

## Features

- Utilizes the AVR<sup>®</sup> Enhanced RISC Architecture
- AVR - High Performance and Low Power RISC Architecture
- 120 Powerful Instructions - Most Single Clock Cycle Execution
- 2K bytes of In-System Reprogrammable Downloadable Flash
  - SPI Serial Interface for Program Downloading
  - Endurance: 1,000 Write/Erase Cycles
- 128 bytes EEPROM
  - Endurance: 100,000 Write/Erase Cycles
- 128 bytes Internal RAM
- 32 x 8 General Purpose Working Registers
- 15 Programmable I/O Lines
- V<sub>CC</sub>: 2.7 - 6.0V
- Fully Static Operation, 0 - 20 MHz
- Instruction Cycle Time: 50 ns @ 20 MHz
- One 8-Bit Timer/Counter with Separate Prescaler
- One 16-Bit Timer/Counter with Separate Prescaler and Compare and Capture Modes
- Full Duplex UART
- Selectable 8, 9 or 10 bit PWM
- External and Internal Interrupt Sources
- Programmable Watchdog Timer with On-Chip Oscillator
- On-Chip Analog Comparator
- Low Power Idle and Power Down Modes
- Programming lock for Software Security
- 20-Pin Device

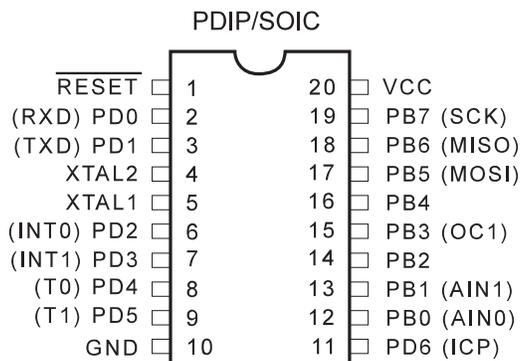
## Description

The AT90S2313 is a low-power CMOS 8-bit microcontroller based on the AVR<sup>®</sup> enhanced RISC architecture. By executing powerful instructions in a single clock cycle, the AT90S2313 achieves throughputs approaching 1 MIPS per MHz allowing the system designer to optimize power consumption versus processing speed.

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.

*(continued)*

## Pin Configuration



**8-Bit AVR<sup>®</sup>**  
**Microcontroller**  
**with 2K bytes**  
**Downloadable**  
**Flash**

**Preliminary**

# Block Diagram

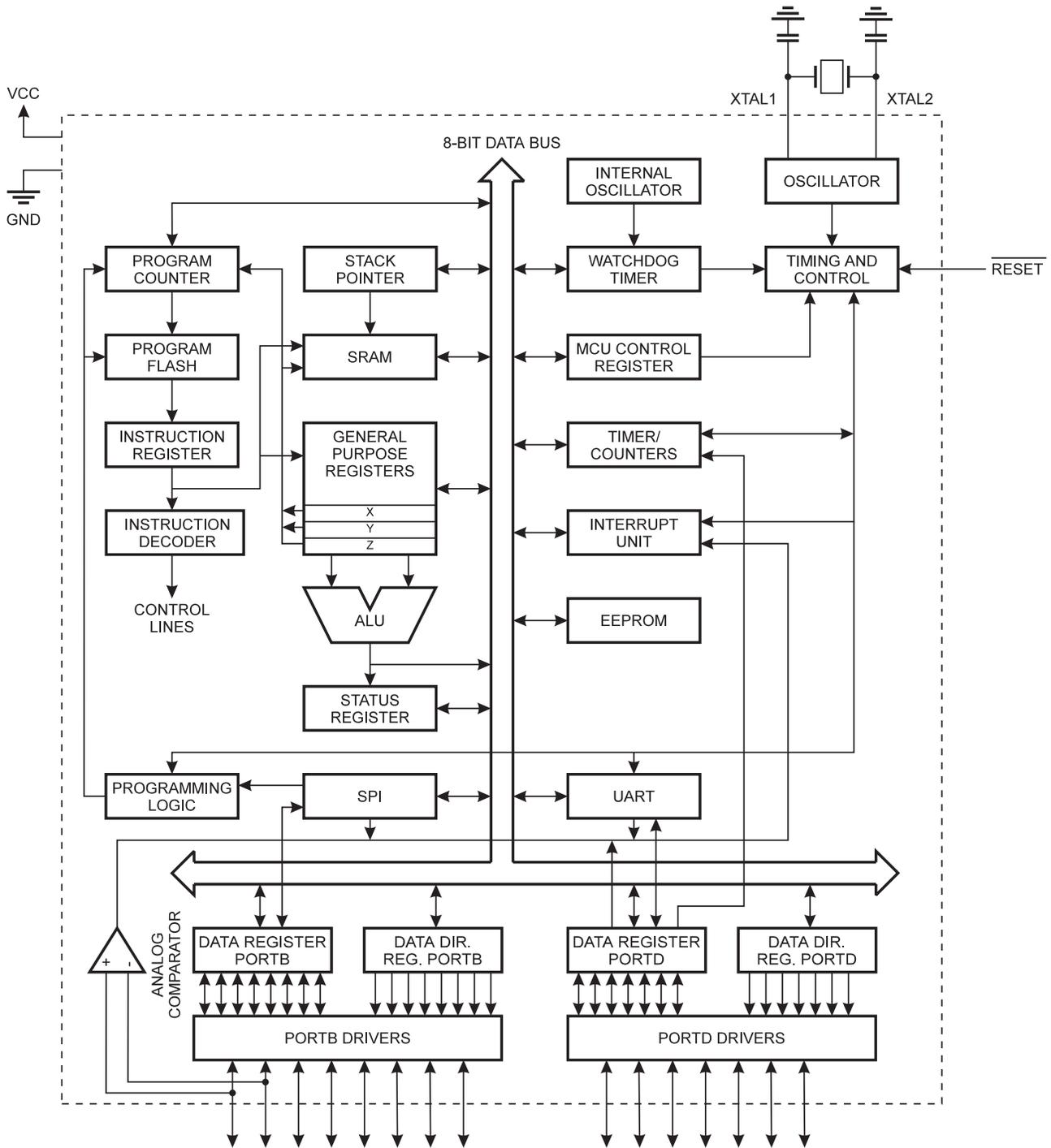


Figure 1. The AT90S2313 Block Diagram

## Description (Continued)

The AT90S2313 provides the following features: 2K bytes of Downloadable Flash, 128 bytes EEPROM, 128 bytes SRAM, 15 general purpose I/O lines, 32 general purpose working registers, flexible timer/counters with compare modes, internal and external interrupts, a programmable serial UART, programmable Watchdog Timer with internal oscillator, an SPI serial port for Flash Memory downloading and two 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.

The device is manufactured using Atmel's high density non-volatile memory technology. The on-chip Downloadable Flash allows the program memory to be reprogrammed in-system through an SPI serial interface or by a conventional nonvolatile memory programmer. By combining an enhanced RISC 8-bit CPU with Downloadable Flash on a monolithic chip, the Atmel AT90S2313 is a powerful microcontroller that provides a highly flexible and cost effective solution to many embedded control applications.

The AT90S2313 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.

## Pin Descriptions

### VCC

Supply voltage pin.

### GND

Ground pin.

### Port B (PB7..PB0)

Port B is an 8-bit bi-directional I/O port. Port pins can provide internal pullups (selected for each bit). PB0 and PB1 also serve as the positive input (AIN0) and the negative input (AIN1), respectively, of the on-chip analog comparator. The Port B output buffers can sink 20mA and can drive LED displays directly. When pins PB0 to PB7 are used as inputs and are externally pulled low, they will source current ( $I_{IL}$ ) if the internal pullups are activated.

Port B also serves the functions of various special features of the AT90S2313 as listed on Page 3-50.

### Port D (PD6..PD0)

Port D has seven bi-directional I/O pins with internal pullups, PD6..PD0. The Port D output buffers can sink 20 mA. As inputs, Port D pins that are externally pulled low will source current ( $I_{IL}$ ) if the pullups are activated.

Port D also serves the functions of various special features of the AT90S2313 as listed on Page 3-55.

### RESET

Reset input. A low on this pin for two machine cycles while the oscillator is running resets the device.

### XTAL1

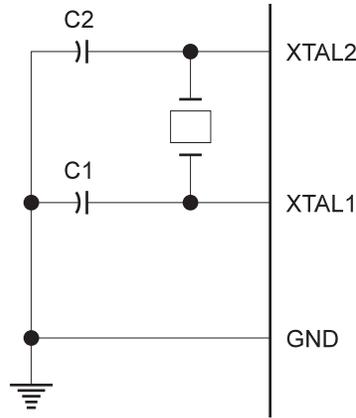
Input to the inverting oscillator amplifier and input to the internal clock operating circuit.

### XTAL2

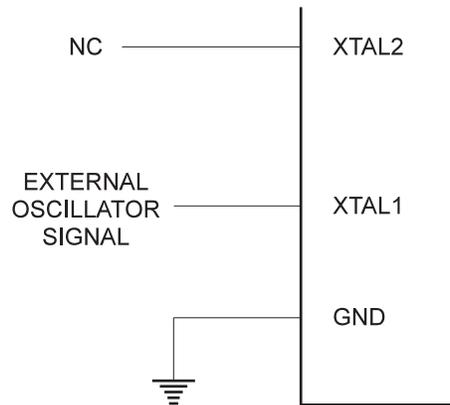
Output from the inverting oscillator amplifier

## 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 2. Either a quartz crystal or a ceramic resonator may be used. To drive the device from an external clock source, XTAL2 should be left unconnected while XTAL1 is driven as shown in Figure 3.



**Figure 2.** Oscillator Connections



**Figure 3.** External Clock Drive Configuration

## **AT90S2313 AVR Enhanced RISC Microcontroller CPU**

The AT90S2313 AVR RISC microcontroller is upward compatible with the AVR Enhanced RISC Architecture. The programs written for the AT90S2313 MCU are fully compatible with the range of AVR 8-bit MCUs (AT90Sxxxx) with respect to source code and clock cycles for execution.

### **Architectural Overview**

The fast-access register file concept contains 32 x 8-bit general purpose working registers with a single clock cycle access time. This means that during one single clock cycle, one ALU (Arithmetic Logic Unit) operation is executed. 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-bits indirect address register pointers for Data Space addressing - enabling efficient address calculations. One of the three address pointers is also used as the address pointer for the constant table look up function. These added function registers are the 16-bits X-register, Y-register and Z-register.

The ALU supports arithmetic and logic functions between registers or between a constant and a register. Single register operations are also executed in the ALU. Figure 4 shows the AT90S2313 AVR Enhanced RISC microcontroller architecture.

In addition to the register operation, the conventional memory addressing modes can be used on the register file as well. This is enabled by the fact that the register file is assigned the 32 lowermost Data Space addresses (\$00 - \$1F), allowing them to be accessed as though they were ordinary memory locations.

The I/O memory space contains 64 addresses for CPU peripheral functions as Control Registers, Timer/Counters, A/D-converters, 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, \$20 - \$5F.

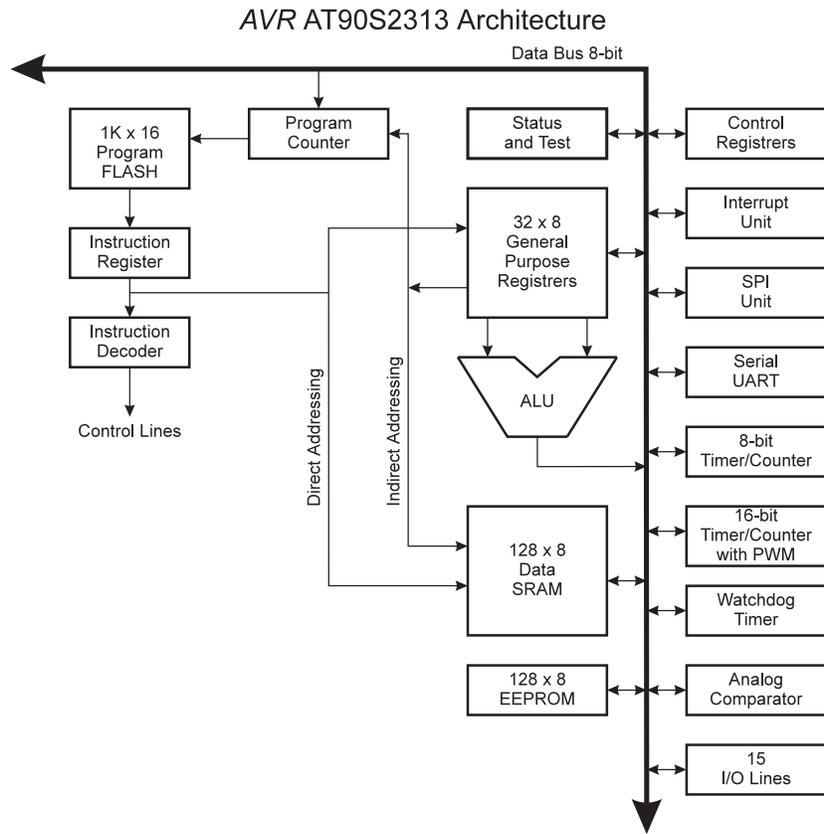
The AVR has Harvard architecture - with separate memories and buses for program and data. The program memory is accessed with a single level pipelining. While one instruction is being executed, the next instruction is pre-fetched from the program memory. This concept enables instructions to be executed in every clock cycle. The program memory is in-system downloadable Flash memory.

With the relative jump and call instructions, the whole 1K address space is directly accessed. Most AVR instructions have a single 16-bit word format. Every program memory address contains a 16- or 32-bit instruction.

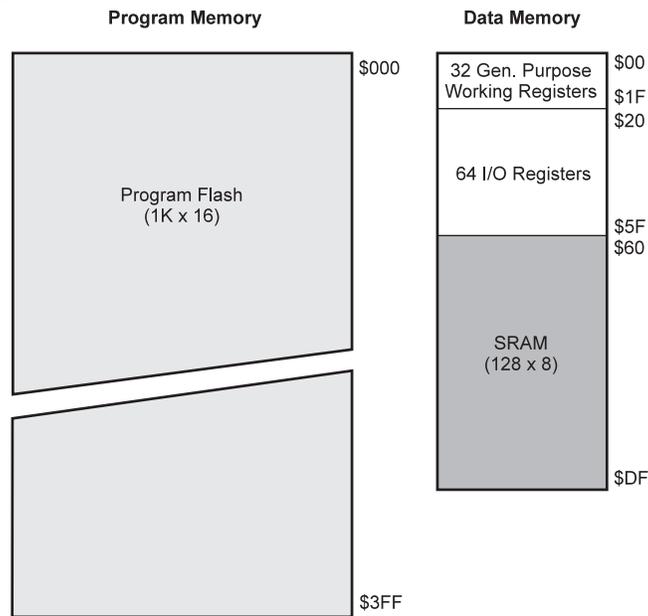
During interrupts and subroutine calls, the return address program counter (PC) is stored on the stack. The stack is effectively allocated in the general data SRAM, and consequently the stack size is only limited by the total SRAM size and the usage of the SRAM. All user programs must initialize the SP in the reset routine (before subroutines or interrupts are executed). The 8-bit stack pointer SP is read/write accessible in the I/O space.

The 128 bytes data SRAM + register file and I/O registers can be easily 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.



**Figure 4.** The AT90S2313 AVR Enhanced RISC Architecture



**Figure 5.** 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 the different interrupts have a separate interrupt vector in the interrupt vector table at the beginning of the program memory. The different interrupts have priority in accordance with their interrupt vector position. The lower the interrupt address vector the higher priority.

### The General Purpose Register File

Figure 6 shows the structure of the 32 general purpose registers in the CPU.

|  |     |   |       |                      |
|--|-----|---|-------|----------------------|
|  | 7   | 0 | Addr. |                      |
| General<br>Purpose<br>Working<br>Registers | R0  |   | \$00  |                      |
|  | R1  |   | \$01  |                      |
|  | R2  |   | \$02  |                      |
|  | ... |   |       |                      |
|  | R13 |   | \$0D  |                      |
|  | R14 |   | \$0E  |                      |
|  | R15 |   | \$0F  |                      |
|  | R16 |   | \$10  |                      |
|  | R17 |   | \$11  |                      |
|  | ... |   |       |                      |
|  | R26 |   | \$1A  | X-register low byte  |
|  | R27 |   | \$1B  | X-register high byte |
|  | R28 |   | \$1C  | Y-register low byte  |
|  | R29 |   | \$1D  | Y-register high byte |
|  | R30 |   | \$1E  | Z-register low byte  |
|  | R31 |   | \$1F  | Z-register high byte |

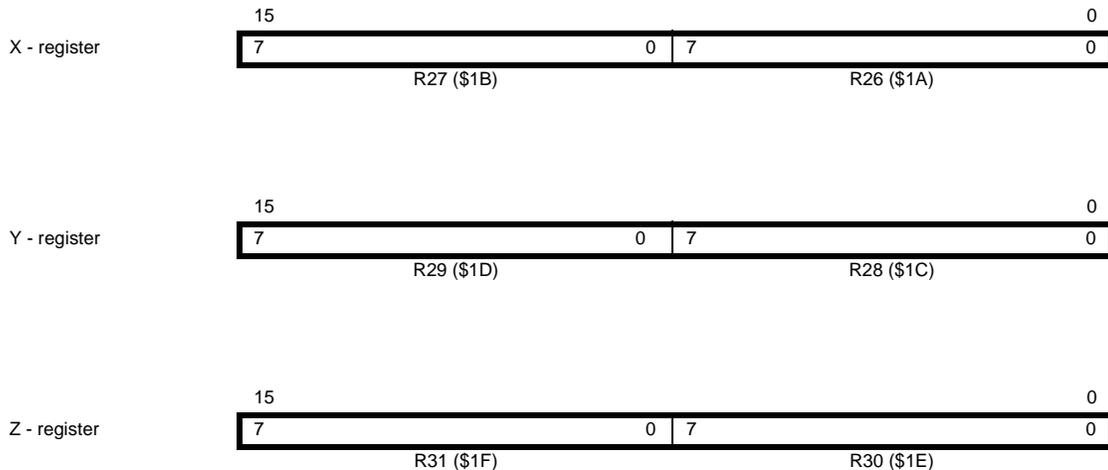
**Figure 6.** AVR CPU General Purpose Working Registers

All the register operating instructions in the instruction set have direct and single cycle access to all registers. The only exception is the five constant arithmetic and logic instructions SBCI, SUBI, CPI, ANDI, ORI between a constant and a register and the LDI instruction for load immediate constant data. These instructions apply to the second half of the registers in the register file - R16..R31. The general SBC, SUB, CP, AND, OR and all other operations between two registers or on a single register apply to the entire register file.

As shown in Figure 6, each register is also assigned a data memory address, mapping them directly into the first 32 locations of the user Data Space. Although the register file is not physically implemented as SRAM locations, this memory organization provides great flexibility in access of the registers, as the X , Y and Z 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 the address pointers for indirect addressing of the Data Space. The three indirect address registers X, Y and Z are defined as:



**Figure 7.** The X, Y, and Z Registers

In the different addressing modes these address registers have functions as fixed displacement, automatic increment and decrement (see the descriptions for the different instructions).

## The 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, ALU operations between registers in the register file are executed. The ALU operations are divided into three main categories - arithmetic, logic and bit-functions. Some microcontrollers in the AVR product family feature a hardware multiplier in the arithmetic part of the ALU.

## The Downloadable Flash Program Memory

The AT90S2313 contains 2K bytes on-chip downloadable Flash memory for program storage. Since all instructions are 16- or 32-bit words, the Flash is organized as 1K x 16. The Flash memory has an endurance of at least 1000 write/erase cycles.

The AT90S2313 Program Counter PC is 10 bits wide, thus addressing the 1024 program memory addresses.

See Page 3-59 for a detailed description on Flash data downloading.

Constant tables must be allocated within the address 0-2K (see the LPM - Load Program Memory instruction description).

See Page 3-14 for the different addressing modes.

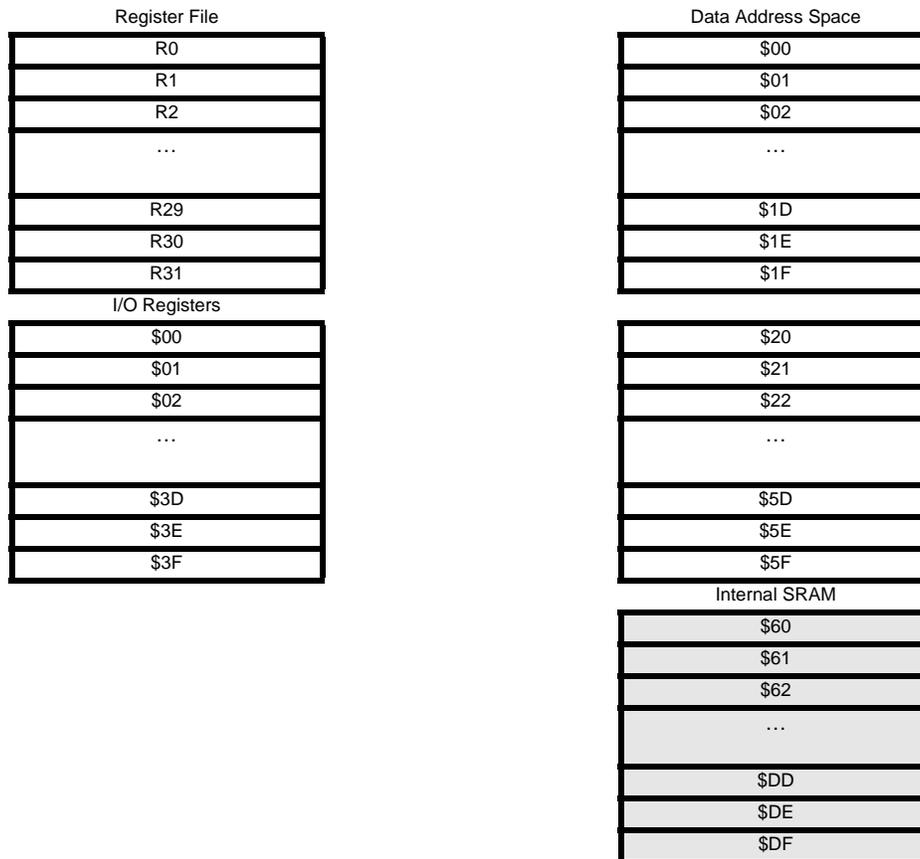
## The EEPROM Data Memory

The AT90S2313 contains 128 bytes of EEPROM data 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 on Page 3-40 specifying the EEPROM address register, the EEPROM data register, and the EEPROM control register.

For the SPI data downloading, see Page 3-64 for a detailed description.

## The SRAM Data Memory

The following figure shows how the AT90S2313 Data Memory is organized:



**Figure 8.** SRAM Organization

The 224 Data Memory locations address the Register file, I/O Memory and the data SRAM. The first 96 locations address the Register File + I/O Memory, and the next 128 locations address the data SRAM.

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 address space.

The Indirect with Displacement mode features 63 address locations reach from the base address given by the Y and Z register.

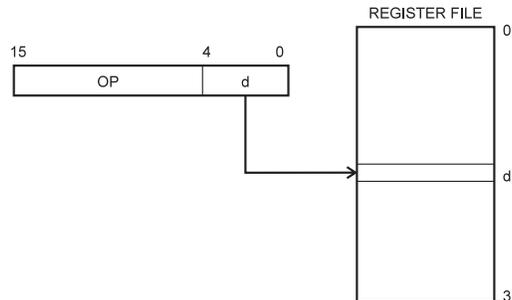
When using register indirect addressing modes with automatic pre-decrement and post-increment, the address registers X, Y and Z are used and decremented and incremented.

The 32 general purpose working registers, 64 I/O registers and the 128 bytes of data SRAM in the AT90S2313 are all directly accessible through all these addressing modes.

### The Program and Data Addressing Modes

The AT90S2313 AVR Enhanced RISC Microcontroller supports powerful and efficient addressing modes for access to the program memory (Flash) and data memory. This section describes the different addressing modes supported by the AVR architecture. In the figures, OP means the operation code part of the instruction word. To simplify, not all figures show the exact location of the addressing bits.

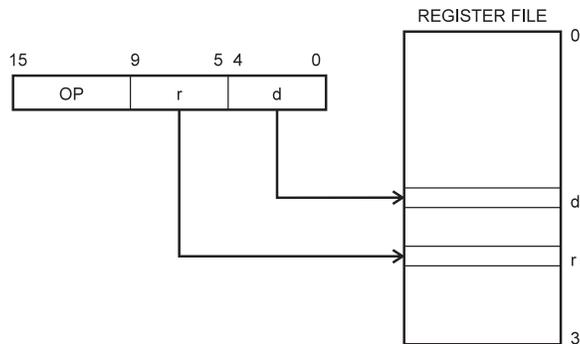
#### REGISTER DIRECT, SINGLE REGISTER RD



**Figure 9.** Direct Single Register Addressing

The operand is contained in register d (Rd).

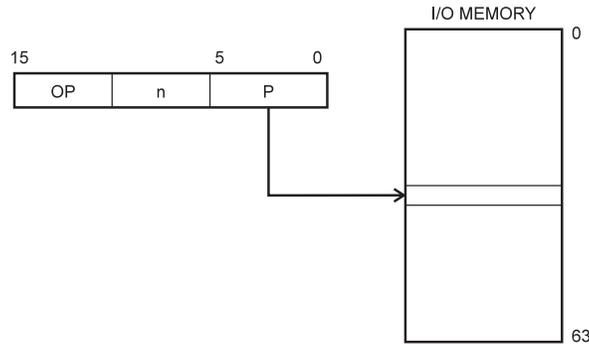
#### REGISTER DIRECT, TWO REGISTERS RD AND RR



**Figure 10.** Direct Register Addressing, Two Registers

Operands are contained in register r (Rr) and d (Rd). The result is stored in register d (Rd).

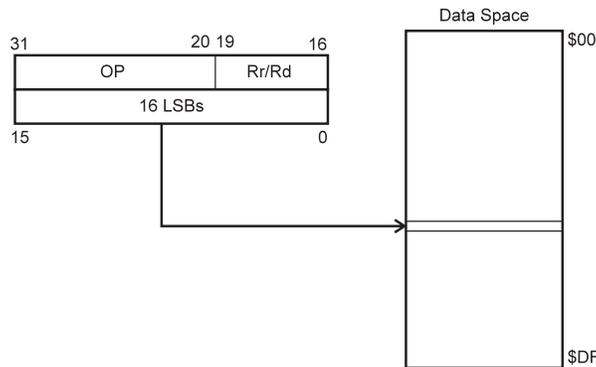
**I/O DIRECT**



**Figure 11.** I/O Direct Addressing

Operand address is contained in 6 bits of the instruction word. n is the destination or source register address.

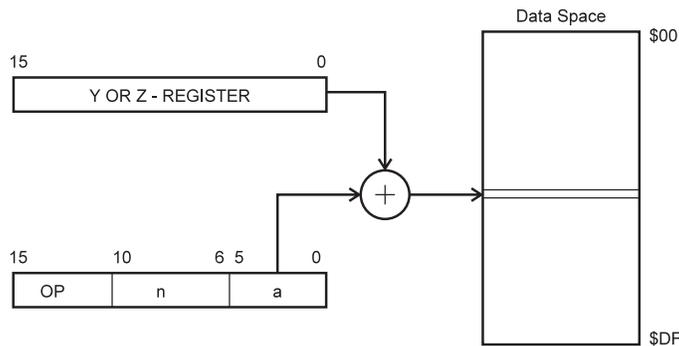
**DATA DIRECT**



**Figure 12.** Direct Data Addressing

A 16-bit Data Address is contained in the 16 LSBs of a two-word instruction. Rd/Rr specify the destination or source register.

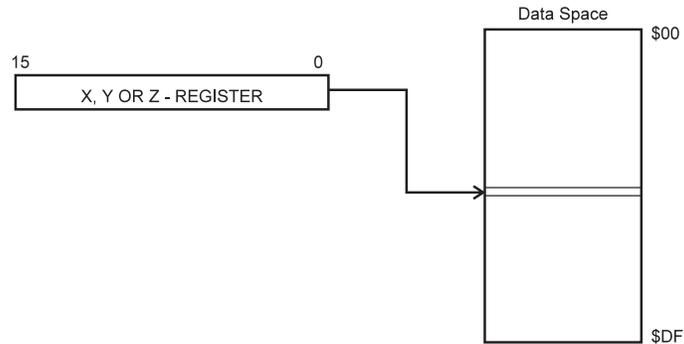
**DATA INDIRECT WITH DISPLACEMENT**



**Figure 13.** Data Indirect with Displacement

Operand address is the result of the Y or Z-register contents added to the address contained in 6 bits of the instruction word.

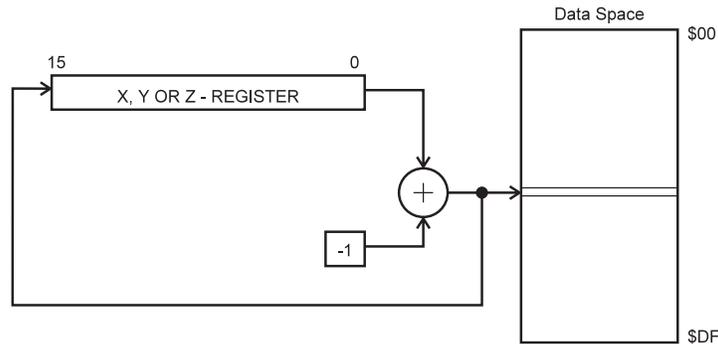
## DATA INDIRECT



**Figure 14.** Data Indirect Addressing

Operand address is the contents of the X, Y or the Z-register.

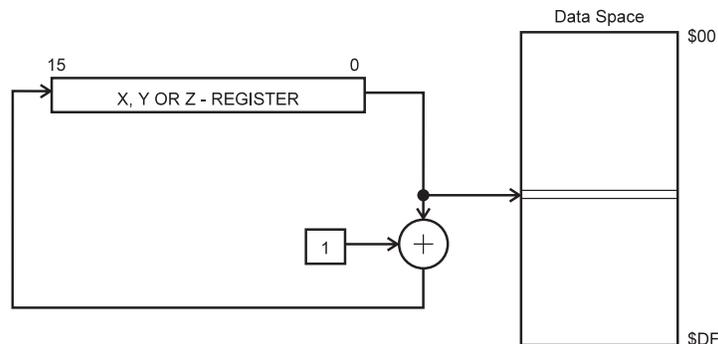
## DATA INDIRECT WITH PRE-DECREMENT



**Figure 15.** Data Indirect Addressing With Pre-Decrement

The X, Y or the Z-register is decremented before the operation. Operand address is the decremented contents of the X, Y or the Z-register.

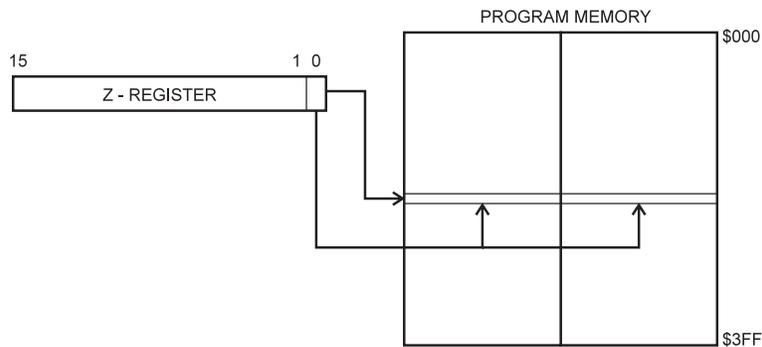
## DATA INDIRECT WITH POST-INCREMENT



**Figure 16.** Data Indirect Addressing With Post-Increment

The X, Y or the Z-register is incremented after the operation. Operand address is the content of the X, Y or the Z-register prior to incrementing.

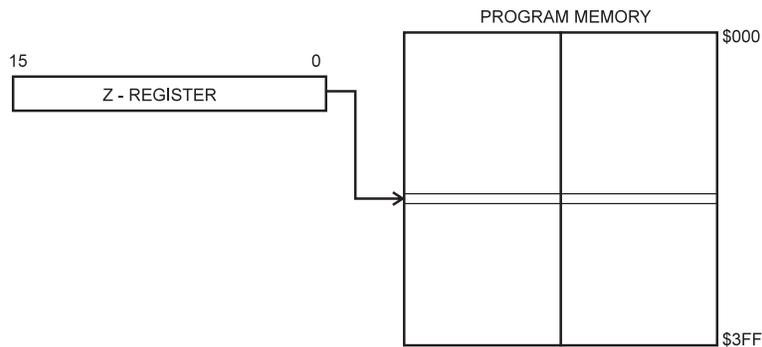
**CONSTANT ADDRESSING USING THE LPM INSTRUCTION**



**Figure 17.** Code Memory Constant Addressing

Constant byte address is specified by the Z-register contents. The 15 MSBs select word address (0 - 1K), and LSB selects low byte if cleared (LSB = 0) or high byte if set (LSB = 1).

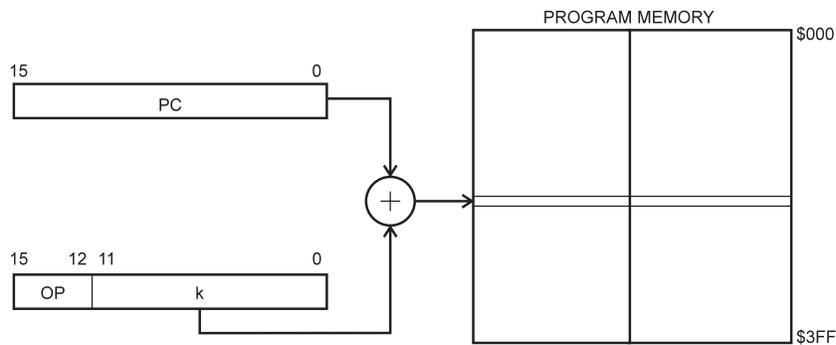
**INDIRECT PROGRAM ADDRESSING, IJMP AND ICALL**



**Figure 18.** Indirect Program Memory Addressing

Program execution continues at address contained by the Z-register (i.e., the PC is loaded with the content of the Z-register).

**RELATIVE PROGRAM ADDRESSING, RJMP AND RCALL**



**Figure 19.** Relative Program Memory Addressing

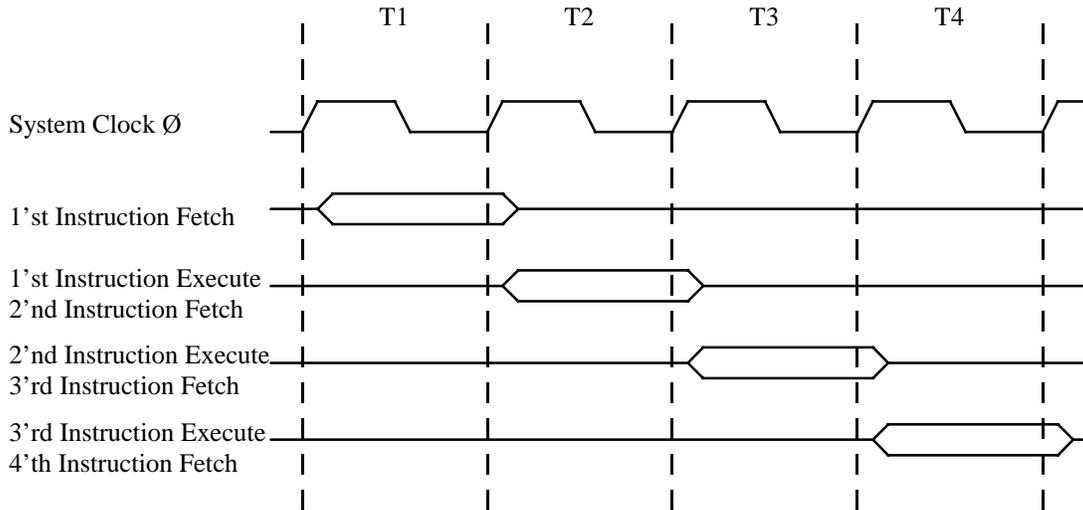
Program execution continues at address  $PC + k$ . The relative address  $k$  is in the range from  $-2K$  to  $+(2K - 1)$ .

## Memory Access and Instruction Execution Timing

This section describes the general access timing concepts for instruction execution and internal memory access.

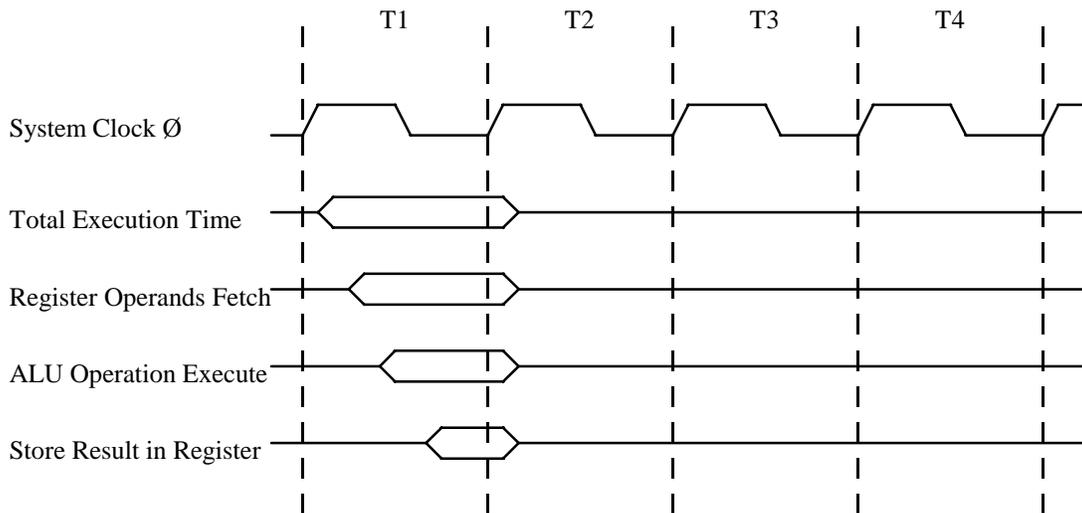
The AVR CPU is driven by the System Clock  $\emptyset$ , directly generated from the external clock crystal for the chip. No internal clock division is used.

Figure 20 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 20.** The Parallel Instruction Fetches and Instruction Executions

Figure 21 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 21.** Single Cycle ALU Operation

The internal data SRAM access is performed in two System Clock cycles as described in Figure 22.

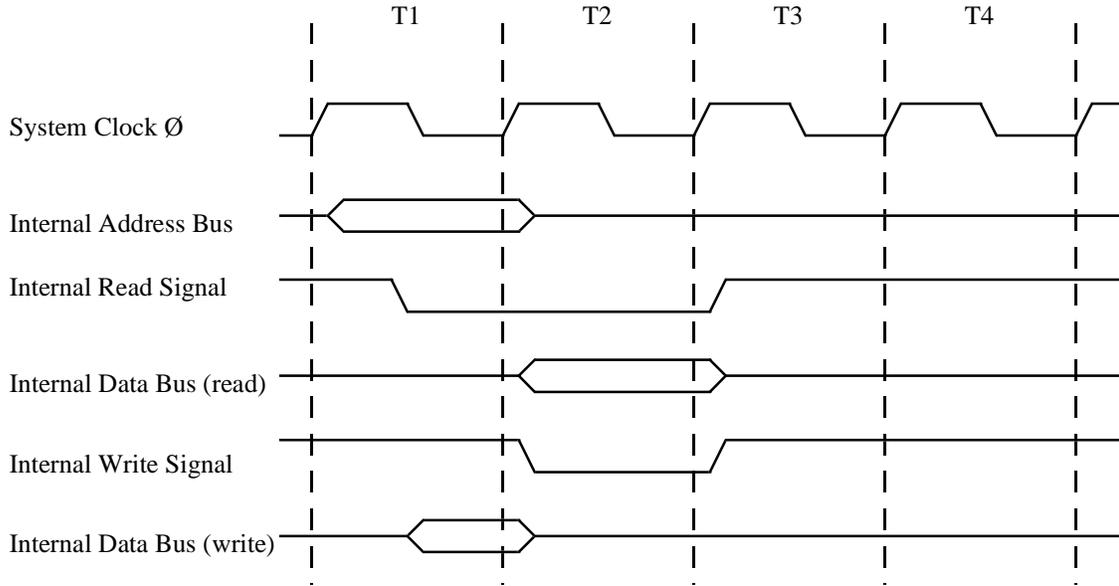


Figure 22. On-Chip Data SRAM Access Cycles



## I/O Memory

The I/O space definition of the AT90S2313 is shown in the following table:

**Table 1.** AT90S2313 I/O Space

| Address Hex | Name   | Function                                      |
|-------------|--------|---|
| \$3F (\$5F) | SREG   | Status REGister                               |
| \$3D (\$5D) | SPL    | Stack Pointer Low                             |
| \$3B (\$5B) | GIMSK  | General Interrupt MaSK register               |
| \$3A (\$5A) | GIFR   | General Interrupt Flag Register               |
| \$39 (\$59) | TIMSK  | Timer/Counter Interrupt MaSK register         |
| \$38 (\$58) | TIFR   | Timer/Counter Interrupt Flag register         |
| \$35 (\$55) | MCUCR  | MCU general Control Register                  |
| \$33 (\$53) | TCCR0  | Timer/Counter 0 Control Register              |
| \$32 (\$52) | TCNT0  | Timer/Counter 0 (8-bit)                       |
| \$2F (\$4F) | TCCR1A | Timer/Counter 1 Control Register A            |
| \$2E (\$4E) | TCCR1B | Timer/Counter 1 Control Register B            |
| \$2D (\$4D) | TCNT1H | Timer/Counter 1 High Byte                     |
| \$2C (\$4C) | TCNT1L | Timer/Counter 1 Low Byte                      |
| \$2B (\$4B) | OCR1H  | Output Compare Register 1 High Byte           |
| \$2A (\$4A) | OCR1L  | Output Compare Register 1 Low Byte            |
| \$25 (\$45) | ICR1H  | T/C 1 Input Capture Register High Byte        |
| \$24 (\$44) | ICR1L  | T/C 1 Input Capture Register Low Byte         |
| \$21 (\$41) | WDTCR  | Watchdog Timer Control Register               |
| \$1E (\$3E) | EEAR   | EEPROM Address Register                       |
| \$1D (\$3D) | EEDR   | EEPROM Data Register                          |
| \$1C (\$3C) | EECR   | EEPROM Control Register                       |
| \$18 (\$38) | PORTB  | Data Register, Port B                         |
| \$17 (\$37) | DDRB   | Data Direction Register, Port B               |
| \$16 (\$36) | PINB   | Input Pins, Port B                            |
| \$12 (\$32) | PORTD  | Data Register, Port D                         |
| \$11 (\$31) | DDRD   | Data Direction Register, Port D               |
| \$10 (\$30) | PIND   | Input Pins, Port D                            |
| \$0C (\$2C) | UDR    | UART I/O Data Register                        |
| \$0B (\$2B) | USR    | UART Status Register                          |
| \$0A (\$2A) | UCR    | UART Control Register                         |
| \$09 (\$29) | UBRR   | UART Baud Rate Register                       |
| \$08 (\$28) | ACSR   | Analog Comparator Control and Status Register |

Note: Reserved and unused locations are not shown in the table.

All the different AT90S2313 I/O and peripherals are placed in the I/O space. The different I/O locations are accessed by the IN and OUT instructions transferring data between the 32 general purpose working registers and the I/O space. I/O registers within the address range \$00 - \$1F 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 chapter for more details.

When using the I/O specific commands, IN, OUT, SBIS and SBIC, the I/O addresses \$00 - \$3F must be used. When addressing I/O registers as SRAM, \$20 must be added to this address. All I/O register addresses throughout this document are shown with the SRAM address in parentheses.

The different I/O and peripherals control registers are explained in the following sections.

## THE STATUS REGISTER - SREG

The AVR status register - SREG - at I/O space location \$3F (\$5F) is defined as:

|               |     |     |     |     |     |     |     |     |      |
|---------------|-----|-----|-----|-----|-----|-----|-----|-----|------|
| Bit           | 7   | 6   | 5   | 4   | 3   | 2   | 1   | 0   |      |
| \$3F (\$5F)   | I   | T   | H   | S   | V   | N   | Z   | C   | SREG |
| Read/Write    | 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 (one) for the interrupts to be enabled. The individual interrupt enable control is then performed in the interrupt mask registers - GIMSK and TIMSK. If the global interrupt enable register is cleared (zero), none of the interrupts are enabled independent of the GIMSK and TIMSK values. The I-bit is cleared by hardware after an interrupt has occurred, and is set by the RETI instruction to enable subsequent interrupts.

### **Bit 6 - T : Bit Copy Storage:**

The bit copy instructions BLD (Bit Load) and BST (Bit Store) use the T bit as source and 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. See the Instruction Set Description for detailed information.

### **Bit 4 - S : Sign Bit, $S = N \oplus V$ :**

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 after the different arithmetic and logic operations. See the Instruction Set Description for detailed information.

### **Bit 1 - Z : Zero Flag:**

The zero flag Z indicates a zero result after the different arithmetic and logic operations. 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.

## THE STACK POINTER - SP

An 8-bit register at I/O address \$3D (\$5D) forms the stack pointer of the AT90S2313. 8 bits are used to address the 128 bytes of SRAM in locations \$60 - \$DF.

|               |     |     |     |     |     |     |     |     |     |
|---------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Bit           | 7   | 6   | 5   | 4   | 3   | 2   | 1   | 0   |     |
| \$3D (\$5D)   | SP7 | SP6 | SP5 | SP4 | SP3 | SP2 | SP1 | SP0 | SPL |
| Read/Write    | R/W |     |
| Initial value | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   |     |

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 is decremented by one when data is pushed onto the Stack with the PUSH instruction, and it is decremented by two when data is pushed onto the Stack with subroutine CALL and 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 IRET.

## Reset and Interrupt Handling

The AT90S2313 provides 10 different interrupt sources. These interrupts and the separate reset vector, each have a separate program vector in the program memory space. All the interrupts are assigned individual enable bits which must be set (one) together with the I-bit in the status register in order to enable the interrupt.

The lowest addresses in the program memory space are automatically defined as the Reset and Interrupt vectors. The complete list of vectors is shown in Table 2. 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, etc.

**Table 2.** Reset and Interrupt Vectors

| Vector No. | Program Address | Source       | Interrupt Definition            |
|------------|-----------------|--------------|---------------------------------|
| 1          | \$000           | RESET        | Hardware Pin and Watchdog Reset |
| 2          | \$001           | INT0         | External Interrupt Request 0    |
| 3          | \$002           | INT1         | External Interrupt Request 1    |
| 4          | \$003           | TIMER1 CAPT1 | Timer/Counter1 Capture Event    |
| 5          | \$004           | TIMER1 COMP1 | Timer/Counter1 Compare Match    |
| 6          | \$005           | TIMER1 OVF1  | Timer/Counter1 Overflow         |
| 7          | \$006           | TIMER0, OVF0 | Timer/Counter0 Overflow         |
| 8          | \$007           | UART, RX     | UART, Rx Complete               |
| 9          | \$008           | UART, UDRE   | UART Data Register Empty        |
| 10         | \$009           | UART, TX     | UART, Tx Complete               |
| 11         | \$00A           | ANA_COMP     | Analog Comparator               |

The most typical and general program setup for the Reset and Interrupt Vector Addresses are:

| Address | Labels | Code           | Comments                   |
|---------|--------|----------------|----------------------------|
| \$000   |        | rjmp RESET     | ; Reset Handle             |
| \$001   |        | rjmp EXT_INT0  | ; IRQ0 Handle              |
| \$002   |        | rjmp EXT_INT1  | ; IRQ1 Handle              |
| \$003   |        | rjmp TIM_CAPT1 | ; Timer1 capture Handle    |
| \$004   |        | rjmp TIM_COMP1 | ; Timer1 compare Handle    |
| \$005   |        | rjmp TIM_OVF1  | ; Timer1 overflow Handle   |
| \$006   |        | rjmp TIM_OVF0  | ; Timer0 overflow Handle   |
| \$007   |        | rjmp UART_RXC  | ; UART RX Complete Handle  |
| \$008   |        | rjmp UART_DRE  | ; UDR Empty Handle         |
| \$009   |        | rjmp UART_TXC  | ; UART TX Complete Handle  |
| \$00a   |        | rjmp ANA_COMP  | ; Analog Comparator Handle |
|         |        | ;              |                            |
| \$00b   | MAIN:  | <instr> xxx    | ; Main program start       |
| ...     | ...    | ...            | ...                        |

## RESET SOURCES

The AT90S2313 has three sources of reset:

- Power-On Reset. The MCU is reset when a supply voltage is applied to the  $V_{CC}$  and GND pins.
- External Reset. The MCU is reset when a low level is present on the **RESET** pin for more than two XTAL cycles
- Watchdog Reset. The MCU is reset when the Watchdog timer period expires and the Watchdog is enabled.

During reset, all I/O registers are then set to their initial values, and the program starts execution from address \$000. The instruction placed in address \$000 must be an RJMP - relative 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. The circuit diagram in Figure 23 shows the reset logic. Table 3 defines the timing and electrical parameters of the reset circuitry.

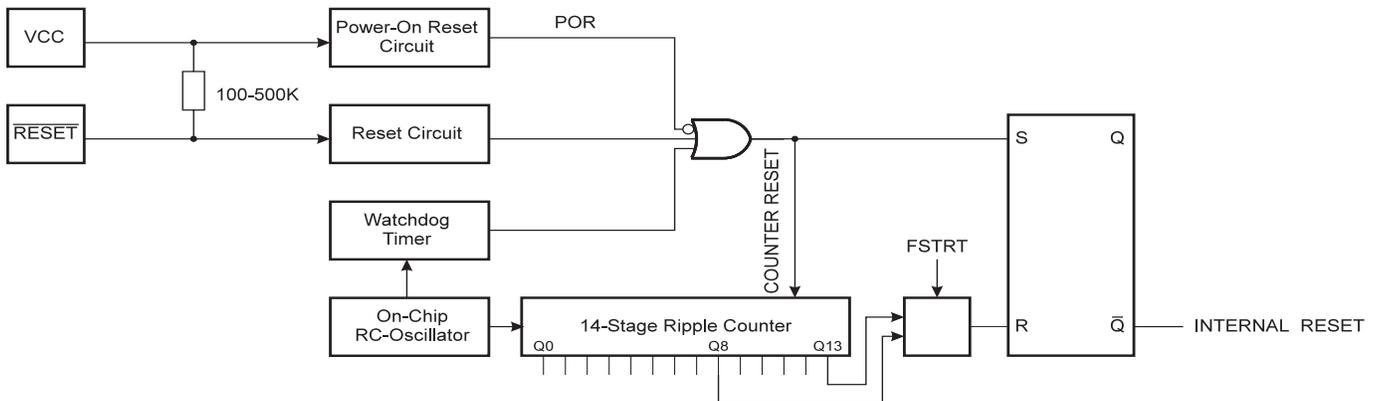


Figure 23. Reset Logic

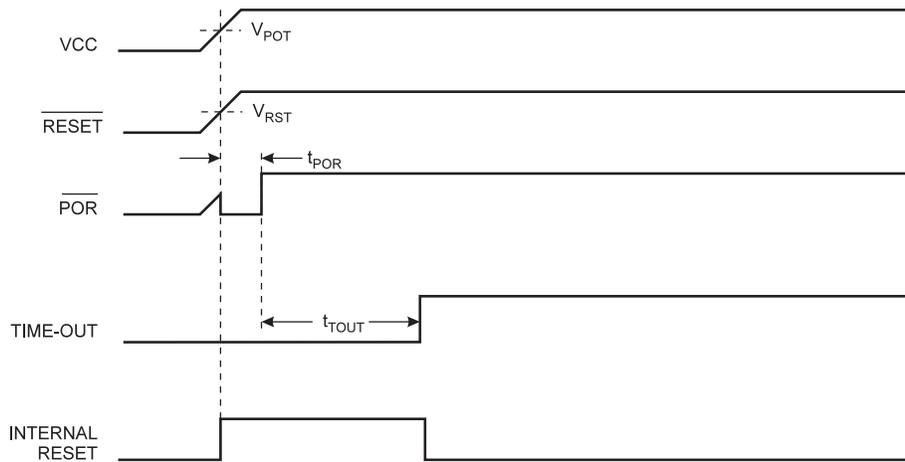
**Table 3.** Reset Characteristics ( $V_{CC} = 5.0V$ )

| Symbol     | Parameter   | Min | Typ        | Max | Units |
|------------|---|-----|------------|-----|-------|
| $V_{POT}$  | Power-On Reset Threshold Voltage                  | 1.8 | 2          | 2.2 | V     |
| $V_{RST}$  | RESET Pin Threshold Voltage                       |     | $V_{CC}/2$ |     | V     |
| $t_{POR}$  | Power-On Reset Period                             | 2   | 3          | 4   | ms    |
| $t_{TOUT}$ | Reset Delay Time-Out Period<br>FSTRT Unprogrammed | 11  | 16         | 21  | ms    |
| $t_{TOUT}$ | Reset Delay Time-Out Period<br>FSTRT Programmed   | 1.0 | 1.1        | 1.2 | ms    |

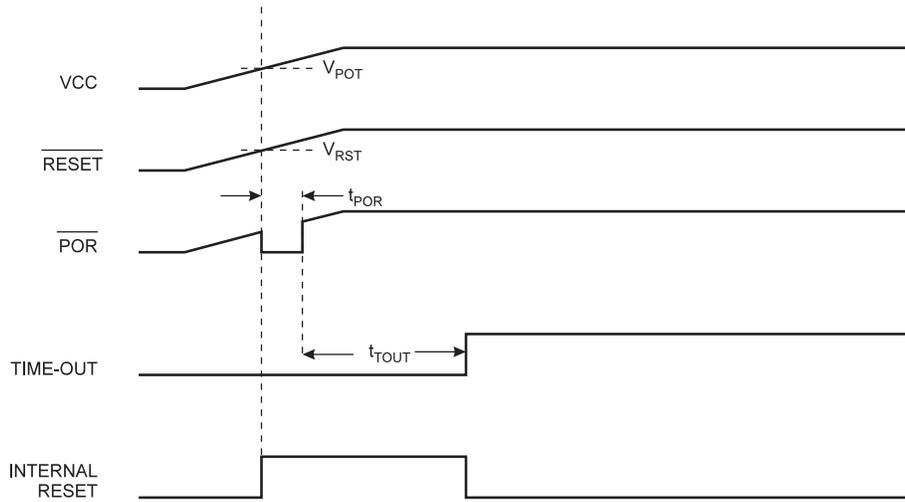
**POWER-ON RESET**

A Power-On Reset (POR) circuit ensures that the device is not started until  $V_{CC}$  has reached a safe level. As shown in Figure 23, an internal timer is clocked from the Watchdog timer. This timer prevents the MCU from starting until after a certain period after  $V_{CC}$  has reached the Power-On Threshold voltage -  $V_{POT}$ . See Figure 24 and Figure 25. The total reset period is the Power-On Reset period -  $t_{POR}$  + the Delay Time-out period -  $t_{TOUT}$ . The FSTRT fuse bit in the Flash can be programmed to give a shorter start-up time if a ceramic resonator or any other fast-start oscillator is used to clock the MCU.

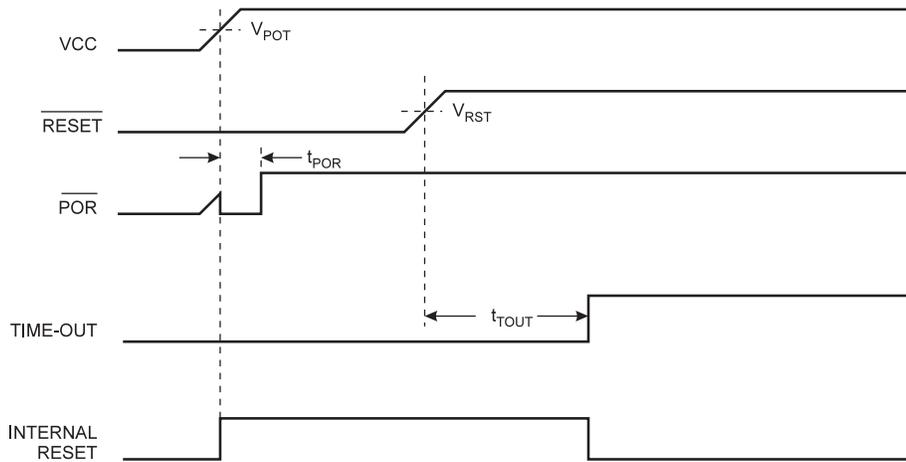
As the **RESET** pin is pulled high by an on-chip resistor, the pin can be left unconnected if no external reset is required. Connecting **RESET** to  $V_{CC}$  will have the same effect. By holding the **RESET** pin low for a period after  $V_{CC}$  has been applied, the Power-On Reset period can be extended. Refer to Figure 26 for a timing example on this.



**Figure 24.** MCU Start-Up, **RESET** Tied to  $V_{CC}$  or Unconnected. Rapidly Rising  $V_{CC}$



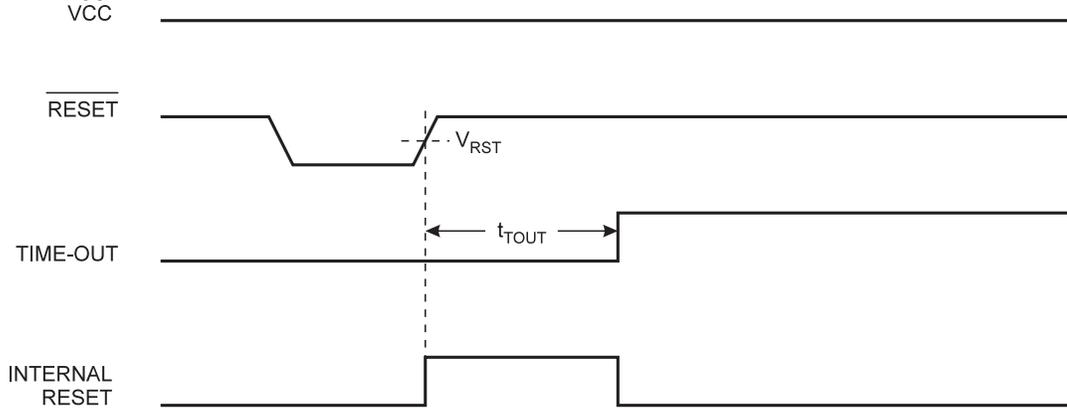
**Figure 25.** MCU Start-Up, RESET Tied to V<sub>CC</sub> or Unconnected. Slowly Rising V<sub>CC</sub>



**Figure 26.** MCU Start-Up, RESET Controlled Externally

## EXTERNAL RESET

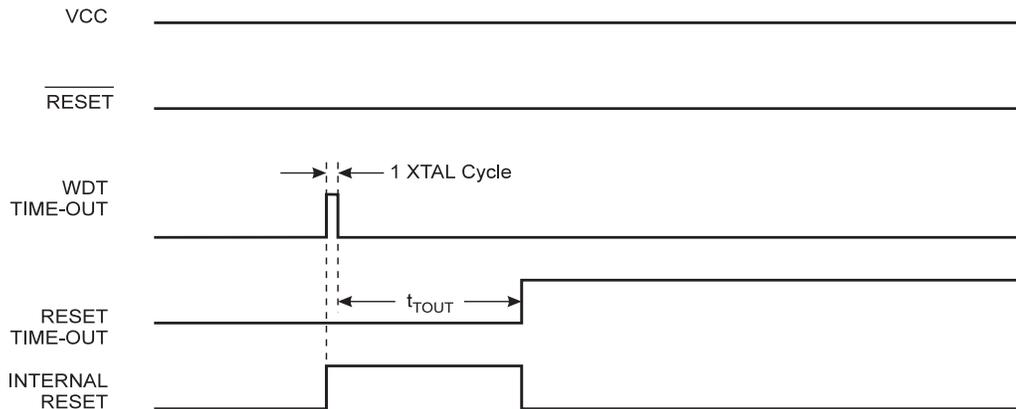
An external reset is generated by a low level on the **RESET** pin. The **RESET** pin must be held low for at least two crystal clock cycles. When reaches the Reset Threshold Voltage -  $V_{RST}$  on its positive edge, the delay timer starts the MCU after the Time-out period  $t_{TOUT}$  has expired.



**Figure 27.** External Reset During Operation

## WATCHDOG RESET

When the Watchdog times out, it will generate a short reset pulse of 1 XTAL cycle duration. On the falling edge of this pulse, the delay timer starts counting the Time-out period  $t_{TOUT}$ . Refer to Page 3-39 for details on operation of the Watchdog.



**Figure 28.** Watchdog Reset During Operation

## INTERRUPT HANDLING

The AT90S2313 has two 8-bit Interrupt Mask control registers; GIMSK - General Interrupt Mask register and TIMSK - Timer/Counter Interrupt Mask register.

When an interrupt occurs, the Global Interrupt Enable I-bit is cleared (zero) and all interrupts are disabled. The user software can set (one) the I-bit to enable interrupts. The I-bit is set (one) when a Return from Interrupt instruction - RETI - is executed.

For Interrupts triggered by events that can remain static (e.g. the Output Compare register1 matching the value of Timer/Counter1) the interrupt flag is set when the event occurs. If the interrupt flag is cleared and the interrupt condition persists, the flag will not be set until the event occurs the next time.

When the Program Counter is vectored to the actual interrupt vector in order to execute the interrupt handling routine, hardware clears the corresponding flag that generated the interrupt. Some of the interrupt flags can also be cleared by writing a logic one to the flag bit position(s) to be cleared.

## THE GENERAL INTERRUPT MASK REGISTER - GIMSK

| Bit           | 7    | 6    | 5 | 4 | 3 | 2 | 1 | 0 |       |
|---------------|------|------|---|---|---|---|---|---|-------|
| \$3B (\$5B)   | INT1 | INT0 | - | - | - | - | - | - | GIMSK |
| Read/Write    | R/W  | R/W  | R | R | R | R | R | R |       |
| 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 activated. The Interrupt Sense Control1 bits 1/0 (ISC11 and ISC10) in the MCU general Control Register (MCUCR) defines whether the external interrupt is activated on rising 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 program memory address \$002. See also “external Interrupts”.

### **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 activated. The Interrupt Sense Control0 bits 1/0 (ISC01 and ISC00) in the MCU general Control Register (MCUCR) defines whether the external interrupt is activated on rising 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 program memory address \$001. See also “External Interrupts.”

### **Bits 5..0 - Res : Reserved bits:**

These bits are reserved bits in the AT90S2313 and always read as zero.

## THE GENERAL INTERRUPT FLAG REGISTER - GIFR

| Bit           | 7     | 6     | 5 | 4 | 3 | 2 | 1 | 0 |      |
|---------------|-------|-------|---|---|---|---|---|---|------|
| \$3A (\$5A)   | INTF1 | INTF0 | - | - | - | - | - | - | GIFR |
| Read/Write    | R/W   | R/W   | R | R | R | R | R | R |      |
| Initial value | 0     | 0     | 0 | 0 | 0 | 0 | 0 | 0 |      |

### **Bit 7 - INTF1 : External Interrupt Flag1:**

When an event on the INT1 pin triggers an interrupt request, INTF1 becomes set (one). If the I-bit in SREG and the INT1 bit in GIMSK are set (one), the MCU will jump to the interrupt vector at address \$002. The flag is cleared when the interrupt routine is executed. Alternatively, the flag can be cleared by writing a logical one to it.

### **Bit 6 - INTF0 : External Interrupt Flag0:**

When an event on the INT0 pin triggers an interrupt request, INTF0 becomes set (one). If the I-bit in SREG and the INT0 bit in GIMSK are set (one), the MCU will jump to the interrupt vector at address \$001. The flag is cleared when the interrupt routine is executed. Alternatively, the flag can be cleared by writing a logical one to it.

### **Bits 5..0 - Res : Reserved bits:**

These bits are reserved bits in the AT90S2313 and always read as zero.

## THE TIMER/COUNTER INTERRUPT MASK REGISTER - TIMSK

| Bit           | 7     | 6      | 5 | 4 | 3      | 2 | 1     | 0 |       |
|---------------|-------|--------|---|---|--------|---|-------|---|-------|
| \$39 (\$59)   | TOIE1 | OCIE1A | - | - | TICIE1 | - | TOIE0 | - | TIMSK |
| Read/Write    | R/W   | R/W    | R | R | R/W    | R | R/W   | R |       |
| Initial value | 0     | 0      | 0 | 0 | 0      | 0 | 0     | 0 |       |

### **Bit 7 - TOIE1 : Timer/Counter1 Overflow Interrupt Enable:**

When the TOIE1 bit is set (one) and the I-bit in the Status Register is set (one), the Timer/Counter1 Overflow interrupt is enabled. The corresponding interrupt (at vector \$005) is executed if an overflow in Timer/Counter1 occurs. The Overflow Flag (Timer/Counter1) is set (one) in the Timer/Counter Interrupt Flag Register - TIFR. When Timer/Counter1 is in PWM mode, the Timer Overflow flag is set when the counter changes counting direction at \$0000.



**Bit 6 - OCIE1A :Timer/Counter1 Output Compare Match Interrupt Enable:**

When the OCIE1A bit is set (one) and the I-bit in the Status Register is set (one), the Timer/Counter1 Compare Match interrupt is enabled. The corresponding interrupt (at vector \$004) is executed if a Compare match in Timer/Counter1 occurs. The Compare Flag in Timer/Counter1 is set (one) in the Timer/Counter Interrupt Flag Register - TIFR.

**Bit 5,4 - Res :Reserved bits:**

These bits are reserved bits in the AT90S2313 and always read zero.

**Bit 3 - TICIE1 : Timer/Counter1 Input Capture Interrupt Enable:**

When the TICIE1 bit is set (one) and the I-bit in the Status Register is set (one), the Timer/Counter1 Input Capture Event Interrupt is enabled. The corresponding interrupt (at vector \$003) is executed if a capture-triggering event occurs on pin 11, PD6(ICP). The Input Capture Flag in Timer/Counter1 is set (one) in the Timer/Counter Interrupt Flag Register - TIFR.

**Bit 2 - Res : Reserved bit:**

This bit is a reserved bit in the AT90S2313 and always reads as zero.

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

When the TOIE0 bit is set (one) and the I-bit in the Status Register is set (one), the Timer/Counter0 Overflow interrupt is enabled. The corresponding interrupt (at vector \$006) is executed if an overflow in Timer/Counter0 occurs. The Overflow Flag (Timer0) is set (one) in the Timer/Counter Interrupt Flag Register - TIFR.

**Bit 0 - Res : Reserved bit:**

This bit is a reserved bit in the AT90S2313 and always reads as zero.

**THE TIMER/COUNTER INTERRUPT FLAG REGISTER - TIFR**

|               |      |       |   |   |      |   |      |   |      |
|---------------|------|-------|---|---|------|---|------|---|------|
| Bit           | 7    | 6     | 5 | 4 | 3    | 2 | 1    | 0 |      |
| \$38 (\$58)   | TOV1 | OCF1A | - | - | ICF1 | - | TOV0 | - | TIFR |
| Read/Write    | R/W  | R/W   | R | R | R/W  | R | R/W  | R |      |
| Initial value | 0    | 0     | 0 | 0 | 0    | 0 | 0    | 0 |      |

**Bit 7 - TOV1 : Timer/Counter1 Overflow Flag:**

The TOV1 is set (one) when an overflow occurs in Timer/Counter1. TOV1 is cleared by hardware when executing the corresponding interrupt handling vector. Alternatively, TOV1 is cleared by writing a logical one to the flag. When the I-bit in SREG, and TOIE1 (Timer/Counter1 Overflow Interrupt Enable), and TOV1 are set (one), the Timer/Counter1 Overflow Interrupt is executed. In PWM mode, this bit is set when Timer/Counter1 changes counting direction at \$0000.

**Bit 6 - OCF1A : Output Compare Flag 1A:**

The OCF1A bit is set (one) when compare match occurs between the Timer/Counter1 and the data in OCR1A - Output Compare Register1 A. OCF1A is cleared by hardware when executing the corresponding interrupt handling vector. Alternatively, OCF1A is cleared by writing a logical one to the flag. When the I-bit in SREG, and OCIE1A (Timer/Counter1 Compare match Interrupt Enable), and the OCF1A is set (one), the Timer/Counter1 Compare match Interrupt is executed.

**Bits 5, 4 - Res : Reserved bits:**

These bits are reserved bits in the AT90S2313 and always read zero.

**Bit 3 - ICF1 : - Input Capture Flag 1:**

The ICF1 bit is set (one) to flag an input capture event, indicating that the Timer/Counter1 value has been transferred to the input capture register - ICR1. ICF1 is cleared by hardware when executing the corresponding interrupt handling vector. Alternatively, ICF1 is cleared by writing a logical one to the flag.

**Bit 2 - Res : Reserved bit:**

This bit is a reserved bit in the AT90S2313 and always reads zero.

**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 logical one to the flag. When the SREG I-bit, and TOIE0 (Timer/Counter0 Overflow Interrupt Enable), and TOV0 are set (one), the Timer/Counter0 Overflow interrupt is executed.

**Bit 0 - Res : Reserved bit:**

This bit is a reserved bit in the AT90S2313 and always reads zero.

**EXTERNAL INTERRUPTS**

The external interrupts are triggered by the INT1 and INT0 pins. Observe that, if enabled, the interrupts will trigger even if the INT0/INT1 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. This is set up as indicated in the specification for the MCU Control Register - MCUCR. When the external interrupt is enabled and is configured as level triggered, the interrupt will trigger as long as the pin is held low.

The external interrupts are set up as described in the specification for the MCU Control Register - MCUCR.

**INTERRUPT RESPONSE TIME**

The interrupt execution response for all the enabled AVR interrupts is 4 clock cycles minimum. After the 4 clock cycles the program vector address for the actual interrupt handling routine is executed. During this 4 clock cycle period, the Program Counter (2 bytes) is pushed onto the Stack, and the Stack Pointer is decremented by 2. The vector is a relative jump to the interrupt routine, and this jump takes 2 clock cycles. If an interrupt occurs during execution of a multi-cycle instruction, this instruction is completed before the interrupt is served.

A return from an interrupt handling routine takes 4 clock cycles. During these 4 clock cycles, the Program Counter (2 bytes) is popped back from the Stack, and the Stack Pointer is incremented by 2. When 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 - SREG - is not handled by the AVR hardware, neither for interrupts nor for subroutines. For the routines requiring a storage of the SREG, this must be performed by user software.

**THE MCU CONTROL REGISTER - MCUCR**

The MCU Control Register contains control bits for general MCU functions.

|               |   |   |     |     |       |       |       |       |       |
|---------------|---|---|-----|-----|-------|-------|-------|-------|-------|
| Bit           | 7 | 6 | 5   | 4   | 3     | 2     | 1     | 0     |       |
| \$35 (\$55)   | - | - | SE  | SM  | ISC11 | ISC10 | ISC01 | ISC00 | MCUCR |
| Read/Write    | R | R | R/W | R/W | R/W   | R/W   | R/W   | R/W   |       |
| Initial value | 0 | 0 | 0   | 0   | 0     | 0     | 0     | 0     |       |

**Bits 7, 6 - Res : Reserved bits:**

These bits are reserved bits in the AT90S2313 and always read as zero.

**Bit 5 - SE : Sleep Enable:**

The SE bit must be set (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 programmers purpose, it is recommended to set the Sleep Enable SE bit just before the execution of the SLEEP instruction.

**Bit 4 - SM : Sleep Mode:**

This bit selects between the two available sleep modes. When SM is cleared (zero), Idle Mode is selected as Sleep Mode. When SM is set (one), Power Down mode is selected as sleep mode. For details, refer to the paragraph "Sleep Modes" below.

**Bits 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-flag and the corresponding interrupt mask in the GIMSK register is set. The level and edges on the external INT1 pin that activate the interrupt are defined in the following table:



**Table 4.** Interrupt 1 Sense Control

| ISC11 | ISC10 | Description  |
|-------|-------|--|
| 0     | 0     | The low level of INT1 generates an interrupt request.    |
| 0     | 1     | Reserved   |
| 1     | 0     | The falling edge of INT1 generates an interrupt request. |
| 1     | 1     | The rising edge of INT1 generates an interrupt request.  |

Note: When changing the ISC11/ISC10 bits, INT1 must be disabled by clearing its Interrupt Enable bit in the GIMSK Register. Otherwise an interrupt can occur when the bits are changed.

**Bits 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 is set. The level and edges on the external INT0 pin that activate the interrupt are defined in the following table:

**Table 5..** Interrupt 0 Sense Control

| ISC01 | ISC00 | Description  |
|-------|-------|--|
| 0     | 0     | The low level of INT0 generates an interrupt request.    |
| 0     | 1     | Reserved   |
| 1     | 0     | The falling edge of INT0 generates an interrupt request. |
| 1     | 1     | The rising edge of INT0 generates an interrupt request.  |

Notes: When changing the ISC10/ISC00 bits, INT0 must be disabled by clearing its Interrupt Enable bit in the GIMSK Register. Otherwise an interrupt can occur when the bits are changed.

**Sleep Modes**

To enter the sleep modes, the SE bit in MCUCR must be set (one) and a SLEEP instruction must be executed. If an enabled interrupt occurs while the MCU is in a sleep mode, the MCU awakes, executes the interrupt routine, and resumes execution from the instruction following SLEEP. The contents of the register file, SRAM and I/O memory are unaltered. If a reset occurs during sleep mode, the MCU wakes up and executes from the Reset vector.

Note that if a *level* triggered interrupt is used for wake-up from power down, the low level must be held for a time longer than the oscillator start-up time of 16 ms. Otherwise, the interrupt flag may return to zero before the MCU starts executing.

**IDLE MODE**

When the SM bit is cleared (zero), the SLEEP instruction forces the MCU into the Idle Mode stopping the CPU but allowing Timer/Counters, Watchdog and the interrupt system to continue operating. This enables the MCU to wake up from external triggered interrupts as well as internal ones like Timer Overflow interrupt and watchdog reset. If wakeup 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 during Idle Mode.

**POWER DOWN MODE**

When the SM bit is set (one), the SLEEP instruction forces the MCU into the Power Down Mode. In this mode, the external oscillator is stopped. The user can select whether the watchdog shall be enabled during power-down mode. If the watchdog is enabled, it will wake up the MCU when the Watchdog Time-out period expires. If the watchdog is disabled, only an external reset or an external level triggered interrupt can wake up the MCU.

**Timer / Counters**

The AT90S2313 provides two general purpose Timer/Counters - one 8-bit T/C and one 16-bit T/C. The Timer/Counters have individual prescaling selection from the same 10-bit prescaling timer. Both Timer/Counters can either be used as a timer with an internal clock timebase or as a counter with an external pin connection which triggers the counting.

### The Timer/Counter Prescaler

Figure 29 shows the general Timer/Counter prescaler.

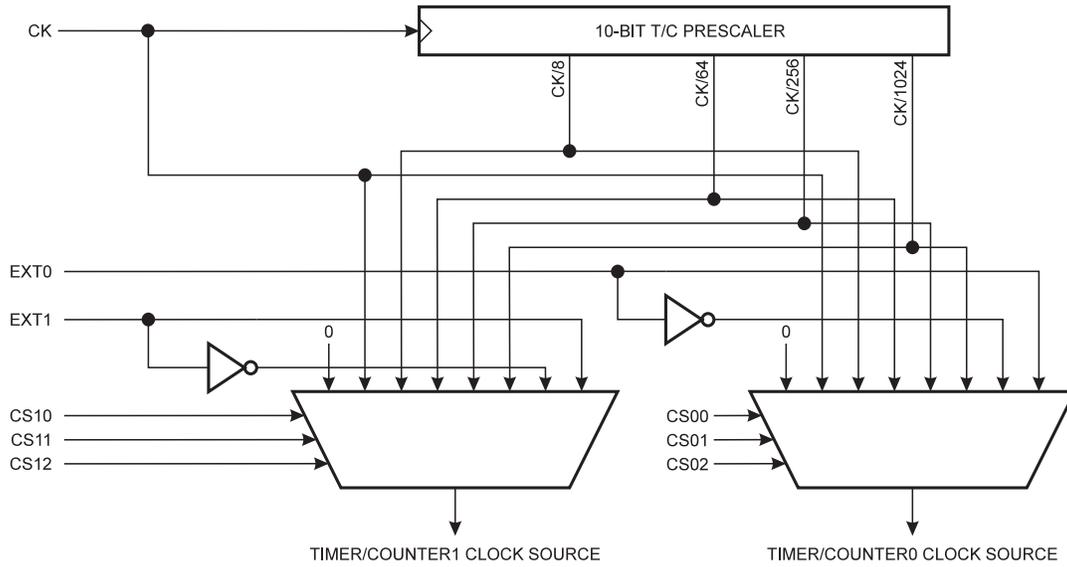


Figure 29. Timer/Counter Prescaler

The four different prescaled selections are: CK/8, CK/64, CK/256 and CK/1024 where CK is the oscillator clock. For the two Timer/Counters, added selections as CK, external source and stop, can be selected as clock sources.

### The 8-Bit Timer/Counter0

Figure 30 shows the block diagram for Timer/Counter0.

The 8-bit Timer/Counter0 can select clock source from CK, prescaled CK, or an external pin. In addition it can be stopped as described in the specification for the Timer/Counter0 Control Register - TCCR0. The overflow status flag is found in the Timer/Counter Interrupt Flag Register - TIFR. Control signals are found in the Timer/Counter0 Control Register - TCCR0. The interrupt enable/disable settings for Timer/Counter0 are found in the Timer/Counter Interrupt Mask Register - TIMSK.

When Timer/Counter0 is externally clocked, the external signal is synchronized with the oscillator frequency of the CPU. To assure proper sampling of the external clock, the minimum time between two external clock transitions must be at least one internal CPU clock period. The external clock signal is sampled on the rising edge of the internal CPU clock.

The 8-bit Timer/Counter0 features both a high resolution and a high accuracy usage with the lower prescaling opportunities. Similarly, the high prescaling opportunities make the Timer/Counter0 useful for lower speed functions or exact timing functions with infrequent actions.

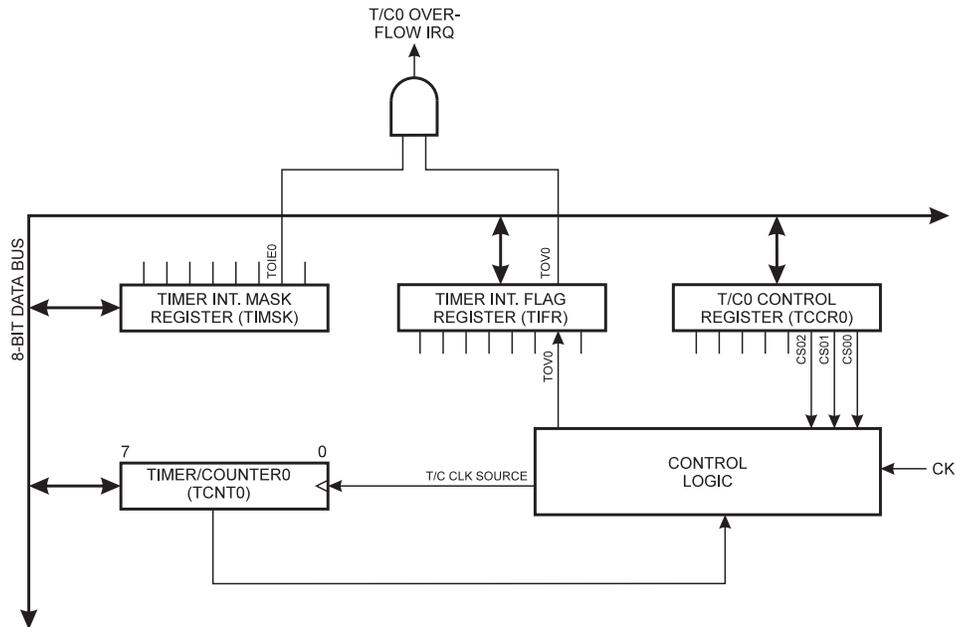


Figure 30. Timer/Counter 0 Block Diagram

**THE TIMER/COUNTER0 CONTROL REGISTER - TCCR0**

|               |   |   |   |   |   |      |      |      |       |
|---------------|---|---|---|---|---|------|------|------|-------|
| Bit           | 7 | 6 | 5 | 4 | 3 | 2    | 1    | 0    |       |
| \$33 (\$53)   | - | - | - | - | - | CS02 | CS01 | CS00 | TCCR0 |
| Read/Write    | R | R | R | R | R | R/W  | R/W  | R/W  |       |
| Initial value | 0 | 0 | 0 | 0 | 0 | 0    | 0    | 0    |       |

**Bits 7..3 - Res : Reserved bits:**

These bits are reserved bits in the AT90S2313 and always read zero.

**Bits 2,1,0 - CS02, CS01, CS00 : Clock Select0, bit 2,1 and 0:**

The Clock Select0 bits 2,1 and 0 define the prescaling source of Timer0.

Table 6. Clock 0 Prescale Select

| CS02 | CS01 | CS00 | Description                          |
|------|------|------|--------------------------------------|
| 0    | 0    | 0    | Stop, the Timer/Counter0 is stopped. |
| 0    | 0    | 1    | CK                                   |
| 0    | 1    | 0    | CK / 8                               |
| 0    | 1    | 1    | CK / 64                              |
| 1    | 0    | 0    | CK / 256                             |
| 1    | 0    | 1    | CK / 1024                            |
| 1    | 1    | 0    | External Pin T0, falling edge        |
| 1    | 1    | 1    | External Pin T0, rising edge         |

The Stop condition provides a Timer Enable/Disable function. The CK down divided modes are scaled directly from the CK oscillator clock. If the external pin modes are used, the corresponding setup must be performed in the actual data direction control register (cleared to zero gives an input pin).



When Timer/Counter1 is externally clocked, the external signal is synchronized with the oscillator frequency of the CPU. To assure proper sampling of the external clock, the minimum time between two external clock transitions must be at least one internal CPU clock period. The external clock signal is sampled on the rising edge of the internal CPU clock.

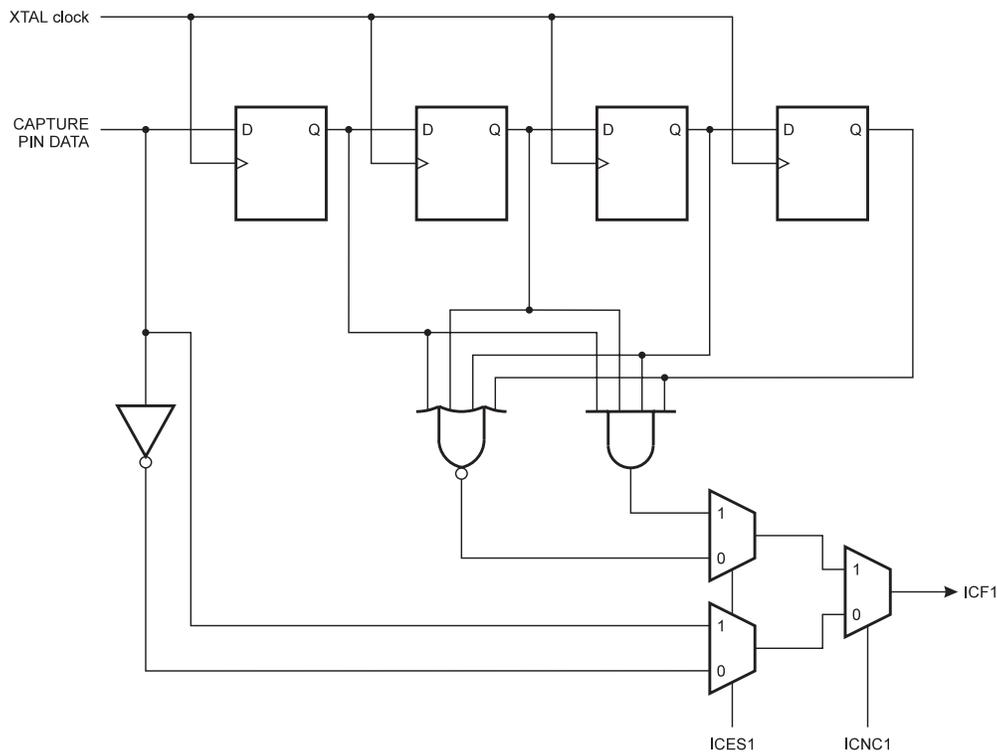
The 16-bit Timer/Counter1 features both a high resolution and a high accuracy usage with the lower prescaling opportunities. Similarly, the high prescaling opportunities makes the Timer/Counter1 useful for lower speed functions or exact timing functions with infrequent actions.

The Timer/Counter1 supports an Output Compare function using the Output Compare Register 1A - OCR1A as the data source to be compared to the Timer/Counter1 contents. The Output Compare functions include optional clearing of the counter on compare matches, and actions on the Output Compare pin 1 on compare matches.

Timer/Counter1 can also be used as a 8, 9 or 10-bit Pulse With Modulator. In this mode the counter and the OCR1 register serve as a glitch-free stand-alone PWM with centered pulses. Refer to Page 3-38 for a detailed description on this function.

The Input Capture function of Timer/Counter1 provides a capture of the Timer/Counter1 contents to the Input Capture Register - ICR1, triggered by an external event on the Input Capture Pin - ICP. The actual capture event settings are defined by the Timer/Counter1 Control Register - TCCR1.

The Timer/Counter1 input capture noise canceler block diagram is shown in Figure 32.



**Figure 32.** The Input Capture Noise Canceler

If the noise canceler function is enabled, the actual trigger condition for the capture event is monitored over 4 samples before the capture is activated. The input pin signal is sampled at XTAL clock frequency.

## THE TIMER/COUNTER1 CONTROL REGISTER A - TCCR1A

|               |        |        |   |   |   |   |       |       |        |
|---------------|--------|--------|---|---|---|---|-------|-------|--------|
| Bit           | 7      | 6      | 5 | 4 | 3 | 2 | 1     | 0     |        |
| \$2F (\$4F)   | COM1A1 | COM1A0 | - | - | - | - | PWM11 | PWM10 | TCCR1A |
| Read/Write    | R/W    | R/W    | R | R | R | R | R/W   | R/W   |        |
| Initial value | 0      | 0      | 0 | 0 | 0 | 0 | 0     | 0     |        |

### Bits 7,6 - COM1A1, COM1A0 : Compare Output Mode1, bits 1 and 0:

The COM1A1 and COM1A0 control bits determine any output pin action following a compare match in Timer/Counter1. Any output pin actions affect pin OC1 - Output Compare pin 1. Since this is an alternative function to an I/O port, the corresponding direction control bit must be set (one) to control an output pin. The control configuration is shown in Table 7.

**Table 7.** Compare 1 Mode Select

| COM1A1 | COM1A0 | Description                                     |
|--------|--------|---|
| 0      | 0      | Timer/Counter1 disconnected from output pin OC1 |
| 0      | 1      | Toggle the OC1 output line.                     |
| 1      | 0      | Clear the OC1 output line (to zero).            |
| 1      | 1      | Set the OC1 output line (to one).               |

In PWM mode, these bits have a different function. Refer to Table 11 for a detailed description.

When changing the COM1A1/COM1A0 bits, Output Compare Interrupt 1A must be disabled by clearing its Interrupt Enable bit in the TIMSK Register. Otherwise an interrupt can occur when the bits are changed.

### Bits 5..2 - Res : Reserved bits:

These bits are reserved bits in the AT90S2313 and always read zero.

### Bits 1,0 - PWM11, PWM10 : Pulse Width Modulator Select Bits:

These bits select PWM operation of Timer/Counter1 as specified in Table 8 . This mode is described on Page 3-38.

**Table 8.** PWM Mode Select

| PWM11 | PWM10 | Description                                 |
|-------|-------|---|
| 0     | 0     | PWM operation of Timer/Counter1 is disabled |
| 0     | 1     | Timer/Counter1 is an 8-bit PWM              |
| 1     | 0     | Timer/Counter1 is a 9-bit PWM               |
| 1     | 1     | Timer/Counter1 is a 10-bit PWM              |

## THE TIMER/COUNTER1 CONTROL REGISTER B - TCCR1B

|               |       |       |   |   |      |      |      |      |        |
|---------------|-------|-------|---|---|------|------|------|------|--------|
| Bit           | 7     | 6     | 5 | 4 | 3    | 2    | 1    | 0    |        |
| \$2E (\$4E)   | ICNC1 | ICES1 | - | - | CTC1 | CS12 | CS11 | CS10 | TCCR1B |
| Read/Write    | R/W   | R/W   | R | R | R/W  | R/W  | R/W  | R/W  |        |
| Initial value | 0     | 0     | 0 | 0 | 0    | 0    | 0    | 0    |        |

### Bit 7 - ICNC1 : Input Capture1 Noise Canceler (4 CKs):

When the ICNC1 bit is cleared (zero), the input capture trigger noise canceler function is disabled. The input capture is triggered at the first rising/falling edge sampled on the ICP - input capture pin - as specified. When the ICNC1 bit is set (one), four successive samples are measures on the ICP - input capture pin, and all samples must be high/low according to the input capture trigger specification in the ICES1 bit. The actual sampling frequency is the XTAL clock frequency.

**Bit 6 - ICES1 : Input Capture1 Edge Select:**

While the ICES1 bit is cleared (zero), the Timer/Counter1 contents are transferred to the Input Capture Register - ICR1 - on the falling edge of the input capture pin - ICP. While the ICES1 bit is set (one), the Timer/Counter1 contents are transferred to the Input Capture Register - ICR1 - on the rising edge of the input capture pin - ICP.

**Bits 5, 4 - Res : Reserved bits:**

These bits are reserved bits in the AT90S2313 and always read zero.

**Bit 3 - CTC1 : Clear Timer/Counter1 on Compare match:**

When the CTC1 control bit is set (one), the Timer/Counter1 is reset to \$0000 in the clock cycle after a compare match. If the CTC1 control bit is cleared, the Timer/Counter1 continues counting until it is stopped, cleared, wraps around (overflow) or changes direction. In PWM mode, this bit has no effect.

**Bits 2,1,0 - CS12, CS11, CS10 : Clock Select1, bit 2,1 and 0:**

The Clock Select1 bits 2,1 and 0 define the prescaling source of Timer/Counter1.

**Table 9.** Clock 1 Prescale Select

| CS12 | CS11 | CS10 | Description                          |
|------|------|------|--------------------------------------|
| 0    | 0    | 0    | Stop, the Timer/Counter1 is stopped. |
| 0    | 0    | 1    | CK                                   |
| 0    | 1    | 0    | CK / 8                               |
| 0    | 1    | 1    | CK / 64                              |
| 1    | 0    | 0    | CK / 256                             |
| 1    | 0    | 1    | CK / 1024                            |
| 1    | 1    | 0    | External Pin T1, falling edge        |
| 1    | 1    | 1    | External Pin T1, rising edge         |

The Stop condition provides a Timer Enable/Disable function. The CK down divided modes are scaled directly from the CK oscillator clock. If the external pin modes are used, the corresponding setup must be performed in the actual direction control register (cleared to zero gives an input pin).

**THE TIMER/COUNTER1 - TCNT1H AND TCNT1L**

|               |            |     |     |     |     |     |     |            |        |        |
|---------------|------------|-----|-----|-----|-----|-----|-----|------------|--------|--------|
| Bit           | 15         | 14  | 13  | 12  | 11  | 10  | 9   | 8          |        |        |
| \$2D (\$4D)   | <b>MSB</b> |     |     |     |     |     |     |            |        | TCNT1H |
| \$2C (\$4C)   |            |     |     |     |     |     |     | <b>LSB</b> | TCNT1L |        |
|               | 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 | R/W        | R/W    |        |
| Initial value | 0          | 0   | 0   | 0   | 0   | 0   | 0   | 0          | 0      |        |
|               | 0          | 0   | 0   | 0   | 0   | 0   | 0   | 0          | 0      |        |

This 16-bit register contains the prescaled value of the 16-bit Timer/Counter1. 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 register (TEMP).

• **TCNT1 Timer/Counter1 Write:**

When the CPU writes to the high byte TCNT1H, the written data is placed in the TEMP register. Next, when the CPU writes the low byte TCNT1L, this byte of data is combined with the byte data in the TEMP register, and all 16 bits are written to the TCNT1 Timer/Counter1 register simultaneously. Consequently, the high byte TCNT1H must be accessed first for a full 16-bit register write operation.

• **TCNT1 Timer/Counter1 Read:**

When the CPU reads the low byte TCNT1L, the data of the low byte TCNT1L is sent to the CPU and the data of the high byte TCNT1H is placed in the TEMP register. When the CPU reads the data in the high byte TCNT1H, the CPU receives the data in the TEMP register. Consequently, the low byte TCNT1L must be accessed first for a full 16-bit register read operation.

The Timer/Counter1 is realized as an up or up/down (in PWM mode) counter with read and write access. If Timer/Counter1 is written to and a clock source is selected, the Timer/Counter1 continues counting in the timer clock cycle after it is preset with the written value.

**TIMER/COUNTER1 OUTPUT COMPARE REGISTER A - OCR1AH AND OCR1AL**

|               |            |     |     |     |     |     |     |            |        |        |
|---------------|------------|-----|-----|-----|-----|-----|-----|------------|--------|--------|
| Bit           | 15         | 14  | 13  | 12  | 11  | 10  | 9   | 8          |        |        |
| \$2B (\$4B)   | <b>MSB</b> |     |     |     |     |     |     |            |        | OCR1AH |
| \$2A (\$4A)   |            |     |     |     |     |     |     | <b>LSB</b> | OCR1AL |        |
|               | 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    |        |
| Initial value | 0          | 0   | 0   | 0   | 0   | 0   | 0   | 0          | 0      |        |

The output compare register is a 16-bit read/write register.

The Timer/Counter1 Output Compare Register contains the data to be continuously compared with Timer/Counter1. Actions on compare matches are specified in the Timer/Counter1 Control and Status register.

Since the Output Compare Register - OCR1A - is a 16-bit register, a temporary register TEMP is used when OCR1A is written to ensure that both bytes are updated simultaneously. When the CPU writes the high byte, OCR1AH, the data is temporarily stored in the TEMP register. When the CPU writes the low byte, OCR1AL, the TEMP register is simultaneously written to OCR1AH. Consequently, the high byte OCR1AH must be written first for a full 16-bit register write operation.

**THE TIMER/COUNTER1 INPUT CAPTURE REGISTER - ICR1H AND ICR1L**

|               |            |    |    |    |    |    |   |            |       |       |
|---------------|------------|----|----|----|----|----|---|------------|-------|-------|
| Bit           | 15         | 14 | 13 | 12 | 11 | 10 | 9 | 8          |       |       |
| \$25 (\$45)   | <b>MSB</b> |    |    |    |    |    |   |            |       | ICR1H |
| \$24 (\$44)   |            |    |    |    |    |    |   | <b>LSB</b> | ICR1L |       |
|               | 7          | 6  | 5  | 4  | 3  | 2  | 1 | 0          |       |       |
| Read/Write    | R          | R  | R  | R  | R  | R  | R | R          | R     |       |
| Initial value | 0          | 0  | 0  | 0  | 0  | 0  | 0 | 0          | 0     |       |

The input capture register is a 16-bit read-only register.

When the rising or falling edge (according to the input capture edge setting - ICES1) of the signal at the input capture pin - ICP - is detected, the current value of the Timer/Counter1 is transferred to the Input Capture Register - ICR1. At the same time, the input capture flag - ICF1 - is set (one).

Since the Input Capture Register - ICR1 - is a 16-bit register, a temporary register TEMP is used when ICR1 is read to ensure that both bytes are read simultaneously. When the CPU reads the low byte ICR1L, the data is sent to the CPU and the data of the high byte ICR1H is placed in the TEMP register. When the CPU reads the data in the high byte ICR1H, the CPU receives the data in the TEMP register. Consequently, the low byte ICR1L must be accessed first for a full 16-bit register read operation.



### TIMER/COUNTER1 IN PWM MODE

When the PWM mode is selected, Timer/Counter1 and the Output Compare Register1 - OCR1A, form a 8, 9 or 10-bit, free-running, glitch-free and phase correct PWM with output on the PB3(OC1) pin. Timer/Counter1 acts as an up/down counter, counting up from \$0000 to TOP (see Table 10), when it turns and counts down again to zero before the cycle is repeated. When the counter value matches the contents of the 8, 9 or 10 least significant bits of OCR1A, the PD1(OC1) pin is set or cleared according to the settings of the COM1A1 and COM1A0 bits in the Timer/Counter1 Control Register TCCR1. Refer to Table 11 for details.

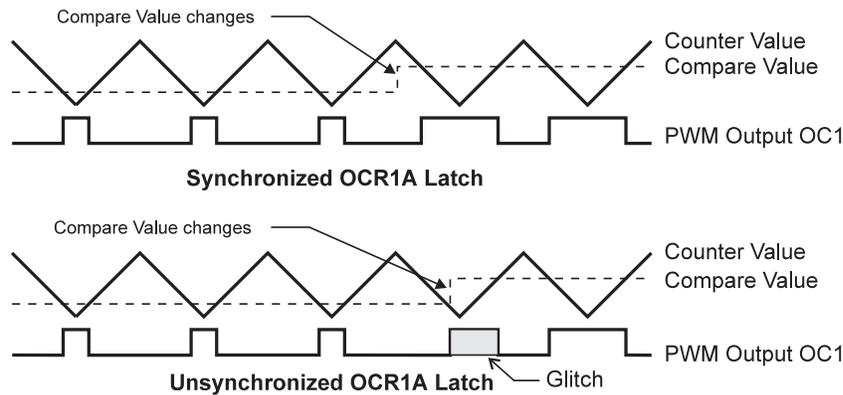
**Table 10.** Timer TOP Values and PWM Frequency

| PWM Resolution | Timer TOP value | Frequency      |
|----------------|-----------------|----------------|
| 8-bit          | \$00FF (255)    | $f_{TC1}/510$  |
| 9-bit          | \$01FF (511)    | $f_{TC1}/1022$ |
| 10-bit         | \$03FF(1023)    | $f_{TC1}/2046$ |

**Table 11.** Compare1 Mode Select in PWM Mode

| COM1A1 | COM1A0 | Effect on OC1  |
|--------|--------|--|
| 0      | 0      | Not connected  |
| 0      | 1      | Not connected  |
| 1      | 0      | Cleared on compare match, upcounting. Set on compare match, downcounting (non-inverted PWM). |
| 1      | 1      | Cleared on compare match, downcounting. Set on compare match, upcounting (inverted PWM).     |

Note that in the PWM mode, the 10 least significant OCR1A bits, when written, are transferred to a temporary location. They are latched when Timer/Counter1 reaches TOP. This prevents the occurrence of odd-length PWM pulses (glitches) in the event of an unsynchronized OCR1A write. See Figure 33 for an example.



**Figure 33.** Effects on Unsynchronized OCR1 Latching

When OCR1A contains \$0000 or TOP, the output OC1 is held low or high according to the settings of COM1A1 and COM1A0. This is shown in Table 12.

**Table 12.** PWM Outputs OCR = \$0000 or TOP

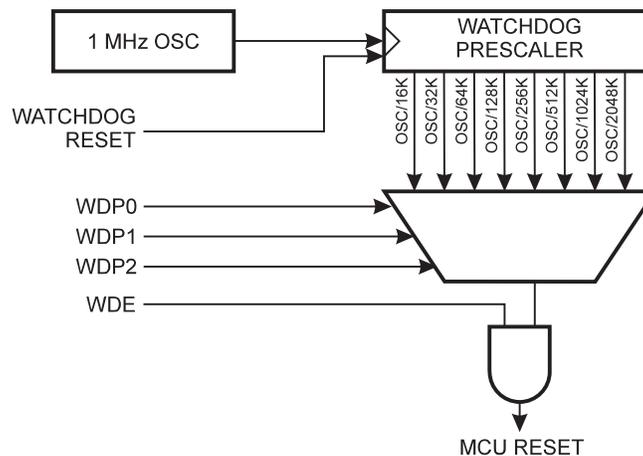
| COM1A1 | COM1A0 | OCR1A  | Output OC1 |
|--------|--------|--------|------------|
| 1      | 0      | \$0000 | L          |
| 1      | 0      | TOP    | H          |
| 1      | 1      | \$0000 | H          |
| 1      | 1      | TOP    | L          |

In PWM mode, the Timer Overflow Flag1, TOV1, is set when the counter changes direction at \$0000. Timer Overflow Interrupt1 operates exactly as in normal Timer/Counter mode, i.e. it is executed when TOV1 is set provided that Timer Overflow Interrupt1 and global interrupts are enabled. This does also apply to the Timer Output Compare1 flag and interrupt.

## The Watchdog Timer

The Watchdog Timer is clocked from a separate on-chip oscillator which runs at 1MHz. This is the typical value 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 from 16 to 2048 ms. The WDR - Watchdog Reset - instruction resets the Watchdog Timer. Eight different clock cycle periods can be selected to determine the reset period. If the reset period expires without another Watchdog reset, the AT90S2313 resets and executes from the reset vector. For timing details on the Watchdog reset, refer to Page 3-26.

To prevent unintentional disabling of the watchdog, a special turn-off sequence must be followed when the watchdog is disabled. Refer to the description of the Watchdog Timer Control Register for details.



**Figure 34.** Watchdog Timer

### THE WATCHDOG TIMER CONTROL REGISTER - WDTCR

| Bit           | 7 | 6 | 5 | 4      | 3   | 2    | 1    | 0    |       |
|---------------|---|---|---|--------|-----|------|------|------|-------|
| \$21 (\$41)   | - | - | - | WDTTOE | 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 AT90S2313 and will always read as zero.

**Bit 4 - WDTOE : Watch Dog Turn-Off Enable:**

This bit must be set (one) when the WDE bit is cleared. Otherwise, the watchdog will not be disabled. Once set, hardware will clear this bit to zero after four clock cycles. Refer to the description of the WDE bit for a watchdog disable procedure.

**Bit 3 - WDE : Watch Dog Enable:**

When the WDE is set (one) the Watchdog Timer is enabled, and if the WDE is cleared (zero) the Watchdog Timer function is disabled. WDE can only be cleared if the WDTOE bit is set(one). To disable an enabled watchdog timer, the following procedure must be followed:

1. In the same operation, write a logical one to WDTOE and WDE. A logical 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 logical 0 to WDE. This disables the watchdog.

**Bits 2..0 - WDP2, WDP1, WDP0 : Watchdog Timer Prescaler 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 13.

**Table 13.** Watch Dog Timer Prescale Select (Typical Values at  $V_{CC} = 5.0V$ )

| WDP2 | WDP1 | WDP0 | Timeout Period |
|------|------|------|----------------|
| 0    | 0    | 0    | 16 ms          |
| 0    | 0    | 1    | 32 ms          |
| 0    | 1    | 0    | 64 ms          |
| 0    | 1    | 1    | 128 ms         |
| 1    | 0    | 0    | 256 ms         |
| 1    | 0    | 1    | 512 ms         |
| 1    | 1    | 0    | 1024 ms        |
| 1    | 1    | 1    | 2048 ms        |

**EEPROM Read/Write Access**

The EEPROM access registers are accessible in the I/O space.

The write access time is in the range of 2.5 - 4ms, depending on the  $V_{CC}$  voltages. A self-timing function, however, lets the user software detect when the next byte can be written. An EEPROM brown-out detection prevents writing to the EEPROM if  $V_{CC}$  is below a certain level.

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 or written, the CPU is halted for two clock cycles before the next instruction is executed.

**THE EEPROM ADDRESS REGISTER - EEAR**

|               |   |       |       |       |       |       |       |       |      |
|---------------|---|-------|-------|-------|-------|-------|-------|-------|------|
| Bit           | 7 | 6     | 5     | 4     | 3     | 2     | 1     | 0     |      |
| \$1E (\$3E)   | - | EEAR6 | EEAR5 | EEAR4 | EEAR3 | EEAR2 | EEAR1 | EEAR0 | EEAR |
| Read/Write    | R | R/W   |      |
| Initial value | 0 | 0     | 0     | 0     | 0     | 0     | 0     | 0     |      |

**Bit 7 - Res : Reserved bit:**

This bit is a reserved bit in the AT90S2313 and will always read as zero.

**Bit 6..0 - EEAR6..0 : EEPROM Address:**

The EEPROM Address Register - EEAR6..0 - specifies the EEPROM address in the 128 bytes EEPROM space. The EEPROM data bytes are addressed linearly between 0 and 127.

## THE EEPROM DATA REGISTER - EEDR

|               |     |     |     |     |     |     |     |     |      |
|---------------|-----|-----|-----|-----|-----|-----|-----|-----|------|
| Bit           | 7   | 6   | 5   | 4   | 3   | 2   | 1   | 0   |      |
| \$1D (\$3D)   | MSB |     |     |     |     |     |     | LSB | EEDR |
| Read/Write    | R/W |      |
| Initial value | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   |      |

### Bit 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    |      |
| \$1C (\$3C)   | - | - | - | - | - | EEMWE | EEWE | EERE | EECR |
| Read/Write    | R | R | R | R | R | R/W   | R/W  | R/W  |      |
| Initial value | 0 | 0 | 0 | 0 | 0 | 0     | 0    | 0    |      |

### Bit 7.3 - Res : Reserved bits:

These bits are reserved bits in the AT90S2313 and will always read as zero.

### 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 (one) setting EEWE will write data to the EEPROM at the selected address. If EEMWE is zero, setting EEWE will have no effect. When EEMWE has been set (one) by software, hardware clears the bit to zero after four clock cycles. See the description of the EEWE bit for a 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 set to write the value into the EEPROM. The EEMWE bit must be set when the 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 2 and 3 is unessential):

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

When the write access time (typically 2.5 ms at  $V_{CC} = 5V$  or 4 ms at  $V_{CC} = 2.7V$ ) has elapsed, the EEWE bit is cleared (zero) 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 set. When the EERE bit is cleared (zero) by hardware, requested data is found in the EEDR register. The EEPROM read access takes one instruction and there is no need to poll the EERE bit. When EERE has been set, the CPU is halted for two 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 when new data or address is written to the EEPROM I/O registers, the write operation will be interrupted, and the result is undefined.

## The UART

The AT90S2313 features a full duplex Universal Asynchronous Receiver and Transmitter (UART). The main features are:

- Baud rate generator generates any baud rate
- High baud rates at low XTAL frequencies
- 8 or 9 bits data
- Noise filtering
- Overrun detection
- Framing Error detection
- False Start Bit detection
- Three separate interrupts on TX Complete, TX Data Register Empty and RX Complete

### Data Transmission

A block schematic of the UART transmitter is shown in Figure 35.

Data transmission is initiated by writing the data to be transmitted to the UART I/O Data Register, UDR. Data is transferred from UDR to the Transmit shift register when:

- A new character has been written to UDR after the stop bit from the previous character has been shifted out. The shift register is loaded immediately.
- A new character has been written to UDR before the stop bit from the previous character has been shifted out. The shift register is loaded when the stop bit of the character currently being transmitted has been shifted out.

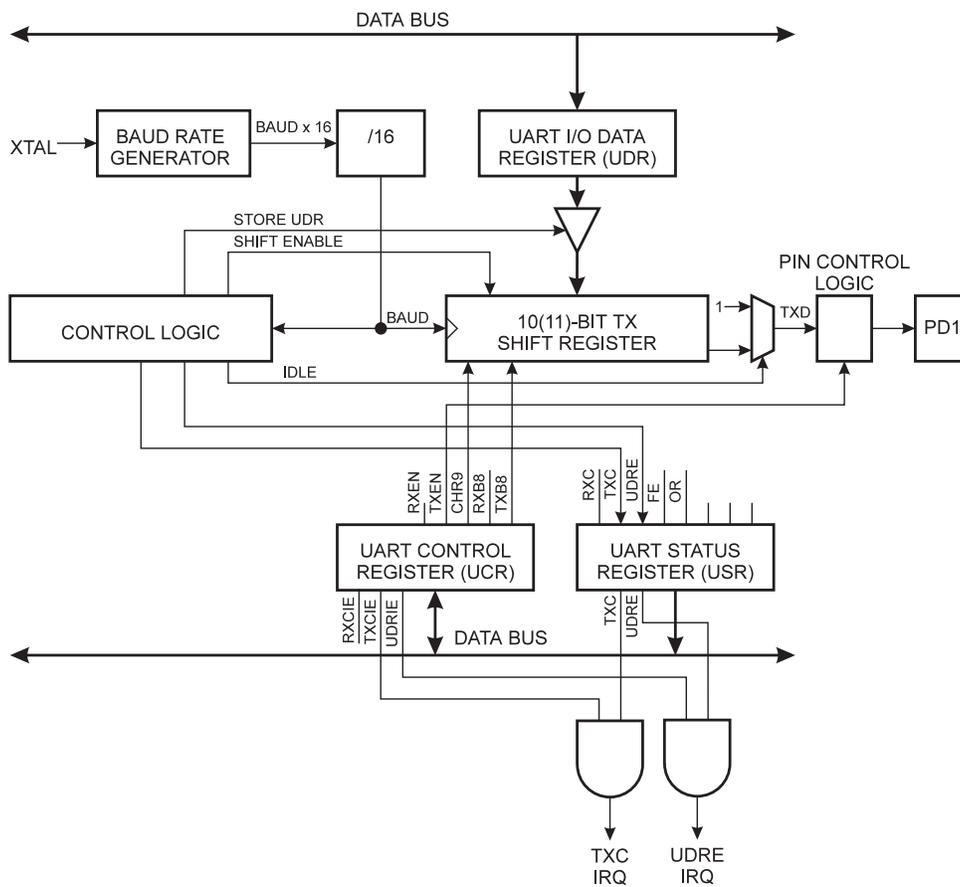
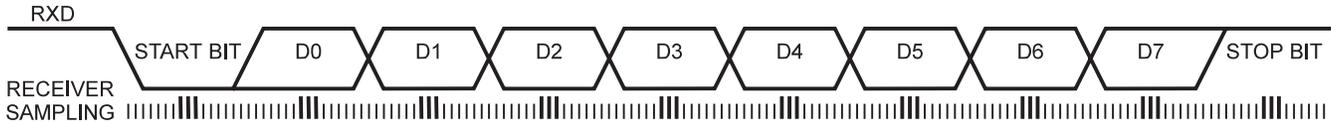


Figure 35. UART Transmitter



The receiver front-end logic samples the signal on the RXD pin at a frequency 16 times the baud rate. While the line is idle, one single sample of logical zero will be interpreted as the falling edge of a start bit, and the start bit detection sequence is initiated. Let sample 1 denote the first zero-sample. Following the 1 to 0-transition, the receiver samples the RXD pin at samples 8, 9 and 10. If two or more of these three samples are found to be logical ones, the start bit is rejected as a noise spike and the receiver starts looking for the next 1 to 0-transition.

If however, a valid start bit is detected, sampling of the data bits following the start bit is performed. These bits are also sampled at samples 8, 9 and 10. The logical value found in at least two of the three samples is taken as the bit value. All bits are shifted into the transmitter shift register as they are sampled. Sampling of an incoming character is shown in Figure 37.



**Figure 37. Sampling Received Data**

When the stop bit enters the receiver, the majority of the three samples must be one to accept the stop bit. If two or more samples are logical zeros, the Framing Error (FE) flag in the UART Status Register (USR) is set. Before reading the UDR register, the user should always check the FE bit to detect Framing Errors.

Whether or not a valid stop bit is detected at the end of a character reception cycle, the data is transferred to UDR and the RXC flag in USR is set. UDR is in fact two physically separate registers, one for transmitted data and one for received data. When UDR is read, the Receive Data register is accessed, and when UDR is written, the Transmit Data register is accessed. If 9 bit data word is selected (the CHR9 bit in the UART Control Register, UCR is set), the RXB8 bit in UCR is loaded with bit 9 in the Transmit shift register when data is transferred to UDR.

If, after having received a character, the UDR register has not been read since the last receive, the OverRun (OR) flag in UCR is set. This means that the last data byte shifted into to the shift register could not be transferred to UDR and has been lost. The OR bit is buffered, and is updated when the valid data byte in UDR is read. Thus, the user should always check the OR bit after reading the UDR register in order to detect any overruns.

By clearing the RXEN bit in the UCR register, the receiver is disabled. This means that the PD0 pin can be used as a general I/O pin. When RXEN is set, the UART Receiver will be connected to the PD0 pin regardless of the setting of the DDD0 bit in DDRD.

## UART Control

### THE UART I/O DATA REGISTER - UDR

|               |            |     |     |     |     |     |     |            |            |
|---------------|------------|-----|-----|-----|-----|-----|-----|------------|------------|
| Bit           | 7          | 6   | 5   | 4   | 3   | 2   | 1   | 0          |            |
| \$0C (\$2C)   | <b>MSB</b> |     |     |     |     |     |     | <b>LSB</b> | <b>UDR</b> |
| 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 UDR register is actually two physically separate registers sharing the same I/O address. When writing to the register, the UART Transmit Data register is written. When reading from UDR, the UART Receive Data register is read.

### THE UART STATUS REGISTER - USR

|               |            |            |             |           |           |   |   |   |            |
|---------------|------------|------------|-------------|-----------|-----------|---|---|---|------------|
| Bit           | 7          | 6          | 5           | 4         | 3         | 2 | 1 | 0 |            |
| \$0B (\$2B)   | <b>RXC</b> | <b>TXC</b> | <b>UDRE</b> | <b>FE</b> | <b>OR</b> | - | - | - | <b>USR</b> |
| Read/Write    | R          | R          | R           | R         | R         | R | R | R |            |
| Initial value | 0          | 0          | 1           | 0         | 0         | 0 | 0 | 0 |            |

The USR register is a read-only register providing information on the UART Status.

**Bit 7 - RXC: UART Receive Complete:**

This bit is set (one) when a received character is transferred from the Receiver Shift register to UDR. The bit is set regardless of any detected framing errors. When the RXCIE bit in UCR is set, the UART Receive Complete interrupt will be executed when RXC is set(one). RXC is cleared by reading UDR. When interrupt-driven data reception is used, the UART Receive Complete Interrupt routine must read UDR in order to clear RXC, otherwise a new interrupt will occur once the interrupt routine terminates.

**Bit 6 - TXC : UART Transmit Complete:**

This bit is set (one) when the entire character (including the stop bit) in the Transmit Shift register has been shifted out and no new data has been written to UDR. This flag is especially useful in half-duplex communications interfaces, where a transmitting application must enter receive mode and free the communications bus immediately after completing the transmission.

When the TXCIE bit in UCR is set, setting of TXC causes the UART Transmit Complete interrupt to be executed. TXC is cleared by hardware when executing the corresponding interrupt handling vector. Alternatively, the TXC bit is cleared (zero) by writing a logical one to the bit.

**Bit 5 - UDRE : UART Data Register Empty:**

This bit is set (one) when a character written to UDR is transferred to the Transmit shift register. Setting of this bit indicates that the transmitter is ready to receive a new character for transmission.

When the UDRIE bit in UCR is set, the UART Transmit Complete interrupt to be executed as long as UDRE is set. UDRE is cleared by writing UDR. When interrupt-driven data transmittal is used, the UART Data Register Empty Interrupt routine must write UDR in order to clear UDRE, otherwise a new interrupt will occur once the interrupt routine terminates.

UDRE is set (one) during reset to indicate that the transmitter is ready.

**Bit 4 - FE : Framing Error:**

This bit is set if a Framing Error condition is detected, i.e. when the stop bit of an incoming character is zero.

The FE bit is cleared when the stop bit of received data is one.

**Bit 3 - OR : OverRun:**

This bit is set if an Overrun condition is detected, i.e. when a character already present in the UDR register is not read before the next character has been shifted into the Receiver Shift register. The OR bit is buffered, which means that it will be set once the valid data still in UDRE is read.

The OR bit is cleared (zero) when data is received and transferred to UDR.

**Bits 2..0 - Res : Reserved bits:**

These bits are reserved bits in the AT90S2313 and will always read as zero.

**THE UART CONTROL REGISTER - UCR**

|               |       |       |       |      |      |      |      |      |     |
|---------------|-------|-------|-------|------|------|------|------|------|-----|
| Bit           | 7     | 6     | 5     | 4    | 3    | 2    | 1    | 0    |     |
| \$0A (\$2A)   | RXCIE | TXCIE | UDRIE | RXEN | TXEN | CHR9 | RXB8 | TXB8 | UCR |
| Read/Write    | 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 - RXCIE : RX Complete Interrupt Enable:**

When this bit is set (one), a setting of the RXC bit in USR will cause the Receive Complete interrupt routine to be executed provided that global interrupts are enabled.

**Bit 6 - TXCIE : TX Complete Interrupt Enable:**

When this bit is set (one), a setting of the TXC bit in USR will cause the Transmit Complete interrupt routine to be executed provided that global interrupts are enabled.

**Bit 5 - UDRIE : UART Data Register Empty Interrupt Enable:**

When this bit is set (one), a setting of the UDRE bit in USR will cause the UART Data Register Empty interrupt routine to be executed provided that global interrupts are enabled.



**Bit 4 - RXEN : Receiver Enable:**

This bit enables the UART receiver when set (one). When the receiver is disabled, the TXC, OR and FE status flags cannot become set. If these flags are set, turning off RXEN does not cause them to be cleared.

**Bit 3 - TXEN : Transmitter Enable:**

This bit enables the UART transmitter when set (one). When disabling the transmitter while transmitting a character, the transmitter is not disabled before the character in the shift register plus any following character in UDR has been completely transmitted.

**Bit 2 - CHR9 : 9 Bit Characters:**

When this bit is set (one) transmitted and received characters are 9 bit long plus start and stop bits. The 9th bit is read and written by using the RXB8 and TXB8 bits in UCR, respectively. The 9th data bit can be used as an extra stop bit or a parity bit.

**Bit 1 - RXB8 : Receive Data Bit 8**

When CHR9 is set (one), RXB8 is the 9th data bit of the received character.

**Bit 0 - TXB8 : Transmit Data Bit 8**

When CHR9 is set (one), TXB8 is the 9th data bit in the character to be transmitted.

**THE BAUD RATE GENERATOR**

The baud rate generator is a frequency divider which generates baud-rates according to the following equation:

$$\text{BAUD} = \frac{f_{\text{CK}}}{16(\text{UBRR} + 1)}$$

- BAUD = Baud-Rate
- $f_{\text{CK}}$  = Crystal Clock frequency
- UBRR = Contents of the UART Baud Rate register, UBRR (0-255)

For standard crystal frequencies, the most commonly used baud rates can be generated by using the UBRR settings in Table 14. UBRR values which yield an actual baud rate differing less than 2% from the target baud rate, are bolded in the table.

**Table 14. UBRR Settings at Various Crystal Frequencies**

| Baud Rate | 1 MHz    | %Error | 1.8432 MHz | %Error | 2 MHz    | %Error | 2.4576 MHz | %Error |
|-----------|----------|--------|------------|--------|----------|--------|------------|--------|
| 2400      | UBRR= 25 | 0.2    | UBRR= 47   | 0.0    | UBRR= 51 | 0.2    | UBRR= 63   | 0.0    |
| 4800      | UBRR= 12 | 0.2    | UBRR= 23   | 0.0    | UBRR= 25 | 0.2    | UBRR= 31   | 0.0    |
| 9600      | UBRR= 6  | 7.5    | UBRR= 11   | 0.0    | UBRR= 12 | 0.2    | UBRR= 15   | 0.0    |
| 14400     | UBRR= 3  | 7.8    | UBRR= 7    | 0.0    | UBRR= 8  | 3.7    | UBRR= 10   | 3.1    |
| 19200     | UBRR= 2  | 7.8    | UBRR= 5    | 0.0    | UBRR= 6  | 7.5    | UBRR= 7    | 0.0    |
| 28800     | UBRR= 1  | 7.8    | UBRR= 3    | 0.0    | UBRR= 3  | 7.8    | UBRR= 4    | 6.3    |
| 57600     | UBRR= 0  | 7.8    | UBRR= 1    | 0.0    | UBRR= 1  | 7.8    | UBRR= 2    | 12.5   |
| 115200    | UBRR= 0  | 84.3   | UBRR= 0    | 0.0    | UBRR= 0  | 7.8    | UBRR= 0    | 25.0   |

| Baud Rate | 3.2768 MHz | %Error | 3.6864 MHz | %Error | 4 MHz     | %Error | 4.608 MHz | %Error |
|-----------|------------|--------|------------|--------|-----------|--------|-----------|--------|
| 2400      | UBRR= 84   | 0.4    | UBRR= 95   | 0.0    | UBRR= 103 | 0.2    | UBRR= 119 | 0.0    |
| 4800      | UBRR= 42   | 0.8    | UBRR= 47   | 0.0    | UBRR= 51  | 0.2    | UBRR= 59  | 0.0    |
| 9600      | UBRR= 20   | 1.6    | UBRR= 23   | 0.0    | UBRR= 25  | 0.2    | UBRR= 29  | 0.0    |
| 14400     | UBRR= 13   | 1.6    | UBRR= 15   | 0.0    | UBRR= 16  | 2.1    | UBRR= 19  | 0.0    |
| 19200     | UBRR= 10   | 3.1    | UBRR= 11   | 0.0    | UBRR= 12  | 0.2    | UBRR= 14  | 0.0    |
| 28800     | UBRR= 6    | 1.6    | UBRR= 7    | 0.0    | UBRR= 8   | 3.7    | UBRR= 9   | 0.0    |
| 57600     | UBRR= 3    | 12.5   | UBRR= 3    | 0.0    | UBRR= 3   | 7.8    | UBRR= 4   | 0.0    |
| 115200    | UBRR= 1    | 12.5   | UBRR= 1    | 0.0    | UBRR= 1   | 7.8    | UBRR= 2   | 20.0   |

| Baud Rate | 7.3728 MHz | %Error | 8 MHz     | %Error | 9.216 MHz | %Error | 11.059 MHz | %Error |
|-----------|------------|--------|-----------|--------|-----------|--------|------------|--------|
| 2400      | UBRR= 191  | 0.0    | UBRR= 207 | 0.2    | UBRR= 239 | 0.0    | UBRR= 287  | -      |
| 4800      | UBRR= 95   | 0.0    | UBRR= 103 | 0.2    | UBRR= 119 | 0.0    | UBRR= 143  | 0.0    |
| 9600      | UBRR= 47   | 0.0    | UBRR= 51  | 0.2    | UBRR= 59  | 0.0    | UBRR= 71   | 0.0    |
| 14400     | UBRR= 31   | 0.0    | UBRR= 34  | 0.8    | UBRR= 39  | 0.0    | UBRR= 47   | 0.0    |
| 19200     | UBRR= 23   | 0.0    | UBRR= 25  | 0.2    | UBRR= 29  | 0.0    | UBRR= 35   | 0.0    |
| 28800     | UBRR= 15   | 0.0    | UBRR= 16  | 2.1    | UBRR= 19  | 0.0    | UBRR= 23   | 0.0    |
| 57600     | UBRR= 7    | 0.0    | UBRR= 8   | 3.7    | UBRR= 9   | 0.0    | UBRR= 11   | 0.0    |
| 115200    | UBRR= 3    | 0.0    | UBRR= 3   | 7.8    | UBRR= 4   | 0.0    | UBRR= 5    | 0.0    |

| Baud Rate | 14.746 MHz | %Error | 16 MHz    | %Error | 18.432 MHz | %Error | 20 MHz    | %Error |
|-----------|------------|--------|-----------|--------|------------|--------|-----------|--------|
| 2400      | UBRR= 383  | -      | UBRR= 416 | -      | UBRR= 479  | -      | UBRR= 520 | -      |
| 4800      | UBRR= 191  | 0.0    | UBRR= 207 | 0.2    | UBRR= 239  | 0.0    | UBRR= 259 | -      |
| 9600      | UBRR= 95   | 0.0    | UBRR= 103 | 0.2    | UBRR= 119  | 0.0    | UBRR= 129 | 0.2    |
| 14400     | UBRR= 63   | 0.0    | UBRR= 68  | 0.6    | UBRR= 79   | 0.0    | UBRR= 86  | 0.2    |
| 19200     | UBRR= 47   | 0.0    | UBRR= 51  | 0.2    | UBRR= 59   | 0.0    | UBRR= 64  | 0.2    |
| 28800     | UBRR= 31   | 0.0    | UBRR= 34  | 0.8    | UBRR= 39   | 0.0    | UBRR= 42  | 0.9    |
| 57600     | UBRR= 15   | 0.0    | UBRR= 16  | 2.1    | UBRR= 19   | 0.0    | UBRR= 21  | 1.4    |
| 115200    | UBRR= 7    | 0.0    | UBRR= 8   | 3.7    | UBRR= 9    | 0.0    | UBRR= 10  | 1.4    |

### THE UART BAUD RATE REGISTER - UBRR

|               |   |     |     |     |     |     |     |     |      |
|---------------|---|-----|-----|-----|-----|-----|-----|-----|------|
| Bit           | 7   | 6   | 5   | 4   | 3   | 2   | 1   | 0   |      |
| \$09 (\$29)   | <div style="display: flex; justify-content: space-between; align-items: center;"> <span>MSB</span> <span style="flex-grow: 1; border: 1px solid black; position: relative;"> <span style="position: absolute; top: -10px; left: 0; right: 0; border-bottom: 1px solid black;"></span> </span> <span>LSB</span> </div> |     |     |     |     |     |     |     | UBRR |
| 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 UBRR register is an 8-bit read/write register which specifies the UART Baud Rate according to the formula on the previous page.



## The Analog Comparator

The analog comparator compares the input values on the positive pin AIN0 (PB0) and the negative pin PB1 (AIN1). When the voltage on the positive pin PB0 (AIN0) is higher than the voltage on the negative PB1 (AIN1), the Analog Comparator Output, ACO is set (one). 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 38.

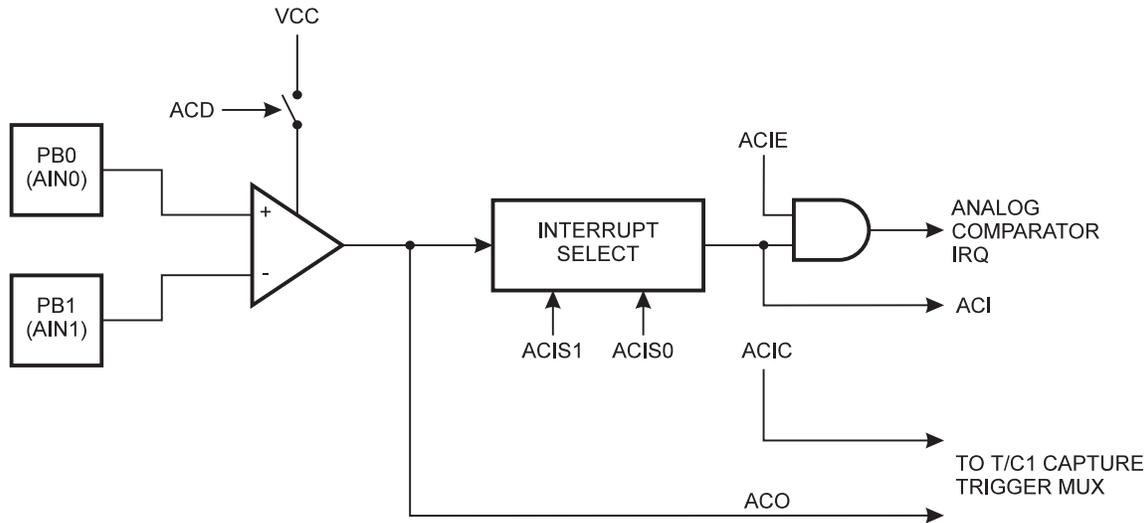


Figure 38. Analog Comparator Block Diagram

### THE ANALOG COMPARATOR CONTROL AND STATUS REGISTER - ACSR

| Bit           | 7   | 6 | 5   | 4   | 3    | 2    | 1     | 0     |      |
|---------------|-----|---|-----|-----|------|------|-------|-------|------|
| \$08 (\$28)   | ACD | - | ACO | ACI | ACIE | ACIC | ACIS1 | ACIS0 | ACSR |
| 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 - ACD : Analog Comparator Disable

When this bit is set (one), the power to the analog comparator is switched off. This bit can be set at any time to turn off the analog comparator. It is most commonly used if power consumption during Idle Mode is critical, and wake-up from the analog comparator is not required. 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 - Res : Reserved bit:

This bit is a reserved bit in the AT90S2313 and will always read as zero.

#### Bit 5 - ACO : Analog Comparator Output:

ACO is directly connected to the comparator output.

#### Bit 4 - ACI : Analog Comparator Interrupt Flag:

This bit is set (one) 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 (one) and the I-bit in SREG is set (one). 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 set (one) and the I-bit in the Status Register is set (one), the analog comparator interrupt is activated. When cleared (zero), the interrupt is disabled.

**Bit 2 - ACIC : Analog Comparator Input Capture enable:**

When set (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 cleared (zero), no connection between the analog comparator and the Input Capture function is given. To make the comparator trigger the Timer/Counter1 Input Capture interrupt, the TICIE1 bit in the Timer Interrupt Mask Register (TIMSK) must be set (one).

**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 15.

**Table 15.** 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  |

Note: 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.

## I/O-Ports

### Port B

Port B is an 8-bit bi-directional I/O port.

Three data memory address locations are allocated for the Port B, one each for the Data Register - PORTB, \$18 (\$38), Data Direction Register - DDRB, \$17(\$37) and the Port B Input Pins - PINB, \$16(\$36). The Port B Input Pins address is read only, while the Data Register and the Data Direction Register are read/write.

All port pins have individually selectable pullups. The Port B output buffers can sink 20mA and thus drive LED displays directly. When pins PB0 to PB7 are used as inputs and are externally pulled low, they will source current ( $I_{IL}$ ) if the internal pullups are activated.

The Port B pins with alternate functions are shown in the following table:

**Table 16.** Port B Pins Alternate Functions

| Port Pin | Alternate Functions                              |
|----------|--|
| PB0      | AIN0 (Analog comparator positive input)          |
| PB1      | AIN1 (Analog comparator negative input)          |
| PB3      | OC1 (Timer/Counter1 Output compare match output) |
| PB5      | MOSI (Data input line for memory downloading)    |
| PB6      | MISO (Data output line for memory uploading)     |
| PB7      | SCK (Serial clock input)                         |

When the pins are used for the alternate function the DDRB and PORTB register has to be set according to the alternate function description.



## THE PORT B DATA REGISTER - PORTB

|               |               |               |               |               |               |               |               |               |              |
|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|--------------|
| Bit           | 7             | 6             | 5             | 4             | 3             | 2             | 1             | 0             |              |
| \$18 (\$38)   | <b>PORTB7</b> | <b>PORTB6</b> | <b>PORTB5</b> | <b>PORTB4</b> | <b>PORTB3</b> | <b>PORTB2</b> | <b>PORTB1</b> | <b>PORTB0</b> | <b>PORTB</b> |
| Read/Write    | R/W           |              |
| Initial value | 0             | 0             | 0             | 0             | 0             | 0             | 0             | 0             |              |

## THE PORT B DATA DIRECTION REGISTER - DDRB

|               |             |             |             |             |             |             |             |             |             |
|---------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
| Bit           | 7           | 6           | 5           | 4           | 3           | 2           | 1           | 0           |             |
| \$17 (\$37)   | <b>DDB7</b> | <b>DDB6</b> | <b>DDB5</b> | <b>DDB4</b> | <b>DDB3</b> | <b>DDB2</b> | <b>DDB1</b> | <b>DDB0</b> | <b>DDRb</b> |
| Read/Write    | R/W         |             |
| Initial value | 0           | 0           | 0           | 0           | 0           | 0           | 0           | 0           |             |

## THE PORT B INPUT PINS ADDRESS - PINB

|               |              |              |              |              |              |              |              |              |             |
|---------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|-------------|
| Bit           | 7            | 6            | 5            | 4            | 3            | 2            | 1            | 0            |             |
| \$16 (\$36)   | <b>PINB7</b> | <b>PINB6</b> | <b>PINB5</b> | <b>PINB4</b> | <b>PINB3</b> | <b>PINB2</b> | <b>PINB1</b> | <b>PINB0</b> | <b>PINB</b> |
| Read/Write    | R            | R            | R            | R            | R            | R            | R            | R            |             |
| Initial value | Hi-Z         |             |

The Port B Input Pins address - PINB - is not a register, and this address enables access to the physical value on each Port B pin. When reading PORTB, the PORTB Data Latch is read, and when reading PINB, the logical values present on the pins are read.

## PORTB AS GENERAL DIGITAL I/O

All 8 bits in port B are equal when used as digital I/O pins.

PB<sub>n</sub>, General I/O pin: The DDB<sub>n</sub> bit in the DDRB register selects the direction of this pin, if DDB<sub>n</sub> is set (one), PB<sub>n</sub> is configured as an output pin. If DDB<sub>n</sub> is cleared (zero), PB<sub>n</sub> is configured as an input pin. If PORTB<sub>n</sub> is set (one) when the pin configured as an input pin, the MOS pull up resistor is activated. To switch the pull up resistor off, the PORTB<sub>n</sub> has to be cleared (zero) or the pin has to be configured as an output pin.

**Table 17.** DDB<sub>n</sub> Effects on Port B Pins

| DDB <sub>n</sub> | PORTB <sub>n</sub> | I/O    | Pull up | Comment  |
|------------------|--------------------|--------|---------|--|
| 0                | 0                  | Input  | No      | Tri-state (Hi-Z)   |
| 0                | 1                  | Input  | Yes     | PB <sub>n</sub> will source current ( $I_{IL}$ ) if ext. pulled low. |
| 1                | 0                  | Output | No      | Push-Pull Zero Output  |
| 1                | 1                  | Output | No      | Push-Pull One Output   |

n: 7,6...0, pin number.

## ALTERNATE FUNCTIONS OF PORTB

The alternate pin functions of Port B are:

### **SCK - PORTB, Bit 7:**

SCK, Clock input pin for Memory up/downloading.

### **MISO - PORTB, Bit 6:**

MISO, Data output pin for Memory uploading.

### **MOSI - PORTB, Bit 5:**

MOSI, Data input pin for Memory downloading.



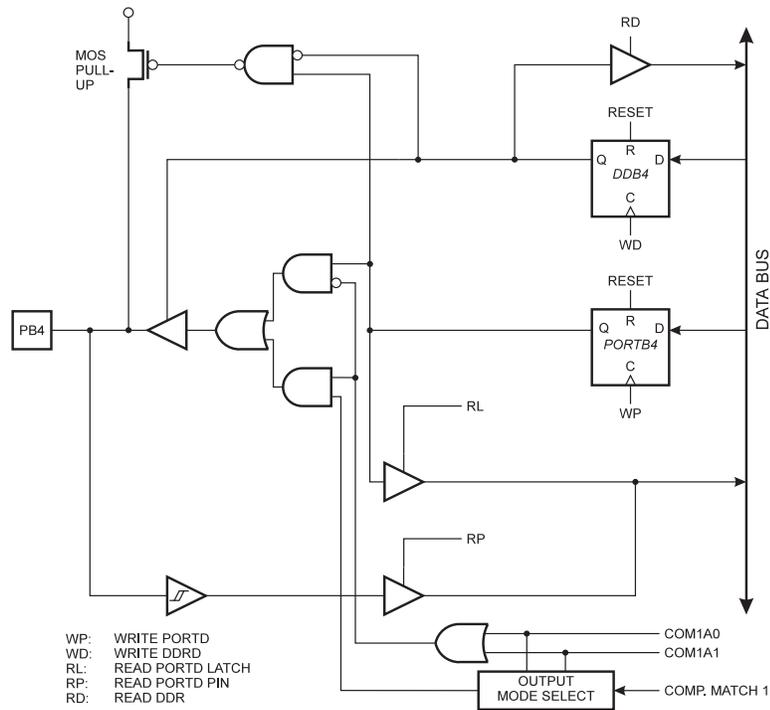


Figure 40. PORTB Schematic Diagram Pin PB4

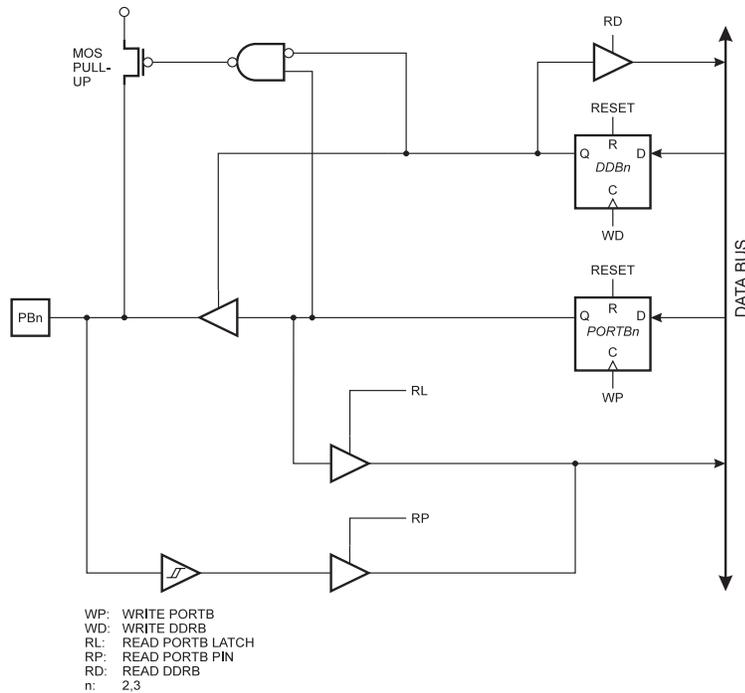


Figure 41. PORTB Schematic Diagram, Pins PB2 and PB3

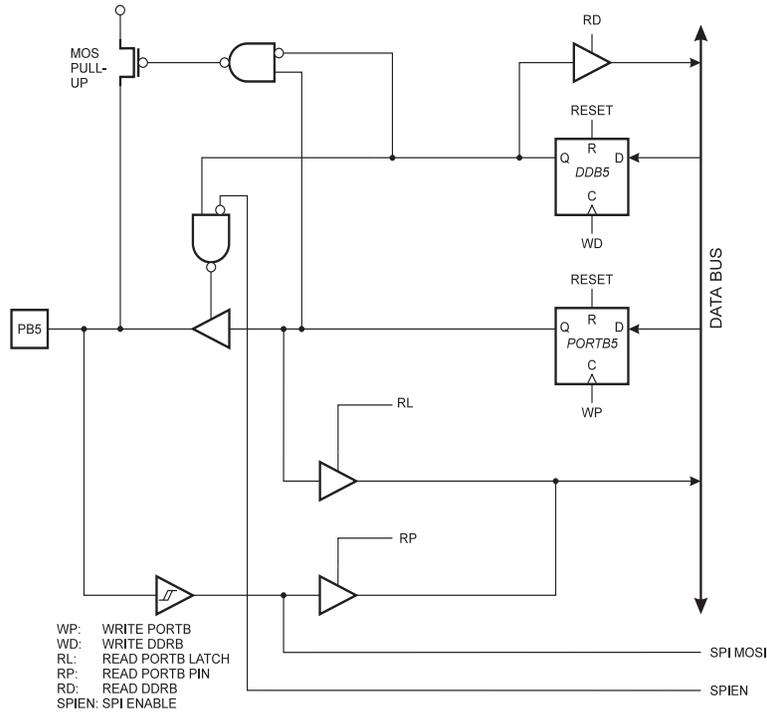


Figure 42. PORTB Schematic Diagram Pin PB5

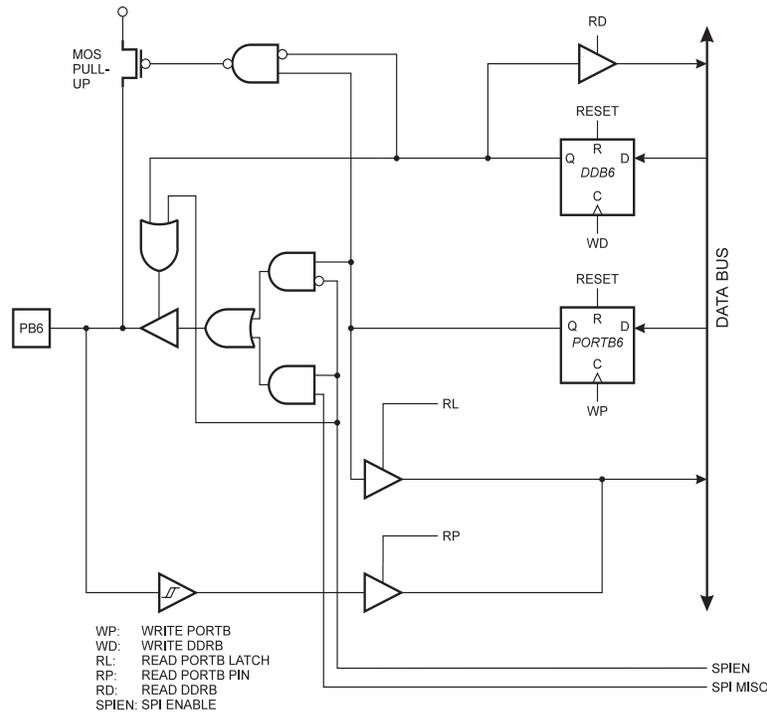


Figure 43. PORTB Schematic Diagram, Pin PB6

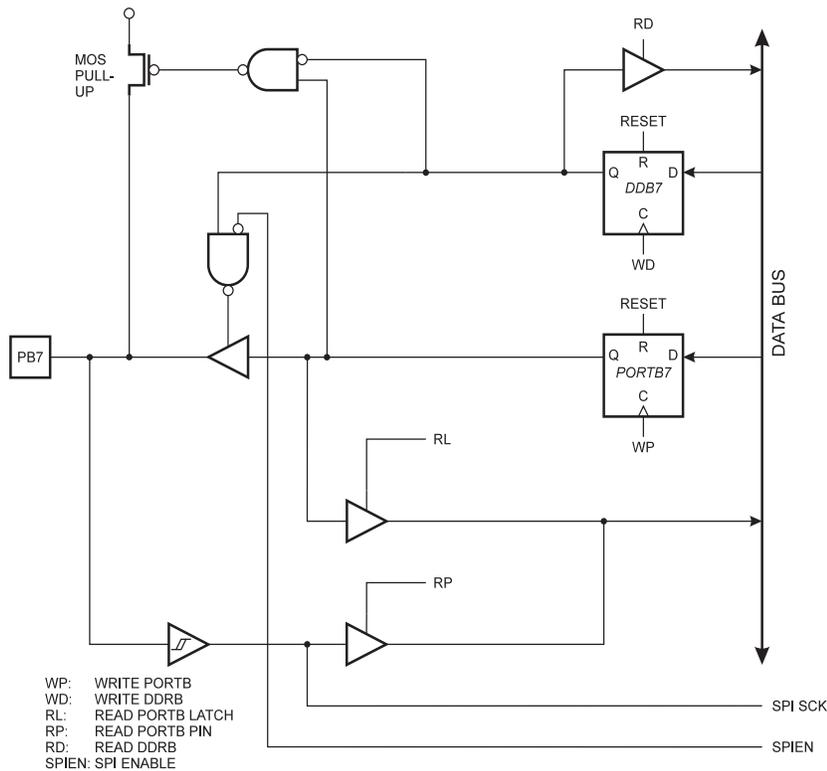


Figure 44. PORTB Schematic Diagram, Pin PB7

## Port D

Three data memory address locations are allocated for the Port D, one each for the Data Register - PORTD, \$12(\$32), Data Direction Register - DDRD, \$11(\$31) and the Port D Input Pins - PIND, \$10(\$30). The Port D Input Pins address is read only, while the Data Register and the Data Direction Register are read/write.

Port D has seven bi-directional I/O pins with internal pullups, PD6..PD0. The Port D output buffers can sink 20 mA. As inputs, Port D pins that are externally pulled low will source current ( $I_{IL}$ ) if the pullups are activated.

Some Port D pins have alternate functions as shown in the following table:

Table 18. Port D Pins Alternate Functions

| Port Pin | Alternate Function                      |
|----------|---|
| PD0      | RXD (Receive data input for the UART)   |
| PD1      | TXD (Transmit data output for the UART) |
| PD2      | INT0 (External interrupt 0 input)       |
| PD3      | INT1 (External interrupt 1 input)       |
| PD4      | TO (Timer/Counter0 external input)      |
| PD5      | T1 (Timer/Counter1 external input)      |
| PD6      | ICP (Timer/Counter1 Input Capture pin)  |

When the pins are used for the alternate function the DDRD and PORTD register has to be set according to the alternate function description.

## THE PORT D DATA REGISTER - PORTD

|               |   |        |        |        |        |        |        |        |       |
|---------------|---|--------|--------|--------|--------|--------|--------|--------|-------|
| Bit           | 7 | 6      | 5      | 4      | 3      | 2      | 1      | 0      |       |
| \$12 (\$32)   | - | PORTD6 | PORTD5 | PORTD4 | PORTD3 | PORTD2 | PORTD1 | PORTD0 | PORTD |
| Read/Write    | R | R/W    |       |
| Initial value | 0 | 0      | 0      | 0      | 0      | 0      | 0      | 0      |       |

## THE PORT D DATA DIRECTION REGISTER - DDRB

|               |   |      |      |      |      |      |      |      |      |
|---------------|---|------|------|------|------|------|------|------|------|
| Bit           | 7 | 6    | 5    | 4    | 3    | 2    | 1    | 0    |      |
| \$11 (\$31)   | - | DDD6 | DDD5 | DDD4 | DDD3 | DDD2 | DDD1 | DDD0 | DDRD |
| Read/Write    | R | R/W  |      |
| Initial value | 0 | 0    | 0    | 0    | 0    | 0    | 0    | 0    |      |

## THE PORT D INPUT PINS ADDRESS

|               |   |       |       |       |       |       |       |       |      |
|---------------|---|-------|-------|-------|-------|-------|-------|-------|------|
| Bit           | 7 | 6     | 5     | 4     | 3     | 2     | 1     | 0     |      |
| \$10 (\$30)   | - | PIND6 | PIND5 | PIND4 | PIND3 | PIND2 | PIND1 | PIND0 | PIND |
| Read/Write    | R | R     | R     | R     | R     | R     | R     | R     |      |
| Initial value | 0 | Hi-Z  |      |

The Port D Input Pins address - PIND - is not a register, and this address enables access to the physical value on each Port D pin. When reading PORTD, the PORTD Data Latch is read, and when reading PIND, the logical values present on the pins are read.

## PORTD AS GENERAL DIGITAL I/O

PD<sub>n</sub>, General I/O pin: The DDD<sub>n</sub> bit in the DDRD register selects the direction of this pin. If DDD<sub>n</sub> is set (one), PD<sub>n</sub> is configured as an output pin. If DDD<sub>n</sub> is cleared (zero), PD<sub>n</sub> is configured as an input pin. If PORTD<sub>n</sub> is set (one) when configured as an input pin the MOS pull up resistor is activated. To switch the pull up resistor off the PORTD<sub>n</sub> has to be cleared (zero) or the pin has to be configured as an output pin.

**Table 19.** DDD<sub>n</sub> Bits on Port D Pins

| DDD <sub>n</sub> | PORTD <sub>n</sub> | I/O    | Pull up | Comment  |
|------------------|--------------------|--------|---------|--|
| 0                | 0                  | Input  | No      | Tri-state (Hi-Z)   |
| 0                | 1                  | Input  | Yes     | PD <sub>n</sub> will source current ( $I_{IL}$ ) if ext. pulled low. |
| 1                | 0                  | Output | No      | Push-Pull Zero Output  |
| 1                | 1                  | Output | No      | Push-Pull One Output   |

n: 6...0, pin number.

## ALTERNATE FUNCTIONS OF PORTD

The alternate functions of Port D are:

### ICP - PORTD, Bit 6:

Timer/Counter1 Input Capture pin. See the Timer/Counter1 description for further details.

### T1 - PORTD, Bit 5:

T1, Timer 1 clock source. See the timer description for further details.

### T0 - PORTD, Bit 4:

T0, Timer/Counter0 clock source. See the Timer description for further details.

### INT1 - PORTD, Bit 3:

INT1, External Interrupt source 1. The PD3 pin can serve as an external interrupt source to the MCU. See the interrupt description for further details, and how to enable the source.

**INT0 - PORTD, Bit 2:**

INT0, External Interrupt source 0. The PD2 pin can serve as an external interrupt source to the MCU. See the interrupt description for further details, and how to enable the source.

**TXD - PORTD, Bit 1:**

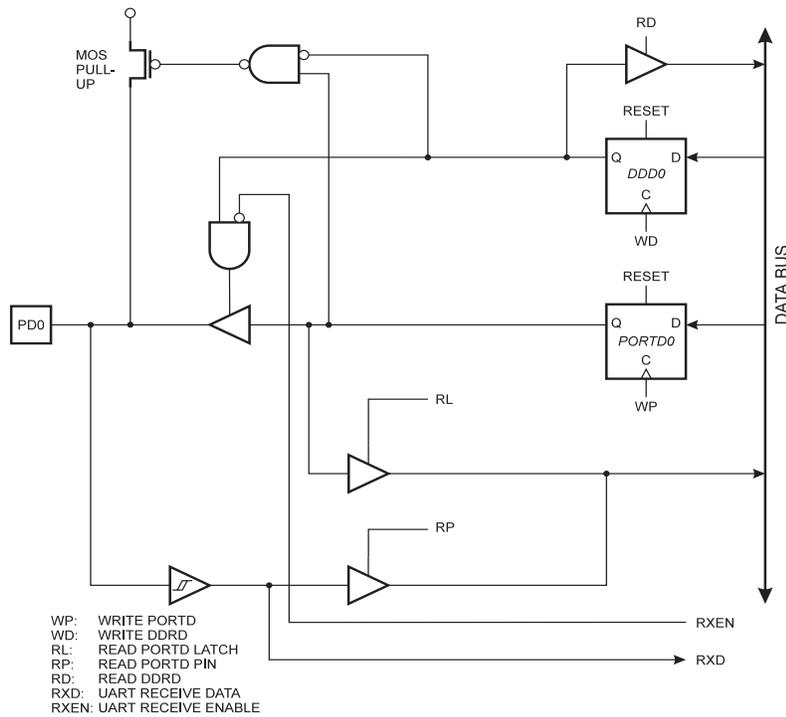
Transmit Data (Data output pin for the UART). When the UART transmitter is enabled, this pin is configured as an output regardless of the value of DDRD1.

**RXD - PORTD, Bit 0:**

Receive Data (Data input pin for the UART). When the UART receiver is enabled this pin is configured as an output regardless of the value of DDRD0. When the UART forces this pin to be an input, a logical one in PORTD0 will turn on the internal pull-up.

**PORTD SCHEMATICS**

Note that all port pins are synchronized. The synchronization latches are however, not shown in the figures.



**Figure 45. PORTD Schematic Diagram (Pin PD0)**

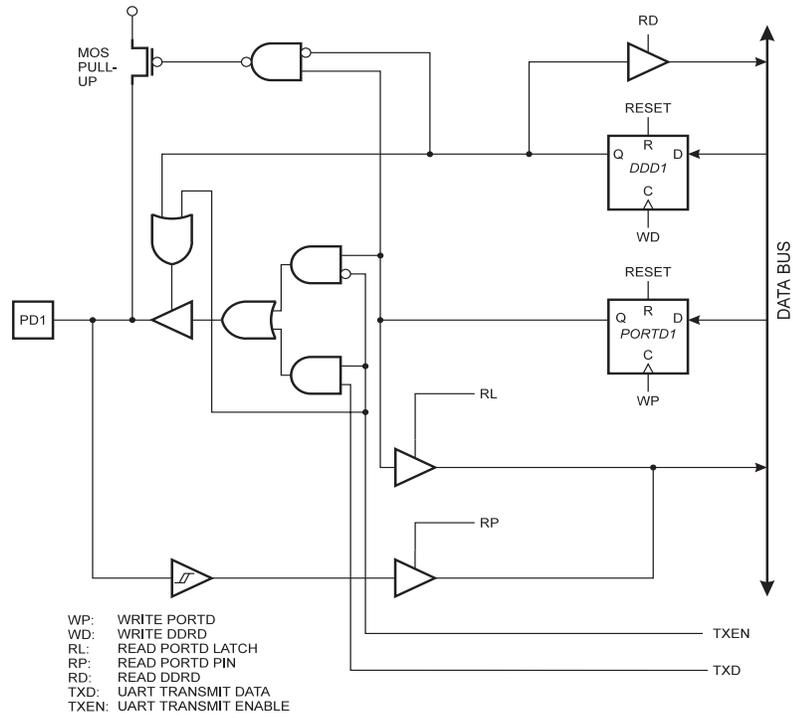


Figure 46. PORTD Schematic Diagram, Pin PD1

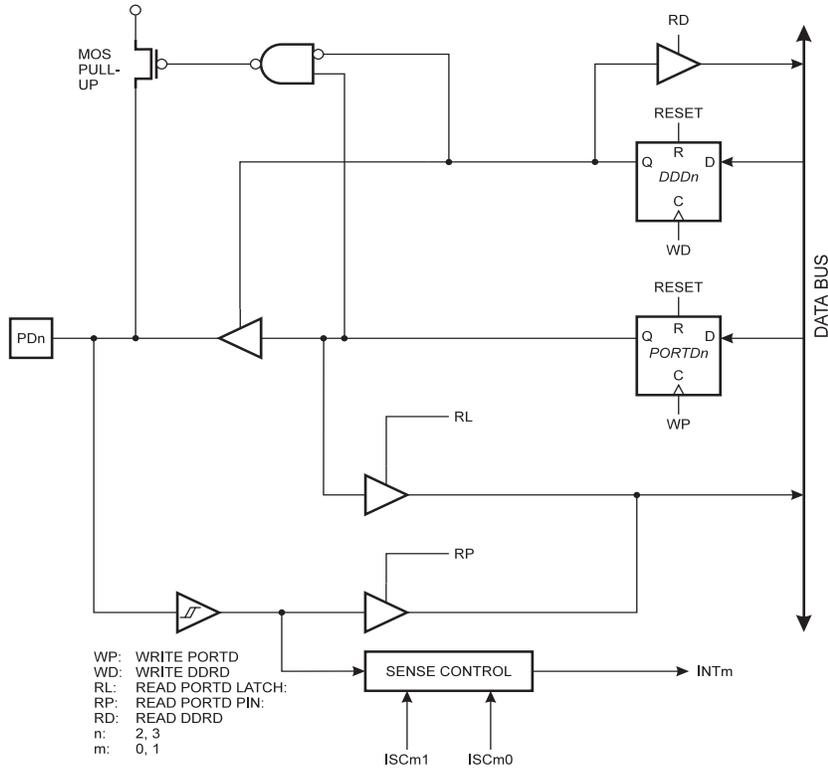
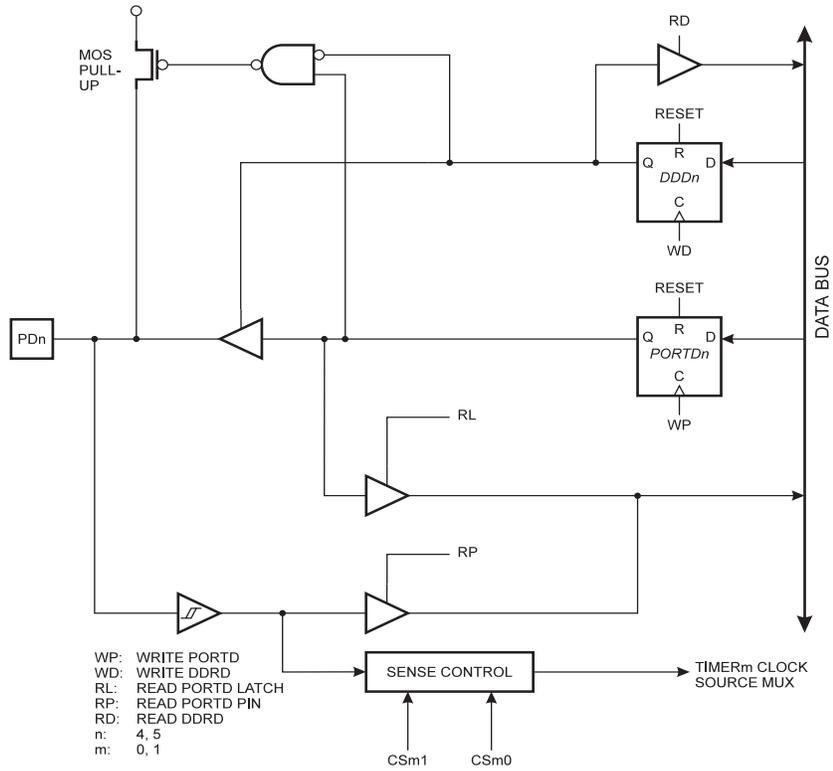
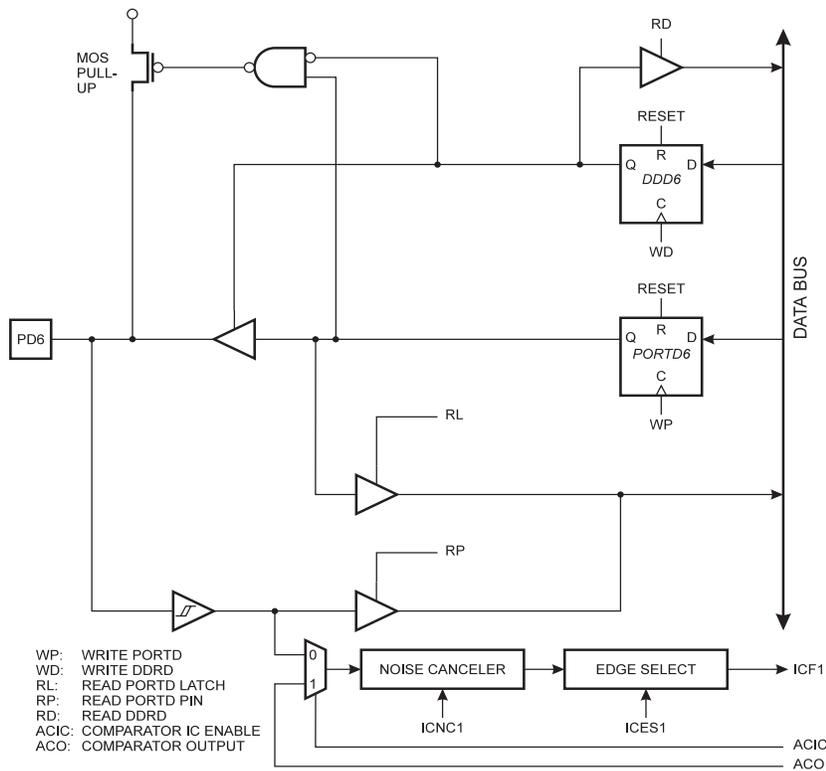


Figure 47. PORTD Schematic Diagram (Pins PD2 and PD3)



**Figure 48. PORTD Schematic Diagram (Pins PD4 and PD5)**



**Figure 49. PORTD Schematic Diagram (Pin PD6)**

## Memory Programming

### Program Memory Lock Bits

The AT90S2313 MCU provides two lock bits which can be left unprogrammed ('1') or can be programmed ('0') to obtain the additional features listed in Table 20.

**Table 20.** Lock Bit Protection Modes

| Program Lock Bits |     |     | Protection Type                              |
|-------------------|-----|-----|--|
| Mode              | LB1 | LB2 |  |
| 1                 | 1   | 1   | No program lock features                     |
| 2                 | 0   | 1   | Further programming of the Flash is disabled |
| 3                 | 0   | 0   | Same as mode 2, but verify is also disabled. |

Note: The Lock Bits can only be erased with the Chip Erase operation.

### Fuse Bits

The AT90S2313 has two fuse bits, SPIEN and FSTRT.

- When SPIEN is programmed ('0'), Serial Program Downloading is enabled. Default value is programmed ('0').
- When FSTRT is programmed ('0'), the short start-up time is selected. Default value is unprogrammed ('1'). Parts with this bit pre-programmed ('0') can be delivered on demand. See

These bits are not accessible in Serial Programming Mode and are not affected by a chip erase.

### Signature Bytes

All Atmel microcontrollers have a three-byte signature code which identifies the device. This code can be read in both serial and parallel mode. The three bytes reside in a separate address space, and for the AT90S2313 they are:

1. \$000: \$1E (indicates manufactured by Atmel)
2. \$001: \$91 (indicates 2 kB Flash memory)
3. \$002: \$01 (indicates 90S2313 device when \$001 is \$90)

### Programming the Flash and EEPROM

Atmel's AT90S2313 offers 2K bytes of in-system reprogrammable Flash Program memory and 128 bytes of EEPROM Data memory.

The AT90S2313 is normally shipped with the on-chip Flash Program and EEPROM Data memory arrays in the erased state (i.e. contents = \$FF) and ready to be programmed. This device supports a High-Voltage (12V) Parallel programming mode and a Low-Voltage Serial programming mode. The +12V is used for programming enable only, and no current of significance is drawn by this pin. The serial programming mode provides a convenient way to download the Program and Data into the AT90S2313 inside the user's system.

The Program and EEPROM memory arrays in the AT90S2313 are programmed byte-by-byte in either programming modes. For the EEPROM, an auto-erase cycle is provided with the self-timed programming operation in the serial programming mode.

## Parallel Programming

This section describes how to parallel program and verify Flash Program memory, EEPROM Data memory + Program Memory Lock bits and Fuse bits in the AT90S2313.

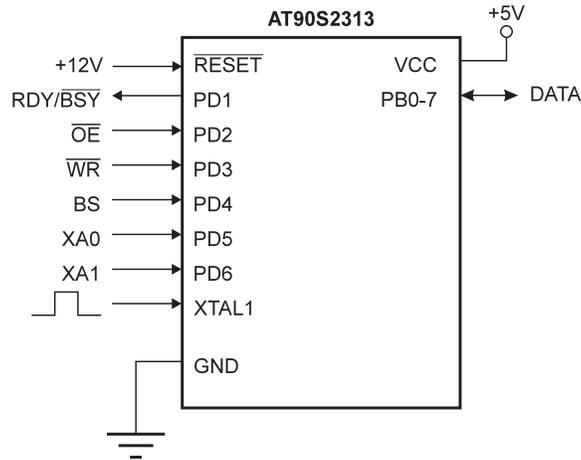


Figure 50. Parallel Programming

### SIGNAL NAMES

In this section, some pins of the AT90S2313 are referenced by signal names describing their functionality during parallel programming rather than their pin names. Pins not described in the following table are referenced by pin names.

Table 21. 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)  |
| BS                              | PD4      | I   | Byte Select   |
| XA0                             | PD5      | I   | XTAL Action Bit 0   |
| XA1                             | PD6      | I   | XTAL Action Bit 1   |

The XA1/XA0 bits determine the action taken when the XTAL1 pin is given a positive pulse. The bit settings are shown in the following table:

Table 22. XA1 and XA0 Coding

| XA1 | XA0 | Action when XTAL1 is Pulsed  |
|-----|-----|--|
| 0   | 0   | Load Flash or EEPROM Address (High or Low address byte for Flash determined by BS) |
| 0   | 1   | Load Data (High or Low data byte for Flash determined by BS)                       |
| 1   | 0   | Load Command   |
| 1   | 1   | No Action, Idle  |

When pulsing  $\overline{\text{WR}}$  or  $\overline{\text{OE}}$ , the command loaded determines the action on input or output. The command is a byte where the different bits are assigned functions as shown in the following table:

**Table 23.** Command Byte Bit Coding

| Bit# | Meaning when Set  |
|------|---|
| 7    | Chip Erase  |
| 6    | Write Fuse Bits. Located in the data byte at the following bit positions:<br>D5: SPIEN Fuse, D0: FSTRT Fuse (Note: Write '0' to program, '1' to erase)              |
| 5    | Write Lock Bits. Located in the data byte at the following bit positions:<br>D1: LB1, D0: LB2 (Note: write '0' to program)  |
| 4    | Write Flash or EEPROM (determined by bit 0)   |
| 3    | Read signature row  |
| 2    | Read Lock and Fuse Bits. Located in the data byte at the following bits positions:<br>D7: LB1, D6: LB2, D5: SPIEN Fuse, D0: FSTRT Fuse (Note: '0' means programmed) |
| 1    | Read from Flash or EEPROM (determined by bit 0)   |
| 0    | 0 : Flash Access, 1 : EEPROM Access   |

### ENTER PROGRAMMING MODE

The following algorithm puts the device in parallel programming mode:

1. Apply 4.5 - 5.5 V between VCC and GND.
2. Set **RESET** and BS pins to '0' and wait at least 100 ns.
3. Apply 12V to **RESET** and wait at least 100 ns before changing BS.

### CHIP ERASE

The chip erase will erase the Flash and EEPROM 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 chip is programmed.

#### *Load Command "Chip Erase"*

1. Set XA1, XA0 to '10'. This enables command loading.
2. Set BS to '0'.
3. Set PB(7:0) to '1000 0000'. This is the command for Chip erase.
4. Give XTAL1 a positive pulse. This loads the command, and starts the erase of the Flash and EEPROM arrays. After pulsing XTAL1, give **WR** a negative pulse to enable lock bit erase at the end of the erase cycle, then wait for at least 10 ms. Chip erase does not generate any activity on the RDY/BSY pin.

### PROGRAMMING THE FLASH

#### *Load Command "Program Flash"*

1. Set XA1, XA0 to '10'. This enables command loading.
2. Set BS to '0'
3. Set PB(7:0) to '0001 0000'. This is the command for Flash programming.
4. Give XTAL1 a positive pulse. This loads the command.

#### *Load Address Low byte*

1. Set XA1, XA0 to '00'. This enables address loading.
2. Set BS to '0'. This selects Low address.
3. Set PB(7:0) = Address Low byte (\$00 - \$FF)
4. Give XTAL1 a positive pulse. This loads the Address Low byte.

#### *Load Address High byte*

1. Set XA1, XA0 to '00'. This enables address loading.
2. Set BS to '1'. This selects High address.
3. Set PB(7:0) = Address High byte (\$00 - \$03)
4. Give XTAL1 a positive pulse. This loads the Address High byte.

*Load Data byte*

1. Set XA1, XA0 to '01'. This enables data loading.
2. Set PB(7:0) = Data Low byte (\$00 - \$FF)
3. Give XTAL1 a positive pulse. This loads the Data byte.

*Write Data Low byte*

1. Set BS to ('0').
2. Give  $\overline{WR}$  a negative pulse. This starts programming of the data byte. RDY/ $\overline{BSY}$  goes low.
3. Wait until RDY/ $\overline{BSY}$  goes high to program the next byte.

*Load Data byte*

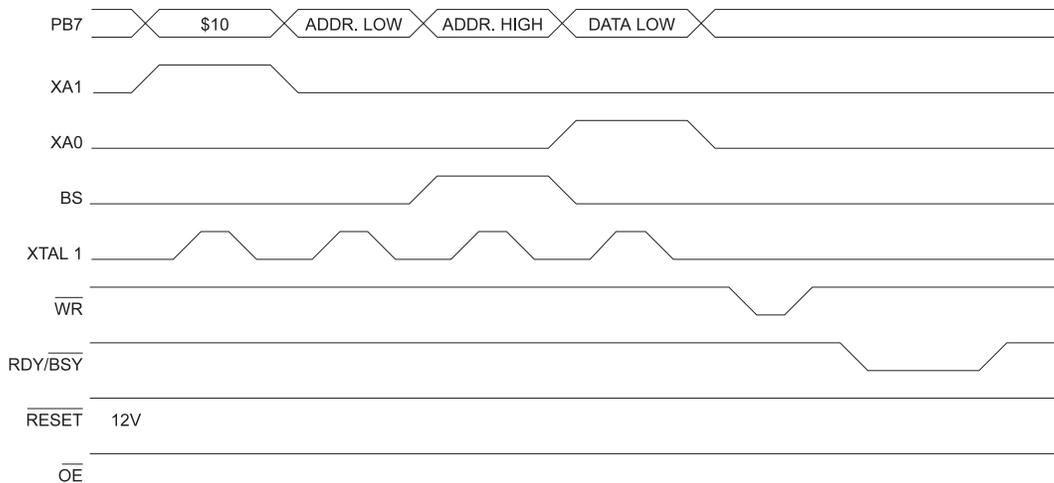
1. Set XA1, XA0 to '01'. This enables data loading.
2. Set PB(7:0) = Data High byte (\$00 - \$FF)
3. Give XTAL1 a positive pulse. This loads the Data byte.

*Write Data High byte*

1. Set BS to '1'.
2. Give  $\overline{WR}$  a negative pulse. This starts programming of the data byte. RDY /  $\overline{BSY}$  goes low.
3. Wait until RDY /  $\overline{BSY}$  goes high to program the next byte.

The loaded command and address are retained in the device during programming. To simplify programming, the following should be considered.

- The command for Flash programming needs only be loaded before programming of the first byte.
- Address High byte needs only be loaded before programming a new 256 word page in the Flash.



**Figure 51.** Programming Flash Low Byte

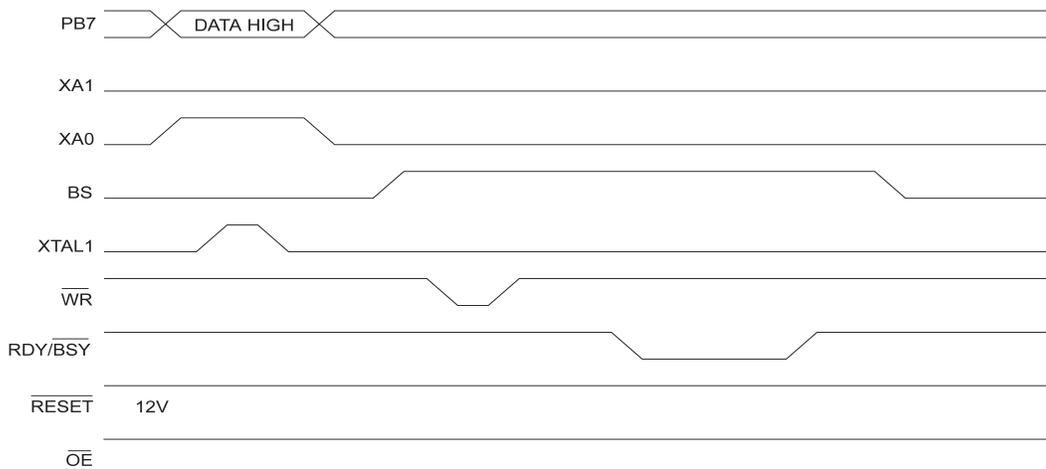


Figure 52. Programming Flash High Byte

**PROGRAMMING THE EEPROM**

The programming algorithm for the EEPROM data memory is as follows (refer to Flash Programming for details on Command, Address and Data loading):

1. Load Command '0001 0001'.
2. Load EEPROM Address (\$00 - \$7F)
3. Load EEPROM Data (\$00 - \$FF)
4. Give  $\overline{WR}$  a negative pulse and wait for  $RDY/\overline{BSY}$  to go high.

The Command needs only be loaded before programming the first byte.

**READING THE FLASH**

The algorithm for reading the Flash memory is as follows (refer to Flash Programming for details on Command, Address and Data loading):

1. Load Command '0000 0010'.
2. Load Low Address (\$00 - \$FF)
3. Load High Address (\$00 - \$03)
4. Set  $\overline{OE}$  to '0', and BS to '0'. The Low Data byte can now be read at PB(7:0)
5. Set BS to '1'. The High Data byte can now be read from PB(7:0)
6. Set  $\overline{OE}$  to '1'.

The Command needs only be loaded before reading the first byte.

**READING THE EEPROM**

The algorithm for reading the EEPROM memory is as follows (refer to Flash Programming for details on Command, Address and Data loading):

1. Load Command '0000 0011'.
2. Load EEPROM Address (\$00 - \$7F)
3. Set  $\overline{OE}$  to '0', and BS to '0'. The EEPROM Data byte can now be read at PB(7:0)
4. Set  $\overline{OE}$  to '1'.

The Command needs only be loaded before reading the first byte.



### PROGRAMMING THE FUSE BITS

The algorithm for programming the Fuse bit is as follows (refer to Flash Programming for details on Command, Address and Data loading):

1. Load Command '0100 0000'.
2. Load Data.  
Bit 5 = '0' programs the SPIEN Fuse bit. Bit 5 = '1' erases the SPIEN Fuse bit.  
Bit 0 = '0' programs the FSTRT fuse bit. Bit 5 = '1' erases the FSTRT fuse bit.
3. Give  $\overline{WR}$  a negative pulse and wait for RDY/ $\overline{BSY}$  to go high.  
IMPORTANT!  $\overline{WR}$  must be held down for at least 1 ms.

### PROGRAMMING THE LOCK BITS

The algorithm for programming the Lock bits is as follows (refer to Flash Programming for details on Command, Address and Data loading):

1. Load Command '0010 0000'.
2. Load Data.  
Bit 2 = '0' programs Lock Bit2  
Bit 1 = '0' programs Lock Bit1
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 a chip erase.

### READING THE FUSE AND LOCK BITS

The algorithm for reading the Fuse and Lock bits is as follows (refer to Flash Programming for details on Command, Address and Data loading):

1. Load Command '0000 0100'.
2. Set  $\overline{OE}$  to '0', and BS to '1'. The Status of Fuse and Lock bits can now be read at PB(7:0)  
Bit 7: Lock Bit1 ('0' means programmed)  
Bit 6: Lock Bit2 ('0' means programmed)  
Bit 5: SPIEN Fuse ('0' means programmed, '1' means erased)  
Bit 0: FSTRT Fuse ('0' means programmed, '1' means erased)
3. Set  $\overline{OE}$  to '1'.

Observe especially that BS needs to be set to '1'.

### READING THE SIGNATURE BYTES

The algorithm for reading the Signature Bytes bits is as follows (refer to Flash Programming for details on Command, Address and Data loading):

1. Load Command '0000 1000'.
2. Load Low address (\$00 - \$02)  
Set  $\overline{OE}$  to '0', and BS to '0'. The Selected Signature byte can now be read at PB(7:0)
3. Set  $\overline{OE}$  to '1'.

The command needs only be programmed before reading the first byte.

### Serial Downloading

Both the Program and Data memory arrays can be programmed using the serial SPI bus while **RESET** is pulled to GND. The serial interface consists of pins SCK, MOSI (input) and MISO (output). After **RESET** is set low, the Programming Enable instruction needs to be executed first before program/erase operations can be executed.

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 \$FF.

The Program and EEPROM memory arrays have separate address spaces, \$000 to \$7FF for Program Flash memory and \$000 to \$07F for EEPROM Data memory.

Either an external system clock is supplied at pin XTAL1 or a crystal needs to be connected across pins XTAL1 and XTAL2. The minimum low and high periods for the serial clock (SCK) input are defined as follows:

Low: > 1 XTAL1 clock cycle

High: > 4 XTAL1 clock cycles

#### **SERIAL PROGRAMMING ALGORITHM**

To program and verify the AT90S2313 in the serial programming mode, the following sequence is recommended (See four byte instruction formats in Table 24):

1. *Power-up sequence:*

Apply power between VCC and GND while **RESET** and SCK are set to '0'. (If the programmer can not guarantee that SCK is held low during power-up, **RESET** must be given a positive pulse after SCK has been set to '0'.) If a crystal is not connected across pins XTAL1 and XTAL2, apply a 0 to 20 MHz clock to the XTAL1 pin.

2. Wait for at least 20 ms and enable serial programming by sending the Programming Enable serial instruction to pin MOSI/PB5. Refer to the above section for minimum high and low periods for the serial clock input (SCK).

3. If a chip erase is performed (must be done to erase the Flash), wait 10ms, give **RESET** a positive pulse and start over again from Step 2.

4. The Flash or EEPROM array is programmed one byte at a time by supplying the address and data together with the appropriate Write instruction. An EEPROM memory location is first automatically erased before new data is written. The next byte can be written after 4 ms.

5. Any memory location can be verified by using the Read instruction which returns the content at the selected address at serial output MISO/PB6.

6. At the end of the programming session, **RESET** can be set high to commence normal operation.

7. *Power-off sequence (if needed):*

Set XTAL1 to '0' (if a crystal is not used).

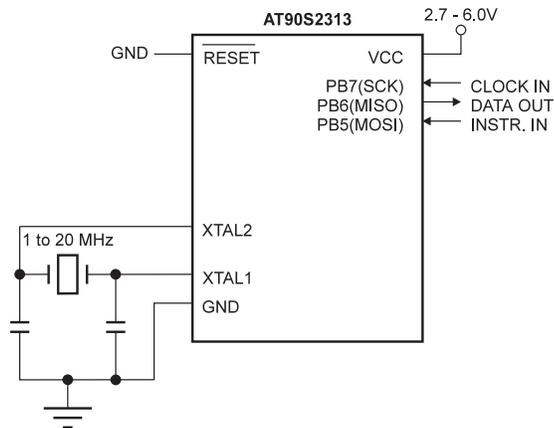
Set **RESET** to '1'.

Turn V<sub>CC</sub> power off..

**Table 24.** Serial Programming Instruction Set

| Instruction          | Instruction Format |           |           |           | Operation  |
|----------------------|--------------------|-----------|-----------|-----------|--|
|                      | Byte 1             | Byte 2    | Byte 3    | Byte4     |  |
| Programming Enable   | 1010 1100          | 0101 0011 | xxxx xxxx | xxxx xxxx | Enable Serial Programming after RESET goes low.                    |
| Chip Erase           | 1010 1100          | 100x xxxx | xxxx xxxx | xxxx xxxx | Chip erase both 2K & 128 byte memory arrays                        |
| Read Program Memory  | 0010 H000          | xxxx xxaa | bbbb bbbb | oooo oooo | Read H(high or low) data o from Program memory at word address a:b |
| Write Program Memory | 0100 H000          | xxxx xxaa | bbbb bbbb | iiii iiii | Write H(high or low) data i to Program memory at word address a:b  |
| Read EEPROM Memory   | 1010 0000          | xxxx xxxx | xbbb bbbb | oooo oooo | Read data o from EEPROM memory at address b                        |
| Write EEPROM Memory  | 1100 0000          | xxxx xxxx | xbbb bbbb | iiii iiii | Write data i to EEPROM memory at address b                         |
| Write Lock Bits      | 1010 1100          | 111x x21x | xxxx xxxx | xxxx xxxx | Write lock bits. Set bits 1,2='0' to program lock bits.            |
| Read Device Code     | 0011 0000          | xxxx xxxx | xxxx xxbb | oooo oooo | Read Device Code o from address b                                  |

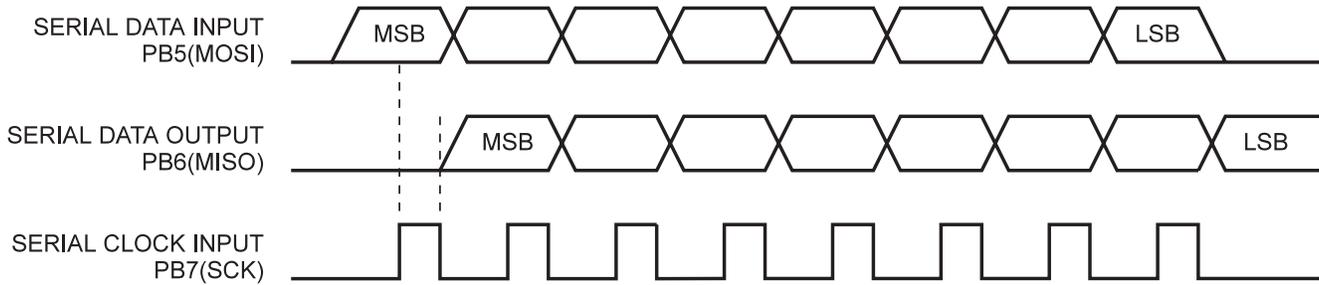
Notes: **a** = address high bits  
**b** = address low bits  
**H** = 0 - Low byte, 1 - High Byte  
**o** = data out  
**i** = data in  
**x** = don't care  
**1** = lock bit 1  
**2** = lock bit 2



**Figure 53.** Serial Programming and Verify

When *writing* serial data to the AT90S2313, data is clocked on the *rising* edge of CLK.  
 When *reading* data from the AT90S2313, data is clocked on the *falling* edge of CLK. See Figure 54 for an explanation.

**Programming Characteristics**



**Figure 54.** Serial Downloading Waveforms

**Absolute Maximum Ratings\***

|  |                 |
|--|-----------------|
| Operating Temperature .....                                    | -40°C to +105°C |
| Storage Temperature.....                                       | -65°C to +150°C |
| Voltage on any Pin except RESET<br>with respect to Ground..... | -1.0V to +7.0V  |
| Maximum Operating Voltage .....                                | 6.6V            |
| I/O Pin Maximum Current .....                                  | 40.0 mA         |
| Maximum Current VCC and GND.....                               | 140.0 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

$T_A = -40^\circ\text{C}$  to  $85^\circ\text{C}$ ,  $V_{CC} = 2.7\text{V}$  to  $6.0\text{V}$  (unless otherwise noted)

| Symbol     | Parameter   | Condition  | Min                | Typ | Max                | Units         |
|------------|---|--|--------------------|-----|--------------------|---------------|
| $V_{IL}$   | Input Low Voltage                                 |  | -0.5               |     | $0.2 V_{CC} - 0.1$ | V             |
| $V_{IH}$   | Input High Voltage                                | (Except XTAL1, RESET)  | $0.2 V_{CC} + 0.9$ |     | $V_{CC} + 0.5$     | V             |
| $V_{IH1}$  | Input High Voltage                                | (XTAL1, RESET)   | $0.7 V_{CC}$       |     | $V_{CC} + 0.5$     | V             |
| $V_{OL}$   | Output Low Voltage <sup>(1)</sup><br>(Ports B, D) | $I_{OL} = 20\text{ mA}$ , $V_{CC} = 5\text{V}$<br>$I_{OL} = 10\text{ mA}$ , $V_{CC} = 2.7\text{V}$ |                    |     | 0.5                | V             |
| $V_{OH}$   | Output High Voltage<br>(Ports B,D)                | $I_{HI} = 10\text{ mA}$ , $V_{CC} = 5\text{V}$<br>$I_{HI} = 5\text{ mA}$ , $V_{CC} = 2.7\text{V}$  | 4.5                |     |                    | V             |
| $I_{OH}$   | Output Source Current<br>(Ports B,D)              | $V_{CC} = 5\text{V}$<br>$V_{CC} = 2.7\text{V}$   |                    |     | 10<br>5            | mA            |
| $I_{OL}$   | Output Sink Current<br>(Port B,D)                 | $V_{CC} = 5\text{V}$<br>$V_{CC} = 2.7\text{V}$   |                    |     | 20<br>10           | mA            |
| RRST       | Reset Pull-Up Resistor                            |  | 100                |     | 500                | k $\Omega$    |
| $R_{I/O}$  | I/O Pin Pull-Up Resistor                          |  | 35                 |     | 120                | k $\Omega$    |
| $I_{CC}$   | Power Supply Current                              | Active Mode, 3V, 4MHz  |                    | 2.5 |                    | mA            |
|            |   | Idle Mode 3V, 4MHz   |                    | 800 |                    | $\mu\text{A}$ |
| $I_{CC}$   | Power Down Mode <sup>(2)</sup>                    | WDT enabled, 3V  |                    | 50  |                    | $\mu\text{A}$ |
|            |   | WDT disabled, 3V   |                    | <1  |                    | $\mu\text{A}$ |
| $V_{ACIO}$ | Analog Comparator Input Offset Voltage            | $V_{CC} = 5\text{V}$   |                    |     | 20                 | mV            |
| $I_{ACLK}$ | Analog Comparator Input Leakage Current           |  | 1                  | 5   | 10                 | nA            |
| $t_{ACPD}$ | Analog Comparator Propagation Delay               | $V_{CC} = 2.7\text{V}$   |                    | 750 |                    | ns            |
|            |   | $V_{CC} = 4.0\text{V}$   |                    | 500 |                    |               |

Notes: 1. Under steady state (non-transient) conditions,  $I_{OL}$  must be externally limited as follows:

Maximum  $I_{OL}$  per port pin: 20mA

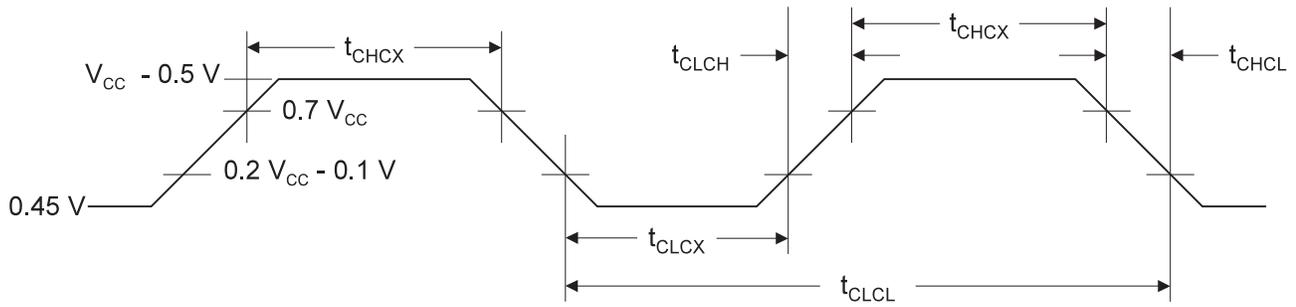
Maximum total  $I_{OL}$  for all output pins: 80mA

If  $I_{OL}$  exceeds the test condition,  $V_{OL}$  may exceed the related specification.

Pins are not guaranteed to sink current greater than the listed test conditions.

2. Minimum  $V_{CC}$  for Power Down is 2V.

### External Clock Drive Waveforms



### External Clock Drive

| Symbol       | Parameter            | $V_{CC} = 2.7V \text{ to } 6.0V$ |     | $V_{CC} = 4.0V \text{ to } 6.0V$ |      | Units |
|--------------|----------------------|----------------------------------|-----|----------------------------------|------|-------|
|              |                      | Min                              | Max | Min                              | Max  |       |
| $1/t_{CLCL}$ | Oscillator Frequency | 0                                | 4   | 0                                | 16   | MHz   |
| $t_{CLCL}$   | Clock Period         | 250                              |     | 62.5                             |      | ns    |
| $t_{CHCX}$   | High Time            | 40                               |     | 16.7                             |      | ns    |
| $t_{CLCX}$   | Low Time             | 40                               |     | 16.7                             |      | ns    |
| $t_{CLCH}$   | Rise Time            |                                  | 10  |                                  | 4.15 | ns    |
| $t_{CHCL}$   | Fall Time            |                                  | 10  |                                  | 4.15 | ns    |



## Ordering Information

| Ordering Code                | Package     | Operation Range               |
|------------------------------|-------------|-------------------------------|
| AT90S2313-PC<br>AT90S2313-SC | 20P3<br>20S | Commercial<br>(0°C to 70°C)   |
| AT90S2313-PI<br>AT90S2313-SI | 20P3<br>20S | Industrial<br>(-40°C to 85°C) |

| Package Type |  |
|--------------|--|
| <b>20P3</b>  | 20 Lead, 0.300" Wide, Plastic Dual In-Line Package (PDIP)    |
| <b>20S</b>   | 20 Lead, 0.300" Wide, Plastic Gull Wing Small Outline (SOIC) |

## AT90S2313 Register Summary

| Address     | Name     | Bit 7   | Bit 6                   | Bit 5  | Bit 4  | Bit 3  | Bit 2  | Bit 1  | Bit 0  | Page |
|-------------|----------|---|-------------------------|--------|--------|--------|--------|--------|--------|------|
| \$3F (\$5F) | SREG     | I   | T                       | H      | S      | V      | N      | Z      | C      | 3-21 |
| \$3E (\$5E) | Reserved |   |                         |        |        |        |        |        |        |      |
| \$3D (\$5D) | SPL      | SP7   | SP6                     | SP5    | SP4    | SP3    | SP2    | SP1    | SP0    | 3-22 |
| \$3C (\$5C) | Reserved |   |                         |        |        |        |        |        |        |      |
| \$3B (\$5B) | GIMSK    | INT1  | INT0                    | -      | -      | -      | -      | -      | -      | 3-27 |
| \$3A (\$5A) | GIFR     | INTF1   | INTF0                   |        |        |        |        |        |        | 3-27 |
| \$39 (\$59) | TIMSK    | TOIE1   | OCIE1A                  | -      | -      | TICIE1 | -      | TOIE0  | -      | 3-27 |
| \$38 (\$58) | TIFR     | TOV1  | OCF1A                   | -      | -      | ICF1   | -      | TOV0   | -      | 3-28 |
| \$37 (\$57) | Reserved |   |                         |        |        |        |        |        |        |      |
| \$36 (\$56) | Reserved |   |                         |        |        |        |        |        |        |      |
| \$35 (\$55) | MCUCR    | -   | -                       | SE     | SM     | ISC11  | ISC10  | ISC01  | ISC00  | 3-29 |
| \$34 (\$54) | Reserved |   |                         |        |        |        |        |        |        |      |
| \$33 (\$53) | TCCR0    | -   | -                       | -      | -      | -      | CS02   | CS01   | CS00   | 3-32 |
| \$32 (\$52) | TCNT0    | Timer/Counter0 (8 Bit)                            |                         |        |        |        |        |        |        | 3-33 |
| \$31 (\$51) | Reserved |   |                         |        |        |        |        |        |        |      |
| \$30 (\$50) | Reserved |   |                         |        |        |        |        |        |        |      |
| \$2F (\$4F) | TCCR1A   | COM1A1  | COM1A0                  | -      | -      | -      | -      | PWM11  | PWM10  | 3-35 |
| \$2E (\$4E) | TCCR1B   | ICNC1   | ICES1                   | -      | -      | CTC1   | CS12   | CS11   | CS10   | 3-35 |
| \$2D (\$4D) | TCNT1H   | Timer/Counter1 - Counter Register High Byte       |                         |        |        |        |        |        |        | 3-36 |
| \$2C (\$4C) | TCNT1L   | Timer/Counter1 - Counter Register Low Byte        |                         |        |        |        |        |        |        | 3-36 |
| \$2B (\$4B) | OCR1AH   | Timer/Counter1 - Compare Register High Byte       |                         |        |        |        |        |        |        | 3-37 |
| \$2A (\$4A) | OCR1AL   | Timer/Counter1 - Compare Register Low Byte        |                         |        |        |        |        |        |        | 3-37 |
| \$29 (\$49) | Reserved |   |                         |        |        |        |        |        |        |      |
| \$28 (\$48) | Reserved |   |                         |        |        |        |        |        |        |      |
| \$27 (\$47) | Reserved |   |                         |        |        |        |        |        |        |      |
| \$26 (\$46) | Reserved |   |                         |        |        |        |        |        |        |      |
| \$25 (\$45) | ICR1H    | Timer/Counter1 - Input Capture Register High Byte |                         |        |        |        |        |        |        | 3-37 |
| \$24 (\$44) | ICR1L    | Timer/Counter1 - Input Capture Register Low Byte  |                         |        |        |        |        |        |        | 3-37 |
| \$23 (\$43) | Reserved |   |                         |        |        |        |        |        |        |      |
| \$22 (\$42) | Reserved |   |                         |        |        |        |        |        |        |      |
| \$21 (\$41) | WDTCR    | -   | -                       | -      | WDTOE  | WDE    | WDP2   | WDP1   | WDP0   | 3-39 |
| \$20 (\$40) | Reserved |   |                         |        |        |        |        |        |        |      |
| \$1F (\$3F) | Reserved |   |                         |        |        |        |        |        |        |      |
| \$1E (\$3E) | EEAR     | -   | EEPROM Address Register |        |        |        |        |        |        | 3-40 |
| \$1D (\$3D) | EEDR     | EEPROM Data register                              |                         |        |        |        |        |        |        | 3-41 |
| \$1C (\$3C) | EECR     | -   | -                       | -      | -      | -      | EEMWE  | EEWE   | EERE   | 3-41 |
| \$1B (\$3B) | Reserved |   |                         |        |        |        |        |        |        |      |
| \$1A (\$3A) | Reserved |   |                         |        |        |        |        |        |        |      |
| \$19 (\$39) | Reserved |   |                         |        |        |        |        |        |        |      |
| \$18 (\$38) | PORTB    | PORTB7  | PORTB6                  | PORTB5 | PORTB4 | PORTB3 | PORTB2 | PORTB1 | PORTB0 | 3-50 |
| \$17 (\$37) | DDRB     | DDB7  | DDB6                    | DDB5   | DDB4   | DDB3   | DDB2   | DDB1   | DDB0   | 3-50 |
| \$16 (\$36) | PINB     | PINB7   | PINB6                   | PINB5  | PINB4  | PINB3  | PINB2  | PINB1  | PINB0  | 3-50 |
| \$15 (\$35) | Reserved |   |                         |        |        |        |        |        |        |      |
| \$14 (\$34) | Reserved |   |                         |        |        |        |        |        |        |      |
| \$13 (\$33) | Reserved |   |                         |        |        |        |        |        |        |      |
| \$12 (\$32) | PORTD    | -   | PORTD6                  | PORTD5 | PORTD4 | PORTD3 | PORTD2 | PORTD1 | PORTD0 | 3-55 |
| \$11 (\$31) | DDRD     | -   | DDD6                    | DDD5   | DDD4   | DDD3   | DDD2   | DDD1   | DDD0   | 3-55 |
| \$10 (\$30) | PIND     | -   | PIND6                   | PIND5  | PIND4  | PIND3  | PIND2  | PIND1  | PIND0  | 3-55 |
| \$0F (\$2F) | Reserved |   |                         |        |        |        |        |        |        |      |
| \$0E (\$2E) | Reserved |   |                         |        |        |        |        |        |        |      |
| \$0D (\$2D) | Reserved |   |                         |        |        |        |        |        |        |      |
| \$0C (\$2C) | UDR      | UART I/O Data Register                            |                         |        |        |        |        |        |        | 3-44 |
| \$0B (\$2B) | USR      | RXC   | TXC                     | UDRE   | FE     | OR     | -      | -      | -      | 3-44 |
| \$0A (\$2A) | UCR      | RXCIE   | TXCIE                   | UDRIE  | RXEN   | TXEN   | CHR9   | RXB8   | TXB8   | 3-45 |
| \$09 (\$29) | UBRR     | UART Baud Rate Register                           |                         |        |        |        |        |        |        | 3-47 |
| \$08 (\$28) | ACSR     | ACD   | -                       | ACO    | ACI    | ACIE   | ACIC   | ACIS1  | ACIS0  | 3-48 |
| ...         | Reserved |   |                         |        |        |        |        |        |        |      |
| \$00 (\$20) | Reserved |   |                         |        |        |        |        |        |        |      |



## AT90S2313 Instruction Set Summary

| Mnemonics                                | Operands | Description                            | Operation   | Flags      | #Clocks |
|--|----------|--|---|------------|---------|
| <b>ARITHMETIC AND LOGIC INSTRUCTIONS</b> |          |  |   |            |         |
| ADD                                      | Rd, Rr   | Add two Registers                      | $Rd \leftarrow Rd + Rr$                               | Z,C,N,V,H  | 1       |
| ADC                                      | Rd, Rr   | Add with Carry two Registers           | $Rd \leftarrow Rd + Rr + C$                           | Z,C,N,V,H  | 1       |
| ADIW                                     | Rdl,K    | Add Immediate to Word                  | $Rdh:Rdl \leftarrow Rdh:Rdl + K$                      | Z,C,N,V,S  | 2       |
| SUB                                      | Rd, Rr   | Subtract two Registers                 | $Rd \leftarrow Rd - Rr$                               | Z,C,N,V,H  | 1       |
| SUBI                                     | Rd, K    | Subtract Constant from Register        | $Rd \leftarrow Rd - K$                                | Z,C,N,V,H  | 1       |
| SBIW                                     | Rdl,K    | Subtract Immediate from Word           | $Rdh:Rdl \leftarrow Rdh:Rdl - K$                      | Z,C,N,V,S  | 2       |
| SBC                                      | Rd, Rr   | Subtract with Carry two Registers      | $Rd \leftarrow Rd - Rr - C$                           | Z,C,N,V,H  | 1       |
| SBCI                                     | Rd, K    | Subtract with Carry Constant from Reg. | $Rd \leftarrow Rd - K - C$                            | Z,C,N,V,H  | 1       |
| AND                                      | Rd, Rr   | Logical AND Registers                  | $Rd \leftarrow Rd \cdot Rr$                           | Z,N,V      | 1       |
| ANDI                                     | Rd, K    | Logical AND Register and Constant      | $Rd \leftarrow Rd \cdot K$                            | Z,N,V      | 1       |
| OR                                       | Rd, Rr   | Logical OR Registers                   | $Rd \leftarrow Rd \vee Rr$                            | Z,N,V      | 1       |
| ORI                                      | Rd, K    | Logical OR Register and Constant       | $Rd \leftarrow Rd \vee K$                             | Z,N,V      | 1       |
| EOR                                      | Rd, Rr   | Exclusive OR Registers                 | $Rd \leftarrow Rd \oplus Rr$                          | Z,N,V      | 1       |
| COM                                      | Rd       | One's Complement                       | $Rd \leftarrow \$FF - Rd$                             | Z,C,N,V    | 1       |
| NEG                                      | Rd       | Two's Complement                       | $Rd \leftarrow \$00 - Rd$                             | Z,C,N,V,H  | 1       |
| SBR                                      | Rd,K     | Set Bit(s) in Register                 | $Rd \leftarrow Rd \vee K$                             | Z,N,V      | 1       |
| CBR                                      | Rd,K     | Clear Bit(s) in Register               | $Rd \leftarrow Rd \cdot (\$FF - K)$                   | Z,N,V      | 1       |
| INC                                      | Rd       | Increment                              | $Rd \leftarrow Rd + 1$                                | Z,N,V      | 1       |
| DEC                                      | Rd       | Decrement                              | $Rd \leftarrow Rd - 1$                                | Z,N,V      | 1       |
| TST                                      | Rd       | Test for Zero or Minus                 | $Rd \leftarrow Rd \cdot Rd$                           | Z,N,V      | 1       |
| CLR                                      | Rd       | Clear Register                         | $Rd \leftarrow Rd \oplus Rd$                          | Z,N,V      | 1       |
| SER                                      | Rd       | Set Register                           | $Rd \leftarrow \$FF$                                  | None       | 1       |
| <b>BRANCH INSTRUCTIONS</b>               |          |  |   |            |         |
| RJMP                                     | k        | Relative Jump                          | $PC \leftarrow PC + k + 1$                            | None       | 2       |
| IJMP                                     |          | Indirect Jump to (Z)                   | $PC \leftarrow Z$                                     | None       | 2       |
| RCALL                                    | k        | Relative Subroutine Call               | $PC \leftarrow PC + k + 1$                            | None       | 3       |
| ICALL                                    |          | Indirect Call to (Z)                   | $PC \leftarrow Z$                                     | None       | 3       |
| RET                                      |          | Subroutine Return                      | $PC \leftarrow STACK$                                 | None       | 4       |
| RETI                                     |          | Interrupt Return                       | $PC \leftarrow STACK$                                 | I          | 4       |
| CPSE                                     | Rd,Rr    | Compare, Skip if Equal                 | if (Rd = Rr) $PC \leftarrow PC + 2$ or 3              | None       | 1 / 2   |
| 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) $PC \leftarrow PC + 2$ or 3              | None       | 1 / 2   |
| SBR                                      | Rr, b    | Skip if Bit in Register is Set         | if (Rr(b)=1) $PC \leftarrow PC + 2$ or 3              | None       | 1 / 2   |
| SBIC                                     | P, b     | Skip if Bit in I/O Register Cleared    | if (P(b)=0) $PC \leftarrow PC + 2$ or 3               | None       | 1 / 2   |
| SBIS                                     | P, b     | Skip if Bit in I/O Register is Set     | if (P(b)=1) $PC \leftarrow PC + 2$ or 3               | None       | 1 / 2   |
| BRBS                                     | s, k     | Branch if Status Flag Set              | if (SREG(s) = 1) then $PC \leftarrow PC + k + 1$      | None       | 1 / 2   |
| BRBC                                     | s, k     | Branch if Status Flag Cleared          | if (SREG(s) = 0) then $PC \leftarrow PC + k + 1$      | None       | 1 / 2   |
| BREQ                                     | k        | Branch if Equal                        | if (Z = 1) then $PC \leftarrow PC + k + 1$            | None       | 1 / 2   |
| BRNE                                     | k        | Branch if Not Equal                    | if (Z = 0) then $PC \leftarrow PC + k + 1$            | None       | 1 / 2   |
| BRCS                                     | k        | Branch if Carry Set                    | if (C = 1) then $PC \leftarrow PC + k + 1$            | None       | 1 / 2   |
| BRCC                                     | k        | Branch if Carry Cleared                | if (C = 0) then $PC \leftarrow PC + k + 1$            | None       | 1 / 2   |
| BRSH                                     | k        | Branch if Same or Higher               | if (C = 0) then $PC \leftarrow PC + k + 1$            | None       | 1 / 2   |
| BRLO                                     | k        | Branch if Lower                        | if (C = 1) then $PC \leftarrow PC + k + 1$            | None       | 1 / 2   |
| BRMI                                     | k        | Branch if Minus                        | if (N = 1) then $PC \leftarrow PC + k + 1$            | None       | 1 / 2   |
| BRPL                                     | k        | Branch if Plus                         | if (N = 0) then $PC \leftarrow PC + k + 1$            | None       | 1 / 2   |
| BRGE                                     | k        | Branch if Greater or Equal, Signed     | if (N $\oplus$ V = 0) then $PC \leftarrow PC + k + 1$ | None       | 1 / 2   |
| BRLT                                     | k        | Branch if Less Than Zero, Signed       | if (N $\oplus$ V = 1) then $PC \leftarrow PC + k + 1$ | None       | 1 / 2   |
| BRHS                                     | k        | Branch if Half Carry Flag Set          | if (H = 1) then $PC \leftarrow PC + k + 1$            | None       | 1 / 2   |
| BRHC                                     | k        | Branch if Half Carry Flag Cleared      | if (H = 0) then $PC \leftarrow PC + k + 1$            | None       | 1 / 2   |
| BRTS                                     | k        | Branch if T Flag Set                   | if (T = 1) then $PC \leftarrow PC + k + 1$            | None       | 1 / 2   |
| BRTC                                     | k        | Branch if T Flag Cleared               | if (T = 0) then $PC \leftarrow PC + k + 1$            | None       | 1 / 2   |
| BRVS                                     | k        | Branch if Overflow Flag is Set         | if (V = 1) then $PC \leftarrow PC + k + 1$            | None       | 1 / 2   |
| BRVC                                     | k        | Branch if Overflow Flag is Cleared     | if (V = 0) then $PC \leftarrow PC + k + 1$            | None       | 1 / 2   |
| BRIE                                     | k        | Branch if Interrupt Enabled            | if (I = 1) then $PC \leftarrow PC + k + 1$            | None       | 1 / 2   |
| BRID                                     | k        | Branch if Interrupt Disabled           | if (I = 0) then $PC \leftarrow PC + k + 1$            | None       | 1 / 2   |

(continued)

| Mnemonics                            | Operands | Description                      | Operation  | Flags      | #Clocks |
|--------------------------------------|----------|----------------------------------|--|------------|---------|
| <b>DATA TRANSFER INSTRUCTIONS</b>    |          |                                  |  |            |         |
| MOV                                  | Rd, Rr   | Move Between Registers           | $Rd \leftarrow Rr$   | None       | 1       |
| LDI                                  | Rd, K    | Load Immediate                   | $Rd \leftarrow K$  | None       | 1       |
| LD                                   | Rd, X    | Load Indirect                    | $Rd \leftarrow (X)$  | None       | 2       |
| LD                                   | Rd, X+   | Load Indirect and Post-Inc.      | $Rd \leftarrow (X), X \leftarrow X + 1$                            | None       | 2       |
| LD                                   | Rd, -X   | Load Indirect and Pre-Dec.       | $X \leftarrow X - 1, Rd \leftarrow (X)$                            | None       | 2       |
| LD                                   | Rd, Y    | Load Indirect                    | $Rd \leftarrow (Y)$  | None       | 2       |
| LD                                   | Rd, Y+   | Load Indirect and Post-Inc.      | $Rd \leftarrow (Y), Y \leftarrow Y + 1$                            | None       | 2       |
| LD                                   | Rd, -Y   | Load Indirect and Pre-Dec.       | $Y \leftarrow Y - 1, Rd \leftarrow (Y)$                            | None       | 2       |
| LDD                                  | Rd, Y+q  | Load Indirect with Displacement  | $Rd \leftarrow (Y + q)$  | None       | 2       |
| LD                                   | Rd, Z    | Load Indirect                    | $Rd \leftarrow (Z)$  | None       | 2       |
| LD                                   | Rd, Z+   | Load Indirect and Post-Inc.      | $Rd \leftarrow (Z), Z \leftarrow Z + 1$                            | None       | 2       |
| LD                                   | Rd, -Z   | Load Indirect and Pre-Dec.       | $Z \leftarrow Z - 1, Rd \leftarrow (Z)$                            | None       | 2       |
| LDD                                  | Rd, Z+q  | Load Indirect with Displacement  | $Rd \leftarrow (Z + q)$  | None       | 2       |
| LDS                                  | Rd, k    | Load Direct from SRAM            | $Rd \leftarrow (k)$  | None       | 3       |
| ST                                   | X, Rr    | Store Indirect                   | $(X) \leftarrow Rr$  | None       | 2       |
| ST                                   | X+, Rr   | Store Indirect and Post-Inc.     | $(X) \leftarrow Rr, X \leftarrow X + 1$                            | None       | 2       |
| ST                                   | -X, Rr   | Store Indirect and Pre-Dec.      | $X \leftarrow X - 1, (X) \leftarrow Rr$                            | None       | 2       |
| ST                                   | Y, Rr    | Store Indirect                   | $(Y) \leftarrow Rr$  | None       | 2       |
| ST                                   | Y+, Rr   | Store Indirect and Post-Inc.     | $(Y) \leftarrow Rr, Y \leftarrow Y + 1$                            | None       | 2       |
| ST                                   | -Y, Rr   | Store Indirect and Pre-Dec.      | $Y \leftarrow Y - 1, (Y) \leftarrow Rr$                            | None       | 2       |
| STD                                  | Y+q, Rr  | Store Indirect with Displacement | $(Y + q) \leftarrow Rr$  | None       | 2       |
| ST                                   | Z, Rr    | Store Indirect                   | $(Z) \leftarrow Rr$  | None       | 2       |
| ST                                   | Z+, Rr   | Store Indirect and Post-Inc.     | $(Z) \leftarrow Rr, Z \leftarrow Z + 1$                            | None       | 2       |
| ST                                   | -Z, Rr   | Store Indirect and Pre-Dec.      | $Z \leftarrow Z - 1, (Z) \leftarrow Rr$                            | None       | 2       |
| STD                                  | Z+q, Rr  | Store Indirect with Displacement | $(Z + q) \leftarrow Rr$  | None       | 2       |
| STS                                  | k, Rr    | Store Direct to SRAM             | $(k) \leftarrow Rr$  | None       | 3       |
| LPM                                  |          | Load Program Memory              | $R0 \leftarrow (Z)$  | None       | 3       |
| IN                                   | Rd, P    | In Port                          | $Rd \leftarrow P$  | None       | 1       |
| OUT                                  | P, Rr    | Out Port                         | $P \leftarrow Rr$  | None       | 1       |
| PUSH                                 | Rr       | Push Register on Stack           | $STACK \leftarrow Rr$  | None       | 2       |
| POP                                  | Rd       | Pop Register from Stack          | $Rd \leftarrow STACK$  | None       | 2       |
| <b>BIT AND BIT-TEST INSTRUCTIONS</b> |          |                                  |  |            |         |
| SBI                                  | P, b     | Set Bit in I/O Register          | $I/O(P, b) \leftarrow 1$   | None       | 2       |
| CBI                                  | P, b     | Clear Bit in I/O Register        | $I/O(P, b) \leftarrow 0$   | None       | 2       |
| LSL                                  | Rd       | Logical Shift Left               | $Rd(n+1) \leftarrow Rd(n), Rd(0) \leftarrow 0$                     | Z, C, N, V | 1       |
| LSR                                  | Rd       | Logical Shift Right              | $Rd(n) \leftarrow Rd(n+1), Rd(7) \leftarrow 0$                     | Z, C, N, V | 1       |
| ROL                                  | Rd       | Rotate Left Through Carry        | $Rd(0) \leftarrow C, Rd(n+1) \leftarrow Rd(n), C \leftarrow Rd(7)$ | Z, C, N, V | 1       |
| ROR                                  | Rd       | Rotate Right Through Carry       | $Rd(7) \leftarrow C, Rd(n) \leftarrow Rd(n+1), C \leftarrow Rd(0)$ | Z, C, N, V | 1       |
| ASR                                  | Rd       | Arithmetic Shift Right           | $Rd(n) \leftarrow Rd(n+1), n=0..6$                                 | Z, C, N, V | 1       |
| SWAP                                 | Rd       | Swap Nibbles                     | $Rd(3..0) \leftarrow Rd(7..4), Rd(7..4) \leftarrow Rd(3..0)$       | None       | 1       |
| BSET                                 | s        | Flag Set                         | $SREG(s) \leftarrow 1$   | SREG(s)    | 1       |
| BCLR                                 | s        | Flag Clear                       | $SREG(s) \leftarrow 0$   | SREG(s)    | 1       |
| BST                                  | Rr, b    | Bit Store from Register to T     | $T \leftarrow Rr(b)$   | T          | 1       |
| BLD                                  | Rd, b    | Bit load from T to Register      | $Rd(b) \leftarrow T$   | None       | 1       |
| SEC                                  |          | Set Carry                        | $C \leftarrow 1$   | C          | 1       |
| CLC                                  |          | Clear Carry                      | $C \leftarrow 0$   | C          | 1       |
| SEN                                  |          | Set Negative Flag                | $N \leftarrow 1$   | N          | 1       |
| CLN                                  |          | Clear Negative Flag              | $N \leftarrow 0$   | N          | 1       |
| SEZ                                  |          | Set Zero Flag                    | $Z \leftarrow 1$   | Z          | 1       |
| CLZ                                  |          | Clear Zero Flag                  | $Z \leftarrow 0$   | Z          | 1       |
| SEI                                  |          | Global Interrupt Enable          | $I \leftarrow 1$   | I          | 1       |
| CLI                                  |          | Global Interrupt Disable         | $I \leftarrow 0$   | I          | 1       |
| SES                                  |          | Set Signed Test Flag             | $S \leftarrow 1$   | S          | 1       |
| CLS                                  |          | Clear Signed Test Flag           | $S \leftarrow 0$   | S          | 1       |
| SEV                                  |          | Set Twos Complement Overflow     | $V \leftarrow 1$   | V          | 1       |
| CLV                                  |          | Clear Twos Complement Overflow   | $V \leftarrow 0$   | V          | 1       |
| SET                                  |          | Set T in SREG                    | $T \leftarrow 1$   | T          | 1       |
| CLT                                  |          | Clear T in SREG                  | $T \leftarrow 0$   | T          | 1       |
| SEH                                  |          | Set Half Carry Flag in SREG      | $H \leftarrow 1$   | H          | 1       |
| CLH                                  |          | Clear Half Carry Flag in SREG    | $H \leftarrow 0$   | H          | 1       |
| NOP                                  |          | No Operation                     |  | None       | 1       |
| SLEEP                                |          | Sleep                            | (see specific descr. for Sleep function)                           | None       | 3       |
| WDR                                  |          | Watchdog Reset                   | (see specific descr. for WDR/timer)                                | None       | 1       |