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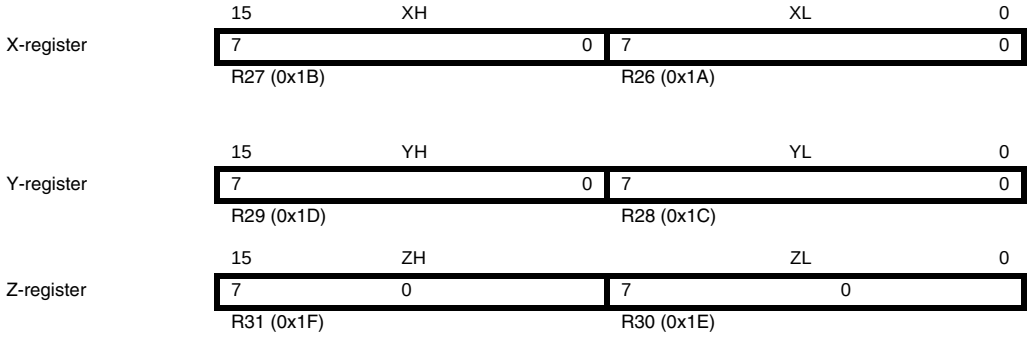
Applications of "Embedded - Microcontrollers"

Details	
Product Status	Obsolete
Core Processor	AVR
Core Size	8-Bit
Speed	10MHz
Connectivity	I²C, SPI, UART/USART
Peripherals	Brown-out Detect/Reset, POR, PWM, WDT
Number of I/O	23
Program Memory Size	8KB (4K x 16)
Program Memory Type	FLASH
EEPROM Size	512 x 8
RAM Size	1K x 8
Voltage - Supply (Vcc/Vdd)	1.8V ~ 5.5V
Data Converters	A/D 8x10b
Oscillator Type	Internal
Operating Temperature	-40°C ~ 85°C (TA)
Mounting Type	Surface Mount
Package / Case	32-TQFP
Supplier Device Package	32-TQFP (7x7)
Purchase URL	https://www.e-xfl.com/product-detail/microchip-technology/atmega88v-10aj

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

The registers R26..R31 have some added functions to their general purpose usage. These registers are 16-bit address pointers for indirect addressing of the data space. The three indirect address registers X, Y, and Z are defined as described in Figure 4-3.

Figure 4-3. The X-, Y-, and Z-registers



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

4.6 Stack Pointer

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

The Stack Pointer points to the data SRAM Stack area where the Subroutine and Interrupt Stacks are located. This Stack space in the data SRAM must be defined by the program before any subroutine calls are executed or interrupts are enabled. The Stack Pointer must be set to point above 0x0100, preferably RAMEND. The Stack Pointer is decremented by one when data is pushed onto the Stack with the PUSH instruction, and it is decremented by two when the return address is pushed onto the Stack with subroutine call or interrupt. The Stack Pointer is incremented by one when data is popped from the Stack with the POP instruction, and it is incremented by two when data is popped from the Stack with return from subroutine RET or return from interrupt RETI.

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

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

8.0.5 Brown-out Detection

ATmega48/88/168 has an On-chip Brown-out Detection (BOD) circuit for monitoring the V_{CC} level during operation by comparing it to a fixed trigger level. The trigger level for the BOD can be selected by the BODLEVEL Fuses. The trigger level has a hysteresis to ensure spike free Brown-out Detection. The hysteresis on the detection level should be interpreted as $V_{BOT+} = V_{BOT} + V_{HYST}/2$ and $V_{BOT-} = V_{BOT} - V_{HYST}/2$.

Table 8-2. BODLEVEL Fuse Coding[1]

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

Notes:
1. V_{BOT} may be below nominal minimum operating voltage for some devices. For devices where this is the case, the device is tested down to $V_{CC} = V_{BOT}$ during the production test. This guarantees that a Brown-Out Reset will occur before V_{CC} drops to a voltage where correct operation of the microcontroller is no longer guaranteed. The test is performed using BODLEVEL = 110 and BODLEVEL = 101 for ATmega48V/88V/168V, and BODLEVEL = 101 and BODLEVEL = 101 for ATmega48/88/168.
2. Min/Max values applicable for ATmega48.

Table 8-3. Brown-out Characteristics

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

When the BOD is enabled, and V_{CC} decreases to a value below the trigger level (V_{BOT-} in Figure 8-5), the Brown-out Reset is immediately activated. When V_{CC} increases above the trigger level (V_{BOT+} in Figure 8-5), the delay counter starts the MCU after the Time-out period t_{TOUT} has expired.

The BOD circuit will only detect a drop in V_{CC} if the voltage stays below the trigger level for longer than t_{BOD} given in Table 8-1.

Table 9-1. Reset and Interrupt Vectors in ATmega48 (Continued)

Vector No.	Program Address	Source	Interrupt Definition
24	0x017	ANALOG COMP	Analog Comparator
25	0x018	TWI	2-wire Serial Interface
26	0x019	SPM READY	Store Program Memory Ready

The most typical and general program setup for the Reset and Interrupt Vector Addresses in ATmega48 is:

```
Address  Labels Code                 Comments
0x000           rjmp   RESET          ; Reset Handler
0x001           rjmp   EXT_INT0       ; IRQ0 Handler
0x002           rjmp   EXT_INT1       ; IRQ1 Handler
0x003           rjmp   PCINT0         ; PCINT0 Handler
0x004           rjmp   PCINT1         ; PCINT1 Handler
0x005           rjmp   PCINT2         ; PCINT2 Handler
0x006           rjmp   WDT            ; Watchdog Timer Handler
0x007           rjmp   TIM2_COMPA     ; Timer2 Compare A Handler
0x008           rjmp   TIM2_COMPB     ; Timer2 Compare B Handler
0x009           rjmp   TIM2_OVF       ; Timer2 Overflow Handler
0x00A           rjmp   TIM1_CAPT      ; Timer1 Capture Handler
0x00B           rjmp   TIM1_COMPA     ; Timer1 Compare A Handler
0x00C           rjmp   TIM1_COMPB     ; Timer1 Compare B Handler
0x00D           rjmp   TIM1_OVF       ; Timer1 Overflow Handler
0x00E           rjmp   TIM0_COMPA     ; Timer0 Compare A Handler
0x00F           rjmp   TIM0_COMPB     ; Timer0 Compare B Handler
0x010           rjmp   TIM0_OVF       ; Timer0 Overflow Handler
0x011           rjmp   SPI_STC        ; SPI Transfer Complete Handler
0x012           rjmp   USART_RXC      ; USART, RX Complete Handler
0x013           rjmp   USART_UDRE     ; USART, UDR Empty Handler
0x014           rjmp   USART_TXC      ; USART, TX Complete Handler
0x015           rjmp   ADC            ; ADC Conversion Complete Handler
0x016           rjmp   EE_RDY         ; EEPROM Ready Handler
0x017           rjmp   ANA_COMP       ; Analog Comparator Handler
0x018           rjmp   TWI            ; 2-wire Serial Interface Handler
0x019           rjmp   SPM_RDY        ; Store Program Memory Ready Handler
;
0x01ARESET:     ldi    r16, high(RAMEND); Main program start
0x01B           out    SPH,r16        ; Set Stack Pointer to top of RAM
0x01C           ldi    r16, low(RAMEND)
0x01D           out    SPL,r16
0x01E           sei                   ; Enable interrupts
0x01F           <instr>  xxx
  ...     ...     ...  ...
```

When the SPI is enabled as a Master, the data direction of this pin is controlled by DDB2. When the pin is forced by the SPI to be an input, the pull-up can still be controlled by the PORTB2 bit.

OC1B, Output Compare Match output: The PB2 pin can serve as an external output for the Timer/Counter1 Compare Match B. The PB2 pin has to be configured as an output (DDB2 set (one)) to serve this function. The OC1B pin is also the output pin for the PWM mode timer function.

PCINT2: Pin Change Interrupt source 2. The PB2 pin can serve as an external interrupt source.

- **OC1A/PCINT1 – Port B, Bit 1**

OC1A, Output Compare Match output: The PB1 pin can serve as an external output for the Timer/Counter1 Compare Match A. The PB1 pin has to be configured as an output (DDB1 set (one)) to serve this function. The OC1A pin is also the output pin for the PWM mode timer function.

PCINT1: Pin Change Interrupt source 1. The PB1 pin can serve as an external interrupt source.

- **ICP1/CLKO/PCINT0 – Port B, Bit 0**

ICP1, Input Capture Pin: The PB0 pin can act as an Input Capture Pin for Timer/Counter1.

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

PCINT0: Pin Change Interrupt source 0. The PB0 pin can serve as an external interrupt source.

Table 10-4 and Table 10-5 relate the alternate functions of Port B to the overriding signals shown in Figure 10-5 on page 69. SPI MSTR INPUT and SPI SLAVE OUTPUT constitute the MISO signal, while MOSI is divided into SPI MSTR OUTPUT and SPI SLAVE INPUT.

11.1.4 Pin Change Interrupt Control Register - PCICR

Bit	7	6	5	4	3	2	1	0	
	–	–	–	–	–	PCIE2	PCIE1	PCIE0	PCICR
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 unused bits in the ATmega48/88/168, and will always read as zero.

- **Bit 2 - PCIE2: Pin Change Interrupt Enable 2**

When the PCIE2 bit is set (one) and the I-bit in the Status Register (SREG) is set (one), pin change interrupt 2 is enabled. Any change on any enabled PCINT23..16 pin will cause an interrupt. The corresponding interrupt of Pin Change Interrupt Request is executed from the PCI2 Interrupt Vector. PCINT23..16 pins are enabled individually by the PCMSK2 Register.

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

When the PCIE1 bit is set (one) and the I-bit in the Status Register (SREG) is set (one), pin change interrupt 1 is enabled. Any change on any enabled PCINT14..8 pin will cause an interrupt. The corresponding interrupt of Pin Change Interrupt Request is executed from the PCI1 Interrupt Vector. PCINT14..8 pins are enabled individually by the PCMSK1 Register.

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

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

11.1.5 Pin Change Interrupt Flag Register - PCIFR

Bit	7	6	5	4	3	2	1	0	
	–	–	–	–	–	PCIF2	PCIF1	PCIF0	PCIFR
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 unused bits in the ATmega48/88/168, and will always read as zero.

- **Bit 2 - PCIF2: Pin Change Interrupt Flag 2**

When a logic change on any PCINT23..16 pin triggers an interrupt request, PCIF2 becomes set (one). If the I-bit in SREG and the PCIE2 bit in PCICR are set (one), the MCU will jump to the corresponding Interrupt Vector. The flag is cleared when the interrupt routine is executed. Alternatively, the flag can be cleared by writing a logical one to it.

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

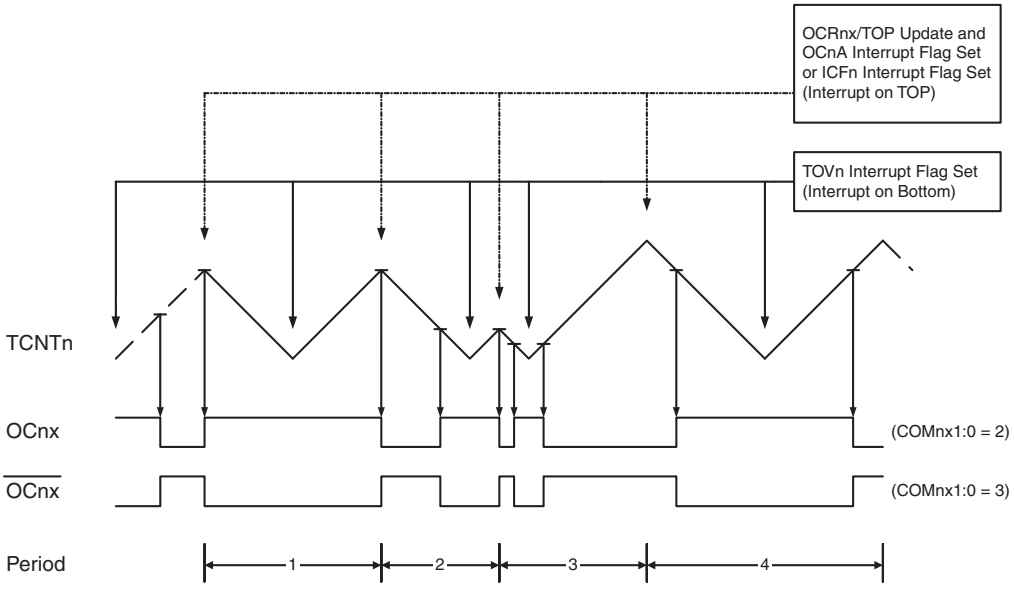
When a logic change on any PCINT14..8 pin triggers an interrupt request, PCIF1 becomes set (one). If the I-bit in SREG and the PCIE1 bit in PCICR are set (one), the MCU will jump to the corresponding Interrupt Vector. The flag is cleared when the interrupt routine is executed. Alternatively, the flag can be cleared by writing a logical one to it.

0x0003), and the maximum resolution is 16-bit (ICR1 or OCR1A set to MAX). The PWM resolution in bits can be calculated by using the following equation:

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

In phase correct PWM mode the counter is incremented until the counter value matches either one of the fixed values 0x00FF, 0x01FF, or 0x03FF (WGM13:0 = 1, 2, or 3), the value in ICR1 (WGM13:0 = 10), or the value in OCR1A (WGM13:0 = 11). The counter has then reached the TOP and changes the count direction. The TCNT1 value will be equal to TOP for one timer clock cycle. The timing diagram for the phase correct PWM mode is shown on Figure 13-8. The figure shows phase correct PWM mode when OCR1A or ICR1 is used to define TOP. The TCNT1 value is in the timing diagram shown as a histogram for illustrating the dual-slope operation. The diagram includes non-inverted and inverted PWM outputs. The small horizontal line marks on the TCNT1 slopes represent compare matches between OCR1x and TCNT1. The OC1x Interrupt Flag will be set when a compare match occurs.

Figure 13-8. Phase Correct PWM Mode, Timing Diagram



The Timer/Counter Overflow Flag (TOV1) is set each time the counter reaches BOTTOM. When either OCR1A or ICR1 is used for defining the TOP value, the OC1A or ICF1 Flag is set accordingly at the same timer clock cycle as the OCR1x Registers are updated with the double buffer value (at TOP). The Interrupt Flags can be used to generate an interrupt each time the counter reaches the TOP or BOTTOM value.

When changing the TOP value the program must ensure that the new TOP value is higher or equal to the value of all of the Compare Registers. If the TOP value is lower than any of the Compare Registers, a compare match will never occur between the TCNT1 and the OCR1x. Note that when using fixed TOP values, the unused bits are masked to zero when any of the OCR1x Registers are written. As the third period shown in Figure 13-8 illustrates, changing the TOP actively while the Timer/Counter is running in the phase correct mode can result in an unsymmetrical output. The reason for this can be found in the time of update of the OCR1x Register. Since the OCR1x update occurs at TOP, the PWM period starts and ends at TOP. This

17.5 Data Transmission – The USART Transmitter

The USART Transmitter is enabled by setting the *Transmit Enable* (TXEN) bit in the UCSRnB Register. When the Transmitter is enabled, the normal port operation of the TxDn pin is overridden by the USART and given the function as the Transmitter's serial output. The baud rate, mode of operation and frame format must be set up once before doing any transmissions. If synchronous operation is used, the clock on the XCKn pin will be overridden and used as transmission clock.

17.5.1 Sending Frames with 5 to 8 Data Bit

A data transmission is initiated by loading the transmit buffer with the data to be transmitted. The CPU can load the transmit buffer by writing to the UDRn I/O location. The buffered data in the transmit buffer will be moved to the Shift Register when the Shift Register is ready to send a new frame. The Shift Register is loaded with new data if it is in idle state (no ongoing transmission) or immediately after the last stop bit of the previous frame is transmitted. When the Shift Register is loaded with new data, it will transfer one complete frame at the rate given by the Baud Register, U2Xn bit or by XCKn depending on mode of operation.

The following code examples show a simple USART transmit function based on polling of the *Data Register Empty* (UDREn) Flag. When using frames with less than eight bits, the most significant bits written to the UDRn are ignored. The USART has to be initialized before the function can be used. For the assembly code, the data to be sent is assumed to be stored in Register R16

Assembly Code Example[1]

```
USART_Transmit:
  ; Wait for empty transmit buffer
  sbis UCSRnA,UDREn
  rjmp USART_Transmit
  ; Put data (r16) into buffer, sends the data
  out  UDRn,r16
  ret
```

C Code Example[1]

```
void USART_Transmit( unsigned char data )
{
  /* Wait for empty transmit buffer */
  while ( !( UCSRnA & (1<<UDREn)) )
       ;
  /* Put data into buffer, sends the data */
  UDRn = data;
}
```

Note: 1. See "About Code Examples" on page 6.
For I/O Registers located in extended I/O map, "IN", "OUT", "SBIS", "SBIC", "CBI", and "SBI" instructions must be replaced with instructions that allow access to extended I/O. Typically "LDS" and "STS" combined with "SBRS", "SBRC", "SBR", and "CBR".

The function simply waits for the transmit buffer to be empty by checking the UDREn Flag, before loading it with new data to be transmitted. If the Data Register Empty interrupt is utilized, the interrupt routine writes the data into the buffer.

Assembly Code Example[1]

```
USART_Receive:
  ; Wait for data to be received
  sbis UCSRnA, RXCn
  rjmp USART_Receive
  ; Get status and 9th bit, then data from buffer
  in   r18, UCSRnA
  in   r17, UCSRnB
  in   r16, UDRn
  ; If error, return -1
  andi r18,(1<<FEn)|(1<<DORn)|(1<<UPEn)
  breq USART_ReceiveNoError
  ldi  r17, HIGH(-1)
  ldi  r16, LOW(-1)
USART_ReceiveNoError:
  ; Filter the 9th bit, then return
  lsr  r17
  andi r17, 0x01
  ret
```

C Code Example[1]

```
unsigned int USART_Receive( void )
{
  unsigned char status, resh, resl;
  /* Wait for data to be received */
  while ( !(UCSRnA & (1<<RXCn)) )
       ;
  /* Get status and 9th bit, then data */
  /* from buffer */
  status = UCSRnA;
  resh = UCSRnB;
  resl = UDRn;
  /* If error, return -1 */
  if ( status & (1<<FEn)|(1<<DORn)|(1<<UPEn) )
    return -1;
  /* Filter the 9th bit, then return */
  resh = (resh >> 1) & 0x01;
  return ((resh << 8) | resl);
}
```

Note: 1. See "About Code Examples" on page 6.
For I/O Registers located in extended I/O map, "IN", "OUT", "SBIS", "SBIC", "CBI", and "SBI" instructions must be replaced with instructions that allow access to extended I/O. Typically "LDS" and "STS" combined with "SBRS", "SBRC", "SBR", and "CBR".

The receive function example reads all the I/O Registers into the Register File before any computation is done. This gives an optimal receive buffer utilization since the buffer location read will be free to accept new data as early as possible.

Table 17-8. UCPOLn Bit Settings

UCPOLn	Transmitted Data Changed (Output of TxDn Pin)	Received Data Sampled (Input on RxDn Pin)
0	Rising XCKn Edge	Falling XCKn Edge
1	Falling XCKn Edge	Rising XCKn Edge

17.9.5 USART Baud Rate Registers – UBRRnL and UBRRnH

Bit	15	14	13	12	11	10	9	8	
	–	–	–	–	UBRRn[11:8]				UBRRnH
	UBRRn[7:0]								UBRRnL
	7	6	5	4	3	2	1	0	
Read/Write	R	R	R	R	R/W	R/W	R/W	R/W	
	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	
	0	0	0	0	0	0	0	0	

- **Bit 15:12 – Reserved Bits**

These bits are reserved for future use. For compatibility with future devices, these bit must be written to zero when UBRRnH is written.

- **Bit 11:0 – UBRR11:0: USART Baud Rate Register**

This is a 12-bit register which contains the USART baud rate. The UBRRnH contains the four most significant bits, and the UBRRnL contains the eight least significant bits of the USART baud rate. Ongoing transmissions by the Transmitter and Receiver will be corrupted if the baud rate is changed. Writing UBRRnL will trigger an immediate update of the baud rate prescaler.

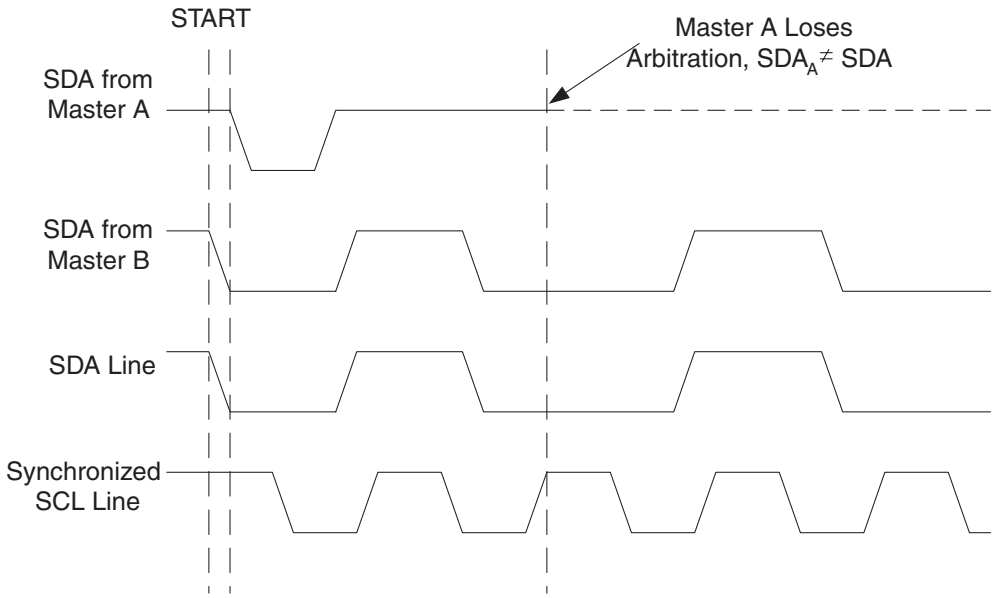
17.10 Examples of Baud Rate Setting

For standard crystal and resonator frequencies, the most commonly used baud rates for asynchronous operation can be generated by using the UBRRn settings in Table 17-9. UBRRn values which yield an actual baud rate differing less than 0.5% from the target baud rate, are bold in the table. Higher error ratings are acceptable, but the Receiver will have less noise resistance when the error ratings are high, especially for large serial frames (see ”Asynchronous Operational Range” on page 184). The error values are calculated using the following equation:

$$\text{Error}[\%] = \left(\frac{\text{BaudRate}_{\text{Closest Match}}}{\text{BaudRate}} - 1\right) \bullet 100\%$$

bits. If several masters are trying to address the same Slave, arbitration will continue into the data packet.

Figure 19-8. Arbitration Between Two Masters



Note that arbitration is not allowed between:

- A REPEATED START condition and a data bit.
- A STOP condition and a data bit.
- A REPEATED START and a STOP condition.

It is the user software's responsibility to ensure that these illegal arbitration conditions never occur. This implies that in multi-master systems, all data transfers must use the same composition of SLA+R/W and data packets. In other words: All transmissions must contain the same number of data packets, otherwise the result of the arbitration is undefined.

21. Analog-to-Digital Converter

21.1 Features

- **10-bit Resolution**
- **0.5 LSB Integral Non-linearity**
- **± 2 LSB Absolute Accuracy**
- **13 - 260 µs Conversion Time**
- **Up to 15 kSPS at Maximum Resolution**
- **6 Multiplexed Single Ended Input Channels**
- **2 Additional Multiplexed Single Ended Input Channels (TQFP and QFN/MLF Package only)**
- **Optional Left Adjustment for ADC Result Readout**
- **0 - V_{CC} ADC Input Voltage Range**
- **Selectable 1.1V ADC Reference Voltage**
- **Free Running or Single Conversion Mode**
- **Interrupt on ADC Conversion Complete**
- **Sleep Mode Noise Canceler**

The ATmega48/88/168 features a 10-bit successive approximation ADC. The ADC is connected to an 8-channel Analog Multiplexer which allows eight single-ended voltage inputs constructed from the pins of Port A. The single-ended voltage inputs refer to 0V (GND).

The ADC contains a Sample and Hold circuit which ensures that the input voltage to the ADC is held at a constant level during conversion. A block diagram of the ADC is shown in Figure 21-1 on page 240.

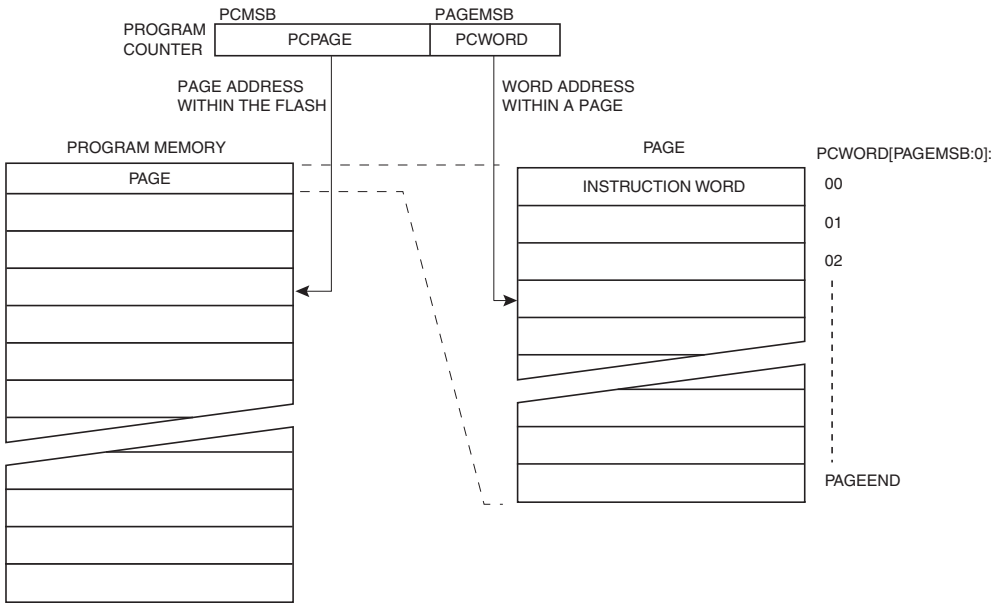
The ADC has a separate analog supply voltage pin, AV_{CC}. AV_{CC} must not differ more than ± 0.3V from V_{CC}. See the paragraph ”ADC Noise Canceler” on page 245 on how to connect this pin.

Internal reference voltages of nominally 1.1V or AV_{CC} are provided On-chip. The voltage reference may be externally decoupled at the AREF pin by a capacitor for better noise performance.

The Power Reduction ADC bit, PRADC, in ”Power Reduction Register - PRR” on page 40 must be disabled by writing a logical zero to enable the ADC.

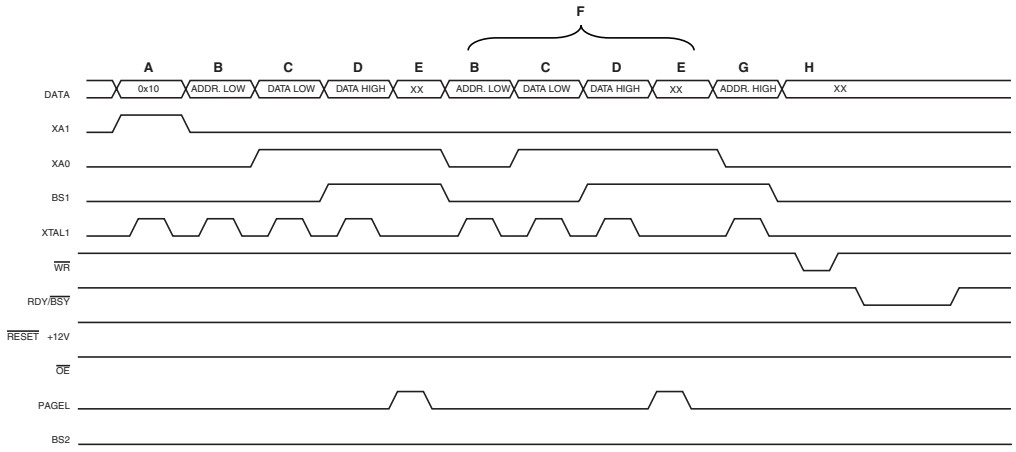
The ADC converts an analog input voltage to a 10-bit digital value through successive approximation. The minimum value represents GND and the maximum value represents the voltage on the AREF pin minus 1 LSB. Optionally, AV_{CC} or an internal 1.1V reference voltage may be connected to the AREF pin by writing to the REFSn bits in the ADMUX Register. The internal voltage reference may thus be decoupled by an external capacitor at the AREF pin to improve noise immunity.

Figure 25-2. Addressing the Flash Which is Organized in Pages[1]



Note: 1. PCPAGE and PCWORD are listed in Table 25-8 on page 284.

Figure 25-3. Programming the Flash Waveforms[1]



Note: 1. "XX" is don't care. The letters refer to the programming description above.

25.7.5 Programming the EEPROM

The EEPROM is organized in pages, see Table 25-9 on page 284. When programming the EEPROM, the program data is latched into a page buffer. This allows one page of data to be programmed simultaneously. The programming algorithm for the EEPROM data memory is as follows (refer to "Programming the Flash" on page 287 for details on Command, Address and Data loading):

1. A: Load Command "0001 0001".
2. G: Load Address High Byte (0x00 - 0xFF).
3. B: Load Address Low Byte (0x00 - 0xFF).
4. C: Load Data (0x00 - 0xFF).

Table 25-14. Parallel Programming Characteristics, V_{CC} = 5V ± 10% (Continued)

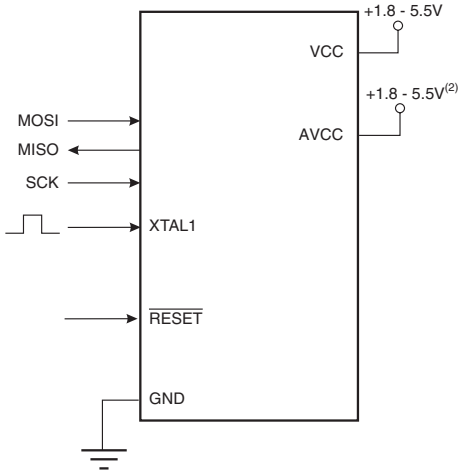
Symbol	Parameter	Min	Typ	Max	Units
t_{BVDV}	BS1 Valid to DATA valid	0		250	ns
t_{OLDV}	$\overline{OE}$ Low to DATA Valid			250	ns
t_{OHDZ}	$\overline{OE}$ High to DATA Tri-stated			250	ns

Notes: 1. t_{WLRH} is valid for the Write Flash, Write EEPROM, Write Fuse bits and Write Lock bits commands.
2. t_{WLRH_CE} is valid for the Chip Erase command.

25.8 Serial Downloading

Both the Flash and EEPROM memory arrays can be programmed using the serial SPI bus while $\overline{RESET}$ is pulled to GND. The serial interface consists of pins SCK, MOSI (input) and MISO (output). After $\overline{RESET}$ is set low, the Programming Enable instruction needs to be executed first before program/erase operations can be executed. NOTE, in Table 25-15 on page 296, the pin mapping for SPI programming is listed. Not all parts use the SPI pins dedicated for the internal SPI interface.

Figure 25-10. Serial Programming and Verify[1]



Notes: 1. If the device is clocked by the internal Oscillator, it is no need to connect a clock source to the XTAL1 pin.
2. V_{CC} - 0.3V < AV_{CC} < V_{CC} + 0.3V, however, AV_{CC} should always be within 1.8 - 5.5V

When programming the EEPROM, an auto-erase cycle is built into the self-timed programming operation (in the Serial mode ONLY) and there is no need to first execute the Chip Erase instruction. The Chip Erase operation turns the content of every memory location in both the Program and EEPROM arrays into 0xFF.

Depending on CKSEL Fuses, a valid clock must be present. The minimum low and high periods for the serial clock (SCK) input are defined as follows:

Low: > 2 CPU clock cycles for f_{ck} < 12 MHz, 3 CPU clock cycles for f_{ck} >= 12 MHz

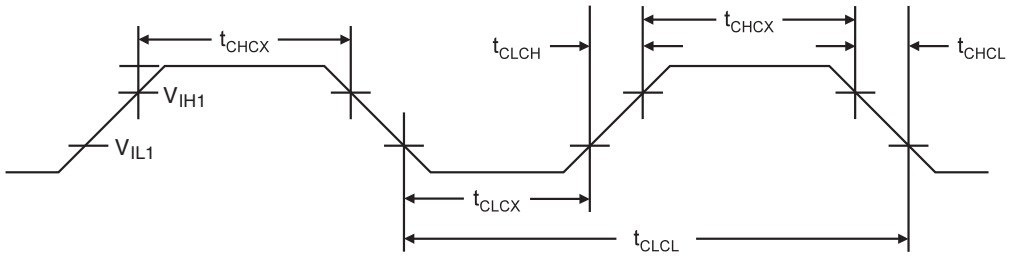
High: > 2 CPU clock cycles for f_{ck} < 12 MHz, 3 CPU clock cycles for f_{ck} >= 12 MHz

If IOH exceeds the test condition, VOH may exceed the related specification. Pins are not guaranteed to source current greater than the listed test condition.

5. All DC Characteristics contained in this datasheet are based on simulation and characterization of other AVR microcontrollers manufactured in the same process technology. These values are preliminary values representing design targets, and will be updated after characterization of actual silicon
6. Values with “Power Reduction Register - PRR” disabled (0x00).

26.3 External Clock Drive Waveforms

Figure 26-1. External Clock Drive Waveforms



26.4 External Clock Drive

Table 26-1. External Clock Drive

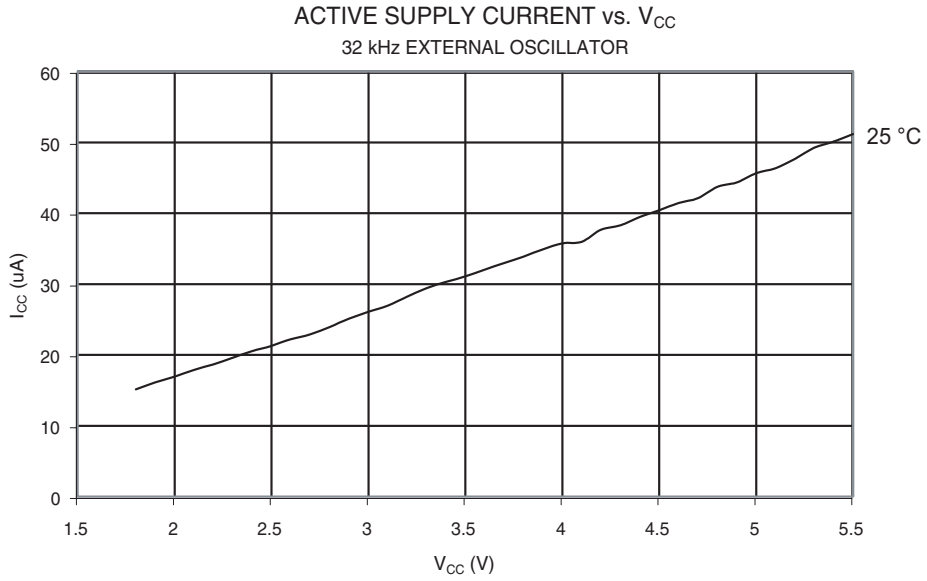
Symbol	Parameter	V_{CC}=1.8-5.5V		V_{CC}=2.7-5.5V		V_{CC}=4.5-5.5V		Units
		Min.	Max.	Min.	Max.	Min.	Max.	
$1/t_{CLCL}$	Oscillator Frequency	0	4	0	10	0	20	MHz
t_{CLCL}	Clock Period	250		100		50		ns
t_{CHCX}	High Time	100		40		20		ns
t_{CLCX}	Low Time	100		40		20		ns
t_{CLCH}	Rise Time		2.0		1.6		0.5	µs
t_{CHCL}	Fall Time		2.0		1.6		0.5	µs
Δt_{CLCL}	Change in period from one clock cycle to the next		2		2		2	%

Note: All DC Characteristics contained in this datasheet are based on simulation and characterization of other AVR microcontrollers manufactured in the same process technology. These values are preliminary values representing design targets, and will be updated after characterization of actual silicon.

26.5 Maximum Speed vs. V_{CC}

Maximum frequency is dependent on V_{CC}. As shown in Figure 26-2 and Figure 26-3, the Maximum Frequency vs. V_{CC} curve is linear between $1.8V < V_{CC} < 2.7V$ and between $2.7V < V_{CC} < 4.5V$.

Figure 27-6. Active Supply Current vs. V_{CC} (32 kHz External Oscillator)



27.2 Idle Supply Current

Figure 27-7. Idle Supply Current vs. Frequency (0.1 - 1.0 MHz)

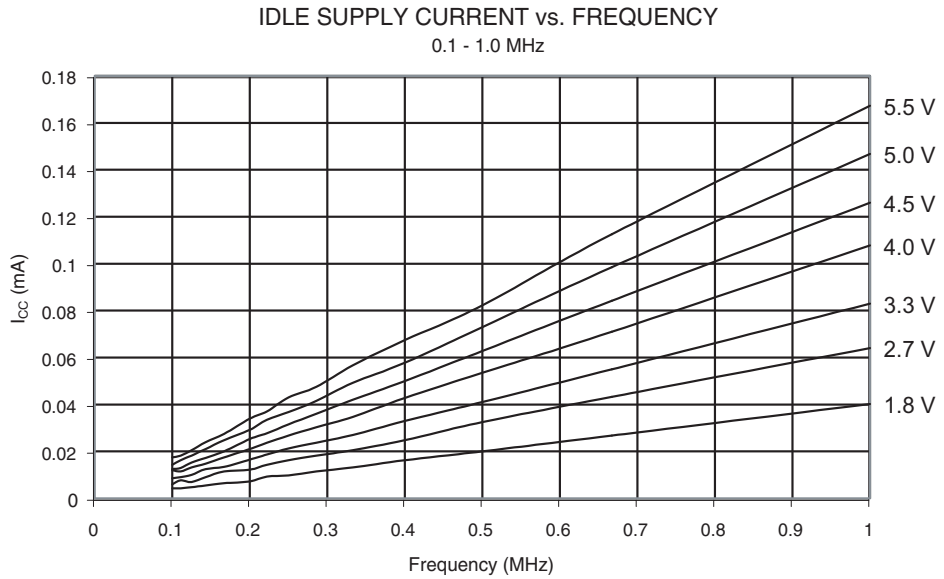
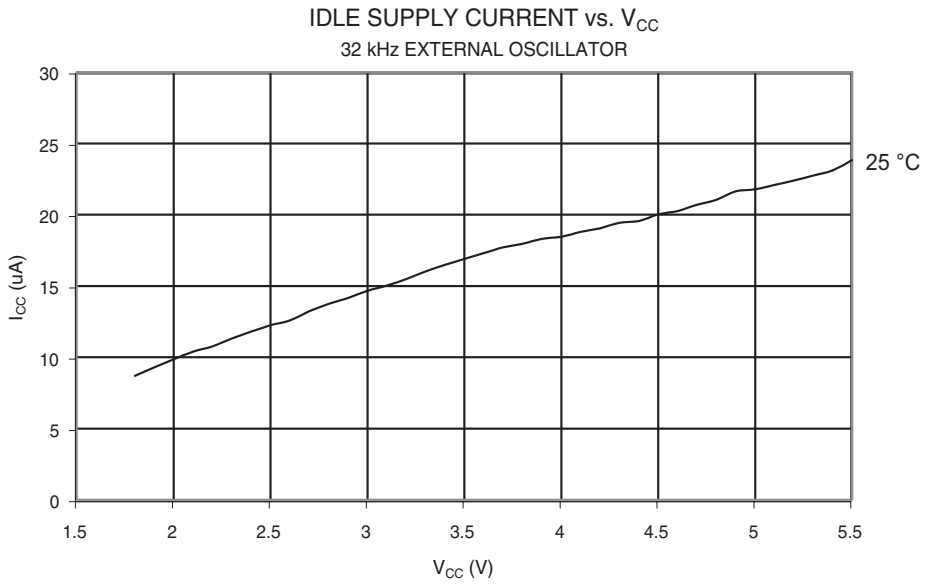


Figure 27-12. Idle Supply Current vs. V_{CC} (32 kHz External Oscillator)



27.3 Supply Current of I/O modules

The tables and formulas below can be used to calculate the additional current consumption for the different I/O modules in Active and Idle mode. The enabling or disabling of the I/O modules are controlled by the Power Reduction Register. See ”Power Reduction Register” on page 39 for details.

Table 27-1. Additional Current Consumption for the different I/O modules (absolute values)

PRR bit	Typical numbers		
	V_{CC} = 2V, F = 1MHz	V_{CC} = 3V, F = 4MHz	V_{CC} = 5V, F = 8MHz
PRUSART0	8.0 uA	51 uA	220 uA
PRTWI	12 uA	75 uA	315 uA
PRTIM2	11 uA	72 uA	300 uA
PRTIM1	5.0 uA	32 uA	130 uA
PRTIM0	4.0 uA	24 uA	100 uA
PRSPI	15 uA	95 uA	400 uA
PRADC	12 uA	75 uA	315 uA

Figure 27-41. Calibrated 8 MHz RC Oscillator Frequency vs. V_{CC}

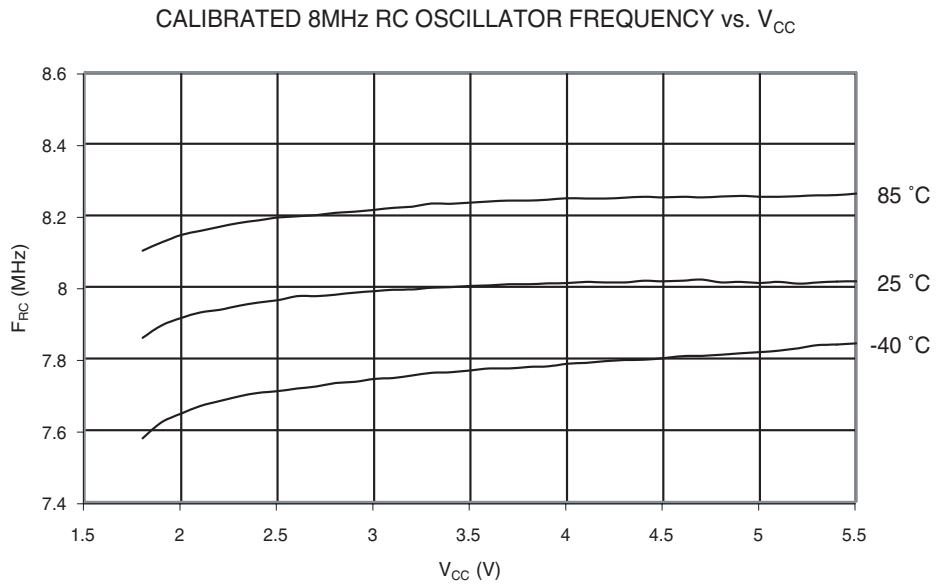
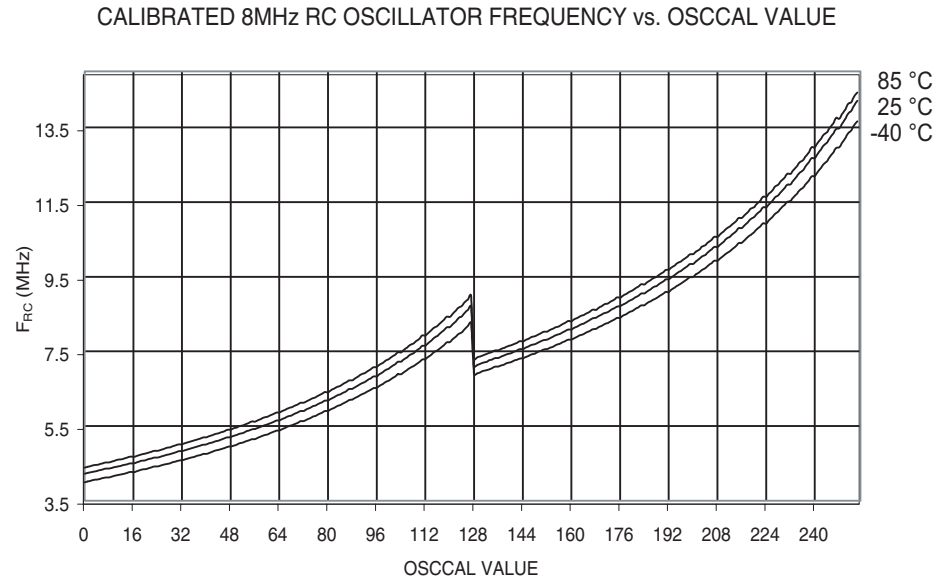


Figure 27-42. Calibrated 8 MHz RC Oscillator Frequency vs. Osccal Value



Mnemonics	Operands	Description	Operation	Flags	#Clocks
POP	Rd	Pop Register from Stack	Rd ← STACK	None	2
MCU CONTROL INSTRUCTIONS					
NOP		No Operation		None	1
SLEEP		Sleep	(see specific descr. for Sleep function)	None	1
WDR		Watchdog Reset	(see specific descr. for WDR/timer)	None	1
BREAK		Break	For On-chip Debug Only	None	N/A

Note: 1. These instructions are only available in ATmega168.

30. Ordering Information

30.1 ATmega48

Speed (MHz)	Power Supply	Ordering Code	Package[1]	Operational Range
10[3]	1.8 - 5.5	ATmega48V-10AI ATmega48V-10PI ATmega48V-10MI ATmega48V-10AU[2] ATmega48V-10PU[2] ATmega48V-10MU[2]	32A 28P3 32M1-A 32A 28P3 32M1-A	Industrial (-40°C to 85°C)
20[3]	2.7 - 5.5	ATmega48-20AI ATmega48-20PI ATmega48-20MI ATmega48-20AU[2] ATmega48-20PU[2] ATmega48-20MU[2]	32A 28P3 32M1-A 32A 28P3 32M1-A	Industrial (-40°C to 85°C)

Note:
1. This device can also be supplied in wafer form. Please contact your local Atmel sales office for detailed ordering information and minimum quantities.
2. Pb-free packaging alternative, complies to the European Directive for Restriction of Hazardous Substances (RoHS directive).Also Halide free and fully Green.
3. See Figure 26-2 on page 302 and Figure 26-3 on page 302.

Package Type	
32A	32-lead, Thin (1.0 mm) Plastic Quad Flat Package (TQFP)
28P3	28-lead, 0.300” Wide, Plastic Dual Inline Package (PDIP)
32M1-A	32-pad, 5 x 5 x 1.0 body, Lead Pitch 0.50 mm Quad Flat No-Lead/Micro Lead Frame Package (QFN/MLF)

32.3 Errata ATmega168

The revision letter in this section refers to the revision of the ATmega168 device.

32.3.1 Rev A

- **Wrong values read after Erase Only operation**
- **Part may hang in reset**

1. Wrong values read after Erase Only operation

At supply voltages below 2.7 V, an EEPROM location that is erased by the Erase Only operation may read as programmed (0x00).

Problem Fix/Workaround

If it is necessary to read an EEPROM location after Erase Only, use an Atomic Write operation with 0xFF as data in order to erase a location. In any case, the Write Only operation can be used as intended. Thus no special considerations are needed as long as the erased location is not read before it is programmed.

2. Part may hang in reset

Some parts may get stuck in a reset state when a reset signal is applied when the internal reset state-machine is in a specific state. The internal reset state-machine is in this state for approximately 10 ns immediately before the part wakes up after a reset, and in a 10 ns window when altering the system clock prescaler. The problem is most often seen during In-System Programming of the device. There are theoretical possibilities of this happening also in run-mode. The following three cases can trigger the device to get stuck in a reset-state:

- Two succeeding resets are applied where the second reset occurs in the 10ns window before the device is out of the reset-state caused by the first reset.

- A reset is applied in a 10 ns window while the system clock prescaler value is updated by software.

- Leaving SPI-programming mode generates an internal reset signal that can trigger this case.

The two first cases can occur during normal operating mode, while the last case occurs only during programming of the device.

Problem Fix/Workaround

The first case can be avoided during run-mode by ensuring that only one reset source is active. If an external reset push button is used, the reset start-up time should be selected such that the reset line is fully debounced during the start-up time.

The second case can be avoided by not using the system clock prescaler.

The third case occurs during In-System programming only. It is most frequently seen when using the internal RC at maximum frequency.

If the device gets stuck in the reset-state, turn power off, then on again to get the device out of this state.

32.3.2 Rev B

No errata.

32.3.3 Rev C

No errata.