCnA/OCnB at TOP.

Note: 1. A special case occurs when OCRnA/OCRnB equals TOP and COMnA1/COMnB1 is set. In this case the Compare Match is ignored, but the set or clear is done at TOP. See “Fast PWM Mode” on page 119. for more details.

Table 55 shows the COMnx1:0 bit functionality when the WGMn3:0 bits are set to the phase correct or the phase and frequency correct, PWM mode.

Table 55. Compare Output Mode, Phase Correct and Phase and Frequency Correct PWM(1)

COMnA1/ COMnB1	COMnA0 COMnB0	Description
0	0	Normal port operation, OCnA/OCnB disconnected.
0	1	WGMn3:0 = 9 or 14: Toggle OCnA on Compare Match, OCnB disconnected (normal port operation). For all other WGMn settings, normal port operation, OCnA/OCnB disconnected.
1	0	Clear OCnA/OCnB on Compare Match when up-counting. Set OCnA/OCnB on Compare Match when down-counting.
1	1	Set OCnA/OCnB on Compare Match when up-counting. Clear OCnA/OCnB on Compare Match when down-counting.

Note: 1. A special case occurs when OCRnA/OCRnB equals TOP and COMnA1/COMnB1 is set. See “Phase Correct PWM Mode” on page 121. for more details.

- **Bit 3 – FOCnA: Force Output Compare for channel A**

- **Bit 2 – FOCnB: Force Output Compare for channel B**

The FOCnA/FOCnB bits are only active when the WGMn3:0 bits specifies a non-PWM mode. However, for ensuring compatibility with future devices, these bits must be set to zero when TCCRnA is written when operating in a PWM mode. When writing a logical one to the FOCnA/FOCnB bit, an immediate Compare Match is forced on the Waveform Generation unit. The OCnA/OCnB output is changed according to its COMnx1:0 bits setting. Note that the FOCnA/FOCnB bits are implemented as strobes. Therefore it is the value present in the COMnx1:0 bits that determine the effect of the forced compare.

A FOCnA/FOCnB strobe will not generate any interrupt nor will it clear the timer in Clear Timer on Compare match (CTC) mode using OCRnA as TOP.

The FOCnA/FOCnB bits are always read as zero.

- **Bit 1:0 – WGMn1:0: Waveform Generation Mode**

Combined with the WGMn3:2 bits found in the TCCRnB Register, these bits control the counting sequence of the counter, the source for maximum (TOP) counter value, and what type of waveform generation to be used, see Table 56. Modes of operation supported by the Timer/Counter unit are: Normal mode (counter), Clear Timer on Compare match (CTC) mode, and three types of Pulse Width Modulation (PWM) modes. (See “Modes of Operation” on page 117.)

Table 56. Waveform Generation Mode Bit Description[1]

Mode	WGMn3	WGMn2 (CTCn)	WGMn1 (PWMn1)	WGMn0 (PWMn0)	Timer/Counter Mode of Operation	TOP	Update of OCRnx at	TOVn Flag Set on
0	0	0	0	0	Normal	0xFFFF	Immediate	MAX
1	0	0	0	1	PWM, Phase Correct, 8-bit	0x00FF	TOP	BOTTOM
2	0	0	1	0	PWM, Phase Correct, 9-bit	0x01FF	TOP	BOTTOM
3	0	0	1	1	PWM, Phase Correct, 10-bit	0x03FF	TOP	BOTTOM
4	0	1	0	0	CTC	OCRnA	Immediate	MAX
5	0	1	0	1	Fast PWM, 8-bit	0x00FF	TOP	TOP
6	0	1	1	0	Fast PWM, 9-bit	0x01FF	TOP	TOP
7	0	1	1	1	Fast PWM, 10-bit	0x03FF	TOP	TOP
8	1	0	0	0	PWM, Phase and Frequency Correct	ICRn	BOTTOM	BOTTOM
9	1	0	0	1	PWM, Phase and Frequency Correct	OCRnA	BOTTOM	BOTTOM
10	1	0	1	0	PWM, Phase Correct	ICRn	TOP	BOTTOM
11	1	0	1	1	PWM, Phase Correct	OCRnA	TOP	BOTTOM
12	1	1	0	0	CTC	ICRn	Immediate	MAX
13	1	1	0	1	Reserved	–	–	–
14	1	1	1	0	Fast PWM	ICRn	TOP	TOP
15	1	1	1	1	Fast PWM	OCRnA	TOP	TOP

Note: 1. The CTCn and PWMn1:0 bit definition names are obsolete. Use the WGMn2:0 definitions. However, the functionality and location of these bits are compatible with previous versions of the timer.

Timer/Counter1 Control Register B – TCCR1B

Bit	7	6	5	4	3	2	1	0	
	ICNC1	ICES1	–	WGM13	WGM12	CS12	CS11	CS10	TCCR1B
Read/Write	R/W	R/W	R	R/W	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

Timer/Counter3 Control Register B – TCCR3B

Bit	7	6	5	4	3	2	1	0	
	ICNC3	ICES3	–	WGM33	WGM32	CS32	CS31	CS30	TCCR3B
Read/Write	R/W	R/W	R	R/W	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

- **Bit 7 – ICNCn: Input Capture Noise Canceler**

Setting this bit (to one) activates the Input Capture noise canceler. When the noise canceler is activated, the input from the Input Capture pin (ICPn) is filtered. The filter function requires four successive equal valued samples of the ICPn pin for changing its output. The Input Capture is therefore delayed by four Oscillator cycles when the noise canceler is enabled.

- **Bit 6 – ICESn: Input Capture Edge Select**

This bit selects which edge on the Input Capture pin (ICPn) that is used to trigger a capture event. When the ICESn bit is written to zero, a falling (negative) edge is used as trigger, and when the ICESn bit is written to one, a rising (positive) edge will trigger the capture.

When a capture is triggered according to the ICESn setting, the counter value is copied into the Input Capture Register (ICRn). The event will also set the Input Capture Flag (ICFn), and this can be used to cause an Input Capture Interrupt, if this interrupt is enabled.

When the ICRn is used as TOP value (see description of the WGMn3:0 bits located in the TCCRnA and the TCCRnB Register), the ICPn is disconnected and consequently the Input Capture function is disabled.

- **Bit 5 – Reserved Bit**

This bit is reserved for future use. For ensuring compatibility with future devices, this bit must be written to zero when TCCRnB is written.

- **Bit 4:3 – WGMn3:2: Waveform Generation Mode**

See TCCRnA Register description.

- **Bit 2:0 – CSn2:0: Clock Select**

The three Clock Select bits select the clock source to be used by the Timer/Counter, see Figure 55 and Figure 56.

Table 57. Clock Select Bit Description Timer/Counter1

CS12	CS11	CS10	Description
0	0	0	No clock source. (Timer/Counter stopped).
0	0	1	$clk_{I/O}$/1 (No prescaling)
0	1	0	$clk_{I/O}$/8 (From prescaler)
0	1	1	$clk_{I/O}$/64 (From prescaler)
1	0	0	$clk_{I/O}$/256 (From prescaler)
1	0	1	$clk_{I/O}$/1024 (From prescaler)
1	1	0	External clock source on T1 pin. Clock on falling edge.
1	1	1	External clock source on T1 pin. Clock on rising edge.

If external pin modes are used for the Timer/Counter1, transitions on the T1 pin will clock the counter even if the pin is configured as an output. This feature allows software control of the counting..

Table 58. Clock Select Bit Description Timer/Counter3

CS32	CS31	CS30	Description
0	0	0	No clock source. (Timer/Counter stopped).
0	0	1	$clk_{I/O}$ / 1 (No prescaling)
0	1	0	$clk_{I/O}$ / 8 (From prescaler).
0	1	1	$clk_{I/O}$ / 64 (From prescaler).
1	0	0	$clk_{I/O}$ / 256 (From prescaler).
1	0	1	$clk_{I/O}$ / 1024 (From prescaler).
1	1	0	$clk_{I/O}$ / 16 (From prescaler).
1	1	1	$clk_{I/O}$ / 32 (From prescaler).

Timer/Counter1 – TCNT1H and TCNT1L

Bit	7	6	5	4	3	2	1	0	
	TCNT1[15:8]								TCNT1H
	TCNT1[7:0]								TCNT1L
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

Timer/Counter3 – TCNT3H and TCNT3L

Bit	7	6	5	4	3	2	1	0	
	TCNT3[15:8]								TCNT3H
	TCNT3[7:0]								TCNT3L
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

The two *Timer/Counter* I/O locations (TCNTnH and TCNTnL, combined TCNTn) give direct access, both for read and for write operations, to the Timer/Counter unit 16-bit counter. To ensure that both the high and low bytes are read and written simultaneously when the CPU accesses these registers, the access is performed using an 8-bit temporary high byte register (TEMP). This temporary register is shared by all the other 16-bit registers. See “Accessing 16-bit Registers” on page 108.

Modifying the counter (TCNTn) while the counter is running introduces a risk of missing a Compare Match between TCNTn and one of the OCRnx Registers.

Writing to the TCNTn Register blocks (removes) the Compare Match on the following timer clock for all compare units.

Output Compare Register 1 A – OCR1AH and OCR1AL

Bit	7	6	5	4	3	2	1	0	
	OCR1A[15:8]								OCR1AH
	OCR1A[7:0]								OCR1AL
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

Output Compare Register 1 B – OCR1BH and OCR1BL

Bit	7	6	5	4	3	2	1	0	
	OCR1B[15:8]								OCR1BH
	OCR1B[7:0]								OCR1BL
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

Output Compare Register 3 A – OCR3AH and OCR3AL

Bit	7	6	5	4	3	2	1	0	
	OCR3A[15:8]								OCR3AH
	OCR3A[7:0]								OCR3AL
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

Output Compare Register 3 B – OCR3BH and OCR3BL

Bit	7	6	5	4	3	2	1	0	
	OCR3B[15:8]								OCR3BH
	OCR3B[7:0]								OCR3BL
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

The Output Compare Registers contain a 16-bit value that is continuously compared with the counter value (TCNTn). A match can be used to generate an output compare interrupt, or to generate a waveform output on the OCnx pin.

The Output Compare Registers are 16-bit in size. To ensure that both the high and low bytes are written simultaneously when the CPU writes to these registers, the access is performed using an 8-bit temporary high byte register (TEMP). This temporary register is shared by all the other 16-bit registers. See “Accessing 16-bit Registers” on page 108.

Input Capture Register 1 – ICR1H and ICR1L

Bit	7	6	5	4	3	2	1	0	
	ICR1[15:8]								ICR1H
	ICR1[7:0]								ICR1L
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

Input Capture Register 3 – ICR3H and ICR3L

Bit	7	6	5	4	3	2	1	0	
	ICR3[15:8]								ICR3H
	ICR3[7:0]								ICR3L
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

The Input Capture is updated with the counter (TCNTn) value each time an event occurs on the ICPn pin (or optionally on the Analog Comparator output for Timer/Counter1). The Input Capture can be used for defining the counter TOP value.

The Input Capture Register is 16-bit in size. To ensure that both the high and low bytes are read simultaneously when the CPU accesses these registers, the access is performed using an 8-bit temporary high byte register (TEMP). This temporary register is shared by all the other 16-bit registers. See “Accessing 16-bit Registers” on page 108.

Timer/Counter Interrupt Mask Register – TIMSK(1)

Bit	7	6	5	4	3	2	1	0	
	TOIE1	OCIE1A	OCIE1B	OCIE2	TICIE1	TOIE2	TOIE0	OCIE0	TIMSK
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

Note: 1. This register contains interrupt control bits for several Timer/Counters, but only Timer1 bits are described in this section. The remaining bits are described in their respective Timer sections.

- **Bit 7 – TOIE1: Timer/Counter1, Overflow Interrupt Enable**

When this bit is written to one, and the I-flag in the Status Register is set (interrupts globally enabled), the Timer/Counter1 overflow interrupt is enabled. The corresponding Interrupt Vector (See “Interrupts” on page 56.) is executed when the TOV1 Flag, located in TIFR, is set.

- **Bit 6 – OCIE1A: Timer/Counter1, Output Compare A Match Interrupt Enable**

When this bit is written to one, and the I-flag in the Status Register is set (interrupts globally enabled), the Timer/Counter1 Output Compare A Match interrupt is enabled. The corresponding Interrupt Vector (See “Interrupts” on page 56.) is executed when the OCF1A Flag, located in TIFR, is set.

- **Bit 5 – OCIE1B: Timer/Counter1, Output Compare B Match Interrupt Enable**

When this bit is written to one, and the I-flag in the Status Register is set (interrupts globally enabled), the Timer/Counter1 Output Compare B Match interrupt is enabled. The corresponding Interrupt Vector (See “Interrupts” on page 56.) is executed when the OCF1B Flag, located in TIFR, is set.

- **Bit 3 – TICIE1: Timer/Counter1, Input Capture Interrupt Enable**

When this bit is written to one, and the I-flag in the Status Register is set (interrupts globally enabled), the Timer/Counter1 Input Capture interrupt is enabled. The corresponding Interrupt Vector (See “Interrupts” on page 56.) is executed when the ICF1 Flag, located in TIFR, is set.

Extended Timer/Counter Interrupt Mask Register – ETIMSK(1)

Bit	7	6	5	4	3	2	1	0	
			TICIE3	OCIE3A	OCIE3B	TOIE3	–	–	ETIMSK
Read/Write	R	R	R/W	R/W	R/W	R/W	R	R	
Initial Value	0	0	0	0	0	0	0	0	

Note: 1. This register contains interrupt control bits for several Timer/Counters, but only Timer3 bits are described in this section. The remaining bits are described in their respective Timer sections.

- **Bit 5 – TICIE3: Timer/Counter3, Input Capture Interrupt Enable**

When this bit is written to one, and the I-flag in the Status Register is set (interrupts globally enabled), the Timer/Counter3 Input Capture interrupt is enabled. The corresponding Interrupt Vector (See “Interrupts” on page 56.) is executed when the ICF3 Flag, located in TIFR, is set.

- **Bit 4 – OCIE3A: Timer/Counter3, Output Compare A Match Interrupt Enable**

When this bit is written to one, and the I-flag in the Status Register is set (interrupts globally enabled), the Timer/Counter3 Output Compare A Match interrupt is enabled. The corresponding Interrupt Vector (See “Interrupts” on page 56.) is executed when the OCF3A Flag, located in TIFR, is set.

- **Bit 3 – OCIE3B: Timer/Counter3, Output Compare B Match Interrupt Enable**

When this bit is written to one, and the I-flag in the Status Register is set (interrupts globally enabled), the Timer/Counter3 Output Compare B Match interrupt is enabled. The corresponding Interrupt Vector (See “Interrupts” on page 56.) is executed when the OCF3B Flag, located in TIFR, is set.

- **Bit 2 – TOIE3: Timer/Counter3, Overflow Interrupt Enable**

When this bit is written to one, and the I-flag in the Status Register is set (interrupts globally enabled), the Timer/Counter3 overflow interrupt is enabled. The corresponding Interrupt Vector (See “Interrupts” on page 56.) is executed when the TOV3 Flag, located in TIFR, is set.

Timer/Counter Interrupt Flag Register – TIFR(1)

Bit	7	6	5	4	3	2	1	0	
	TOV1	OCF1A	OC1FB	OCF2	ICF1	TOV2	TOV0	OCF0	TIFR
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

Note: 1. This register contains flag bits for several Timer/Counters, but only Timer1 bits are described in this section. The remaining bits are described in their respective Timer sections.

- **Bit 7 – TOV1: Timer/Counter1, Overflow Flag**

The setting of this flag is dependent of the WGMn3:0 bits setting. In Normal and CTC modes, the TOV1 Flag is set when the timer overflows. Refer to Table 56 on page 129 for the TOV1 Flag behavior when using another WGMn3:0 bit setting.

TOV1 is automatically cleared when the Timer/Counter1 Overflow Interrupt Vector is executed. Alternatively, TOV1 can be cleared by writing a logic one to its bit location.

- **Bit 6 – OCF1A: Timer/Counter1, Output Compare A Match Flag**

This flag is set in the timer clock cycle after the counter (TCNT1) value matches the Output Compare Register A (OCR1A).

Note that a Forced Output Compare (FOC1A) strobe will not set the OCF1A Flag.

OCF1A is automatically cleared when the Output Compare Match A Interrupt Vector is executed. Alternatively, OCF1A can be cleared by writing a logic one to its bit location.

- **Bit 5 – OCF1B: Timer/Counter1, Output Compare B Match Flag**

This flag is set in the timer clock cycle after the counter (TCNT1) value matches the Output Compare Register B (OCR1B).

Note that a Forced Output Compare (FOC1B) strobe will not set the OCF1B Flag.

OCF1B is automatically cleared when the Output Compare Match B Interrupt Vector is executed. Alternatively, OCF1B can be cleared by writing a logic one to its bit location.

- **Bit 3 – ICF1: Timer/Counter1, Input Capture Flag**

This flag is set when a capture event occurs on the ICP1 pin. When the Input Capture Register (ICR1) is set by the WGMn3:0 to be used as the TOP value, the ICF1 Flag is set when the counter reaches the TOP value.

ICF1 is automatically cleared when the Input Capture Interrupt Vector is executed. Alternatively, ICF1 can be cleared by writing a logic one to its bit location.

Extended Timer/Counter Interrupt Flag Register – ETIFR(1)

Bit	7	6	5	4	3	2	1	0	
			ICF3	OCF3A	OC3FB	TOV3	–	–	ETIFR
Read/Write	R	R	R/W	R/W	R/W	R/W	R	R	
Initial Value	0	0	0	0	0	0	0	0	

Note: 1. This register contains flag bits for several Timer/Counters, but only Timer3 bits are described in this section. The remaining bits are described in their respective Timer sections.

- **Bit 5 – ICF3: Timer/Counter3, Input Capture Flag**

This flag is set when a capture event occurs on the ICP3 pin. When the Input Capture Register (ICR3) is set by the WGMn3:0 to be used as the TOP value, the ICF3 Flag is set when the counter reaches the TOP value.

ICF3 is automatically cleared when the Input Capture Interrupt Vector is executed. Alternatively, ICF3 can be cleared by writing a logic one to its bit location.

- **Bit 4 – OCF3A: Timer/Counter3, Output Compare A Match Flag**

This flag is set in the timer clock cycle after the counter (TCNT3) value matches the Output Compare Register A (OCR3A).

Note that a Forced Output Compare (FOC3A) strobe will not set the OCF3A Flag.

OCF3A is automatically cleared when the Output Compare Match A Interrupt Vector is executed. Alternatively, OCF3A can be cleared by writing a logic one to its bit location.

- **Bit 3 – OCF3B: Timer/Counter3, Output Compare B Match Flag**

This flag is set in the timer clock cycle after the counter (TCNT3) value matches the Output Compare Register B (OCR3B).

Note that a Forced Output Compare (FOC3B) strobe will not set the OCF3B Flag.

OCF3B is automatically cleared when the Output Compare Match B Interrupt Vector is executed. Alternatively, OCF3B can be cleared by writing a logic one to its bit location.

- **Bit 2 – TOV3: Timer/Counter3, Overflow Flag**

The setting of this flag is dependent of the WGMn3:0 bits setting. In normal and CTC modes, the TOV3 Flag is set when the timer overflows. Refer to Table 56 on page 129 for the TOV3 Flag behavior when using another WGMn3:0 bit setting.

TOV3 is automatically cleared when the Timer/Counter3 Overflow Interrupt Vector is executed. Alternatively, TOV3 can be cleared by writing a logic one to its bit location.

8-bit Timer/Counter2 with PWM and Asynchronous operation

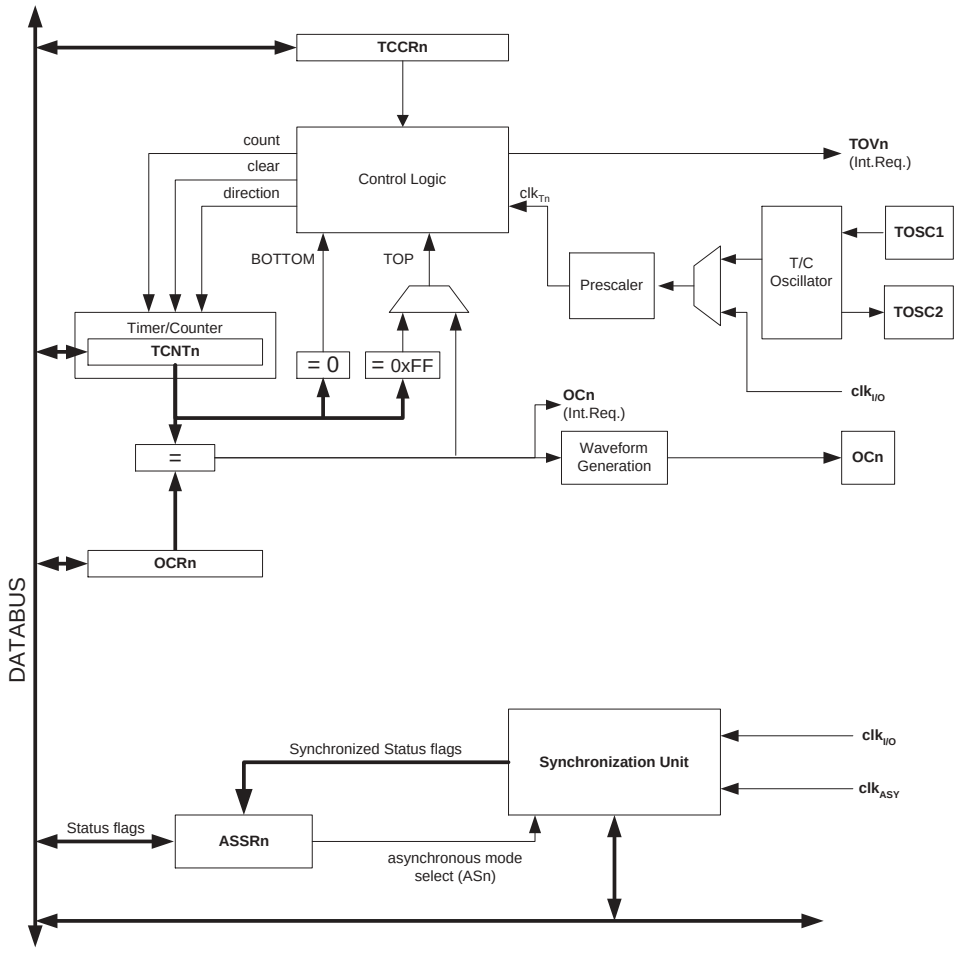
Timer/Counter2 is a general purpose, single channel, 8-bit Timer/Counter module. The main features are:

- **Single Channel Counter**
- **Clear Timer on Compare Match (Auto Reload)**
- **Glitch-free, Phase Correct Pulse Width Modulator (PWM)**
- **Frequency Generator**
- **10-bit Clock Prescaler**
- **Overflow and Compare Match Interrupt Sources (TOV2 and OCF2)**
- **Allows Clocking from External 32 kHz Watch Crystal Independent of the I/O Clock**

Overview

A simplified block diagram of the 8-bit Timer/Counter is shown in Figure 59. For the actual placement of I/O pins, refer to “Pinout ATmega162” on page 2. CPU accessible I/O Registers, including I/O bits and I/O pins, are shown in bold. The device-specific I/O Register and bit locations are listed in the “8-bit Timer/Counter Register Description” on page 148.

Figure 59. 8-bit Timer/Counter Block Diagram



Registers

The Timer/Counter (TCNT2) and Output Compare Register (OCR2) are 8-bit registers. Interrupt request (shorten as Int.Req.) signals are all visible in the Timer Interrupt Flag Register (TIFR). All interrupts are individually masked with the Timer Interrupt Mask Register (TIMSK). TIFR and TIMSK are not shown in the figure since these registers are shared by other timer units.

The Timer/Counter can be clocked internally, via the prescaler, or asynchronously clocked from the TOSC1/2 pins, as detailed later in this section. The asynchronous operation is controlled by the Asynchronous Status Register (ASSR). The Clock Select logic block controls which clock source the Timer/Counter uses to increment (or decrement) its value. The Timer/Counter is inactive when no clock source is selected. The output from the clock select logic is referred to as the Timer Clock (clk_T2).

The double buffered Output Compare Register (OCR2) is compared with the Timer/Counter value at all times. The result of the compare can be used by the waveform generator to generate a PWM or variable frequency output on the Output Compare Pin (OC2). See “Output Compare Unit” on page 139. for details. The Compare Match event will also set the Compare Flag (OCF2) which can be used to generate an output compare interrupt request.

Definitions

Many register and bit references in this document are written in general form. A lower case “n” replaces the Timer/Counter number, in this case 2. However, when using the register or bit defines in a program, the precise form must be used i.e., TCNT2 for accessing Timer/Counter2 counter value and so on.

The definitions in Table 59 are also used extensively throughout the section.

Table 59. Definitions

BOTTOM	The counter reaches the BOTTOM when it becomes zero (0x00).
MAX	The counter reaches its MAXimum when it becomes 0xFF (decimal 255).
TOP	The counter reaches the TOP when it becomes equal to the highest value in the count sequence. The TOP value can be assigned to be the fixed value 0xFF (MAX) or the value stored in the OCR2 Register. The assignment is dependent on the mode of operation.

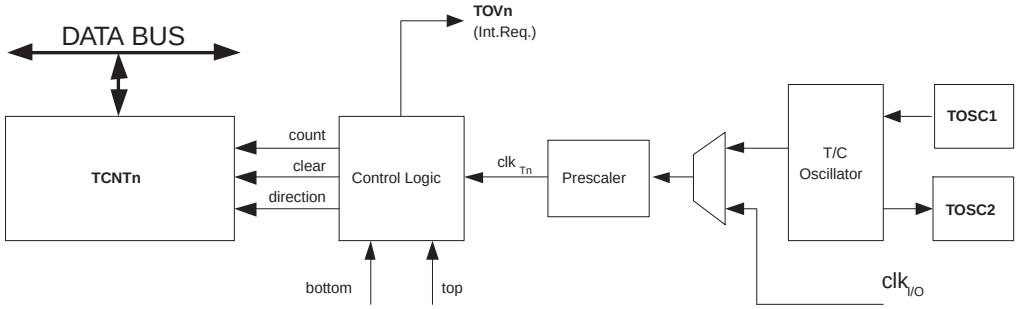
Timer/Counter Clock Sources

The Timer/Counter can be clocked by an internal synchronous or an external asynchronous clock source. The clock source clk_T2 is by default equal to the MCU clock, $clk_{I/O}$. When the AS2 bit in the ASSR Register is written to logic one, the clock source is taken from the Timer/Counter Oscillator connected to TOSC1 and TOSC2. For details on asynchronous operation, see “Asynchronous Status Register – ASSR” on page 152. For details on clock sources and prescaler, see “Timer/Counter Prescaler” on page 156.

Counter Unit

The main part of the 8-bit Timer/Counter is the programmable bi-directional counter unit. Figure 60 shows a block diagram of the counter and its surrounding environment.

Figure 60. Counter Unit Block Diagram



Signal description (internal signals):

count Increment or decrement TCNT2 by 1.

direction Selects between increment and decrement.

clear Clear TCNT2 (set all bits to zero).

clk_T2 Timer/Counter clock.

top Signalizes that TCNT2 has reached maximum value.

bottom Signalizes that TCNT2 has reached minimum value (zero).

Depending on the mode of operation used, the counter is cleared, incremented, or decremented at each timer clock (clk_T2). clk_T2 can be generated from an external or internal clock source, selected by the Clock Select bits (CS22:0). When no clock source is selected (CS22:0 = 0) the timer is stopped. However, the TCNT2 value can be accessed by the CPU, regardless of whether clk_T2 is present or not. A CPU write overrides (has priority over) all counter clear or count operations.

The counting sequence is determined by the setting of the WGM21 and WGM20 bits located in the Timer/Counter Control Register (TCCR2). There are close connections between how the counter behaves (counts) and how waveforms are generated on the Output Compare output OC2. For more details about advanced counting sequences and waveform generation, see “Modes of Operation” on page 142.

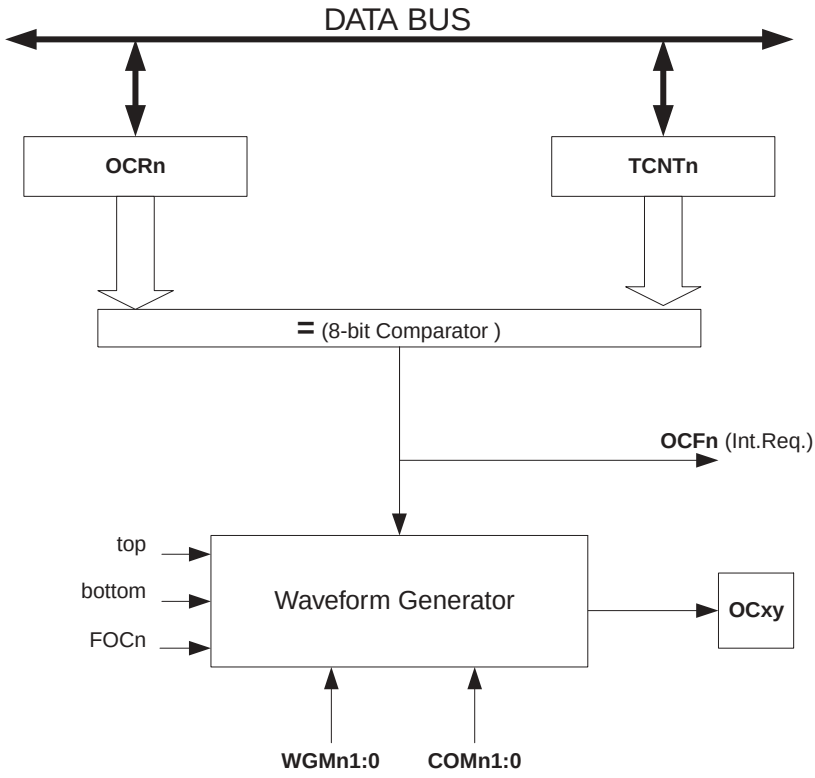
The Timer/Counter Overflow Flag (TOV2) is set according to the mode of operation selected by the WGM21:0 bits. TOV2 can be used for generating a CPU interrupt.

Output Compare Unit

The 8-bit comparator continuously compares TCNT2 with the Output Compare Register (OCR2). Whenever TCNT2 equals OCR2, the comparator signals a match. A match will set the Output Compare Flag (OCF2) at the next timer clock cycle. If enabled (OCIE2 = 1), the Output Compare Flag generates an output compare interrupt. The OCF2 Flag is automatically cleared when the interrupt is executed. Alternatively, the OCF2 Flag can be cleared by software by writing a logical one to its I/O bit location. The waveform generator uses the match signal to generate an output according to operating mode set by the WGM21:0 bits and Compare Output mode (COM21:0) bits. The max and bottom signals are used by the waveform generator for handling the special cases of the extreme values in some modes of operation (“Modes of Operation” on page 142).

Figure 61 shows a block diagram of the output compare unit.

Figure 61. Output Compare Unit, Block Diagram



The OCR2 Register is double buffered when using any of the Pulse Width Modulation (PWM) modes. For the normal and Clear Timer on Compare (CTC) modes of operation, the double buffering is disabled. The double buffering synchronizes the update of the OCR2 Compare Register to either top or bottom of the counting sequence. The synchronization prevents the occurrence of odd-length, non-symmetrical PWM pulses, thereby making the output glitch-free.

The OCR2 Register access may seem complex, but this is not case. When the double buffering is enabled, the CPU has access to the OCR2 Buffer Register, and if double buffering is disabled the CPU will access the OCR2 directly.

Force Output Compare

In non-PWM waveform generation modes, the match output of the comparator can be forced by writing a one to the Force Output Compare (FOC2) bit. Forcing Compare Match will not set the OCF2 Flag or reload/clear the timer, but the OC2 pin will be updated as if a real Compare Match had occurred (the COM21:0 bits settings define whether the OC2 pin is set, cleared or toggled).

Compare Match Blocking by TCNT2 Write

All CPU write operations to the TCNT2 Register will block any Compare Match that occurs in the next timer clock cycle, even when the timer is stopped. This feature allows OCR2 to be initialized to the same value as TCNT2 without triggering an interrupt when the Timer/Counter clock is enabled.

Using the Output Compare Unit

Since writing TCNT2 in any mode of operation will block all compare matches for one timer clock cycle, there are risks involved when changing TCNT2 when using the output compare channel, independently of whether the Timer/Counter is running or not. If the value written to TCNT2 equals the OCR2 value, the Compare Match will be missed,

resulting in incorrect Waveform Generation. Similarly, do not write the TCNT2 value equal to BOTTOM when the counter is down-counting.

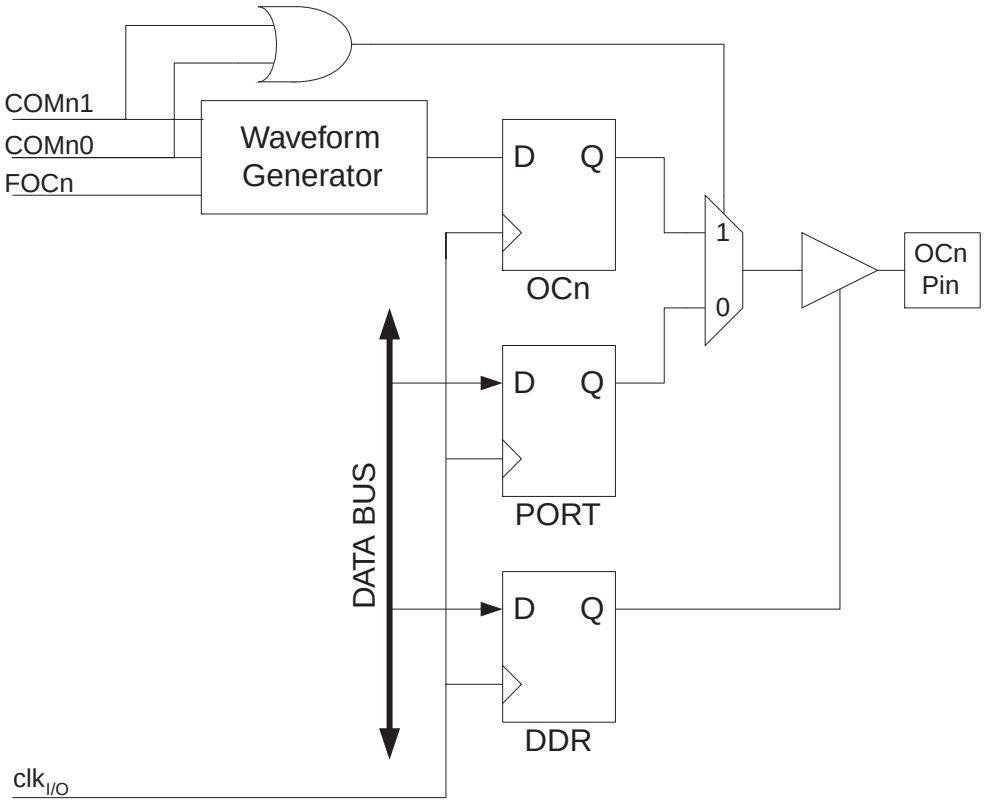
The Setup of the OC2 should be performed before setting the Data Direction Register for the port pin to output. The easiest way of setting the OC2 value is to use the Force Output Compare (FOC2) strobe bit in Normal mode. The OC2 Register keeps its value even when changing between Waveform Generation modes.

Be aware that the COM21:0 bits are not double buffered together with the compare value. Changing the COM21:0 bits will take effect immediately.

Compare Match Output Unit

The Compare Output mode (COM21:0) bits have two functions. The waveform generator uses the COM21:0 bits for defining the Output Compare (OC2) state at the next Compare Match. Also, the COM21:0 bits control the OC2 pin output source. Figure 62 shows a simplified schematic of the logic affected by the COM21:0 bit setting. The I/O Registers, I/O bits, and I/O pins in the figure are shown in bold. Only the parts of the general I/O Port Control Registers (DDR and PORT) that are affected by the COM21:0 bits are shown. When referring to the OC2 state, the reference is for the internal OC2 Register, not the OC2 pin.

Figure 62. Compare Match Output Unit, Schematic



The general I/O port function is overridden by the Output Compare (OC2) from the waveform generator if either of the COM21:0 bits are set. However, the OC2 pin direction (input or output) is still controlled by the Data Direction Register (DDR) for the port pin. The Data Direction Register bit for the OC2 pin (DDR_OC2) must be set as output before the OC2 value is visible on the pin. The port override function is independent of the Waveform Generation mode.

The design of the Output Compare pin logic allows initialization of the OC2 state before the output is enabled. Note that some COM21:0 bit settings are reserved for certain modes of operation. See “8-bit Timer/Counter Register Description” on page 148.

Compare Output Mode and Waveform Generation

The Waveform Generator uses the COM21:0 bits differently in Normal, CTC, and PWM modes. For all modes, setting the COM21:0 = 0 tells the Waveform Generator that no action on the OC2 Register is to be performed on the next Compare Match. For compare output actions in the non-PWM modes refer to Table 61 on page 150. For fast PWM mode, refer to Table 62 on page 150, and for phase correct PWM refer to Table 63 on page 150.

A change of the COM21:0 bits state will have effect at the first Compare Match after the bits are written. For non-PWM modes, the action can be forced to have immediate effect by using the FOC2 strobe bits.

Modes of Operation

The mode of operation, i.e., the behavior of the Timer/Counter and the Output Compare pins, is defined by the combination of the Waveform Generation mode (WGM21:0) and Compare Output mode (COM21:0) bits. The Compare Output mode bits do not affect the counting sequence, while the Waveform Generation mode bits do. The COM21:0 bits control whether the PWM output generated should be inverted or not (inverted or non-inverted PWM). For non-PWM modes the COM21:0 bits control whether the output should be set, cleared, or toggled at a Compare Match (See “Compare Match Output Unit” on page 141.).

For detailed timing information refer to “Timer/Counter Timing Diagrams” on page 146.

Normal Mode

The simplest mode of operation is the Normal mode (WGM21:0 = 0). In this mode the counting direction is always up (incrementing), and no counter clear is performed. The counter simply overruns when it passes its maximum 8-bit value (TOP = 0xFF) and then restarts from the bottom (0x00). In normal operation the Timer/Counter Overflow Flag (TOV2) will be set in the same timer clock cycle as the TCNT2 becomes zero. The TOV2 Flag in this case behaves like a ninth bit, except that it is only set, not cleared. However, combined with the timer overflow interrupt that automatically clears the TOV2 Flag, the timer resolution can be increased by software. There are no special cases to consider in the normal mode, a new counter value can be written anytime.

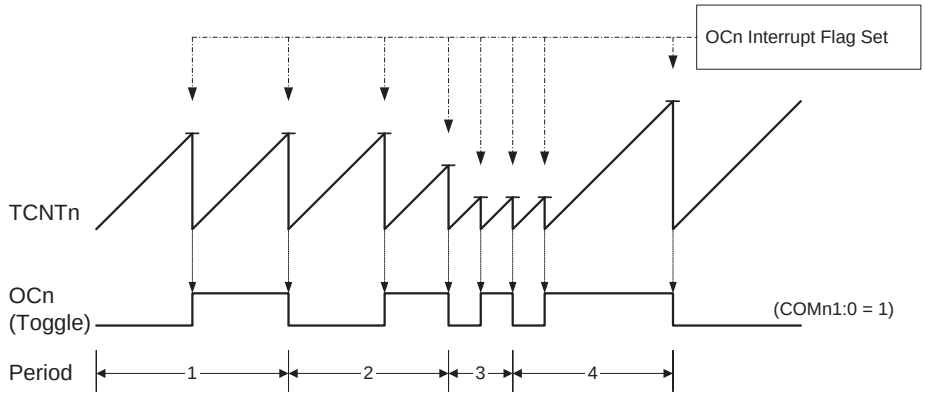
The Output Compare unit can be used to generate interrupts at some given time. Using the Output Compare to generate waveforms in Normal mode is not recommended, since this will occupy too much of the CPU time.

Clear Timer on Compare Match (CTC) Mode

In Clear Timer on Compare or CTC mode (WGM21:0 = 2), the OCR2 Register is used to manipulate the counter resolution. In CTC mode the counter is cleared to zero when the counter value (TCNT2) matches the OCR2. The OCR2 defines the top value for the counter, hence also its resolution. This mode allows greater control of the Compare Match output frequency. It also simplifies the operation of counting external events.

The timing diagram for the CTC mode is shown in Figure 63. The counter value (TCNT2) increases until a Compare Match occurs between TCNT2 and OCR2, and then counter (TCNT2) is cleared.

Figure 63. CTC Mode, Timing Diagram



An interrupt can be generated each time the counter value reaches the TOP value by using the OCF2 Flag. If the interrupt is enabled, the interrupt handler routine can be used for updating the TOP value. However, changing the TOP to a value close to BOTTOM when the counter is running with none or a low prescaler value must be done with care since the CTC mode does not have the double buffering feature. If the new value written to OCR2 is lower than the current value of TCNT2, the counter will miss the Compare Match. The counter will then have to count to its maximum value (0xFF) and wrap around starting at 0x00 before the Compare Match can occur.

For generating a waveform output in CTC mode, the OC2 output can be set to toggle its logical level on each Compare Match by setting the Compare Output mode bits to toggle mode (COM21:0 = 1). The OC2 value will not be visible on the port pin unless the data direction for the pin is set to output. The waveform generated will have a maximum frequency of $f_{OC}2 = f_{clk\_I/O}/2$ when OCR2 is set to zero (0x00). The waveform frequency is defined by the following equation:

$$f_{OCn} = \frac{f_{clk\_I/O}}{2 \cdot N \cdot (1 + OCRn)}$$

The N variable represents the prescale factor (1, 8, 32, 64, 128, 256, or 1024).

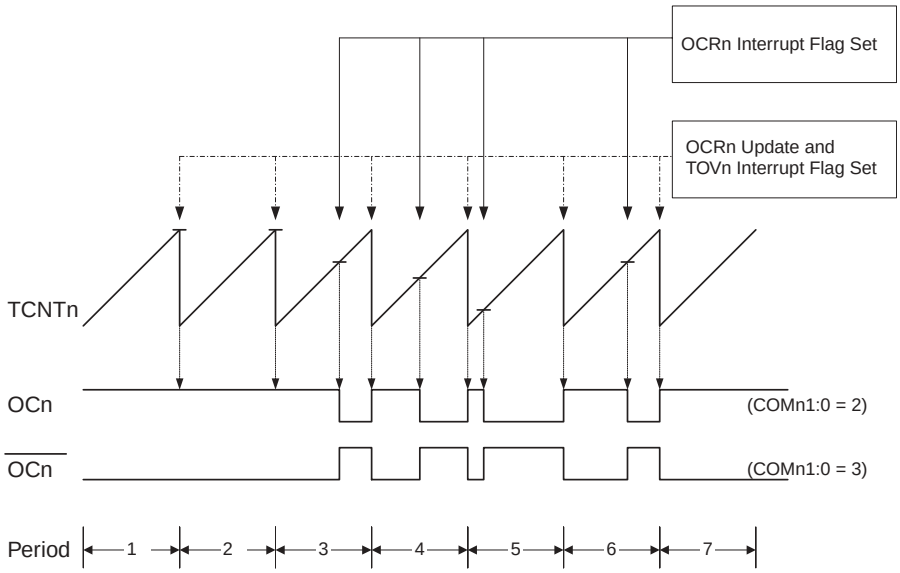
As for the Normal mode of operation, the TOV2 Flag is set in the same timer clock cycle that the counter counts from MAX to 0x00.

Fast PWM Mode

The fast Pulse Width Modulation or fast PWM mode (WGM21:0 = 1) provides a high frequency PWM waveform generation option. The fast PWM differs from the other PWM option by its single-slope operation. The counter counts from BOTTOM to MAX then restarts from BOTTOM. In non-inverting Compare Output mode, the Output Compare (OC2) is cleared on the Compare Match between TCNT2 and OCR2, and set at BOTTOM. In inverting Compare Output mode, the output is set on Compare Match and cleared at BOTTOM. Due to the single-slope operation, the operating frequency of the fast PWM mode can be twice as high as the phase correct PWM mode that uses dual-slope operation. This high frequency makes the fast PWM mode well suited for power regulation, rectification, and DAC applications. High frequency allows physically small sized external components (coils, capacitors), and therefore reduces total system cost.

In fast PWM mode, the counter is incremented until the counter value matches the MAX value. The counter is then cleared at the following timer clock cycle. The timing diagram for the fast PWM mode is shown in Figure 64. The TCNT2 value is in the timing diagram shown as a histogram for illustrating the single-slope operation. The diagram includes non-inverted and inverted PWM outputs. The small horizontal line marks on the TCNT2 slopes represent compare matches between OCR2 and TCNT2.

Figure 64. Fast PWM Mode, Timing Diagram



The Timer/Counter Overflow Flag (TOV2) is set each time the counter reaches MAX. If the interrupt is enabled, the interrupt handler routine can be used for updating the compare value.

In fast PWM mode, the compare unit allows generation of PWM waveforms on the OC2 pin. Setting the COM21:0 bits to two will produce a non-inverted PWM and an inverted PWM output can be generated by setting the COM21:0 to three (See Table 62 on page 150). The actual OC2 value will only be visible on the port pin if the data direction for the port pin is set as output. The PWM waveform is generated by setting (or clearing) the OC2 Register at the Compare Match between OCR2 and TCNT2, and clearing (or setting) the OC2 Register at the timer clock cycle the counter is cleared (changes from MAX to BOTTOM).

The PWM frequency for the output can be calculated by the following equation:

$$f_{OCnPWM} = \frac{f_{clk\_I/O}}{N \cdot 256}$$

The N variable represents the prescale factor (1, 8, 32, 64, 128, 256, or 1024).

The extreme values for the OCR2 Register represent special cases when generating a PWM waveform output in the fast PWM mode. If the OCR2 is set equal to BOTTOM, the output will be a narrow spike for each MAX+1 timer clock cycle. Setting the OCR2 equal to MAX will result in a constantly high or low output (depending on the polarity of the output set by the COM21:0 bits.)

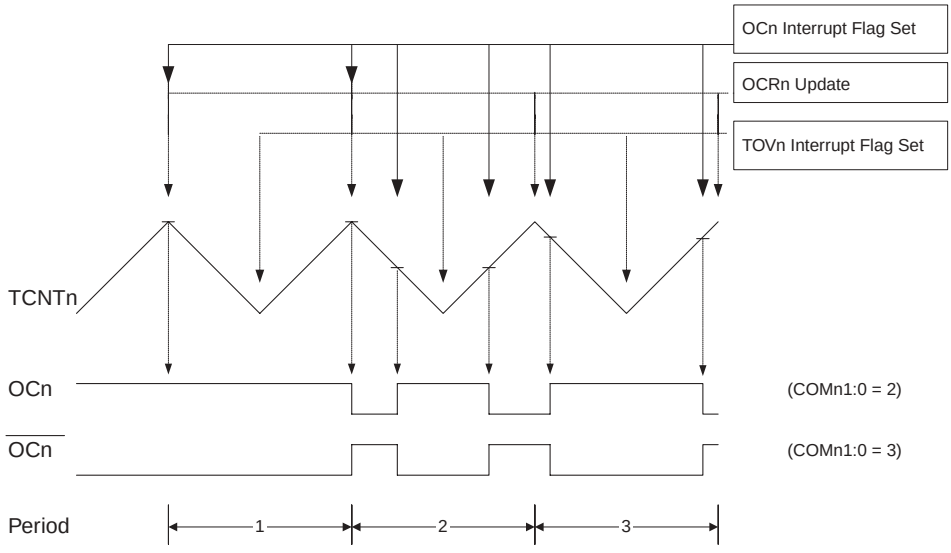
A frequency (with 50% duty cycle) waveform output in fast PWM mode can be achieved by setting OC2 to toggle its logical level on each Compare Match (COM21:0 = 1). The waveform generated will have a maximum frequency of $f_{oc}2 = f_{clk\_I/O}/2$ when OCR2 is set to zero. This feature is similar to the OC2 toggle in CTC mode, except the double buffer feature of the Output Compare unit is enabled in the fast PWM mode.

Phase Correct PWM Mode

The phase correct PWM mode (WGM21:0 = 3) provides a high resolution phase correct PWM waveform generation option. The phase correct PWM mode is based on a dual-slope operation. The counter counts repeatedly from BOTTOM to MAX and then from MAX to BOTTOM. In non-inverting Compare Output mode, the Output Compare (OC2) is cleared on the Compare Match between TCNT2 and OCR2 while up-counting, and set on the Compare Match while down-counting. In inverting output compare mode, the operation is inverted. The dual-slope operation has lower maximum operation frequency than single slope operation. However, due to the symmetric feature of the dual-slope PWM modes, these modes are preferred for motor control applications.

The PWM resolution for the phase correct PWM mode is fixed to eight bits. In phase correct PWM mode the counter is incremented until the counter value matches MAX. When the counter reaches MAX, it changes the count direction. The TCNT2 value will be equal to MAX for one timer clock cycle. The timing diagram for the phase correct PWM mode is shown on Figure 65. The TCNT2 value is in the timing diagram shown as a histogram for illustrating the dual-slope operation. The diagram includes non-inverted and inverted PWM outputs. The small horizontal line marks on the TCNT2 slopes represent compare matches between OCR2 and TCNT2.

Figure 65. Phase Correct PWM Mode, Timing Diagram



The Timer/Counter Overflow Flag (TOV2) is set each time the counter reaches BOTTOM. The Interrupt Flag can be used to generate an interrupt each time the counter reaches the BOTTOM value.

In phase correct PWM mode, the compare unit allows generation of PWM waveforms on the OC2 pin. Setting the COM21:0 bits to two will produce a non-inverted PWM. An inverted PWM output can be generated by setting the COM21:0 to three (See Table 63 on page 150). The actual OC2 value will only be visible on the port pin if the data direction for the port pin is set as output. The PWM waveform is generated by clearing (or setting) the OC2 Register at the Compare Match between OCR2 and TCNT2 when the counter increments, and setting (or clearing) the OC2 Register at Compare Match between OCR2 and TCNT2 when the counter decrements. The PWM frequency for the output when using phase correct PWM can be calculated by the following equation:

$$f_{OCnPCPWM} = \frac{f_{clk\_I/O}}{N \cdot 510}$$

The N variable represents the prescale factor (1, 8, 32, 64, 128, 256, or 1024).

The extreme values for the OCR2 Register represent special cases when generating a PWM waveform output in the phase correct PWM mode. If the OCR2 is set equal to BOTTOM, the output will be continuously low and if set equal to MAX the output will be continuously high for non-inverted PWM mode. For inverted PWM the output will have the opposite logic values.

At the very start of period 2 in Figure 65 OCn has a transition from high to low even though there is no Compare Match. The point of this transition is to guarantee symmetry around BOTTOM. There are two cases that give a transition without a Compare Match.

- OCR2 changes its value from MAX, like in Figure 65. When the OCR2 value is MAX the OCn pin value is the same as the result of a down-counting Compare Match. To ensure symmetry around BOTTOM the OCn value at MAX must correspond to the result of an up-counting Compare Match.
- The timer starts counting from a value higher than the one in OCR2, and for that reason misses the Compare Match and hence the OCn change that would have happened on the way up.

Timer/Counter Timing Diagrams

The following figures show the Timer/Counter in synchronous mode, and the timer clock (clk_T2) is therefore shown as a clock enable signal. In asynchronous mode, $clk_{I/O}$ should be replaced by the Timer/Counter Oscillator clock. The figures include information on when Interrupt Flags are set. Figure 66 contains timing data for basic Timer/Counter operation. The figure shows the count sequence close to the MAX value in all modes other than phase correct PWM mode.

Figure 66. Timer/Counter Timing Diagram, no Prescaling

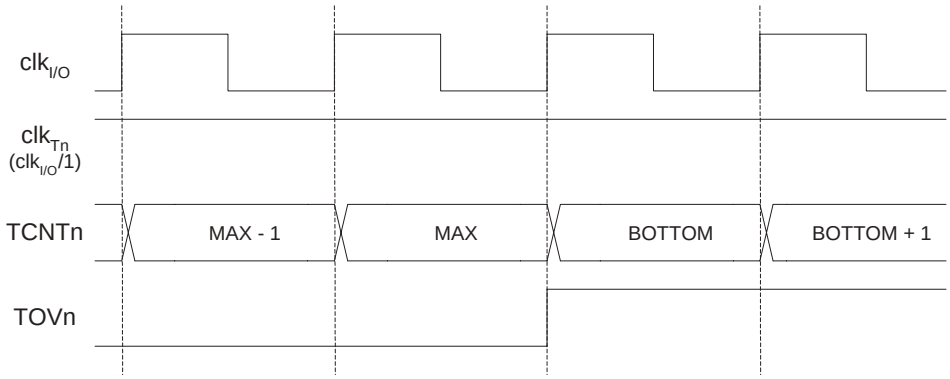


Figure 67 shows the same timing data, but with the prescaler enabled.

Figure 67. Timer/Counter Timing Diagram, with Prescaler ($f_{clk\_I/O}/8$)

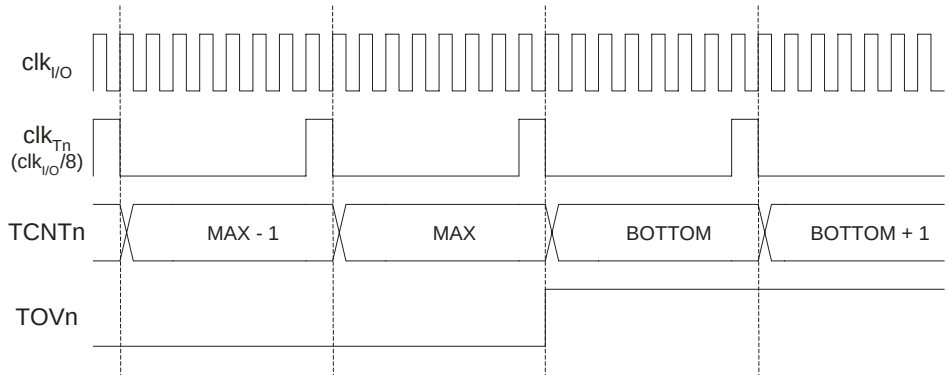


Figure 68 shows the setting of OCF2 in all modes except CTC mode.

Figure 68. Timer/Counter Timing Diagram, Setting of OCF2, with Prescaler ($f_{clk\_I/O}/8$)

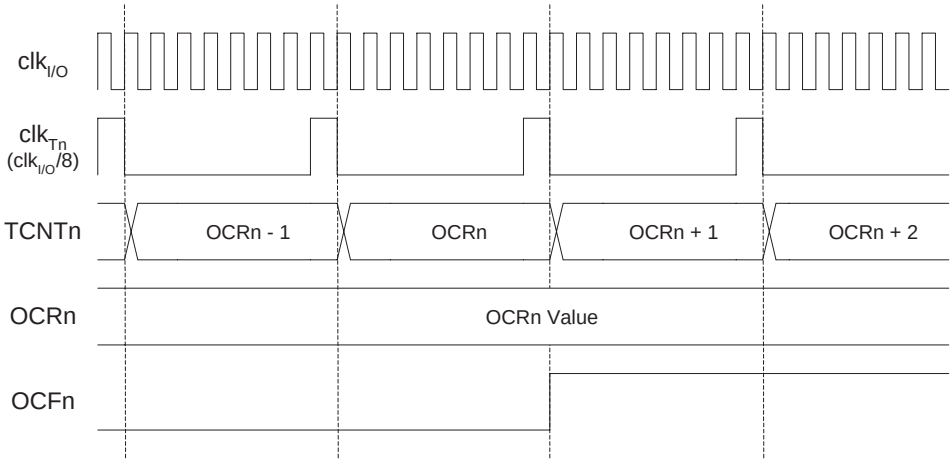
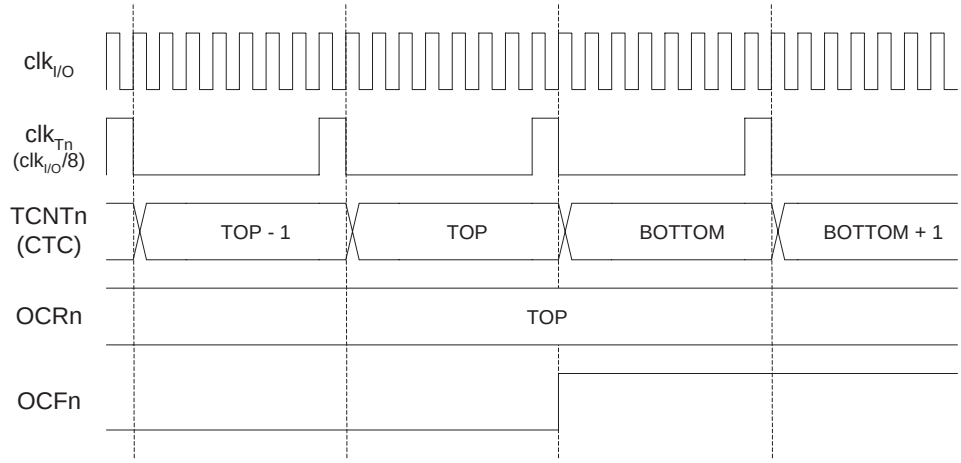


Figure 69 shows the setting of OCF2 and the clearing of TCNT2 in CTC mode.

Figure 69. Timer/Counter Timing Diagram, Clear Timer on Compare Match mode, with Prescaler ($f_{clk\_I/O}/8$)



8-bit Timer/Counter Register Description

Timer/Counter Control Register – TCCR2

Bit	7	6	5	4	3	2	1	0	
	FOC2	WGM20	COM21	COM20	WGM21	CS22	CS21	CS20	TCCR2
Read/Write	W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

- **Bit 7 – FOC2: Force Output Compare**

The FOC2 bit is only active when the WGM bits specify a non-PWM mode. However, for ensuring compatibility with future devices, this bit must be set to zero when TCCR2 is written when operating in PWM mode. When writing a logical one to the FOC2 bit, an immediate Compare Match is forced on the Waveform Generation unit. The OC2 output is changed according to its COM21:0 bits setting. Note that the FOC2 bit is implemented as a strobe. Therefore it is the value present in the COM21:0 bits that determines the effect of the forced compare.

A FOC2 strobe will not generate any interrupt, nor will it clear the timer in CTC mode using OCR2 as TOP.

The FOC2 bit is always read as zero.

- **Bit 6, 3 – WGM21:0: Waveform Generation Mode**

These bits control the counting sequence of the counter, the source for the maximum (TOP) counter value, and what type of waveform generation to be used. Modes of operation supported by the Timer/Counter unit are: Normal mode, Clear Timer on Compare

match (CTC) mode, and two types of Pulse Width Modulation (PWM) modes. See Table 60 and “Modes of Operation” on page 142.

Table 60. Waveform Generation Mode Bit Description[1]

Mode	WGM21 (CTC2)	WGM20 (PWM2)	Timer/Counter Mode of Operation	TOP	Update of OCR2 at	TOV2 Flag Set on
0	0	0	Normal	0xFF	Immediate	MAX
1	0	1	PWM, Phase Correct	0xFF	TOP	BOTTOM
2	1	0	CTC	OCR2	Immediate	MAX
3	1	1	Fast PWM	0xFF	TOP	MAX

Note: 1. The CTC2 and PWM2 bit definition names are now obsolete. Use the WGM21:0 definitions. However, the functionality and location of these bits are compatible with previous versions of the timer.

- **Bit 5:4 – COM21:0: Compare Match Output Mode**

These bits control the Output Compare pin (OC2) behavior. If one or both of the COM21:0 bits are set, the OC2 output overrides the normal port functionality of the I/O pin it is connected to. However, note that the Data Direction Register (DDR) bit corresponding to OC2 pin must be set in order to enable the output driver.

When OC2 is connected to the pin, the function of the COM21:0 bits depends on the WGM21:0 bit setting. Table 61 shows the COM21:0 bit functionality when the WGM21:0 bits are set to a normal or CTC mode (non-PWM).

Table 61. Compare Output Mode, non-PWM Mode

COM21	COM20	Description
0	0	Normal port operation, OC2 disconnected.
0	1	Toggle OC2 on Compare Match.
1	0	Clear OC2 on Compare Match.
1	1	Set OC2 on Compare Match.

Table 62 shows the COM21:0 bit functionality when the WGM21:0 bits are set to fast PWM mode.

Table 62. Compare Output Mode, Fast PWM Mode(1)

COM21	COM20	Description
0	0	Normal port operation, OC2 disconnected.
0	1	Reserved
1	0	Clear OC2 on Compare Match, set OC2 at TOP.
1	1	Set OC2 on Compare Match, clear OC2 at TOP.

Note: 1. A special case occurs when OCR2 equals TOP and COM21 is set. In this case, the Compare Match is ignored, but the set or clear is done at TOP. See “Fast PWM Mode” on page 144 for more details.

Table 63 shows the COM21:0 bit functionality when the WGM21:0 bits are set to phase correct PWM mode.

Table 63. Compare Output Mode, Phase Correct PWM Mode(1)

COM21	COM20	Description
0	0	Normal port operation, OC2 disconnected.
0	1	Reserved
1	0	Clear OC2 on Compare Match when up-counting. Set OC2 on Compare Match when down-counting.
1	1	Set OC2 on Compare Match when up-counting. Clear OC2 on Compare Match when down-counting.

Note: 1. A special case occurs when OCR2 equals TOP and COM21 is set. In this case, the Compare Match is ignored, but the set or clear is done at TOP. See “Phase Correct PWM Mode” on page 145 for more details.

- **Bit 2:0 – CS22:0: Clock Select**

The three Clock Select bits select the clock source to be used by the Timer/Counter, see Table 64.

Table 64. Clock Select Bit Description

CS22	CS21	CS20	Description
0	0	0	No clock source (Timer/Counter stopped).
0	0	1	clk_T2_S/(No prescaling)
0	1	0	clk_T2_S/8 (From prescaler)
0	1	1	clk_T2_S/32 (From prescaler)
1	0	0	clk_T2_S/64 (From prescaler)
1	0	1	clk_T2_S/128 (From prescaler)
1	1	0	clk_T2_S/256 (From prescaler)
1	1	1	clk_T2_S/1024 (From prescaler)

Timer/Counter Register – TCNT2

Bit	7	6	5	4	3	2	1	0	
	TCNT2[7:0]								TCNT2
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

The Timer/Counter Register gives direct access, both for read and write operations, to the Timer/Counter unit 8-bit counter. Writing to the TCNT2 Register blocks (removes) the Compare Match on the following timer clock. Modifying the counter (TCNT2) while the counter is running, introduces a risk of missing a Compare Match between TCNT2 and the OCR2 Register.

Output Compare Register – OCR2

Bit	7	6	5	4	3	2	1	0	
	OCR2[7:0]								OCR2
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

The Output Compare Register contains an 8-bit value that is continuously compared with the counter value (TCNT2). A match can be used to generate an output compare interrupt, or to generate a waveform output on the OC2 pin.

Asynchronous operation of the Timer/Counter

Asynchronous Status Register – ASSR

Bit	7	6	5	4	3	2	1	0	
	–	–	–	–	AS2	TCN2UB	OCR2UB	TCR2UB	ASSR
Read/Write	R	R	R	R	R/W	R	R	R	
Initial Value	0	0	0	0	0	0	0	0	

- **Bit 3 – AS2: Asynchronous Timer/Counter2**

When AS2 is written to zero, Timer/Counter2 is clocked from the I/O clock, $clk_{I/O}$. When AS2 is written to one, Timer/Counter2 is clocked from a crystal Oscillator connected to the Timer Oscillator 1 (TOSC1) pin. When the value of AS2 is changed, the contents of TCNT2, OCR2, and TCCR2 might be corrupted.

- **Bit 2 – TCN2UB: Timer/Counter2 Update Busy**

When Timer/Counter2 operates asynchronously and TCNT2 is written, this bit becomes set. When TCNT2 has been updated from the temporary storage register, this bit is cleared by hardware. A logical zero in this bit indicates that TCNT2 is ready to be updated with a new value.

- **Bit 1 – OCR2UB: Output Compare Register2 Update Busy**

When Timer/Counter2 operates asynchronously and OCR2 is written, this bit becomes set. When OCR2 has been updated from the temporary storage register, this bit is cleared by hardware. A logical zero in this bit indicates that OCR2 is ready to be updated with a new value.

- **Bit 0 – TCR2UB: Timer/Counter Control Register2 Update Busy**

When Timer/Counter2 operates asynchronously and TCCR2 is written, this bit becomes set. When TCCR2 has been updated from the temporary storage register, this bit is cleared by hardware. A logical zero in this bit indicates that TCCR2 is ready to be updated with a new value.

If a write is performed to any of the three Timer/Counter2 Registers while its update Busy Flag is set, the updated value might get corrupted and cause an unintentional interrupt to occur.

The mechanisms for reading TCNT2, OCR2, and TCCR2 are different. When reading TCNT2, the actual timer value is read. When reading OCR2 or TCCR2, the value in the temporary storage register is read.

Asynchronous Operation of Timer/Counter2

When Timer/Counter2 operates asynchronously, some considerations must be taken.

- Warning: When switching between asynchronous and synchronous clocking of Timer/Counter2, the Timer Registers TCNT2, OCR2, and TCCR2 might be corrupted. A safe procedure for switching clock source is:
  1. Disable the Timer/Counter2 interrupts by clearing OCIE2 and TOIE2.
  2. Select clock source by setting AS2 as appropriate.
  3. Write new values to TCNT2, OCR2, and TCCR2.
  4. To switch to asynchronous operation: Wait for TCN2UB, OCR2UB, and TCR2UB.
  5. Clear the Timer/Counter2 Interrupt Flags.
  6. Enable interrupts, if needed.
- The Oscillator is optimized for use with a 32.768 kHz watch crystal. Applying an external clock to the TOSC1 pin may result in incorrect Timer/Counter2 operation. The CPU main clock frequency must be more than four times the Oscillator frequency.
- When writing to one of the registers TCNT2, OCR2, or TCCR2, the value is transferred to a temporary register, and latched after two positive edges on TOSC1. The user should not write a new value before the contents of the temporary register have been transferred to its destination. Each of the three mentioned registers have their individual temporary register, which means that e.g., writing to TCNT2 does not disturb an OCR2 write in progress. To detect that a transfer to the destination register has taken place, the Asynchronous Status Register – ASSR has been implemented.
- When entering Power-save or Extended Standby mode after having written to TCNT2, OCR2, or TCCR2, the user must wait until the written register has been updated if Timer/Counter2 is used to wake up the device. Otherwise, the MCU will enter sleep mode before the changes are effective. This is particularly important if the Output Compare2 interrupt is used to wake up the device, since the output compare function is disabled during writing to OCR2 or TCNT2. If the write cycle is not finished, and the MCU enters sleep mode before the OCR2UB bit returns to zero, the device will never receive a Compare Match interrupt, and the MCU will not wake up.
- If Timer/Counter2 is used to wake the device up from Power-save or Extended Standby mode, precautions must be taken if the user wants to re-enter one of these modes: The interrupt logic needs one TOSC1 cycle to be reset. If the time between wake-up and re-entering sleep mode is less than one TOSC1 cycle, the interrupt will not occur, and the device will fail to wake up. If the user is in doubt whether the time before re-entering Power-save or Extended Standby mode is sufficient, the following algorithm can be used to ensure that one TOSC1 cycle has elapsed:
  1. Write a value to TCCR2, TCNT2, or OCR2.
  2. Wait until the corresponding Update Busy Flag in ASSR returns to zero.
  3. Enter Power-save or Extended Standby mode.
- When the asynchronous operation is selected, the 32.768 kHz Oscillator for Timer/Counter2 is always running, except in Power-down and Standby modes. After a Power-up Reset or wake-up from Power-down or Standby mode, the user should be aware of the fact that this Oscillator might take as long as one second to stabilize. The user is advised to wait for at least one second before using Timer/Counter2 after Power-up or wake-up from Power-down or Standby mode. The contents of all Timer/Counter2 Registers must be considered lost after a wake-up from Power-

down or Standby mode due to unstable clock signal upon start-up, no matter whether the Oscillator is in use or a clock signal is applied to the TOSC1 pin.

- Description of wake up from Power-save or Extended Standby mode when the Timer is clocked asynchronously: When the interrupt condition is met, the wake up process is started on the following cycle of the timer clock, that is, the Timer is always advanced by at least one before the processor can read the counter value. After wake-up, the MCU is halted for four cycles, it executes the interrupt routine, and resumes execution from the instruction following SLEEP.
- Reading of the TCNT2 Register shortly after wake-up from Power-save may give an incorrect result. Since TCNT2 is clocked on the asynchronous TOSC clock, reading TCNT2 must be done through a register synchronized to the internal I/O clock domain. Synchronization takes place for every rising TOSC1 edge. When waking up from Power-save mode, and the I/O clock ($clk_{I/O}$) again becomes active, TCNT2 will read as the previous value (before entering sleep) until the next rising TOSC1 edge. The phase of the TOSC clock after waking up from Power-save mode is essentially unpredictable, as it depends on the wake-up time. The recommended procedure for reading TCNT2 is thus as follows:
  1. Write any value to either of the registers OCR2 or TCCR2.
  2. Wait for the corresponding Update Busy Flag to be cleared.
  3. Read TCNT2.
- During asynchronous operation, the synchronization of the Interrupt Flags for the Asynchronous Timer takes three processor cycles plus one timer cycle. The Timer is therefore advanced by at least one before the processor can read the Timer value causing the setting of the Interrupt Flag. The output compare pin is changed on the Timer clock and is not synchronized to the processor clock.

Timer/Counter Interrupt Mask Register – TIMSK

Bit	7	6	5	4	3	2	1	0	
	TOIE1	OCIE1A	OCIE1B	OCIE2	TICIE1	TOIE2	TOIE0	OCIE0	TIMSK
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

- **Bit 4 – OCIE2: Timer/Counter2 Output Compare Match Interrupt Enable**

When the OCIE2 bit is written to one and the I-bit in the Status Register is set (one), the Timer/Counter2 Compare Match interrupt is enabled. The corresponding interrupt is executed if a Compare Match in Timer/Counter2 occurs, i.e., when the OCF2 bit is set in the Timer/Counter Interrupt Flag Register – TIFR.

- **Bit 2 – TOIE2: Timer/Counter2 Overflow Interrupt Enable**

When the TOIE2 bit is written to one and the I-bit in the Status Register is set (one), the Timer/Counter2 Overflow interrupt is enabled. The corresponding interrupt is executed if an overflow in Timer/Counter2 occurs, i.e., when the TOV2 bit is set in the Timer/Counter Interrupt Flag Register – TIFR.

Timer/Counter Interrupt Flag Register – TIFR

Bit	7	6	5	4	3	2	1	0	
	TOV1	OCF1A	OC1FB	OCF2	ICF1	TOV2	TOV0	OCF0	TIFR
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

- **Bit 4 – OCF2: Output Compare Flag 2**

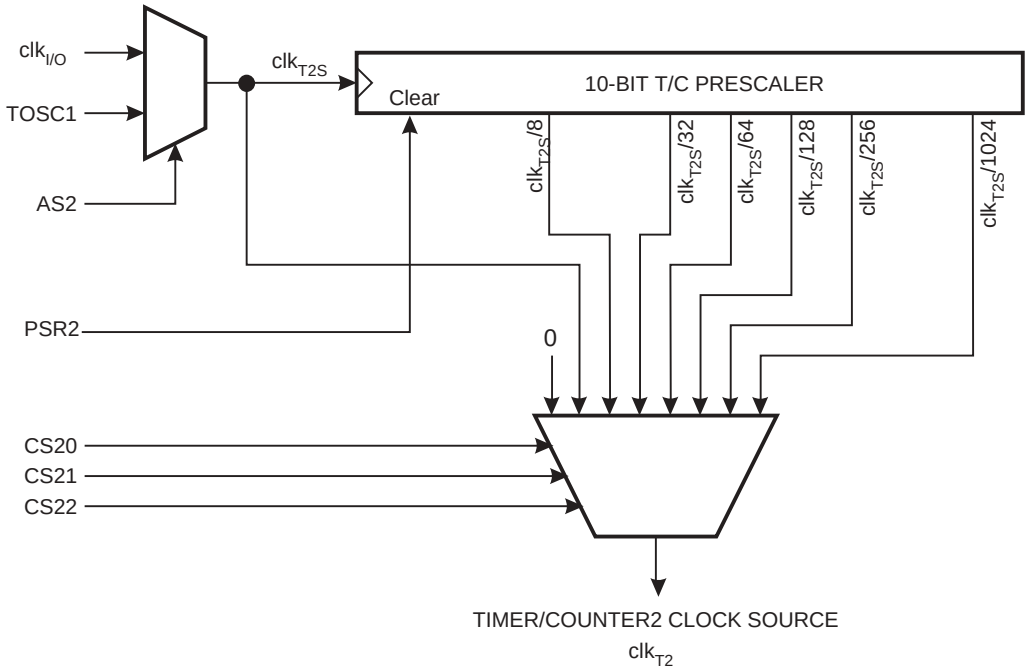
The OCF2 bit is set (one) when a Compare Match occurs between the Timer/Counter2 and the data in OCR2 – Output Compare Register2. OCF2 is cleared by hardware when executing the corresponding interrupt handling vector. Alternatively, OCF2 is cleared by writing a logic one to the flag. When the I-bit in SREG, OCIE2 (Timer/Counter2 Compare Match Interrupt Enable), and OCF2 are set (one), the Timer/Counter2 Compare Match Interrupt is executed.

- **Bit 2 – TOV2: Timer/Counter2 Overflow Flag**

The TOV2 bit is set (one) when an overflow occurs in Timer/Counter2. TOV2 is cleared by hardware when executing the corresponding interrupt handling vector. Alternatively, TOV2 is cleared by writing a logic one to the flag. When the SREG I-bit, TOIE2 (Timer/Counter2 Overflow Interrupt Enable), and TOV2 are set (one), the Timer/Counter2 Overflow interrupt is executed. In PWM mode, this bit is set when Timer/Counter2 changes counting direction at 0x00.

Timer/Counter Prescaler

Figure 70. Prescaler for Timer/Counter2



The clock source for Timer/Counter2 is named clk_{T2S}. clk_{T2S} is by default connected to the main system I/O clock clk_{IO}. By setting the AS2 bit in ASSR, Timer/Counter2 is asynchronously clocked from the TOSC1 pin. This enables use of Timer/Counter2 as a Real Time Counter (RTC). When AS2 is set, pins TOSC1 and TOSC2 are disconnected from Port D. A crystal can then be connected between the TOSC1 and TOSC2 pins to serve as an independent clock source for Timer/Counter2. The Oscillator is optimized for use with a 32.768 kHz crystal. Applying an external clock source to TOSC1 is not recommended.

For Timer/Counter2, the possible prescaled selections are: $clk_{T2S}/8$, $clk_{T2S}/32$, $clk_{T2S}/64$, $clk_{T2S}/128$, $clk_{T2S}/256$, and $clk_{T2S}/1024$. Additionally, clk_{T2S} as well as 0 (stop) may be selected. Setting the PSR2 bit in SFIOR resets the prescaler. This allows the user to operate with a predictable prescaler.

Special Function IO Register – SFIOR

Bit	7	6	5	4	3	2	1	0	
	TSM	XMBK	XMM2	XMM1	XMM0	PUD	PSR2	PSR310	SFIOR
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

- **Bit 1 – PSR2: Prescaler Reset Timer/Counter2**

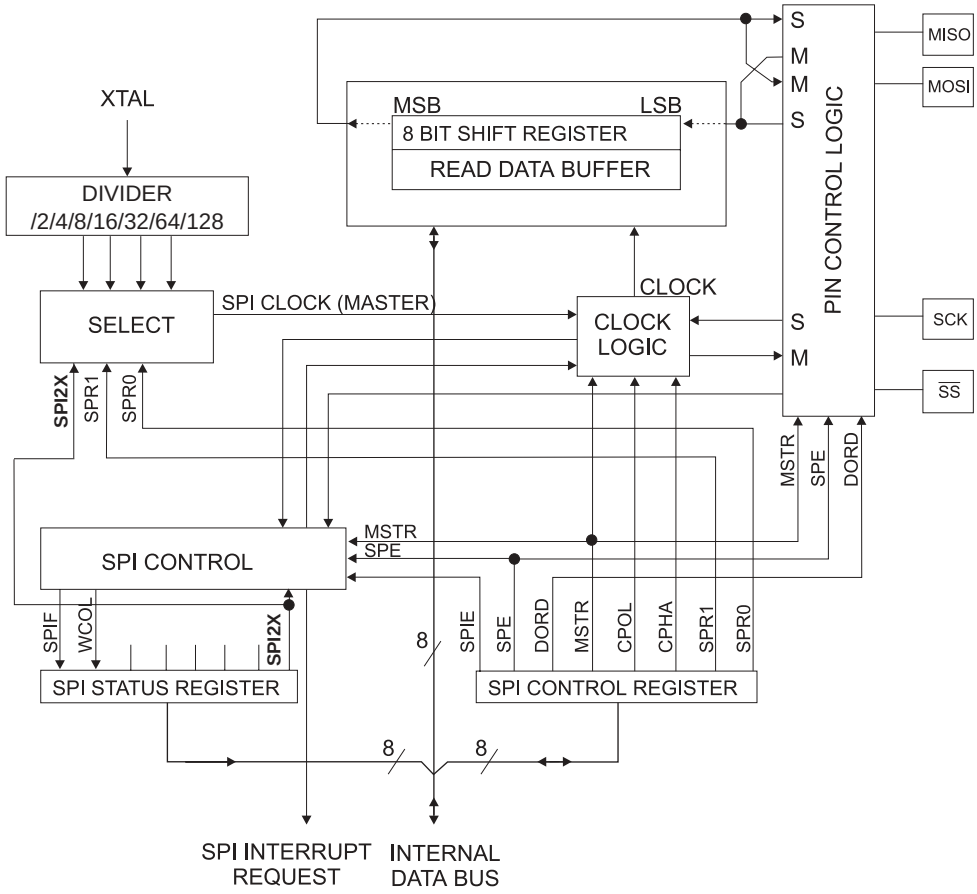
When this bit is one, the Timer/Counter2 prescaler will be reset. This bit is normally cleared immediately by hardware. If this bit is written when Timer/Counter2 is operating in asynchronous mode, the bit will remain one until the prescaler has been reset. The bit will not be cleared by hardware if the TSM bit is set. Refer to the description of the “Bit 7 – TSM: Timer/Counter Synchronization Mode” on page 104 for a description of the Timer/Counter Synchronization mode.

Serial Peripheral Interface – SPI

The Serial Peripheral Interface (SPI) allows high-speed synchronous data transfer between the ATmega162 and peripheral devices or between several AVR devices. The ATmega162 SPI includes the following features:

- **Full-duplex, Three-wire Synchronous Data Transfer**
- **Master or Slave Operation**
- **LSB First or MSB First Data Transfer**
- **Seven Programmable Bit Rates**
- **End of Transmission Interrupt Flag**
- **Write Collision Flag Protection**
- **Wake-up from Idle Mode**
- **Double Speed (CK/2) Master SPI Mode**

Figure 71. SPI Block Diagram(1)



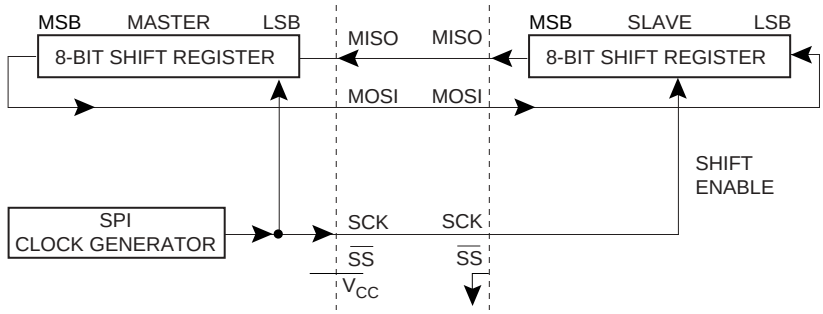
Note: 1. Refer to Figure 1 on page 2, and Table 32 on page 71 for SPI pin placement.

The interconnection between Master and Slave CPUs with SPI is shown in Figure 72. The system consists of two Shift Registers, and a Master clock generator. The SPI Master initiates the communication cycle when pulling low the Slave Select $\overline{SS}$ pin of the desired Slave. Master and Slave prepare the data to be sent in their respective Shift Registers, and the Master generates the required clock pulses on the SCK line to interchange data. Data is always shifted from Master to Slave on the Master Out – Slave In, MOSI, line, and from Slave to Master on the Master In – Slave Out, MISO, line. After each data packet, the Master will synchronize the Slave by pulling high the Slave Select, $\overline{SS}$, line.

When configured as a Master, the SPI interface has no automatic control of the $\overline{SS}$ line. This must be handled by user software before communication can start. When this is done, writing a byte to the SPI Data Register starts the SPI clock generator, and the hardware shifts the eight bits into the Slave. After shifting one byte, the SPI clock generator stops, setting the End of Transmission Flag (SPIF). If the SPI Interrupt Enable bit (SPIE) in the SPCR Register is set, an interrupt is requested. The Master may continue to shift the next byte by writing it into SPDR, or signal the end of packet by pulling high the Slave Select, $\overline{SS}$ line. The last incoming byte will be kept in the buffer register for later use.

When configured as a Slave, the SPI interface will remain sleeping with MISO tri-stated as long as the $\overline{SS}$ pin is driven high. In this state, software may update the contents of the SPI Data Register, SPDR, but the data will not be shifted out by incoming clock pulses on the SCK pin until the $\overline{SS}$ pin is driven low. As one byte has been completely shifted, the End of Transmission Flag, SPIF is set. If the SPI interrupt enable bit, SPIE, in the SPCR Register is set, an interrupt is requested. The Slave may continue to place new data to be sent into SPDR before reading the incoming data. The last incoming byte will be kept in the Buffer Register for later use.

Figure 72. SPI Master-slave Interconnection



The system is single buffered in the transmit direction and double buffered in the receive direction. This means that bytes to be transmitted cannot be written to the SPI Data Register before the entire shift cycle is completed. When receiving data, however, a received character must be read from the SPI Data Register before the next character has been completely shifted in. Otherwise, the first byte is lost.

In SPI Slave mode, the control logic will sample the incoming signal of the SCK pin. To ensure correct sampling of the clock signal, the frequency of the SPI clock should never exceed $f_{osc}/4$.

When the SPI is enabled, the data direction of the MOSI, MISO, SCK, and $\overline{SS}$ pins is overridden according to Table 65. For more details on automatic port overrides, refer to “Alternate Port Functions” on page 67.

Table 65. SPI Pin Overrides[1]

Pin	Direction, Master SPI	Direction, Slave SPI
MOSI	User Defined	Input
MISO	Input	User Defined
SCK	User Defined	Input
$\overline{SS}$	User Defined	Input

Note: 1. See “Alternate Functions Of Port B” on page 71 for a detailed description of how to define the direction of the user defined SPI pins.

The following code examples show how to initialize the SPI as a Master and how to perform a simple transmission. DDR_SPI in the examples must be replaced by the actual Data Direction Register controlling the SPI pins. DD_MOSI, DD_MISO, and DD_SCK must be replaced by the actual data direction bits for these pins. E.g., if MOSI is placed on pin PB5, replace DD_MOSI with DDB5 and DDR_SPI with DDRB.

Assembly Code Example[1]

```
SPI_MasterInit:
  ; Set MOSI and SCK output, all others input
  ldi   r17,(1<<DD_MOSI)|(1<<DD_SCK)
  out   DDR_SPI,r17
  ; Enable SPI, Master, set clock rate fck/16
  ldi   r17,(1<<SPE)|(1<<MSTR)|(1<<SPR0)
  out   SPCR,r17
  ret

SPI_MasterTransmit:
  ; Start transmission of data (r16)
  out   SPDR,r16
Wait_Transmit:
  ; Wait for transmission complete
  sbis  SPSR,SPIF
  rjmp  Wait_Transmit
  ret
```

C Code Example[1]

```
void SPI_MasterInit(void)
{
  /* Set MOSI and SCK output, all others input */
  DDR_SPI = (1<<DD_MOSI)|(1<<DD_SCK);
  /* Enable SPI, Master, set clock rate fck/16 */
  SPCR = (1<<SPE)|(1<<MSTR)|(1<<SPR0);
}

void SPI_MasterTransmit(char cData)
{
  /* Start transmission */
  SPDR = cData;
  /* Wait for transmission complete */
  while(!(SPSR & (1<<SPIF)))
    ;
}
```

Note: 1. The example code assumes that the part specific header file is included.

The following code examples show how to initialize the SPI as a slave and how to perform a simple reception.

Assembly Code Example[1]

```
SPI_SlaveInit:
  ; Set MISO output, all others input
  ldi   r17,(1<<DD_MISO)
  out   DDR_SPI,r17
  ; Enable SPI
  ldi   r17,(1<<SPE)
  out   SPCR,r17
  ret

SPI_SlaveReceive:
  ; Wait for reception complete
  sbis  SPSR,SPIF
  rjmp  SPI_SlaveReceive
  ; Read received data and return
  in    r16,SPDR
  ret
```

C Code Example[1]

```
void SPI_SlaveInit(void)
{
  /* Set MISO output, all others input */
  DDR_SPI = (1<<DD_MISO);
  /* Enable SPI */
  SPCR = (1<<SPE);
}

char SPI_SlaveReceive(void)
{
  /* Wait for reception complete */
  while(!(SPSR & (1<<SPIF)))
    ;
  /* Return data register */
  return SPDR;
}
```

Note: 1. The example code assumes that the part specific header file is included.

$\overline{SS}$ Pin Functionality

Slave Mode

When the SPI is configured as a slave, the Slave Select ($\overline{SS}$) pin is always input. When $\overline{SS}$ is held low, the SPI is activated, and MISO becomes an output if configured so by the user. All other pins are inputs. When $\overline{SS}$ is driven high, all pins are inputs, and the SPI is passive, which means that it will not receive incoming data. Note that the SPI logic will be reset once the $\overline{SS}$ pin is driven high.

The $\overline{SS}$ pin is useful for packet/byte synchronization to keep the slave bit counter synchronous with the master clock generator. When the $\overline{SS}$ pin is driven high, the SPI Slave will immediately reset the send and receive logic, and drop any partially received data in the Shift Register.

Master Mode

When the SPI is configured as a Master (MSTR in SPCR is set), the user can determine the direction of the $\overline{SS}$ pin.

If $\overline{SS}$ is configured as an output, the pin is a general output pin which does not affect the SPI system. Typically, the pin will be driving the $\overline{SS}$ pin of the SPI Slave.

If $\overline{SS}$ is configured as an input, it must be held high to ensure Master SPI operation. If the $\overline{SS}$ pin is driven low by peripheral circuitry when the SPI is configured as a Master with the $\overline{SS}$ pin defined as an input, the SPI system interprets this as another Master selecting the SPI as a slave And starting to send data to it. To avoid bus contention, the SPI system takes the following actions:

1. The MSTR bit in SPCR is cleared and the SPI system becomes a Slave. As a result of the SPI becoming a Slave, the MOSI and SCK pins become inputs.
2. The SPIF Flag in SPSR is set, and if the SPI interrupt is enabled, and the I-bit in SREG is set, the interrupt routine will be executed.

Thus, when interrupt-driven SPI transmission is used in Master mode, and there exists a possibility that $\overline{SS}$ is driven low, the interrupt should always check that the MSTR bit is still set. If the MSTR bit has been cleared by a slave select, it must be set by the user to re-enable SPI Master mode.

SPI Control Register – SPCR

Bit	7	6	5	4	3	2	1	0	
	SPIE	**SPE**	**DORD**	**MSTR**	**CPOL**	**CPHA**	**SPR1**	**SPR0**	**SPCR**
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

- **Bit 7 – SPIE: SPI Interrupt Enable**

This bit causes the SPI interrupt to be executed if SPIF bit in the SPSR Register is set and the if the Global Interrupt Enable bit in SREG is set.

- **Bit 6 – SPE: SPI Enable**

When the SPE bit is written to one, the SPI is enabled. This bit must be set to enable any SPI operations.

- **Bit 5 – DORD: Data Order**

When the DORD bit is written to one, the LSB of the data word is transmitted first.

When the DORD bit is written to zero, the MSB of the data word is transmitted first.

- **Bit 4 – MSTR: Master/Slave Select**

This bit selects Master SPI mode when written to one, and Slave SPI mode when written logic zero. If $\overline{SS}$ is configured as an input and is driven low while MSTR is set, MSTR will be cleared, and SPIF in SPSR will become set. The user will then have to set MSTR to re-enable SPI Master mode.

- **Bit 3 – CPOL: Clock Polarity**

When this bit is written to one, SCK is high when idle. When CPOL is written to zero, SCK is low when idle. Refer to Figure 73 and Figure 74 for an example. The CPOL functionality is summarized below:

Table 66. CPOL Functionality

CPOL	Leading Edge	Trailing Edge
0	Rising	Falling
1	Falling	Rising

- **Bit 2 – CPHA: Clock Phase**

The settings of the Clock Phase bit (CPHA) determine if data is sampled on the leading (first) or trailing (last) edge of SCK. Refer to Figure 73 and Figure 74 for an example. The CPHA functionality is summarized below:

Table 67. CPHA Functionality

CPHA	Leading Edge	Trailing Edge
0	Sample	Setup
1	Setup	Sample

- **Bits 1, 0 – SPR1, SPR0: SPI Clock Rate Select 1 and 0**

These two bits control the SCK rate of the device configured as a Master. SPR1 and SPR0 have no effect on the Slave. The relationship between SCK and the Oscillator Clock frequency f_{osc} is shown in the following table:

Table 68. Relationship Between SCK and the Oscillator Frequency

SPI2X	SPR1	SPR0	SCK Frequency
0	0	0	$f_{osc}/4$
0	0	1	$f_{osc}/16$
0	1	0	$f_{osc}/64$
0	1	1	$f_{osc}/128$
1	0	0	$f_{osc}/2$
1	0	1	$f_{osc}/8$
1	1	0	$f_{osc}/32$
1	1	1	$f_{osc}/64$

SPI Status Register – SPSR

Bit	7	6	5	4	3	2	1	0	
	SPIF	WCOL	–	–	–	–	–	SPI2X	SPSR
Read/Write	R	R	R	R	R	R	R	R/W	
Initial Value	0	0	0	0	0	0	0	0	

- **Bit 7 – SPIF: SPI Interrupt Flag**

When a serial transfer is complete, the SPIF Flag is set. An interrupt is generated if SPIE in SPCR is set and global interrupts are enabled. If $\overline{SS}$ is an input and is driven low when the SPI is in master mode, this will also set the SPIF Flag. SPIF is cleared by hardware when executing the corresponding interrupt handling vector. Alternatively, the SPIF bit is cleared by first reading the SPI Status Register with SPIF set, then accessing the SPI Data Register (SPDR).

- **Bit 6 – WCOL: Write COLlision Flag**

The WCOL bit is set if the SPI Data Register (SPDR) is written during a data transfer. The WCOL bit (and the SPIF bit) are cleared by first reading the SPI Status Register with WCOL set, and then accessing the SPI Data Register.

- **Bit 5..1 – Res: Reserved Bits**

These bits are reserved bits in the ATmega162 and will always read as zero.

- **Bit 0 – SPI2X: Double SPI Speed Bit**

When this bit is written logic one the SPI speed (SCK Frequency) will be doubled when the SPI is in Master mode (see Table 68). This means that the minimum SCK period will be two CPU clock periods. When the SPI is configured as Slave, the SPI is only guaranteed to work at $f_{osc}/4$ or lower.

The SPI interface on the ATmega162 is also used for program memory and EEPROM downloading or uploading. See page 244 for SPI serial programming and verification.

SPI Data Register – SPDR

Bit	7	6	5	4	3	2	1	0		
	MSB							LSB	SPDR	
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W		
Initial Value	X	X	X	X	X	X	X	X		Undefined

The SPI Data Register is a read/write register used for data transfer between the Register File and the SPI Shift Register. Writing to the register initiates data transmission. Reading the register causes the Shift Register receive buffer to be read.

Data Modes

There are four combinations of SCK phase and polarity with respect to serial data, which are determined by control bits CPHA and CPOL. The SPI data transfer formats are shown in Figure 73 and Figure 74. Data bits are shifted out and latched in on opposite edges of the SCK signal, ensuring sufficient time for data signals to stabilize. This is clearly seen by summarizing Table 66 and Table 67, as done below:

Table 69. CPOL and CPHA Functionality

	Leading Edge	Trailing Edge	SPI Mode
CPOL=0, CPHA=0	Sample (Rising)	Setup (Falling)	0
CPOL=0, CPHA=1	Setup (Rising)	Sample (Falling)	1
CPOL=1, CPHA=0	Sample (Falling)	Setup (Rising)	2
CPOL=1, CPHA=1	Setup (Falling)	Sample (Rising)	3

Figure 73. SPI Transfer Format with CPHA = 0

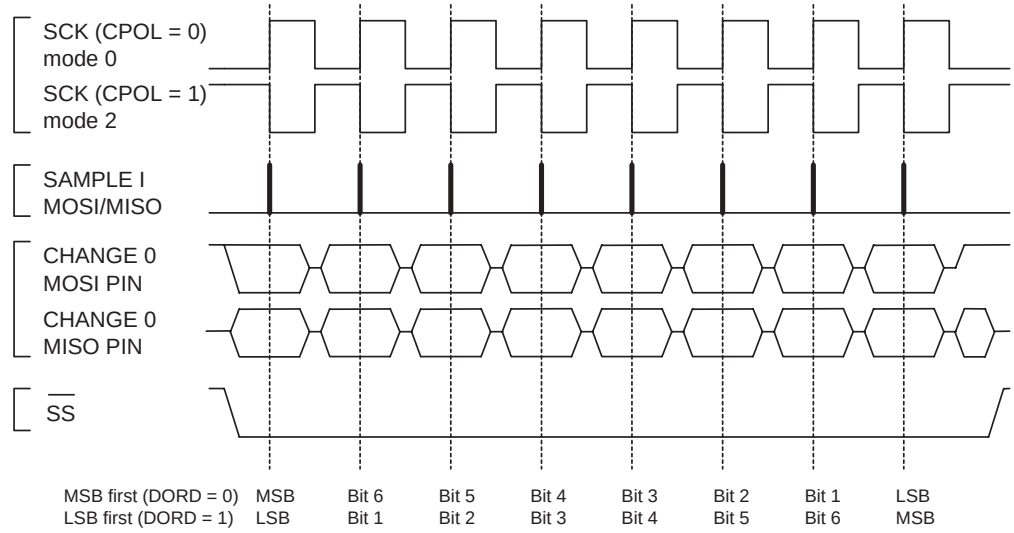
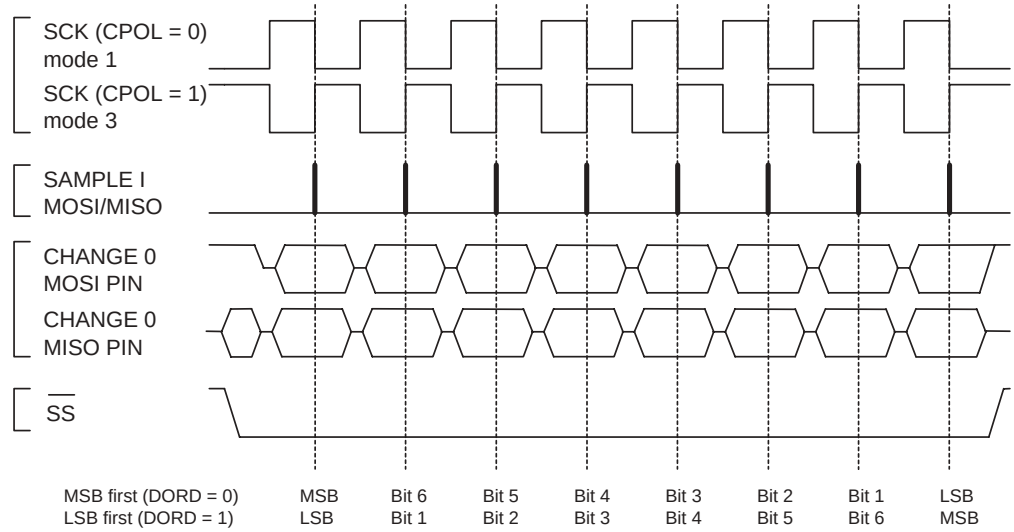


Figure 74. SPI Transfer Format with CPHA = 1



USART

The Universal Synchronous and Asynchronous serial Receiver and Transmitter (USART) is a highly flexible serial communication device. The main features are:

- **Full Duplex Operation (Independent Serial Receive and Transmit Registers)**
- **Asynchronous or Synchronous Operation**
- **Master or Slave Clocked Synchronous Operation**
- **High Resolution Baud Rate Generator**
- **Supports Serial Frames with 5, 6, 7, 8, or 9 Data Bits and 1 or 2 Stop Bits**
- **Odd or Even Parity Generation and Parity Check Supported by Hardware**
- **Data OverRun Detection**
- **Framing Error Detection**
- **Noise Filtering Includes False Start Bit Detection and Digital Low Pass Filter**
- **Three Separate Interrupts on TX Complete, TX Data Register Empty and RX Complete**
- **Multi-processor Communication Mode**
- **Double Speed Asynchronous Communication Mode**

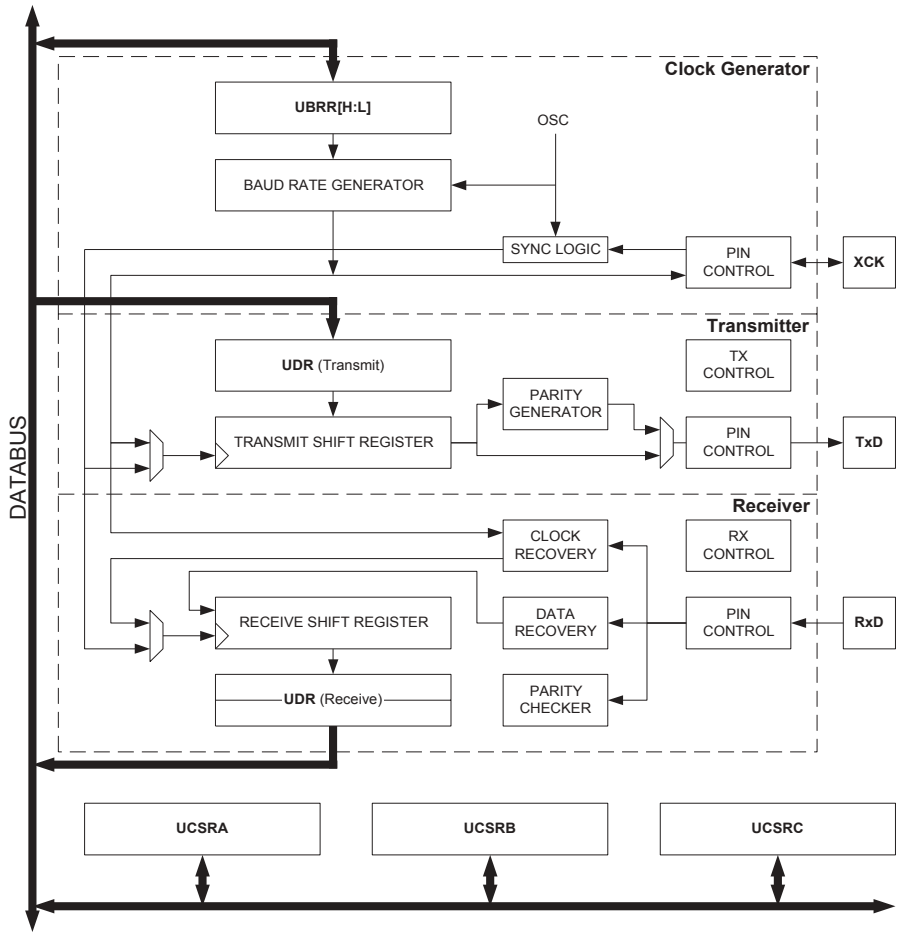
Dual USART

The ATmega162 has two USARTs, USART0 and USART1. The functionality for both USARTs is described below.

USART0 and USART1 have different I/O Registers as shown in “Register Summary” on page 303. Note that in ATmega161 compatibility mode, the double buffering of the USART Receive Register is disabled. For details, see “AVR USART vs. AVR UART – Compatibility” on page 167. Note also that the shared UBRRHI Register in ATmega161 has been split into two separate registers, UBRR0H and UBRR1H, in ATmega162.

A simplified block diagram of the USART Transmitter is shown in Figure 75. CPU accessible I/O Registers and I/O pins are shown in bold.

Figure 75. USART Block Diagram[1]



Note: 1. Refer to Figure 1 on page 2, Table 34 on page 73, Table 39 on page 79, and Table 40 on page 79 for USART pin placement.

The dashed boxes in the block diagram separate the three main parts of the USART (listed from the top): Clock Generator, Transmitter and Receiver. Control registers are shared by all units. The Clock Generation logic consists of synchronization logic for external clock input used by synchronous slave operation, and the baud rate generator. The XCK (Transfer Clock) pin is only used by synchronous transfer mode. The Transmitter consists of a single write buffer, a serial Shift Register, parity generator and control logic for handling different serial frame formats. The write buffer allows a continuous transfer of data without any delay between frames. The Receiver is the most complex part of the USART module due to its clock and data recovery units. The recovery units are used for asynchronous data reception. In addition to the recovery units, the Receiver includes a Parity Checker, Control logic, a Shift Register and a two level receive buffer (UDR). The receiver supports the same frame formats as the Transmitter, and can detect Frame Error, Data OverRun and Parity Errors.

AVR USART vs. AVR UART – Compatibility

The USART is fully compatible with the AVR UART regarding:

- Bit locations inside all USART Registers
- Baud Rate Generation
- Transmitter Operation
- Transmit Buffer Functionality
- Receiver Operation

However, the receive buffering has two improvements that will affect the compatibility in some special cases:

- A second Buffer Register has been added. The two buffer registers operate as a circular FIFO buffer. Therefore the UDR must only be read once for each incoming data! More important is the fact that the Error Flags (FE and DOR) and the ninth data bit (RXB8) are buffered with the data in the receive buffer. Therefore the status bits must always be read before the UDR Register is read. Otherwise the error status will be lost since the buffer state is lost.
- The Receiver Shift Register can now act as a third buffer level. This is done by allowing the received data to remain in the serial Shift Register (see Figure 75) if the Buffer Registers are full, until a new start bit is detected. The USART is therefore more resistant to Data OverRun (DOR) error conditions.

The following control bits have changed name, but have same functionality and register location:

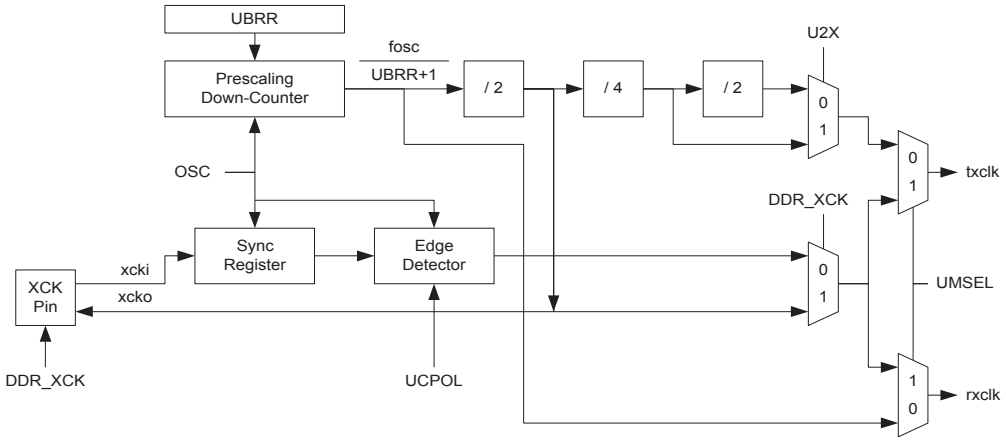
- CHR9 is changed to UCSZ2.
- OR is changed to DOR.

Clock Generation

The Clock Generation logic generates the base clock for the Transmitter and Receiver. The USART supports four modes of clock operation: Normal asynchronous, Double Speed asynchronous, Master synchronous and Slave synchronous mode. The UMSEL bit in USART Control and Status Register C (UCSRC) selects between asynchronous and synchronous operation. Double Speed (asynchronous mode only) is controlled by the U2X found in the UCSRA Register. When using synchronous mode (UMSEL = 1), the Data Direction Register for the XCK pin (DDR_XCK) controls whether the clock source is internal (Master mode) or external (Slave mode). The XCK pin is only active when using synchronous mode.

Figure 76 shows a block diagram of the clock generation logic.

Figure 76. Clock Generation Logic, Block Diagram



Signal description:

txclk Transmitter clock. (Internal Signal)

rxclk Receiver base clock. (Internal Signal)

xcki Input from XCK pin (internal Signal). Used for synchronous slave operation.

xcko Clock output to XCK pin (Internal Signal). Used for synchronous master operation.

fosc XTAL pin frequency (System Clock).

Internal Clock Generation – The Baud Rate Generator

Internal clock generation is used for the asynchronous and the synchronous master modes of operation. The description in this section refers to Figure 76.

The USART Baud Rate Register (UBRR) and the down-counter connected to it function as a programmable prescaler or baud rate generator. The down-counter, running at system clock (fosc), is loaded with the UBRR value each time the counter has counted down to zero or when the UBRRL Register is written. A clock is generated each time the counter reaches zero. This clock is the baud rate generator clock output (= fosc/(UBRR+1)). The Transmitter divides the baud rate generator clock output by 2, 8 or 16 depending on mode. The baud rate generator output is used directly by the receiver's clock and data recovery units. However, the recovery units use a state machine that uses 2, 8 or 16 states depending on mode set by the state of the UMSEL, U2X and DDR_XCK bits.

Table 70 contains equations for calculating the baud rate (in bits per second) and for calculating the UBRR value for each mode of operation using an internally generated clock source.

Table 70. Equations for Calculating Baud Rate Register Setting

Operating Mode	Equation for Calculating Baud Rate[1]	Equation for Calculating UBRR Value
Asynchronous Normal Mode (U2X = 0)	$BAUD = \frac{f_{OSC}}{16(\boldsymbol{UBRR}+1)}$	$\boldsymbol{UBRR} = \frac{f_{OSC}}{16BAUD} - 1$
Asynchronous Double Speed Mode (U2X = 1)	$BAUD = \frac{f_{OSC}}{8(\boldsymbol{UBRR}+1)}$	$\boldsymbol{UBRR} = \frac{f_{OSC}}{8BAUD} - 1$
Synchronous Master Mode	$BAUD = \frac{f_{OSC}}{2(\boldsymbol{UBRR}+1)}$	$\boldsymbol{UBRR} = \frac{f_{OSC}}{2BAUD} - 1$

Note: 1. The baud rate is defined to be the transfer rate in bit per second (bps).

BAUD Baud rate (in bits per second, bps)

f_{osc} System Oscillator clock frequency

UBRR Contents of the UBRRH and UBRRL Registers, (0 - 4095)

Some examples of UBRR values for some system clock frequencies are found in Table 78 (see page 190).

Double Speed Operation (U2X)

The transfer rate can be doubled by setting the U2X bit in UCSRA. Setting this bit only has effect for the asynchronous operation. Set this bit to zero when using synchronous operation.

Setting this bit will reduce the divisor of the baud rate divider from 16 to 8, effectively doubling the transfer rate for asynchronous communication. Note however that the Receiver will in this case only use half the number of samples (reduced from 16 to 8) for data sampling and clock recovery, and therefore a more accurate baud rate setting and system clock are required when this mode is used. For the Transmitter, there are no downsides.

External Clock

External clocking is used by the synchronous slave modes of operation. The description in this section refers to Figure 76 for details.

External clock input from the XCK pin is sampled by a synchronization register to minimize the chance of meta-stability. The output from the synchronization register must then pass through an edge detector before it can be used by the Transmitter and Receiver. This process introduces a two CPU clock period delay and therefore the maximum external XCK clock frequency is limited by the following equation:

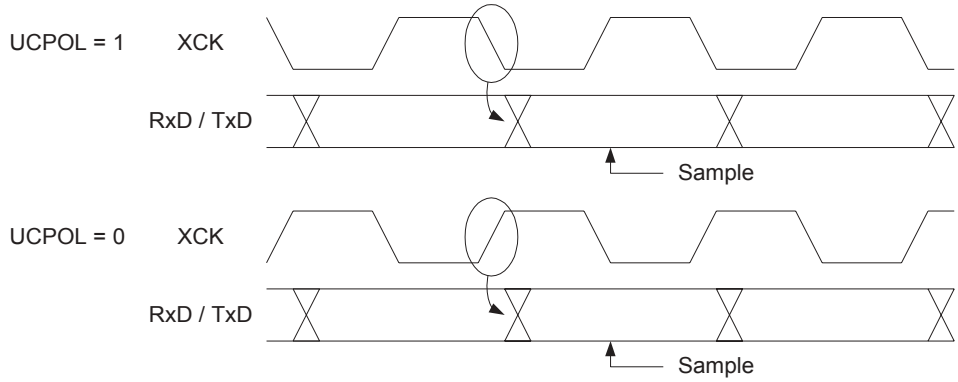
$$f_{XCK} < \frac{f_{OSC}}{4}$$

Note that f_{osc} depends on the stability of the system clock source. It is therefore recommended to add some margin to avoid possible loss of data due to frequency variations.

Synchronous Clock Operation

When synchronous mode is used (UMSEL = 1), the XCK pin will be used as either clock input (Slave) or clock output (Master). The dependency between the clock edges and data sampling or data change is the same. The basic principle is that data input (on RxD) is sampled at the opposite XCK clock edge of the edge the data output (TxD) is changed.

Figure 77. Synchronous Mode XCK Timing.



The UCPOL bit UCRSC selects which XCK clock edge is used for data sampling and which is used for data change. As Figure 77 shows, when UCPOL is zero the data will be changed at rising XCK edge and sampled at falling XCK edge. If UCPOL is set, the data will be changed at falling XCK edge and sampled at rising XCK edge.

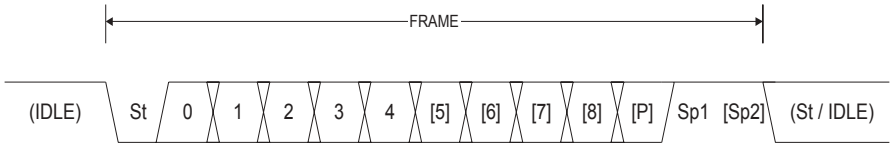
Frame Formats

A serial frame is defined to be one character of data bits with synchronization bits (start and stop bits), and optionally a parity bit for error checking. The USART accepts all 30 combinations of the following as valid frame formats:

- 1 start bit
- 5, 6, 7, 8, or 9 data bits
- no, even or odd parity bit
- 1 or 2 stop bits

A frame starts with the start bit followed by the least significant data bit. Then the next data bits, up to a total of nine, are succeeding, ending with the most significant bit. If enabled, the parity bit is inserted after the data bits, before the stop bits. When a complete frame is transmitted, it can be directly followed by a new frame, or the communication line can be set to an idle (high) state. Figure 78 illustrates the possible combinations of the frame formats. Bits inside brackets are optional.

Figure 78. Frame Formats



St Start bit, always low.

(n) Data bits (0 to 8).

P Parity bit. Can be odd or even.

Sp Stop bit, always high.

IDLE No transfers on the communication line (RxD or TxD). An IDLE line must be high.

The frame format used by the USART is set by the UCSZ2:0, UPM1:0 and USBS bits in UCSRB and UCSRC. The Receiver and Transmitter use the same setting. Note that changing the setting of any of these bits will corrupt all ongoing communication for both the Receiver and Transmitter.

The USART Character SiZe (UCSZ2:0) bits select the number of data bits in the frame. The USART Parity mode (UPM1:0) bits enable and set the type of parity bit. The selection between one or two stop bits is done by the USART Stop Bit Select (USBS) bit. The receiver ignores the second stop bit. An FE (Frame Error) will therefore only be detected in the cases where the first stop bit is zero.

Parity Bit Calculation

The parity bit is calculated by doing an exclusive-or of all the data bits. If odd parity is used, the result of the exclusive or is inverted. The relation between the parity bit and data bits is as follows::

$$P_{even} = d_{n-1} \oplus \ldots \oplus d_3 \oplus d_2 \oplus d_1 \oplus d_0 \oplus 0$$
$$P_{odd} = d_{n-1} \oplus \ldots \oplus d_3 \oplus d_2 \oplus d_1 \oplus d_0 \oplus 1$$

P_{even} Parity bit using even parity

P_{odd} Parity bit using odd parity

d_n Data bit n of the character

If used, the parity bit is located between the last data bit and first stop bit of a serial frame.

USART Initialization

The USART has to be initialized before any communication can take place. The initialization process normally consists of setting the baud rate, setting frame format and enabling the Transmitter or the Receiver depending on the usage. For interrupt driven USART operation, the Global Interrupt Flag should be cleared (and interrupts globally disabled) when doing the initialization.

Before doing a re-initialization with changed baud rate or frame format, be sure that there are no ongoing transmissions during the period the registers are changed. The TXC Flag can be used to check that the Transmitter has completed all transfers, and the RXC Flag can be used to check that there are no unread data in the receive buffer. Note that the TXC Flag must be cleared before each transmission (before UDR is written) if it is used for this purpose.

The following simple USART initialization code examples show one assembly and one C function that are equal in functionality. The examples assume asynchronous operation using polling (no interrupts enabled) and a fixed frame format. The baud rate is given as a function parameter. For the assembly code, the baud rate parameter is assumed to be stored in the r17:r16 Registers. When the function writes to the UCSRC Register, the URSEL bit (MSB) must be set due to the sharing of I/O location by UBRRH and UCSRC.

Assembly Code Example[1]

```
USART_Init:
  ; Set baud rate
  out   UBRRH, r17
  out   UBRRL, r16
  ; Enable receiver and transmitter
  ldi   r16, (1<<RXEN)|(1<<TXEN)
  out   UCSRB,r16
  ; Set frame format: 8data, 2stop bit
  ldi   r16, (1<<URSEL)|(1<<USBS)|(3<<UCSZ0)
  out   UCSRC,r16
  ret
```

C Code Example[1]

```
void USART_Init( unsigned int baud )
{
  /* Set baud rate */
  UBRRH = (unsigned char)(baud>>8);
  UBRRL = (unsigned char)baud;
  /* Enable receiver and transmitter */
  UCSRB = (1<<RXEN)|(1<<TXEN);
  /* Set frame format: 8data, 2stop bit */
  UCSRC = (1<<URSEL)|(1<<USBS)|(3<<UCSZ0);
}
```

Note: 1. The example code assumes that the part specific header file is included.

More advanced initialization routines can be made that include frame format as parameters, disable interrupts and so on. However, many applications use a fixed setting of the

Baud and Control Registers, and for these types of applications the initialization code can be placed directly in the main routine, or be combined with initialization code for other I/O modules.

Data Transmission – The USART Transmitter

The USART Transmitter is enabled by setting the *Transmit Enable* (TXEN) bit in the UCSRB Register. When the Transmitter is enabled, the normal port operation of the TxD pin is overridden by the USART and given the function as the transmitter's serial output. The baud rate, mode of operation and frame format must be set up once before doing any transmissions. If synchronous operation is used, the clock on the XCK pin will be overridden and used as transmission clock.

Sending Frames with 5 to 8 Data Bit

A data transmission is initiated by loading the transmit buffer with the data to be transmitted. The CPU can load the transmit buffer by writing to the UDR I/O location. The buffered data in the transmit buffer will be moved to the Shift Register when the Shift Register is ready to send a new frame. The Shift Register is loaded with new data if it is in idle state (no ongoing transmission) or immediately after the last stop bit of the previous frame is transmitted. When the Shift Register is loaded with new data, it will transfer one complete frame at the rate given by the Baud Register, U2X bit or by XCK depending on mode of operation.

The following code examples show a simple USART transmit function based on polling of the *Data Register Empty* (UDRE) Flag. When using frames with less than eight bits, the most significant bits written to the UDR are ignored. The USART has to be initialized before the function can be used. For the assembly code, the data to be sent is assumed to be stored in Register R16

Assembly Code Example[1]

```
USART_Transmit:
  ; Wait for empty transmit buffer
  sbis  UCSRA,UDRE
  rjmp  USART_Transmit
  ; Put data (r16) into buffer, sends the data
  out   UDR,r16
  ret
```

C Code Example[1]

```
void USART_Transmit( unsigned char data )
{
  /* Wait for empty transmit buffer */
  while ( !( UCSRA & (1<<UDRE)) )
        ;
  /* Put data into buffer, sends the data */
  UDR = data;
}
```

Note: 1. The example code assumes that the part specific header file is included.

The function simply waits for the transmit buffer to be empty by checking the UDRE Flag, before loading it with new data to be transmitted. If the Data Register Empty interrupt is utilized, the interrupt routine writes the data into the buffer.

Sending Frames with 9 Data Bit

If 9-bit characters are used (UCSZ = 7), the ninth bit must be written to the TXB8 bit in UCSRB before the low byte of the character is written to UDR. The following code examples show a transmit function that handles 9-bit characters. For the assembly code, the data to be sent is assumed to be stored in Registers R17:R16.

Assembly Code Example(1)

```
USART_Transmit:
  ; Wait for empty transmit buffer
  sbis  UCSRA,UDRE
  rjmp  USART_Transmit
  ; Copy 9th bit from r17 to TXB8
  cbi   UCSRB,TXB8
  sbrc  r17,0
  sbi   UCSRB,TXB8
  ; Put LSB data (r16) into buffer, sends the data
  out   UDR,r16
  ret
```

C Code Example(1)

```
void USART_Transmit( unsigned int data )
{
  /* Wait for empty transmit buffer */
  while ( !( UCSRA & (1<<UDRE)) )
        ;
  /* Copy 9th bit to TXB8 */
  UCSRB &= ~(1<<TXB8);
  if ( data & 0x0100 )
    UCSRB |= (1<<TXB8);
  /* Put data into buffer, sends the data */
  UDR = data;
}
```

Note: 1. These transmit functions are written to be general functions. They can be optimized if the contents of the UCSRB is static. For example, only the TXB8 bit of the UCSRB Register is used after initialization.

The ninth bit can be used for indicating an address frame when using multi processor communication mode or for other protocol handling as for example synchronization.

Transmitter Flags and Interrupts

The USART Transmitter has two flags that indicate its state: USART Data Register Empty (UDRE) and Transmit Complete (TXC). Both flags can be used for generating interrupts.

The Data Register Empty (UDRE) Flag indicates whether the transmit buffer is ready to receive new data. This bit is set when the transmit buffer is empty, and cleared when the transmit buffer contains data to be transmitted that has not yet been moved into the Shift Register. For compatibility with future devices, always write this bit to zero when writing the UCSRA Register.

When the Data Register Empty Interrupt Enable (UDRIE) bit in UCSRB is written to one, the USART Data Register Empty Interrupt will be executed as long as UDRE is set (provided that global interrupts are enabled). UDRE is cleared by writing UDR. When interrupt-driven data transmission is used, the Data Register Empty Interrupt routine must either write new data to UDR in order to clear UDRE or disable the Data Register

Empty Interrupt, otherwise a new interrupt will occur once the interrupt routine terminates.

The Transmit Complete (TXC) Flag bit is set one when the entire frame in the Transmit Shift Register has been shifted out and there are no new data currently present in the transmit buffer. The TXC Flag bit is automatically cleared when a transmit complete interrupt is executed, or it can be cleared by writing a one to its bit location. The TXC Flag is useful in half-duplex communication interfaces (like the RS-485 standard), where a transmitting application must enter Receive mode and free the communication bus immediately after completing the transmission.

When the Transmit Compete Interrupt Enable (TXCIE) bit in UCSRB is set, the USART Transmit Complete Interrupt will be executed when the TXC Flag becomes set (provided that global interrupts are enabled). When the transmit complete interrupt is used, the interrupt handling routine does not have to clear the TXC Flag, this is done automatically when the interrupt is executed.

Parity Generator

The Parity Generator calculates the parity bit for the serial frame data. When parity bit is enabled (UPM1 = 1), the transmitter control logic inserts the parity bit between the last data bit and the first stop bit of the frame that is sent.

Disabling the Transmitter

The disabling of the Transmitter (setting the TXEN to zero) will not become effective until ongoing and pending transmissions are completed, i.e., when the Transmit Shift Register and Transmit Buffer Register do not contain data to be transmitted. When disabled, the Transmitter will no longer override the TxD pin.

Data Reception – The USART Receiver

The USART Receiver is enabled by writing the Receive Enable (RXEN) bit in the UCSRB Register to one. When the receiver is enabled, the normal pin operation of the RxD pin is overridden by the USART and given the function as the receiver's serial input. The baud rate, mode of operation and frame format must be set up once before any serial reception can be done. If synchronous operation is used, the clock on the XCK pin will be used as transfer clock.

Receiving Frames with 5 to 8 Data Bits

The Receiver starts data reception when it detects a valid start bit. Each bit that follows the start bit will be sampled at the baud rate or XCK clock, and shifted into the Receive Shift Register until the first stop bit of a frame is received. A second stop bit will be ignored by the Receiver. When the first stop bit is received, i.e., a complete serial frame is present in the Receive Shift Register, the contents of the Shift Register will be moved into the receive buffer. The receive buffer can then be read by reading the UDR I/O location.

The following code example shows a simple USART receive function based on polling of the Receive Complete (RXC) Flag. When using frames with less than eight bits the most significant bits of the data read from the UDR will be masked to zero. The USART has to be initialized before the function can be used.

Assembly Code Example(1)

```
USART_Receive:
  ; Wait for data to be received
  sbis  UCSRA, RXC
  rjmp  USART_Receive
  ; Get and return received data from buffer
  in    r16, UDR
  ret
```

C Code Example(1)

```
unsigned char USART_Receive( void )
{
  /* Wait for data to be received */
  while ( !(UCSRA & (1<<RXC)) )
        ;
  /* Get and return received data from buffer */
  return UDR;
}
```

Note: 1. The example code assumes that the part specific header file is included.

The function simply waits for data to be present in the receive buffer by checking the RXC Flag, before reading the buffer and returning the value.

Receiving Frames with 9 Data Bits

If 9-bit characters are used (UCSZ=7) the ninth bit must be read from the RXB8 bit in UCSRB **before** reading the low bits from the UDR. This rule applies to the FE, DOR and UPE Status Flags as well. Read status from UCSRA, then data from UDR. Reading the UDR I/O location will change the state of the receive buffer FIFO and consequently the TXB8, FE, DOR and UPE bits, which all are stored in the FIFO, will change.

The following code example shows a simple USART receive function that handles both nine bit characters and the status bits.

Assembly Code Example(1)

```
USART_Receive:
  ; Wait for data to be received
  sbis  UCSRA, RXC
  rjmp  USART_Receive
  ; Get status and 9th bit, then data from buffer
  in    r18, UCSRA
  in    r17, UCSRB
  in    r16, UDR
  ; If error, return -1
  andi  r18,(1<<FE)|(1<<DOR)|(1<<UPE)
  breq  USART_ReceiveNoError
  ldi   r17, HIGH(-1)
  ldi   r16, LOW(-1)
USART_ReceiveNoError:
  ; Filter the 9th bit, then return
  lsr   r17
  andi  r17, 0x01
  ret
```

C Code Example(1)

```
unsigned int USART_Receive( void )
{
  unsigned char status, resh, resl;
  /* Wait for data to be received */
  while ( !(UCSRA & (1<<RXC)) )
        ;
  /* Get status and 9th bit, then data */
  /* from buffer */
  status = UCSRA;
  resh = UCSRB;
  resl = UDR;
  /* If error, return -1 */
  if ( status & (1<<FE)|(1<<DOR)|(1<<UPE) )
    return -1;
  /* Filter the 9th bit, then return */
  resh = (resh >> 1) & 0x01;
  return ((resh << 8) | resl);
}
```

Note: 1. The example code assumes that the part specific header file is included.

The receive function example reads all the I/O Registers into the Register File before any computation is done. This gives an optimal receive buffer utilization since the buffer location read will be free to accept new data as early as possible.

Receive Compete Flag and Interrupt

The USART Receiver has one flag that indicates the receiver state.

The Receive Complete (RXC) Flag indicates if there are unread data present in the receive buffer. This flag is one when unread data exist in the receive buffer, and zero when the receive buffer is empty (i.e., does not contain any unread data). If the Receiver is disabled (RXEN = 0), the receive buffer will be flushed and consequently the RXC bit will become zero.

When the Receive Complete Interrupt Enable (RXCIE) in UCSRB is set, the USART Receive Complete Interrupt will be executed as long as the RXC Flag is set (provided that global interrupts are enabled). When interrupt-driven data reception is used, the receive complete routine must read the received data from UDR in order to clear the RXC Flag, otherwise a new interrupt will occur once the interrupt routine terminates.

Receiver Error Flags

The USART Receiver has three Error Flags: Frame Error (FE), Data OverRun (DOR) and Parity Error (UPE). All can be accessed by reading UCSRA. Common for the Error Flags is that they are located in the receive buffer together with the frame for which they indicate the error status. Due to the buffering of the Error Flags, the UCSRA must be read before the receive buffer (UDR), since reading the UDR I/O location changes the buffer read location. Another equality for the Error Flags is that they can not be altered by software doing a write to the flag location. However, all flags must be set to zero when the UCSRA is written for upward compatibility of future USART implementations. None of the Error Flags can generate interrupts.

The Frame Error (FE) Flag indicates the state of the first stop bit of the next readable frame stored in the receive buffer. The FE Flag is zero when the stop bit was correctly read (as one), and the FE Flag will be one when the stop bit was incorrect (zero). This flag can be used for detecting out-of-sync conditions, detecting break conditions and protocol handling. The FE Flag is not affected by the setting of the USBS bit in UCSRC since the receiver ignores all, except for the first, stop bits. For compatibility with future devices, always set this bit to zero when writing to UCSRA.

The Data OverRun (DOR) Flag indicates data loss due to a receiver buffer full condition. A Data OverRun occurs when the receive buffer is full (two characters), it is a new character waiting in the Receive Shift Register, and a new start bit is detected. If the DOR Flag is set there was one or more serial frame lost between the frame last read from UDR, and the next frame read from UDR. For compatibility with future devices, always write this bit to zero when writing to UCSRA. The DOR Flag is cleared when the frame received was successfully moved from the Shift Register to the receive buffer.

The Parity Error (UPE) Flag indicates that the next frame in the receive buffer had a Parity Error when received. If parity check is not enabled the UPE bit will always be read zero. For compatibility with future devices, always set this bit to zero when writing to UCSRA. For more details see “Parity Bit Calculation” on page 170 and “Parity Checker” on page 178.

Parity Checker

The Parity Checker is active when the high USART Parity mode (UPM1) bit is set. Type of parity check to be performed (odd or even) is selected by the UPM0 bit. When enabled, the Parity Checker calculates the parity of the data bits in incoming frames and compares the result with the parity bit from the serial frame. The result of the check is stored in the receive buffer together with the received data and stop bits. The Parity Error (UPE) Flag can then be read by software to check if the frame had a Parity Error.

The UPE bit is set if the next character that can be read from the receive buffer had a parity error when received and the parity checking was enabled at that point (UPM1 = 1). This bit is valid until the receive buffer (UDR) is read.

Disabling the Receiver

In contrast to the Transmitter, disabling of the Receiver will be immediate. Data from ongoing receptions will therefore be lost. When disabled (i.e., the RXEN is set to zero) the receiver will no longer override the normal function of the RxD port pin. The receiver buffer FIFO will be flushed when the receiver is disabled. Remaining data in the buffer will be lost

Flushing the Receive Buffer

The receiver buffer FIFO will be flushed when the Receiver is disabled, i.e., the buffer will be emptied of its contents. Unread data will be lost. If the buffer has to be flushed during normal operation, due to for instance an error condition, read the UDR I/O location until the RXC Flag is cleared. The following code example shows how to flush the receive buffer.

Assembly Code Example[1]

```
USART_Flush:
  sbis  UCSRA, RXC
  ret
  in    r16, UDR
  rjmp  USART_Flush
```

C Code Example[1]

```
void USART_Flush( void )
{
  unsigned char dummy;
  while ( UCSRA & (1<<RXC) ) dummy = UDR;
}
```

Note: 1. The example code assumes that the part specific header file is included.

Asynchronous Data Reception

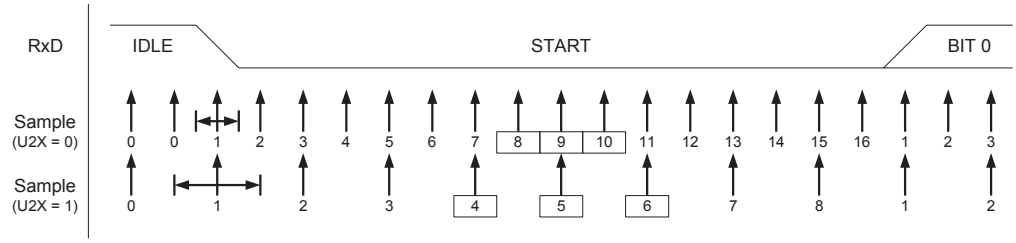
The USART includes a clock recovery and a data recovery unit for handling asynchronous data reception. The clock recovery logic is used for synchronizing the internally generated baud rate clock to the incoming asynchronous serial frames at the RxD pin. The data recovery logic samples and low pass filters each incoming bit, thereby improving the noise immunity of the receiver. The asynchronous reception operational range depends on the accuracy of the internal baud rate clock, the rate of the incoming frames, and the frame size in number of bits.

Asynchronous Clock Recovery

The clock recovery logic synchronizes internal clock to the incoming serial frames. Figure 79 illustrates the sampling process of the start bit of an incoming frame. The sample rate is 16 times the baud rate for Normal mode, and 8 times the baud rate for Double Speed mode. The horizontal arrows illustrate the synchronization variation due to the sampling process. Note the larger time variation when using the double speed mode

(U2X = 1) of operation. Samples denoted zero are samples done when the RxD line is idle (i.e., no communication activity).

Figure 79. Start Bit Sampling

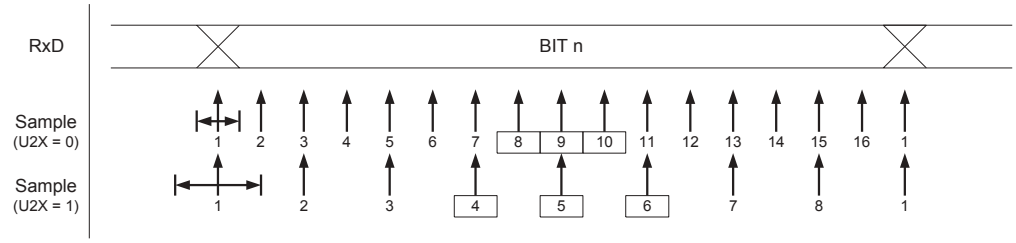


When the clock recovery logic detects a high (idle) to low (start) transition on the RxD line, the start bit detection sequence is initiated. Let sample 1 denote the first zero-sample as shown in the figure. The clock recovery logic then uses samples 8, 9 and 10 for Normal mode, and samples 4, 5 and 6 for Double Speed mode (indicated with sample numbers inside boxes on the figure), to decide if a valid start bit is received. If two or more of these three samples have logical high levels (the majority wins), the start bit is rejected as a noise spike and the receiver starts looking for the next high to low-transition. If however, a valid start bit is detected, the clock recovery logic is synchronized and the data recovery can begin. The synchronization process is repeated for each start bit.

Asynchronous Data Recovery

When the receiver clock is synchronized to the start bit, the data recovery can begin. The data recovery unit uses a state machine that has 16 states for each bit in Normal mode and 8 states for each bit in Double Speed mode. Figure 80 shows the sampling of the data bits and the parity bit. Each of the samples is given a number that is equal to the state of the recovery unit.

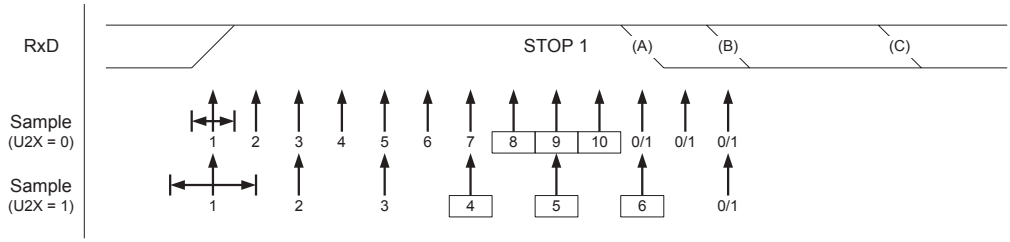
Figure 80. Sampling of Data and Parity Bit



The decision of the logic level of the received bit is taken by doing a majority voting of the logic value to the three samples in the center of the received bit. The center samples are emphasized on the figure by having the sample number inside boxes. The majority voting process is done as follows: If two or all three samples have high levels, the received bit is registered to be a logic 1. If two or all three samples have low levels, the received bit is registered to be a logic 0. This majority voting process acts as a low pass filter for the incoming signal on the RxD pin. The recovery process is then repeated until a complete frame is received. Including the first stop bit. Note that the receiver only uses the first stop bit of a frame.

Figure 81 shows the sampling of the stop bit and the earliest possible beginning of the start bit of the next frame.

Figure 81. Stop Bit Sampling and Next Start Bit Sampling



The same majority voting is done to the stop bit as done for the other bits in the frame. If the stop bit is registered to have a logic 0 value, the Frame Error (FE) Flag will be set.

A new high to low transition indicating the start bit of a new frame can come right after the last of the bits used for majority voting. For Normal Speed mode, the first low level sample can be at point marked (A) in Figure 81. For Double Speed mode the first low level must be delayed to (B). (C) marks a stop bit of full length. The early start bit detection influences the operational range of the receiver.

Asynchronous Operational Range

The operational range of the receiver is dependent on the mismatch between the received bit rate and the internally generated baud rate. If the Transmitter is sending frames at too fast or too slow bit rates, or the internally generated baud rate of the receiver does not have a similar (see Table 71) base frequency, the receiver will not be able to synchronize the frames to the start bit.

The following equations can be used to calculate the ratio of the incoming data rate and internal receiver baud rate.

$$R_{slow} = \frac{(D+1)S}{S-1+D\cdot S+S_F} \qquad R_{fast} = \frac{(D+2)S}{(D+1)S+S_M}$$

D Sum of character size and parity size (D = 5 to 10 bit)

S Samples per bit. S = 16 for Normal Speed mode and S = 8 for Double Speed mode.

S_F First sample number used for majority voting. S_F = 8 for Normal Speed and S_F = 4 for Double Speed mode.

S_M Middle sample number used for majority voting. S_M = 9 for Normal Speed and S_M = 5 for Double Speed mode.

R_{slow} is the ratio of the slowest incoming data rate that can be accepted in relation to the receiver baud rate. R_{fast} is the ratio of the fastest incoming data rate that can be accepted in relation to the receiver baud rate.

Table 71 and Table 72 list the maximum receiver baud rate error that can be tolerated. Note that normal speed mode has higher toleration of baud rate variations.

Table 71. Recommended Maximum Receiver Baud Rate Error for Normal Speed Mode (U2X = 0)

D # (Data+Parity Bit)	R_{slow} (%)	R_{fast} (%)	Max. Total Error (%)	Recommended Max. Receiver Error (%)
5	93.20	106.67	+6.67/-6.8%	± 3.0
6	94.12	105.79	+5.79/-5.88	± 2.5
7	94.81	105.11	+5.11/-5.19	± 2.0
8	95.36	104.58	+4.58/-4.54	± 2.0
9	95.81	104.14	+4.14/-4.19	± 1.5
10	96.17	103.78	+3.7 /-3.83	± 1.5

Table 72. Recommended Maximum Receiver Baud Rate Error for Double Speed Mode (U2X = 1)

D # (Data+Parity Bit)	R_{slow} (%)	R_{fast} (%)	Max. Total Error (%)	Recommended Max. Receiver Error (%)
5	94.12	105.66	+5.66/-5.88	± 2.5
6	94.92	104.92	+4.92/-5.08	± 2.0
7	95.52	104.35	+4.35/-4.48	± 1.5
8	96.00	103.90	+3.90/-4.00	± 1.5
9	96.39	103.53	+3.53/-3.61	± 1.5
10	96.70	103.23	+3.23/-3.30	± 1.0

The recommendations of the maximum receiver baud rate error was made under the assumption that the Receiver and Transmitter equally divides the maximum total error.

There are two possible sources for the receivers baud rate error. The receiver's system clock (XTAL) will always have some minor instability over the supply voltage range and the temperature range. When using a crystal to generate the system clock, this is rarely a problem, but for a resonator the system clock may differ more than 2% depending of the resonators tolerance. The second source for the error is more controllable. The baud rate generator can not always do an exact division of the system frequency to get the baud rate wanted. In this case an UBRR value that gives an acceptable low error can be used if possible.

Multi-processor Communication Mode

Setting the Multi-processor Communication mode (MPCM) bit in UCSRA enables a filtering function of incoming frames received by the USART Receiver. Frames that do not contain address information will be ignored and not put into the receive buffer. This effectively reduces the number of incoming frames that has to be handled by the CPU, in a system with multiple MCUs that communicate via the same serial bus. The Transmitter is unaffected by the MPCM setting, but has to be used differently when it is a part of a system utilizing the Multi-processor Communication mode.

If the receiver is set up to receive frames that contain 5 to 8 data bits, then the first stop bit indicates if the frame contains data or address information. If the receiver is set up for frames with nine data bits, then the ninth bit (RXB8) is used for identifying address and data frames. When the frame type bit (the first stop or the ninth bit) is one, the frame contains an address. When the frame type bit is zero the frame is a data frame.

The Multi-processor Communication mode enables several slave MCUs to receive data from a Master MCU. This is done by first decoding an address frame to find out which MCU has been addressed. If a particular slave MCU has been addressed, it will receive the following data frames as normal, while the other slave MCUs will ignore the received frames until another address frame is received.

Using MPCM

For an MCU to act as a Master MCU, it can use a 9-bit character frame format (UCSZ = 7). The ninth bit (TXB8) must be set when an address frame (TXB8 = 1) or cleared when a data frame (TXB = 0) is being transmitted. The slave MCUs must in this case be set to use a 9-bit character frame format.

The following procedure should be used to exchange data in Multi-processor Communication mode:

1. All Slave MCUs are in Multi-processor Communication mode (MPCM in UCSRA is set).
2. The Master MCU sends an address frame, and all slaves receive and read this frame. In the slave MCUs, the RXC Flag in UCSRA will be set as normal.
3. Each Slave MCU reads the UDR Register and determines if it has been selected. If so, it clears the MPCM bit in UCSRA, otherwise it waits for the next address byte and keeps the MPCM setting.
4. The addressed MCU will receive all data frames until a new address frame is received. The other Slave MCUs, which still have the MPCM bit set, will ignore the data frames.
5. When the last data frame is received by the addressed MCU, the addressed MCU sets the MPCM bit and waits for a new address frame from master. The process then repeats from 2.

Using any of the 5- to 8-bit character frame formats is possible, but impractical since the receiver must change between using n and n+1 character frame formats. This makes full-duplex operation difficult since the Transmitter and Receiver uses the same character size setting. If 5 to 8 bit character frames are used, the Transmitter must be set to use two stop bit (USBS = 1) since the first stop bit is used for indicating the frame type.

Do not use Read-Modify-Write instructions (SBI and CBI) to set or clear the MPCM bit. The MPCM bit shares the same I/O location as the TXC Flag and this might accidentally be cleared when using SBI or CBI instructions.

Accessing UBRRH/ UCSRC Registers

The UBRRH Register shares the same I/O location as the UCSRC Register. Therefore some special consideration must be taken when accessing this I/O location.

Write Access

When doing a write access of this I/O location, the high bit of the value written, the USART Register Select (URSEL) bit, controls which one of the two registers that will be written. If URSEL is zero during a write operation, the UBRRH value will be updated. If URSEL is one, the UCSRC setting will be updated.

The following code examples show how to access the two registers.

Assembly Code Examples[1]

```
...
; Set UBRRH to 2
ldi r16,0x02
out UBRRH,r16
...
; Set the USBS and the UCSZ1 bit to one, and
; the remaining bits to zero.
ldi r16,(1<<URSEL)|(1<<USBS)|(1<<UCSZ1)
out UCSRC,r16
...
```

C Code Examples[1]

```
...
/* Set UBRRH to 2 */
UBRRH = 0x02;
...
/* Set the USBS and the UCSZ1 bit to one, and */
/* the remaining bits to zero. */
UCSRC = (1<<URSEL)|(1<<USBS)|(1<<UCSZ1);
...
```

Note: 1. The example code assumes that the part specific header file is included.

As the code examples illustrate, write accesses of the two registers are relatively unaffected of the sharing of I/O location.

Read Access

Doing a read access to the UBRRH or the UCSRC Register is a more complex operation. However, in most applications, it is rarely necessary to read any of these registers.

The read access is controlled by a timed sequence. Reading the I/O location once returns the UBRRH Register contents. If the register location was read in previous system clock cycle, reading the register in the current clock cycle will return the UCSRC contents. Note that the timed sequence for reading the UCSRC is an atomic operation. Interrupts must therefore be controlled (e.g., by disabling interrupts globally) during the read operation.

The following code example shows how to read the UCSRC Register contents.

Assembly Code Example(1)

```
USART_ReadUCSRC:
  ; Read UCSRC
  in  r16,UBRRH
  in  r16,UCSRC
  ret
```

C Code Example(1)

```
unsigned char USART_ReadUCSRC( void )
{
  unsigned char ucsrc;
  /* Read UCSRC */
  ucsrc = UBRRH;
  ucsrc = UCSRC;
  return ucsrc;
}
```

Note: 1. The example code assumes that the part specific header file is included.

The assembly code example returns the UCSRC value in r16.

Reading the UBRRH contents is not an atomic operation and therefore it can be read as an ordinary register, as long as the previous instruction did not access the register location.

USART Register Description

USART I/O Data Register – UDR

Bit	7	6	5	4	3	2	1	0	
	RXB[7:0]								UDR (Read)
	TXB[7:0]								UDR (Write)
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

The USART Transmit Data Buffer Register and USART Receive Data Buffer Registers share the same I/O address referred to as USART Data Register or UDR. The Transmit Data Buffer Register (TXB) will be the destination for data written to the UDR Register location. Reading the UDR Register location will return the contents of the Receive Data Buffer Register (RXB).

For 5-, 6-, or 7-bit characters the upper unused bits will be ignored by the Transmitter and set to zero by the Receiver.

The transmit buffer can only be written when the UDRE Flag in the UCSRA Register is set. Data written to UDR when the UDRE Flag is not set, will be ignored by the USART Transmitter. When data is written to the transmit buffer, and the Transmitter is enabled, the Transmitter will load the data into the Transmit Shift Register when the Shift Register is empty. Then the data will be serially transmitted on the TxD pin.

The receive buffer consists of a two level FIFO. The FIFO will change its state whenever the receive buffer is accessed. Due to this behavior of the receive buffer, do not use read modify write instructions (SBI and CBI) on this location. Be careful when using bit test instructions (SBIC and SBIS), since these also will change the state of the FIFO.

USART Control and Status Register A – UCSRA

Bit	7	6	5	4	3	2	1	0	
	RXC	TXC	UDRE	FE	DOR	UPE	U2X	MPCM	UCSRA
Read/Write	R	R/W	R	R	R	R	R/W	R/W	
Initial Value	0	0	1	0	0	0	0	0	

- **Bit 7 – RXC: USART Receive Complete**

This flag bit is set when there are unread data in the receive buffer and cleared when the receive buffer is empty (i.e., does not contain any unread data). If the receiver is disabled, the receive buffer will be flushed and consequently the RXC bit will become zero. The RXC Flag can be used to generate a Receive Complete interrupt (see description of the RXCIE bit).

- **Bit 6 – TXC: USART Transmit Complete**

This flag bit is set when the entire frame in the Transmit Shift Register has been shifted out and there are no new data currently present in the transmit buffer (UDR). The TXC Flag bit is automatically cleared when a transmit complete interrupt is executed, or it can be cleared by writing a one to its bit location. The TXC Flag can generate a Transmit Complete interrupt (see description of the TXCIE bit).

- **Bit 5 – UDRE: USART Data Register Empty**

The UDRE Flag indicates if the transmit buffer (UDR) is ready to receive new data. If UDRE is one, the buffer is empty, and therefore ready to be written. The UDRE Flag can generate a Data Register Empty interrupt (see description of the UDRIE bit).

UDRE is set after a Reset to indicate that the transmitter is ready.

- **Bit 4 – FE: Frame Error**

This bit is set if the next character in the receive buffer had a Frame Error when received. I.e., when the first stop bit of the next character in the receive buffer is zero. This bit is valid until the receive buffer (UDR) is read. The FE bit is zero when the stop bit of received data is one. Always set this bit to zero when writing to UCSRA.

- **Bit 3 – DOR: Data OverRun**

This bit is set if a Data OverRun condition is detected. A data overrun occurs when the receive buffer is full (two characters), it is a new character waiting in the reCeive Shift Register, and a new start bit is detected. This bit is valid until the receive buffer (UDR) is read. Always set this bit to zero when writing to UCSRA.

- **Bit 2 – UPE: Parity Error**

This bit is set if the next character in the receive buffer had a Parity Error when received and the Parity Checking was enabled at that point (UPM1 = 1). This bit is valid until the receive buffer (UDR) is read. Always set this bit to zero when writing to UCSRA.

- **Bit 1 – U2X: Double the USART Transmission Speed**

This bit only has effect for the asynchronous operation. Write this bit to zero when using synchronous operation.

Writing this bit to one will reduce the divisor of the baud rate divider from 16 to 8 effectively doubling the transfer rate for asynchronous communication.

- **Bit 0 – MPCM: Multi-processor Communication Mode**

This bit enables the Multi-processor Communication mode. When the MPCM bit is written to one, all the incoming frames received by the USART receiver that do not contain address information will be ignored. The transmitter is unaffected by the MPCM setting. For more detailed information see “Multi-processor Communication Mode” on page 181.

USART Control and Status Register B – UCSRB

Bit	7	6	5	4	3	2	1	0	
	RXCIE	TXCIE	UDRIE	RXEN	TXEN	UCSZ2	RXB8	TXB8	UCSRB
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R	R/W	
Initial Value	0	0	0	0	0	0	0	0	

- **Bit 7 – RXCIE: RX Complete Interrupt Enable**

Writing this bit to one enables interrupt on the RXC Flag. A USART Receive Complete interrupt will be generated only if the RXCIE bit is written to one, the Global Interrupt Flag in SREG is written to one and the RXC bit in UCSRA is set.

- **Bit 6 – TXCIE: TX Complete Interrupt Enable**

Writing this bit to one enables interrupt on the TXC Flag. A USART Transmit Complete interrupt will be generated only if the TXCIE bit is written to one, the Global Interrupt Flag in SREG is written to one and the TXC bit in UCSRA is set.

- **Bit 5 – UDRIE: USART Data Register Empty Interrupt Enable**

Writing this bit to one enables interrupt on the UDRE Flag. A Data Register Empty interrupt will be generated only if the UDRIE bit is written to one, the Global Interrupt Flag in SREG is written to one and the UDRE bit in UCSRA is set.

- **Bit 4 – RXEN: Receiver Enable**

Writing this bit to one enables the USART Receiver. The Receiver will override normal port operation for the RxD pin when enabled. Disabling the Receiver will flush the receive buffer invalidating the FE, DOR and UPE Flags.

- **Bit 3 – TXEN: Transmitter Enable**

Writing this bit to one enables the USART Transmitter. The Transmitter will override normal port operation for the TxD pin when enabled. The disabling of the Transmitter (writing TXEN to zero) will not become effective until ongoing and pending transmissions are completed, i.e., when the Transmit Shift Register and Transmit Buffer Register do not contain data to be transmitted. When disabled, the Transmitter will no longer override the TxD port.

- **Bit 2 – UCSZ2: Character Size**

The UCSZ2 bits combined with the UCSZ1:0 bit in UCSRC sets the number of data bits (character size) in a frame the Receiver and Transmitter use.

- **Bit 1 – RXB8: Receive Data Bit 8**

RXB8 is the ninth data bit of the received character when operating with serial frames with nine data bits. Must be read before reading the low bits from UDR.

- **Bit 0 – TXB8: Transmit Data Bit 8**

TXB8 is the 9th data bit in the character to be transmitted when operating with serial frames with 9 data bits. Must be written before writing the low bits to UDR.

USART Control and Status Register C – UCSRC(1)

Bit	7	6	5	4	3	2	1	0	
	URSEL	UMSEL	UPM1	UPM0	USBS	UCSZ1	UCSZ0	UCPOL	UCSRC
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	
Initial Value	1	0	0	0	0	1	1	0	

Note: 1. The UCSRC Register shares the same I/O location as the UBRRH Register. See the “Accessing UBRRH/ UCSRC Registers” on page 183 section which describes how to access this register.

- **Bit 7 – URSEL: Register Select**

This bit selects between accessing the UCSRC or the UBRRH Register. It is read as one when reading UCSRC. The URSEL must be one when writing the UCSRC.

- **Bit 6 – UMSEL: USART Mode Select**

This bit selects between asynchronous and synchronous mode of operation.

Table 73. UMSEL Bit Settings

UMSEL	Mode
0	Asynchronous Operation
1	Synchronous Operation

- **Bit 5:4 – UPM1:0: Parity Mode**

These bits enable and set type of parity generation and check. If enabled, the transmitter will automatically generate and send the parity of the transmitted data bits within each frame. The receiver will generate a parity value for the incoming data and compare it to the UPM0 setting. If a mismatch is detected, the UPE Flag in UCSRA will be set.

Table 74. UPM Bits Settings

UPM1	UPM0	Parity Mode
0	0	Disabled
0	1	Reserved
1	0	Enabled, Even Parity
1	1	Enabled, Odd Parity

- **Bit 3 – USBS: Stop Bit Select**

This bit selects the number of stop bits to be inserted by the transmitter. The receiver ignores this setting.

Table 75. USBS Bit Settings

USBS	Stop Bit(s)
0	1-bit
1	2-bit

- **Bit 2:1 – UCSZ1:0: Character Size**

The UCSZ1:0 bits combined with the UCSZ2 bit in UCSRB sets the number of data bits (Character Size) in a frame the receiver and transmitter use.

Table 76. UCSZ Bits Settings

UCSZ2	UCSZ1	UCSZ0	Character Size
0	0	0	5-bit
0	0	1	6-bit
0	1	0	7-bit
0	1	1	8-bit
1	0	0	Reserved
1	0	1	Reserved
1	1	0	Reserved
1	1	1	9-bit

- **Bit 0 – UCPOL: Clock Polarity**

This bit is used for synchronous mode only. Write this bit to zero when asynchronous mode is used. The UCPOL bit sets the relationship between data output change and data input sample, and the synchronous clock (XCK).

Table 77. UCPOL Bit Settings

UCPOL	Transmitted Data Changed (Output of TxD Pin)	Received Data Sampled (Input on RxD Pin)
0	Rising XCK Edge	Falling XCK Edge
1	Falling XCK Edge	Rising XCK Edge

USART Baud Rate Registers – UBRRL and UBRRH(1)

Bit	15	14	13	12	11	10	9	8	
	URSEL	–	–	–	UBRR[11:8]				UBRRH
	UBRR[7:0]								UBRRL
	7	6	5	4	3	2	1	0	
Read/Write	R/W	R	R	R	R/W	R/W	R/W	R/W	
	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	
	0	0	0	0	0	0	0	0	

Note: 1. The UBRRH Register shares the same I/O location as the UCSRC Register. See the “Accessing UBRRH/ UCSRC Registers” on page 183 section which describes how to access this register.

- **Bit 15 – URSEL: Register Select**

This bit selects between accessing the UBRRH or the UCSRC Register. It is read as zero when reading UBRRH. The URSEL must be zero when writing the UBRRH.

- **Bit 14:12 – Reserved Bits**

These bits are reserved for future use. For compatibility with future devices, these bit must be written to zero when UBRRH is written.

- **Bit 11:0 – UBRR11:0: USART Baud Rate Register**

This is a 12-bit register which contains the USART baud rate. The UBRRH contains the four most significant bits, and the UBRRL contains the eight least significant bits of the USART baud rate. Ongoing transmissions by the transmitter and receiver will be corrupted if the baud rate is changed. Writing UBRRL will trigger an immediate update of the baud rate prescaler.

Examples of Baud Rate Setting

For standard crystal and resonator frequencies, the most commonly used baud rates for asynchronous operation can be generated by using the UBRR settings in Table 78. UBRR values which yield an actual baud rate differing less than 0.5% from the target baud rate, are bold in the table. Higher error ratings are acceptable, but the receiver will have less noise resistance when the error ratings are high, especially for large serial frames (see “Asynchronous Operational Range” on page 180). The error values are calculated using the following equation:

$$\text{Error}[\%] = \left(\frac{\text{BaudRate}_{\text{Closest Match}}}{\text{BaudRate}} - 1\right) \bullet 100\%$$

Table 78. Examples of UBRR Settings for Commonly Used Oscillator Frequencies

Baud Rate (bps)	f_{osc} = 1.0000 MHz				f_{osc} = 1.8432 MHz				f_{osc} = 2.0000 MHz			
	U2X = 0		U2X = 1		U2X = 0		U2X = 1		U2X = 0		U2X = 1	
	UBRR	Error	UBRR	Error	UBRR	Error	UBRR	Error	UBRR	Error	UBRR	Error
2400	25	0.2%	51	0.2%	47	0.0%	95	0.0%	51	0.2%	103	0.2%
4800	12	0.2%	25	0.2%	23	0.0%	47	0.0%	25	0.2%	51	0.2%
9600	6	-7.0%	12	0.2%	11	0.0%	23	0.0%	12	0.2%	25	0.2%
14.4k	3	8.5%	8	-3.5%	7	0.0%	15	0.0%	8	-3.5%	16	2.1%
19.2k	2	8.5%	6	-7.0%	5	0.0%	11	0.0%	6	-7.0%	12	0.2%
28.8k	1	8.5%	3	8.5%	3	0.0%	7	0.0%	3	8.5%	8	-3.5%
38.4k	1	-18.6%	2	8.5%	2	0.0%	5	0.0%	2	8.5%	6	-7.0%
57.6k	0	8.5%	1	8.5%	1	0.0%	3	0.0%	1	8.5%	3	8.5%
76.8k	–	–	1	-18.6%	1	-25.0%	2	0.0%	1	-18.6%	2	8.5%
115.2k	–	–	0	8.5%	0	0.0%	1	0.0%	0	8.5%	1	8.5%
230.4k	–	–	–	–	–	–	0	0.0%	–	–	–	–
250k	–	–	–	–	–	–	–	–	–	–	0	0.0%
Max. (1)	62.5 kbps		125 kbps		115.2 kbps		230.4 kbps		125 kbps		250 kbps	

1. UBRR = 0, Error = 0.0%

Table 79. Examples of UBRR Settings for Commonly Used Oscillator Frequencies (Continued)

Baud Rate (bps)	f_{osc} = 3.6864 MHz				f_{osc} = 4.0000 MHz				f_{osc} = 7.3728 MHz			
	U2X = 0		U2X = 1		U2X = 0		U2X = 1		U2X = 0		U2X = 1	
	UBRR	Error	UBRR	Error	UBRR	Error	UBRR	Error	UBRR	Error	UBRR	Error
2400	95	0.0%	191	0.0%	103	0.2%	207	0.2%	191	0.0%	383	0.0%
4800	47	0.0%	95	0.0%	51	0.2%	103	0.2%	95	0.0%	191	0.0%
9600	23	0.0%	47	0.0%	25	0.2%	51	0.2%	47	0.0%	95	0.0%
14.4k	15	0.0%	31	0.0%	16	2.1%	34	-0.8%	31	0.0%	63	0.0%
19.2k	11	0.0%	23	0.0%	12	0.2%	25	0.2%	23	0.0%	47	0.0%
28.8k	7	0.0%	15	0.0%	8	-3.5%	16	2.1%	15	0.0%	31	0.0%
38.4k	5	0.0%	11	0.0%	6	-7.0%	12	0.2%	11	0.0%	23	0.0%
57.6k	3	0.0%	7	0.0%	3	8.5%	8	-3.5%	7	0.0%	15	0.0%
76.8k	2	0.0%	5	0.0%	2	8.5%	6	-7.0%	5	0.0%	11	0.0%
115.2k	1	0.0%	3	0.0%	1	8.5%	3	8.5%	3	0.0%	7	0.0%
230.4k	0	0.0%	1	0.0%	0	8.5%	1	8.5%	1	0.0%	3	0.0%
250k	0	-7.8%	1	-7.8%	0	0.0%	1	0.0%	1	-7.8%	3	-7.8%
0.5M	–	–	0	-7.8%	–	–	0	0.0%	0	-7.8%	1	-7.8%
1M	–	–	–	–	–	–	–	–	–	–	0	-7.8%
Max. (1)	230.4 kbps		460.8 kbps		250 kbps		0.5 Mbps		460.8 kbps		921.6 kbps	

1. UBRR = 0, Error = 0.0%

Table 80. Examples of UBRR Settings for Commonly Used Oscillator Frequencies (Continued)

Baud Rate (bps)	f_{osc} = 8.0000 MHz				f_{osc} = 11.0592 MHz				f_{osc} = 14.7456 MHz			
	U2X = 0		U2X = 1		U2X = 0		U2X = 1		U2X = 0		U2X = 1	
	UBRR	Error	UBRR	Error	UBRR	Error	UBRR	Error	UBRR	Error	UBRR	Error
2400	207	0.2%	416	-0.1%	287	0.0%	575	0.0%	383	0.0%	767	0.0%
4800	103	0.2%	207	0.2%	143	0.0%	287	0.0%	191	0.0%	383	0.0%
9600	51	0.2%	103	0.2%	71	0.0%	143	0.0%	95	0.0%	191	0.0%
14.4k	34	-0.8%	68	0.6%	47	0.0%	95	0.0%	63	0.0%	127	0.0%
19.2k	25	0.2%	51	0.2%	35	0.0%	71	0.0%	47	0.0%	95	0.0%
28.8k	16	2.1%	34	-0.8%	23	0.0%	47	0.0%	31	0.0%	63	0.0%
38.4k	12	0.2%	25	0.2%	17	0.0%	35	0.0%	23	0.0%	47	0.0%
57.6k	8	-3.5%	16	2.1%	11	0.0%	23	0.0%	15	0.0%	31	0.0%
76.8k	6	-7.0%	12	0.2%	8	0.0%	17	0.0%	11	0.0%	23	0.0%
115.2k	3	8.5%	8	-3.5%	5	0.0%	11	0.0%	7	0.0%	15	0.0%
230.4k	1	8.5%	3	8.5%	2	0.0%	5	0.0%	3	0.0%	7	0.0%
250k	1	0.0%	3	0.0%	2	-7.8%	5	-7.8%	3	-7.8%	6	5.3%
0.5M	0	0.0%	1	0.0%	–	–	2	-7.8%	1	-7.8%	3	-7.8%
1M	–	–	0	0.0%	–	–	–	–	0	-7.8%	1	-7.8%
Max. (1)	0.5 Mbps		1 Mbps		691.2 kbps		1.3824 Mbps		921.6 kbps		1.8432 Mbps	

1. UBRR = 0, Error = 0.0%

Table 81. Examples of UBRR Settings for Commonly Used Oscillator Frequencies (Continued)

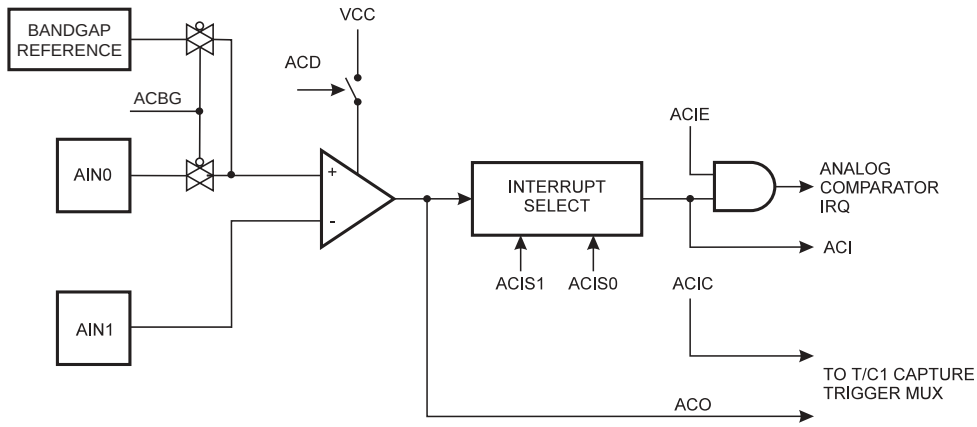
Baud Rate (bps)	f_{osc} = 16.0000 MHz				f_{osc} = 18.4320 MHz				f_{osc} = 20.0000 MHz			
	U2X = 0		U2X = 1		U2X = 0		U2X = 1		U2X = 0		U2X = 1	
	UBRR	Error	UBRR	Error	UBRR	Error	UBRR	Error	UBRR	Error	UBRR	Error
2400	416	-0.1%	832	0.0%	479	0.0%	959	0.0%	520	0.0%	1041	0.0%
4800	207	0.2%	416	-0.1%	239	0.0%	479	0.0%	259	0.2%	520	0.0%
9600	103	0.2%	207	0.2%	119	0.0%	239	0.0%	129	0.2%	259	0.2%
14.4k	68	0.6%	138	-0.1%	79	0.0%	159	0.0%	86	-0.2%	173	-0.2%
19.2k	51	0.2%	103	0.2%	59	0.0%	119	0.0%	64	0.2%	129	0.2%
28.8k	34	-0.8%	68	0.6%	39	0.0%	79	0.0%	42	0.9%	86	-0.2%
38.4k	25	0.2%	51	0.2%	29	0.0%	59	0.0%	32	-1.4%	64	0.2%
57.6k	16	2.1%	34	-0.8%	19	0.0%	39	0.0%	21	-1.4%	42	0.9%
76.8k	12	0.2%	25	0.2%	14	0.0%	29	0.0%	15	1.7%	32	-1.4%
115.2k	8	-3.5%	16	2.1%	9	0.0%	19	0.0%	10	-1.4%	21	-1.4%
230.4k	3	8.5%	8	-3.5%	4	0.0%	9	0.0%	4	8.5%	10	-1.4%
250k	3	0.0%	7	0.0%	4	-7.8%	8	2.4%	4	0.0%	9	0.0%
0.5M	1	0.0%	3	0.0%	–	–	4	-7.8%	–	–	4	0.0%
1M	0	0.0%	1	0.0%	–	–	–	–	–	–	–	–
Max. (1)	1 Mbps		2 Mbps		1.152 Mbps		2.304 Mbps		1.25 Mbps		2.5 Mbps	

1. UBRR = 0, Error = 0.0%

Analog Comparator

The Analog Comparator compares the input values on the positive pin AIN0 and negative pin AIN1. When the voltage on the positive pin AIN0 is higher than the voltage on the negative pin AIN1, the Analog Comparator Output, ACO, is set. The comparator's output can be set to trigger the Timer/Counter1 Input Capture function. In addition, the comparator can trigger a separate interrupt, exclusive to the Analog Comparator. The user can select Interrupt triggering on comparator output rise, fall or toggle. A block diagram of the comparator and its surrounding logic is shown in Figure 82.

Figure 82. Analog Comparator Block Diagram(1)



Note: 1. Refer to Figure 1 on page 2 and Table 32 on page 71 for Analog Comparator pin placement.

Analog Comparator Control and Status Register – ACSR

Bit	7	6	5	4	3	2	1	0	
	ACD	**ACBG**	**ACO**	**ACI**	**ACIE**	**ACIC**	**ACIS1**	**ACIS0**	**ACSR**
Read/Write	R/W	R/W	R	R/W	R/W	R/W	R/W	R/W	
Initial Value	0	0	N/A	0	0	0	0	0	

- **Bit 7 – ACD: Analog Comparator Disable**

When this bit is written logic one, the power to the Analog Comparator is switched off. This bit can be set at any time to turn off the Analog Comparator. This will reduce power consumption in Active and Idle mode. When changing the ACD bit, the Analog Comparator Interrupt must be disabled by clearing the ACIE bit in ACSR. Otherwise an interrupt can occur when the bit is changed.

- **Bit 6 – ACBG: Analog Comparator Bandgap Select**

When this bit is set, a fixed bandgap reference voltage replaces the positive input to the Analog Comparator. When this bit is cleared, AIN0 is applied to the positive input of the Analog Comparator. See "Internal Voltage Reference" on page 51.

- **Bit 5 – ACO: Analog Comparator Output**

The output of the Analog Comparator is synchronized and then directly connected to ACO. The synchronization introduces a delay of 1 - 2 clock cycles.

- **Bit 4 – ACI: Analog Comparator Interrupt Flag**

This bit is set by hardware when a comparator output event triggers the interrupt mode defined by ACIS1 and ACIS0. The Analog Comparator interrupt routine is executed if

the ACIE bit is set and the I-bit in SREG is set. ACI is cleared by hardware when executing the corresponding interrupt handling vector. Alternatively, ACI is cleared by writing a logic one to the flag.

- **Bit 3 – ACIE: Analog Comparator Interrupt Enable**

When the ACIE bit is written logic one and the I-bit in the Status Register is set, the Analog Comparator interrupt is activated. When written logic zero, the interrupt is disabled.

- **Bit 2 – ACIC: Analog Comparator Input Capture Enable**

When written logic one, this bit enables the Input Capture function in Timer/Counter1 to be triggered by the Analog Comparator. The comparator output is in this case directly connected to the Input Capture front-end logic, making the comparator utilize the noise canceler and edge select features of the Timer/Counter1 Input Capture interrupt. When written logic zero, no connection between the Analog Comparator and the Input Capture function exists. To make the comparator trigger the Timer/Counter1 Input Capture interrupt, the TICIE1 bit in the Timer Interrupt Mask Register (TIMSK) must be set.

- **Bits 1, 0 – ACIS1, ACIS0: Analog Comparator Interrupt Mode Select**

These bits determine which comparator events that trigger the Analog Comparator interrupt. The different settings are shown in Table 82.

Table 82. ACIS1/ACIS0 Settings

ACIS1	ACIS0	Interrupt Mode
0	0	Comparator Interrupt on Output Toggle.
0	1	Reserved
1	0	Comparator Interrupt on Falling Output Edge.
1	1	Comparator Interrupt on Rising Output Edge.

When changing the ACIS1/ACIS0 bits, the Analog Comparator Interrupt must be disabled by clearing its Interrupt Enable bit in the ACSR Register. Otherwise an interrupt can occur when the bits are changed.

JTAG Interface and On-chip Debug System

Features

- **JTAG (IEEE std. 1149.1 Compliant) Interface**
- **Boundary-scan Capabilities According to the IEEE std. 1149.1 (JTAG) Standard**
- **Debugger Access to:**
  - **All Internal Peripheral Units**
  - **Internal and External RAM**
  - **The Internal Register File**
  - **Program Counter**
  - **EEPROM and Flash Memories**
- **Extensive On-chip Debug Support for Break Conditions, Including**
  - **AVR Break Instruction**
  - **Break on Change of Program Memory Flow**
  - **Single Step Break**
  - **Program Memory Breakpoints on Single Address or Address Range**
  - **Data Memory Breakpoints on Single Address or Address Range**
- **Programming of Flash, EEPROM, Fuses, and Lock Bits through the JTAG Interface**
- **On-chip Debugging Supported by AVR Studio®**

Overview

The AVR IEEE std. 1149.1 compliant JTAG interface can be used for

- Testing PCBs by using the JTAG Boundary-scan capability.
- Programming the non-volatile memories, Fuses and Lock bits.
- On-chip debugging.

A brief description is given in the following sections. Detailed descriptions for Programming via the JTAG interface, and using the Boundary-scan Chain can be found in the sections “Programming via the JTAG Interface” on page 249 and “IEEE 1149.1 (JTAG) Boundary-scan” on page 203**,** respectively. The On-chip Debug support is considered being private JTAG instructions, and distributed within ATMEL and to selected third party vendors only.

Figure 83 shows a block diagram of the JTAG interface and the On-chip Debug system. The TAP Controller is a state machine controlled by the TCK and TMS signals. The TAP Controller selects either the JTAG Instruction Register or one of several Data Registers as the scan chain (Shift Register) between the TDI – input and TDO – output. The Instruction Register holds JTAG instructions controlling the behavior of a Data Register.

The ID-Register, Bypass Register, and the Boundary-scan Chain are the Data Registers used for board-level testing. The JTAG Programming Interface (actually consisting of several physical and virtual Data Registers) is used for serial programming via the JTAG interface. The Internal Scan Chain and Break Point Scan Chain are used for On-chip debugging only.

Test Access Port – TAP

The JTAG interface is accessed through four of the AVR’s pins. In JTAG terminology, these pins constitute the Test Access Port – TAP. These pins are:

- TMS: Test mode select. This pin is used for navigating through the TAP-controller state machine.
- TCK: Test Clock. JTAG operation is synchronous to TCK.
- TDI: Test Data In. Serial input data to be shifted in to the Instruction Register or Data Register (Scan Chains).
- TDO: Test Data Out. Serial output data from Instruction Register or Data Register.

The IEEE std. 1149.1 also specifies an optional TAP signal; TRST – Test ReSeT – which is not provided.

When the JTAGEN fuse is unprogrammed, these four TAP pins are normal port pins and the TAP controller is in reset. When programmed and the JTD bit in MCUCSR is cleared, the TAP input signals are internally pulled high and the JTAG is enabled for Boundary-scan and programming. In this case, the TAP output pin (TDO) is left floating in states where the JTAG TAP controller is not shifting data, and must therefore be connected to a pull-up resistor or other hardware having pull-ups (for instance the TDI-input of the next device in the scan chain). The device is shipped with this fuse programmed.

For the On-chip Debug system, in addition to the JTAG interface pins, the $\overline{\text{RESET}}$ pin is monitored by the debugger to be able to detect External Reset sources. The debugger can also pull the $\overline{\text{RESET}}$ pin low to reset the whole system, assuming only open collectors on the reset line are used in the application.

Figure 83. Block Diagram

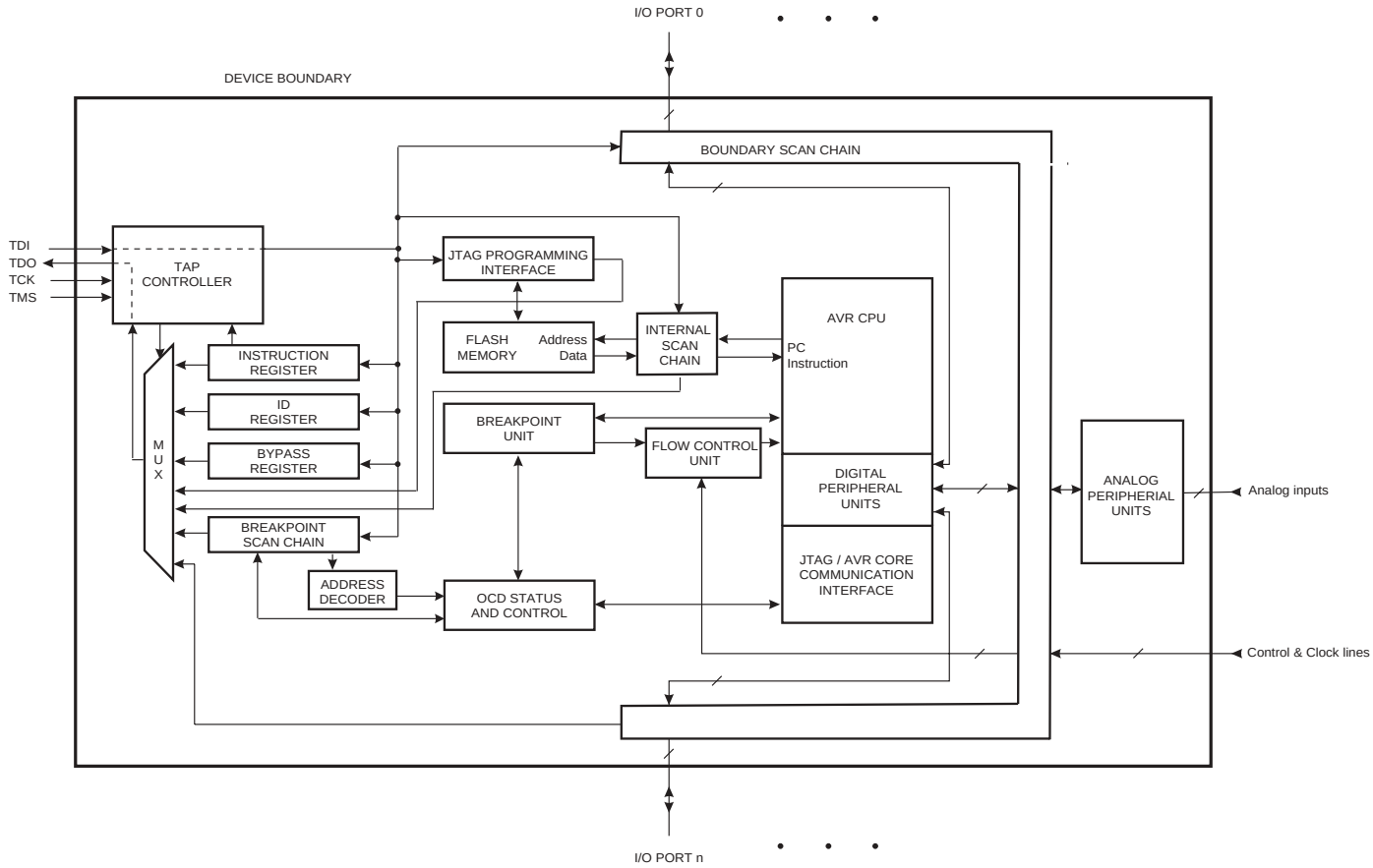
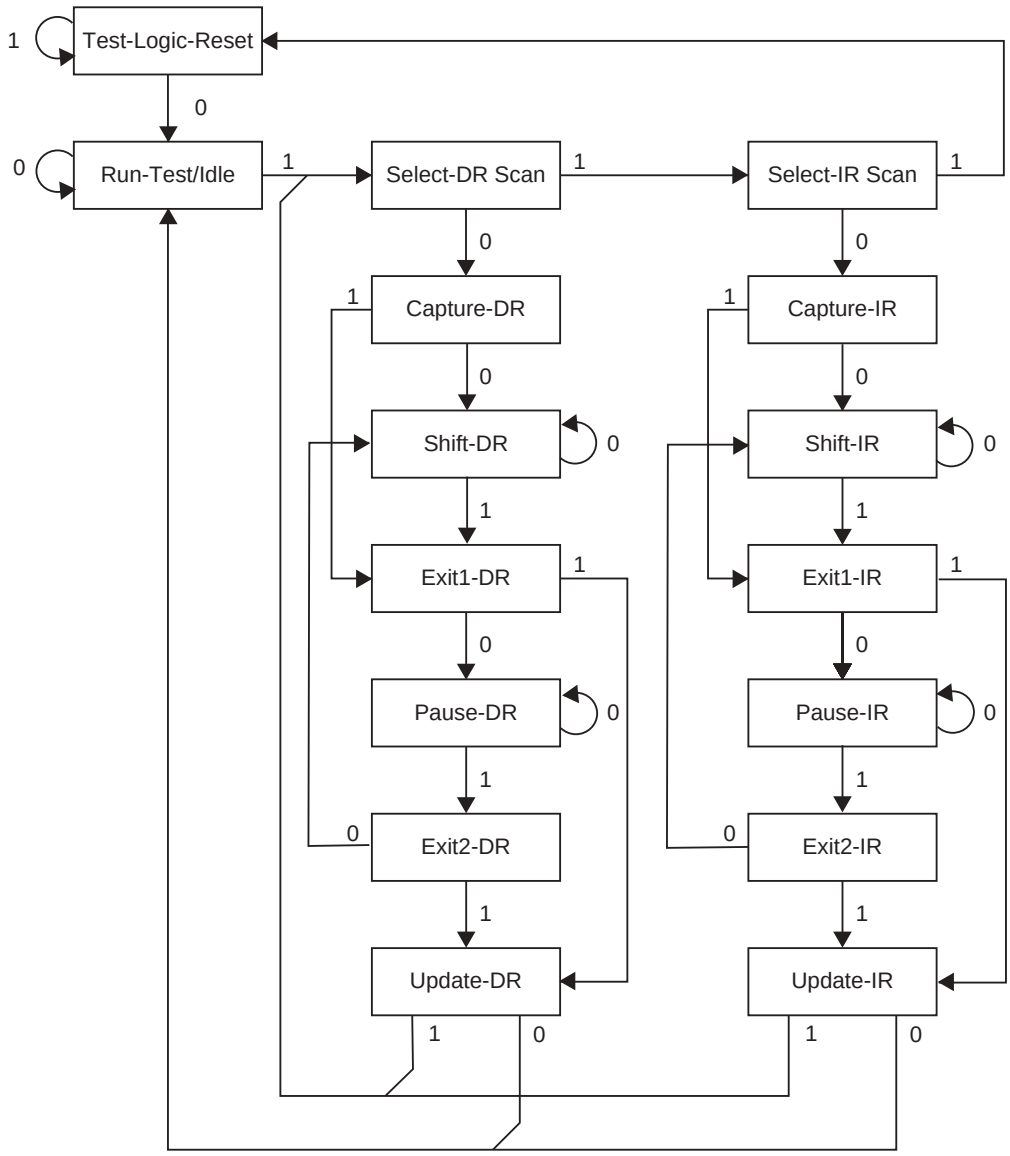


Figure 84. TAP Controller State Diagram



TAP Controller

The TAP controller is a 16-state finite state machine that controls the operation of the Boundary-scan circuitry, JTAG programming circuitry, or On-chip Debug system. The state transitions depicted in Figure 84 depend on the signal present on TMS (shown adjacent to each state transition) at the time of the rising edge at TCK. The initial state after a Power-on Reset is Test-Logic-Reset.

As a definition in this document, the LSB is shifted in and out first for all Shift Registers.

Assuming Run-Test/Idle is the present state, a typical scenario for using the JTAG interface is:

- At the TMS input, apply the sequence 1, 1, 0, 0 at the rising edges of TCK to enter the Shift Instruction Register – Shift-IR state. While in this state, shift the four bits of the JTAG instructions into the JTAG Instruction Register from the TDI input at the rising edge of TCK. The TMS input must be held low during input of the 3 LSBs in order to remain in the Shift-IR state. The MSB of the instruction is shifted in when this state is left by setting TMS high. While the instruction is shifted in from the TDI pin, the captured IR-state 0x01 is shifted out on the TDO pin. The JTAG Instruction selects a particular Data Register as path between TDI and TDO and controls the circuitry surrounding the selected Data Register.
- Apply the TMS sequence 1, 1, 0 to re-enter the Run-Test/Idle state. The instruction is latched onto the parallel output from the Shift Register path in the Update-IR state. The Exit-IR, Pause-IR, and Exit2-IR states are only used for navigating the state machine.
- At the TMS input, apply the sequence 1, 0, 0 at the rising edges of TCK to enter the Shift Data Register – Shift-DR state. While in this state, upload the selected data register (selected by the present JTAG instruction in the JTAG Instruction Register) from the TDI input at the rising edge of TCK. In order to remain in the Shift-DR state, the TMS input must be held low during input of all bits except the MSB. The MSB of the data is shifted in when this state is left by setting TMS high. While the Data Register is shifted in from the TDI pin, the parallel inputs to the Data Register captured in the Capture-DR state is shifted out on the TDO pin.
- Apply the TMS sequence 1, 1, 0 to re-enter the Run-Test/Idle state. If the selected data register has a latched parallel-output, the latching takes place in the Update-DR state. The Exit-DR, Pause-DR, and Exit2-DR states are only used for navigating the state machine.

As shown in the state diagram, the Run-Test/Idle state need not be entered between selecting JTAG instruction and using Data Registers, and some JTAG instructions may select certain functions to be performed in the Run-Test/Idle, making it unsuitable as an Idle state.

Note: Independent of the initial state of the TAP Controller, the Test-Logic-Reset state can always be entered by holding TMS high for five TCK clock periods.

For detailed information on the JTAG specification, refer to the literature listed in “Bibliography” on page 202.

Using the Boundary-scan Chain

A complete description of the Boundary-scan capabilities are given in the section “IEEE 1149.1 (JTAG) Boundary-scan” on page 203.

Using the On-chip Debug system

As shown in Figure 83, the hardware support for On-chip Debugging consists mainly of

- A scan chain on the interface between the internal AVR CPU and the internal peripheral units
- Break Point unit
- Communication interface between the CPU and JTAG system

All read or modify/write operations needed for implementing the Debugger are done by applying AVR instructions via the internal AVR CPU Scan Chain. The CPU sends the result to an I/O memory mapped location which is part of the communication interface between the CPU and the JTAG system.

The Break Point unit implements Break on Change of program flow, Single Step Break, two Program memory Break Points, and two Combined Break Points. Together, the four Break Points can be configured as either:

- 4 single Program Memory Break Points
- 3 Single Program Memory Break Point + 1 single Data Memory Break Point
- 2 single Program Memory Break Points + 2 single Data Memory Break Points
- 2 single Program Memory Break Points + 1 Program Memory Break Point with mask (“range Break Point”)
- 2 single Program Memory Break Points + 1 Data Memory Break Point with mask (“range Break Point”)

A debugger, like the AVR Studio®, may however use one or more of these resources for its internal purpose, leaving less flexibility to the end-user.

A list of the On-chip Debug specific JTAG instructions is given in “On-chip debug specific JTAG instructions” on page 201.

The JTAGEN Fuse must be programmed to enable the JTAG Test Access Port. In addition, the OCDEN Fuse must be programmed and no Lock bits must be set for the On-chip debug system to work. As a security feature, the On-chip debug system is disabled when *either of the LB1 or LB2* Lock bits are set. Otherwise, the On-chip debug system would have provided a backdoor into a secured device.

The AVR Studio enables the user to fully control execution of programs on an AVR device with On-chip Debug capability, AVR In-Circuit Emulator, or the built-in AVR Instruction Set Simulator. AVR Studio supports source level execution of Assembly programs assembled with Atmel Corporation’s AVR Assembler and C programs compiled with third party vendors’ compilers.

AVR Studio runs under Microsoft® Windows® 95/98/2000, Windows NT®, and Windows XP®.

For a full description of the AVR Studio, please refer to the **AVR Studio User Guide**. Only highlights are presented in this document.

All necessary execution commands are available in AVR Studio, both on source level and on disassembly level. The user can execute the program, single step through the code either by tracing into or stepping over functions, step out of functions, place the cursor on a statement and execute until the statement is reached, stop the execution, and reset the execution target. In addition, the user can have an unlimited number of code Break Points (using the BREAK instruction) and up to two data memory Break Points, alternatively combined as a mask (range) Break Point.

On-chip debug specific JTAG instructions

The On-chip debug support is considered being private JTAG instructions, and distributed within ATMEL and to selected 3rd party vendors only. Instruction opcodes are listed for reference.

PRIVATE0; 0x8 Private JTAG instruction for accessing On-chip debug system.

PRIVATE1; 0x9 Private JTAG instruction for accessing On-chip debug system.

PRIVATE2; 0xA Private JTAG instruction for accessing On-chip debug system.

PRIVATE3; 0xB Private JTAG instruction for accessing On-chip debug system.

On-chip Debug Related Register in I/O Memory

On-chip Debug Register – OCDR

Bit	7	6	5	4	3	2	1	0	
	MSB/IDRD							LSB	OCDR
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

The OCDR Register provides a communication channel from the running program in the microcontroller to the debugger. The CPU can transfer a byte to the debugger by writing to this location. At the same time, an internal flag; I/O Debug Register Dirty – IDRD – is set to indicate to the debugger that the register has been written. When the CPU reads the OCDR Register the 7 LSB will be from the OCDR Register, while the MSB is the IDRD bit. The debugger clears the IDRD bit when it has read the information.

In some AVR devices, this register is shared with a standard I/O location. In this case, the OCDR Register can only be accessed if the OCDEN Fuse is programmed, and the debugger enables access to the OCDR Register. In all other cases, the standard I/O location is accessed.

Refer to the debugger documentation for further information on how to use this register.

Using the JTAG Programming Capabilities

Programming of AVR parts via JTAG is performed via the 4-pin JTAG port, TCK, TMS, TDI and TDO. These are the only pins that need to be controlled/observed to perform JTAG programming (in addition to power pins). It is not required to apply 12V externally. The JTAGEN Fuse must be programmed and the JTD bit in the MCUSR Register must be cleared to enable the JTAG Test Access Port.

The JTAG programming capability supports:

- Flash programming and verifying.
- EEPROM programming and verifying.
- Fuse programming and verifying.
- Lock bit programming and verifying.

The Lock bit security is exactly as in parallel programming mode. If the Lock bits LB1 or LB2 are programmed, the OCDEN Fuse cannot be programmed unless first doing a chip erase. This is a security feature that ensures no backdoor exists for reading out the content of a secured device.

The details on programming through the JTAG interface and programming specific JTAG instructions are given in the section “Programming via the JTAG Interface” on page 249.

Bibliography

For more information about general Boundary-scan, the following literature can be consulted:

- IEEE: IEEE Std. 1149.1-1990. IEEE Standard Test Access Port and Boundary-scan Architecture, IEEE, 1993
- Colin Maunder: The Board Designers Guide to Testable Logic Circuits, Addison-Wesley, 1992

IEEE 1149.1 (JTAG) Boundary-scan

Features

- **JTAG (IEEE std. 1149.1 Compliant) Interface**
- **Boundary-scan Capabilities According to the JTAG Standard**
- **Full Scan of all Port Functions as well as Analog Circuitry Having Off-chip Connections**
- **Supports the Optional IDCODE Instruction**
- **Additional Public AVR_RESET Instruction to Reset the AVR**

System Overview

The Boundary-scan chain has the capability of driving and observing the logic levels on the digital I/O pins, as well as the boundary between digital and analog logic for analog circuitry having Off-chip connections. At system level, all ICs having JTAG capabilities are connected serially by the TDI/TDO signals to form a long Shift Register. An external controller sets up the devices to drive values at their output pins, and observe the input values received from other devices. The controller compares the received data with the expected result. In this way, Boundary-scan provides a mechanism for testing interconnections and integrity of components on Printed Circuits Boards by using the four TAP signals only.

The four IEEE 1149.1 defined mandatory JTAG instructions IDCODE, BYPASS, SAMPLE/PRELOAD, and EXTEST, as well as the AVR specific public JTAG instruction AVR_RESET can be used for testing the Printed Circuit Board. Initial scanning of the Data Register path will show the ID-code of the device, since IDCODE is the default JTAG instruction. It may be desirable to have the AVR device in Reset during Test mode. If not Reset, inputs to the device may be determined by the scan operations, and the internal software may be in an undetermined state when exiting the test mode. Entering Reset, the outputs of any Port Pin will instantly enter the high impedance state, making the HIGHZ instruction redundant. If needed, the BYPASS instruction can be issued to make the shortest possible scan chain through the device. The device can be set in the Reset state either by pulling the external $\overline{\text{RESET}}$ pin low, or issuing the AVR_RESET instruction with appropriate setting of the Reset Data Register.

The EXTEST instruction is used for sampling external pins and loading output pins with data. The data from the output latch will be driven out on the pins as soon as the EXTEST instruction is loaded into the JTAG IR-Register. Therefore, the SAMPLE/PRELOAD should also be used for setting initial values to the scan ring, to avoid damaging the board when issuing the EXTEST instruction for the first time. SAMPLE/PRELOAD can also be used for taking a snapshot of the external pins during normal operation of the part.

The JTAGEN Fuse must be programmed and the JTD bit in the I/O Register MCUCSR must be cleared to enable the JTAG Test Access Port.

When using the JTAG interface for Boundary-scan, using a JTAG TCK clock frequency higher than the internal chip frequency is possible. The chip clock is not required to run.

Data Registers

The data registers relevant for Boundary-scan operations are:

- Bypass Register
- Device Identification Register
- Reset Register
- Boundary-scan Chain

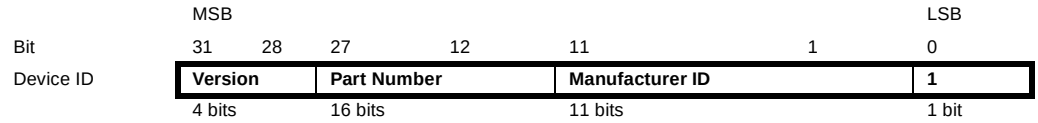
Bypass Register

The Bypass Register consists of a single Shift Register stage. When the Bypass Register is selected as path between TDI and TDO, the register is reset to 0 when leaving the Capture-DR controller state. The Bypass Register can be used to shorten the scan chain on a system when the other devices are to be tested.

Device Identification Register

Figure 85 shows the structure of the Device Identification Register.

Figure 85. The Format of the Device Identification Register



Version

Version is a 4-bit number identifying the revision of the component. The relevant version number is shown in Table 83.

Table 83. JTAG Version Numbers

Version	JTAG Version number (Hex)
ATmega162 revision A	0x0
ATmega162 revision B	0x1
ATmega162 revision C	0x2
ATmega162 revision D	0x3

Part Number

The part number is a 16-bit code identifying the component. The JTAG Part Number for ATmega162 is listed in Table 84.

Table 84. AVR JTAG Part Number

Part number	JTAG Part Number (Hex)
ATmega162	0x9404

Manufacturer ID

The Manufacturer ID is a 11-bit code identifying the manufacturer. The JTAG manufacturer ID for ATMEL is listed in Table 85.

Table 85. Manufacturer ID

Manufacturer	JTAG Man. ID (Hex)
ATMEL	0x01F

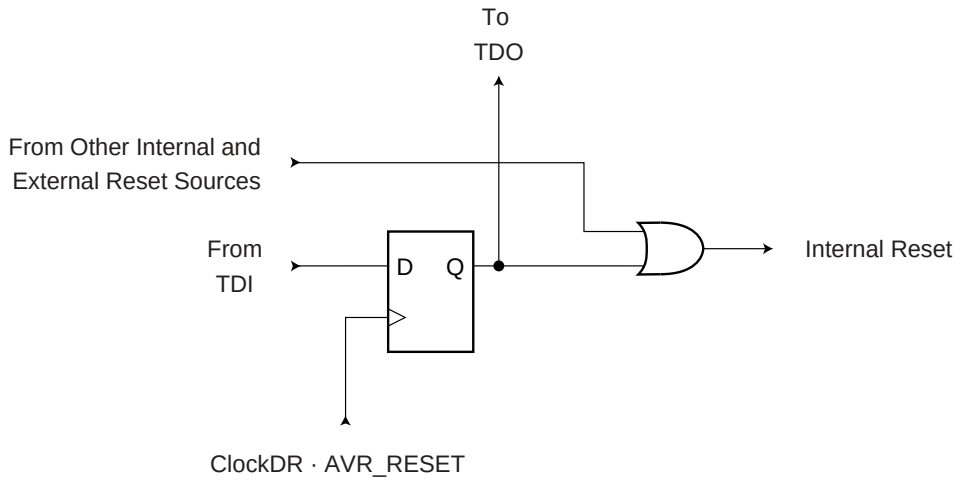
Reset Register

The Reset Register is a test data register used to reset the part. Since the AVR tri-states Port Pins when reset, the Reset Register can also replace the function of the unimplemented optional JTAG instruction HIGHZ.

A high value in the Reset Register corresponds to pulling the external Reset low. The part is reset as long as there is a high value present in the Reset Register. Depending

on the Fuse settings for the clock options, the part will remain reset for a Reset Time-out Period (refer to “Clock Sources” on page 34) after releasing the Reset Register. The output from this data register is not latched, so the reset will take place immediately, as shown in Figure 86.

Figure 86. Reset Register



Boundary-scan Chain

The Boundary-scan Chain has the capability of driving and observing the logic levels on the digital I/O pins, as well as the boundary between digital and analog logic for analog circuitry having Off-chip connections.

See “Boundary-scan Chain” on page 207 for a complete description.

Boundary-scan Specific JTAG Instructions

The Instruction Register is 4-bit wide, supporting up to 16 instructions. Listed below are the JTAG instructions useful for Boundary-scan operation. Note that the optional HIGHZ instruction is not implemented, but all outputs with tri-state capability can be set in high-impedant state by using the AVR_RESET instruction, since the initial state for all port pins is tri-state.

As a definition in this datasheet, the LSB is shifted in and out first for all Shift Registers.

The OPCODE for each instruction is shown behind the instruction name in hex format. The text describes which Data Register is selected as path between TDI and TDO for each instruction.

EXTEST; 0x0

Mandatory JTAG instruction for selecting the Boundary-scan Chain as Data Register for testing circuitry external to the AVR package. For port-pins, Pull-up Disable, Output Control, Output Data, and Input Data are all accessible in the scan chain. For analog circuits having Off-chip connections, the interface between the analog and the digital logic is in the scan chain. The contents of the latched outputs of the Boundary-scan chain is driven out as soon as the JTAG IR-Register is loaded with the EXTEST instruction.

The active states are:

- Capture-DR: Data on the external pins are sampled into the Boundary-scan Chain.
- Shift-DR: The Internal Scan Chain is shifted by the TCK input.
- Update-DR: Data from the scan chain is applied to output pins.

IDCODE; 0x1

Optional JTAG instruction selecting the 32-bit ID-register as data register. The ID-Register consists of a version number, a device number and the manufacturer code chosen by JEDEC. This is the default instruction after Power-up.

The active states are:

- Capture-DR: Data in the IDCODE Register is sampled into the Boundary-scan Chain.
- Shift-DR: The IDCODE scan chain is shifted by the TCK input.

SAMPLE_PRELOAD; 0x2

Mandatory JTAG instruction for preloading the output latches and taking a snapshot of the input/output pins without affecting the system operation. However, the output latches are not connected to the pins. The Boundary-scan Chain is selected as Data Register.

The active states are:

- Capture-DR: Data on the external pins are sampled into the Boundary-scan Chain.
- Shift-DR: The Boundary-scan Chain is shifted by the TCK input.
- Update-DR: Data from the Boundary-scan chain is applied to the output latches. However, the output latches are not connected to the pins.

AVR_RESET; 0xC

The AVR specific public JTAG instruction for forcing the AVR device into the Reset mode or releasing the JTAG Reset source. The TAP controller is not reset by this instruction. The one bit Reset Register is selected as data register. Note that the reset will be active as long as there is a logic 'one' in the Reset Chain. The output from this chain is not latched.

The active states are:

- Shift-DR: The Reset Register is shifted by the TCK input.

BYPASS; 0xF

Mandatory JTAG instruction selecting the Bypass Register for data register.

The active states are:

- Capture-DR: Loads a logic “0” into the Bypass Register.
- Shift-DR: The Bypass Register cell between TDI and TDO is shifted.

Boundary-scan Related Register in I/O Memory

MCU Control and Status Register – MCUCSR

The MCU Control and Status Register contains control bits for general MCU functions, and provides information on which reset source caused an MCU Reset.

Bit	7	6	5	4	3	2	1	0	
	JTD	–	SM2	JTRF	WDRF	BORF	EXTRF	PORF	MCUCSR
Read/Write	R/W	R/W	R	R/W	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	See Bit Description					

- **Bit 7 – JTD: JTAG Interface Disable**

When this bit is zero, the JTAG interface is enabled if the JTAGEN Fuse is programmed. If this bit is one, the JTAG interface is disabled. In order to avoid unintentional disabling or enabling of the JTAG interface, a timed sequence must be followed when changing this bit: The application software must write this bit to the desired value twice within four cycles to change its value.

If the JTAG interface is left unconnected to other JTAG circuitry, the JTD bit should be set to one. The reason for this is to avoid static current at the TDO pin in the JTAG interface.

- **Bit 4 – JTRF: JTAG Reset Flag**

This bit is set if a reset is being caused by a logic one in the JTAG Reset Register selected by the JTAG instruction AVR_RESET. This bit is reset by a Power-on Reset, or by writing a logic zero to the flag.

Boundary-scan Chain

The Boundary-scan Chain has the capability of driving and observing the logic levels on the digital I/O pins, as well as the boundary between digital and analog logic for analog circuitry having Off-chip connection.

Scanning the Digital Port Pins

Figure 87 shows the Boundary-scan Cell for a bi-directional port pin with pull-up function. The cell consists of a standard Boundary-scan cell for the Pull-up Enable – PUExn – function, and a bi-directional pin cell that combines the three signals Output Control – OCxn, Output Data – ODxn, and Input Data – IDxn, into only a two-stage Shift Register. The port and pin indexes are not used in the following description

The Boundary-scan logic is not included in the figures in the datasheet. Figure 88 shows a simple digital Port Pin as described in the section “I/O-Ports” on page 62. The Boundary-scan details from Figure 87 replaces the dashed box in Figure 88.

When no alternate port function is present, the Input Data – ID – corresponds to the PINxn Register value (but ID has no synchronizer), Output Data corresponds to the PORT Register, Output Control corresponds to the Data Direction – DD Register, and the Pull-up Enable – PUExn – corresponds to logic expression $\overline{PUD} \cdot \overline{DDxn} \cdot PORTxn$.

Digital alternate port functions are connected outside the dotted box in Figure 88 to make the scan chain read the actual pin value. For Analog function, there is a direct connection from the external pin to the analog circuit, and a scan chain is inserted on the interface between the digital logic and the analog circuitry.

Figure 87. Boundary-scan Cell for Bi-directional Port Pin with Pull-up Function.

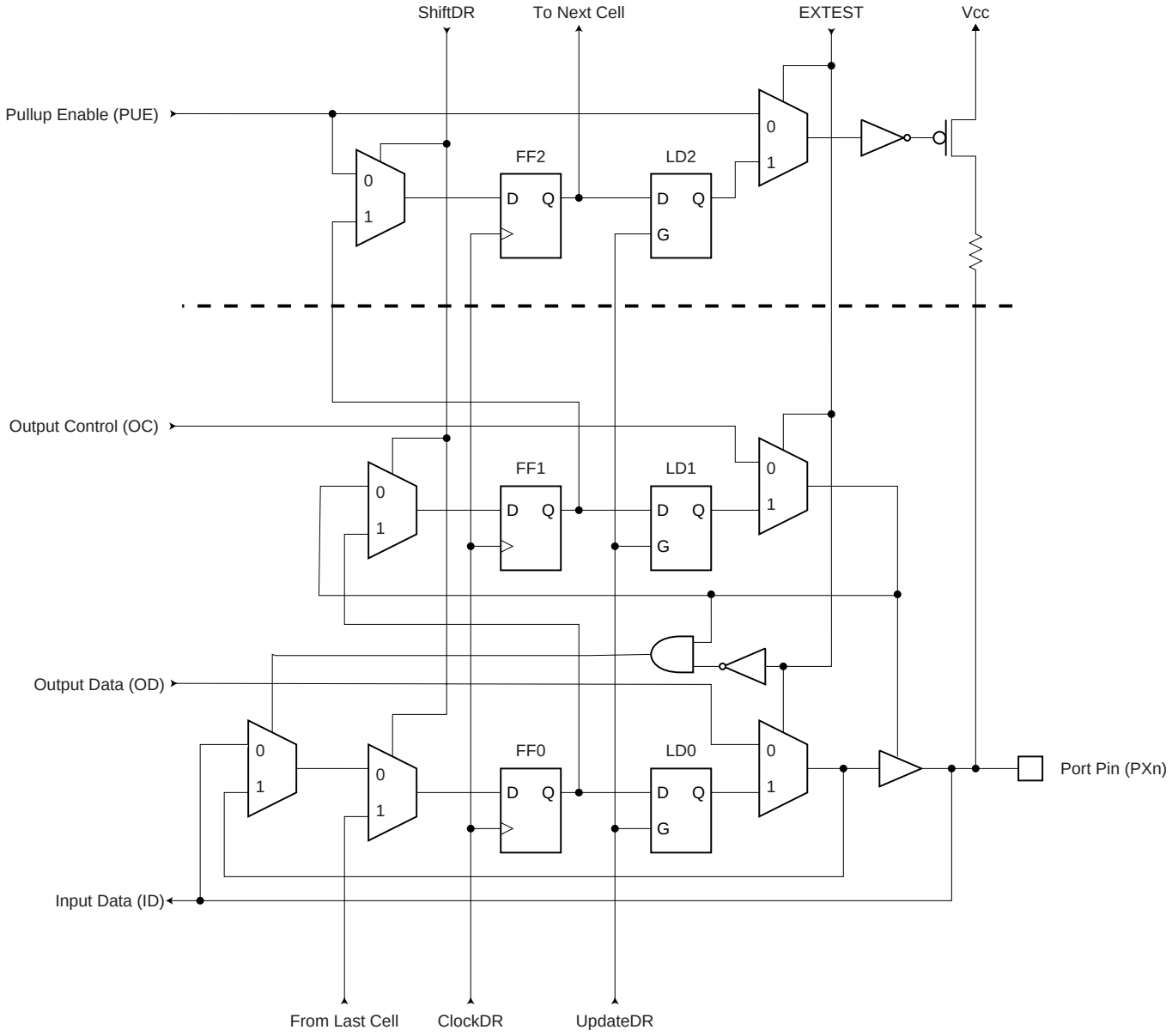
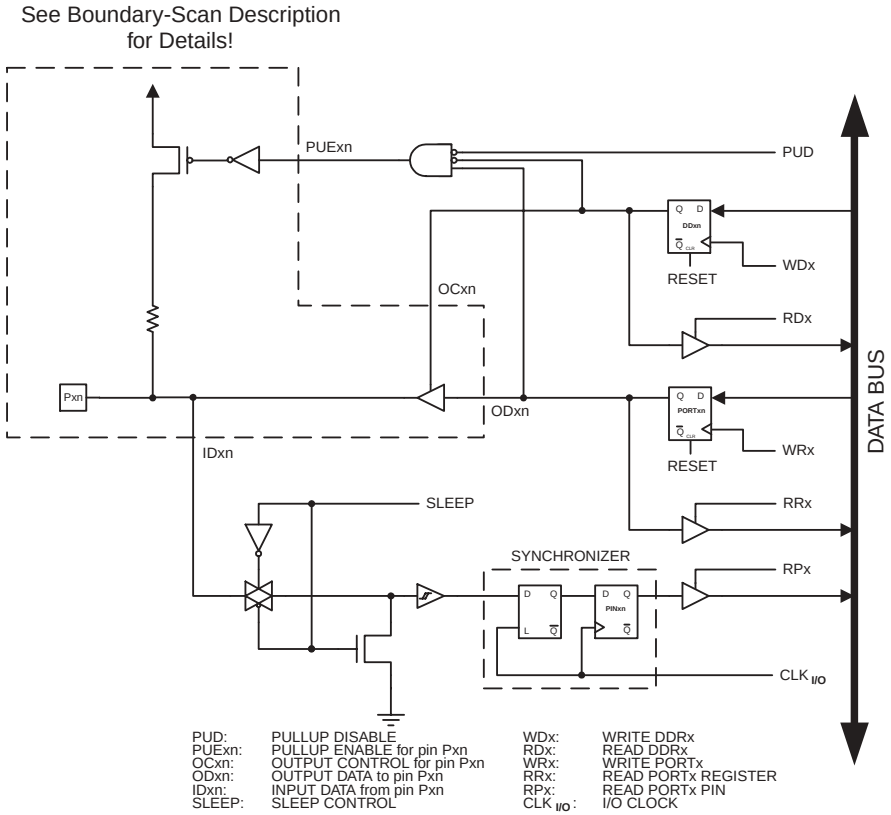


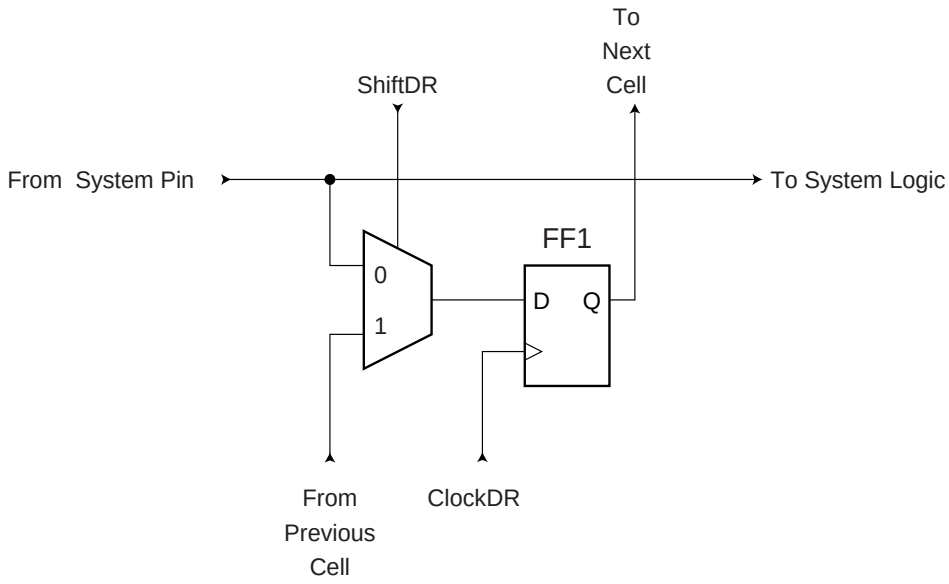
Figure 88. General Port Pin Schematic Diagram



Scanning the RESET pin

The RESET pin accepts 5V active low logic for standard reset operation, and 12V active high logic for high voltage parallel programming. An observe-only cell as shown in Figure 89 is inserted both for the 5V reset signal; RSTT, and the 12V reset signal; RSTHV.

Figure 89. Observe-only Cell



Scanning the Clock Pins

The AVR devices have many clock options selectable by fuses. These are: Internal RC Oscillator, External Clock, (High Frequency) Crystal Oscillator, Low Frequency Crystal Oscillator, and Ceramic Resonator.

Figure 90 shows how each Oscillator with external connection is supported in the scan chain. The Enable signal is supported with a general Boundary-scan cell, while the Oscillator/clock output is attached to an observe-only cell. In addition to the main clock, the Timer Oscillator is scanned in the same way. The output from the internal RC Oscillator is not scanned, as this Oscillator does not have external connections.

Figure 90. Boundary-scan Cells for Oscillators and Clock Options

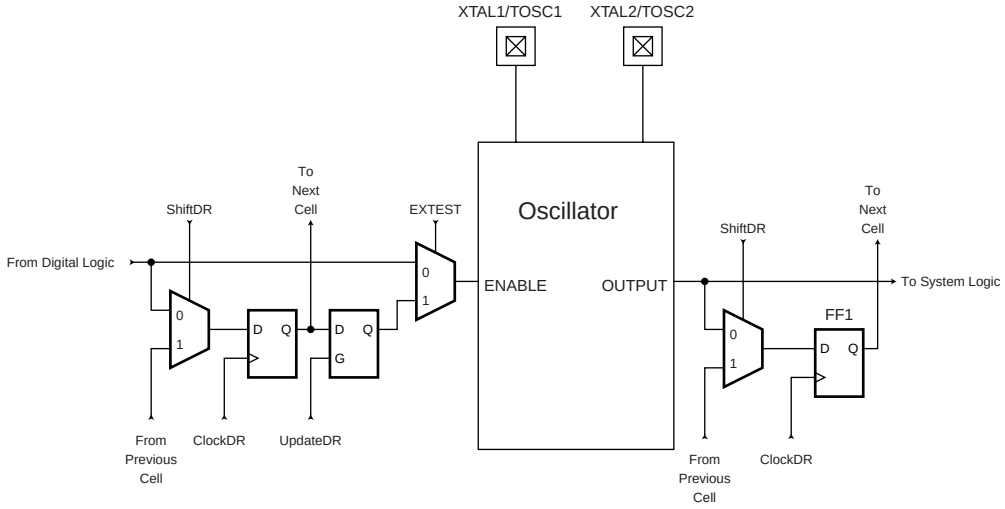


Table 86 summaries the scan registers for the external clock pin XTAL1, oscillators with XTAL1/XTAL2 connections as well as 32 kHz Timer Oscillator.

Table 86. Scan Signals for the Oscillator(1)(2)(3)

Enable Signal	Scanned Clock Line	Clock Option	Scanned Clock Line when Not Used
EXTCLKEN	EXTCLK (XTAL1)	External Clock	0
OSCON	OSCCK	External Crystal External Ceramic Resonator	0
OSC32EN	OSC32CK	Low Freq. External Crystal	0
TOSKON	TOSCK	32 kHz Timer Oscillator	0

Notes:
1. Do not enable more than one clock source as main clock at a time.
2. Scanning an Oscillator output gives unpredictable results as there is a frequency drift between the Internal Oscillator and the JTAG TCK clock. If possible, scanning an external clock is preferred.
3. The clock configuration is programmed by fuses. As a fuse is not changed run-time, the clock configuration is considered fixed for a given application. The user is advised to scan the same clock option as to be used in the final system. The enable signals are supported in the scan chain because the system logic can disable clock options in sleep modes, thereby disconnecting the Oscillator pins from the scan path if not provided. The INTCAP selection is not supported in the scan-chain, so the boundary scan chain can not make a XTAL Oscillator requiring internal capacitors to run unless the fuses are correctly programmed.

Scanning the Analog Comparator

The relevant Comparator signals regarding Boundary-scan are shown in Figure 91. The Boundary-scan cell from Figure 92 is attached to each of these signals. The signals are described in Table 87.

The Comparator need not be used for pure connectivity testing, since all analog inputs are shared with a digital port pin as well.

Figure 91. Analog Comparator

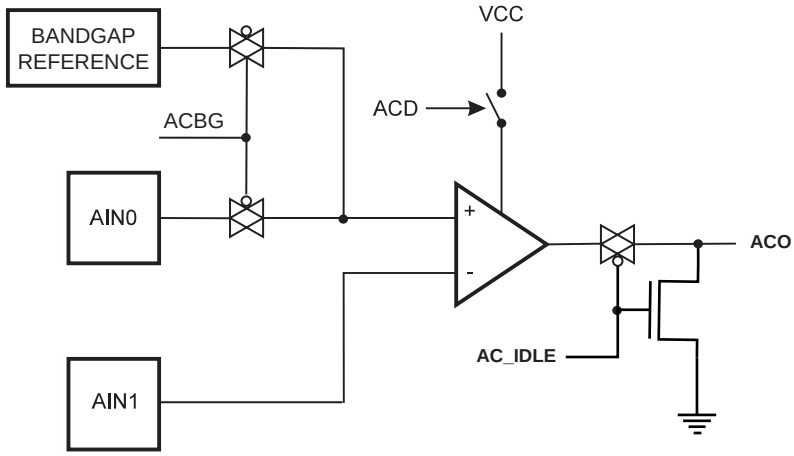


Figure 92. General Boundary-scan Cell used for Signals for Comparator

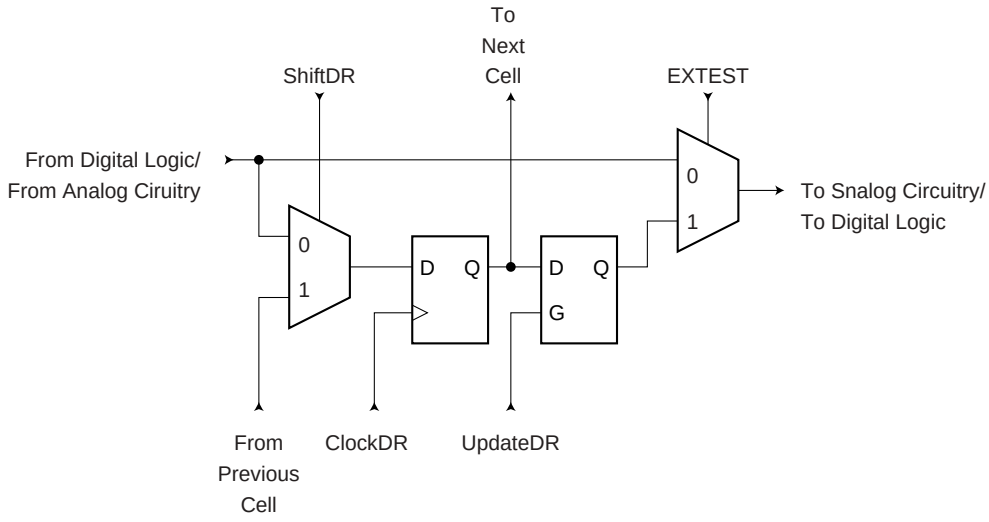


Table 87. Boundary-scan Signals for the Analog Comparator

Signal Name	Direction as seen from the Comparator	Description	Recommended Input when Not in Use	Output Values when Recommended Inputs are Used
AC_IDLE	input	Turns off Analog comparator when true	1	Depends upon µC code being executed
ACO	output	Analog Comparator Output	Will become input to µC code being executed	0
ACBG	input	Bandgap Reference enable	0	Depends upon µC code being executed

ATmega162 Boundary-scan Order

Table 88 shows the Scan order between TDI and TDO when the Boundary-scan chain is selected as data path. Bit 0 is the LSB; the first bit scanned in, and the first bit scanned out. The scan order follows the pinout order as far as possible. Therefore, the bits of Port A and Port E is scanned in the opposite bit order of the other ports. Exceptions from the rules are the Scan chains for the analog circuits, which constitute the most significant bits of the scan chain regardless of which physical pin they are connected to. In Figure 87, PXn. Data corresponds to FF0, PXn. Control corresponds to FF1, and PXn. Pullup_enable corresponds to FF2. Bit 4, 5, 6, and 7of Port C is not in the scan chain, since these pins constitute the TAP pins when the JTAG is enabled.

Table 88. ATmega162 Boundary-scan Order

Bit Number	Signal Name	Module
105	AC_IDLE	Comparator
104	ACO	
103	ACBG	
102	PB0.Data	Port B
101	PB0.Control	
100	PB0.Pullup_Enable	
99	PB1.Data	
98	PB1.Control	
97	PB1.Pullup_Enable	
96	PB2.Data	
95	PB2.Control	
94	PB2.Pullup_Enable	
93	PB3.Data	
92	PB3.Control	
91	PB3.Pullup_Enable	
90	PB4.Data	
89	PB4.Control	
88	PB4.Pullup_Enable	

Table 88. ATmega162 Boundary-scan Order (Continued)

Bit Number	Signal Name	Module
87	PB5.Data	Port B
86	PB5.Control	
85	PB5.Pullup_Enable	
84	PB6.Data	
83	PB6.Control	
82	PB6.Pullup_Enable	
81	PB7.Data	
80	PB7.Control	
79	PB7.Pullup_Enable	
78	RSTT	Reset Logic (Observe-only)
77	RSTHV	
76	TOSC	32 kHz Timer Oscillator
75	TOSCON	
74	PD0.Data	Port D
73	PD0.Control	
72	PD0.Pullup_Enable	
71	PD1.Data	
70	PD1.Control	
69	PD1.Pullup_Enable	
68	PD2.Data	
67	PD2.Control	
66	PD2.Pullup_Enable	
65	PD3.Data	
64	PD3.Control	
63	PD3.Pullup_Enable	
62	PD4.Data	
61	PD4.Control	
60	PD4.Pullup_Enable	
59	PD5.Data	Port D
58	PD5.Control	
57	PD5.Pullup_Enable	
56	PD6.Data	
55	PD6.Control	
54	PD6.Pullup_Enable	
53	PD7.Data	
52	PD7.Control	

Table 88. ATmega162 Boundary-scan Order (Continued)

Bit Number	Signal Name	Module
51	PD7.Pullup_Enable	Port D
50	EXTCLKEN	Enable signals for main Clock/Oscillators
49	OSCON	
48	OSC32EN	
47	EXTCLK (XTAL1)	Clock input and Oscillators for the main clock (Observe-only)
46	OSCCK	
45	OSC32CK	
44	PC0.Data	Port C
43	PC0.Control	
42	PC0.Pullup_Enable	
41	PC1.Data	
40	PC1.Control	
39	PC1.Pullup_Enable	
38	PC2.Data	
37	PC2.Control	
36	PC2.Pullup_Enable	
35	PC3.Data	
34	PC3.Control	
33	PC3.Pullup_Enable	
32	PE2.Data	Port E
31	PE2.Control	
30	PE2.Pullup_Enable	
29	PE1.Data	
28	PE1.Control	
27	PE1.Pullup_Enable	
26	PE0.Data	
25	PE0.Control	
24	PE0.Pullup_Enable	
23	PA7.Data	Port A
22	PA7.Control	
21	PA7.Pullup_Enable	
20	PA6.Data	
19	PA6.Control	
18	PA6.Pullup_Enable	
17	PA5.Data	
16	PA5.Control	

Table 88. ATmega162 Boundary-scan Order (Continued)

Bit Number	Signal Name	Module
15	PA5.Pullup_Enable	Port A
14	PA4.Data	
13	PA4.Control	
12	PA4.Pullup_Enable	
11	PA3.Data	
10	PA3.Control	
9	PA3.Pullup_Enable	
8	PA2.Data	
7	PA2.Control	
6	PA2.Pullup_Enable	
5	PA1.Data	
4	PA1.Control	
3	PA1.Pullup_Enable	
2	PA0.Data	
1	PA0.Control	
0	PA0.Pullup_Enable	

Note: 1. PRIVATE_SIGNAL1 should always be scanned in as zero.

Boundary-scan Description Language Files

Boundary-scan Description Language (BSDL) files describe Boundary-scan capable devices in a standard format used by automated test-generation software. The order and function of bits in the Boundary-scan Data Register are included in this description. A BSDL file for ATmega162 is available.

Boot Loader Support – Read-While-Write Self-programming

The Boot Loader Support provides a real Read-While-Write Self-programming mechanism for downloading and uploading program code by the MCU itself. This feature allows flexible application software updates controlled by the MCU using a Flash-resident Boot Loader program. The Boot Loader program can use any available data interface and associated protocol to read code and write (program) that code into the Flash memory, or read the code from the program memory. The program code within the Boot Loader section has the capability to write into the entire Flash, including the Boot Loader memory. The Boot Loader can thus even modify itself, and it can also erase itself from the code if the feature is not needed anymore. The size of the Boot Loader memory is configurable with Fuses and the Boot Loader has two separate sets of Boot Lock bits which can be set independently. This gives the user a unique flexibility to select different levels of protection.

Features

- **Read-While-Write Self-programming**
- **Flexible Boot Memory Size**
- **High Security (Separate Boot Lock Bits for a Flexible Protection)**
- **Separate Fuse to Select Reset Vector**
- **Optimized Page[1] Size**
- **Code Efficient Algorithm**
- **Efficient Read-Modify-Write Support**

Note: 1. A page is a section in the Flash consisting of several bytes (see Table 106 on page 235) used during programming. The page organization does not affect normal operation.

Application and Boot Loader Flash Sections

The Flash memory is organized in two main sections, the Application section and the Boot Loader section (see Figure 94). The size of the different sections is configured by the BOOTSZ Fuses as shown in Table 94 on page 228 and Figure 94. These two sections can have different level of protection since they have different sets of Lock bits.

Application Section

The Application section is the section of the Flash that is used for storing the application code. The protection level for the application section can be selected by the Application Boot Lock bits (Boot Lock bits 0), see Table 90 on page 219. The Application section can never store any Boot Loader code since the SPM instruction is disabled when executed from the Application section.

BLS – Boot Loader Section

While the Application section is used for storing the application code, the The Boot Loader software must be located in the BLS since the SPM instruction can initiate a programming when executing from the BLS only. The SPM instruction can access the entire Flash, including the BLS itself. The protection level for the Boot Loader section can be selected by the Boot Loader Lock bits (Boot Lock bits 1), see Table 91 on page 219.

Read-While-Write and No Read-While-Write Flash Sections

Whether the CPU supports Read-While-Write or if the CPU is halted during a Boot Loader software update is dependent on which address that is being programmed. In addition to the two sections that are configurable by the BOOTSZ Fuses as described above, the Flash is also divided into two fixed sections, the Read-While-Write (RWW) section and the No Read-While-Write (NRWW) section. The limit between the RWW- and NRWW sections is given in Table 95 on page 228 and Figure 94 on page 218. The main difference between the two sections is:

- When erasing or writing a page located inside the RWW section, the NRWW section can be read during the operation.
- When erasing or writing a page located inside the NRWW section, the CPU is halted during the entire operation.

Note that the user software can never read any code that is located inside the RWW section during a Boot Loader software operation. The syntax “Read-While-Write section” refers to which section that is being programmed (erased or written), not which section that actually is being read during a Boot Loader software update.

RWW – Read-While-Write Section

If a Boot Loader software update is programming a page inside the RWW section, it is possible to read code from the Flash, but only code that is located in the NRWW section. During an ongoing programming, the software must ensure that the RWW section never is being read. If the user software is trying to read code that is located inside the RWW section (i.e., by a call/jmp/lpm or an interrupt) during programming, the software might end up in an unknown state. To avoid this, the interrupts should either be disabled or moved to the Boot Loader section. The Boot Loader section is always located in the NRWW section. The RWW Section Busy bit (RWWSB) in the Store Program Memory Control Register (SPMCR) will be read as logical one as long as the RWW section is blocked for reading. After a programming is completed, the RWWSB must be cleared by software before reading code located in the RWW section. See “Store Program Memory Control Register – SPMCR” on page 220. for details on how to clear RWWSB.

NRWW – No Read-While-Write Section

The code located in the NRWW section can be read when the Boot Loader software is updating a page in the RWW section. When the Boot Loader code updates the NRWW section, the CPU is halted during the entire Page Erase or Page Write operation.

Table 89. Read-While-Write Features

Which Section does the Z-pointer Address During the Programming?	Which Section Can be Read During Programming?	Is the CPU Halted?	Read-While-Write Supported?
RWW section	NRWW section	No	Yes
NRWW section	None	Yes	No

Figure 93. Read-While-Write vs. No Read-While-Write

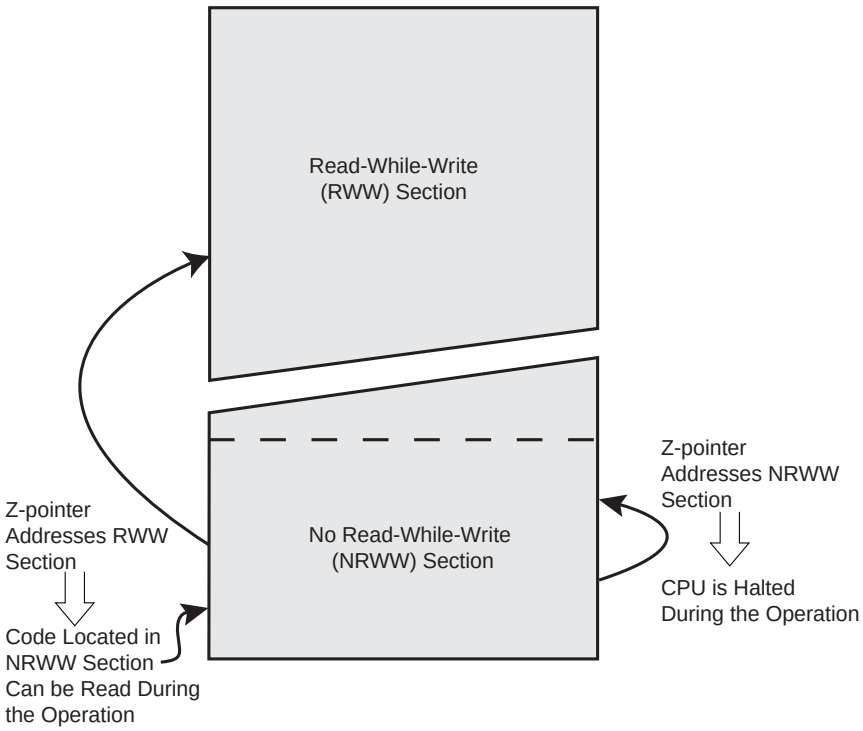
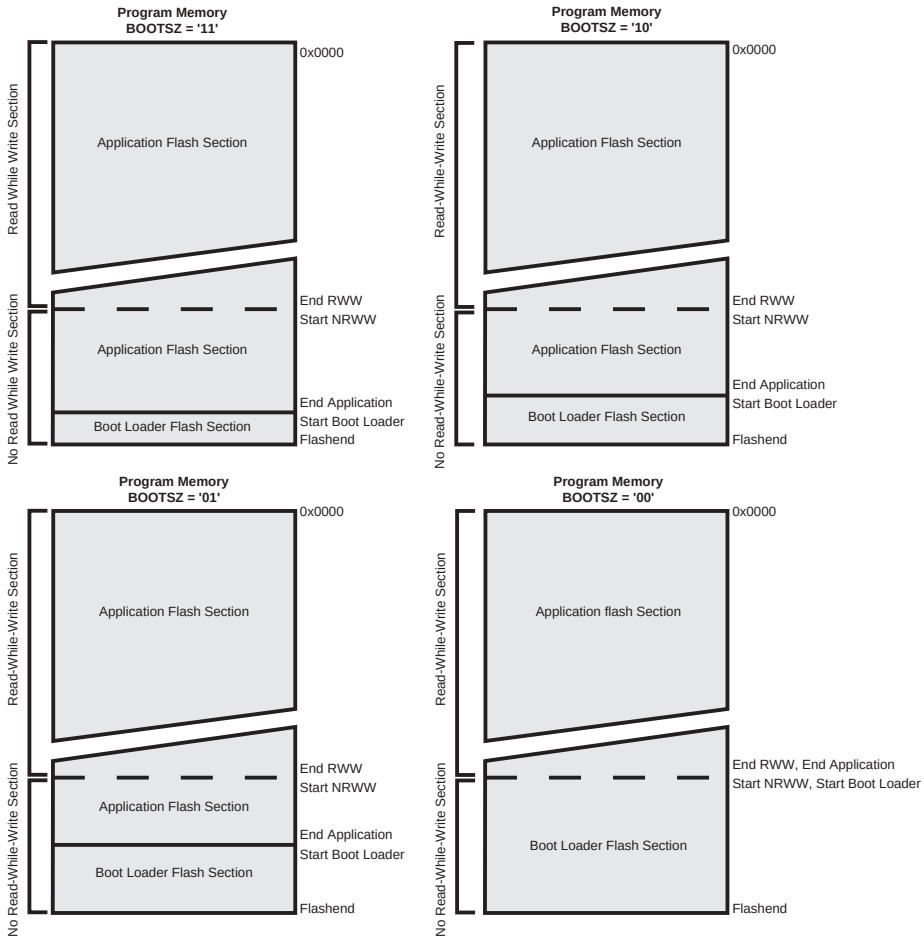


Figure 94. Memory Sections[1]



Note: 1. The parameters are given in Table 94 on page 228.

Boot Loader Lock Bits

If no Boot Loader capability is needed, the entire Flash is available for application code. The Boot Loader has two separate sets of Boot Lock bits which can be set independently. This gives the user a unique flexibility to select different levels of protection.

The user can select:

- To protect the entire Flash from a software update by the MCU
- To protect only the Boot Loader Flash section from a software update by the MCU
- To protect only the Application Flash section from a software update by the MCU
- Allow software update in the entire Flash

See Table 90 and Table 91 for further details. The Boot Lock bits can be set in software and in Serial or Parallel Programming mode, but they can be cleared by a chip erase command only. The general Write Lock (Lock bit mode 2) does not control the program-

ming of the Flash memory by SPM instruction. Similarly, the general Read/Write Lock (Lock bit mode 1) does not control reading nor writing by LPM/SPM, if it is attempted.

Table 90. Boot Lock Bit0 Protection Modes (Application Section)[1]

BLB0 Mode	BLB02	BLB01	Protection
1	1	1	No restrictions for SPM or LPM accessing the Application section.
2	1	0	SPM is not allowed to write to the Application section.
3	0	0	SPM is not allowed to write to the Application section, and LPM executing from the Boot Loader section is not allowed to read from the Application section. If Interrupt Vectors are placed in the Boot Loader section, interrupts are disabled while executing from the Application section.
4	0	1	LPM executing from the Boot Loader section is not allowed to read from the Application section. If Interrupt Vectors are placed in the Boot Loader section, interrupts are disabled while executing from the Application section.

Note: 1. “1” means unprogrammed, “0” means programmed

Table 91. Boot Lock Bit1 Protection Modes (Boot Loader Section)[1]

BLB1 Mode	BLB12	BLB11	Protection
1	1	1	No restrictions for SPM or LPM accessing the Boot Loader section.
2	1	0	SPM is not allowed to write to the Boot Loader section.
3	0	0	SPM is not allowed to write to the Boot Loader section, and LPM executing from the Application section is not allowed to read from the Boot Loader section. If Interrupt Vectors are placed in the Application section, interrupts are disabled while executing from the Boot Loader section.
4	0	1	LPM executing from the Application section is not allowed to read from the Boot Loader section. If Interrupt Vectors are placed in the Application section, interrupts are disabled while executing from the Boot Loader section.

Note: 1. “1” means unprogrammed, “0” means programmed

Entering the Boot Loader Program

Entering the Boot Loader takes place by a jump or call from the application program. This may be initiated by a trigger such as a command received via USART, or SPI interface. Alternatively, the Boot Reset Fuse can be programmed so that the Reset Vector is pointing to the Boot Flash start address after a reset. In this case, the Boot Loader is started after a reset. After the application code is loaded, the program can start executing the application code. Note that the fuses cannot be changed by the MCU itself. This means that once the Boot Reset Fuse is programmed, the Reset Vector will always point to the Boot Loader Reset and the fuse can only be changed through the Serial or Parallel Programming interface.

Table 92. Boot Reset Fuse(1)

BOOTRST	Reset Address
1	Reset Vector = Application Reset (address 0x0000).
0	Reset Vector = Boot Loader Reset (see Table 94 on page 228).

Note: 1. “1” means unprogrammed, “0” means programmed

Store Program Memory Control Register – SPMCR

The Store Program Memory Control Register contains the control bits needed to control the Boot Loader operations.

Bit	7	6	5	4	3	2	1	0	
	SPMIE	RWWSB	–	RWWSRE	BLBSET	PGWRT	PGERS	SPMEN	SPMCR
Read/Write	R/W	R	R	R/W	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

- **Bit 7 – SPMIE: SPM Interrupt Enable**

When the SPMIE bit is written to one, and the I-bit in the Status Register is set (one), the SPM ready interrupt will be enabled. The SPM ready Interrupt will be executed as long as the SPMEN bit in the SPMCR Register is cleared.

- **Bit 6 – RWWSB: Read-While-Write Section Busy**

When a Self-programming (Page Erase or Page Write) operation to the RWW section is initiated, the RWWSB will be set (one) by hardware. When the RWWSB bit is set, the RWW section cannot be accessed. The RWWSB bit will be cleared if the RWWSRE bit is written to one after a Self-programming operation is completed. Alternatively the RWWSB bit will automatically be cleared if a page load operation is initiated.

- **Bit 5 – Res: Reserved Bit**

This bit is a reserved bit in the ATmega162 and always read as zero.

- **Bit 4 – RWWSRE: Read-While-Write Section Read Enable**

When programming (Page Erase or Page Write) to the RWW section, the RWW section is blocked for reading (the RWWSB will be set by hardware). To re-enable the RWW section, the user software must wait until the programming is completed (SPMEN will be cleared). Then, if the RWWSRE bit is written to one at the same time as SPMEN, the next SPM instruction within four clock cycles re-enables the RWW section. The RWW section cannot be re-enabled while the Flash is busy with a Page Erase or a Page Write (SPMEN is set). If the RWWSRE bit is written while the Flash is being loaded, the Flash load operation will abort and the data loaded will be lost.

- **Bit 3 – BLBSET: Boot Lock Bit Set**

If this bit is written to one at the same time as SPMEN, the next SPM instruction within four clock cycles sets Boot Lock bits, according to the data in R0. The data in R1 and the address in the Z-pointer are ignored. The BLBSET bit will automatically be cleared upon completion of the Lock bit set, or if no SPM instruction is executed within four clock cycles.

An LPM instruction within three cycles after BLBSET and SPMEN are set in the SPMCR Register, will read either the Lock bits or the Fuse bits (depending on Z0 in the Z-pointer) into the destination register. See “Reading the Fuse and Lock Bits from Software” on page 224 for details.

- **Bit 2 – PGWRT: Page Write**

If this bit is written to one at the same time as SPMEN, the next SPM instruction within four clock cycles executes Page Write, with the data stored in the temporary buffer. The page address is taken from the high part of the Z-pointer. The data in R1 and R0 are ignored. The PGWRT bit will auto–clear upon completion of a Page Write, or if no SPM instruction is executed within four clock cycles. The CPU is halted during the entire Page Write operation if the NRWW section is addressed.

- **Bit 1 – PGERS: Page Erase**

If this bit is written to one at the same time as SPMEN, the next SPM instruction within four clock cycles executes Page Erase. The page address is taken from the high part of the Z-pointer. The data in R1 and R0 are ignored. The PGERS bit will auto-clear upon completion of a Page Erase, or if no SPM instruction is executed within four clock cycles. The CPU is halted during the entire Page Write operation if the NRWW section is addressed.

- **Bit 0 – SPMEN: Store Program Memory Enable**

This bit enables the SPM instruction for the next four clock cycles. If written to one together with either RWWSRE, BLBSET, PGWRT’ or PGERS, the following SPM instruction will have a special meaning, see description above. If only SPMEN is written, the following SPM instruction will store the value in R1:R0 in the temporary page buffer addressed by the Z-pointer. The LSB of the Z-pointer is ignored. The SPMEN bit will auto-clear upon completion of an SPM instruction, or if no SPM instruction is executed within four clock cycles. During Page Erase and Page Write, the SPMEN bit remains high until the operation is completed.

Writing any other combination than “10001”, “01001”, “00101”, “00011” or “00001” in the lower five bits will have no effect.

Addressing the Flash During Self-programming

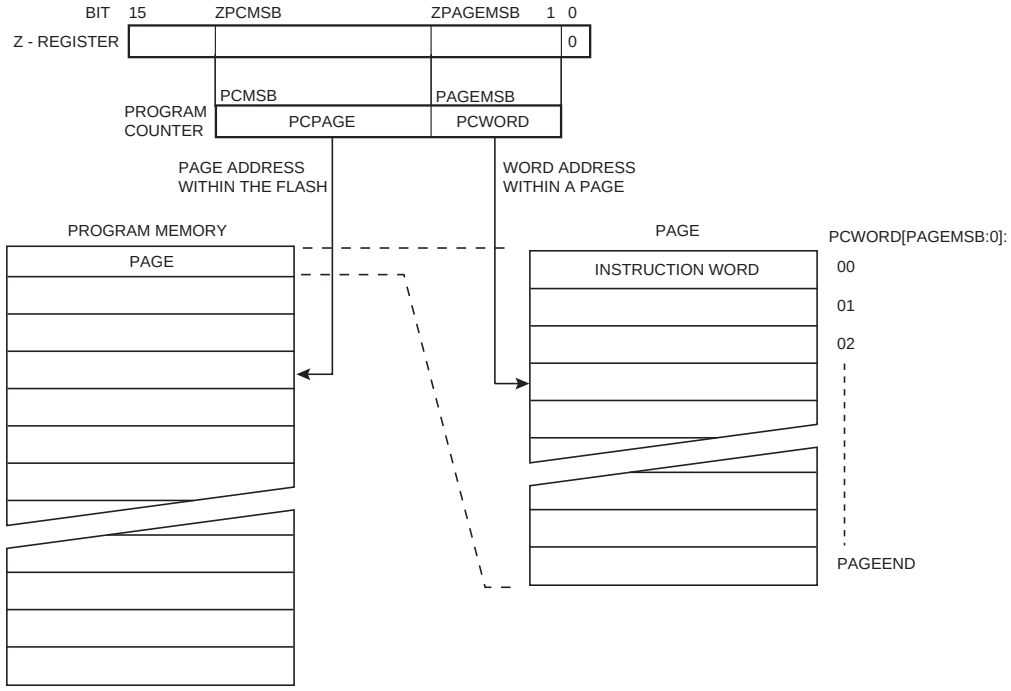
The Z-pointer is used to address the SPM commands.

Bit	15	14	13	12	11	10	9	8
ZH (R31)	Z15	Z14	Z13	Z12	Z11	Z10	Z9	Z8
ZL (R30)	Z7	Z6	Z5	Z4	Z3	Z2	Z1	Z0
	7	6	5	4	3	2	1	0

Since the Flash is organized in pages (see Table 106 on page 235), the Program Counter can be treated as having two different sections. One section, consisting of the least significant bits, is addressing the words within a page, while the most significant bits are addressing the pages. This is shown in Figure 95. Note that the Page Erase and Page Write operations are addressed independently. Therefore it is of major importance that the Boot Loader software addresses the same page in both the Page Erase and Page Write operation. Once a programming operation is initiated, the address is latched and the Z-pointer can be used for other operations.

The only SPM operation that does not use the Z-pointer is Setting the Boot Loader Lock bits. The content of the Z-pointer is ignored and will have no effect on the operation. The LPM instruction does also use the Z-pointer to store the address. Since this instruction addresses the Flash byte-by-byte, also the LSB (bit Z0) of the Z-pointer is used.

Figure 95. Addressing the Flash during SPM(1)



Notes: 1. The different variables used in Figure 95 are listed in Table 96 on page 229.
2. PCPAGE and PCWORD are listed in Table 106 on page 235.

Self-programming the Flash

The program memory is updated in a page by page fashion. Before programming a page with the data stored in the temporary page buffer, the page must be erased. The temporary page buffer is filled one word at a time using SPM and the buffer can be filled either before the Page Erase command or between a Page Erase and a Page Write operation:

Alternative 1, fill the buffer before a Page Erase

- Fill temporary page buffer
- Perform a Page Erase
- Perform a Page Write

Alternative 2, fill the buffer after Page Erase

- Perform a Page Erase
- Fill temporary page buffer
- Perform a Page Write

If only a part of the page needs to be changed, the rest of the page must be stored (for example in the temporary page buffer) before the erase, and then be rewritten. When using alternative 1, the Boot Loader provides an effective Read-Modify-Write feature which allows the user software to first read the page, do the necessary changes, and then write back the modified data. If alternative 2 is used, it is not possible to read the old data while loading since the page is already erased. The temporary page buffer can be accessed in a random sequence. It is essential that the page address used in both the Page Erase and Page Write operation is addressing the same page. See “Simple Assembly Code Example for a Boot Loader” on page 226 for an assembly code example.

Performing Page Erase by SPM

To execute Page Erase, set up the address in the Z-pointer, write “X0000011” to SPMCR and execute SPM within four clock cycles after writing SPMCR. The data in R1 and R0 is ignored. The page address must be written to PCPAGE in the Z-register. Other bits in the Z-pointer will be ignored during this operation.

- Page Erase to the RWW section: The NRWW section can be read during the Page Erase.
- Page Erase to the NRWW section: The CPU is halted during the operation.

Filling the Temporary Buffer (Page Loading)

To write an instruction word, set up the address in the Z-pointer and data in R1:R0, write “00000001” to SPMCR and execute SPM within four clock cycles after writing SPMCR. The content of PCWORD in the Z-register is used to address the data in the temporary buffer. The temporary buffer will auto-erase after a Page Write operation or by writing the RWWSRE bit in SPMCR. It is also erased after a System Reset. Note that it is not possible to write more than one time to each address without erasing the temporary buffer.

Note: If the EEPROM is written in the middle of an SPM Page Load operation, all data loaded will be lost.

Performing a Page Write

To execute Page Write, set up the address in the Z-pointer, write “X0000101” to SPMCR and execute SPM within four clock cycles after writing SPMCR. The data in R1 and R0 is ignored. The page address must be written to PCPAGE. Other bits in the Z-pointer must be written zero during this operation.

- Page Write to the RWW section: The NRWW section can be read during the Page Write.
- Page Write to the NRWW section: The CPU is halted during the operation.

Using the SPM Interrupt

If the SPM interrupt is enabled, the SPM interrupt will generate a constant interrupt when the SPMEN bit in SPMCR is cleared. This means that the interrupt can be used instead of polling the SPMCR Register in software. When using the SPM interrupt, the Interrupt Vectors should be moved to the BLS section to avoid that an interrupt is accessing the RWW section when it is blocked for reading. How to move the interrupts is described in “Interrupts” on page 56.

Consideration while Updating BLS

Special care must be taken if the user allows the Boot Loader section to be updated by leaving Boot Lock bit11 unprogrammed. An accidental write to the Boot Loader itself can corrupt the entire Boot Loader, and further software updates might be impossible. If it is not necessary to change the Boot Loader software itself, it is recommended to program the Boot Lock bit11 to protect the Boot Loader software from any internal software changes.

Prevent Reading the RWW Section During Self-programming

During Self-programming (either Page Erase or Page Write), the RWW section is always blocked for reading. The user software itself must prevent that this section is addressed during the self programming operation. The RWWSB in the SPMCR will be set as long as the RWW section is busy. During Self-programming the Interrupt Vector table should be moved to the BLS as described in “Interrupts” on page 56, or the interrupts must be disabled. Before addressing the RWW section after the programming is completed, the user software must clear the RWWSB by writing the RWWSRE. See “Simple Assembly Code Example for a Boot Loader” on page 226 for an example.

Setting the Boot Loader Lock Bits by SPM

To set the Boot Loader Lock bits, write the desired data to R0, write “X0001001” to SPMCR and execute SPM within four clock cycles after writing SPMCR. The only accessible Lock bits are the Boot Lock bits that may prevent the Application and Boot Loader section from any software update by the MCU.

Bit	7	6	5	4	3	2	1	0
R0	**1**	**1**	**BLB12**	**BLB11**	**BLB02**	**BLB01**	**1**	**1**

See Table 90 and Table 91 for how the different settings of the Boot Loader bits affect the Flash access.

If bits 5..2 in R0 are cleared (zero), the corresponding Boot Lock bit will be programmed if an SPM instruction is executed within four cycles after BLBSET and SPMEN are set in SPMCR. The Z-pointer is don’t care during this operation, but for future compatibility it is recommended to load the Z-pointer with 0x0001 (same as used for reading the Lock bits). For future compatibility it is also recommended to set bits 7, 6, 1, and 0 in R0 to “1” when writing the Lock bits. When programming the Lock bits the entire Flash can be read during the operation.

EEPROM Write Prevents Writing to SPMCR

Note that an EEPROM write operation will block all software programming to Flash. Reading the Fuses and Lock bits from software will also be prevented during the EEPROM write operation. It is recommended that the user checks the status bit (EEWE) in the EECR Register and verifies that the bit is cleared before writing to the SPMCR Register.

Reading the Fuse and Lock Bits from Software

It is possible to read both the Fuse and Lock bits from software. To read the Lock bits, load the Z-pointer with 0x0001 and set the BLBSET and SPMEN bits in SPMCR. When an LPM instruction is executed within three CPU cycles after the BLBSET and SPMEN bits are set in SPMCR, the value of the Lock bits will be loaded in the destination register. The BLBSET and SPMEN bits will auto-clear upon completion of reading the Lock bits or if no LPM instruction is executed within three CPU cycles or no SPM instruction is

executed within four CPU cycles. When BLBSET and SPMEN are cleared, LPM will work as described in the Instruction set Manual.

Bit	7	6	5	4	3	2	1	0
Rd	–	–	BLB12	BLB11	BLB02	BLB01	LB2	LB1

The algorithm for reading the Fuse Low byte is similar to the one described above for reading the Lock bits. To read the Fuse Low byte, load the Z-pointer with 0x0000 and set the BLBSET and SPMEN bits in SPMCR. When an LPM instruction is executed within three cycles after the BLBSET and SPMEN bits are set in the SPMCR, the value of the Fuse Low byte (FLB) will be loaded in the destination register as shown below. Refer to Table 101 on page 232 for a detailed description and mapping of the Fuse Low byte.

Bit	7	6	5	4	3	2	1	0
Rd	FLB7	FLB6	FLB5	FLB4	FLB3	FLB2	FLB1	FLB0

Similarly, when reading the Fuse High byte, load 0x0003 in the Z-pointer. When an LPM instruction is executed within three cycles after the BLBSET and SPMEN bits are set in the SPMCR, the value of the Fuse High byte (FHB) will be loaded in the destination register as shown below. Refer to Table 99 on page 231 for detailed description and mapping of the Fuse High byte.

Bit	7	6	5	4	3	2	1	0
Rd	FHB7	FHB6	FHB5	FHB4	FHB3	FHB2	FHB1	FHB0

When reading the Extended Fuse byte, load 0x0002 in the Z-pointer. When an LPM instruction is executed within three cycles after the BLBSET and SPMEN bits are set in the SPMCR, the value of the Extended Fuse byte (EFB) will be loaded in the destination register as shown below. Refer to Table 99 on page 231 for detailed description and mapping of the Extended Fuse byte.

Bit	7	6	5	4	3	2	1	0
Rd	–	–	–	EFB4	EFB3	EFB2	EFB1	–

Fuse and Lock bits that are programmed, will be read as zero. Fuse and Lock bits that are unprogrammed, will be read as one.

Preventing Flash Corruption

During periods of low V_{CC}, the Flash program can be corrupted because the supply voltage is too low for the CPU and the Flash to operate properly. These issues are the same as for board level systems using the Flash, and the same design solutions should be applied.

A Flash program corruption can be caused by two situations when the voltage is too low. First, a regular write sequence to the Flash requires a minimum voltage to operate correctly. Secondly, the CPU itself can execute instructions incorrectly, if the supply voltage for executing instructions is too low.

Flash corruption can easily be avoided by following these design recommendations (one is sufficient):

1. If there is no need for a Boot Loader update in the system, program the Boot Loader Lock bits to prevent any Boot Loader software updates.
2. Keep the AVR RESET active (low) during periods of insufficient power supply voltage. This can be done by enabling the internal Brown-out Detector (BOD) if the operating voltage matches the detection level. If not, an external low V_{CC} Reset Protection circuit can be used. If a Reset occurs while a write operation is in progress, the write operation will be completed provided that the power supply voltage is sufficient.

3. Keep the AVR core in Power-down sleep mode during periods of low V_{CC}. This will prevent the CPU from attempting to decode and execute instructions, effectively protecting the SPMCR Register and thus the Flash from unintentional writes.

Programming Time for Flash When Using SPM

The calibrated RC Oscillator is used to time Flash accesses. Table 93 shows the typical programming time for Flash accesses from the CPU.

Table 93. SPM Programming Time

Symbol	Min Programming Time	Max Programming Time
Flash Write (Page Erase, Page Write, and Write Lock bits by SPM)	3.7ms	4.5ms

Simple Assembly Code Example for a Boot Loader

```
  ;-the routine writes one page of data from RAM to Flash
  ; the first data location in RAM is pointed to by the Y pointer
  ; the first data location in Flash is pointed to by the Z-pointer
  ;-error handling is not included
  ;-the routine must be placed inside the boot space
  ; (at least the Do_spm sub routine). Only code inside NRWW section can
  ; be read during self-programming (page erase and page write).
  ;-registers used: r0, r1, temp1 (r16), temp2 (r17), looplo (r24),
  ; loophi (r25), spmcrval (r20)
  ; storing and restoring of registers is not included in the routine
  ; register usage can be optimized at the expense of code size
  ;-It is assumed that either the interrupt table is moved to the Boot
  ; loader section or that the interrupts are disabled.
.equ  PAGESIZEB = PAGESIZE*2        ;PAGESIZEB is page size in BYTES, not
                                    ; words
.org SMALLBOOTSTART
Write_page:
  ; page erase
  ldi   spmcrval, (1<<PGERS) | (1<<SPMEN)
  call  Do_spm

  ; re-enable the RWW section
  ldi   spmcrval, (1<<RWWSRE) | (1<<SPMEN)
  call  Do_spm

  ; transfer data from RAM to Flash page buffer
  ldi   looplo, low(PAGESIZEB)      ;init loop variable
  ldi   loophi, high(PAGESIZEB)     ;not required for PAGESIZEB<=256
Wrloop:
  ld    r0, Y+
  ld    r1, Y+
  ldi   spmcrval, (1<<SPMEN)
  call  Do_spm
  adiw  ZH:ZL, 2
  sbiw  loophi:looplo, 2            ;use subi for PAGESIZEB<=256
  brne  Wrloop

  ; execute page write
  subi  ZL, low(PAGESIZEB)          ;restore pointer
  sbci  ZH, high(PAGESIZEB)         ;not required for PAGESIZEB<=256
  ldi   spmcrval, (1<<PGWRT) | (1<<SPMEN)
  call  Do_spm

  ; re-enable the RWW section
  ldi   spmcrval, (1<<RWWSRE) | (1<<SPMEN)
  call  Do_spm

  ; read back and check, optional
```

```
  ldi   looplo, low(PAGESIZEB)      ;init loop variable
  ldi   loophi, high(PAGESIZEB)     ;not required for PAGESIZEB<=256
  subi  YL, low(PAGESIZEB)          ;restore pointer
  sbci  YH, high(PAGESIZEB)
Rdloop:
  lpm   r0, Z+
  ld    r1, Y+
  cpse  r0, r1
  jmp   Error
  sbiw  loophi:looplo, 1            ;use subi for PAGESIZEB<=256
  brne  Rdloop

  ; return to RWW section
  ; verify that RWW section is safe to read
Return:
  in    temp1, SPMCR
  sbrs  temp1, RWWSB              ; If RWWSB is set, the RWW section is not
                                  ; ready yet
  ret
  ; re-enable the RWW section
  ldi   spmcrval, (1<<RWWSRE) | (1<<SPMEN)
  call  Do_spm
  rjmp  Return

Do_spm:
  ; check for previous SPM complete
Wait_spm:
  in    temp1, SPMCR
  sbrc  temp1, SPMEN
  rjmp  Wait_spm
  ; input: spmcrval determines SPM action
  ; disable interrupts if enabled, store status
  in    temp2, SREG
  cli
  ; check that no EEPROM write access is present
Wait_ee:
  sbic  EECR, EEWE
  rjmp  Wait_ee
  ; SPM timed sequence
  out   SPMCR, spmcrval
  spm
  ; restore SREG (to enable interrupts if originally enabled)
  out   SREG, temp2
  ret
```

ATmega162 Boot Loader Parameters

In Table 94 through Table 96, the parameters used in the description of the self programming are given.

Table 94. Boot Size Configuration(1)

BOOTSZ1	BOOTSZ0	Boot Size	Pages	Application Flash Section	Boot Loader Flash Section	End Application Section	Boot Reset Address (Start Boot Loader Section)
1	1	128 words	2	0x0000 - 0x1F7F	0x1F80 - 0x1FFF	0x1F7F	0x1F80
1	0	256 words	4	0x0000 - 0x1EFF	0x1F00 - 0x1FFF	0x1EFF	0x1F00
0	1	512 words	8	0x0000 - 0x1DFF	0x1E00 - 0x1FFF	0x1DFF	0x1E00
0	0	1024 words	16	0x0000 - 0x1BFF	0x1C00 - 0x1FFF	0x1BFF	0x1C00

Note: 1. The different BOOTSZ Fuse configurations are shown in Figure 94

Table 95. Read-While-Write Limit

Section	Pages	Address
Read-While-Write section (RWW)	112	0x0000 - 0x1BFF
No Read-While-Write section (NRWW)	16	0x1C00 - 0x1FFF

Note: 1. For details about these two section, see “NRWW – No Read-While-Write Section” on page 217 and “RWW – Read-While-Write Section” on page 217

Table 96. Explanation of Different Variables Used in Figure 95 and the Mapping to the Z-pointer(1)

Variable		Corresponding Z-value	Description
PCMSB	12		Most significant bit in the Program Counter. (The Program Counter is 13 bits PC[12:0])
PAGEMSB	5		Most significant bit which is used to address the words within one page (64 words in a page requires 6 bits PC [5:0]).
ZPCMSB		Z13	Bit in Z-register that is mapped to PCMSB. Because Z0 is not used, the ZPCMSB equals PCMSB + 1.
ZPAGEMSB		Z6	Bit in Z-register that is mapped to PCMSB. Because Z0 is not used, the ZPAGEMSB equals PAGEMSB + 1.
PCPAGE	PC[12:6]	Z13:Z7	Program Counter page address: Page select, for Page Erase and Page Write
PCWORD	PC[5:0]	Z6:Z1	Program Counter word address: Word select, for filling temporary buffer (must be zero during Page Write operation)

Note: 1. Z15:Z14: always ignored
Z0: should be zero for all SPM commands, byte select for the LPM instruction.
See “Addressing the Flash During Self-programming” on page 222 for details about the use of Z-pointer during Self-programming.

Program And Data Memory Lock Bits

The ATmega162 provides six Lock bits which can be left unprogrammed (“1”) or can be programmed (“0”) to obtain the additional features listed in Table 98. The Lock bits can only be erased to “1” with the Chip Erase command.

Table 97. Lock Bit Byte[1]

Lock Bit Byte	Bit no	Description	Default Value
	7	–	1 (unprogrammed)
	6	–	1 (unprogrammed)
BLB12	5	Boot Lock bit	1 (unprogrammed)
BLB11	4	Boot Lock bit	1 (unprogrammed)
BLB02	3	Boot Lock bit	1 (unprogrammed)
BLB01	2	Boot Lock bit	1 (unprogrammed)
LB2	1	Lock bit	1 (unprogrammed)
LB1	0	Lock bit	1 (unprogrammed)

Note: 1. “1” means unprogrammed, “0” means programmed

Table 98. Lock Bit Protection Modes[1][2]

Memory Lock Bits			Protection Type
LB Mode	**LB2**	**LB1**	
1	1	1	No memory lock features enabled.
2	1	0	Further programming of the Flash and EEPROM is disabled in Parallel and SPI/JTAG Serial Programming mode. The Fuse bits are locked in both Serial and Parallel Programming mode[1].
3	0	0	Further programming and verification of the Flash and EEPROM is disabled in Parallel and SPI/JTAG Serial Programming mode. Also the Boot Lock bits and the Fuse bits are locked in both Serial and Parallel Programming mode[1].
BLB0 Mode	**BLB02**	**BLB01**	
1	1	1	No restrictions for SPM or LPM accessing the Application section.
2	1	0	SPM is not allowed to write to the Application section.
3	0	0	SPM is not allowed to write to the Application section, and LPM executing from the Boot Loader section is not allowed to read from the Application section. If Interrupt Vectors are placed in the Boot Loader section, interrupts are disabled while executing from the Application section.
4	0	1	LPM executing from the Boot Loader section is not allowed to read from the Application section. If Interrupt Vectors are placed in the Boot Loader section, interrupts are disabled while executing from the Application section.

Table 98. Lock Bit Protection Modes[1][2] (Continued)

Memory Lock Bits			Protection Type
BLB1 Mode	**BLB12**	**BLB11**	
1	1	1	No restrictions for SPM or LPM accessing the Boot Loader section.
2	1	0	SPM is not allowed to write to the Boot Loader section.
3	0	0	SPM is not allowed to write to the Boot Loader section, and LPM executing from the Application section is not allowed to read from the Boot Loader section. If Interrupt Vectors are placed in the Application section, interrupts are disabled while executing from the Boot Loader section.
4	0	1	LPM executing from the Application section is not allowed to read from the Boot Loader section. If Interrupt Vectors are placed in the Application section, interrupts are disabled while executing from the Boot Loader section.

Notes: 1. Program the Fuse bits and Boot Lock bits before programming the LB1 and LB2.
2. “1” means unprogrammed, “0” means programmed

Fuse Bits

The ATmega162 has three Fuse bytes. Table 100 and Table 101 describe briefly the functionality of all the fuses and how they are mapped into the Fuse bytes. Note that the fuses are read as logical zero, “0”, if they are programmed.

Table 99. Extended Fuse Byte[1][2]

Fuse Low Byte	Bit no	Description	Default Value
–	7	–	1
–	6	–	1
–	5	–	1
M161C	4	ATmega161 compatibility mode	1 (unprogrammed)
BODLEVEL2[2]	3	Brown-out Detector trigger level	1 (unprogrammed)
BODLEVEL1[2]	2	Brown-out Detector trigger level	1 (unprogrammed)
BODLEVEL0[2]	1	Brown-out Detector trigger level	1 (unprogrammed)
–	0	–	1

Notes: 1. See “ATmega161 Compatibility Mode” on page 5 for details.
2. See Table 19 on page 49 for BODLEVEL Fuse decoding.

Table 100. Fuse High Byte

Fuse Low Byte	Bit no	Description	Default Value
OCDEN[3]	7	Enable OCD	1 (unprogrammed, OCD disabled)
JTAGEN[4]	6	Enable JTAG	0 (programmed, JTAG enabled)
SPIEN[1]	5	Enable Serial Program and Data Downloading	0 (programmed, SPI prog. enabled)
WDTON	4	Watchdog Timer always on	1 (unprogrammed)
EESAVE	3	EEPROM memory is preserved through the Chip Erase	1 (unprogrammed, EEPROM not preserved)
BOOTSZ1	2	Select Boot Size (see Table 94 for details)	0 (programmed)[2]
BOOTSZ0	1	Select Boot Size (see Table 94 for details)	0 (programmed)[2]
BOOTRST	0	Select Reset Vector	1 (unprogrammed)

Notes:
1. The SPIEN Fuse is not accessible in SPI Serial Programming mode.
2. The default value of BOOTSZ1:0 results in maximum Boot Size. See Table 94 on page 228 for details.
3. Never ship a product with the OCDEN Fuse programmed regardless of the setting of Lock bits and the JTAGEN Fuse. A programmed OCDEN Fuse enables some parts of the clock system to be running in all sleep modes. This may increase the power consumption.
4. If the JTAG interface is left unconnected, the JTAGEN fuse should if possible be disabled. This to avoid static current at the TDO pin in the JTAG interface.

Table 101. Fuse Low Byte

Fuse Low Byte	Bit no	Description	Default value
CKDIV8[4]	7	Divide clock by 8	0 (programmed)
CKOUT[3]	6	Clock Output	1 (unprogrammed)
SUT1	5	Select start-up time	1 (unprogrammed)[1]
SUT0	4	Select start-up time	0 (programmed)[1]
CKSEL3	3	Select Clock source	0 (programmed)[2]
CKSEL2	2	Select Clock source	0 (programmed)[2]
CKSEL1	1	Select Clock source	1 (unprogrammed)[2]
CKSEL0	0	Select Clock source	0 (programmed)[2]

Notes:
1. The default value of SUT1:0 results in maximum start-up time for the default clock source. See Table 12 on page 37 for details.
2. The default setting of CKSEL3:0 results in Internal RC Oscillator @ 8 MHz. See Table 5 on page 34 for details.
3. The CKOUT Fuse allow the system clock to be output on PortB 0. See “Clock output buffer” on page 38 for details.
4. See “System Clock Prescaler” on page 39 for details.

The status of the Fuse bits is not affected by Chip Erase. Note that the Fuse bits are locked if Lock bit1 (LB1) is programmed. Program the Fuse bits before programming the Lock bits.

Latching of Fuses

The Fuse values are latched when the device enters Programming mode and changes of the Fuse values will have no effect until the part leaves Programming mode. This does not apply to the EESAVE Fuse which will take effect once it is programmed. The Fuses are also latched on Power-up in Normal mode.

Signature Bytes

All Atmel microcontrollers have a 3-byte signature code which identifies the device. This code can be read in both Serial and Parallel mode, also when the device is locked. The three bytes reside in a separate address space.

For the ATmega162 the signature bytes are:

1. 0x000: 0x1E (indicates manufactured by Atmel).
2. 0x001: 0x94 (indicates 16KB Flash memory).
3. 0x002: 0x04 (indicates ATmega162 device when 0x001 is 0x94).

Calibration Byte

The ATmega162 has a one-byte calibration value for the internal RC Oscillator. This byte resides in the high byte of address 0x000 in the signature address space. During Reset, this byte is automatically written into the OSCCAL Register to ensure correct frequency of the calibrated RC Oscillator.

Parallel Programming Parameters, Pin Mapping, and Commands

This section describes how to parallel program and verify Flash Program memory, EEPROM Data memory, Memory Lock bits, and Fuse bits in the ATmega162. Pulses are assumed to be at least 250 ns unless otherwise noted.

Signal Names

In this section, some pins of the ATmega162 are referenced by signal names describing their functionality during parallel programming, see Figure 96 and Table 102. Pins not described in the following table are referenced by pin names.

The XA1/XA0 pins determine the action executed when the XTAL1 pin is given a positive pulse. The bit coding is shown in Table 104.

When pulsing $\overline{WR}$ or $\overline{OE}$, the command loaded determines the action executed. The different Commands are shown in Table 105.

Figure 96. Parallel Programming

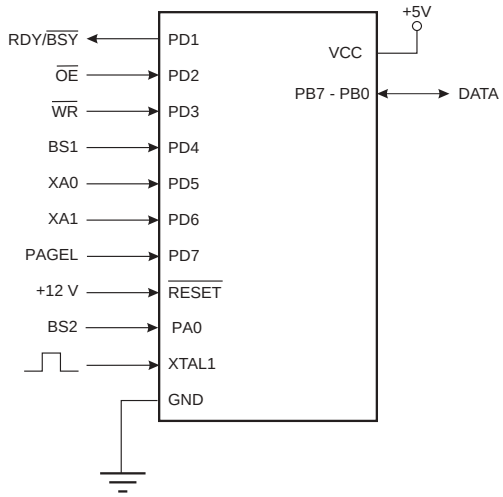


Table 102. Pin Name Mapping

Signal Name in Programming Mode	Pin Name	I/O	Function
RDY/$\overline{\text{BSY}}$	PD1	O	0: Device is busy programming, 1: Device is ready for new command
$\overline{\text{OE}}$	PD2	I	Output Enable (Active low)
$\overline{\text{WR}}$	PD3	I	Write Pulse (Active low)
BS1	PD4	I	Byte Select 1 (“0” selects low byte, “1” selects high byte)
XA0	PD5	I	XTAL Action Bit 0
XA1	PD6	I	XTAL Action Bit 1
PAGEL	PD7	I	Program Memory and EEPROM data Page Load
BS2	PA0	I	Byte Select 2 (“0” selects low byte, “1” selects 2’nd high byte)
DATA	PB7 - 0	I/O	Bi-directional Data bus (Output when $\overline{\text{OE}}$ is low)

Table 103. Pin Values used to Enter Programming Mode

Pin	Symbol	Value
PAGEL	Prog_enable[3]	0
XA1	Prog_enable[2]	0
XA0	Prog_enable[1]	0
BS1	Prog_enable[0]	0

Table 104. XA1 and XA0 Coding

XA1	XA0	Action when XTAL1 is Pulsed
0	0	Load Flash or EEPROM address (High or low address byte determined by BS1)
0	1	Load Data (High or Low data byte for Flash determined by BS1).
1	0	Load Command
1	1	No Action, Idle

Table 105. Command Byte Bit Coding

Command Byte	Command Executed
1000 0000	Chip Erase
0100 0000	Write Fuse Bits
0010 0000	Write Lock Bits
0001 0000	Write Flash
0001 0001	Write EEPROM
0000 1000	Read Signature Bytes and Calibration byte
0000 0100	Read Fuse and Lock Bits
0000 0010	Read Flash
0000 0011	Read EEPROM

Table 106. No. of Words in a Page and no. of Pages in the Flash

Flash Size	Page Size	PCWORD	No. of Pages	PCPAGE	PCMSB
8K words (16K bytes)	64 words	PC[5:0]	128	PC[12:6]	12

Table 107. No. of Words in a Page and no. of Pages in the EEPROM

EEPROM Size	Page Size	PCWORD	No. of pages	PCPAGE	EEAMSB
512 bytes	4 bytes	EEA[1:0]	128	EEA[8:2]	8

Parallel Programming

Enter Programming Mode

The following algorithm puts the device in Parallel Programming mode:

1. Apply 4.5 - 5.5V between V_{CC} and GND, and wait at least 100 µs.
2. Set $\overline{\text{RESET}}$ to “0” and toggle XTAL1 at least six times.
3. Set the Prog_enable pins listed in Table 103 on page 234 to “0000” and wait at least 100 ns.
4. Apply 11.5 - 12.5V to $\overline{\text{RESET}}$. Any activity on Prog_enable pins within 100 ns after +12V has been applied to $\overline{\text{RESET}}$, will cause the device to fail entering Programming mode.

Considerations for Efficient Programming

The loaded command and address are retained in the device during programming. For efficient programming, the following should be considered.

- The command needs only be loaded once when writing or reading multiple memory locations.
- Skip writing the data value 0xFF, that is the contents of the entire EEPROM (unless the EESAVE Fuse is programmed) and Flash after a Chip Erase.
- Address high byte needs only be loaded before programming or reading a new 256-word window in Flash or 256 byte EEPROM. This consideration also applies to Signature bytes reading.

Chip Erase

The Chip Erase will erase the Flash and EEPROM[1] memories plus Lock bits. The Lock bits are not reset until the program memory has been completely erased. The Fuse bits are not changed. A Chip Erase must be performed before the Flash or EEPROM are reprogrammed.

Note: 1. The EEPRPOM memory is preserved during chip erase if the EESAVE Fuse is programmed.

Load Command “Chip Erase”

1. Set XA1, XA0 to “10”. This enables command loading.
2. Set BS1 to “0”.
3. Set DATA to “1000 0000”. This is the command for Chip Erase.
4. Give XTAL1 a positive pulse. This loads the command.
5. Give $\overline{WR}$ a negative pulse. This starts the Chip Erase. RDY/$\overline{BSY}$ goes low.
6. Wait until RDY/$\overline{BSY}$ goes high before loading a new command.

Programming the Flash

The Flash is organized in pages, see Table 106 on page 235. When programming the Flash, the program data is latched into a page buffer. This allows one page of program data to be programmed simultaneously. The following procedure describes how to program the entire Flash memory:

A. Load Command “Write Flash”

1. Set XA1, XA0 to “10”. This enables command loading.
2. Set BS1 to “0”.
3. Set DATA to “0001 0000”. This is the command for Write Flash.
4. Give XTAL1 a positive pulse. This loads the command.

B. Load Address Low byte

1. Set XA1, XA0 to “00”. This enables address loading.
2. Set BS1 to “0”. This selects low address.
3. Set DATA = Address low byte (0x00 - 0xFF).
4. Give XTAL1 a positive pulse. This loads the address low byte.

C. Load Data Low Byte

1. Set XA1, XA0 to “01”. This enables data loading.
2. Set DATA = Data low byte (0x00 - 0xFF).
3. Give XTAL1 a positive pulse. This loads the data byte.

D. Load Data High Byte

1. Set BS1 to “1”. This selects high data byte.
2. Set XA1, XA0 to “01”. This enables data loading.
3. Set DATA = Data high byte (0x00 - 0xFF).
4. Give XTAL1 a positive pulse. This loads the data byte.

E. Latch Data

1. Set BS1 to “1”. This selects high data byte.
2. Give PAGEL a positive pulse. This latches the data bytes (See Figure 98 for signal waveforms).

F. Repeat B through E until the entire buffer is filled or until all data within the page is loaded.

While the lower bits in the address are mapped to words within the page, the higher bits address the pages within the FLASH. This is illustrated in Figure 97 on page 237. Note that if less than eight bits are required to address words in the page (pagesize < 256), the most significant bit(s) in the address low byte are used to address the page when performing a Page Write.

G. Load Address High byte

1. Set XA1, XA0 to “00”. This enables address loading.
2. Set BS1 to “1”. This selects high address.
3. Set DATA = Address high byte (0x00 - 0xFF).
4. Give XTAL1 a positive pulse. This loads the address high byte.

H. Program Page

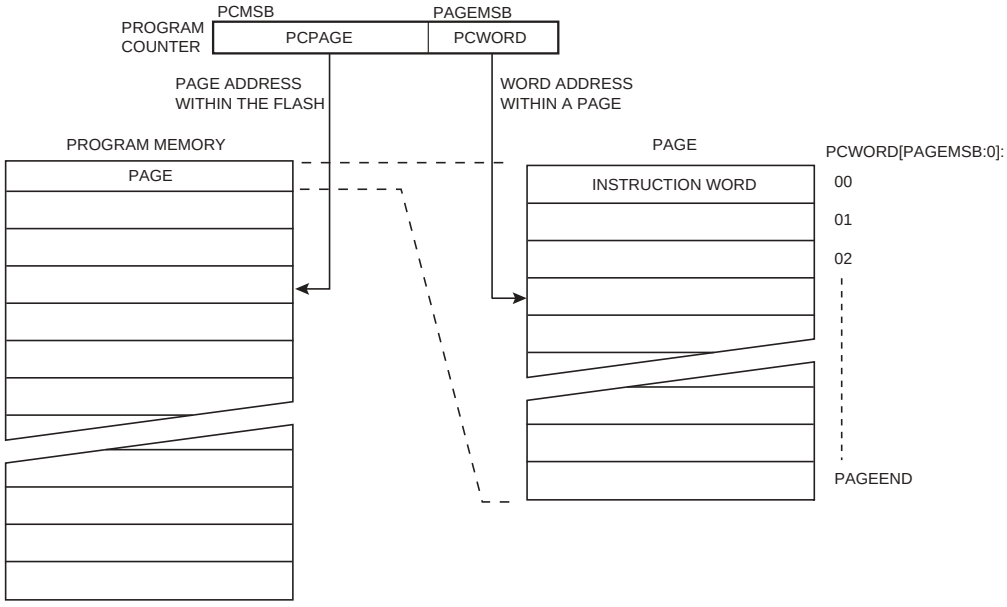
1. Give $\overline{WR}$ a negative pulse. This starts programming of the entire page of data. RDY/$\overline{BSY}$ goes low.
2. Wait until RDY/$\overline{BSY}$ goes high. (See Figure 98 for signal waveforms)

I. Repeat B through H until the entire Flash is programmed or until all data has been programmed.

J. End Page Programming

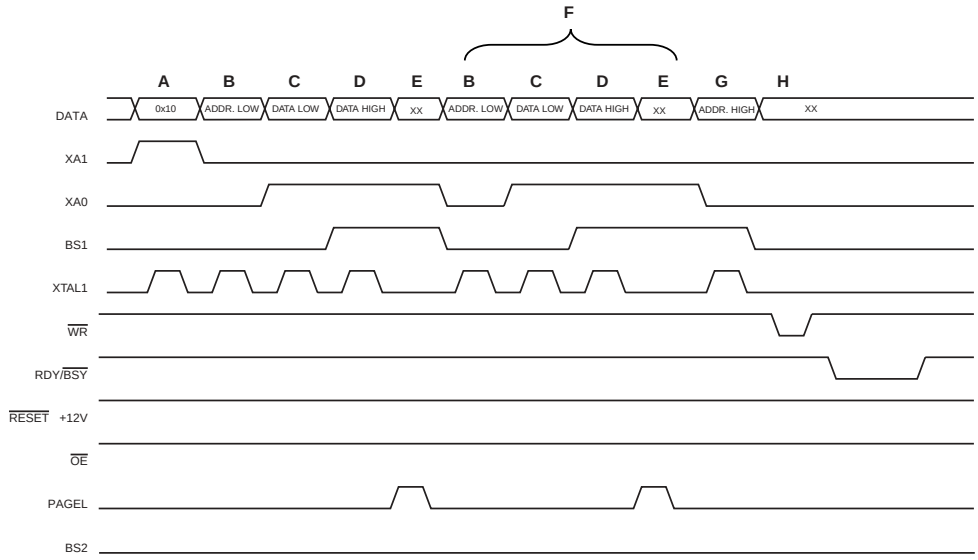
1. 1. Set XA1, XA0 to “10”. This enables command loading.
2. Set DATA to “0000 0000”. This is the command for No Operation.
3. Give XTAL1 a positive pulse. This loads the command, and the internal write signals are reset.

Figure 97. Addressing the Flash which is Organized in Pages(1)



Note: 1. PCPAGE and PCWORD are listed in Table 106 on page 235.

Figure 98. Programming the Flash Waveforms



Note: "XX" is don't care. The letters refer to the programming description above.

Programming the EEPROM

The EEPROM is organized in pages, see Table 107 on page 235. When programming the EEPROM, the program data is latched into a page buffer. This allows one page of data to be programmed simultaneously. The programming algorithm for the EEPROM data memory is as follows (refer to "Programming the Flash" on page 236 for details on Command, Address and Data loading):

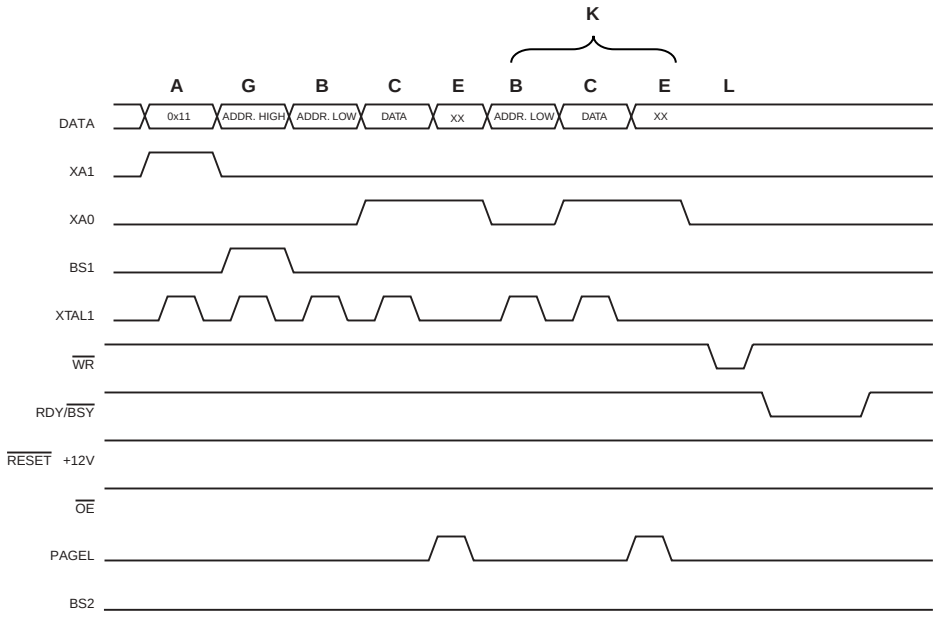
1. A: Load Command "0001 0001".
2. G: Load Address High Byte (0x00 - 0xFF).
3. B: Load Address Low Byte (0x00 - 0xFF).
4. C: Load Data (0x00 - 0xFF).
5. E: Latch data (give PAGEL a positive pulse).

K: Repeat 3 through 5 until the entire buffer is filled.

L: Program EEPROM page

1. Set BS to "0".
2. Give $\overline{WR}$ a negative pulse. This starts programming of the EEPROM page. RDY/$\overline{BSY}$ goes low.
3. Wait until to RDY/$\overline{BSY}$ goes high before programming the next page (See Figure 99 for signal waveforms).

Figure 99. Programming the EEPROM Waveforms



Reading the Flash

The algorithm for reading the Flash memory is as follows (refer to “Programming the Flash” on page 236 for details on Command and Address loading):

1. A: Load Command “0000 0010”.
2. G: Load Address High Byte (0x00 - 0xFF).
3. B: Load Address Low Byte (0x00 - 0xFF).
4. Set $\overline{OE}$ to “0”, and BS1 to “0”. The Flash word low byte can now be read at DATA.
5. Set BS to “1”. The Flash word high byte can now be read at DATA.
6. Set $\overline{OE}$ to “1”.

Reading the EEPROM

The algorithm for reading the EEPROM memory is as follows (refer to “Programming the Flash” on page 236 for details on Command and Address loading):

1. A: Load Command “0000 0011”.
2. G: Load Address High Byte (0x00 - 0xFF).
3. B: Load Address Low Byte (0x00 - 0xFF).
4. Set $\overline{OE}$ to “0”, and BS1 to “0”. The EEPROM Data byte can now be read at DATA.
5. Set $\overline{OE}$ to “1”.

Programming the Fuse Low Bits

The algorithm for programming the Fuse Low bits is as follows (refer to “Programming the Flash” on page 236 for details on Command and Data loading):

1. A: Load Command “0100 0000”.
2. C: Load Data Low Byte. Bit n = “0” programs and bit n = “1” erases the Fuse bit.
3. Set BS1 to “0” and BS2 to “0”. This selects low data byte.
4. Give $\overline{WR}$ a negative pulse and wait for RDY/$\overline{BSY}$ to go high.

Programming the Fuse High Bits

The algorithm for programming the Fuse high bits is as follows (refer to “Programming the Flash” on page 236 for details on Command and Data loading):

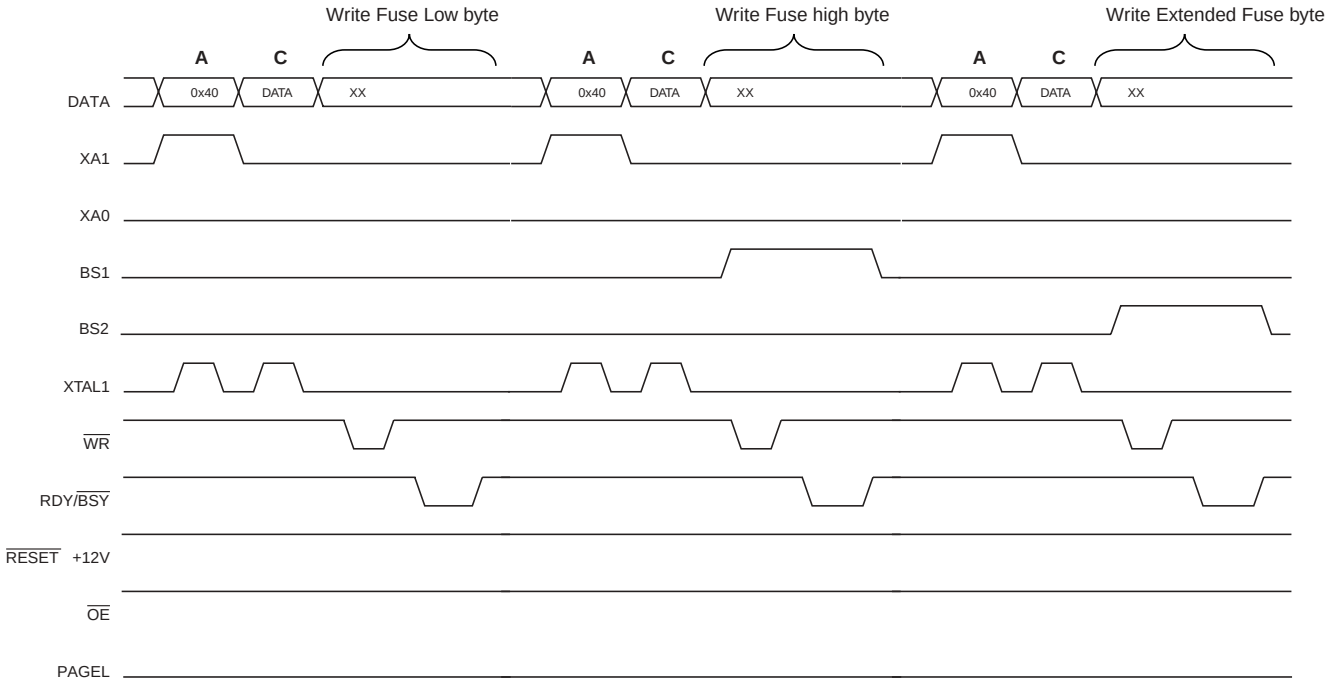
1. A: Load Command “0100 0000”.
2. C: Load Data Low Byte. Bit n = “0” programs and bit n = “1” erases the Fuse bit.
3. Set BS1 to “1” and BS2 to “0”. This selects high data byte.
4. Give $\overline{WR}$ a negative pulse and wait for RDY/$\overline{BSY}$ to go high.
5. Set BS1 to “0”. This selects low data byte.

Programming the Extended Fuse Bits

The algorithm for programming the Extended Fuse bits is as follows (refer to “Programming the Flash” on page 236 for details on Command and Data loading):

1. 1. A: Load Command “0100 0000”.
2. 2. C: Load Data Low Byte. Bit n = “0” programs and bit n = “1” erases the Fuse bit.
3. 3. Set BS1 to “0” and BS2 to “1”. This selects extended data byte.
4. 4. Give $\overline{WR}$ a negative pulse and wait for RDY/$\overline{BSY}$ to go high.
5. 5. Set BS2 to “0”. This selects low data byte.

Figure 100. Programming the FUSES Waveforms



Programming the Lock Bits

The algorithm for programming the Lock bits is as follows (refer to “Programming the Flash” on page 236 for details on Command and Data loading):

1. A: Load Command “0010 0000”.
2. C: Load Data Low Byte. Bit n = “0” programs the Lock bit. If LB mode 3 is programmed (LB1 and LB2 is programmed), it is not possible to program the Boot Lock Bits by any external Programming mode.
3. Give $\overline{WR}$ a negative pulse and wait for RDY/$\overline{BSY}$ to go high.

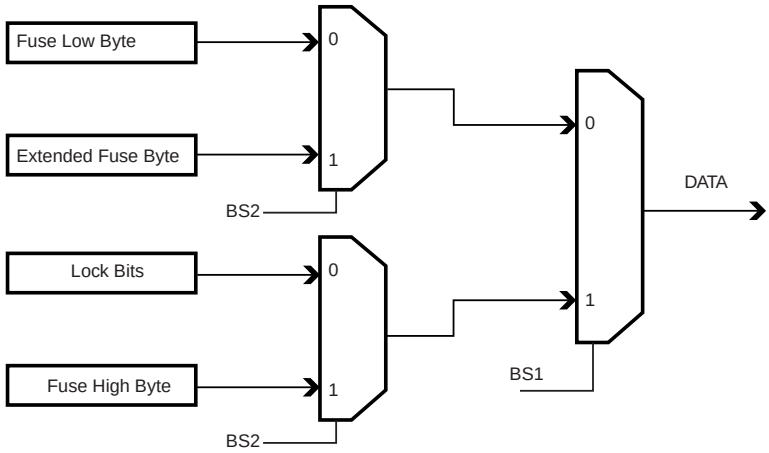
The Lock bits can only be cleared by executing Chip Erase.

Reading the Fuse and Lock Bits

The algorithm for reading the Fuse and Lock bits is as follows (refer to “Programming the Flash” on page 236 for details on Command loading):

1. A: Load Command “0000 0100”.
2. Set $\overline{OE}$ to “0”, BS2 to “0” and BS1 to “0”. The status of the Fuse Low bits can now be read at DATA (“0” means programmed).
3. Set $\overline{OE}$ to “0”, BS2 to “1” and BS1 to “1”. The status of the Fuse High bits can now be read at DATA (“0” means programmed).
4. Set $\overline{OE}$ to “0”, BS2 to “1” and BS1 to “0”. The status of the Extended Fuse bits can now be read at DATA (“0” means programmed).
5. Set $\overline{OE}$ to “0”, BS2 to “0” and BS1 to “1”. The status of the Lock bits can now be read at DATA (“0” means programmed).
6. Set $\overline{OE}$ to “1”.

Figure 101. Mapping Between BS1, BS2 and the Fuse and Lock Bits During Read



Reading the Signature Bytes

The algorithm for reading the signature bytes is as follows (refer to “Programming the Flash” on page 236 for details on Command and Address loading):

1. A: Load Command “0000 1000”.
2. B: Load Address Low Byte (0x00 - 0x02).
3. Set $\overline{OE}$ to “0”, and BS to “0”. The selected Signature byte can now be read at DATA.
4. Set $\overline{OE}$ to “1”.

Reading the Calibration Byte

The algorithm for reading the calibration byte is as follows (refer to “Programming the Flash” on page 236 for details on Command and Address loading):

1. A: Load Command “0000 1000”.
2. B: Load Address Low Byte, 0x00.
3. Set $\overline{OE}$ to “0”, and BS1 to “1”. The Calibration byte can now be read at DATA.
4. Set $\overline{OE}$ to “1”.

Parallel Programming Characteristics

Figure 102. Parallel Programming Timing, Including some General Timing Requirements

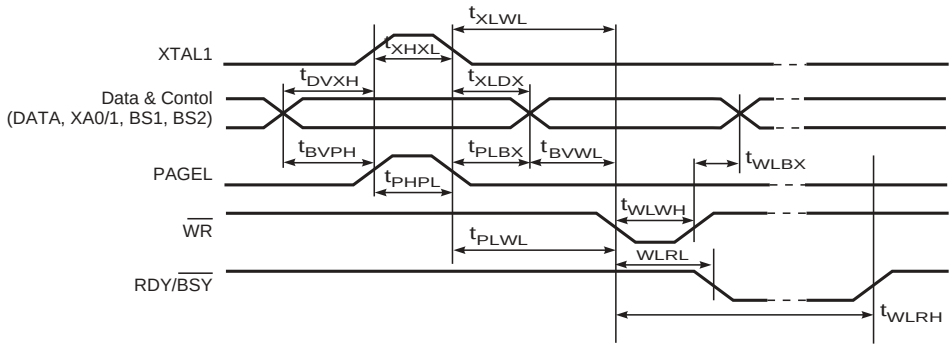
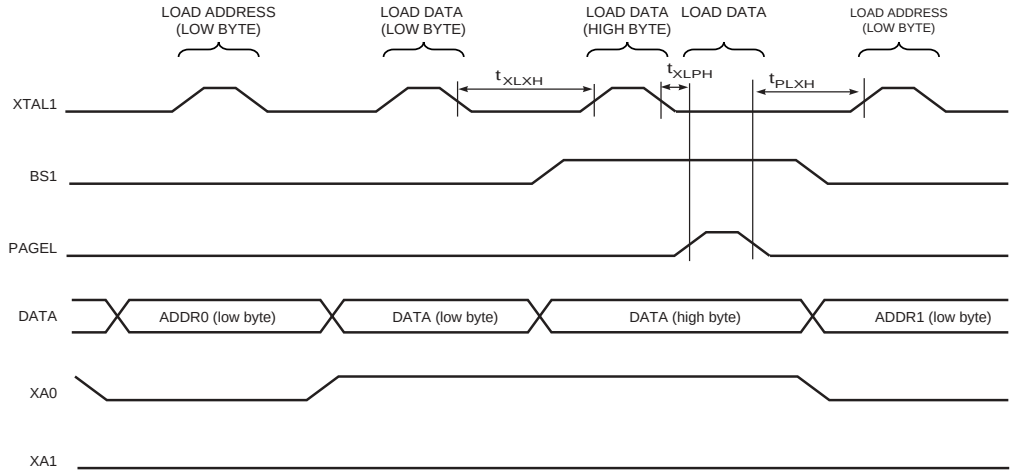
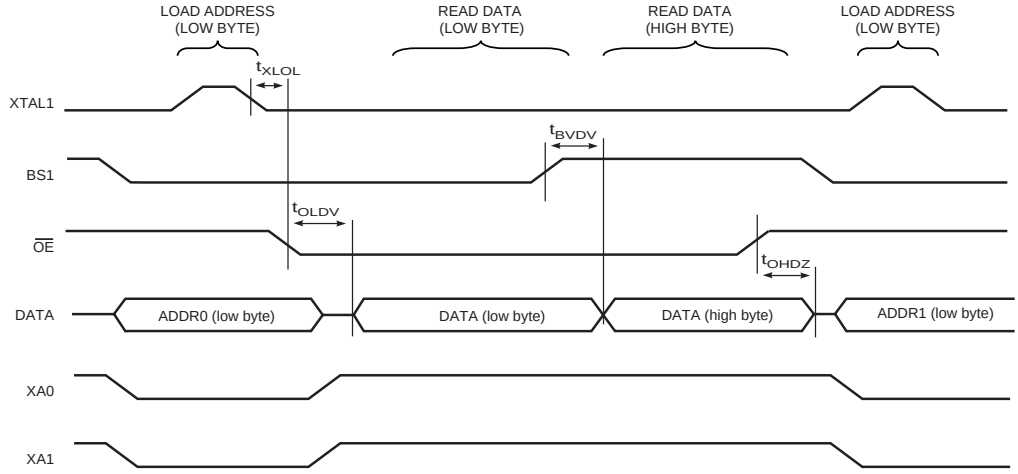


Figure 103. Parallel Programming Timing, Loading Sequence with Timing Requirements[1]



Note: 1. The timing requirements shown in Figure 102 (i.e., t_{DVXH}, t_{XHXL}, and t_{XLDX}) also apply to loading operation.

Figure 104. Parallel Programming Timing, Reading Sequence (within the Same Page) with Timing Requirements(1)



Note: 1. The timing requirements shown in Figure 102 (i.e., t_{DVXH}, t_{XHXL}, and t_{XLDX}) also apply to reading operation.

Table 108. Parallel Programming Characteristics, V_{CC} = 5 V ± 10%

Symbol	Parameter	Min	Typ	Max	Units
V_{PP}	Programming Enable Voltage	11.5		12.5	V
I_{PP}	Programming Enable Current			250	µA
t_{DVXH}	Data and Control Valid before XTAL1 High	67			ns
t_{XLXH}	XTAL1 Low to XTAL1 High	200			ns
t_{XHXL}	XTAL1 Pulse Width High	150			ns
t_{XLDX}	Data and Control Hold after XTAL1 Low	67			ns
t_{XLWL}	XTAL1 Low to $\overline{WR}$ Low	0			ns
t_{XLPH}	XTAL1 Low to PAGEL high	0			ns
t_{PLXH}	PAGEL low to XTAL1 high	150			ns
t_{BVPH}	BS1 Valid before PAGEL High	67			ns
t_{PHPL}	PAGEL Pulse Width High	150			ns
t_{PLBX}	BS1 Hold after PAGEL Low	67			ns
t_{WLBX}	BS2/1 Hold after $\overline{WR}$ Low	67			ns
t_{PLWL}	PAGEL Low to $\overline{WR}$ Low	67			ns
t_{BVWL}	BS1 Valid to $\overline{WR}$ Low	67			ns
t_{WLWH}	$\overline{WR}$ Pulse Width Low	150			ns
t_{WLRL}	$\overline{WR}$ Low to RDY/$\overline{BSY}$ Low	0		1	µs
t_{WLRH}	$\overline{WR}$ Low to RDY/$\overline{BSY}$ High(1)	3.7		4.5	ms
t_{WLRH_CE}	$\overline{WR}$ Low to RDY/$\overline{BSY}$ High for Chip Erase(2)	7.5		9	ms
t_{XLOL}	XTAL1 Low to $\overline{OE}$ Low	0			ns

Table 108. Parallel Programming Characteristics, V_{CC} = 5 V ± 10% (Continued)

Symbol	Parameter	Min	Typ	Max	Units
t_{BVDV}	BS1 Valid to DATA valid	0		250	ns
t_{OLDV}	$\overline{OE}$ Low to DATA Valid			250	ns
t_{OHDZ}	$\overline{OE}$ High to DATA Tri-stated			250	ns

Notes: 1. t_{WLRH} is valid for the Write Flash, Write EEPROM, Write Fuse Bits and Write Lock Bits commands.
2. t_{WLRH_CE} is valid for the Chip Erase command.

Serial Downloading

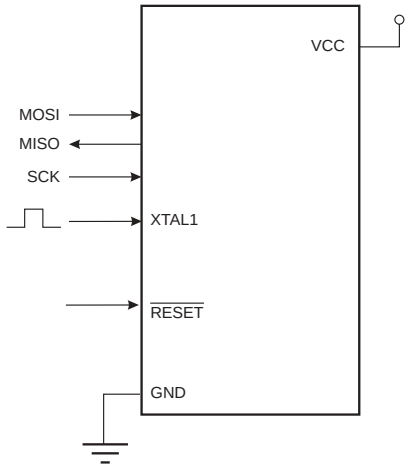
SPI Serial Programming Pin Mapping

Table 109. Pin Mapping SPI Serial Programming

Symbol	Pins	I/O	Description
MOSI	PB5	I	Serial Data in
MISO	PB6	O	Serial Data out
SCK	PB7	I	Serial Clock

Both the Flash and EEPROM memory arrays can be programmed using the serial SPI bus while $\overline{RESET}$ is pulled to GND. The serial interface consists of pins SCK, MOSI (input) and MISO (output). After $\overline{RESET}$ is set low, the Programming Enable instruction needs to be executed first before program/erase operations can be executed. NOTE, in Table 109 on page 244, the pin mapping for SPI programming is listed. Not all parts use the SPI pins dedicated for the internal SPI interface.

Figure 105. SPI Serial Programming and Verify(1)



Note: 1. If the device is clocked by the Internal Oscillator, it is no need to connect a clock source to the XTAL1 pin.

When programming the EEPROM, an auto-erase cycle is built into the self-timed programming operation (in the Serial mode ONLY) and there is no need to first execute the Chip Erase instruction. The Chip Erase operation turns the content of every memory location in both the Program and EEPROM arrays into 0xFF.

Depending on CKSEL Fuses, a valid clock must be present. The minimum low and high periods for the serial clock (SCK) input are defined as follows:

Low:> 2 CPU clock cycles for f_{ck} < 12 MHz, 3 CPU clock cycles for f_{ck} >= 12 MHz

High:> 2 CPU clock cycles for f_{ck} < 12 MHz, 3 CPU clock cycles for f_{ck} >= 12 MHz

SPI Serial Programming Algorithm

When writing serial data to the ATmega162, data is clocked on the rising edge of SCK.

When reading data from the ATmega162, data is clocked on the falling edge of SCK. See Figure 106.

To program and verify the ATmega162 in the SPI Serial Programming mode, the following sequence is recommended (See four byte instruction formats in Table 111):

1. Power-up sequence:
   Apply power between V_{CC} and GND while $\overline{\text{RESET}}$ and SCK are set to “0”. In some systems, the programmer can not guarantee that SCK is held low during Power-up. In this case, $\overline{\text{RESET}}$ must be given a positive pulse of at least two CPU clock cycles duration after SCK has been set to “0”.
2. Wait for at least 20 ms and enable SPI Serial Programming by sending the Programming Enable serial instruction to pin MOSI.
3. The SPI Serial Programming instructions will not work if the communication is out of synchronization. When in sync. the second byte (0x53), will echo back when issuing the third byte of the Programming Enable instruction. Whether the echo is correct or not, all four bytes of the instruction must be transmitted. If the 0x53 did not echo back, give $\overline{\text{RESET}}$ a positive pulse and issue a new Programming Enable command.
4. The Flash is programmed one page at a time. The page size is found in Table 106 on page 235. The memory page is loaded one byte at a time by supplying the 6 LSB of the address and data together with the Load Program Memory Page instruction. To ensure correct loading of the page, the data low byte must be loaded before data high byte is applied for a given address. The Program Memory Page is stored by loading the Write Program Memory Page instruction with the 8 MSB of the address. If polling is not used, the user must wait at least t_{WD_FLASH} before issuing the next page. (See Table 110.) Accessing the SPI serial programming interface before the Flash write operation completes can result in incorrect programming.
5. The EEPROM array can either be programmed one page at a time or it can be programmed byte by byte.

For Page Programming, the following algorithm is used:

The EEPROM memory page is loaded one byte at a time by supplying the 2 LSB of the address and data together with the Load EEPROM Memory Page instruction. The EEPROM Memory Page is stored by loading the Write EEPROM Memory Page instruction with the 8 MSB of the address. If polling is not used, the user must wait at least t_{WD_EEPROM} before issuing the next page. (See Table 100.) Accessing the SPI Serial Programming interface before the EEPROM write operation completes can result in incorrect programming.

Alternatively, the EEPROM can be programmed bytewise:

The EEPROM array is programmed one byte at a time by supplying the address and data together with the Write EEPROM instruction. An EEPROM memory location is first automatically erased before new data is written. If polling is not used, the user must wait at least t_{WD_EEPROM} before issuing the next byte. (See Table 110.) In a chip erased device, no 0xFFs in the data file(s) need to be programmed.

6. Any memory location can be verified by using the Read instruction which returns the content at the selected address at serial output MISO.
7. At the end of the programming session, $\overline{\text{RESET}}$ can be set high to commence normal operation.
8. Power-off sequence (if needed):
   Set $\overline{\text{RESET}}$ to “1”.
   Turn V_{CC} power off.

Data Polling Flash

When a page is being programmed into the Flash, reading an address location within the page being programmed will give the value 0xFF. At the time the device is ready for a new page, the programmed value will read correctly. This is used to determine when the next page can be written. Note that the entire page is written simultaneously and any address within the page can be used for polling. Data polling of the Flash will not work for the value 0xFF, so when programming this value, the user will have to wait for at least t_{WD_FLASH} before programming the next page. As a chip erased device contains 0xFF in all locations, programming of addresses that are meant to contain 0xFF, can be skipped. See Table 110 for t_{WD_FLASH} value.

Data Polling EEPROM

When a new byte has been written and is being programmed into EEPROM, reading the address location being programmed will give the value 0xFF. At the time the device is ready for a new byte, the programmed value will read correctly. This is used to determine when the next byte can be written. This will not work for the value 0xFF, but the user should have the following in mind: As a chip erased device contains 0xFF in all locations, programming of addresses that are meant to contain 0xFF, can be skipped. This does not apply if the EEPROM is re-programmed without chip erasing the device. In this case, data polling cannot be used for the value 0xFF, and the user will have to wait at least t_{WD_EEPROM} before programming the next byte. See Table 110 for t_{WD_EEPROM} value.

Table 110. Minimum Wait Delay before Writing the Next Flash or EEPROM Location

Symbol	Minimum Wait Delay
t_{WD_FLASH}	4.5 ms
t_{WD_EEPROM}	9.0 ms
t_{WD_ERASE}	9.0 ms
t_{WD_FUSE}	4.5 ms

Figure 106. SPI Serial Programming Waveforms

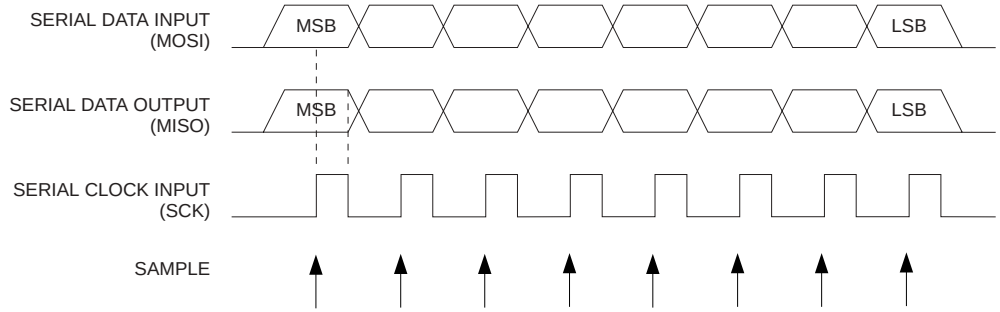


Table 111. SPI Serial Programming Instruction Set[1]

Instruction	Instruction Format				Operation
	Byte 1	Byte 2	Byte 3	Byte4	
Programming Enable	1010 1100	0101 0011	xxxx xxxx	xxxx xxxx	Enable SPI Serial Programming after $\overline{\text{RESET}}$ goes low.
Chip Erase	1010 1100	100x xxxx	xxxx xxxx	xxxx xxxx	Chip Erase EEPROM and Flash.
Read Program Memory	0010 **H**000	00**aa aaaa**	**bbbb bbbb**	**oooo oooo**	Read **H** (high or low) data **o** from Program memory at word address **a**:**b**.
Load Program Memory Page	0100 **H**000	00xx xxxx	xx**bb bbbb**	**iiii iiii**	Write **H** (high or low) data **i** to Program Memory page at word address **b**. Data low byte must be loaded before Data high byte is applied within the same address.
Write Program Memory Page	0100 1100	00**aa aaaa**	**bb**xx xxxx	xxxx xxxx	Write Program Memory Page at address **a**:**b**.
Read EEPROM Memory	1010 0000	00xx xx**aa**	**bbbb bbbb**	**oooo oooo**	Read data **o** from EEPROM memory at address **a**:**b**.
Write EEPROM Memory (byte access)	1100 0000	00xx xx**aa**	**bbbb bbbb**	**iiii iiii**	Write data **i** to EEPROM memory at address **a**:**b**.
Load EEPROM Memory Page (page access)	1100 0001	0000 0000	0000 00**bb**	**iiii iiii**	Load data **i** to EEPROM memory page buffer. After data is loaded, program EEPROM page.
Write EEPROM Memory Page (page access)	1100 0010	00xx xx**aa**	**bbbb bb**00	xxxx xxxx	Write EEPROM page at address **a**:**b**.
Read Lock Bits	0101 1000	0000 0000	xxxx xxxx	xx**oo oooo**	Read Lock bits. “0” = programmed, “1” = unprogrammed. See Table 97 on page 230 for details.
Write Lock Bits	1010 1100	111x xxxx	xxxx xxxx	11**ii iiii**	Write Lock bits. Set bits = “0” to program Lock bits. See Table 97 on page 230 for details.
Read Signature Byte	0011 0000	00xx xxxx	xxxx xx**bb**	**oooo oooo**	Read Signature Byte **o** at address **b**.
Write Fuse Bits	1010 1100	1010 0000	xxxx xxxx	**iiii iiii**	Set bits = “0” to program, “1” to unprogram. See Table 101 on page 232 for details.
Write Fuse High Bits	1010 1100	1010 1000	xxxx xxxx	**iiii iiii**	Set bits = “0” to program, “1” to unprogram. See Table 100 on page 232 for details.
Write Extended Fuse Bits	1010 1100	1010 0100	xxxx xxxx	**xxxx xxii**	Set bits = “0” to program, “1” to unprogram. See Table 99 on page 231 for details.
Read Fuse Bits	0101 0000	0000 0000	xxxx xxxx	**oooo oooo**	Read Fuse bits. “0” = programmed, “1” = unprogrammed. See Table 101 on page 232 for details.

Table 111. SPI Serial Programming Instruction Set[1] (Continued)

Instruction	Instruction Format				Operation
	Byte 1	Byte 2	Byte 3	Byte4	
Read Fuse High Bits	0101 1000	0000 1000	xxxx xxxx	**oooo oooo**	Read Fuse high bits. “0” = pro-grammed, “1” = unprogrammed. See Table 100 on page 232 for details.
Read Extended Fuse Bits	0101 0000	0000 1000	xxxx xxxx	**oooo oooo**	Read Extended Fuse bits. “0” = pro-grammed, “1” = unprogrammed. See Table 99 on page 231 for details.
Read Calibration Byte	0011 1000	00xx xxxx	0000 0000	**oooo oooo**	Read Calibration Byte
Poll RDY/$\overline{\text{BSY}}$	1111 0000	0000 0000	xxxx xxxx	xxxx xxx**o**	If **o** = “1”, a programming operation is still busy. Wait until this bit returns to “0” before applying another command.

Note: 1. **a** = address high bits, **b** = address low bits, **H** = 0 – Low byte, 1 – High Byte, **o** = data out, **i** = data in, x = don’t care

SPI Serial Programming Characteristics

For characteristics of the SPI module, see “SPI Timing Characteristics” on page 267.

Programming via the JTAG Interface

Programming through the JTAG interface requires control of the four JTAG specific pins: TCK, TMS, TDI, and TDO. Control of the Reset and clock pins is not required.

To be able to use the JTAG interface, the JTAGEN Fuse must be programmed. The device is default shipped with the Fuse programmed. In addition, the JTD bit in MCUCSR must be cleared. Alternatively, if the JTD bit is set, the External Reset can be forced low. Then, the JTD bit will be cleared after two chip clocks, and the JTAG pins are available for programming. This provides a means of using the JTAG pins as normal port pins in running mode while still allowing In-System Programming via the JTAG interface. Note that this technique can not be used when using the JTAG pins for Boundary-scan or On-chip Debug. In these cases the JTAG pins must be dedicated for this purpose.

As a definition in this datasheet, the LSB is shifted in and out first of all Shift Registers.

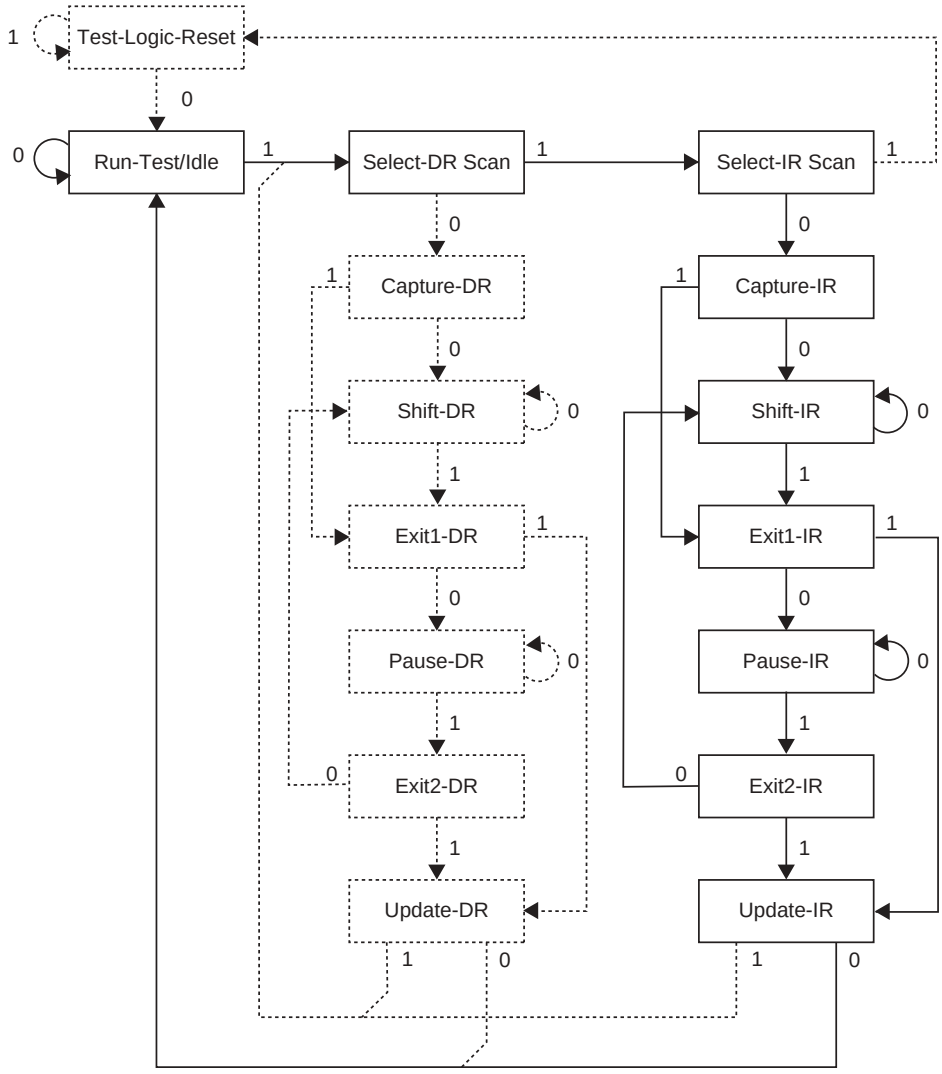
Programming Specific JTAG Instructions

The Instruction Register is 4-bit wide, supporting up to 16 instructions. The JTAG instructions useful for Programming are listed below.

The OPCODE for each instruction is shown behind the instruction name in hex format. The text describes which Data Register is selected as path between TDI and TDO for each instruction.

The Run-Test/Idle state of the TAP controller is used to generate internal clocks. It can also be used as an idle state between JTAG sequences. The state machine sequence for changing the instruction word is shown in Figure 107.

Figure 107. State machine sequence for changing the instruction word



AVR_RESET (0xC)

The AVR specific public JTAG instruction for setting the AVR device in the Reset mode or taking the device out from the Reset mode. The TAP controller is not reset by this instruction. The one bit Reset Register is selected as data register. Note that the reset will be active as long as there is a logic “one” in the Reset Chain. The output from this chain is not latched.

The active states are:

- Shift-DR: The Reset Register is shifted by the TCK input.

PROG_ENABLE (0x4)

The AVR specific public JTAG instruction for enabling programming via the JTAG port. The 16-bit Programming Enable Register is selected as data register. The active states are the following:

- Shift-DR: The programming enable signature is shifted into the Data Register.
- Update-DR: The programming enable signature is compared to the correct value, and Programming mode is entered if the signature is valid.

PROG_COMMANDS (0x5)

The AVR specific public JTAG instruction for entering programming commands via the JTAG port. The 15-bit Programming Command Register is selected as data register. The active states are the following:

- Capture-DR: The result of the previous command is loaded into the Data Register.
- Shift-DR: The Data Register is shifted by the TCK input, shifting out the result of the previous command and shifting in the new command.
- Update-DR: The programming command is applied to the Flash inputs.
- Run-Test/Idle: One clock cycle is generated, executing the applied command (not always required, see Table 112 below).

PROG_PAGELOAD (0x6)

The AVR specific public JTAG instruction to directly load the Flash data page via the JTAG port. The 1024 bit Virtual Flash Page Load Register is selected as register. This is a virtual scan chain with length equal to the number of bits in one Flash page. Internally the Shift Register is 8-bit. Unlike most JTAG instructions, the Update-DR state is not used to transfer data from the Shift Register. The data are automatically transferred to the Flash page buffer byte-by-byte in the Shift-DR state by an internal state machine. This is the only active state:

- Shift-DR: Flash page data are shifted in from TDI by the TCK input, and automatically loaded into the Flash page one byte at a time.

Note: The JTAG instruction PROG_PAGELOAD can only be used if the AVR device is the first device in JTAG scan chain. If the AVR cannot be the first device in the scan chain, the byte-wise programming algorithm must be used.

PROG_PAGEREAD (0x7)

The AVR specific public JTAG instruction to read one full Flash data page via the JTAG port. The 1032 bit Virtual Flash Page Read Register is selected as data register. This is a virtual scan chain with length equal to the number of bits in one Flash page plus eight. Internally the Shift Register is 8-bit. Unlike most JTAG instructions, the Capture-DR state is not used to transfer data to the Shift Register. The data are automatically transferred from the Flash page buffer byte-by-byte in the Shift-DR state by an internal state machine. This is the only active state:

- Shift-DR: Flash data are automatically read one byte at a time and shifted out on TDO by the TCK input. The TDI input is ignored.

Note: The JTAG instruction PROG_PAGEREAD can only be used if the AVR device is the first device in JTAG scan chain. If the AVR cannot be the first device in the scan chain, the byte-wise programming algorithm must be used.

Data Registers

The Data Registers are selected by the JTAG Instruction Registers described in section “Programming Specific JTAG Instructions” on page 249. The Data Registers relevant for programming operations are:

- Reset Register
- Programming Enable Register.
- Programming Command Register.
- Virtual Flash Page Load Register.
- Virtual Flash Page Read Register.

Reset Register

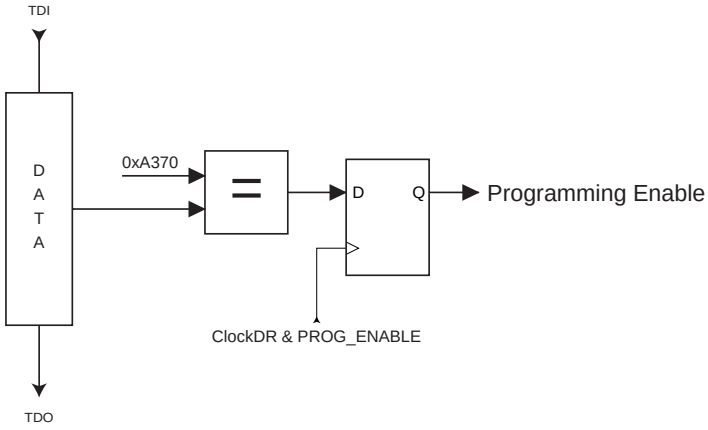
The Reset Register is a test data register used to reset the part during programming. It is required to reset the part before entering Programming mode.

A high value in the Reset Register corresponds to pulling the external reset low. The part is reset as long as there is a high value present in the Reset Register. Depending on the fuse settings for the clock options, the part will remain reset for a Reset Time-out period (refer to “Clock Sources” on page 34) after releasing the Reset Register. The output from this data register is not latched, so the reset will take place immediately, as shown in Figure 86 on page 205.

Programming Enable Register

The Programming Enable Register is a 16-bit register. The contents of this register is compared to the programming enable signature, binary code 1010_0011_0111_0000. When the contents of the register is equal to the programming enable signature, programming via the JTAG port is enabled. The register is reset to 0 on Power-on Reset, and should always be reset when leaving Programming mode.

Figure 108. Programming Enable Register



Programming Command Register

The Programming Command Register is a 15-bit register. This register is used to serially shift in programming commands, and to serially shift out the result of the previous command, if any. The JTAG Programming Instruction Set is shown in Table 112. The state sequence when shifting in the programming commands is illustrated in Figure 110.

Figure 109. Programming Command Register

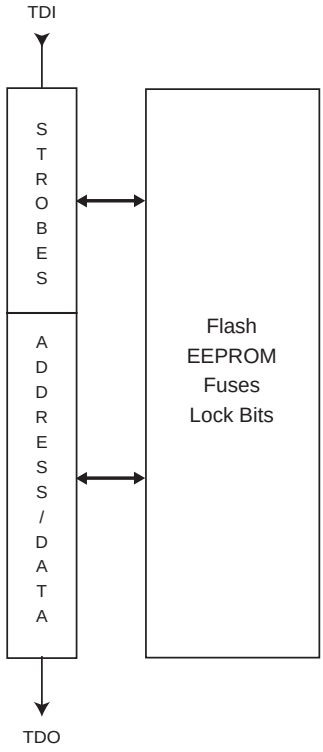


Table 112. JTAG Programming Instruction Set

Instruction	TDI sequence	TDO sequence	Notes
1a. Chip eRase	0100011_10000000 0110001_10000000 0110011_10000000 0110011_10000000	xxxxxxx_xxxxxxxx xxxxxxx_xxxxxxxx xxxxxxx_xxxxxxxx xxxxxxx_xxxxxxxx	
1b. Poll for Chip Erase complete	0110011_10000000	xxxxx**o**x_xxxxxxxx	(2)
2a. Enter Flash Write	0100011_00010000	xxxxxxx_xxxxxxxx	
2b. Load Address High Byte	0000111_**aaaaaaaa**	xxxxxxx_xxxxxxxx	(9)
2c. Load Address Low Byte	0000011_**bbbbbbbb**	xxxxxxx_xxxxxxxx	
2d. Load Data Low Byte	0010011_**iiiiiiii**	xxxxxxx_xxxxxxxx	
2e. Load Data High Byte	0010111_**iiiiiiii**	xxxxxxx_xxxxxxxx	
2f. Latch Data	0110111_00000000 1110111_00000000 0110111_00000000	xxxxxxx_xxxxxxxx xxxxxxx_xxxxxxxx xxxxxxx_xxxxxxxx	(1)
2g. Write Flash Page	0110111_00000000 0110101_00000000 0110111_00000000 0110111_00000000	xxxxxxx_xxxxxxxx xxxxxxx_xxxxxxxx xxxxxxx_xxxxxxxx xxxxxxx_xxxxxxxx	(1)
2h. Poll for Page Write complete	0110111_00000000	xxxxx**o**x_xxxxxxxx	(2)
3a. Enter Flash Read	0100011_00000010	xxxxxxx_xxxxxxxx	
3b. Load Address High Byte	0000111_**aaaaaaaa**	xxxxxxx_xxxxxxxx	(9)
3c. Load Address Low Byte	0000011_**bbbbbbbb**	xxxxxxx_xxxxxxxx	
3d. Read Data Low and High Byte	0110010_00000000 0110110_00000000 0110111_00000000	xxxxxxx_xxxxxxxx xxxxxxx_**oooooooo** xxxxxxx_**oooooooo**	 low byte high byte
4a. Enter EEPROM Write	0100011_00010001	xxxxxxx_xxxxxxxx	
4b. Load Address High Byte	0000111_**aaaaaaaa**	xxxxxxx_xxxxxxxx	(9)
4c. Load Address Low Byte	0000011_**bbbbbbbb**	xxxxxxx_xxxxxxxx	
4d. Load Data Byte	0010011_**iiiiiiii**	xxxxxxx_xxxxxxxx	
4e. Latch Data	0110111_00000000 1110111_00000000 0110111_00000000	xxxxxxx_xxxxxxxx xxxxxxx_xxxxxxxx xxxxxxx_xxxxxxxx	(1)
4f. Write EEPROM Page	0110011_00000000 0110001_00000000 0110011_00000000 0110011_00000000	xxxxxxx_xxxxxxxx xxxxxxx_xxxxxxxx xxxxxxx_xxxxxxxx xxxxxxx_xxxxxxxx	(1)
4g. Poll for Page Write complete	0110011_00000000	xxxxx**o**x_xxxxxxxx	(2)
5a. Enter EEPROM Read	0100011_00000011	xxxxxxx_xxxxxxxx	
5b. Load Address High Byte	0000111_**aaaaaaaa**	xxxxxxx_xxxxxxxx	(9)
5c. Load Address Low Byte	0000011_**bbbbbbbb**	xxxxxxx_xxxxxxxx	

Table 112. JTAG Programming Instruction Set (Continued)

Instruction	TDI sequence	TDO sequence	Notes
5d. Read Data Byte	0110011_**bbbbbbbb** 0110010_00000000 0110011_00000000	xxxxxxx_xxxxxxxx xxxxxxx_xxxxxxxx xxxxxxx_**oooooooo**	
6a. Enter Fuse Write	0100011_01000000	xxxxxxx_xxxxxxxx	
6b. Load Data Low Byte(6)	0010011_**iiiiiiii**	xxxxxxx_xxxxxxxx	(3)
6c. Write Fuse Extended Byte	0111011_00000000 0111001_00000000 0111011_00000000 0111011_00000000	xxxxxxx_xxxxxxxx xxxxxxx_xxxxxxxx xxxxxxx_xxxxxxxx xxxxxxx_xxxxxxxx	(1)
6d. Poll for Fuse Write complete	0110111_00000000	xxxxx**o**x_xxxxxxxx	(2)
6e. Load Data Low Byte(7)	0010011_**iiiiiiii**	xxxxxxx_xxxxxxxx	(3)
6f. Write Fuse High byte	0110111_00000000 0110101_00000000 0110111_00000000 0110111_00000000	xxxxxxx_xxxxxxxx xxxxxxx_xxxxxxxx xxxxxxx_xxxxxxxx xxxxxxx_xxxxxxxx	(1)
6g. Poll for Fuse Write complete	0110111_00000000	xxxxx**o**x_xxxxxxxx	(2)
6h. Load Data Low Byte(8)	0010011_**iiiiiiii**	xxxxxxx_xxxxxxxx	(3)
6i. Write Fuse Low Byte	0110011_00000000 0110001_00000000 0110011_00000000 0110011_00000000	xxxxxxx_xxxxxxxx xxxxxxx_xxxxxxxx xxxxxxx_xxxxxxxx xxxxxxx_xxxxxxxx	(1)
6j. Poll for Fuse Write complete	0110011_00000000	xxxxx**o**x_xxxxxxxx	(2)
7a. Enter Lock Bit Write	0100011_00100000	xxxxxxx_xxxxxxxx	
7b. Load Data Byte(9)	0010011_11**iiiiii**	xxxxxxx_xxxxxxxx	(4)
7c. Write Lock Bits	0110011_00000000 0110001_00000000 0110011_00000000 0110011_00000000	xxxxxxx_xxxxxxxx xxxxxxx_xxxxxxxx xxxxxxx_xxxxxxxx xxxxxxx_xxxxxxxx	(1)
7d. Poll for Lock Bit Write complete	0110011_00000000	xxxxx**o**x_xxxxxxxx	(2)
8a. Enter Fuse/Lock Bit Read	0100011_00000100	xxxxxxx_xxxxxxxx	
8b. Read Fuse Extended Byte(6)	0111010_00000000 0111111_00000000	xxxxxxx_xxxxxxxx xxxxxxx_**oooooooo**	
8c. Read Fuse High Byte(7)	0111110_00000000 0111111_00000000	xxxxxxx_xxxxxxxx xxxxxxx_**oooooooo**	
8d. Read Fuse Low Byte(8)	0110010_00000000 0110011_00000000	xxxxxxx_xxxxxxxx xxxxxxx_**oooooooo**	
8e. Read Lock Bits(9)	0110110_00000000 0110111_00000000	xxxxxxx_xxxxxxxx xxxxxxx_xx**oooooo**	(5)

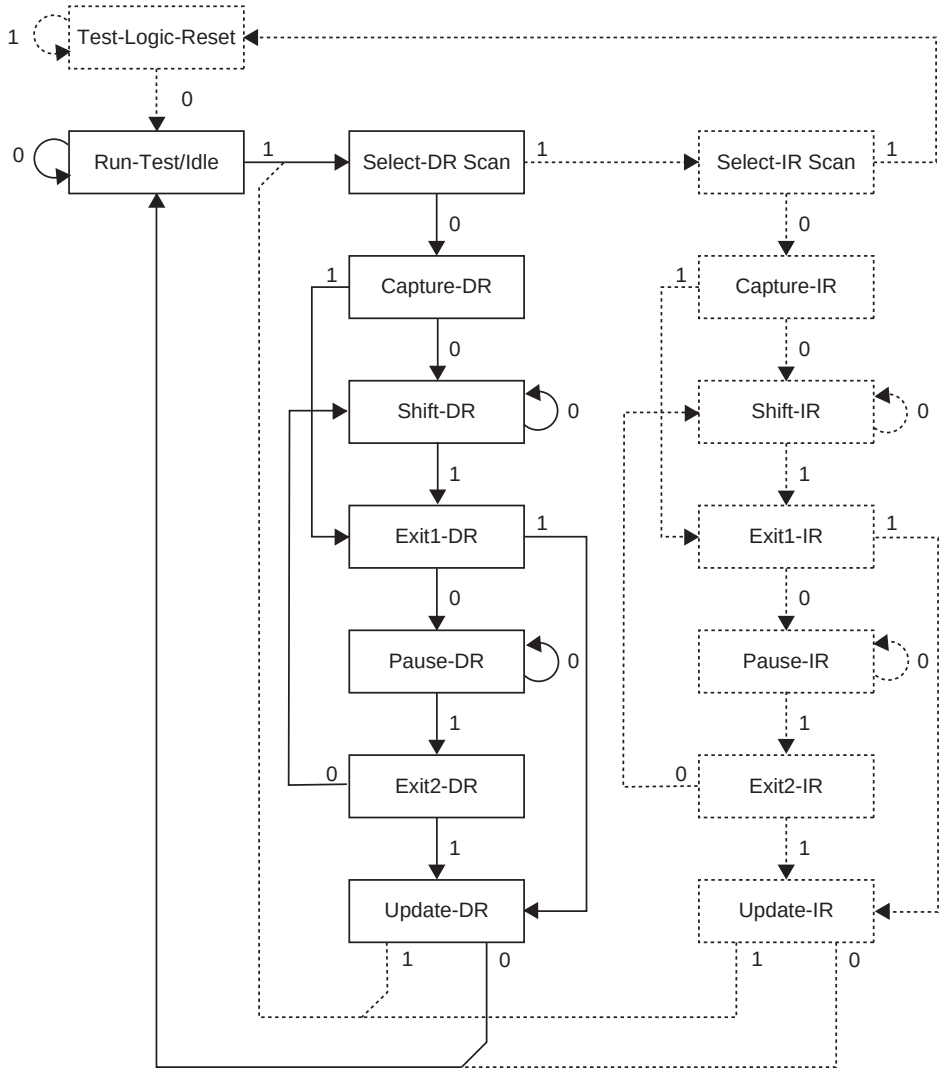
Table 112. JTAG Programming Instruction Set (Continued)

Instruction	TDI sequence	TDO sequence	Notes
8f. Read Fuses and Lock Bits	0111010_00000000 0111110_00000000 0110010_00000000 0110110_00000000 0110111_00000000	xxxxxxx_xxxxxxxx xxxxxxx_**oooooooo** xxxxxxx_**oooooooo** xxxxxxx_**oooooooo** xxxxxxx_**oooooooo**	(5) Fuse ext. byte Fuse high byte Fuse low byte Lock bits
9a. Enter Signature Byte Read	0100011_00001000	xxxxxxx_xxxxxxxx	
9b. Load Address Byte	0000011_**bbbbbbbb**	xxxxxxx_xxxxxxxx	
9c. Read Signature Byte	0110010_00000000 0110011_00000000	xxxxxxx_xxxxxxxx xxxxxxx_**oooooooo**	
10a. Enter Calibration Byte Read	0100011_00001000	xxxxxxx_xxxxxxxx	
10b. Load Address Byte	0000011_**bbbbbbbb**	xxxxxxx_xxxxxxxx	
10c. Read Calibration Byte	0110110_00000000 0110111_00000000	xxxxxxx_xxxxxxxx xxxxxxx_**oooooooo**	
11a. Load No Operation Command	0100011_00000000 0110011_00000000	xxxxxxx_xxxxxxxx xxxxxxx_xxxxxxxx	

Notes:
1. This command sequence is not required if the seven MSB are correctly set by the previous command sequence (which is normally the case).
2. Repeat until **o** = “1”.
3. Set bits to “0” to program the corresponding Fuse, “1” to unprogram the Fuse.
4. Set bits to “0” to program the corresponding lock bit, “1” to leave the Lock bit unchanged.
5. “0” = programmed, “1” = unprogrammed.
6. The bit mapping for Fuses Extended byte is listed in Table 99 on page 231.
7. The bit mapping for Fuses High byte is listed in Table 100 on page 232.
8. The bit mapping for Fuses Low byte is listed in Table 101 on page 232.
9. The bit mapping for Lock Bits byte is listed in Table 97 on page 230.
10. Address bits exceeding PCMSB and EEAMSB (Table 106 and Table 107) are don’t care

Note:
a = address high bits
b = address low bits
H = 0 – Low byte, 1 – High Byte
o = data out
i = data in
x = don’t care

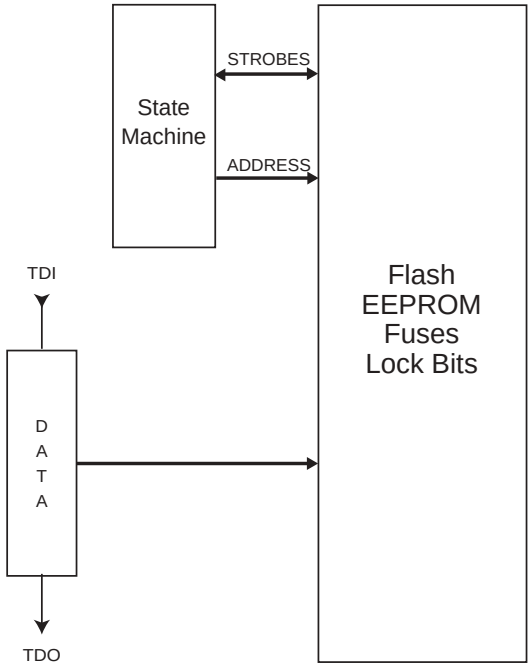
Figure 110. State Machine Sequence for Changing/Reading the Data Word



Virtual Flash Page Load Register

The Virtual Flash Page Load Register is a virtual scan chain with length equal to the number of bits in one Flash page. Internally the Shift Register is 8-bit, and the data are automatically transferred to the Flash page buffer byte-by-byte. Shift in all instruction words in the page, starting with the LSB of the first instruction in the page and ending with the MSB of the last instruction in the page. This provides an efficient way to load the entire Flash page buffer before executing Page Write.

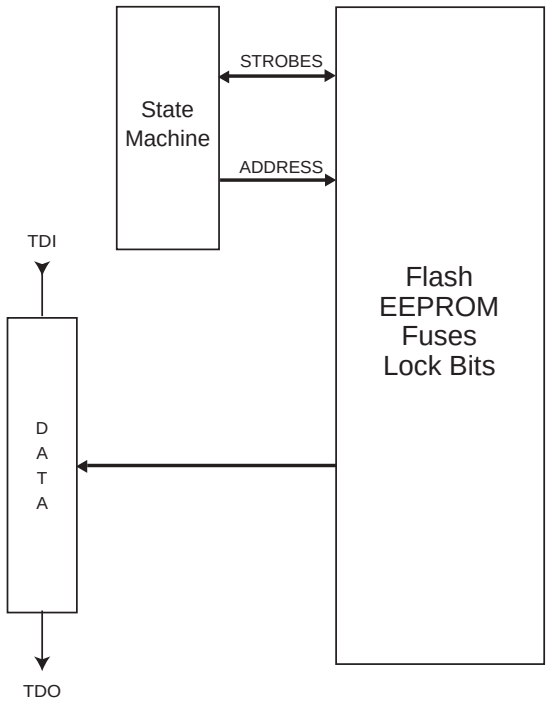
Figure 111. Virtual Flash Page Load Register



Virtual Flash Page Read Register

The Virtual Flash Page Read Register is a virtual scan chain with length equal to the number of bits in one Flash page plus eight. Internally the Shift Register is 8-bit, and the data are automatically transferred from the Flash data page byte-by-byte. The first eight cycles are used to transfer the first byte to the internal Shift Register, and the bits that are shifted out during these right cycles should be ignored. Following this initialization, data are shifted out starting with the LSB of the first instruction in the page and ending with the MSB of the last instruction in the page. This provides an efficient way to read one full Flash page to verify programming.

Figure 112. Virtual Flash Page Read Register



Programming Algorithm

All references below of type “1a”, “1b”, and so on, refer to Table 112.

Entering Programming Mode

1. Enter JTAG instruction AVR_RESET and shift one in the Reset Register.
2. Enter instruction PROG_ENABLE and shift 1010_0011_0111_0000 in the Programming Enable Register.

Leaving Programming Mode

1. Enter JTAG instruction PROG_COMMANDS.
2. Disable all programming instructions by using no operation instruction 11a.
3. Enter instruction PROG_ENABLE and shift 0000_0000_0000_0000 in the Programming Enable Register.
4. Enter JTAG instruction AVR_RESET and shift 0 in the Reset Register.

Performing Chip Erase

1. Enter JTAG instruction PROG_COMMANDS.
2. Start Chip Erase using programming instruction 1a.
3. Poll for Chip Erase complete using programming instruction 1b, or wait for t_{WLRH_CE} (refer to Table 108 on page 243).

Programming the Flash

Before programming the Flash a Chip Erase must be performed. See “Performing Chip Erase” on page 259.

1. Enter JTAG instruction PROG_COMMANDS.
2. Enable Flash write using programming instruction 2a.
3. Load address high byte using programming instruction 2b.
4. Load address low byte using programming instruction 2c.
5. Load data using programming instructions 2d, 2e and 2f.
6. Repeat steps 4 and 5 for all instruction words in the page.
7. Write the page using programming instruction 2g.

8. Poll for Flash write complete using programming instruction 2h, or wait for t_{WLRH_FLASH} (refer to Table 108 on page 243).
9. Repeat steps 3 to 7 until all data have been programmed.

A more efficient data transfer can be achieved using the PROG_PAGELOAD instruction:

1. Enter JTAG instruction PROG_COMMANDS.
2. Enable Flash write using programming instruction 2a.
3. Load the page address using programming instructions 2b and 2c. PCWORD (refer to Table 106 on page 235) is used to address within one page and must be written as 0.
4. Enter JTAG instruction PROG_PAGELOAD.
5. Load the entire page by shifting in all instruction words in the page, starting with the LSB of the first instruction in the page and ending with the MSB of the last instruction in the page.
6. Enter JTAG instruction PROG_COMMANDS.
7. Write the page using programming instruction 2g.
8. Poll for Flash write complete using programming instruction 2h, or wait for t_{WLRH_FLASH} (refer to Table 108 on page 243).
9. Repeat steps 3 to 8 until all data have been programmed.

Reading the Flash

1. Enter JTAG instruction PROG_COMMANDS.
2. Enable Flash read using programming instruction 3a.
3. Load address using programming instructions 3b and 3c.
4. Read data using programming instruction 3d.
5. Repeat steps 3 and 4 until all data have been read.

A more efficient data transfer can be achieved using the PROG_PAGEREAD instruction:

1. Enter JTAG instruction PROG_COMMANDS.
2. Enable Flash read using programming instruction 3a.
3. Load the page address using programming instructions 3b and 3c. PCWORD (refer to Table 106 on page 235) is used to address within one page and must be written as 0.
4. Enter JTAG instruction PROG_PAGEREAD.
5. Read the entire page by shifting out all instruction words in the page, starting with the LSB of the first instruction in the page and ending with the MSB of the last instruction in the page. Remember that the first 8 bits shifted out should be ignored.
6. Enter JTAG instruction PROG_COMMANDS.
7. Repeat steps 3 to 6 until all data have been read.

Programming the EEPROM

Before programming the EEPROM a Chip Erase must be performed. See “Performing Chip Erase” on page 259.

1. Enter JTAG instruction PROG_COMMANDS.
2. Enable EEPROM write using programming instruction 4a.
3. Load address high byte using programming instruction 4b.
4. Load address low byte using programming instruction 4c.
5. Load data using programming instructions 4d and 4e.
6. Repeat steps 4 and 5 for all data bytes in the page.
7. Write the data using programming instruction 4f.
8. Poll for EEPROM write complete using programming instruction 4g, or wait for t_{WLRH} (refer to Table 108 on page 243).
9. Repeat steps 3 to 8 until all data have been programmed.

Note: The PROG_PAGELOAD instruction can not be used when programming the EEPROM

Reading the EEPROM

1. Enter JTAG instruction PROG_COMMANDS.
2. Enable EEPROM read using programming instruction 5a.
3. Load address using programming instructions 5b and 5c.
4. Read data using programming instruction 5d.
5. Repeat steps 3 and 4 until all data have been read.

Note: The PROG_PAGEREAD instruction can not be used when reading the EEPROM

Programming the Fuses

1. Enter JTAG instruction PROG_COMMANDS.
2. Enable Fuse write using programming instruction 6a.
3. Load data low byte using programming instructions 6b. A bit value of “0” will program the corresponding Fuse, a “1” will unprogram the Fuse.
4. Write Fuse extended byte using programming instruction 6c.
5. Poll for Fuse write complete using programming instruction 6d, or wait for t_{WLRH} (refer to Table 108 on page 243).
6. Load data low byte using programming instructions 6e. A bit value of “0” will program the corresponding Fuse, a “1” will unprogram the Fuse.
7. Write Fuse High byte using programming instruction 6f.
8. Poll for Fuse write complete using programming instruction 6g, or wait for t_{WLRH} (refer to Table 108 on page 243).
9. Load data low byte using programming instructions 6h. A “0” will program the Fuse, a “1” will unprogram the Fuse.
10. Write Fuse Low byte using programming instruction 6i.
11. Poll for Fuse write complete using programming instruction 6j, or wait for t_{WLRH} (refer to Table 108 on page 243).

Programming the Lock Bits

1. Enter JTAG instruction PROG_COMMANDS.
2. Enable Lock bit write using programming instruction 7a.
3. Load data using programming instructions 7b. A bit value of “0” will program the corresponding Lock bit, a “1” will leave the Lock bit unchanged.
4. Write Lock bits using programming instruction 7c.
5. Poll for Lock bit write complete using programming instruction 7d, or wait for t_{WLRH} (refer to Table 108 on page 243).

Reading the Fuses and Lock Bits

1. Enter JTAG instruction PROG_COMMANDS.
2. Enable Fuse/Lock bit read using programming instruction 8a.
3. To read all Fuses and Lock bits, use programming instruction 8f.
   To only read Fuse Extended byte, use programming instruction 8b.
   To only read Fuse High byte, use programming instruction 8c.
   To only read Fuse Low byte, use programming instruction 8d.
   To only read Lock bits, use programming instruction 8e.

Reading the Signature Bytes

1. Enter JTAG instruction PROG_COMMANDS.
2. Enable Signature byte read using programming instruction 9a.
3. Load address 0x00 using programming instruction 9b.
4. Read first signature byte using programming instruction 9c.
5. Repeat steps 3 and 4 with address 0x01 and address 0x02 to read the second and third signature bytes, respectively.

Reading the Calibration Byte

1. Enter JTAG instruction PROG_COMMANDS.
2. Enable Calibration byte read using programming instruction 10a.
3. Load address 0x00 using programming instruction 10b.
4. Read the calibration byte using programming instruction 10c.

Electrical Characteristics

Absolute Maximum Ratings*

Operating Temperature	-55°C to +125°C
Storage Temperature	-65°C to +150°C
Voltage on any Pin except $\overline{\text{RESET}}$ with respect to Ground	-0.5V to V_{CC}+0.5V
Voltage on $\overline{\text{RESET}}$ with respect to Ground	-0.5V to +13.0V
Maximum Operating Voltage	6.0V
DC Current per I/O Pin	40.0 mA
DC Current V_{CC} and GND Pins	200.0 mA

*NOTICE: Stresses beyond those listed under “Absolute Maximum Ratings” may cause permanent damage to the device. This is a stress rating only and functional operation of the device at these or other conditions beyond those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

DC Characteristics

T_A = -40°C to 85°C, V_{CC} = 1.8V to 5.5V (unless otherwise noted)

Symbol	Parameter	Condition	Min.	Typ.	Max.	Units
V_{IL}	Input Low Voltage, Except XTAL1 pin	V_{CC} = 1.8 - 2.4V V_{CC} = 2.4 - 5.5V	-0.5 -0.5		0.2 V_{CC}(1) 0.3 V_{CC}(1)	V
V_{IL1}	Input Low Voltage, XTAL1 pin	V_{CC} = 1.8 - 5.5V	-0.5		0.1 V_{CC}(1)	V
V_{IH}	Input High Voltage, Except XTAL1 and RESET pin	V_{CC} = 1.8 - 2.4V V_{CC} = 2.4 - 5.5V	0.7 V_{CC}(2) 0.6 V_{CC}(2)		V_{CC} + 0.5 V_{CC} + 0.5	V
V_{IH1}	Input High Voltage, XTAL1 pin	V_{CC} = 1.8 - 2.4V V_{CC} = 2.4 - 5.5V	0.8 V_{CC}(2) 0.7 V_{CC}(2)		V_{CC} + 0.5 V_{CC} + 0.5	V
V_{IH2}	Input High Voltage, RESET pin	V_{CC} = 1.8 - 5.5V	0.9 V_{CC}(2)		V_{CC} + 0.5	V
V_{OL}	Output Low Voltage(3), Ports A, B, C, D, and E	I_{OL} = 20 mA, V_{CC} = 5V I_{OL} = 10 mA, V_{CC} = 3V			0.7 0.5	V V
V_{OH}	Output High Voltage(4), Ports A, B, C, D, and E	I_{OL} = -20 mA, V_{CC} = 5V I_{OL} = -5 mA, V_{CC} = 3V	4.2 2.3			V V
I_{IL}	Input Leakage Current I/O Pin	Vcc = 5.5V, pin low (absolute value)			1	µA
I_{IH}	Input Leakage Current I/O Pin	Vcc = 5.5V, pin high (absolute value)			1	µA
R_{RST}	Reset Pull-up Resistor		30		60	kΩ
R_{pu}	I/O Pin Pull-up Resistor		20		50	kΩ

T_A = -40°C to 85°C, V_{CC} = 1.8V to 5.5V (unless otherwise noted) (Continued)

Symbol	Parameter	Condition	Min.	Typ.	Max.	Units
I_{CC}	Power Supply Current	Active 1 MHz, V_{CC} = 2V (ATmega162V)			0.8	mA
		Active 4 MHz, V_{CC} = 3V (ATmega162/V)			5	mA
		Active 8 MHz, V_{CC} = 5V (ATmega162)			16	mA
		Idle 1 MHz, V_{CC} = 2V (ATmega162V)			0.3	mA
		Idle 4 MHz, V_{CC} = 3V (ATmega162/V)			2	mA
		Idle 8 MHz, V_{CC} = 5V (ATmega162)			8	mA
	Power-down mode	WDT Enabled, V_{CC} = 3.0V		< 10	14	µA
		WDT Disabled, V_{CC} = 3.0V		< 1.5	2	µA
V_{ACIO}	Analog Comparator Input Offset Voltage	V_{CC} = 5V V_{in} = V_{CC}/2		< 10	40	mV
I_{ACLK}	Analog Comparator Input Leakage Current	V_{CC} = 5V V_{in} = V_{CC}/2	-50		50	nA
t_{ACID}	Analog Comparator Propagation Delay	V_{CC} = 2.7V V_{CC} = 4.0V		750 500		ns

Notes:
1. “Max” means the highest value where the pin is guaranteed to be read as low
2. “Min” means the lowest value where the pin is guaranteed to be read as high
3. Although each I/O port can sink more than the test conditions (20 mA at Vcc = 5V, 10 mA at Vcc = 3V) under steady state conditions (non-transient), the following must be observed:
   PDIP Package:
   1] The sum of all IOL, for all ports, should not exceed 300 mA.
   2] The sum of all IOL, for port B0 - B7, D0 - D7, and XTAL2, should not exceed 150 mA.
   3] The sum of all IOL, for ports A0 - A7, E0 - E2, C0 - C7, should not exceed 150 mA.
   TQFP and MLF Package:
   1] The sum of all IOL, for all ports, should not exceed 400 mA.
   2] The sum of all IOL, for ports B0 - B7, D0 - D7, and XTAL2, should not exceed 200 mA.
   3] The sum of all IOL, for ports C0 - C7 and E1 - E2, should not exceed 200 mA.
   4] The sum of all IOL, for ports A0 - A7 and E0, should not exceed 200 mA.
   If IOL exceeds the test condition, VOL may exceed the related specification. Pins are not guaranteed to sink current greater than the listed test condition.
4. Although each I/O port can source more than the test conditions (20 mA at Vcc = 5V, 10 mA at Vcc = 3V) under steady state conditions (non-transient), the following must be observed:
   PDIP Package:
   1] The sum of all IOH, for all ports, should not exceed 300 mA.
   2] The sum of all IOH, for port B0 - B7, D0 - D7, and XTAL2, should not exceed 150 mA.
   3] The sum of all IOH, for ports A0 - A7, E0 - E2, C0 - C7, should not exceed 150 mA.
   TQFP and MLF Package:
   1] The sum of all IOH, for all ports, should not exceed 400 mA.
   2] The sum of all IOH, for ports B0 - B7, D0 - D7, and XTAL2, should not exceed 200 mA.
   3] The sum of all IOH, for ports C0 - C7 and E1 - E2, should not exceed 200 mA.
   4] The sum of all IOH, for ports A0 - A7 and E0, should not exceed 200 mA.
   If IOH exceeds the test condition, VOH may exceed the related specification. Pins are not guaranteed to source current greater than the listed test condition.

Figure 113. Absolute Maximum Frequency as a function of VCC, ATmega162V

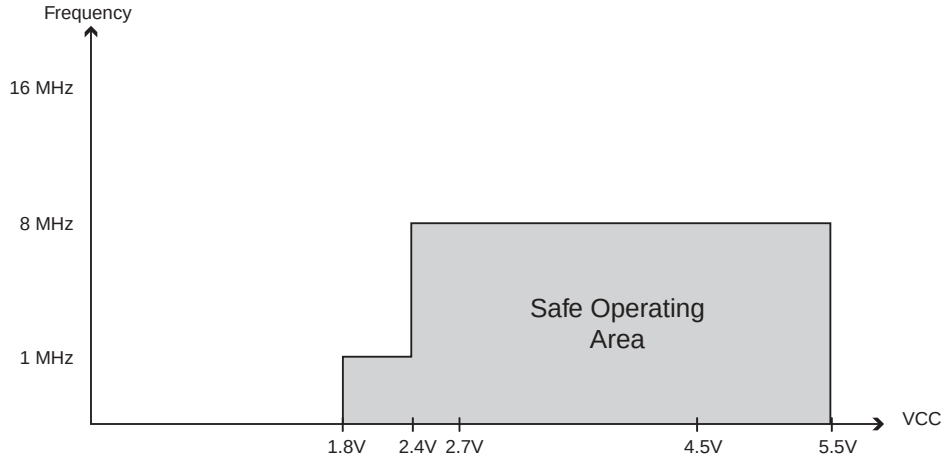
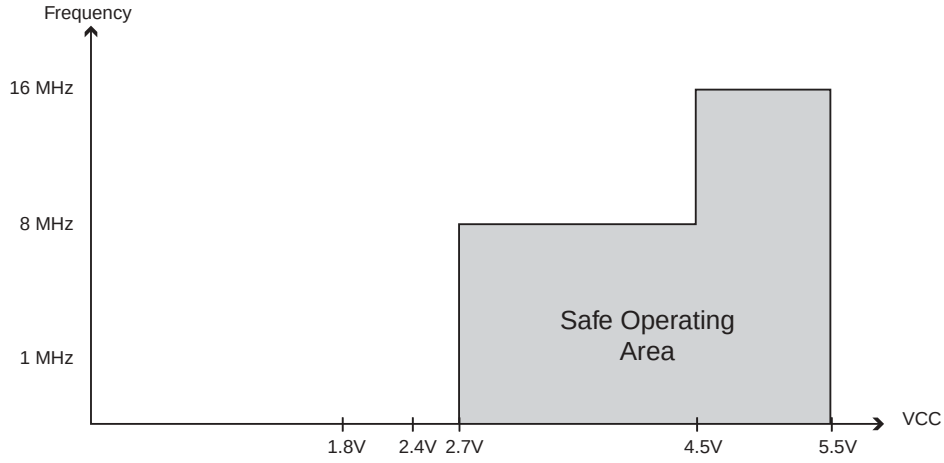
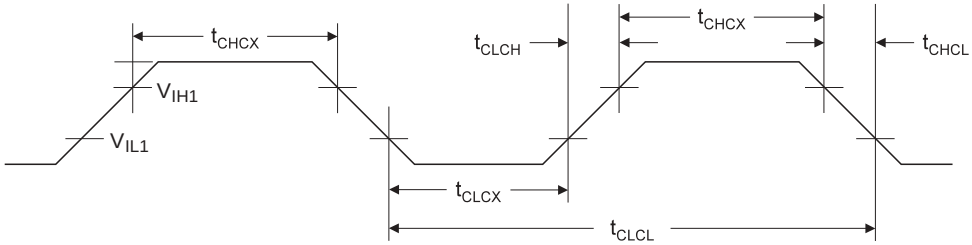


Figure 114. Absolute Maximum Frequency as a function of VCC, ATmega162



External Clock Drive Waveforms

Figure 115. External Clock Drive Waveforms



External Clock Drive

Table 113. External Clock Drive

Symbol	Parameter	V_{CC} = 1.8 - 5.5V		V_{CC} =2.7 - 5.5V		V_{CC} = 4.5 - 5.5V		Units
		Min.	Max.	Min.	Max.	Min.	Max.	
$1/t_{CLCL}$	Oscillator Frequency	0	1	0	8	0	16	MHz
t_{CLCL}	Clock Period	1000		125		62.5		ns
t_{CHCX}	High Time	400		50		25		ns
t_{CLCX}	Low Time	400		50		25		ns
t_{CLCH}	Rise Time		2.0		1.6		0.5	µs
t_{CHCL}	Fall Time		2.0		1.6		0.5	µs
Δt_{CLCL}	Change in period from one clock cycle to the next		2		2		2	%

SPI Timing Characteristics

See Figure 116 and Figure 117 for details.

Table 114. SPI Timing Parameters

	Description	Mode	Min	Typ	Max	
1	SCK period	Master		See Table 68		
2	SCK high/low	Master		50% duty cycle		
3	Rise/Fall time	Master		3.6		
4	Setup	Master		10		
5	Hold	Master		10		
6	Out to SCK	Master		0.5 • t_{sck}		ns
7	SCK to out	Master		10		
8	SCK to out high	Master		10		
9	SS low to out	Slave		15		
10	SCK period	Slave	4 • t_{ck}			
11	SCK high/low(1)	Slave	2 • t_{ck}			
12	Rise/Fall time	Slave			1.6	µs
13	Setup	Slave	10			
14	Hold	Slave	t_{ck}			
15	SCK to out	Slave		15		ns
16	SCK to $\overline{SS}$ high	Slave	20			
17	$\overline{SS}$ high to tri-state	Slave		10		
18	$\overline{SS}$ low to SCK	Slave	2 • t_{ck}			

Note: 1. In SPI Programming mode, the minimum SCK high/low period is:
– 2 t_{CLCL} for f_{CK} < 12 MHz
– 3 t_{CLCL} for f_{CK} > 12 MHz.

Figure 116. SPI Interface Timing Requirements (Master Mode)

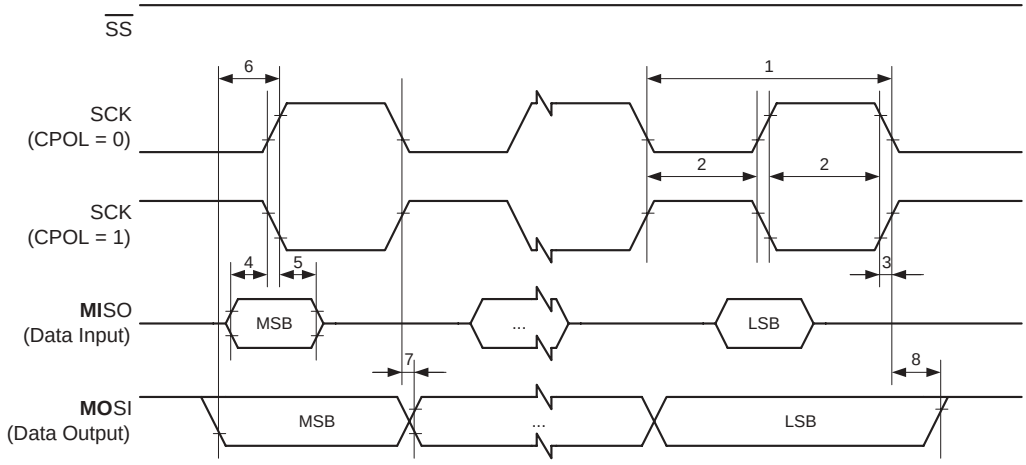
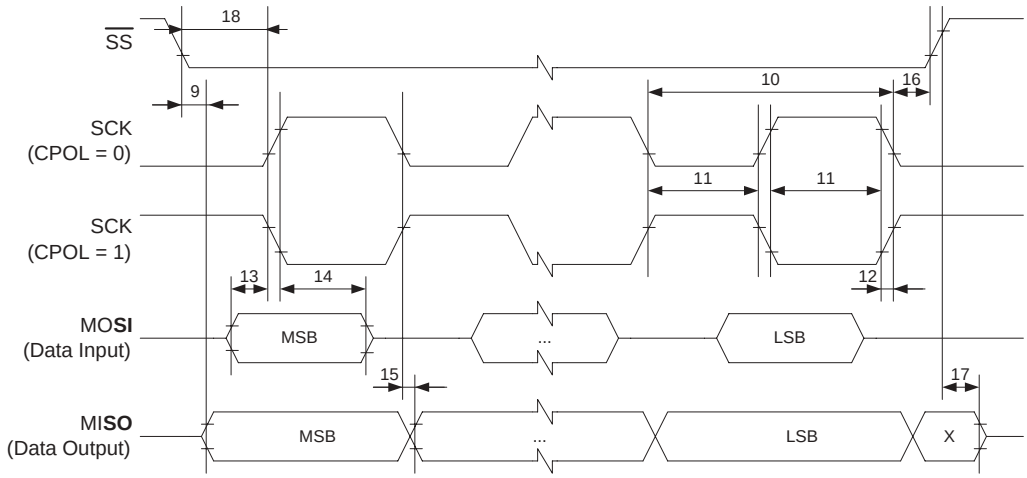


Figure 117. SPI Interface Timing Requirements (Slave Mode)



External Data Memory Timing

Table 115. External Data Memory Characteristics, 4.5 - 5.5 Volts, no Wait-state

			8 MHz Oscillator		Variable Oscillator		
	Symbol	Parameter	Min	Max	Min	Max	Unit
0	$1/t_{CLCL}$	Oscillator Frequency			0.0	16	MHz
1	t_{LHLL}	ALE Pulse Width	115		$1.0t_{CLCL}$-10		ns
2	t_{AVLL}	Address Valid A to ALE Low	57.5		$0.5t_{CLCL}$-5(1)		ns
3a	t_{LLAX_ST}	Address Hold After ALE Low, write access	5		5		ns
3b	t_{LLAX_LD}	Address Hold after ALE Low, read access	5		5		ns
4	t_{AVLLC}	Address Valid C to ALE Low	57.5		$0.5t_{CLCL}$-5(1)		ns
5	t_{AVRL}	Address Valid to RD Low	115		$1.0t_{CLCL}$-10		ns
6	t_{AVWL}	Address Valid to WR Low	115		$1.0t_{CLCL}$-10		ns
7	t_{LLWL}	ALE Low to WR Low	47.5	67.5	$0.5t_{CLCL}$-15(2)	$0.5t_{CLCL}$+5(2)	ns
8	t_{LLRL}	ALE Low to RD Low	47.5	67.5	$0.5t_{CLCL}$-15(2)	$0.5t_{CLCL}$+5(2)	ns
9	t_{DVRH}	Data Setup to RD High	40		40		ns
10	t_{RLDV}	Read Low to Data Valid		75		$1.0t_{CLCL}$-50	ns
11	t_{RHDX}	Data Hold After RD High	0		0		ns
12	t_{RLRH}	RD Pulse Width	115		$1.0t_{CLCL}$-10		ns
13	t_{DVWL}	Data Setup to WR Low	42.5		$0.5t_{CLCL}$-20(1)		ns
14	t_{WHDX}	Data Hold After WR High	115		$1.0t_{CLCL}$-10		ns
15	t_{DVWH}	Data Valid to WR High	125		$1.0t_{CLCL}$		ns
16	t_{WLWH}	WR Pulse Width	115		$1.0t_{CLCL}$-10		ns

Notes: 1. This assumes 50% clock duty cycle. The half period is actually the high time of the external clock, XTAL1.
2. This assumes 50% clock duty cycle. The half period is actually the low time of the external clock, XTAL1.

Table 116. External Data Memory Characteristics, 4.5 - 5.5 Volts, 1 Cycle Wait-state

			8 MHz Oscillator		Variable Oscillator		
	Symbol	Parameter	Min	Max	Min	Max	Unit
0	$1/t_{CLCL}$	Oscillator Frequency			0.0	16	MHz
10	t_{RLDV}	Read Low to Data Valid		200		$2.0t_{CLCL}$-50	ns
12	t_{RLRH}	RD Pulse Width	240		$2.0t_{CLCL}$-10		ns
15	t_{DVWH}	Data Valid to WR High	240		$2.0t_{CLCL}$		ns
16	t_{WLWH}	WR Pulse Width	240		$2.0t_{CLCL}$-10		ns

Table 117. External Data Memory Characteristics, 4.5 - 5.5 Volts, SRWn1 = 1, SRWn0 = 0

			4 MHz Oscillator		Variable Oscillator		
	Symbol	Parameter	Min	Max	Min	Max	Unit
0	$1/t_{CLCL}$	Oscillator Frequency			0.0	16	MHz
10	t_{RLDV}	Read Low to Data Valid		325		$3.0t_{CLCL}$-50	ns
12	t_{RLRH}	RD Pulse Width	365		$3.0t_{CLCL}$-10		ns
15	t_{DVWH}	Data Valid to WR High	375		$3.0t_{CLCL}$		ns
16	t_{WLWH}	WR Pulse Width	365		$3.0t_{CLCL}$-10		ns

Table 118. External Data Memory Characteristics, 4.5 - 5.5 Volts, SRWn1 = 1, SRWn0 = 1

			4 MHz Oscillator		Variable Oscillator		
	Symbol	Parameter	Min	Max	Min	Max	Unit
0	$1/t_{CLCL}$	Oscillator Frequency			0.0	16	MHz
10	t_{RLDV}	Read Low to Data Valid		325		$3.0t_{CLCL}$-50	ns
12	t_{RLRH}	RD Pulse Width	365		$3.0t_{CLCL}$-10		ns
14	t_{WHDX}	Data Hold After WR High	240		$2.0t_{CLCL}$-10		ns
15	t_{DVWH}	Data Valid to WR High	375		$3.0t_{CLCL}$		ns
16	t_{WLWH}	WR Pulse Width	365		$3.0t_{CLCL}$-10		ns

Table 119. External Data Memory Characteristics, 2.7 - 5.5 Volts, no Wait-state

			4 MHz Oscillator		Variable Oscillator		
	Symbol	Parameter	Min	Max	Min	Max	Unit
0	$1/t_{CLCL}$	Oscillator Frequency			0.0	8	MHz
1	t_{LHLL}	ALE Pulse Width	235		t_{CLCL}-15		ns
2	t_{AVLL}	Address Valid A to ALE Low	115		$0.5t_{CLCL}$-10[1]		ns
3a	t_{LLAX_ST}	Address Hold After ALE Low, write access	5		5		ns
3b	t_{LLAX_LD}	Address Hold after ALE Low, read access	5		5		ns
4	t_{AVLLC}	Address Valid C to ALE Low	115		$0.5t_{CLCL}$-10[1]		ns
5	t_{AVRL}	Address Valid to RD Low	235		$1.0t_{CLCL}$-15		ns
6	t_{AVWL}	Address Valid to WR Low	235		$1.0t_{CLCL}$-15		ns
7	t_{LLWL}	ALE Low to WR Low	115	130	$0.5t_{CLCL}$-10[2]	$0.5t_{CLCL}$+5[2]	ns
8	t_{LLRL}	ALE Low to RD Low	115	130	$0.5t_{CLCL}$-10[2]	$0.5t_{CLCL}$+5[2]	ns
9	t_{DVRH}	Data Setup to RD High	45		45		ns
10	t_{RLDV}	Read Low to Data Valid		190		$1.0t_{CLCL}$-60	ns
11	t_{RHDX}	Data Hold After RD High	0		0		ns

Table 119. External Data Memory Characteristics, 2.7 - 5.5 Volts, no Wait-state (Continued)

			4 MHz Oscillator		Variable Oscillator		
	Symbol	Parameter	Min	Max	Min	Max	Unit
12	t_{RLRH}	RD Pulse Width	235		$1.0t_{CLCL}$-15		ns
13	t_{DVWL}	Data Setup to WR Low	105		$0.5t_{CLCL}$-20(1)		ns
14	t_{WHDX}	Data Hold After WR High	235		$1.0t_{CLCL}$-15		ns
15	t_{DVWH}	Data Valid to WR High	250		$1.0t_{CLCL}$		ns
16	t_{WLWH}	WR Pulse Width	235		$1.0t_{CLCL}$-15		ns

Notes: 1. This assumes 50% clock duty cycle. The half period is actually the high time of the external clock, XTAL1.
2. This assumes 50% clock duty cycle. The half period is actually the low time of the external clock, XTAL1.

Table 120. External Data Memory Characteristics, 2.7 - 5.5 Volts, SRWn1 = 0, SRWn0 = 1

			4 MHz Oscillator		Variable Oscillator		
	Symbol	Parameter	Min	Max	Min	Max	Unit
0	$1/t_{CLCL}$	Oscillator Frequency			0.0	8	MHz
10	t_{RLDV}	Read Low to Data Valid		440		$2.0t_{CLCL}$-60	ns
12	t_{RLRH}	RD Pulse Width	485		$2.0t_{CLCL}$-15		ns
15	t_{DVWH}	Data Valid to WR High	500		$2.0t_{CLCL}$		ns
16	t_{WLWH}	WR Pulse Width	485		$2.0t_{CLCL}$-15		ns

Table 121. External Data Memory Characteristics, 2.7 - 5.5 Volts, SRWn1 = 1, SRWn0 = 0

			4 MHz Oscillator		Variable Oscillator		
	Symbol	Parameter	Min	Max	Min	Max	Unit
0	$1/t_{CLCL}$	Oscillator Frequency			0.0	8	MHz
10	t_{RLDV}	Read Low to Data Valid		690		$3.0t_{CLCL}$-60	ns
12	t_{RLRH}	RD Pulse Width	735		$3.0t_{CLCL}$-15		ns
15	t_{DVWH}	Data Valid to WR High	750		$3.0t_{CLCL}$		ns
16	t_{WLWH}	WR Pulse Width	735		$3.0t_{CLCL}$-15		ns

Table 122. External Data Memory Characteristics, 2.7 - 5.5 Volts, SRWn1 = 1, SRWn0 = 1

			4 MHz Oscillator		Variable Oscillator		
	Symbol	Parameter	Min	Max	Min	Max	Unit
0	$1/t_{CLCL}$	Oscillator Frequency			0.0	8	MHz
10	t_{RLDV}	Read Low to Data Valid		690		$3.0t_{CLCL}$-60	ns
12	t_{RLRH}	RD Pulse Width	735		$3.0t_{CLCL}$-15		ns
14	t_{WHDX}	Data Hold After WR High	485		$2.0t_{CLCL}$-15		ns
15	t_{DVWH}	Data Valid to WR High	750		$3.0t_{CLCL}$		ns
16	t_{WLWH}	WR Pulse Width	735		$3.0t_{CLCL}$-15		ns

Figure 118. External Memory Timing (SRWn1 = 0, SRWn0 = 0

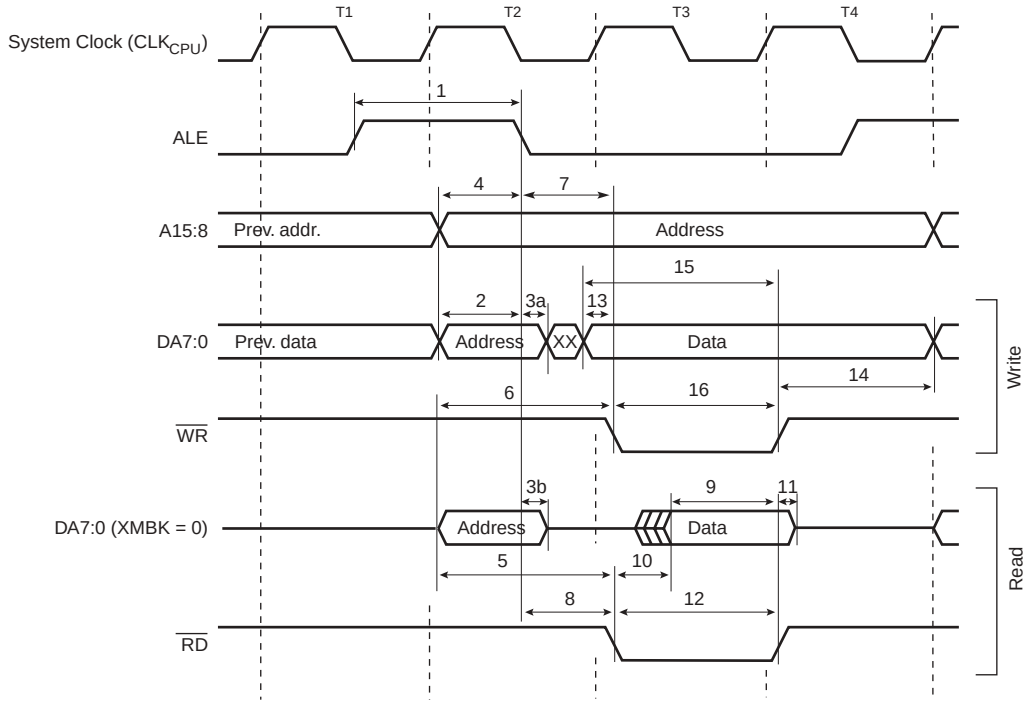


Figure 119. External Memory Timing (SRWn1 = 0, SRWn0 = 1)

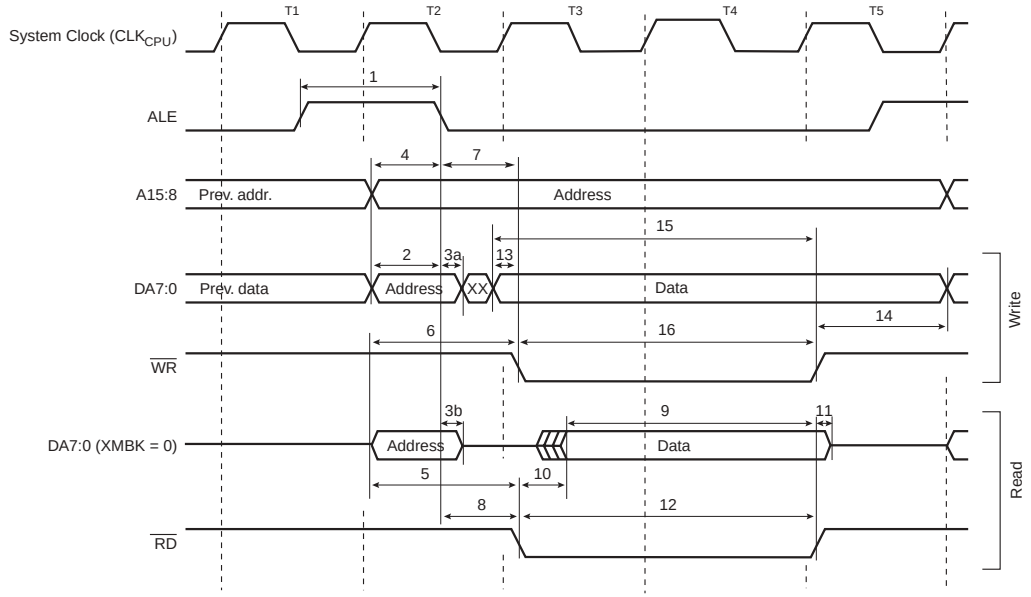


Figure 120. External Memory Timing (SRWn1 = 1, SRWn0 = 0)

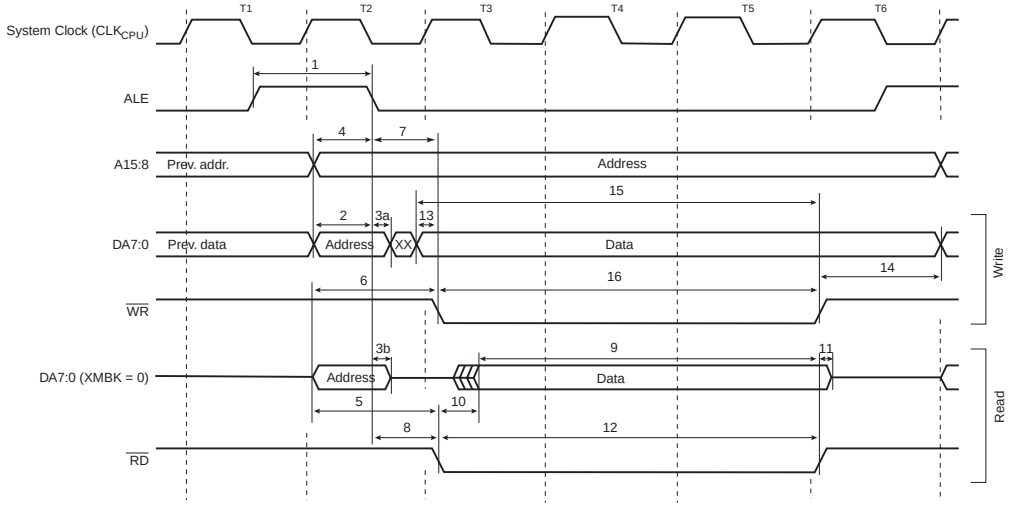
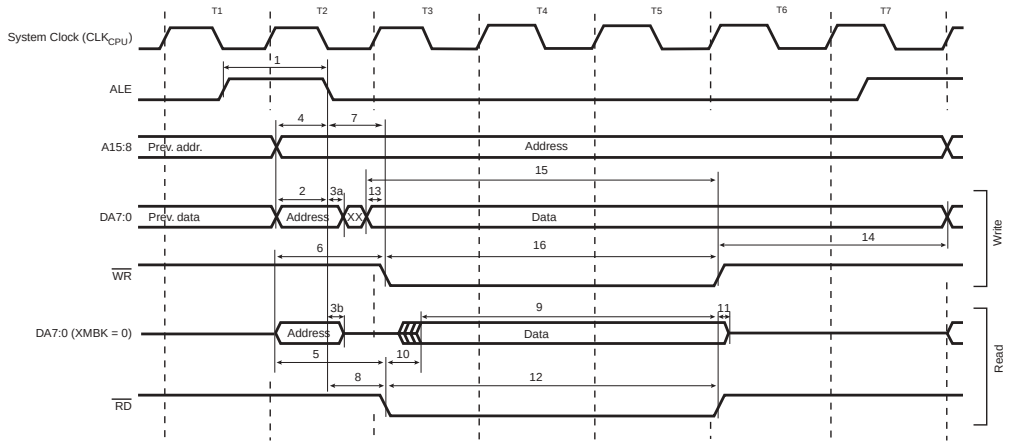


Figure 121. External Memory Timing (SRWn1 = 1, SRWn0 = 1)[1]



Note: 1. The ALE pulse in the last period (T4 - T7) is only present if the next instruction accesses the RAM (internal or external).

ATmega162 Typical Characteristics

The following charts show typical behavior. These figures are not tested during manufacturing. All current consumption measurements are performed with all I/O pins configured as inputs and with internal pull-ups enabled. A sine wave generator with rail-to-rail output is used as clock source. The CKSEL Fuses are programmed to select external clock.

The power consumption in Power-down mode is independent of clock selection.

The current consumption is a function of several factors such as: Operating voltage, operating frequency, loading of I/O pins, switching rate of I/O pins, code executed and ambient temperature. The dominating factors are operating voltage and frequency.

The current drawn from capacitive loaded pins may be estimated (for one pin) as C_L*V_{CC}*f where C_L = load capacitance, V_{CC} = operating voltage and f = average switching frequency of I/O pin.

The parts are characterized at frequencies higher than test limits. Parts are not guaranteed to function properly at frequencies higher than the ordering code indicates.

The difference between current consumption in Power-down mode with Watchdog Timer enabled and Power-down mode with Watchdog Timer disabled represents the differential current drawn by the Watchdog Timer.

Active Supply Current

Figure 122. Active Supply Current vs. Frequency (0.1 - 1.0 MHz)

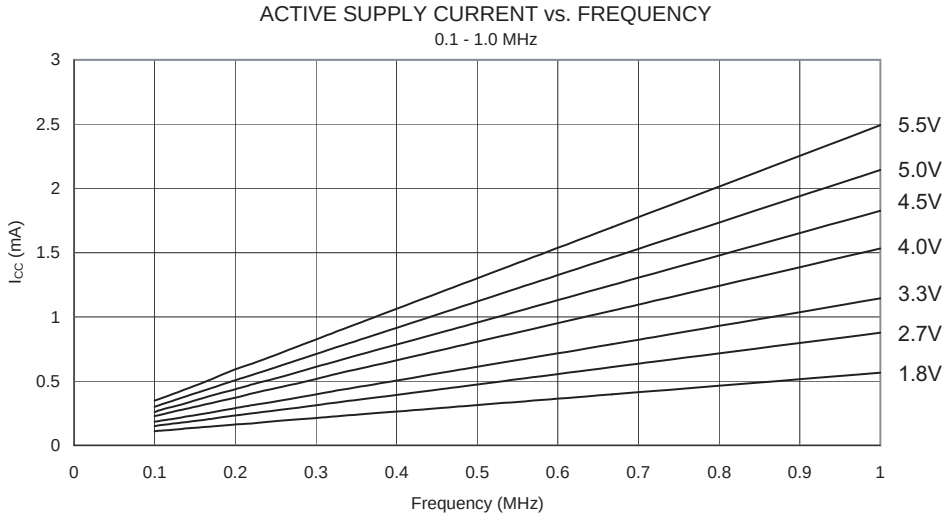


Figure 123. Active Supply Current vs. Frequency (1 - 20 MHz)

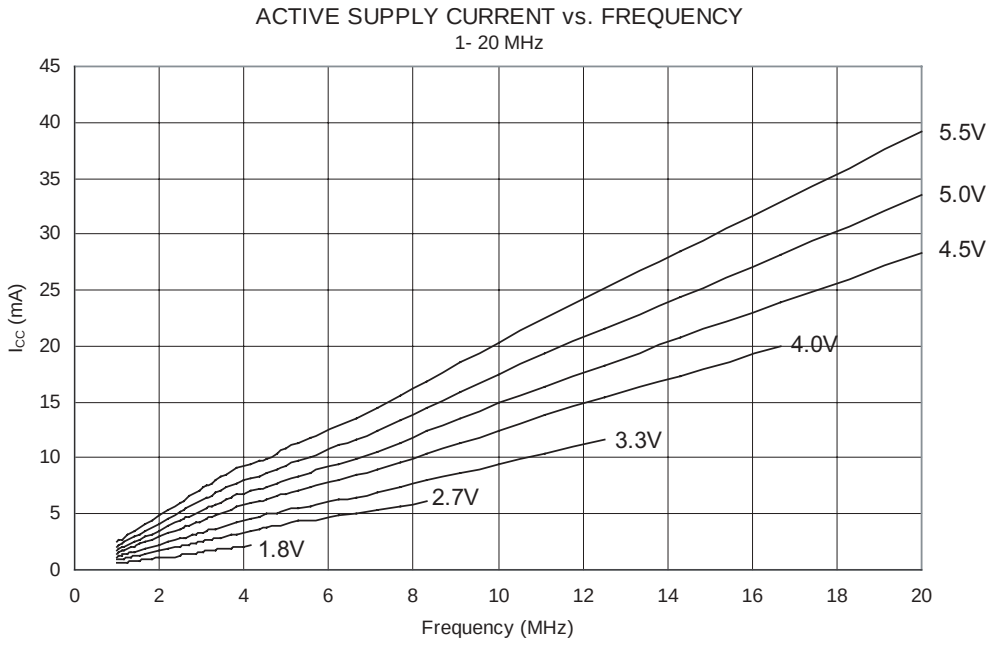


Figure 124. Active Supply Current vs. V_{CC} (Internal RC Oscillator, 8 MHz)

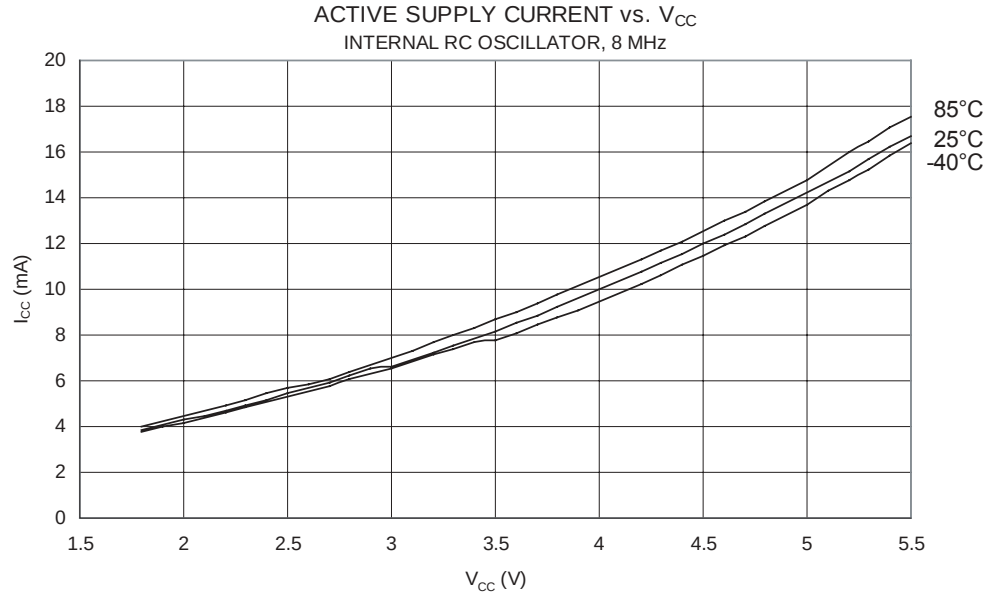
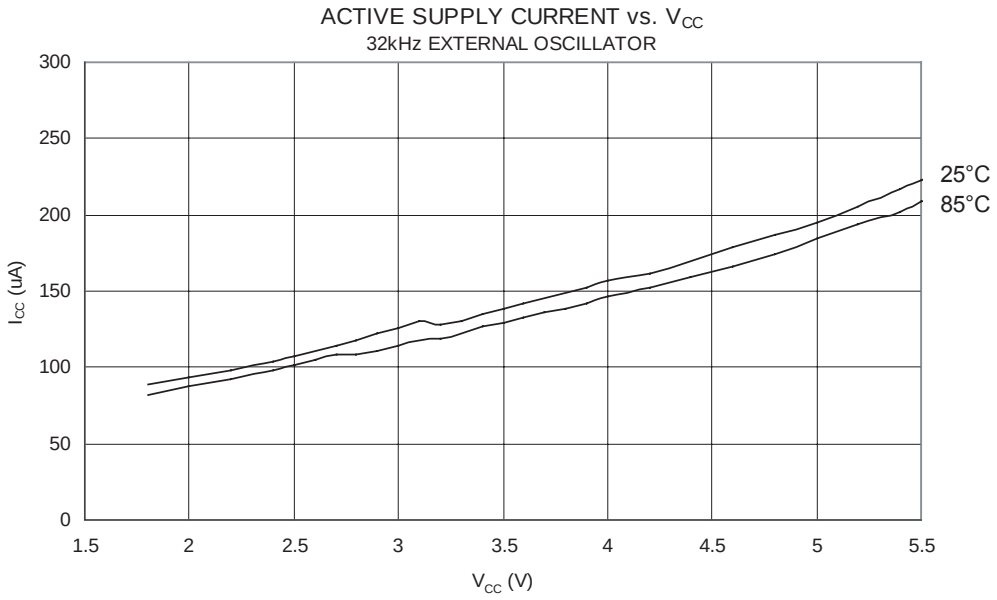


Figure 125. Active Supply Current vs. V_{CC} (32 kHz External Oscillator)



Idle Supply Current

Figure 126. Idle Supply Current vs. Frequency (0.1 - 1.0 MHz)

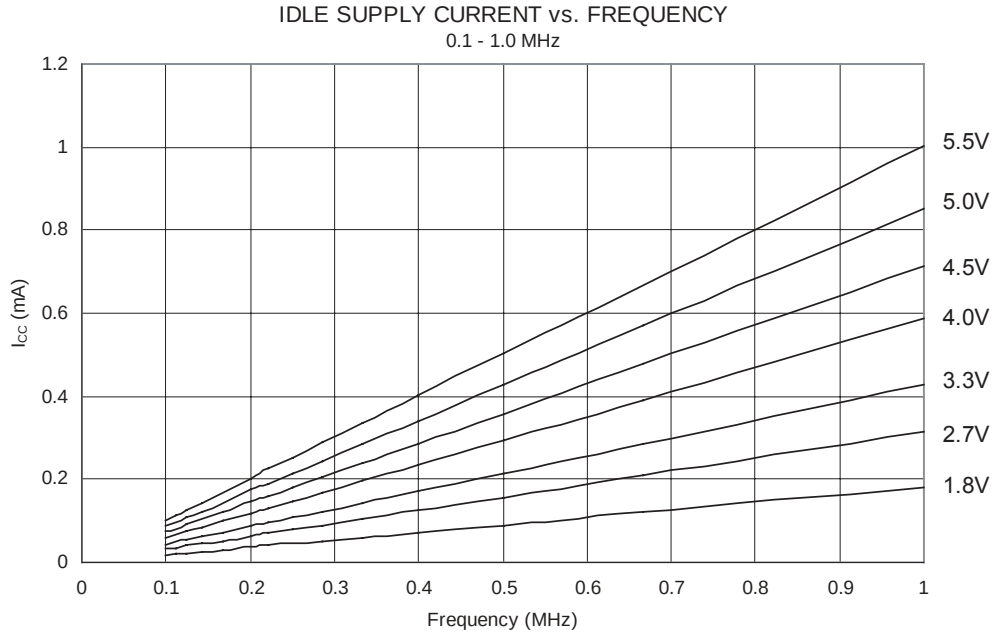


Figure 127. Idle Supply Current vs. Frequency (1 - 20 MHz)

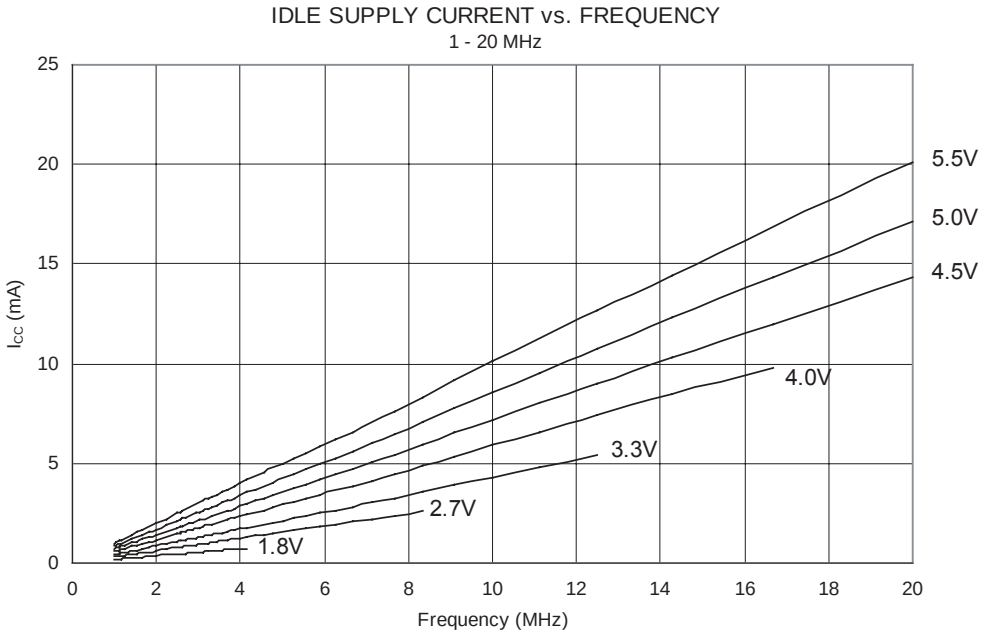


Figure 128. Idle Supply Current vs. V_{CC} (Internal RC Oscillator, 8 MHz)

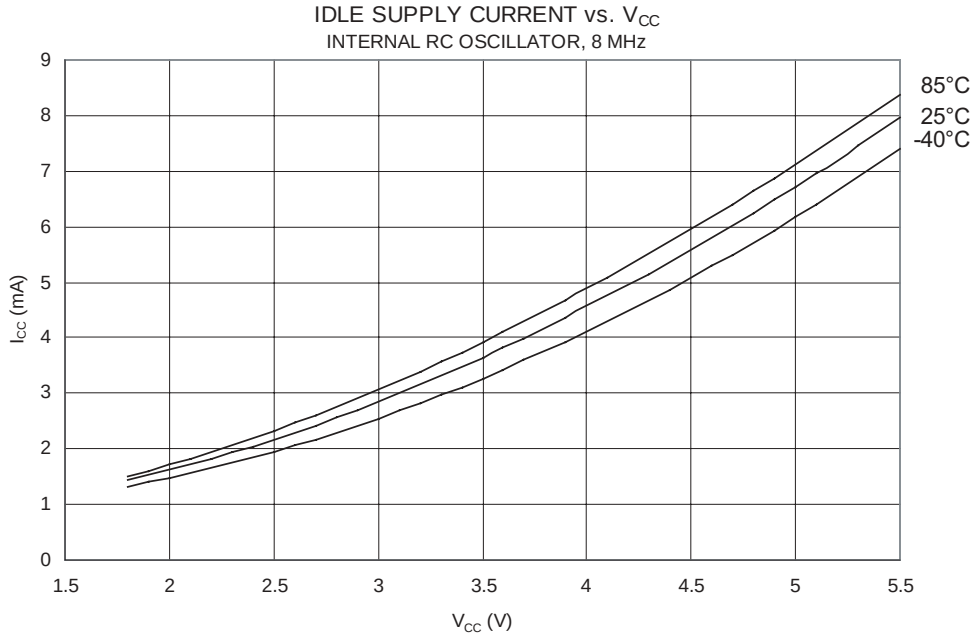
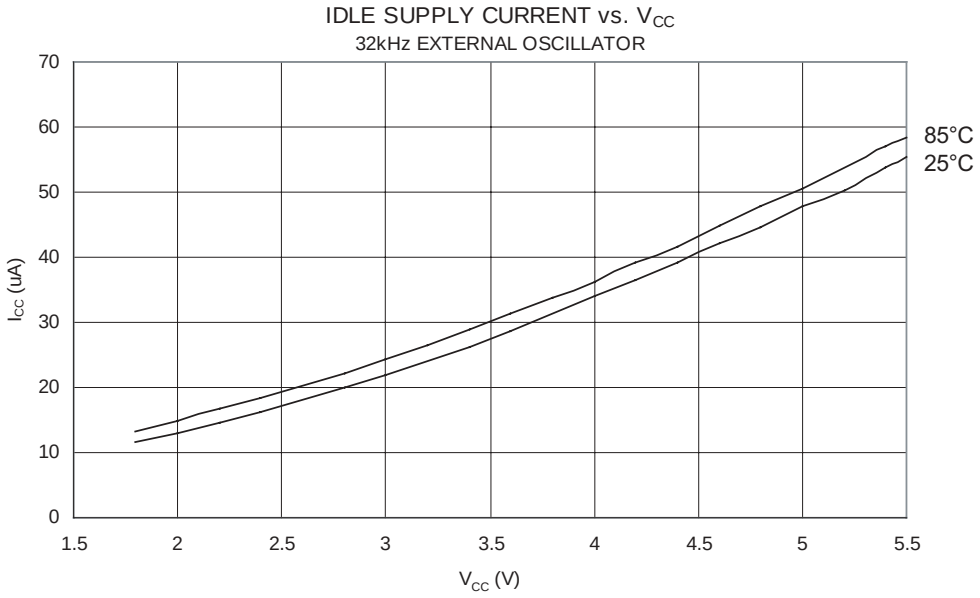


Figure 129. Idle Supply Current vs. V_{CC} (32 kHz External Oscillator)



Power-down Supply Current

Figure 130. Power-down Supply Current vs. V_{CC} (Watchdog Timer Disabled)

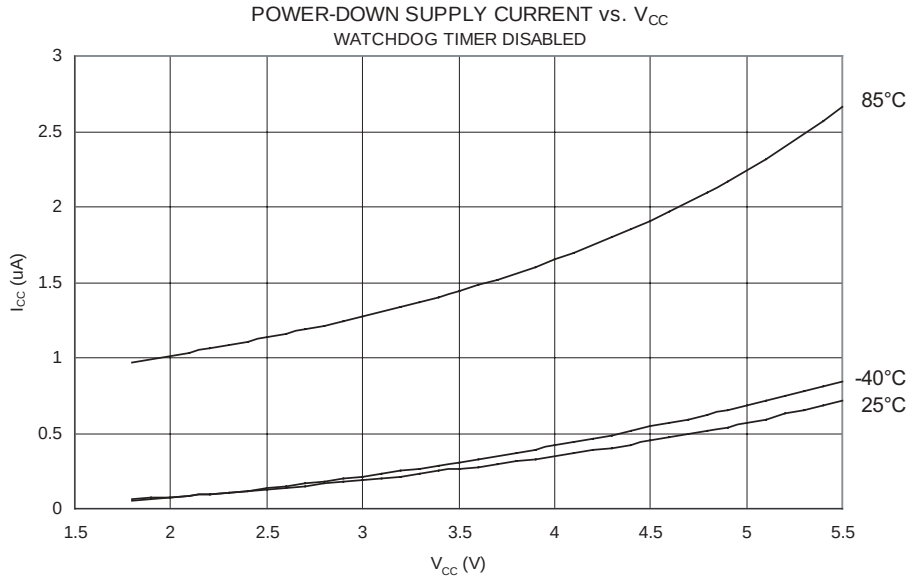
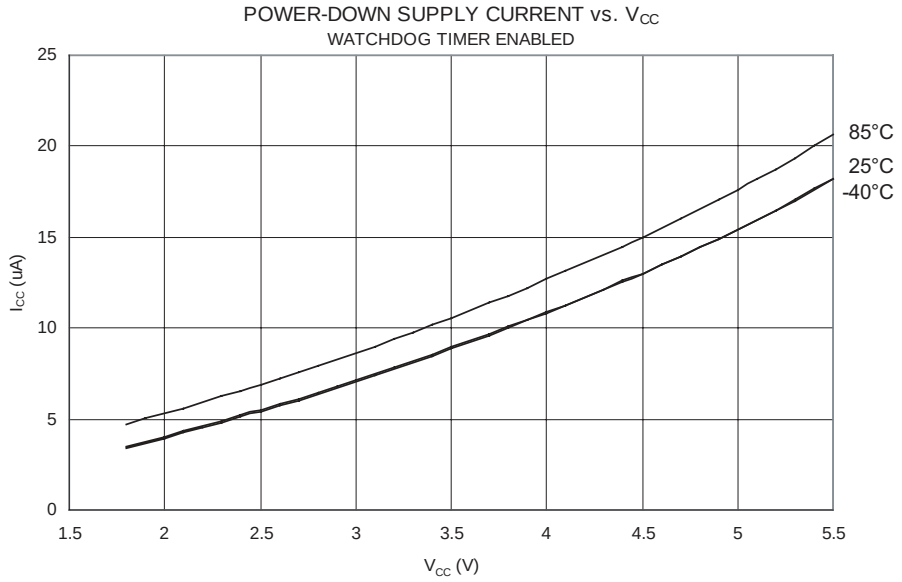
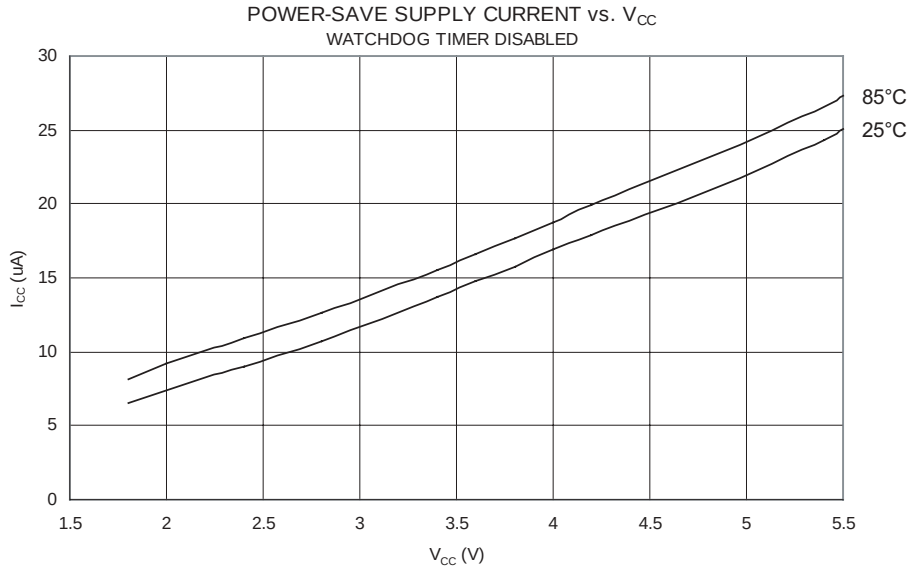


Figure 131. Power-down Supply Current vs. V_{CC} (Watchdog Timer Enabled)



Power-save Supply Current

Figure 132. Power-save Supply Current vs. V_{CC} (Watchdog Timer Disabled)



Standby Supply Current

Figure 133. Standby Supply Current vs. V_{CC} (455 kHz Resonator, Watchdog Timer Disabled)

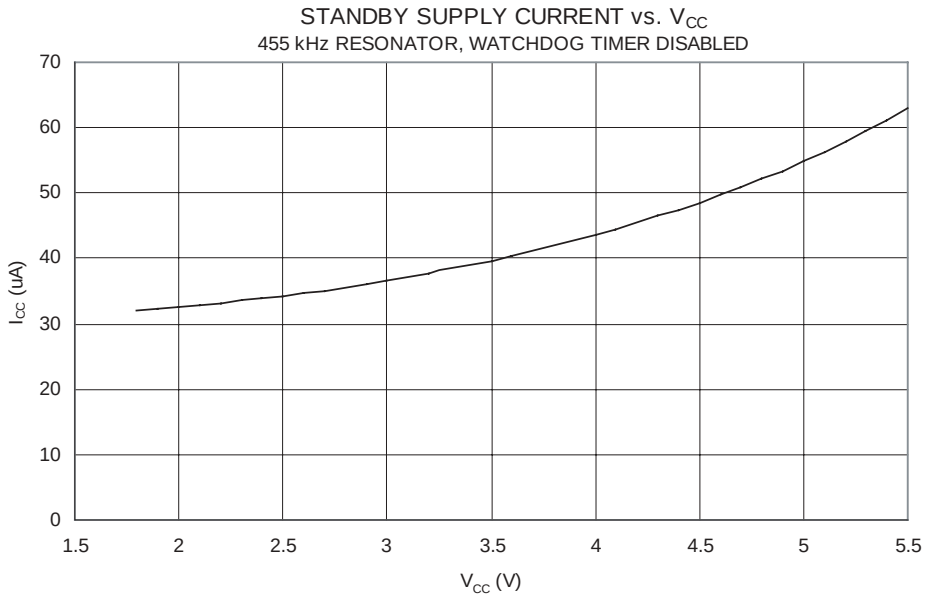


Figure 134. Standby Supply Current vs. V_{CC} (1 MHz Resonator, Watchdog Timer Disabled)

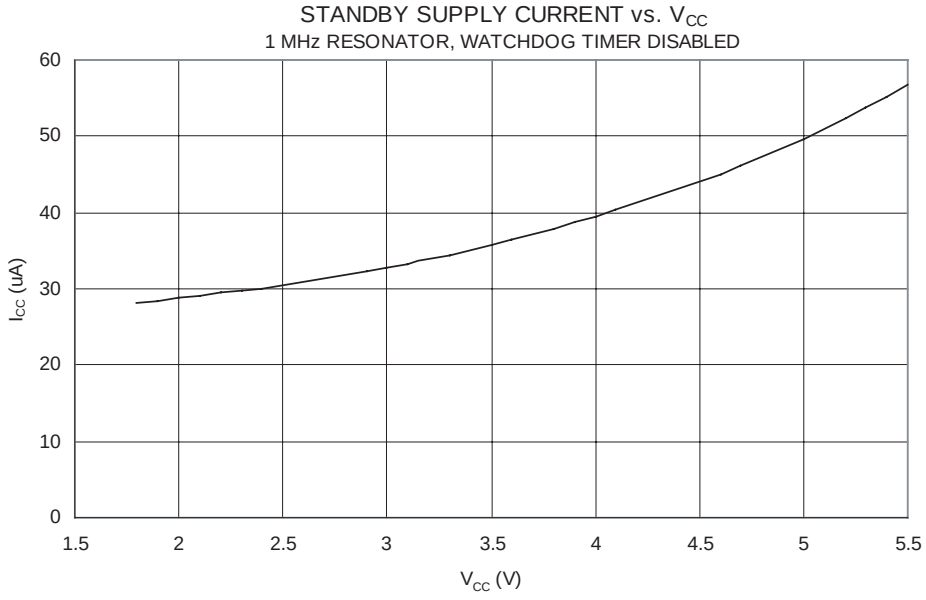


Figure 135. Standby Supply Current vs. V_{CC} (2 MHz Resonator, Watchdog Timer Disabled)

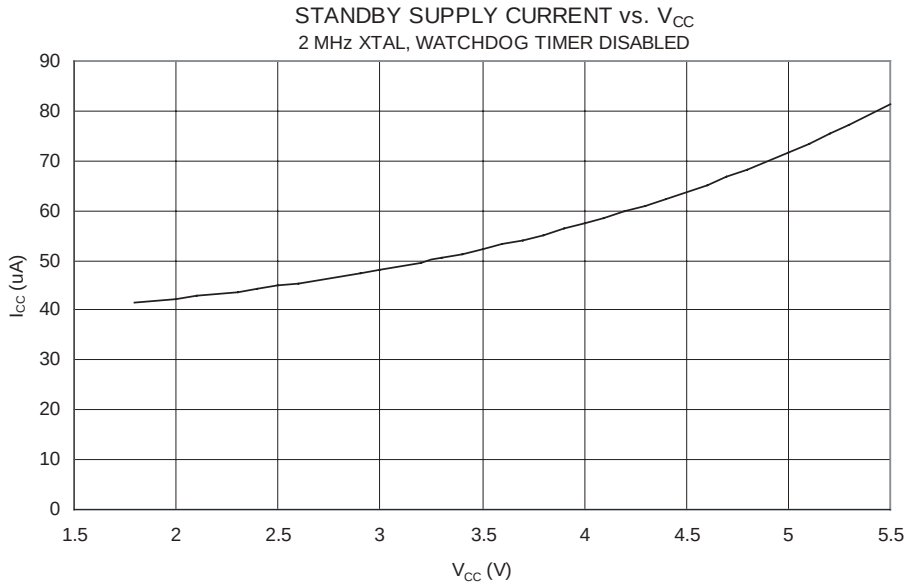


Figure 136. Standby Supply Current vs. V_{CC} (2 MHz Xtal, Watchdog Timer Disabled)

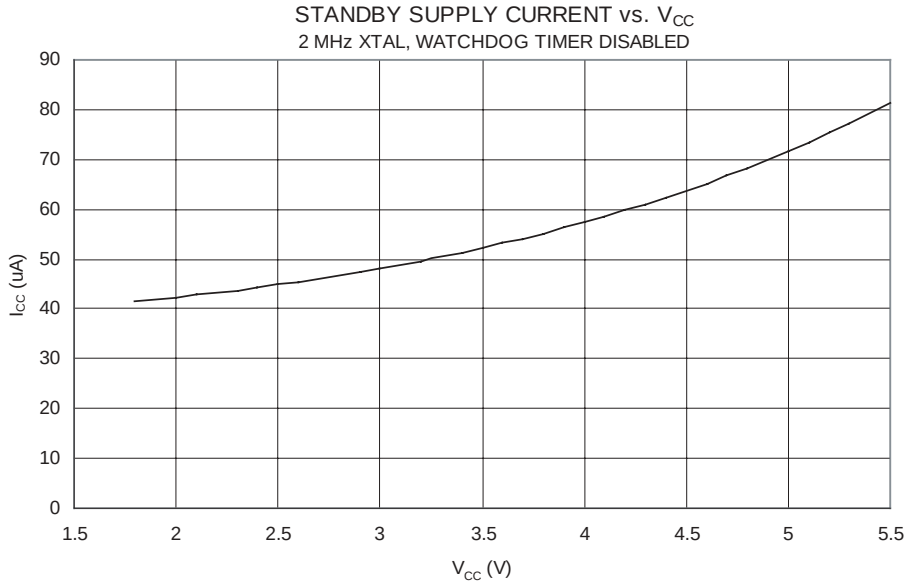


Figure 137. Standby Supply Current vs. V_{CC} (4 MHz Resonator, Watchdog Timer Disabled)

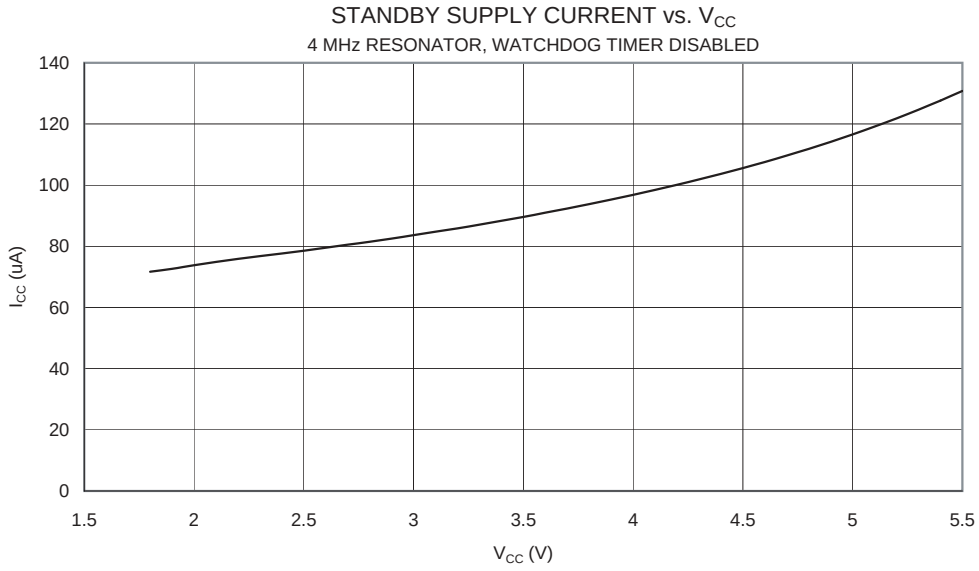


Figure 138. Standby Supply Current vs. V_{CC} (4 MHz Xtal, Watchdog Timer Disabled)

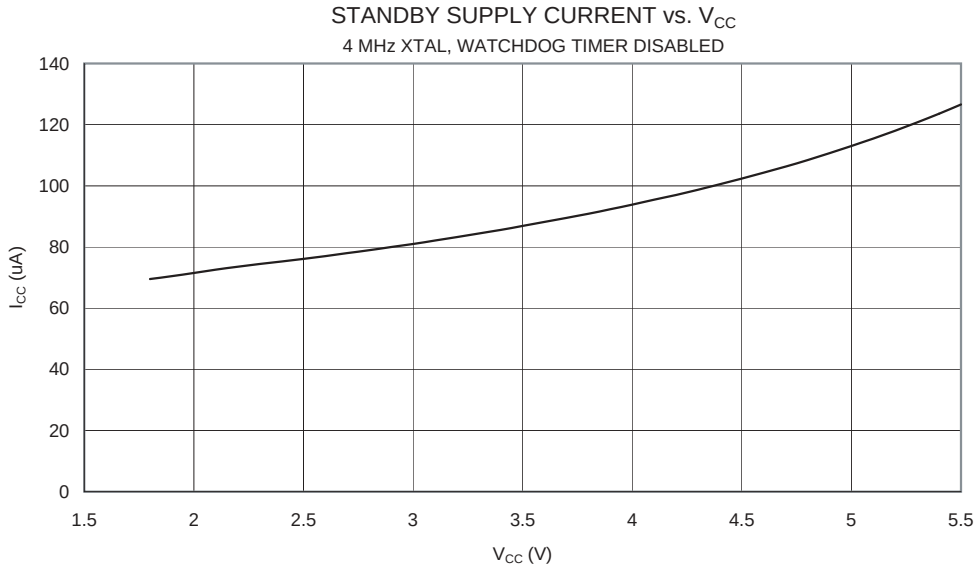


Figure 139. Standby Supply Current vs. V_{CC} (6 MHz Resonator, Watchdog Timer Disabled)

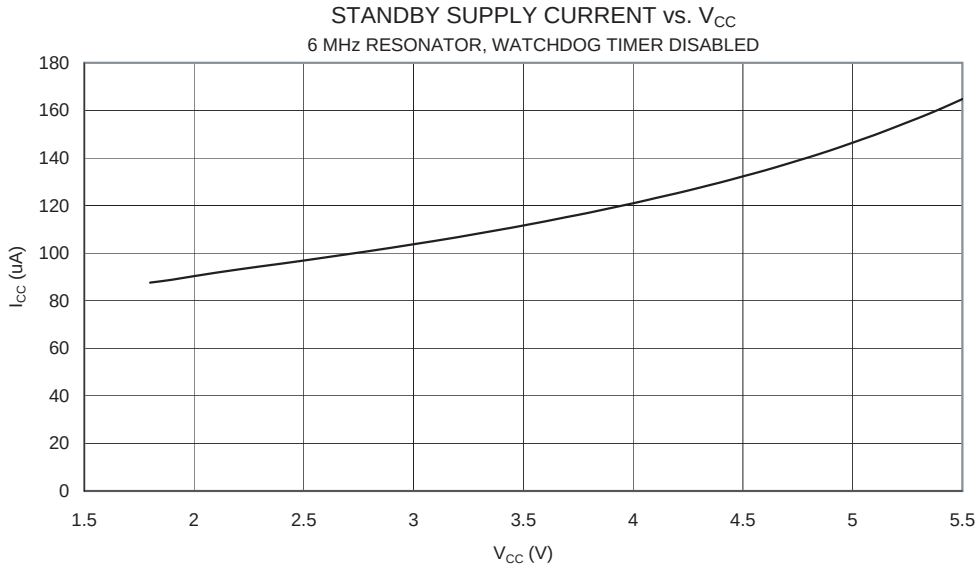
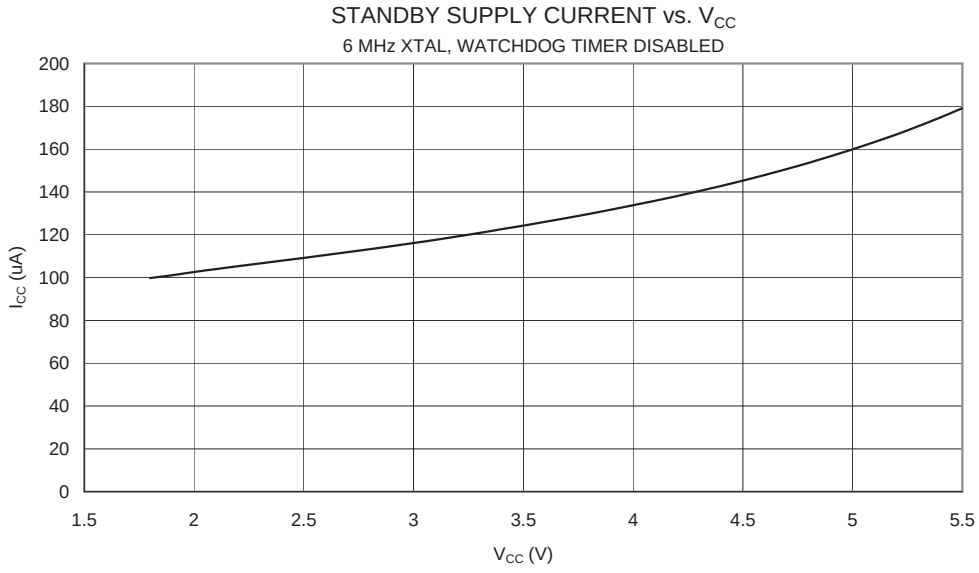


Figure 140. Standby Supply Current vs. V_{CC} (6 MHz Xtal, Watchdog Timer Disabled)



Pin Pull-up

Figure 141. I/O Pin Pull-up Resistor Current vs. Input Voltage (V_{CC} = 5V)

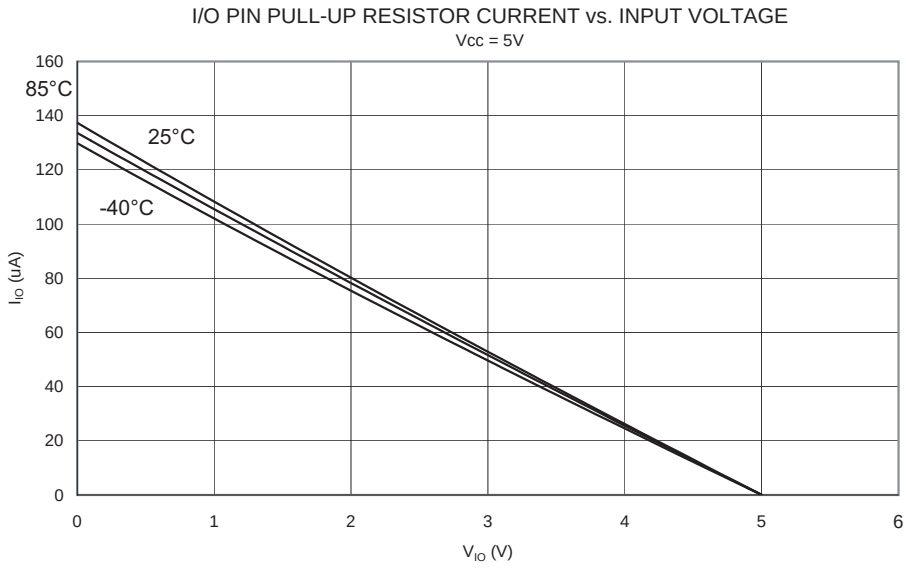


Figure 142. I/O Pin Pull-up Resistor Current vs. Input Voltage (V_{CC} = 2.7V)

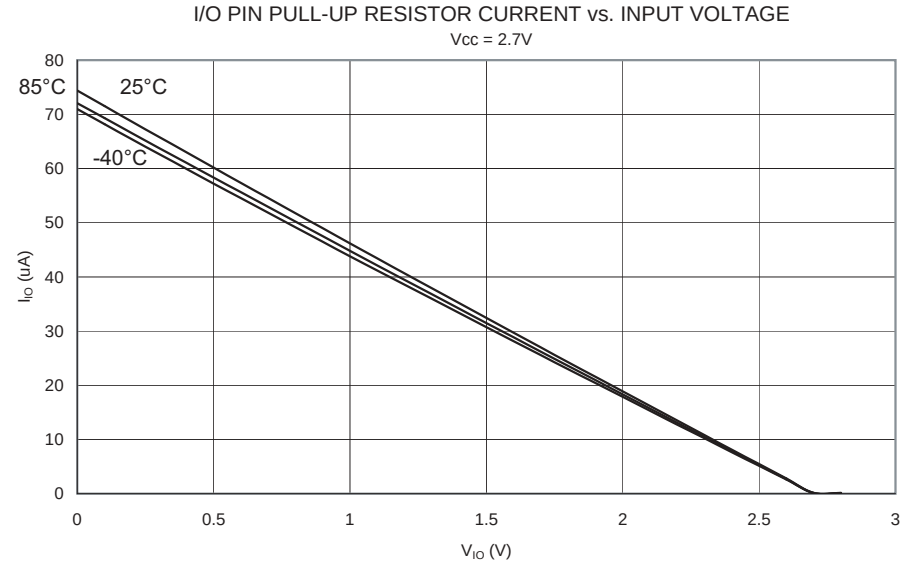


Figure 143. I/O Pin Pull-up Resistor Current vs. Input Voltage (V_{CC} = 1.8V)

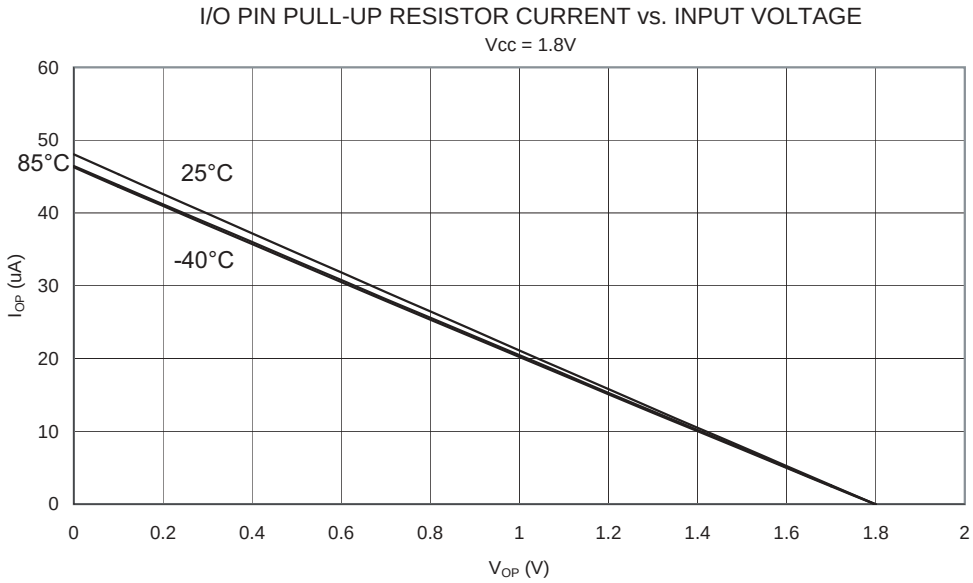


Figure 144. Reset Pull-up Resistor Current vs. Reset Pin Voltage (V_{CC} = 5V)

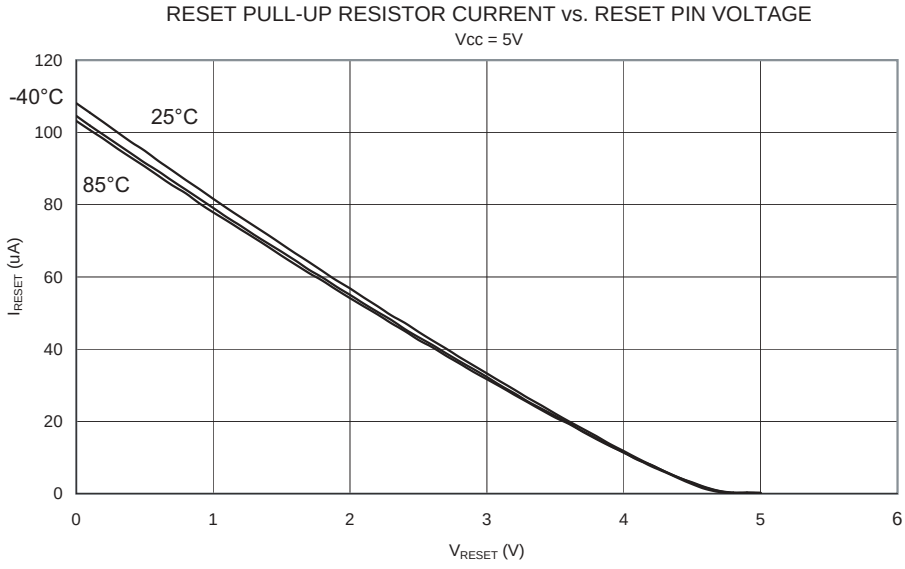


Figure 145. Reset Pull-up Resistor Current vs. Reset Pin Voltage (V_{CC} = 2.7V)

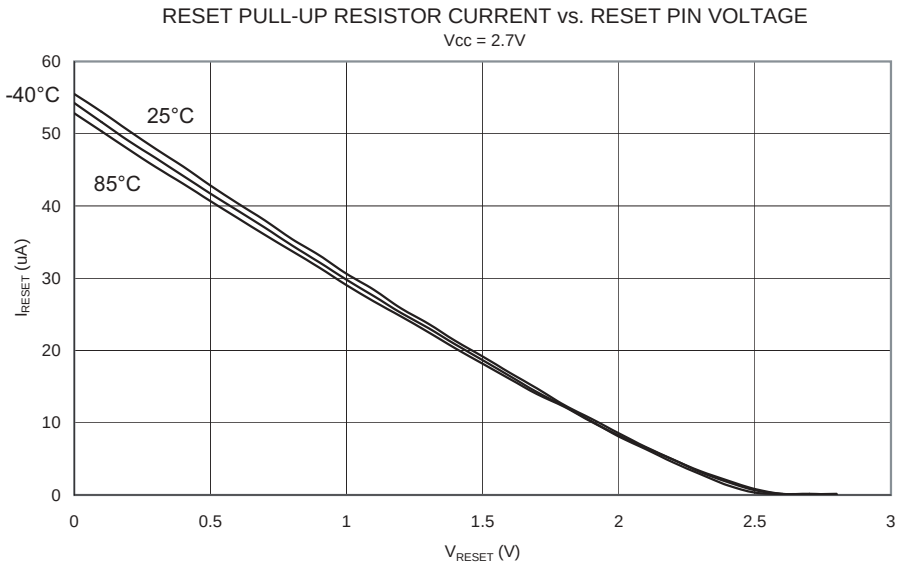
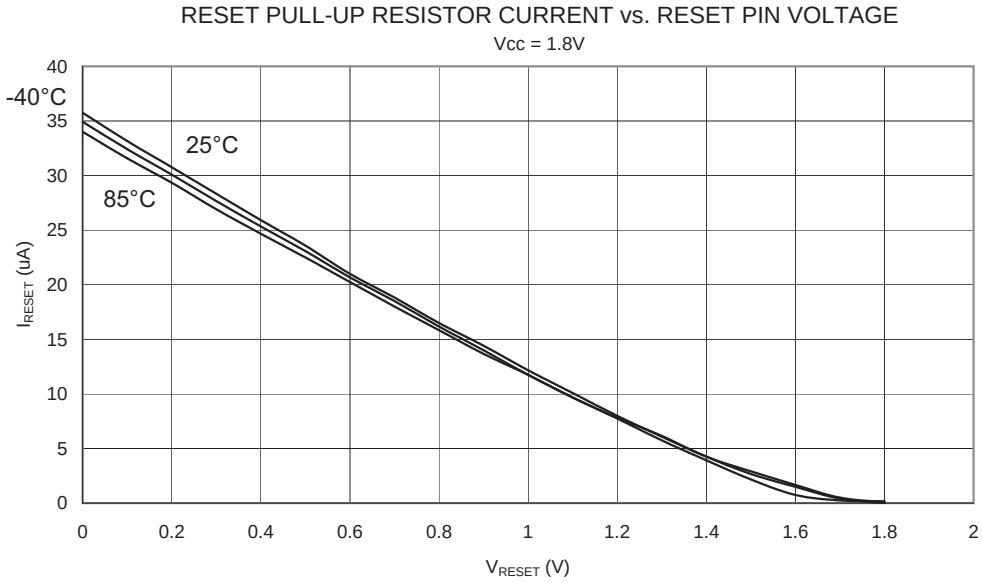


Figure 146. Reset Pull-up Resistor Current vs. Reset Pin Voltage (V_{CC} = 1.8V)



Pin Driver Strength

Figure 147. I/O Pin Source Current vs. Output Voltage (V_{CC} = 5V)

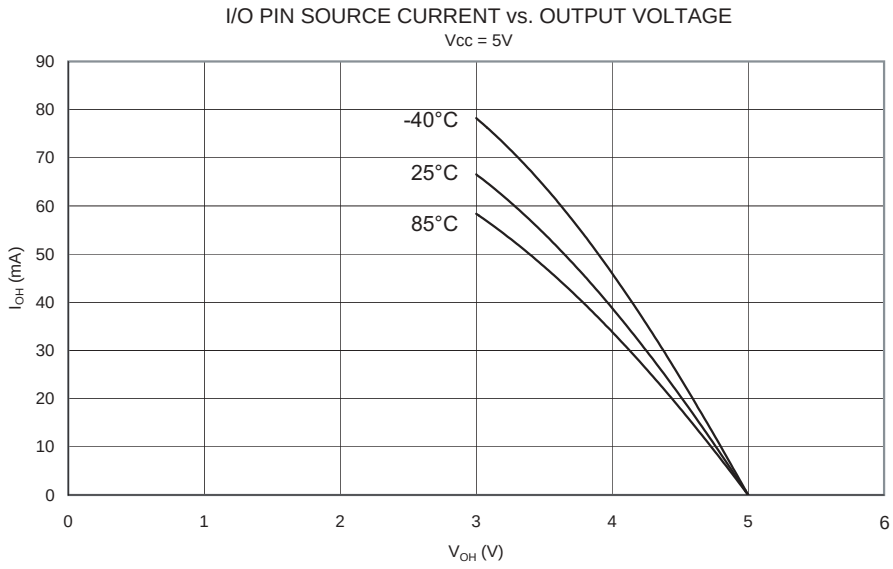


Figure 148. I/O Pin Source Current vs. Output Voltage (V_{CC} = 2.7V)

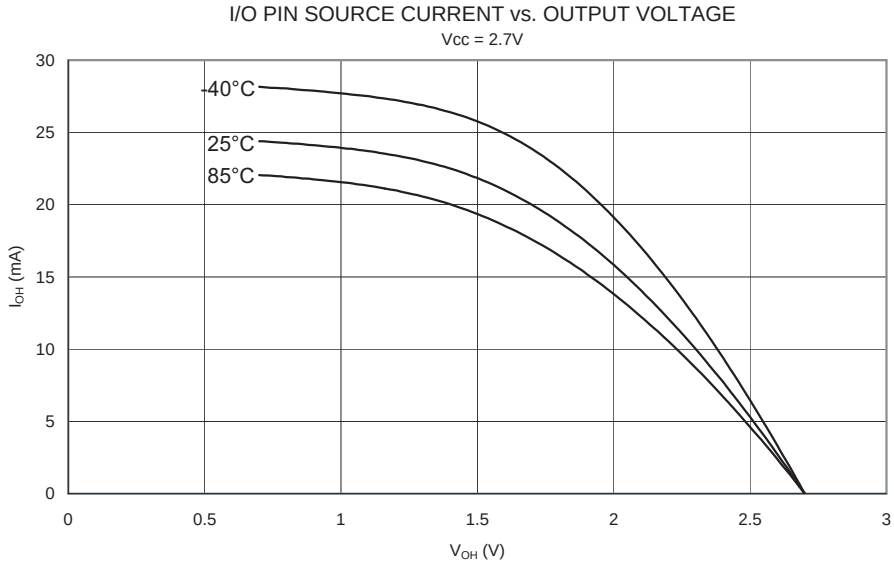


Figure 149. I/O Pin Source Current vs. Output Voltage (V_{CC} = 1.8V)

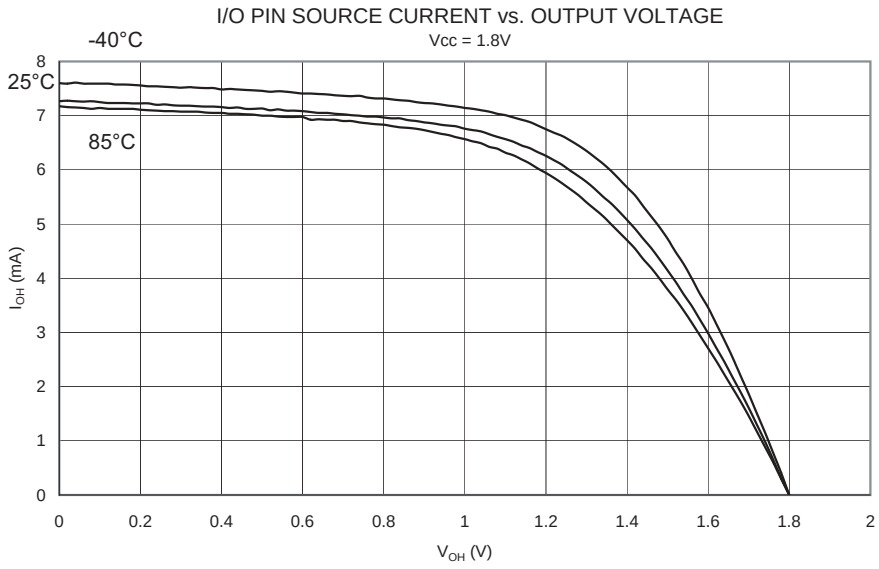


Figure 150. I/O Pin Sink Current vs. Output Voltage (V_{CC} = 5V)

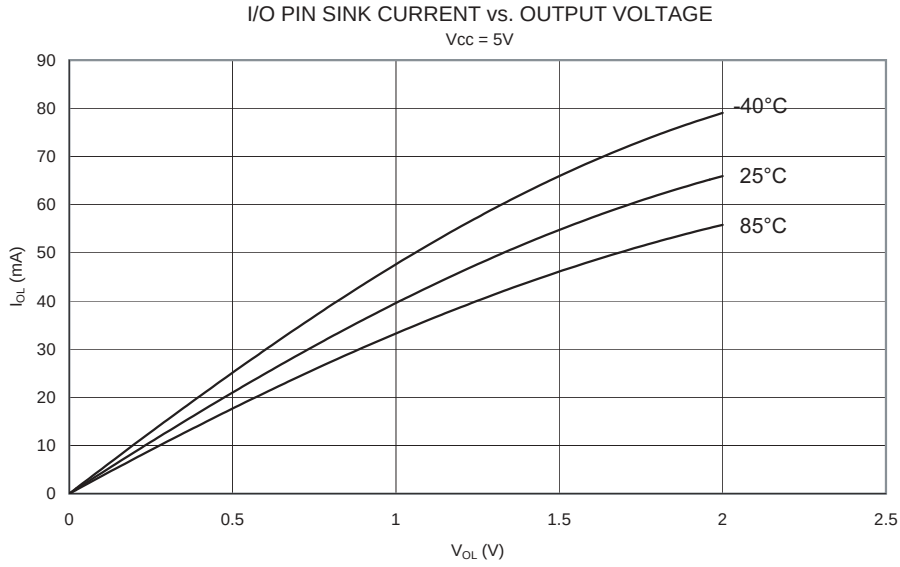


Figure 151. I/O Pin Sink Current vs. Output Voltage (V_{CC} = 2.7V)

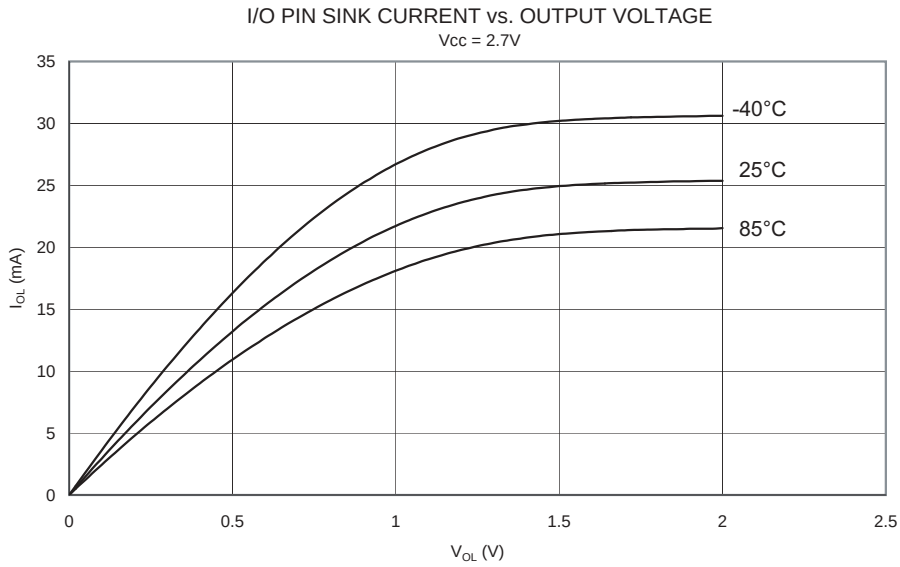
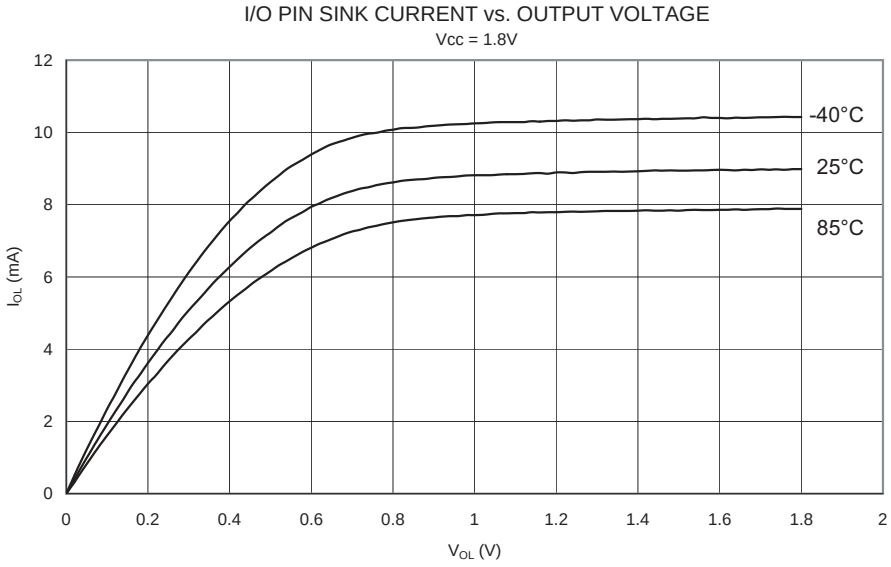


Figure 152. I/O Pin Sink Current vs. Output Voltage (V_{CC} = 1.8V)



Pin Thresholds and Hysteresis

Figure 153. I/O Pin Input Threshold Voltage vs. V_{CC} (V_{IH}, I/O Pin Read as “1”)

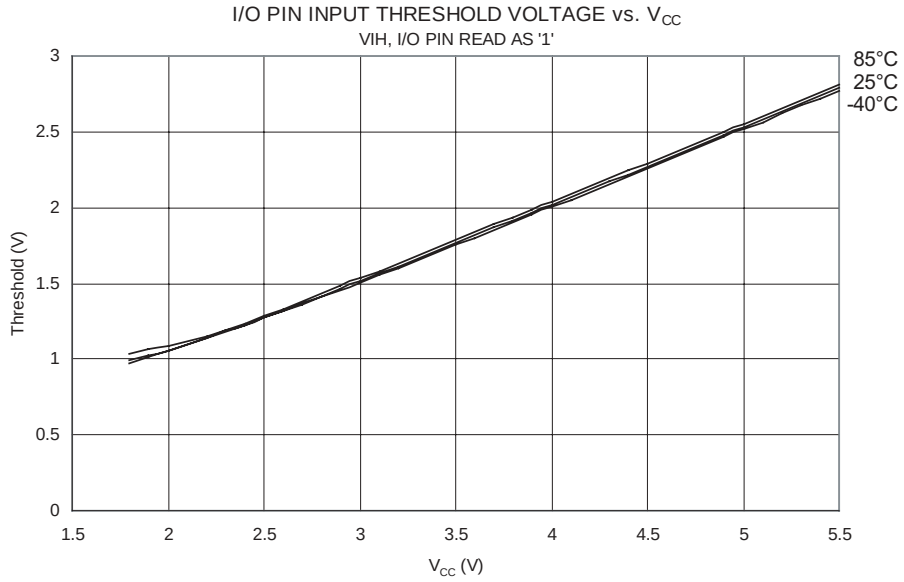


Figure 154. I/O Pin Input Threshold Voltage vs. V_{CC} (V_{IL}, I/O Pin Read as “0”)

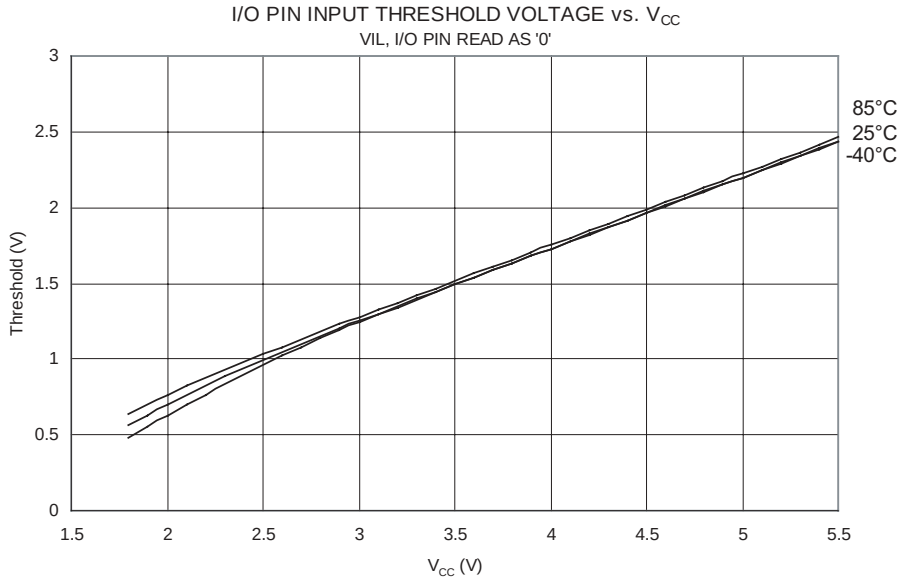


Figure 155. I/O Pin Input Hysteresis vs. V_{CC}

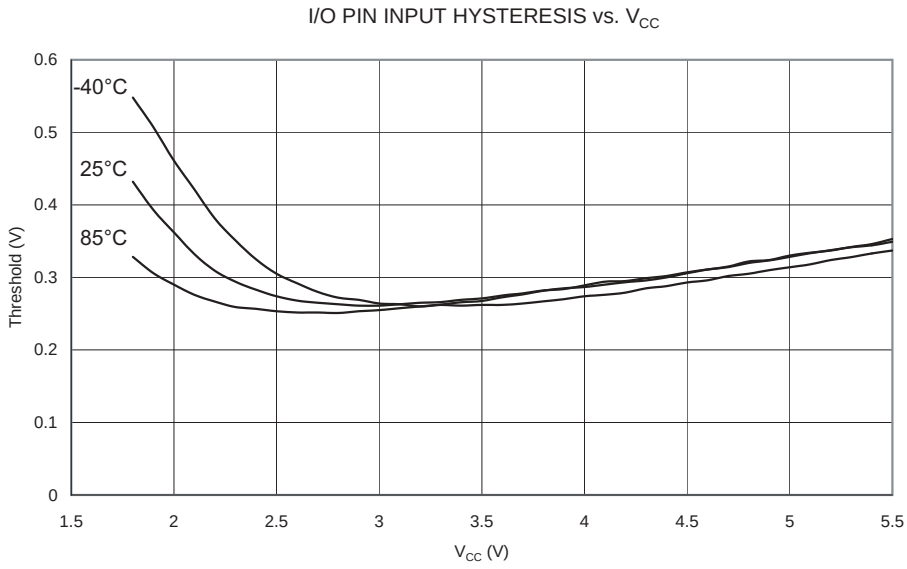


Figure 156. Reset Input Threshold Voltage vs. V_{CC} (V_{IH}, Reset Pin Read as “1”)

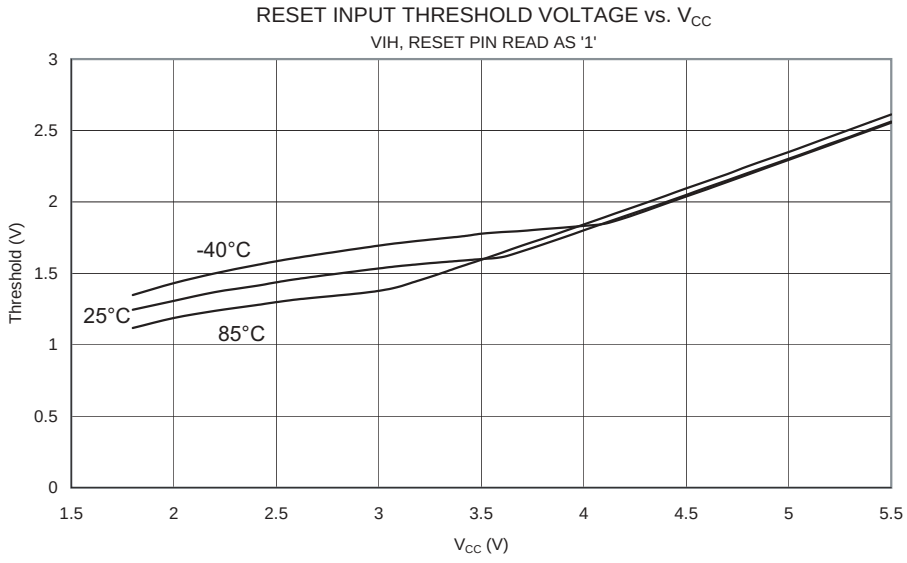


Figure 157. Reset Input Threshold Voltage vs. V_{CC} (V_{IL}, Reset Pin Read as “0”)

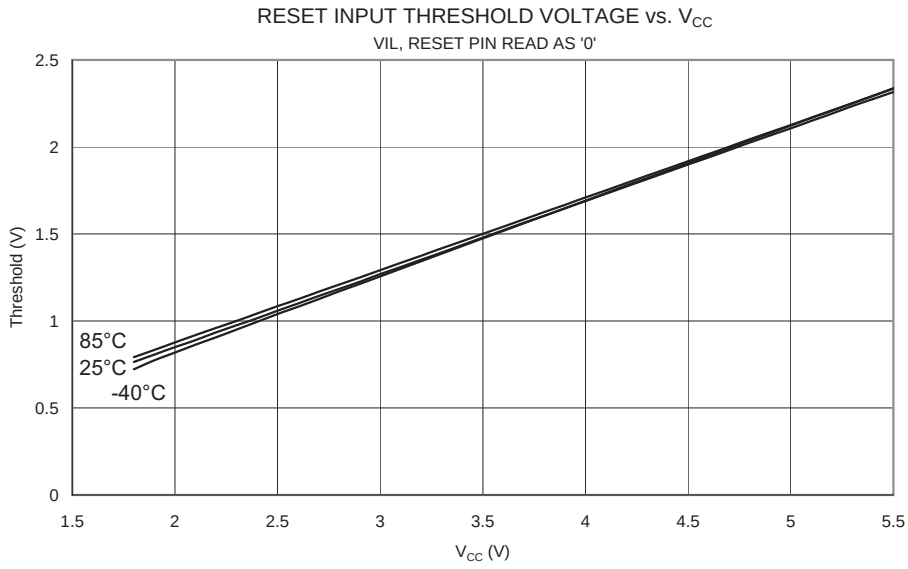
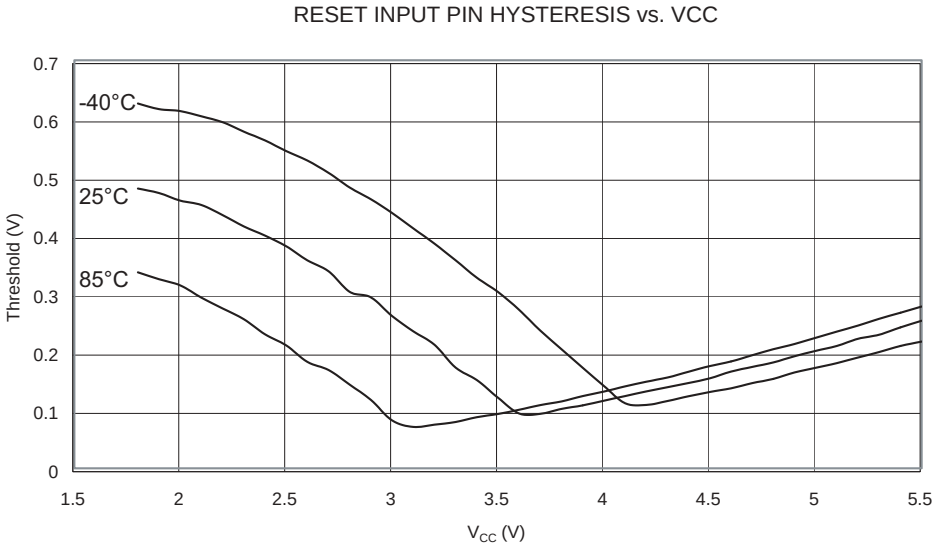


Figure 158. Reset Input Pin Hysteresis vs. V_{CC}



BOD Thresholds and Analog Comparator Offset

Figure 159. BOD Thresholds vs. Temperature (BOD Level is 4.3V)

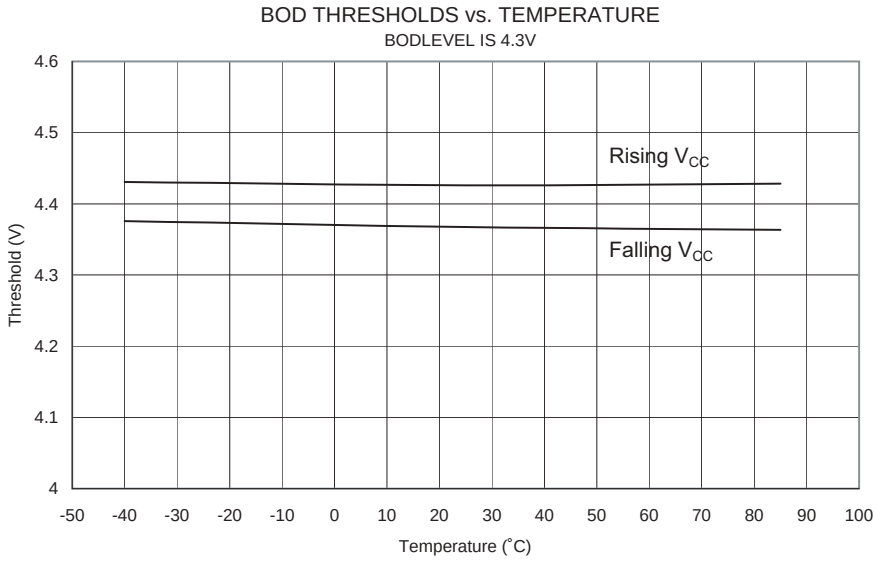


Figure 160. BOD Thresholds vs. Temperature (BOD Level is 2.7V)

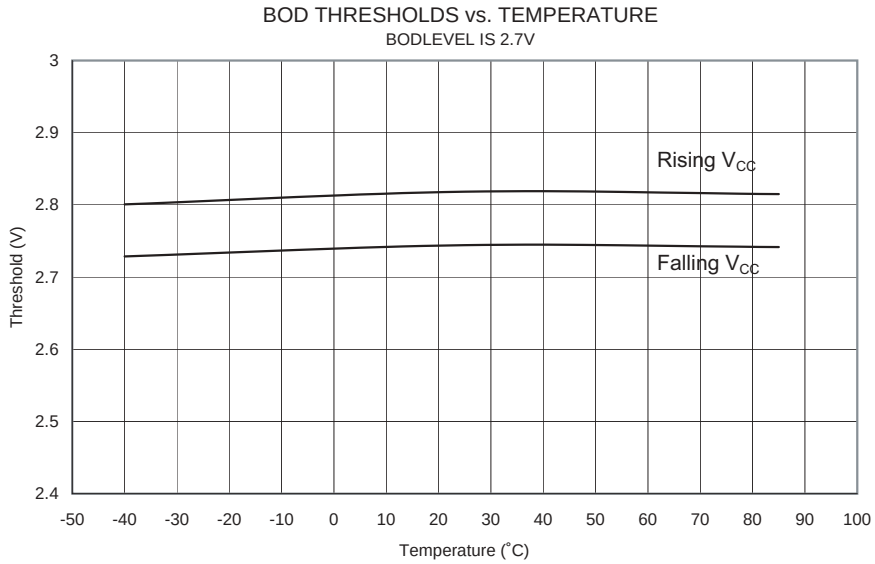


Figure 161. BOD Thresholds vs. Temperature (BOD Level is 2.3V)

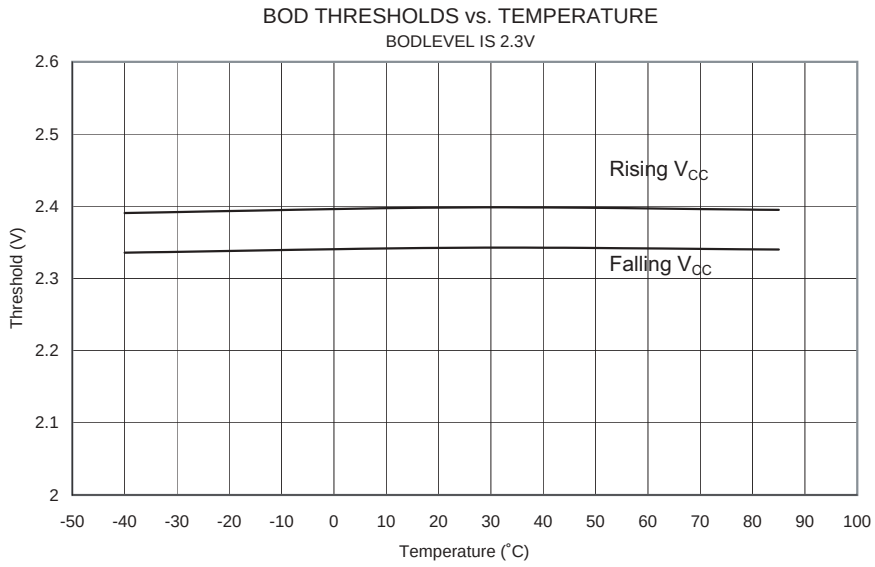


Figure 162. BOD Thresholds vs. Temperature (BOD Level is 1.8V)

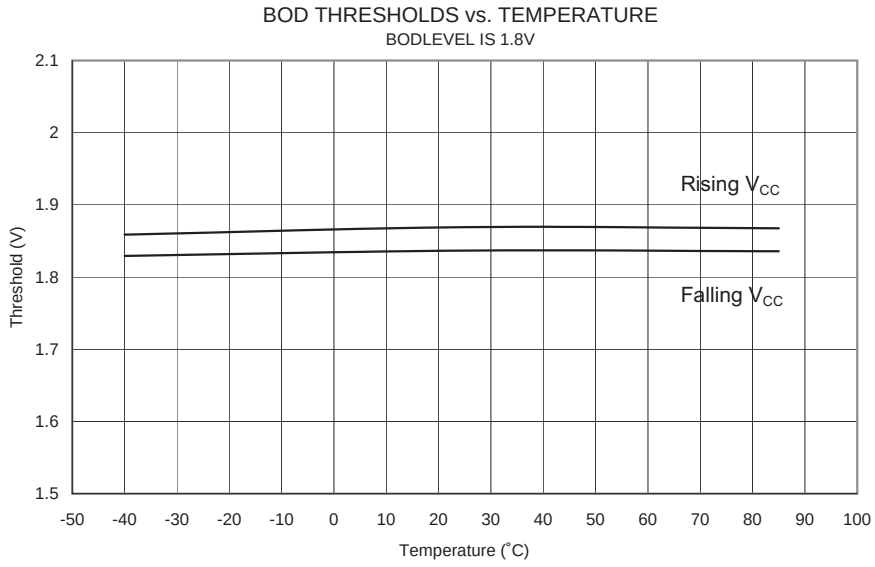


Figure 163. Bandgap Voltage vs. V_{CC}

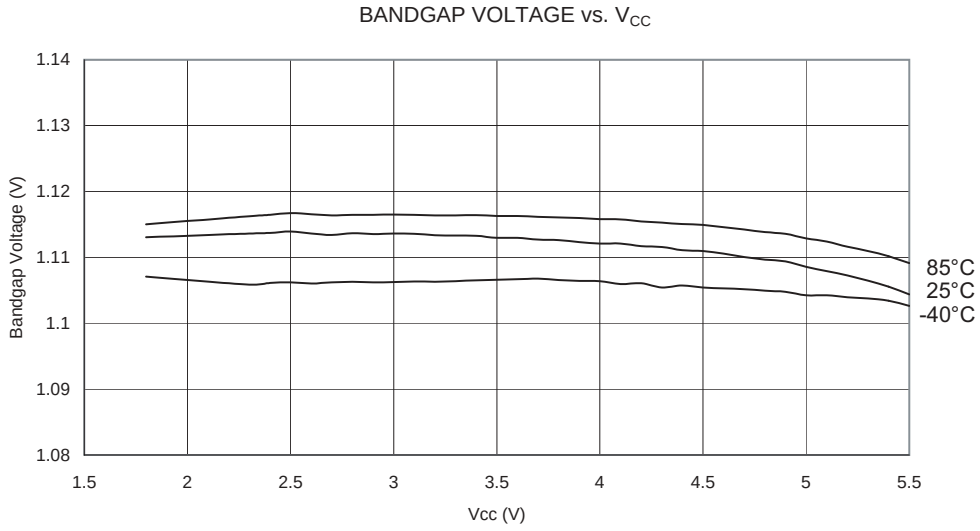


Figure 164. Analog Comparator Offset Voltage vs. Common Mode Voltage (V_{CC} = 5V)

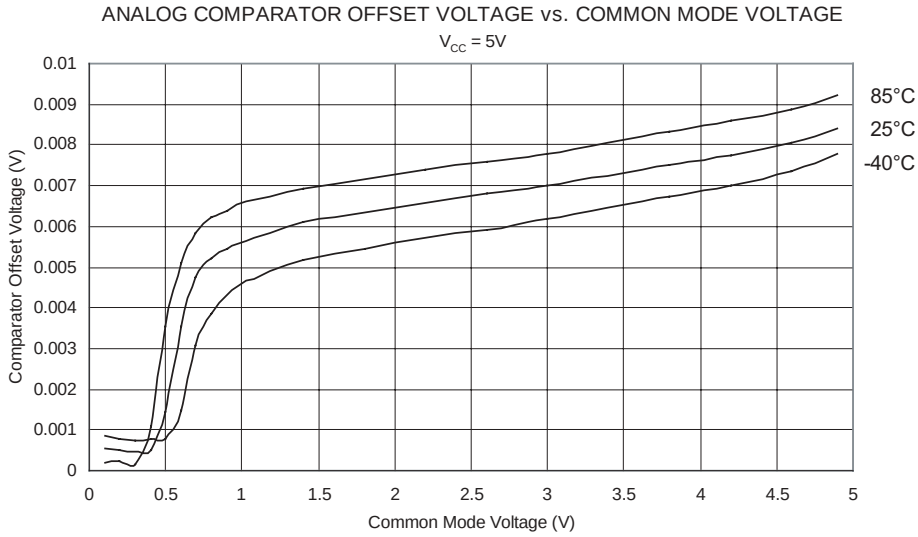
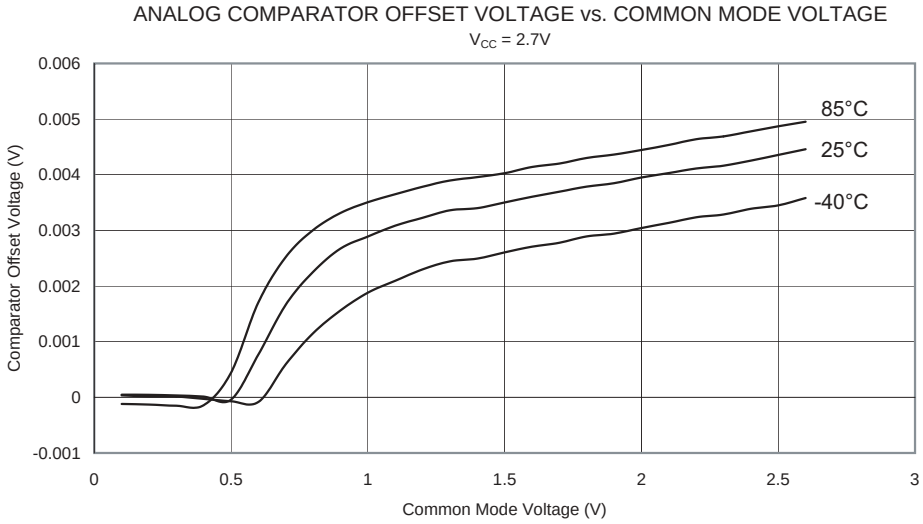


Figure 165. Analog Comparator Offset Voltage vs. Common Mode Voltage (V_{CC} = 2.7V)



Internal Oscillator Speed

Figure 166. Watchdog Oscillator Frequency vs. V_{CC}

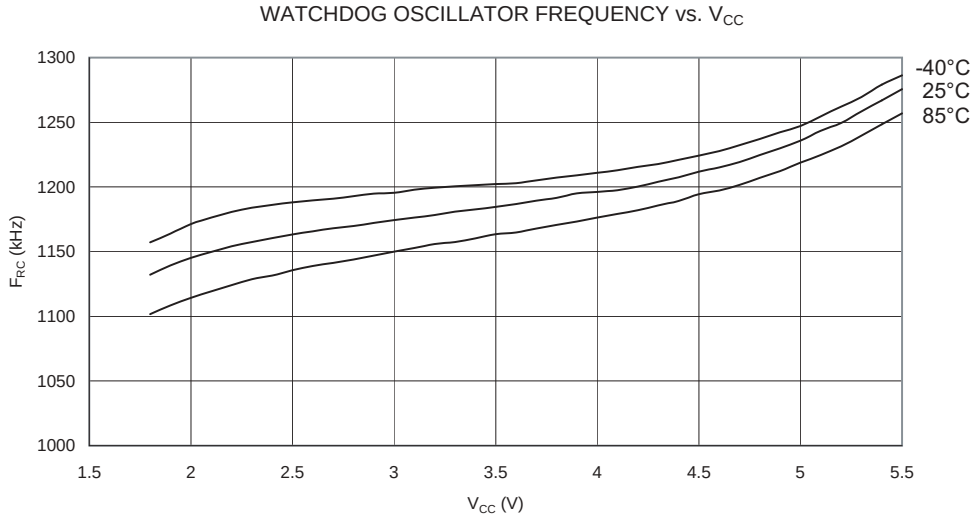


Figure 167. Calibrated 8 MHz RC Oscillator Frequency vs. Temperature

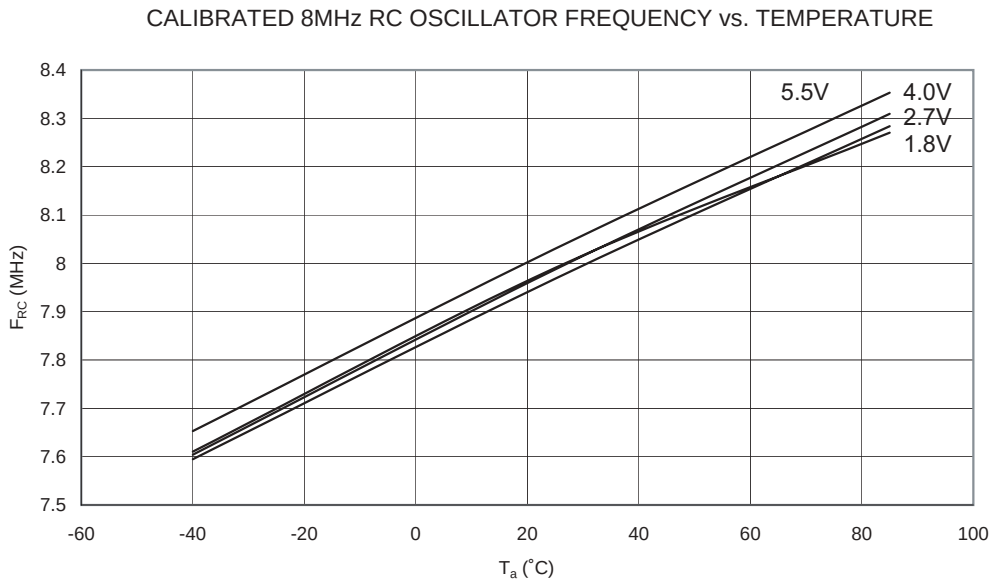


Figure 168. Calibrated 8 MHz RC Oscillator Frequency vs.V_{CC}

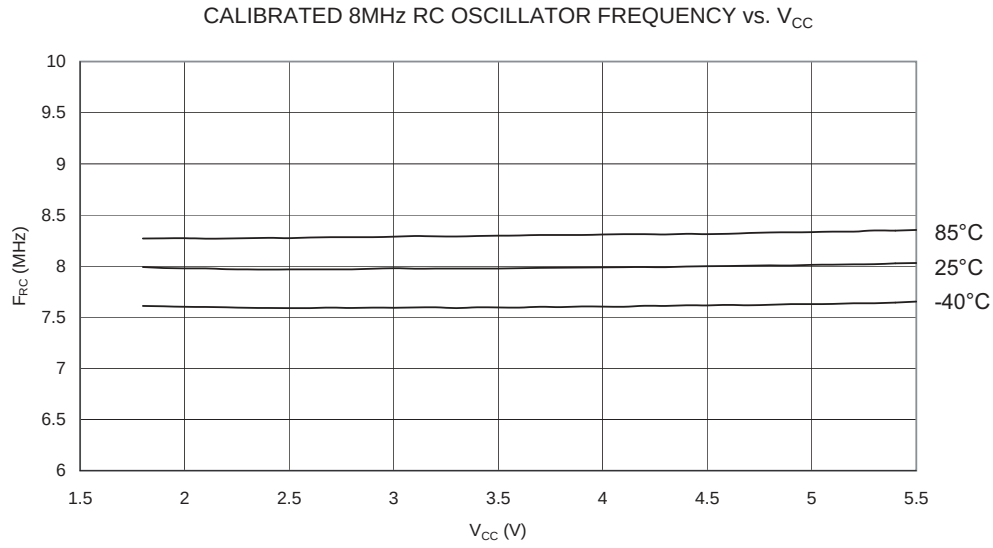
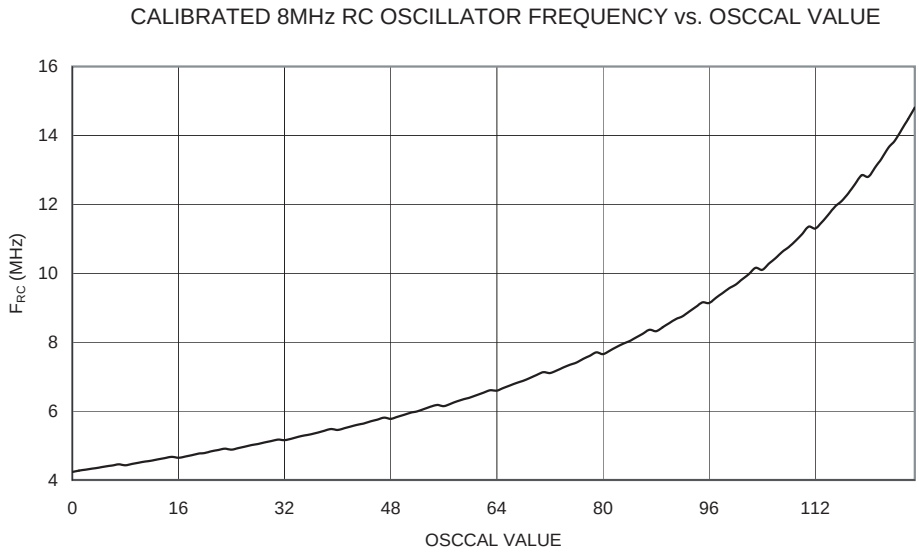


Figure 169. Calibrated 8 MHz RC Oscillator Frequency vs. Osccal Value



Current Consumption of Peripheral Units

Figure 170. Brownout Detector Current vs. V_{CC}

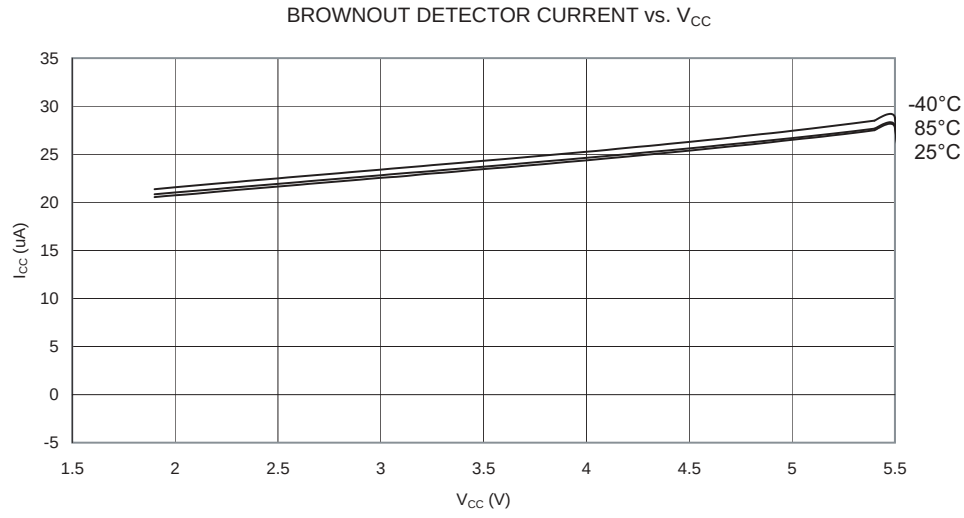


Figure 171. 32 kHz TOSC Current vs. V_{CC} (Watchdog Timer Disabled)

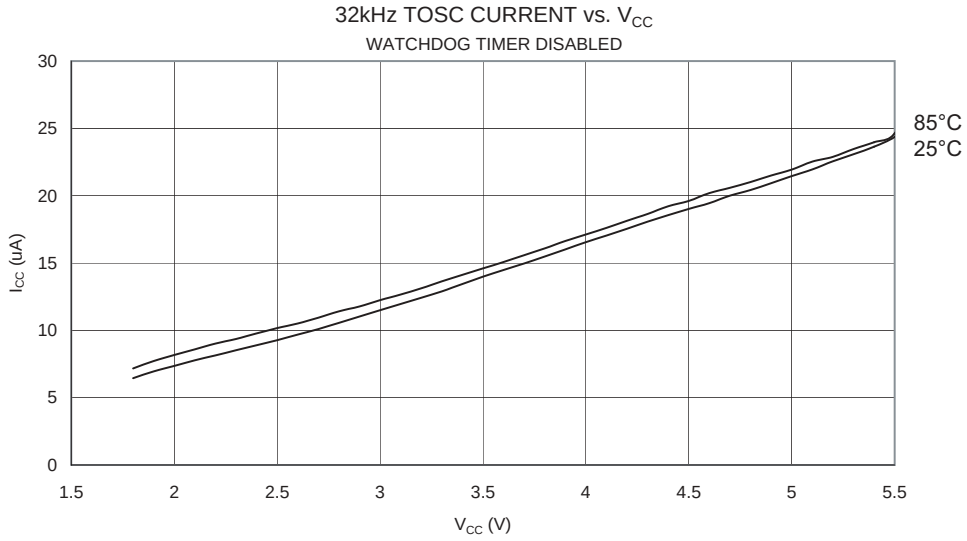


Figure 172. Watchdog TImer Current vs. V_{CC}

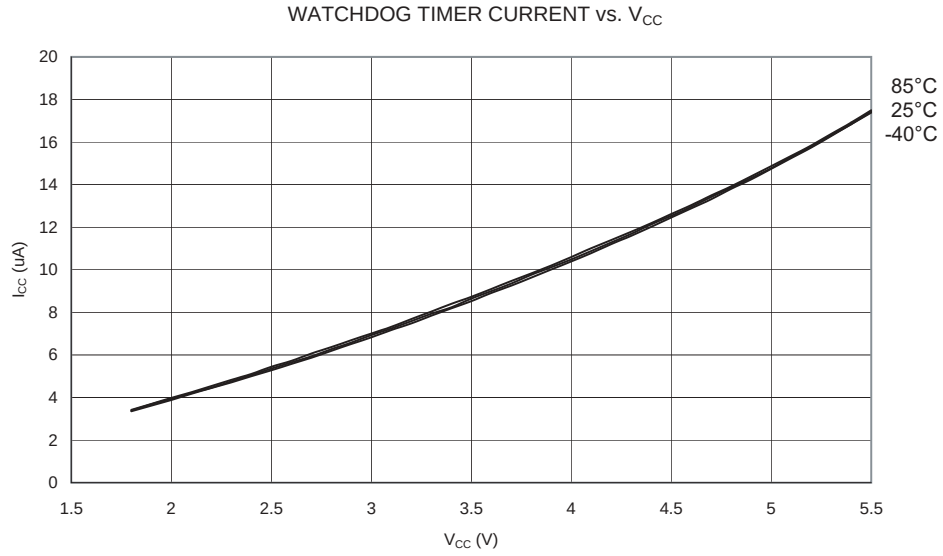


Figure 173. Analog Comparator Current vs. V_{CC}

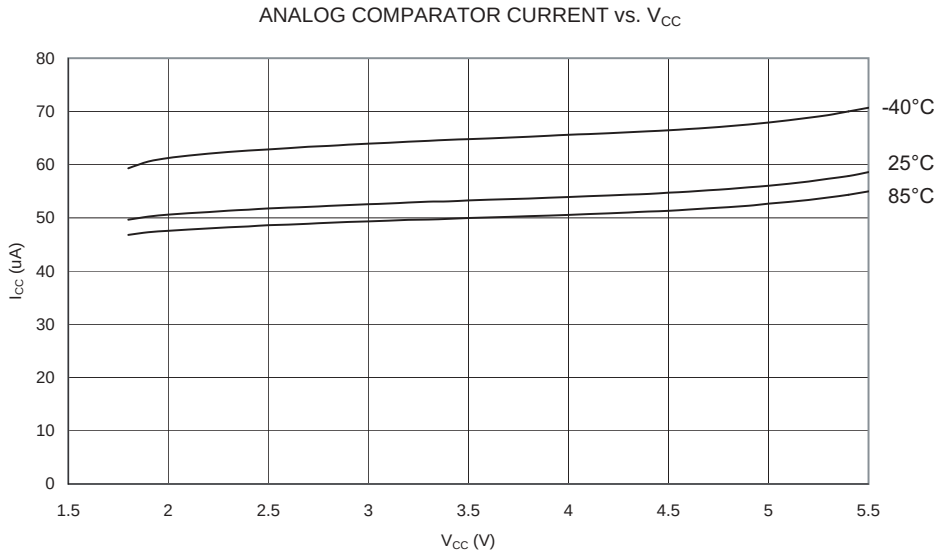
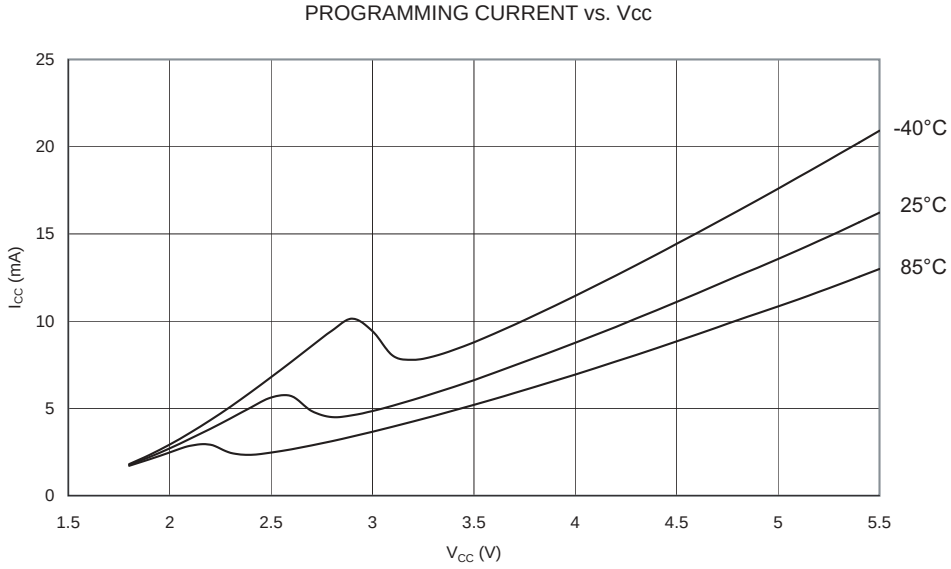


Figure 174. Programming Current vs. V_{CC}



Current Consumption in Reset and Reset Pulsewidth

Figure 175. Reset Supply Current vs. Frequency (0.1 - 1.0 MHz, Excluding Current Through The Reset Pull-up)

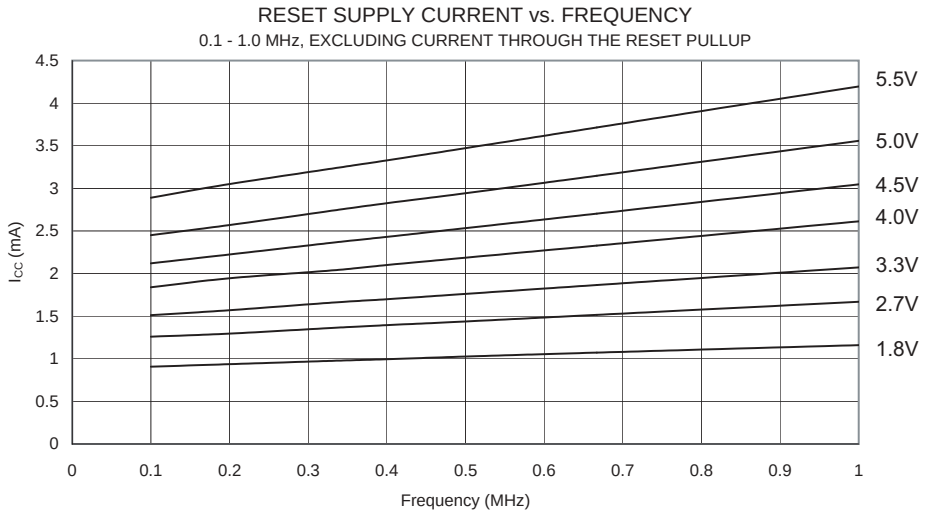


Figure 176. Reset Supply Current vs. Frequency (1 - 20 MHz, Excluding Current Through The Reset Pull-up)

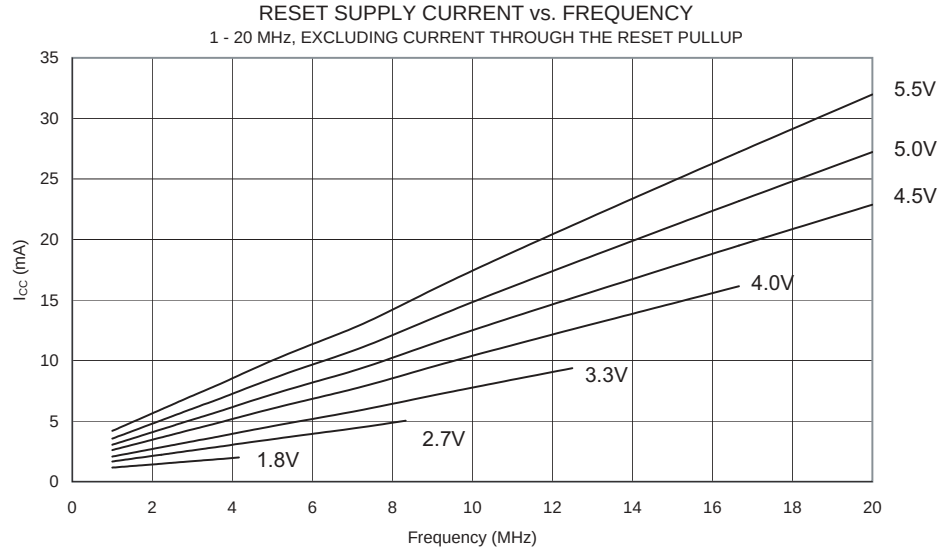
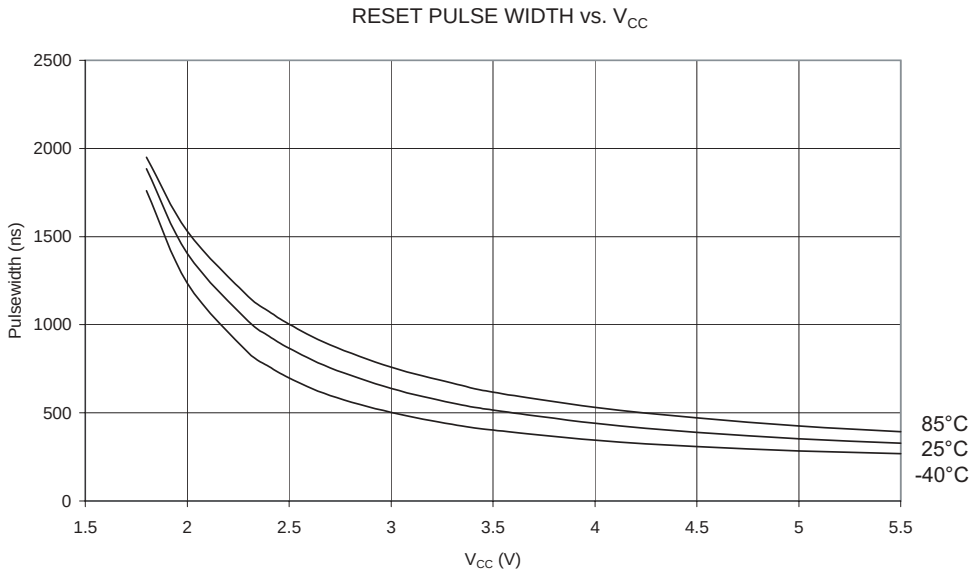


Figure 177. Reset Pulse Width vs. V_{CC}



Register Summary

Address	Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Page
(0xFF)	Reserved	–	–	–	–	–	–	–	–	
..	Reserved	–	–	–	–	–	–	–	–	
(0x9E)	Reserved	–	–	–	–	–	–	–	–	
(0x9D)	Reserved	–	–	–	–	–	–	–	–	
(0x9C)	Reserved	–	–	–	–	–	–	–	–	
(0x9B)	Reserved	–	–	–	–	–	–	–	–	
(0x9A)	Reserved	–	–	–	–	–	–	–	–	
(0x99)	Reserved	–	–	–	–	–	–	–	–	
(0x98)	Reserved	–	–	–	–	–	–	–	–	
(0x97)	Reserved	–	–	–	–	–	–	–	–	
(0x96)	Reserved	–	–	–	–	–	–	–	–	
(0x95)	Reserved	–	–	–	–	–	–	–	–	
(0x94)	Reserved	–	–	–	–	–	–	–	–	
(0x93)	Reserved	–	–	–	–	–	–	–	–	
(0x92)	Reserved	–	–	–	–	–	–	–	–	
(0x91)	Reserved	–	–	–	–	–	–	–	–	
(0x90)	Reserved	–	–	–	–	–	–	–	–	
(0x8F)	Reserved	–	–	–	–	–	–	–	–	
(0x8E)	Reserved	–	–	–	–	–	–	–	–	
(0x8D)	Reserved	–	–	–	–	–	–	–	–	
(0x8C)	Reserved	–	–	–	–	–	–	–	–	
(0x8B)	TCCR3A	COM3A1	COM3A0	COM3B1	COM3B0	FOC3A	FOC3B	WGM31	WGM30	130
(0x8A)	TCCR3B	ICNC3	ICES3	–	WGM33	WGM32	CS32	CS31	CS30	127
(0x89)	TCNT3H	Timer/Counter3 – Counter Register High Byte								132
(0x88)	TCNT3L	Timer/Counter3 – Counter Register Low Byte								132
(0x87)	OCR3AH	Timer/Counter3 – Output Compare Register A High Byte								132
(0x86)	OCR3AL	Timer/Counter3 – Output Compare Register A Low Byte								132
(0x85)	OCR3BH	Timer/Counter3 – Output Compare Register B High Byte								132
(0x84)	OCR3BL	Timer/Counter3 – Output Compare Register B Low Byte								132
(0x83)	Reserved	–	–	–	–	–	–	–	–	
(0x82)	Reserved	–	–	–	–	–	–	–	–	
(0x81)	ICR3H	Timer/Counter3 – Input Capture Register High Byte								133
(0x80)	ICR3L	Timer/Counter3 – Input Capture Register Low Byte								133
(0x7F)	Reserved	–	–	–	–	–	–	–	–	
(0x7E)	Reserved	–	–	–	–	–	–	–	–	
(0x7D)	ETIMSK	–	–	TICIE3	OCIE3A	OCIE3B	TOIE3	–	–	134
(0x7C)	ETIFR	–	–	ICF3	OCF3A	OCF3B	TOV3	–	–	135
(0x7B)	Reserved	–	–	–	–	–	–	–	–	
(0x7A)	Reserved	–	–	–	–	–	–	–	–	
(0x79)	Reserved	–	–	–	–	–	–	–	–	
(0x78)	Reserved	–	–	–	–	–	–	–	–	
(0x77)	Reserved	–	–	–	–	–	–	–	–	
(0x76)	Reserved	–	–	–	–	–	–	–	–	
(0x75)	Reserved	–	–	–	–	–	–	–	–	
(0x74)	Reserved	–	–	–	–	–	–	–	–	
(0x73)	Reserved	–	–	–	–	–	–	–	–	
(0x72)	Reserved	–	–	–	–	–	–	–	–	
(0x71)	Reserved	–	–	–	–	–	–	–	–	
(0x70)	Reserved	–	–	–	–	–	–	–	–	
(0x6F)	Reserved	–	–	–	–	–	–	–	–	
(0x6E)	Reserved	–	–	–	–	–	–	–	–	
(0x6D)	Reserved	–	–	–	–	–	–	–	–	
(0x6C)	PCMSK1	PCINT15	PCINT14	PCINT13	PCINT12	PCINT11	PCINT10	PCINT9	PCINT8	87
(0x6B)	PCMSK0	PCINT7	PCINT6	PCINT5	PCINT4	PCINT3	PCINT2	PCINT1	PCINT0	87
(0x6A)	Reserved	–	–	–	–	–	–	–	–	
(0x69)	Reserved	–	–	–	–	–	–	–	–	
(0x68)	Reserved	–	–	–	–	–	–	–	–	
(0x67)	Reserved	–	–	–	–	–	–	–	–	
(0x66)	Reserved	–	–	–	–	–	–	–	–	
(0x65)	Reserved	–	–	–	–	–	–	–	–	
(0x64)	Reserved	–	–	–	–	–	–	–	–	
(0x63)	Reserved	–	–	–	–	–	–	–	–	
(0x62)	Reserved	–	–	–	–	–	–	–	–	
(0x61)	CLKPR	CLKPCE	–	–	–	CLKPS3	CLKPS2	CLKPS1	CLKPS0	39

Address	Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Page
(0x60)	Reserved	–	–	–	–	–	–	–	–	
0x3F (0x5F)	SREG	I	T	H	S	V	N	Z	C	8
0x3E (0x5E)	SPH	SP15	SP14	SP13	SP12	SP11	SP10	SP9	SP8	11
0x3D (0x5D)	SPL	SP7	SP6	SP5	SP4	SP3	SP2	SP1	SP0	11
0x3C[2](0x5C)[2]	UBRR1H	URSEL1				UBRR1[11:8]				189
	UCSR1C	URSEL1	UMSEL1	UPM11	UPM10	USBS1	UCSZ11	UCSZ10	UCPOL1	188
0x3B (0x5B)	GICR	INT1	INT0	INT2	PCIE1	PCIE0	–	IVSEL	IVCE	60, 85
0x3A (0x5A)	GIFR	INTF1	INTF0	INTF2	PCIF1	PCIF0	–	–	–	86
0x39 (0x59)	TIMSK	TOIE1	OCIE1A	OCIE1B	OCIE2	TICIE1	TOIE2	TOIE0	OCIE0	101, 133, 154
0x38 (0x58)	TIFR	TOV1	OCF1A	OCF1B	OCF2	ICF1	TOV2	TOV0	OCF0	102, 135, 155
0x37 (0x57)	SPMCR	SPMIE	RWWSB	–	RWWSRE	BLBSET	PGWRT	PGERS	SPMEN	220
0x36 (0x56)	EMCUCR	SM0	SRL2	SRL1	SRL0	SRW01	SRW00	SRW11	ISC2	28,42,84
0x35 (0x55)	MCUCR	SRE	SRW10	SE	SM1	ISC11	ISC10	ISC01	ISC00	28,41,83
0x34 (0x54)	MCUCSR	JTD	–	SM2	JTRF	WDRF	BORF	EXTRF	PORF	41,50,206
0x33 (0x53)	TCCR0	FOC0	WGM00	COM01	COM00	WGM01	CS02	CS01	CS00	99
0x32 (0x52)	TCNT0	Timer/Counter0 (8 Bits)								101
0x31 (0x51)	OCR0	Timer/Counter0 Output Compare Register								101
0x30 (0x50)	SFIOR	TSM	XMBK	XMM2	XMM1	XMM0	PUD	PSR2	PSR310	30,69,104,156
0x2F (0x4F)	TCCR1A	COM1A1	COM1A0	COM1B1	COM1B0	FOC1A	FOC1B	WGM11	WGM10	127
0x2E (0x4E)	TCCR1B	ICNC1	ICES1	–	WGM13	WGM12	CS12	CS11	CS10	130
0x2D (0x4D)	TCNT1H	Timer/Counter1 – Counter Register High Byte								132
0x2C (0x4C)	TCNT1L	Timer/Counter1 – Counter Register Low Byte								132
0x2B (0x4B)	OCR1AH	Timer/Counter1 – Output Compare Register A High Byte								132
0x2A (0x4A)	OCR1AL	Timer/Counter1 – Output Compare Register A Low Byte								132
0x29 (0x49)	OCR1BH	Timer/Counter1 – Output Compare Register B High Byte								132
0x28 (0x48)	OCR1BL	Timer/Counter1 – Output Compare Register B Low Byte								132
0x27 (0x47)	TCCR2	FOC2	WGM20	COM21	COM20	WGM21	CS22	CS21	CS20	148
0x26 (0x46)	ASSR	–	–	–	–	AS2	TCON2UB	OCR2UB	TCR2UB	152
0x25 (0x45)	ICR1H	Timer/Counter1 – Input Capture Register High Byte								133
0x24 (0x44)	ICR1L	Timer/Counter1 – Input Capture Register Low Byte								133
0x23 (0x43)	TCNT2	Timer/Counter2 (8 Bits)								151
0x22 (0x42)	OCR2	Timer/Counter2 Output Compare Register								151
0x21 (0x41)	WDTCR	–	–	–	WDCE	WDE	WDP2	WDP1	WDP0	52
0x20[2] (0x40)[2]	UBRR0H	URSEL0	–	–	–	UBRR0[11:8]				189
	UCSR0C	URSEL0	UMSEL0	UPM01	UPM00	USBS0	UCSZ01	UCSZ00	UCPOL0	188
0x1F (0x3F)	EEARH	–	–	–	–	–	–	–	EEAR8	18
0x1E (0x3E)	EEARL	EEPROM Address Register Low Byte								18
0x1D (0x3D)	EEDR	EEPROM Data Register								19
0x1C (0x3C)	EECR	–	–	–	–	EERIE	EEMWE	EEWE	EERE	19
0x1B (0x3B)	PORTA	PORTA7	PORTA6	PORTA5	PORTA4	PORTA3	PORTA2	PORTA1	PORTA0	81
0x1A (0x3A)	DDRA	DDA7	DDA6	DDA5	DDA4	DDA3	DDA2	DDA1	DDA0	81
0x19 (0x39)	PINA	PINA7	PINA6	PINA5	PINA4	PINA3	PINA2	PINA1	PINA0	81
0x18 (0x38)	PORTB	PORTB7	PORTB6	PORTB5	PORTB4	PORTB3	PORTB2	PORTB1	PORTB0	81
0x17 (0x37)	DDRB	DDB7	DDB6	DDB5	DDB4	DDB3	DDB2	DDB1	DDB0	81
0x16 (0x36)	PINB	PINB7	PINB6	PINB5	PINB4	PINB3	PINB2	PINB1	PINB0	81
0x15 (0x35)	PORTC	PORTC7	PORTC6	PORTC5	PORTC4	PORTC3	PORTC2	PORTC1	PORTC0	81
0x14 (0x34)	DDRC	DDC7	DDC6	DDC5	DDC4	DDC3	DDC2	DDC1	DDC0	81
0x13 (0x33)	PINC	PINC7	PINC6	PINC5	PINC4	PINC3	PINC2	PINC1	PINC0	82
0x12 (0x32)	PORTD	PORTD7	PORTD6	PORTD5	PORTD4	PORTD3	PORTD2	PORTD1	PORTD0	82
0x11 (0x31)	DDRD	DDD7	DDD6	DDD5	DDD4	DDD3	DDD2	DDD1	DDD0	82
0x10 (0x30)	PIND	PIND7	PIND6	PIND5	PIND4	PIND3	PIND2	PIND1	PIND0	82
0x0F (0x2F)	SPDR	SPI Data Register								163
0x0E (0x2E)	SPSR	SPIF	WCOL	–	–	–	–	–	SPI2X	163
0x0D (0x2D)	SPCR	SPIE	SPE	DORD	MSTR	CPOL	CPHA	SPR1	SPR0	161
0x0C (0x2C)	UDR0	USART0 I/O Data Register								185
0x0B (0x2B)	UCSR0A	RXC0	TXC0	UDRE0	FE0	DOR0	UPE0	U2X0	MPCM0	185
0x0A (0x2A)	UCSR0B	RXCIE0	TXCIE0	UDRIE0	RXEN0	TXEN0	UCSZ02	RXB80	TXB80	186
0x09 (0x29)	UBRR0L	USART0 Baud Rate Register Low Byte								189
0x08 (0x28)	ACSR	ACD	ACBG	ACO	ACI	ACIE	ACIC	ACIS1	ACIS0	194
0x07 (0x27)	PORTE	–	–	–	–	–	PORTE2	PORTE1	PORTE0	82
0x06 (0x26)	DDRE	–	–	–	–	–	DDE2	DDE1	DDE0	82
0x05 (0x25)	PINE	–	–	–	–	–	PINE2	PINE1	PINE0	82
0x04[1] (0x24)[1]	OSCCAL	–	CAL6	CAL5	CAL4	CAL3	CAL2	CAL1	CAL0	37
	OCDR	On-chip Debug Register								201
0x03 (0x23)	UDR1	USART1 I/O Data Register								185
0x02 (0x22)	UCSR1A	RXC1	TXC1	UDRE1	FE1	DOR1	UPE1	U2X1	MPCM1	185

Address	Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Page
0x01 (0x21)	UCSR1B	RXCIE1	TXCIE1	UDRIE1	RXEN1	TXEN1	UCSZ12	RXB81	TXB81	186
0x00 (0x20)	UBRR1L	USART1 Baud Rate Register Low Byte								189

Notes:
1. When the OCDEN Fuse is unprogrammed, the OSCCAL Register is always accessed on this address. Refer to the debugger specific documentation for details on how to use the OCDR Register.
2. Refer to the USART description for details on how to access UBRRH and UCSRC.
3. For compatibility with future devices, reserved bits should be written to zero if accessed. Reserved I/O memory addresses should never be written.
4. Some of the Status Flags are cleared by writing a logical one to them. Note that the CBI and SBI instructions will operate on all bits in the I/O Register, writing a one back into any flag read as set, thus clearing the flag. The CBI and SBI instructions work with registers 0x00 to 0x1F only.

Instruction Set Summary

Mnemonics	Operands	Description	Operation	Flags	#Clocks
ARITHMETIC AND LOGIC INSTRUCTIONS					
ADD	Rd, Rr	Add two Registers	Rd ← Rd + Rr	Z,C,N,V,H	1
ADC	Rd, Rr	Add with Carry two Registers	Rd ← Rd + Rr + C	Z,C,N,V,H	1
ADIW	Rdl,K	Add Immediate to Word	Rdh:Rdl ← Rdh:Rdl + K	Z,C,N,V,S	2
SUB	Rd, Rr	Subtract two Registers	Rd ← Rd - Rr	Z,C,N,V,H	1
SUBI	Rd, K	Subtract Constant from Register	Rd ← Rd - K	Z,C,N,V,H	1
SBC	Rd, Rr	Subtract with Carry two Registers	Rd ← Rd - Rr - C	Z,C,N,V,H	1
SBCI	Rd, K	Subtract with Carry Constant from Reg.	Rd ← Rd - K - C	Z,C,N,V,H	1
SBIW	Rdl,K	Subtract Immediate from Word	Rdh:Rdl ← Rdh:Rdl - K	Z,C,N,V,S	2
AND	Rd, Rr	Logical AND Registers	Rd ← Rd • Rr	Z,N,V	1
ANDI	Rd, K	Logical AND Register and Constant	Rd ← Rd • K	Z,N,V	1
OR	Rd, Rr	Logical OR Registers	Rd ← Rd v Rr	Z,N,V	1
ORI	Rd, K	Logical OR Register and Constant	Rd ← Rd v K	Z,N,V	1
EOR	Rd, Rr	Exclusive OR Registers	Rd ← Rd ⊕ Rr	Z,N,V	1
COM	Rd	One's Complement	Rd ← 0xFF – Rd	Z,C,N,V	1
NEG	Rd	Two's Complement	Rd ← 0x00 – Rd	Z,C,N,V,H	1
SBR	Rd,K	Set Bit(s) in Register	Rd ← Rd v K	Z,N,V	1
CBR	Rd,K	Clear Bit(s) in Register	Rd ← Rd • (0xFF - K)	Z,N,V	1
INC	Rd	Increment	Rd ← Rd + 1	Z,N,V	1
DEC	Rd	Decrement	Rd ← Rd – 1	Z,N,V	1
TST	Rd	Test for Zero or Minus	Rd ← Rd • Rd	Z,N,V	1
CLR	Rd	Clear Register	Rd ← Rd ⊕ Rd	Z,N,V	1
SER	Rd	Set Register	Rd ← 0xFF	None	1
MUL	Rd, Rr	Multiply Unsigned	R1:R0 ← Rd x Rr	Z,C	2
MULS	Rd, Rr	Multiply Signed	R1:R0 ← Rd x Rr	Z,C	2
MULSU	Rd, Rr	Multiply Signed with Unsigned	R1:R0 ← Rd x Rr	Z,C	2
FMUL	Rd, Rr	Fractional Multiply Unsigned	R1:R0 ← (Rd x Rr) << 1	Z,C	2
FMULS	Rd, Rr	Fractional Multiply Signed	R1:R0 ← (Rd x Rr) << 1	Z,C	2
FMULSU	Rd, Rr	Fractional Multiply Signed with Unsigned	R1:R0 ← (Rd x Rr) << 1	Z,C	2
BRANCH INSTRUCTIONS					
RJMP	k	Relative Jump	PC ← PC + k + 1	None	2
IJMP		Indirect Jump to (Z)	PC ← Z	None	2
JMP	k	Direct Jump	PC ← k	None	3
RCALL	k	Relative Subroutine Call	PC ← PC + k + 1	None	3
ICALL		Indirect Call to (Z)	PC ← Z	None	3
CALL	k	Direct Subroutine Call	PC ← k	None	4
RET		Subroutine Return	PC ← STACK	None	4
RETI		Interrupt Return	PC ← STACK	I	4
CPSE	Rd,Rr	Compare, Skip if Equal	if (Rd = Rr) PC ← PC + 2 or 3	None	1/2/3
CP	Rd,Rr	Compare	Rd – Rr	Z, N,V,C,H	1
CPC	Rd,Rr	Compare with Carry	Rd – Rr – C	Z, N,V,C,H	1
CPI	Rd,K	Compare Register with Immediate	Rd – K	Z, N,V,C,H	1
SBRC	Rr, b	Skip if Bit in Register Cleared	if (Rr(b)=0) PC ← PC + 2 or 3	None	1/2/3
SBRS	Rr, b	Skip if Bit in Register is Set	if (Rr(b)=1) PC ← PC + 2 or 3	None	1/2/3
SBIC	P, b	Skip if Bit in I/O Register Cleared	if (P(b)=0) PC ← PC + 2 or 3	None	1/2/3
SBIS	P, b	Skip if Bit in I/O Register is Set	if (P(b)=1) PC ← PC + 2 or 3	None	1/2/3
BRBS	s, k	Branch if Status Flag Set	if (SREG(s) = 1) then PC←PC+k + 1	None	1/2
BRBC	s, k	Branch if Status Flag Cleared	if (SREG(s) = 0) then PC←PC+k + 1	None	1/2
BREQ	k	Branch if Equal	if (Z = 1) then PC ← PC + k + 1	None	1/2
BRNE	k	Branch if Not Equal	if (Z = 0) then PC ← PC + k + 1	None	1/2
BRCS	k	Branch if Carry Set	if (C = 1) then PC ← PC + k + 1	None	1/2
BRCC	k	Branch if Carry Cleared	if (C = 0) then PC ← PC + k + 1	None	1/2
BRSH	k	Branch if Same or Higher	if (C = 0) then PC ← PC + k + 1	None	1/2
BRLO	k	Branch if Lower	if (C = 1) then PC ← PC + k + 1	None	1/2
BRMI	k	Branch if Minus	if (N = 1) then PC ← PC + k + 1	None	1/2
BRPL	k	Branch if Plus	if (N = 0) then PC ← PC + k + 1	None	1/2
BRGE	k	Branch if Greater or Equal, Signed	if (N ⊕ V= 0) then PC ← PC + k + 1	None	1/2
BRLT	k	Branch if Less Than Zero, Signed	if (N ⊕ V= 1) then PC ← PC + k + 1	None	1/2
BRHS	k	Branch if Half Carry Flag Set	if (H = 1) then PC ← PC + k + 1	None	1/2
BRHC	k	Branch if Half Carry Flag Cleared	if (H = 0) then PC ← PC + k + 1	None	1/2
BRTS	k	Branch if T Flag Set	if (T = 1) then PC ← PC + k + 1	None	1/2
BRTC	k	Branch if T Flag Cleared	if (T = 0) then PC ← PC + k + 1	None	1/2
BRVS	k	Branch if Overflow Flag is Set	if (V = 1) then PC ← PC + k + 1	None	1/2
BRVC	k	Branch if Overflow Flag is Cleared	if (V = 0) then PC ← PC + k + 1	None	1/2

Mnemonics	Operands	Description	Operation	Flags	#Clocks
BRIE	k	Branch if Interrupt Enabled	if (I = 1) then PC ← PC + k + 1	None	1/2
BRID	k	Branch if Interrupt Disabled	if (I = 0) then PC ← PC + k + 1	None	1/2
DATA TRANSFER INSTRUCTIONS					
MOV	Rd, Rr	Move Between Registers	Rd ← Rr	None	1
MOVW	Rd, Rr	Copy Register Word	Rd+1:Rd ← Rr+1:Rr	None	1
LDI	Rd, K	Load Immediate	Rd ← K	None	1
LD	Rd, X	Load Indirect	Rd ← (X)	None	2
LD	Rd, X+	Load Indirect and Post-Inc.	Rd ← (X), X ← X + 1	None	2
LD	Rd, - X	Load Indirect and Pre-Dec.	X ← X - 1, Rd ← (X)	None	2
LD	Rd, Y	Load Indirect	Rd ← (Y)	None	2
LD	Rd, Y+	Load Indirect and Post-Inc.	Rd ← (Y), Y ← Y + 1	None	2
LD	Rd, - Y	Load Indirect and Pre-Dec.	Y ← Y - 1, Rd ← (Y)	None	2
LDD	Rd,Y+q	Load Indirect with Displacement	Rd ← (Y + q)	None	2
LD	Rd, Z	Load Indirect	Rd ← (Z)	None	2
LD	Rd, Z+	Load Indirect and Post-Inc.	Rd ← (Z), Z ← Z+1	None	2
LD	Rd, -Z	Load Indirect and Pre-Dec.	Z ← Z - 1, Rd ← (Z)	None	2
LDD	Rd, Z+q	Load Indirect with Displacement	Rd ← (Z + q)	None	2
LDS	Rd, k	Load Direct from SRAM	Rd ← (k)	None	2
ST	X, Rr	Store Indirect	(X) ← Rr	None	2
ST	X+, Rr	Store Indirect and Post-Inc.	(X) ← Rr, X ← X + 1	None	2
ST	- X, Rr	Store Indirect and Pre-Dec.	X ← X - 1, (X) ← Rr	None	2
ST	Y, Rr	Store Indirect	(Y) ← Rr	None	2
ST	Y+, Rr	Store Indirect and Post-Inc.	(Y) ← Rr, Y ← Y + 1	None	2
ST	- Y, Rr	Store Indirect and Pre-Dec.	Y ← Y - 1, (Y) ← Rr	None	2
STD	Y+q,Rr	Store Indirect with Displacement	(Y + q) ← Rr	None	2
ST	Z, Rr	Store Indirect	(Z) ← Rr	None	2
ST	Z+, Rr	Store Indirect and Post-Inc.	(Z) ← Rr, Z ← Z + 1	None	2
ST	-Z, Rr	Store Indirect and Pre-Dec.	Z ← Z - 1, (Z) ← Rr	None	2
STD	Z+q,Rr	Store Indirect with Displacement	(Z + q) ← Rr	None	2
STS	k, Rr	Store Direct to SRAM	(k) ← Rr	None	2
LPM		Load Program Memory	R0 ← (Z)	None	3
LPM	Rd, Z	Load Program Memory	Rd ← (Z)	None	3
LPM	Rd, Z+	Load Program Memory and Post-Inc	Rd ← (Z), Z ← Z+1	None	3
SPM		Store Program Memory	(Z) ← R1:R0	None	-
IN	Rd, P	In Port	Rd ← P	None	1
OUT	P, Rr	Out Port	P ← Rr	None	1
PUSH	Rr	Push Register on Stack	STACK ← Rr	None	2
POP	Rd	Pop Register from Stack	Rd ← STACK	None	2
BIT AND BIT-TEST INSTRUCTIONS					
SBI	P,b	Set Bit in I/O Register	I/O(P,b) ← 1	None	2
CBI	P,b	Clear Bit in I/O Register	I/O(P,b) ← 0	None	2
LSL	Rd	Logical Shift Left	Rd(n+1) ← Rd(n), Rd(0) ← 0	Z,C,N,V	1
LSR	Rd	Logical Shift Right	Rd(n) ← Rd(n+1), Rd(7) ← 0	Z,C,N,V	1
ROL	Rd	Rotate Left Through Carry	Rd(0)←C,Rd(n+1)← Rd(n),C←Rd(7)	Z,C,N,V	1
ROR	Rd	Rotate Right Through Carry	Rd(7)←C,Rd(n)← Rd(n+1),C←Rd(0)	Z,C,N,V	1
ASR	Rd	Arithmetic Shift Right	Rd(n) ← Rd(n+1), n=0..6	Z,C,N,V	1
SWAP	Rd	Swap Nibbles	Rd(3..0)←Rd(7..4),Rd(7..4)←Rd(3..0)	None	1
BSET	s	Flag Set	SREG(s) ← 1	SREG(s)	1
BCLR	s	Flag Clear	SREG(s) ← 0	SREG(s)	1
BST	Rr, b	Bit Store from Register to T	T ← Rr(b)	T	1
BLD	Rd, b	Bit load from T to Register	Rd(b) ← T	None	1
SEC		Set Carry	C ← 1	C	1
CLC		Clear Carry	C ← 0	C	1
SEN		Set Negative Flag	N ← 1	N	1
CLN		Clear Negative Flag	N ← 0	N	1
SEZ		Set Zero Flag	Z ← 1	Z	1
CLZ		Clear Zero Flag	Z ← 0	Z	1
SEI		Global Interrupt Enable	I ← 1	I	1
CLI		Global Interrupt Disable	I ← 0	I	1
SES		Set Signed Test Flag	S ← 1	S	1
CLS		Clear Signed Test Flag	S ← 0	S	1
SEV		Set Twos Complement Overflow.	V ← 1	V	1
CLV		Clear Twos Complement Overflow	V ← 0	V	1
SET		Set T in SREG	T ← 1	T	1
CLT		Clear T in SREG	T ← 0	T	1
SEH		Set Half Carry Flag in SREG	H ← 1	H	1

Mnemonics	Operands	Description	Operation	Flags	#Clocks
CLH		Clear Half Carry Flag in SREG	H ← 0	H	1
MCU CONTROL INSTRUCTIONS					
NOP		No Operation		None	1
SLEEP		Sleep	(see specific descr. for Sleep function)	None	1
WDR		Watchdog Reset	(see specific descr. for WDR/Timer)	None	1
BREAK		Break	For On-chip Debug Only	None	N/A

Ordering Information

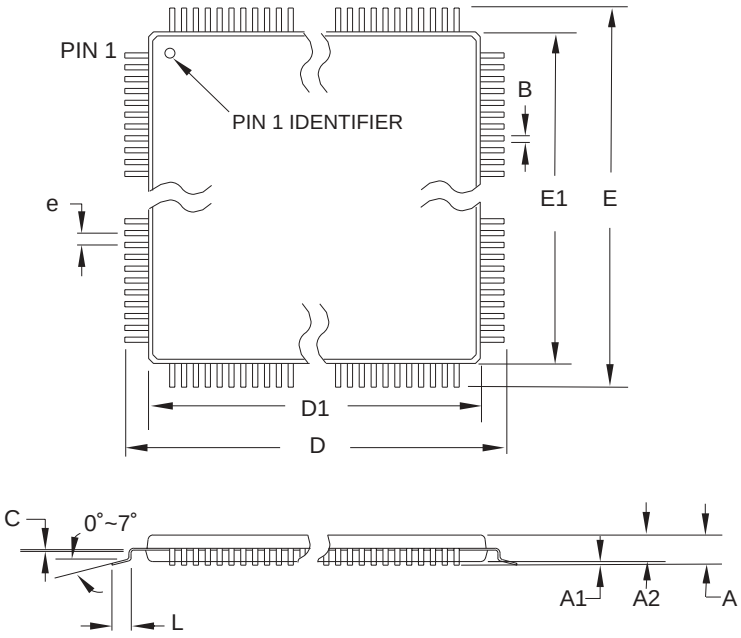
Speed (MHz)	Power Supply	Ordering Code	Package	Operation Range
8[2]	1.8 - 5.5V	ATmega162V-8AI ATmega162V-8PI ATmega162V-8MI	44A 40P6 44M1	Industrial (-40°C to 85°C)
16[3]	2.7 - 5.5V	ATmega162-16AI ATmega162-16PI ATmega162-16MI	44A 40P6 44M1	Industrial (-40°C to 85°C)

Notes:
1. This device can also be supplied in wafer form. Please contact your local Atmel sales office for detailed ordering information and minimum quantities.
2. See Figure 113 on page 265.
3. See Figure 114 on page 265.

Package Type	
44A	44-lead, Thin (1.0 mm) Plastic Gull Wing Quad Flat Package (TQFP)
40P6	40-pin, 0.600” Wide, Plastic Dual Inline Package (PDIP)
44M1	44-pad, 7 x 7 x 1.0 mm body, lead pitch 0.50 mm, Micro Lead Frame Package (MLF)

Packaging Information

44A



COMMON DIMENSIONS
(Unit of Measure = mm)

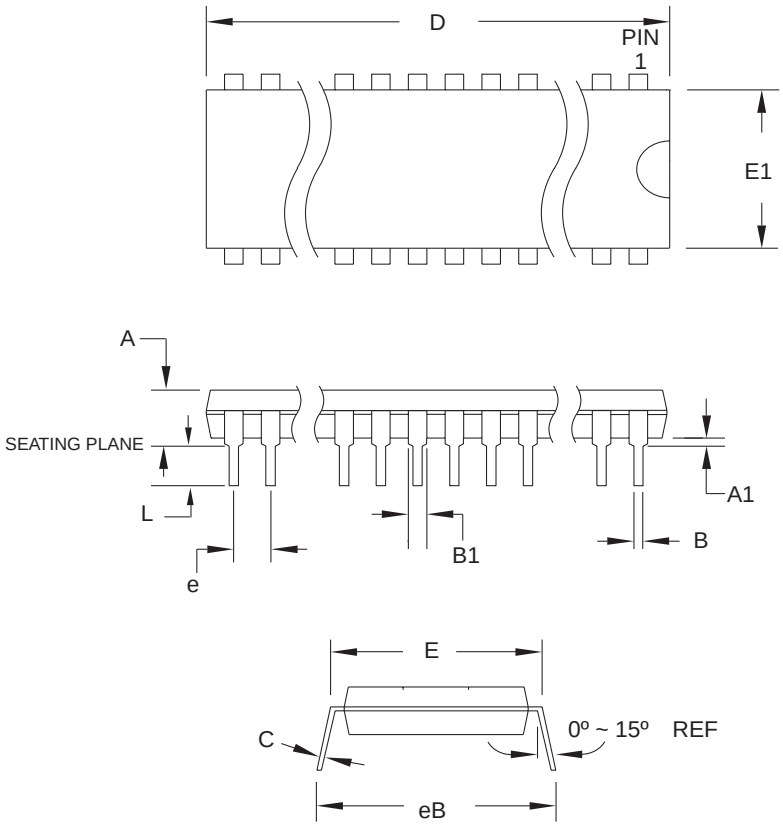
SYMBOL	MIN	NOM	MAX	NOTE
A	–	–	1.20	
A1	0.05	–	0.15	
A2	0.95	1.00	1.05	
D	11.75	12.00	12.25	
D1	9.90	10.00	10.10	Note 2
E	11.75	12.00	12.25	
E1	9.90	10.00	10.10	Note 2
B	0.30	–	0.45	
C	0.09	–	0.20	
L	0.45	–	0.75	
e	0.80 TYP			

Notes:
1. This package conforms to JEDEC reference MS-026, Variation ACB.
2. Dimensions D1 and E1 do not include mold protrusion. Allowable protrusion is 0.25 mm per side. Dimensions D1 and E1 are maximum plastic body size dimensions including mold mismatch.
3. Lead coplanarity is 0.10 mm maximum.

10/5/2001

	TITLE	DRAWING NO.	REV.
2325 Orchard Parkway San Jose, CA 95131	**44A,** 44-lead, 10 x 10 mm Body Size, 1.0 mm Body Thickness, 0.8 mm Lead Pitch, Thin Profile Plastic Quad Flat Package (TQFP)	44A	B

40P6



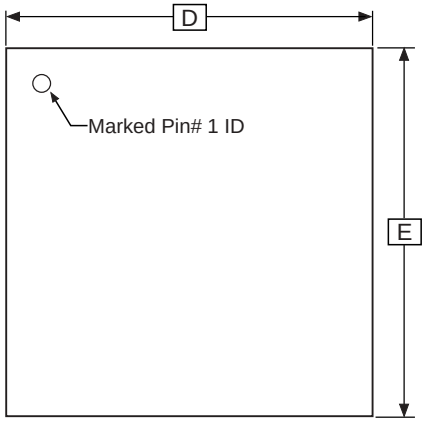
COMMON DIMENSIONS
(Unit of Measure = mm)

SYMBOL	MIN	NOM	MAX	NOTE
A	–	–	4.826	
A1	0.381	–	–	
D	52.070	–	52.578	Note 2
E	15.240	–	15.875	
E1	13.462	–	13.970	Note 2
B	0.356	–	0.559	
B1	1.041	–	1.651	
L	3.048	–	3.556	
C	0.203	–	0.381	
eB	15.494	–	17.526	
e	2.540 TYP			

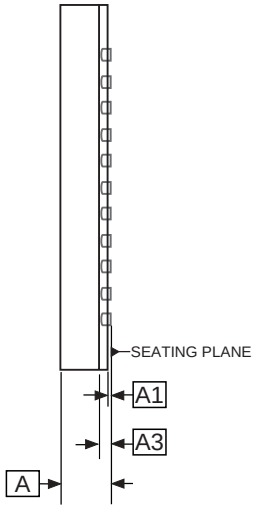
Notes:
1. This package conforms to JEDEC reference MS-011, Variation AC.
2. Dimensions D and E1 do not include mold Flash or Protrusion. Mold Flash or Protrusion shall not exceed 0.25 mm (0.010").

09/28/01

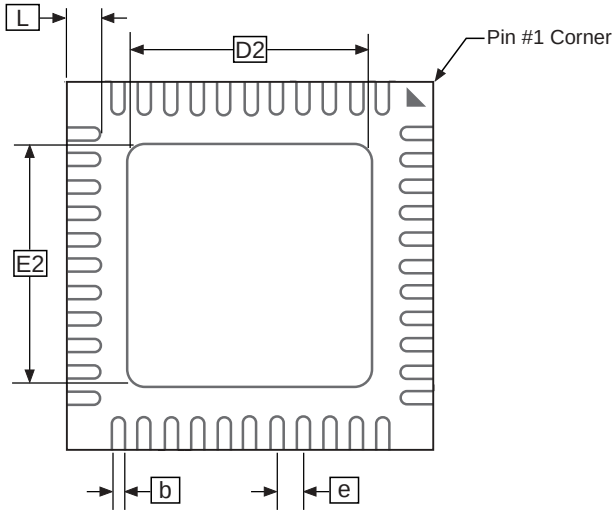
	TITLE	DRAWING NO.	REV.
2325 Orchard Parkway San Jose, CA 95131	**40P6**, 40-lead (0.600"/15.24 mm Wide) Plastic Dual Inline Package (PDIP)	40P6	B



TOP VIEW



SIDE VIEW



BOTTOM VIEW

COMMON DIMENSIONS
(Unit of Measure = mm)

SYMBOL	MIN	NOM	MAX	NOTE
A	0.80	0.90	1.00	
A1	–	0.02	0.05	
A3		0.25 REF		
b	0.18	0.23	0.30	
D		7.00 BSC		
D2	5.00	5.20	5.40	
E		7.00 BSC		
E2	5.00	5.20	5.40	
e		0.50 BSC		
L	0.35	0.55	0.75	

Notes: 1. JEDEC Standard MO-220, Fig. 1 (SAW Singulation) VKKD-1.

01/15/03

	TITLE	DRAWING NO.	REV.
2325 Orchard Parkway San Jose, CA 95131	**44M1**, 44-pad, 7 x 7 x 1.0 mm Body, Lead Pitch 0.50 mm Micro Lead Frame Package (MLF)	44M1	C

Erratas

The revision letter in this section refers to the revision of the ATmega162 device.

ATmega162, all rev.

There are no errata for this revision of ATmega162. However, a proposal for solving problems regarding the JTAG instruction IDCODE is presented below.

IDCODE masks data from TDI input

The public but optional JTAG instruction IDCODE is not implemented correctly according to IEEE1149.1; a logic one is scanned into the shift register instead of the TDI input while shifting the Device ID Register. Hence, captured data from the preceding devices in the boundary scan chain are lost and replaced by all-ones, and data to succeeding devices are replaced by all-ones during Update-DR.

If ATmega162 is the only device in the scan chain, the problem is not visible.

Problem Fix/ Workaround

Select the Device ID Register of the ATmega162 (Either by issuing the IDCODE instruction or by entering the Test-Logic-Reset state of the TAP controller) to read out the contents of its Device ID Register and possibly data from succeeding devices of the scan chain. Note that data to succeeding devices cannot be entered during this scan, but data to preceding devices can. Issue the BYPASS instruction to the ATmega162 to select its Bypass Register while reading the Device ID Registers of preceding devices of the boundary scan chain. Never read data from succeeding devices in the boundary scan chain or upload data to the succeeding devices while the Device ID Register is selected for the ATmega162. Note that the IDCODE instruction is the default instruction selected by the Test-Logic-Reset state of the TAP-controller.

Alternative Problem Fix/ Workaround

If the Device IDs of all devices in the boundary scan chain must be captured simultaneously (for instance if blind interrogation is used), the boundary scan chain can be connected in such way that the ATmega162 is the fist device in the chain. Update-DR will still not work for the succeeding devices in the boundary scan chain as long as IDCODE is present in the JTAG Instruction Register, but the Device ID registered cannot be uploaded in any case.

Datasheet Change Log for ATmega162

Please note that the referring page numbers in this section are referring to this document. The referring revision in this section are referring to the document revision.

Changes from Rev. 2513E-09/03 to Rev. 2513F-12/03

1. **Updated “Calibrated Internal RC Oscillator” on page 36.**

Changes from Rev. 2513D-04/03 to Rev. 2513E-09/03

1. **Removed “Preliminary” from the datasheet.**
2. **Added note on Figure 1 on page 2.**
3. **Renamed and updated “On-chip Debug System” to “JTAG Interface and On-chip Debug System” on page 44.**
4. **Updated Table 18 on page 47 and Table 19 on page 49.**
5. **Updated “Test Access Port – TAP” on page 196 regarding JTAGEN.**
6. **Updated description for the JTD bit on page 206.**
7. **Added note on JTAGEN in Table 100 on page 232.**
8. **Updated Absolute Maximum Ratings* and DC Characteristics in “Electrical Characteristics” on page 263.**
9. **Added a proposal for solving problems regarding the JTAG instruction IDCODE in “Erratas” on page 313.**

Changes from Rev. 2513C-09/02 to Rev. 2513D-04/03

1. **Updated the “Ordering Information” on page 309 and “Packaging Information” on page 310.**
2. **Updated “Features” on page 1.**
3. **Added characterization plots under “ATmega162 Typical Characteristics” on page 274.**
4. **Added Chip Erase as a first step under “Programming the Flash” on page 259 and “Programming the EEPROM” on page 261.**
5. **Changed CAL7, the highest bit in the OSCCAL Register, to a reserved bit on page 37 and in “Register Summary” on page 303.**
6. **Changed CPCE to CLKPCE on page 39.**
7. **Corrected code examples on page 54.**
8. **Corrected OCn waveforms in Figure 52 on page 119.**
9. **Various minor Timer1 corrections.**
10. **Added note under “Filling the Temporary Buffer (Page Loading)” on page 223 about writing to the EEPROM during an SPM Page Load.**

11. **Added section “EEPROM Write During Power-down Sleep Mode” on page 22.**
12. **Added information about PWM symmetry for Timer0 on page 97 and Timer2 on page 146.**
13. **Updated Table 18 on page 47, Table 20 on page 49, Table 36 on page 76, Table 83 on page 204, Table 110 on page 246, Table 113 on page 266, and Table 114 on page 267.**
14. **Added Figures for “Absolute Maximum Frequency as a function of VCC, ATmega162” on page 265.**
15. **Updated Figure 29 on page 63, Figure 32 on page 67, and Figure 88 on page 209.**
16. **Removed Table 114, “External RC Oscillator, Typical Frequencies(1),” on page 265.**
17. **Updated “Electrical Characteristics” on page 263.**

Changes from Rev. 2513B-09/02 to Rev. 2513C-09/02

1. **Changed the Endurance on the Flash to 10,000 Write/Erase Cycles.**

Changes from Rev. 2513A-05/02 to Rev. 2513B-09/02

1. **Added information for ATmega162U.**

   Information about ATmega162U included in “Features” on page 1, Table 19, “BODLEVEL Fuse Coding,” on page 49, and “Ordering Information” on page 309.

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