

Features

- High performance, low power Atmel® AVR® 8-Bit Microcontroller
- Advanced RISC architecture
 - 130 powerful instructions – most single clock cycle execution
 - 32 × 8 general purpose working registers
 - Fully static operation
 - Up to 16MIPS throughput at 16MHz (Atmel ATmega165PA/645P)
 - Up to 20MIPS throughput at 20MHz (Atmel ATmega165A/325A/325PA/645A/3250A/3250PA/6450A/6450P)
 - On-chip 2-cycle multiplier
- High endurance non-volatile memory segments
 - In-system self-programmable flash program memory
 - 16KBytes (ATmega165A/ATmega165PA)
 - 32KBytes (ATmega325A/ATmega325PA/ATmega3250A/ATmega3250PA)
 - 64KBytes (ATmega645A/ATmega645P/ATmega6450A/ATmega6450P)
 - EEPROM
 - 512Bytes (ATmega165A/ATmega165PA)
 - 1Kbytes (ATmega325A/ATmega325PA/ATmega3250A/ATmega3250PA)
 - 2Kbytes (ATmega645A/ATmega645P/ATmega6450A/ATmega6450P)
 - Internal SRAM
 - 1KBytes (ATmega165A/ATmega165PA)
 - 2KBytes (ATmega325A/ATmega325PA/ATmega3250A/ATmega3250PA)
 - 4KBytes (ATmega645A/ATmega645P/ATmega6450A/ATmega6450P)
 - Write/erase cycles: 10,000 flash/100,000 EEPROM
 - Data retention: 20 years at 85°C/100 years at 25°C ⁽¹⁾
 - Optional Boot Code Section with Independent Lock Bits
 - In-System Programming by On-chip Boot Program
 - True read-while-write operation
 - Programming lock for software security
- Atmel QTouch® library support
 - Capacitive touch buttons, sliders and wheels
 - Atmel QTouch and QMatrix acquisition
 - Up to 64 sense channels
- JTAG (IEEE std. 1149.1 compliant) interface
 - Boundary-scan capabilities according to the JTAG standard
 - Extensive on-chip debug support
 - Programming of Flash, EEPROM, Fuses, and Lock Bits through the JTAG Interface
- Peripheral Features
 - Two 8-bit Timer/Counters with Separate Prescaler and Compare Mode
 - One 16-bit Timer/Counter with Separate Prescaler, Compare Mode, and Capture Mode
 - Real time counter with separate oscillator
 - Four PWM channels
 - 8-channel, 10-bit ADC

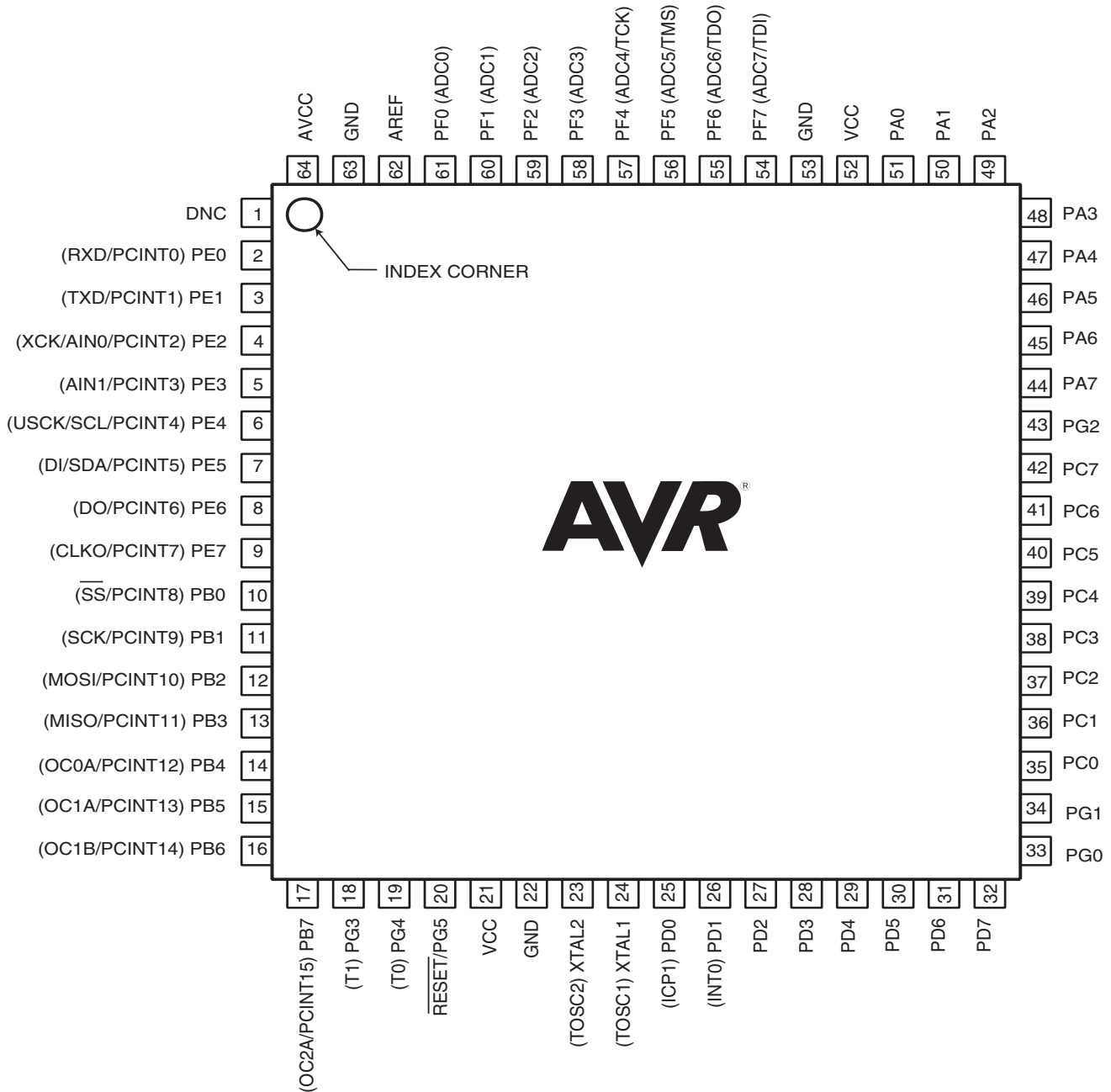
- Programmable serial USART
- Master/Slave SPI Serial Interface
- Universal Serial Interface with Start Condition detector
- Programmable Watchdog Timer with separate on-chip oscillator
- On-chip Analog Comparator
- Interrupt and Wake-up on pin change
- Special microcontroller features
 - Power-on reset and programmable Brown-out detection
 - Internal calibrated oscillator
 - External and internal interrupt sources
 - Five sleep modes: Idle, ADC Noise Reduction, Power-save, Power-down and Standby
- I/O and packages
 - 54/69 programmable I/O lines
 - 64/100-lead TQFP, 64-pad QFN/MLF and 64-pad DRQFN
- Speed grade:
 - ATmega 165A/165PA/645A/645P: 0 - 16MHz @ 1.8 - 5.5V
 - ATmega325A/325PA/3250A/3250PA/6450A/6450P: 0 - 20MHz @ 1.8 - 5.5V
- Temperature range:
 - -40°C to 85°C industrial
- Ultra-low power consumption (picoPower® devices)
 - Active mode:
 - 1MHz, 1.8V: 215µA
 - 32kHz, 1.8V: 8µA (including oscillator)
 - Power-down mode: 0.1µA at 1.8V
 - Power-save mode: 0.6µA at 1.8V (Including 32kHz RTC)

Note: 1. Reliability Qualification results show that the projected data retention failure rate is much less than 1 PPM over 20 years at 85°C or 100 years at 25°C.

1. Pin configurations

1.1 Pinout - TQFP and QFN/MLF

Figure 1-1. 64A (TQFP) and 64M1 (QFN/MLF) pinout Atmel
 ATmega165A/ATmega165PA/ATmega325A/ATmega325PA/ATmega645A/ATmega645P.



Note: The large center pad underneath the QFN/MLF packages is made of metal and internally connected to GND. It should be soldered or glued to the board to ensure good mechanical stability. If the center pad is left unconnected, the package might loosen from the board.

1.2 Pinout - 100A (TQFP)

Figure 1-2. Pinout Atmel ATmega3250A/ATmega3250PA/ATmega6450A/ATmega6450P.



2. Overview

The Atmel ATmega165A/165PA/325A/325PA/3250A/3250PA/645A/645P/6450A/6450P is a low-power CMOS 8-bit microcontroller based on the AVR enhanced RISC architecture. By executing powerful instructions in a single clock cycle, this microcontroller achieves throughputs approaching 1 MIPS per MHz allowing the system designer to optimize power consumption versus processing speed.

2.1 Block diagram

Figure 2-1. Block diagram.



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

The Atmel ATmega165A/165PA/325A/325PA/3250A/3250PA/645A/645P/6450A/6450P provides the following features: 16K/32K/64K bytes of In-System Programmable Flash with Read-While-Write capabilities, 512/1K/2K bytes EEPROM, 1K/2K/4K byte SRAM, 54/69 general purpose I/O lines, 32 general purpose working registers, a JTAG interface for Boundary-scan, On-chip Debugging support and programming, three flexible Timer/Counters with compare modes, internal and external interrupts, a serial programmable USART, Universal Serial Interface with Start Condition Detector, an 8-channel, 10-bit ADC, a programmable Watchdog Timer with internal Oscillator, an SPI serial port, and five software selectable power saving modes. The Idle mode stops the CPU while allowing the SRAM, Timer/Counters, SPI port, and interrupt system to continue functioning. The Power-down mode saves the register contents but freezes the Oscillator, disabling all other chip functions until the next interrupt or hardware reset. In Power-save mode, the asynchronous timer continues to run, allowing the user to maintain a timer base while the rest of the device is sleeping. The ADC Noise Reduction mode stops the CPU and all I/O modules except asynchronous timer and ADC, to minimize switching noise during ADC conversions. In Standby mode, the XTAL/resonator Oscillator is running while the rest of the device is sleeping. This allows very fast start-up combined with low-power consumption.

Atmel offers the QTouch® library for embedding capacitive touch buttons, sliders and wheels functionality into AVR microcontrollers. The patented charge-transfer signal acquisition offers robust sensing and includes fully debounced reporting of touch keys and includes Adjacent Key Suppression® (AKS®) technology for unambiguous detection of key events. The easy-to-use QTouch Suite toolchain allows you to explore, develop and debug your own touch applications.

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

The ATmega165A/165PA/325A/325PA/3250A/3250PA/645A/645P/6450A/6450P 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.

2.2 Comparison between Atmel

ATmega165A/165PA/325A/325PA/3250A/3250PA/645A/645P/6450A/6450P

Table 2-1. Differences between: ATmega165A/165PA/325A/325PA/3250A/3250PA/645A/645P/6450A/6450P.

| Device | Flash | EEPROM | RAM | MHz |
|--------------|----------|----------|--------|-----|
| ATmega165A | 16Kbyte | 512Bytes | 1Kbyte | 16 |
| ATmega165PA | 16Kbyte | 512Bytes | 1Kbyte | 16 |
| ATmega325A | 32Kbyte | 1Kbyte | 2Kbyte | 20 |
| ATmega325PA | 32Kbyte | 1Kbyte | 2Kbyte | 20 |
| ATmega3250A | 32Kbytes | 1Kbyte | 2Kbyte | 20 |
| ATmega3250PA | 32Kbyte | 1Kbyte | 2Kbyte | 20 |
| ATmega645A | 64Kbyte | 2Kbyte | 4Kbyte | 16 |
| ATmega645P | 64Kbyte | 2Kbyte | 4Kbyte | 16 |
| ATmega6450A | 64Kbyte | 2Kbyte | 4Kbyte | 20 |
| ATmega6450P | 64Kbyte | 2Kbyte | 4Kbyte | 20 |

2.3 Pin descriptions

2.3.1 VCC

Digital supply voltage.

2.3.2 GND

Ground.

2.3.3 Port A (PA7:PA0)

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

Port A also serves the functions of various special features of the ATmega165A/165PA/325A/325PA/3250A/3250PA/645A/645P/6450A/6450P as listed on ["Alternate functions of Port B" on page 73](#).

2.3.4 Port B (PB7:PB0)

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

Port B has better driving capabilities than the other ports.

Port B also serves the functions of various special features of the ATmega165A/165PA/325A/325PA/3250A/3250PA/645A/645P/6450A/6450P as listed on ["Alternate functions of Port B" on page 73](#).

2.3.5 Port C (PC7:PC0)

Port C is an 8-bit bi-directional I/O port with internal pull-up resistors (selected for each bit). The Port C output buffers have symmetrical drive characteristics with both high sink and source capability. As inputs, Port C pins

that are externally pulled low will source current if the pull-up resistors are activated. The Port C pins are tri-stated when a reset condition becomes active, even if the clock is not running.

Port C also serves the functions of special features of the Atmel ATmega165A/165PA/325A/325PA/3250A/3250PA/645A/645P/6450A/6450P as listed on ["Alternate functions of Port D" on page 75](#).

2.3.6 Port D (PD7:PD0)

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

Port D also serves the functions of various special features of the ATmega165A/165PA/325A/325PA/3250A/3250PA/645A/645P/6450A/6450P as listed on ["Alternate functions of Port D" on page 75](#).

2.3.7 Port E (PE7:PE0)

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

Port E also serves the functions of various special features of the ATmega165A/165PA/325A/325PA/3250A/3250PA/645A/645P/6450A/6450P as listed on ["Alternate functions of Port E" on page 76](#).

2.3.8 Port F (PF7:PF0)

Port F serves as the analog inputs to the A/D Converter.

Port F also serves as an 8-bit bi-directional I/O port, if the A/D Converter is not used. Port pins can provide internal pull-up resistors (selected for each bit). The Port F output buffers have symmetrical drive characteristics with both high sink and source capability. As inputs, Port F pins that are externally pulled low will source current if the pull-up resistors are activated. The Port F pins are tri-stated when a reset condition becomes active, even if the clock is not running. If the JTAG interface is enabled, the pull-up resistors on pins PF7(TDI), PF5(TMS), and PF4(TCK) will be activated even if a reset occurs.

Port F also serves the functions of the JTAG interface, see ["Alternate functions of Port F" on page 78](#).

2.3.9 Port G (PG5:PG0)

Port G is a 6-bit bi-directional I/O port with internal pull-up resistors (selected for each bit). The Port G output buffers have symmetrical drive characteristics with both high sink and source capability. As inputs, Port G pins that are externally pulled low will source current if the pull-up resistors are activated. The Port G pins are tri-stated when a reset condition becomes active, even if the clock is not running.

Port G also serves the functions of various special features of the ATmega165A/165PA/325A/325PA/3250A/3250PA/645A/645P/6450A/6450P as listed on [page 80](#).

2.3.10 Port H (PH7:PH0)

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

Port H also serves the functions of various special features of the ATmega3250A/3250PA/6450A/6450P as listed on [page 81](#).

2.3.11 Port J (PJ6:PJ0)

Port J is a 7-bit bi-directional I/O port with internal pull-up resistors (selected for each bit). The Port J output buffers have symmetrical drive characteristics with both high sink and source capability. As inputs, Port J pins that are externally pulled low will source current if the pull-up resistors are activated. The Port J pins are tri-stated when a reset condition becomes active, even if the clock is not running.

Port J also serves the functions of various special features of the Atmel ATmega3250A/3250PA/6450A/6450P as listed on [page 83](#).

2.3.12 RESET

Reset input. A low level on this pin for longer than the minimum pulse length will generate a reset, even if the clock is not running. The minimum pulse length is given in [Table 28-13 on page 304](#). Shorter pulses are not guaranteed to generate a reset.

2.3.13 XTAL1

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

2.3.14 XTAL2

Output from the inverting Oscillator amplifier.

2.3.15 AVCC

AVCC is the supply voltage pin for Port F and the A/D Converter. It should be externally connected to V_{CC} , even if the ADC is not used. If the ADC is used, it should be connected to V_{CC} through a low-pass filter.

2.3.16 AREF

This is the analog reference pin for the A/D Converter.

3. Resources

A comprehensive set of development tools, application notes and datasheets are available for download on <http://www.atmel.com/avr>.

4. Data retention

Reliability Qualification results show that the projected data retention failure rate is much less than 1 PPM over 20 years at 85°C or 100 years at 25°C.

5. About code examples

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

These code examples assume that the part specific header file is included before compilation. 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".

6. Capacitive touch sensing

The Atmel QTouch Library provides a simple to use solution to realize touch sensitive interfaces on most Atmel AVR microcontrollers. The QTouch Library includes support for the Atmel QTouch and QMatrix acquisition methods.

Touch sensing can be added to any application by linking the appropriate Atmel QTouch Library for the AVR Microcontroller. This is done by using a simple set of APIs to define the touch channels and sensors, and then calling the touch sensing API's to retrieve the channel information and determine the touch sensor states.

The QTouch Library is FREE and downloadable from the Atmel website at the following location: www.atmel.com/qtouchlibrary. For implementation details and other information, refer to the [Atmel QTouch Library User Guide](#) - also available for download from the Atmel website.

7. Register Summary

Note: Registers with bold type only available in ATmega3250A/3250PA/6450A/6450P.

| | | | | | | | | | | |
|--------|--------------|--------------------------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|-----|
| (0xFF) | Reserved | | | | | | | | | |
| (0xFE) | Reserved | | | | | | | | | |
| (0xFD) | Reserved | | | | | | | | | |
| (0xFC) | Reserved | | | | | | | | | |
| (0xFB) | Reserved | | | | | | | | | |
| (0xFA) | Reserved | | | | | | | | | |
| (0xF9) | Reserved | | | | | | | | | |
| (0xF8) | Reserved | | | | | | | | | |
| (0xF7) | Reserved | | | | | | | | | |
| (0xF6) | Reserved | | | | | | | | | |
| (0xF5) | Reserved | | | | | | | | | |
| (0xF4) | Reserved | | | | | | | | | |
| (0xF3) | Reserved | | | | | | | | | |
| (0xF2) | Reserved | | | | | | | | | |
| (0xF1) | Reserved | | | | | | | | | |
| (0xF0) | Reserved | | | | | | | | | |
| (0xEF) | Reserved | | | | | | | | | |
| (0xEE) | Reserved | | | | | | | | | |
| (0xED) | Reserved | | | | | | | | | |
| (0xEC) | Reserved | | | | | | | | | |
| (0xEB) | Reserved | - | - | - | - | - | - | - | - | |
| (0xEA) | Reserved | - | - | - | - | - | - | - | - | |
| (0xE9) | Reserved | - | - | - | - | - | - | - | - | |
| (0xE8) | Reserved | - | - | - | - | - | - | - | - | |
| (0xE7) | Reserved | | | | | | | | | |
| (0xE6) | Reserved | | | | | | | | | |
| (0xE5) | Reserved | | | | | | | | | |
| (0xE4) | Reserved | | | | | | | | | |
| (0xE3) | Reserved | - | - | - | - | - | - | - | - | |
| (0xE2) | Reserved | - | - | - | - | - | - | - | - | |
| (0xE1) | Reserved | - | - | - | - | - | - | - | - | |
| (0xE0) | Reserved | - | - | - | - | - | - | - | - | |
| (0xDF) | Reserved | - | - | - | - | - | - | - | - | |
| (0xDE) | Reserved | - | - | - | - | - | - | - | - | |
| (0xDD) | PORTJ | - | PORTJ6 | PORTJ5 | PORTJ4 | PORTJ3 | PORTJ2 | PORTJ1 | PORTJ0 | 88 |
| (0xDC) | DDRJ | - | DDJ6 | DDJ5 | DDJ4 | DDJ3 | DDJ2 | DDJ1 | DDJ0 | 88 |
| (0xDB) | PINJ | - | PINJ6 | PINJ5 | PINJ4 | PINJ3 | PINJ2 | PINJ1 | PINJ0 | 88 |
| (0xDA) | PORTR | PORTR7 | PORTR6 | PORTR5 | PORTR4 | PORTR3 | PORTR2 | PORTR1 | PORTR0 | 87 |
| (0xD9) | DDRH | DDH7 | DDH6 | DDH5 | DDH4 | DDH3 | DDH2 | DDH1 | DDH0 | 87 |
| (0xD8) | PINH | PINH7 | PINH6 | PINH5 | PINH4 | PINH3 | PINH2 | PINH1 | PINH0 | 88 |
| (0xD7) | Reserved | - | - | - | - | - | - | - | - | |
| (0xD6) | Reserved | - | - | - | - | - | - | - | - | |
| (0xD5) | Reserved | - | - | - | - | - | - | - | - | |
| (0xD4) | Reserved | - | - | - | - | - | - | - | - | |
| (0xD3) | Reserved | - | - | - | - | - | - | - | - | |
| (0xD2) | Reserved | - | - | - | - | - | - | - | - | |
| (0xD1) | Reserved | - | - | - | - | - | - | - | - | |
| (0xD0) | Reserved | - | - | - | - | - | - | - | - | |
| (0xCF) | Reserved | - | - | - | - | - | - | - | - | |
| (0xCE) | Reserved | - | - | - | - | - | - | - | - | |
| (0xCD) | Reserved | - | - | - | - | - | - | - | - | |
| (0xCC) | Reserved | - | - | - | - | - | - | - | - | |
| (0xCB) | Reserved | - | - | - | - | - | - | - | - | |
| (0xCA) | Reserved | - | - | - | - | - | - | - | - | |
| (0xC9) | Reserved | - | - | - | - | - | - | - | - | |
| (0xC8) | Reserved | - | - | - | - | - | - | - | - | |
| (0xC7) | Reserved | - | - | - | - | - | - | - | - | |
| (0xC6) | UDR0 | USART0 Data Register | | | | | | | | 178 |
| (0xC5) | UBRR0H | USART0 Baud Rate Register High | | | | | | | | 182 |

| | | | | | | | | | | |
|--------|----------|---|--------|--------|--------|---------|---------|---------|---------|-----|
| (0xC4) | UBRR0L | USART0 Baud Rate Register Low | | | | | | | | 182 |
| (0xC3) | Reserved | - | - | - | - | - | - | - | - | |
| (0xC2) | UCSR0C | - | UMSEL0 | UPM01 | UPM00 | USBS0 | UCSZ01 | UCSZ00 | UCPOL0 | 180 |
| (0xC1) | UCSR0B | RXCIE0 | TXCIE0 | UDRIE0 | RXEN0 | TXEN0 | UCSZ02 | RXB80 | TXB80 | 179 |
| (0xC0) | UCSR0A | RXC0 | TXC0 | UDRE0 | FE0 | DOR0 | UPE0 | U2X0 | MPCM0 | 178 |
| (0xBF) | Reserved | - | - | - | - | - | - | - | - | |
| (0xBE) | Reserved | - | - | - | - | - | - | - | - | |
| (0xBD) | Reserved | - | - | - | - | - | - | - | - | |
| (0xBC) | Reserved | - | - | - | - | - | - | - | - | |
| (0xBB) | Reserved | - | - | - | - | - | - | - | - | |
| (0xBA) | USIDR | USI Data Register | | | | | | | | 190 |
| (0xB9) | USISR | USISIF | USIOIF | USIPF | USIDC | USICNT3 | USICNT2 | USICNT1 | USICNT0 | 190 |
| (0xB8) | USICR | USISIE | USIOIE | USIWM1 | USIWM0 | USICS1 | USICS0 | USICLK | USITC | 191 |
| (0xB7) | Reserved | - | - | - | - | - | - | - | - | |
| (0xB6) | ASSR | - | - | - | EXCLK | AS2 | TCN2UB | OCR2UB | TCR2UB | 146 |
| (0xB5) | Reserved | - | - | - | - | - | - | - | - | |
| (0xB4) | Reserved | - | - | - | - | - | - | - | - | |
| (0xB3) | OCR2A | Timer/Counter 2 Output Compare Register A | | | | | | | | 145 |
| (0xB2) | TCNT2 | Timer/Counter2 | | | | | | | | 144 |
| (0xB1) | Reserved | - | - | - | - | - | - | - | - | |
| (0xB0) | TCCR2A | FOC2A | WGM20 | COM2A1 | COM2A0 | WGM21 | CS22 | CS21 | CS20 | 143 |
| (0xAF) | Reserved | - | - | - | - | - | - | - | - | |
| (0xAE) | Reserved | - | - | - | - | - | - | - | - | |
| (0xAD) | Reserved | - | - | - | - | - | - | - | - | |
| (0xAC) | Reserved | - | - | - | - | - | - | - | - | |
| (0xAB) | Reserved | - | - | - | - | - | - | - | - | |
| (0xAA) | Reserved | - | - | - | - | - | - | - | - | |
| (0xA9) | Reserved | - | - | - | - | - | - | - | - | |
| (0xA8) | Reserved | - | - | - | - | - | - | - | - | |
| (0xA7) | Reserved | - | - | - | - | - | - | - | - | |
| (0xA6) | Reserved | - | - | - | - | - | - | - | - | |
| (0xA5) | Reserved | - | - | - | - | - | - | - | - | |
| (0xA4) | Reserved | - | - | - | - | - | - | - | - | |
| (0xA3) | Reserved | - | - | - | - | - | - | - | - | |
| (0xA2) | Reserved | - | - | - | - | - | - | - | - | |
| (0xA1) | Reserved | - | - | - | - | - | - | - | - | |
| (0xA0) | Reserved | - | - | - | - | - | - | - | - | |
| (0x9F) | Reserved | - | - | - | - | - | - | - | - | |
| (0x9E) | Reserved | - | - | - | - | - | - | - | - | |
| (0x9D) | Reserved | - | - | - | - | - | - | - | - | |
| (0x9C) | Reserved | - | - | - | - | - | - | - | - | |
| (0x9B) | Reserved | - | - | - | - | - | - | - | - | |
| (0x9A) | Reserved | - | - | - | - | - | - | - | - | |
| (0x99) | Reserved | - | - | - | - | - | - | - | - | |
| (0x98) | Reserved | - | - | - | - | - | - | - | - | |
| (0x97) | Reserved | - | - | - | - | - | - | - | - | |
| (0x96) | Reserved | - | - | - | - | - | - | - | - | |
| (0x95) | Reserved | - | - | - | - | - | - | - | - | |
| (0x94) | Reserved | - | - | - | - | - | - | - | - | |
| (0x93) | Reserved | - | - | - | - | - | - | - | - | |
| (0x92) | Reserved | - | - | - | - | - | - | - | - | |
| (0x91) | Reserved | - | - | - | - | - | - | - | - | |
| (0x90) | Reserved | - | - | - | - | - | - | - | - | |
| (0x8F) | Reserved | - | - | - | - | - | - | - | - | |
| (0x8E) | Reserved | - | - | - | - | - | - | - | - | |
| (0x8D) | Reserved | - | - | - | - | - | - | - | - | |
| (0x8C) | Reserved | - | - | - | - | - | - | - | - | |
| (0x8B) | OCR1BH | Timer/Counter1 Output Compare Register B High | | | | | | | | 126 |
| (0x8A) | OCR1BL | Timer/Counter1 Output Compare Register B Low | | | | | | | | 126 |
| (0x89) | OCR1AH | Timer/Counter1 Output Compare Register A High | | | | | | | | 126 |
| (0x88) | OCR1AL | Timer/Counter1 Output Compare Register A Low | | | | | | | | 126 |
| (0x87) | ICR1H | Timer/Counter1 Input Capture Register High | | | | | | | | 126 |
| (0x86) | ICR1L | Timer/Counter1 Input Capture Register Low | | | | | | | | 126 |
| (0x85) | TCNT1H | Timer/Counter1 High | | | | | | | | 126 |
| (0x84) | TCNT1L | Timer/Counter1 Low | | | | | | | | 126 |

| | | | | | | | | | | | |
|-------------|----------|--|---------|---------|---------|---------|---------|----------|---------|-------|-----------|
| (0x83) | Reserved | – | – | – | – | – | – | – | – | – | – |
| (0x82) | TCCR1C | FOC1A | FOC1B | – | – | – | – | – | – | – | 125 |
| (0x81) | TCCR1B | ICNC1 | ICES1 | – | – | WGM13 | WGM12 | CS12 | CS11 | CS10 | 124 |
| (0x80) | TCCR1A | COM1A1 | COM1A0 | COM1B1 | COM1B0 | – | – | – | WGM11 | WGM10 | 122 |
| (0x7F) | DIDR1 | – | – | – | – | – | – | – | AIN1D | AIN0D | 197 |
| (0x7E) | DIDR0 | ADC7D | ADC6D | ADC5D | ADC4D | ADC3D | ADC2D | ADC1D | ADC0D | – | 215 |
| (0x7D) | Reserved | – | – | – | – | – | – | – | – | – | – |
| (0x7C) | ADMUX | REFS1 | REFS0 | ADLAR | MUX4 | MUX3 | MUX2 | MUX1 | MUX0 | – | 211 |
| (0x7B) | ADCSRB | – | ACME | – | – | – | ADTS2 | ADTS1 | ADTS0 | – | 214 |
| (0x7A) | ADCSRA | ADEN | ADSC | ADATE | ADIF | ADIE | ADPS2 | ADPS1 | ADPS0 | – | 213 |
| (0x79) | ADCH | ADC Data Register High | | | | | | | | | 214 |
| (0x78) | ADCL | ADC Data Register Low | | | | | | | | | 214 |
| (0x77) | Reserved | – | – | – | – | – | – | – | – | – | – |
| (0x76) | Reserved | – | – | – | – | – | – | – | – | – | – |
| (0x75) | Reserved | – | – | – | – | – | – | – | – | – | – |
| (0x74) | Reserved | – | – | – | – | – | – | – | – | – | – |
| (0x73) | PCMSK3 | – | PCINT30 | PCINT29 | PCINT28 | PCINT27 | PCINT26 | PCINT25 | PCINT24 | – | 63 |
| (0x72) | Reserved | – | – | – | – | – | – | – | – | – | – |
| (0x71) | Reserved | – | – | – | – | – | – | – | – | – | – |
| (0x70) | TIMSK2 | – | – | – | – | – | – | OCIE2A | TOIE2 | – | 145 |
| (0x6F) | TIMSK1 | – | – | ICIE1 | – | – | – | OCIE1B | OCIE1A | TOIE1 | 127 |
| (0x6E) | TIMSK0 | – | – | – | – | – | – | OCIE0A | TOIE0 | – | 101 |
| (0x6D) | PCMSK2 | PCINT23 | PCINT22 | PCINT21 | PCINT20 | PCINT19 | PCINT18 | PCINT17 | PCINT16 | – | 63 |
| (0x6C) | PCMSK1 | PCINT15 | PCINT14 | PCINT13 | PCINT12 | PCINT11 | PCINT10 | PCINT9 | PCINT8 | – | 63 |
| (0x6B) | PCMSK0 | PCINT7 | PCINT6 | PCINT5 | PCINT4 | PCINT3 | PCINT2 | PCINT1 | PCINT0 | – | 63 |
| (0x6A) | Reserved | – | – | – | – | – | – | – | – | – | – |
| (0x69) | EICRA | – | – | – | – | – | – | ISC01 | ISC00 | – | 61 |
| (0x68) | Reserved | – | – | – | – | – | – | – | – | – | – |
| (0x67) | Reserved | – | – | – | – | – | – | – | – | – | – |
| (0x66) | OSCCAL | Oscillator Calibration Register [CAL7:0] | | | | | | | | | 36 |
| (0x65) | Reserved | – | – | – | – | – | – | – | – | – | – |
| (0x64) | PRR | – | – | – | – | PRTIM1 | PRSPI | PSUSART0 | PRADC | – | 43 |
| (0x63) | Reserved | – | – | – | – | – | – | – | – | – | – |
| (0x62) | Reserved | – | – | – | – | – | – | – | – | – | – |
| (0x61) | CLKPR | CLKPCE | – | – | – | CLKPS3 | CLKPS2 | CLKPS1 | CLKPS0 | – | 36 |
| (0x60) | WDTCSR | – | – | – | WDCE | WDE | WDP2 | WDP1 | WDP0 | – | 50 |
| 0x3F (0x5F) | SREG | I | T | H | S | V | N | Z | C | – | 13 |
| 0x3E (0x5E) | SPH | Stack Pointer High | | | | | | | | | 15 |
| 0x3D (0x5D) | SPL | Stack Pointer Low | | | | | | | | | 15 |
| 0x3C (0x5C) | Reserved | – | – | – | – | – | – | – | – | – | – |
| 0x3B (0x5B) | Reserved | – | – | – | – | – | – | – | – | – | – |
| 0x3A (0x5A) | Reserved | – | – | – | – | – | – | – | – | – | – |
| 0x39 (0x59) | Reserved | – | – | – | – | – | – | – | – | – | – |
| 0x38 (0x58) | Reserved | – | – | – | – | – | – | – | – | – | – |
| 0x37 (0x57) | SPMCSR | SPMIE | RWWSB | – | RWWSRE | BLBSET | PGWRT | PGERS | SPMEN | – | 262 |
| 0x36 (0x56) | Reserved | – | – | – | – | – | – | – | – | – | – |
| 0x35 (0x55) | MCUCR | JTD | BODS | BODSE | PUD | – | – | IVSEL | IVCE | – | 58/85/247 |
| 0x34 (0x54) | MCUSR | – | – | – | JTRF | WDRF | BORF | EXTRF | PORF | – | 50 |
| 0x33 (0x53) | SMCR | – | – | – | – | SM2 | SM1 | SM0 | SE | – | 50 |
| 0x32 (0x52) | Reserved | – | – | – | – | – | – | – | – | – | – |
| 0x31 (0x51) | OCDR | IDRD/OCDR7 | OCDR6 | OCDR5 | OCDR4 | OCDR3 | OCDR2 | OCDR1 | OCDR0 | – | 221 |
| 0x30 (0x50) | ACSR | ACD | ACBG | ACO | ACI | ACIE | ACIC | ACIS1 | ACIS0 | – | 196 |
| 0x2F (0x4F) | Reserved | – | – | – | – | – | – | – | – | – | – |
| 0x2E (0x4E) | SPDR | SPI Data Register | | | | | | | | | 155 |
| 0x2D (0x4D) | SPSR | SPIF | WCOL | – | – | – | – | – | – | SPI2X | 155 |
| 0x2C (0x4C) | SPCR | SPIE | SPE | DORD | MSTR | CPOL | CPHA | SPR1 | SPR0 | – | 154 |
| 0x2B (0x4B) | GPIOR2 | General Purpose I/O Register | | | | | | | | | 27 |
| 0x2A (0x4A) | GPIOR1 | General Purpose I/O Register | | | | | | | | | 27 |
| 0x29 (0x49) | Reserved | – | – | – | – | – | – | – | – | – | – |
| 0x28 (0x48) | Reserved | – | – | – | – | – | – | – | – | – | – |
| 0x27 (0x47) | OCR0A | Timer/Counter0 Output Compare A | | | | | | | | | 101 |
| 0x26 (0x46) | TCNT0 | Timer/Counter0 | | | | | | | | | 100 |
| 0x25 (0x45) | Reserved | – | – | – | – | – | – | – | – | – | – |
| 0x24 (0x44) | TCCR0A | FOC0A | WGM00 | COM0A1 | COM0A0 | WGM01 | CS02 | CS01 | CS00 | – | 98 |
| 0x23 (0x43) | GTCCR | TSM | – | – | – | – | – | PSR2 | PSR10 | – | 130/146 |

8. Instruction Set Summary

| Mnemonics | Operands | Description | Operation | Flags | #Clocks |
|--|----------|--|---|------------|---------|
| ARITHMETIC AND LOGIC INSTRUCTIONS | | | | | |
| 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 | RdI,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 |
| 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 |
| SBIW | RdI,K | Subtract Immediate from Word | $Rdh:Rdl \leftarrow Rdh:Rdl - K$ | Z,C,N,V,S | 2 |
| AND | Rd, Rr | Logical AND Registers | $Rd \leftarrow Rd \bullet Rr$ | Z,N,V | 1 |
| ANDI | Rd, K | Logical AND Register and Constant | $Rd \leftarrow Rd \bullet K$ | 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 | $Rd \leftarrow 0xFF - Rd$ | Z,C,N,V | 1 |
| NEG | Rd | Two's Complement | $Rd \leftarrow 0x00 - Rd$ | 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 | $Rd \leftarrow Rd \bullet (0xFF - K)$ | 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 | $Rd \leftarrow Rd \bullet Rd$ | Z,N,V | 1 |
| CLR | Rd | Clear Register | $Rd \leftarrow Rd \oplus Rd$ | Z,N,V | 1 |
| SER | Rd | Set Register | $Rd \leftarrow 0xFF$ | None | 1 |
| MUL | Rd, Rr | Multiply Unsigned | $R1:R0 \leftarrow Rd \times Rr$ | Z,C | 2 |
| MULS | Rd, Rr | Multiply Signed | $R1:R0 \leftarrow Rd \times Rr$ | Z,C | 2 |
| MULSU | Rd, Rr | Multiply Signed with Unsigned | $R1:R0 \leftarrow Rd \times Rr$ | Z,C | 2 |
| FMUL | Rd, Rr | Fractional Multiply Unsigned | $R1:R0 \leftarrow (Rd \times Rr) \ll 1$ | Z,C | 2 |
| FMULS | Rd, Rr | Fractional Multiply Signed | $R1:R0 \leftarrow (Rd \times Rr) \ll 1$ | Z,C | 2 |
| FMULSU | Rd, Rr | Fractional Multiply Signed with Unsigned | $R1:R0 \leftarrow (Rd \times Rr) \ll 1$ | Z,C | 2 |
| BRANCH INSTRUCTIONS | | | | | |
| RJMP | k | Relative Jump | $PC \leftarrow PC + k + 1$ | None | 2 |
| IJMP | | Indirect Jump to (Z) | $PC \leftarrow Z$ | None | 2 |
| JMP | k | Direct Jump | $PC \leftarrow k$ | None | 3 |
| RCALL | k | Relative Subroutine Call | $PC \leftarrow PC + k + 1$ | None | 3 |
| ICALL | | Indirect Call to (Z) | $PC \leftarrow Z$ | None | 3 |
| CALL | k | Direct Subroutine Call | $PC \leftarrow k$ | None | 4 |
| 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 | 1/2/3 |
| CP | Rd,Rr | Compare | $Rd - Rr$ | Z, N,V,C,H | 1 |
| CPC | Rd,Rr | Compare with Carry | $Rd - Rr - C$ | Z, N,V,C,H | 1 |
| CPI | Rd,K | Compare Register with Immediate | $Rd - K$ | Z, N,V,C,H | 1 |
| SBRC | Rr, b | Skip if Bit in Register Cleared | if $(Rr(b)=0) PC \leftarrow PC + 2$ or 3 | None | 1/2/3 |
| SBRS | Rr, b | Skip if Bit in Register is Set | if $(Rr(b)=1) PC \leftarrow PC + 2$ or 3 | None | 1/2/3 |
| SBIC | P, b | Skip if Bit in I/O Register Cleared | if $(P(b)=0) PC \leftarrow PC + 2$ or 3 | None | 1/2/3 |
| SBIS | P, b | Skip if Bit in I/O Register is Set | if $(P(b)=1) PC \leftarrow PC + 2$ or 3 | None | 1/2/3 |
| 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 |

| Mnemonics | Operands | Description | Operation | Flags | #Clocks |
|--------------------------------------|----------|------------------------------------|--|---------|---------|
| BRVC | k | Branch if Overflow Flag is Cleared | if (V = 0) then PC ← PC + k + 1 | None | 1/2 |
| BRIE | k | Branch if Interrupt Enabled | if (I = 1) then PC ← PC + k + 1 | None | 1/2 |
| BRID | k | Branch if Interrupt Disabled | if (I = 0) then PC ← PC + k + 1 | None | 1/2 |
| BIT AND BIT-TEST INSTRUCTIONS | | | | | |
| SBI | P,b | Set Bit in I/O Register | I/O(P,b) ← 1 | None | 2 |
| CBI | P,b | Clear Bit in I/O Register | I/O(P,b) ← 0 | None | 2 |
| LSL | Rd | Logical Shift Left | Rd(n+1) ← Rd(n), Rd(0) ← 0 | Z,C,N,V | 1 |
| LSR | Rd | Logical Shift Right | Rd(n) ← Rd(n+1), Rd(7) ← 0 | Z,C,N,V | 1 |
| ROL | Rd | Rotate Left Through Carry | Rd(0) ← C, Rd(n+1) ← Rd(n), C ← Rd(7) | Z,C,N,V | 1 |
| ROR | Rd | Rotate Right Through Carry | Rd(7) ← C, Rd(n) ← Rd(n+1), C ← Rd(0) | Z,C,N,V | 1 |
| ASR | Rd | Arithmetic Shift Right | Rd(n) ← Rd(n+1), n=0..6 | Z,C,N,V | 1 |
| SWAP | Rd | Swap Nibbles | Rd(3..0) ← Rd(7..4), Rd(7..4) ← Rd(3..0) | None | 1 |
| BSET | s | Flag Set | SREG(s) ← 1 | SREG(s) | 1 |
| BCLR | s | Flag Clear | SREG(s) ← 0 | SREG(s) | 1 |
| BST | Rr, b | Bit Store from Register to T | T ← Rr(b) | T | 1 |
| BLD | Rd, b | Bit load from T to Register | Rd(b) ← T | None | 1 |
| SEC | | Set Carry | C ← 1 | C | 1 |
| CLC | | Clear Carry | C ← 0 | C | 1 |
| SEN | | Set Negative Flag | N ← 1 | N | 1 |
| CLN | | Clear Negative Flag | N ← 0 | N | 1 |
| SEZ | | Set Zero Flag | Z ← 1 | Z | 1 |
| CLZ | | Clear Zero Flag | Z ← 0 | Z | 1 |
| SEI | | Global Interrupt Enable | I ← 1 | I | 1 |
| CLI | | Global Interrupt Disable | I ← 0 | I | 1 |
| SES | | Set Signed Test Flag | S ← 1 | S | 1 |
| CLS | | Clear Signed Test Flag | S ← 0 | S | 1 |
| SEV | | Set Twos Complement Overflow. | V ← 1 | V | 1 |
| CLV | | Clear Twos Complement Overflow | V ← 0 | V | 1 |
| SET | | Set T in SREG | T ← 1 | T | 1 |
| CLT | | Clear T in SREG | T ← 0 | T | 1 |
| SEH | | Set Half Carry Flag in SREG | H ← 1 | H | 1 |
| CLH | | Clear Half Carry Flag in SREG | H ← 0 | H | 1 |
| DATA TRANSFER INSTRUCTIONS | | | | | |
| MOV | Rd, Rr | Move Between Registers | Rd ← Rr | None | 1 |
| MOVW | Rd, Rr | Copy Register Word | Rd+1:Rd ← Rr+1:Rr | None | 1 |
| LDI | Rd, K | Load Immediate | Rd ← K | None | 1 |
| LD | Rd, X | Load Indirect | Rd ← (X) | None | 2 |
| LD | Rd, X+ | Load Indirect and Post-Inc. | Rd ← (X), X ← X + 1 | None | 2 |
| LD | Rd, -X | Load Indirect and Pre-Dec. | X ← X - 1, Rd ← (X) | None | 2 |
| LD | Rd, Y | Load Indirect | Rd ← (Y) | None | 2 |
| LD | Rd, Y+ | Load Indirect and Post-Inc. | Rd ← (Y), Y ← Y + 1 | None | 2 |
| LD | Rd, -Y | Load Indirect and Pre-Dec. | Y ← Y - 1, Rd ← (Y) | None | 2 |
| LDD | Rd, Y+q | Load Indirect with Displacement | Rd ← (Y + q) | None | 2 |
| LD | Rd, Z | Load Indirect | Rd ← (Z) | None | 2 |
| LD | Rd, Z+ | Load Indirect and Post-Inc. | Rd ← (Z), Z ← Z+1 | None | 2 |
| LD | Rd, -Z | Load Indirect and Pre-Dec. | Z ← Z - 1, Rd ← (Z) | None | 2 |
| LDD | Rd, Z+q | Load Indirect with Displacement | Rd ← (Z + q) | None | 2 |
| LDS | Rd, k | Load Direct from SRAM | Rd ← (k) | None | 2 |
| ST | X, Rr | Store Indirect | (X) ← Rr | None | 2 |
| ST | X+, Rr | Store Indirect and Post-Inc. | (X) ← Rr, X ← X + 1 | None | 2 |
| ST | -X, Rr | Store Indirect and Pre-Dec. | X ← X - 1, (X) ← Rr | None | 2 |
| ST | Y, Rr | Store Indirect | (Y) ← Rr | None | 2 |
| ST | Y+, Rr | Store Indirect and Post-Inc. | (Y) ← Rr, Y ← Y + 1 | None | 2 |
| ST | -Y, Rr | Store Indirect and Pre-Dec. | Y ← Y - 1, (Y) ← Rr | None | 2 |
| STD | Y+q, Rr | Store Indirect with Displacement | (Y + q) ← Rr | None | 2 |
| ST | Z, Rr | Store Indirect | (Z) ← Rr | None | 2 |
| ST | Z+, Rr | Store Indirect and Post-Inc. | (Z) ← Rr, Z ← Z + 1 | None | 2 |
| ST | -Z, Rr | Store Indirect and Pre-Dec. | Z ← Z - 1, (Z) ← Rr | None | 2 |
| STD | Z+q, Rr | Store Indirect with Displacement | (Z + q) ← Rr | None | 2 |
| STS | k, Rr | Store Direct to SRAM | (k) ← Rr | None | 2 |
| LPM | | Load Program Memory | R0 ← (Z) | None | 3 |
| LPM | Rd, Z | Load Program Memory | Rd ← (Z) | None | 3 |
| LPM | Rd, Z+ | Load Program Memory and Post-Inc | Rd ← (Z), Z ← Z+1 | None | 3 |
| SPM | | Store Program Memory | (Z) ← R1:R0 | None | - |
| IN | Rd, P | In Port | Rd ← P | None | 1 |
| OUT | P, Rr | Out Port | P ← Rr | None | 1 |
| PUSH | Rr | Push Register on Stack | STACK ← Rr | None | 2 |
| POP | Rd | Pop Register from Stack | Rd ← STACK | None | 2 |

| Mnemonics | Operands | Description | Operation | Flags | #Clocks |
|---------------------------------|----------|----------------|--|-------|---------|
| 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 |

9. Ordering Information

9.1 ATmega165A

| Speed (MHz) ⁽³⁾ | Power Supply | Ordering Code ⁽²⁾ | Package ⁽¹⁾ | Operation Range |
|----------------------------|--------------|--|--|---|
| 16 | 1.8 - 5.5V | ATmega165A-AU ATmega165A-AUR ⁽⁴⁾ ATmega165A-MU ATmega165A-MUR ⁽⁴⁾ ATmega165A-MCH ATmega165A-MCHR ⁽⁴⁾ | 64A 64A 64M1 64M1 64MC 64MC | Industrial (-40°C to 85°C) |
| | | ATmega165A-AN ATmega165A-ANR ⁽⁴⁾ ATmega165A-MN ATmega165A-MNR ⁽⁴⁾ | 64A 64A 64M1 64M1 | Extended (-40°C to 105°C) ⁽⁵⁾ |

- Notes:
1. This device can also be supplied in wafer form. Please contact your local Atmel sales office for detailed ordering information and minimum quantities.
 2. Pb-free packaging, complies to the European Directive for Restriction of Hazardous Substances (RoHS directive). Also Halide free and fully Green.
 3. For Speed vs. V_{CC} , see [Figure 28-1 on page 302](#).
 4. Tape & Reel
 5. See characterization specifications at 105°C.

| Package Type | |
|--------------|--|
| 64A | 64-Lead, Thin (1.0mm) Plastic Gull Wing Quad Flat Package (TQFP) |
| 64M1 | 64-pad, 9 x 9 x 1.0mm body, lead pitch 0.50mm, Quad Flat No-Lead/Micro Lead Frame Package (QFN/MLF) |
| 64MC | 64-lead (2-row Staggered), 7 x 7 x 1.0 mm body, 4.0 x 4.0mm Exposed Pad, Quad Flat No-Lead Package (QFN) |

9.2 ATmega165PA

| Speed (MHz) ⁽³⁾ | Power Supply | Ordering Code ⁽²⁾ | Package ⁽¹⁾ | Operation Range |
|--------------------------------|--------------|---------------------------------|------------------------|---|
| 16 | 1.8 - 5.5V | ATmega165PA-AU | 64A | Industrial (-40°C to 85°C) |
| | | ATmega165PA-AUR ⁽⁴⁾ | 64A | |
| | | ATmega165PA-MU | 64M1 | |
| | | ATmega165PA-MUR ⁽⁴⁾ | 64M1 | |
| | | ATmega165PA-MCH | 64MC | |
| | | ATmega165PA-MCHR ⁽⁴⁾ | 64MC | |
| | | ATmega165PA-AN | 64A | Extended (-40°C to 105°C) ⁽⁵⁾ |
| | | ATmega165PA-ANR ⁽⁴⁾ | 64A | |
| ATmega165PA-MN | 64M1 | | | |
| ATmega165PA-MNR ⁽⁴⁾ | 64M1 | | | |

- Notes:
1. This device can also be supplied in wafer form. Please contact your local Atmel sales office for detailed ordering information and minimum quantities.
 2. Pb-free packaging, complies to the European Directive for Restriction of Hazardous Substances (RoHS directive). Also Halide free and fully Green.
 3. For Speed vs. V_{CC} , see [Figure 28-1 on page 302](#).
 4. Tape & Reel.
 5. See characterization specifications at 105°C.

| Package Type | |
|--------------|--|
| 64A | 64-Lead, Thin (1.0mm) Plastic Gull Wing Quad Flat Package (TQFP) |
| 64M1 | 64-pad, 9 x 9 x 1.0mm body, lead pitch 0.50mm, Quad Flat No-Lead/Micro Lead Frame Package (QFN/MLF) |
| 64MC | 64-lead (2-row Staggered), 7 x 7 x 1.0mm body, 4.0 x 4.0 mm Exposed Pad, Quad Flat No-Lead Package (QFN) |

9.3 ATmega325A

| Speed (MHz) ⁽³⁾ | Power Supply | Ordering Code ⁽²⁾ | Package ⁽¹⁾ | Operation Range |
|----------------------------|--------------|--|----------------------------|---|
| 20 | 1.8 - 5.5V | ATmega325A-AU ATmega325A-AUR ⁽⁴⁾ ATmega325A-MU ATmega325A-MUR ⁽⁴⁾ | 64A 64A 64M1 64M1 | Industrial (-40°C to 85°C) |
| | | ATmega325A-AN ATmega325A-ANR ⁽⁴⁾ ATmega325A-MN ATmega325A-MNR ⁽⁴⁾ | 64A 64A 64M1 64M1 | Extended (-40°C to 105°C) ⁽⁵⁾ |

- Notes:
1. This device can also be supplied in wafer form. Please contact your local Atmel sales office for detailed ordering information and minimum quantities.
 2. Pb-free packaging, complies to the European Directive for Restriction of Hazardous Substances (RoHS directive). Also Halide free and fully Green.
 3. For Speed vs. V_{CC} , see [Figure 28-1 on page 302](#).
 4. Tape & Reel
 5. See characterizations specifications at 105°C.

| Package Type | |
|--------------|---|
| 64A | 64-Lead, Thin (1.0mm) Plastic Gull Wing Quad Flat Package (TQFP) |
| 64M1 | 64-pad, 9 x 9 x 1.0mm body, lead pitch 0.50mm, Quad Flat No-Lead/Micro Lead Frame Package (QFN/MLF) |

9.4 ATmega325PA

| Speed (MHz) ⁽³⁾ | Power Supply | Ordering Code ⁽²⁾ | Package ⁽¹⁾ | Operation Range |
|----------------------------|--------------|--|----------------------------|---|
| 20 | 1.8 - 5.5V | ATmega325PA-AU ATmega325PA-AUR ⁽⁴⁾ ATmega325PA-MU ATmega325PA-MUR ⁽⁴⁾ | 64A 64A 64M1 64M1 | Industrial (-40°C to 85°C) |
| | | ATmega325PA-AN ATmega325PA-ANR ⁽⁴⁾ ATmega325PA-MN ATmega325PA-MNR ⁽⁴⁾ | 64A 64A 64M1 64M1 | Extended (-40°C to 105°C) ⁽⁵⁾ |

- Notes:
1. This device can also be supplied in wafer form. Please contact your local Atmel sales office for detailed ordering information and minimum quantities.
 2. Pb-free packaging, complies to the European Directive for Restriction of Hazardous Substances (RoHS directive). Also Halide free and fully Green.
 3. For Speed vs. V_{CC} , see [Figure 28-1 on page 302](#).
 4. Tape & Reel
 5. See characterization specifications at 105°C.

| Package Type | |
|--------------|---|
| 64A | 64-Lead, Thin (1.0mm) Plastic Gull Wing Quad Flat Package (TQFP) |
| 64M1 | 64-pad, 9 x 9 x 1.0mm body, lead pitch 0.50mm, Quad Flat No-Lead/Micro Lead Frame Package (QFN/MLF) |

9.5 ATmega3250A

| Speed (MHz) ⁽³⁾ | Power Supply | Ordering Code ⁽²⁾ | Package ⁽¹⁾ | Operation Range |
|----------------------------|--------------|--|------------------------|---|
| 20 | 1.8 - 5.5V | ATmega3250A-AU ATmega3250A-AUR ⁽⁴⁾ | 100A 100A | Industrial (-40°C to 85°C) |
| | | ATmega3250A-AN ATmega3250A-ANR ⁽⁴⁾ | 100A 100A | Extended (-40°C to 105°C) ⁽⁵⁾ |

- Notes:
1. This device can also be supplied in wafer form. Please contact your local Atmel sales office for detailed ordering information and minimum quantities.
 2. Pb-free packaging, complies to the European Directive for Restriction of Hazardous Substances (RoHS directive). Also Halide free and fully Green.
 3. For Speed vs. V_{CC} , see [Figure 28-1 on page 302](#).
 4. Tape & Reel
 5. See characterization specifications at 105°C.

| Package Type | |
|--------------|--|
| 100A | 100-lead, 14 x 14 x 1.0mm, 0.5mm Lead Pitch, Thin Profile Plastic Quad Flat Package (TQFP) |

9.6 ATmega3250PA

| Speed (MHz) ⁽³⁾ | Power Supply | Ordering Code ⁽²⁾ | Package ⁽¹⁾ | Operation Range |
|----------------------------|--------------|--|------------------------|---|
| 20 | 1.8 - 5.5V | ATmega3250PA-AU ATmega3250PA-AUR ⁽⁴⁾ | 100A 100A | Industrial (-40°C to 85°C) |
| | | ATmega3250PA-AN ATmega3250PA-ANR ⁽⁴⁾ | 100A 100A | Extended (-40°C to 105°C) ⁽⁵⁾ |

- Notes:
1. This device can also be supplied in wafer form. Please contact your local Atmel sales office for detailed ordering information and minimum quantities.
 2. Pb-free packaging, complies to the European Directive for Restriction of Hazardous Substances (RoHS directive). Also Halide free and fully Green.
 3. For Speed vs. V_{CC} , see [Figure 28-1 on page 302](#).
 4. Tape & Reel
 5. See characterization specifications at 105°C.

| Package Type | |
|--------------|--|
| 100A | 100-lead, 14 x 14 x 1.0mm, 0.5mm Lead Pitch, Thin Profile Plastic Quad Flat Package (TQFP) |

9.7 ATmega645A

| Speed (MHz) ⁽³⁾ | Power Supply | Ordering Code ⁽²⁾ | Package ⁽¹⁾ | Operation Range |
|----------------------------|--------------|--|----------------------------|-------------------------------|
| 20 | 1.8 - 5.5V | ATmega645A-AU ATmega645A-AUR ⁽⁴⁾ ATmega645A-MU ATmega645A-MUR ⁽⁴⁾ | 64A 64A 64M1 64M1 | Industrial (-40°C to 85°C) |

- Notes:
1. This device can also be supplied in wafer form. Please contact your local Atmel sales office for detailed ordering information and minimum quantities.
 2. Pb-free packaging, complies to the European Directive for Restriction of Hazardous Substances (RoHS directive). Also Halide free and fully Green.
 3. For Speed vs. V_{CC} , see [Figure 28-1 on page 302](#).
 4. Tape & Reel

| Package Type | |
|--------------|---|
| 64A | 64-Lead, Thin (1.0mm) Plastic Gull Wing Quad Flat Package (TQFP) |
| 64M1 | 64-pad, 9 x 9 x 1.0mm body, lead pitch 0.50mm, Quad Flat No-Lead/Micro Lead Frame Package (QFN/MLF) |

9.8 ATmega645P

| Speed (MHz) ⁽³⁾ | Power Supply | Ordering Code ⁽²⁾ | Package ⁽¹⁾ | Operation Range |
|----------------------------|--------------|--|----------------------------|-------------------------------|
| 20 | 1.8 - 5.5V | ATmega645P-AU ATmega645P-AUR ⁽⁴⁾ ATmega645P-MU ATmega645P-MUR ⁽⁴⁾ | 64A 64A 64M1 64M1 | Industrial (-40°C to 85°C) |

- Notes:
1. This device can also be supplied in wafer form. Please contact your local Atmel sales office for detailed ordering information and minimum quantities.
 2. Pb-free packaging, complies to the European Directive for Restriction of Hazardous Substances (RoHS directive). Also Halide free and fully Green.
 3. For Speed vs. V_{CC} , see [Figure 28-1 on page 302](#).
 4. Tape & Reel

| Package Type | |
|--------------|---|
| 64A | 64-Lead, Thin (1.0mm) Plastic Gull Wing Quad Flat Package (TQFP) |
| 64M1 | 64-pad, 9 x 9 x 1.0mm body, lead pitch 0.50mm, Quad Flat No-Lead/Micro Lead Frame Package (QFN/MLF) |

9.9 ATmega6450A

| Speed (MHz) ⁽³⁾ | Power Supply | Ordering Code ⁽²⁾ | Package ⁽¹⁾ | Operation Range |
|----------------------------|--------------|--|------------------------|-------------------------------|
| 20 | 1.8 - 5.5V | ATmega6450A-AU ATmega6450A-AUR ⁽⁴⁾ | 100A 100A | Industrial (-40°C to 85°C) |

- Notes:
1. This device can also be supplied in wafer form. Please contact your local Atmel sales office for detailed ordering information and minimum quantities.
 2. Pb-free packaging, complies to the European Directive for Restriction of Hazardous Substances (RoHS directive). Also Halide free and fully Green.
 3. For Speed vs. V_{CC} , see [Figure 28-1 on page 302](#).
 4. Tape & Reel

| Package Type | |
|--------------|--|
| 100A | 100-lead, 14 x 14 x 1.0mm, 0.5mm Lead Pitch, Thin Profile Plastic Quad Flat Package (TQFP) |

9.10 ATmega6450P

| Speed (MHz) ⁽³⁾ | Power Supply | Ordering Code ⁽²⁾ | Package ⁽¹⁾ | Operation Range |
|----------------------------|--------------|--|------------------------|-------------------------------|
| 20 | 1.8 - 5.5V | ATmega6450P-AU ATmega6450P-AUR ⁽⁴⁾ | 100A 100A | Industrial (-40°C to 85°C) |

- Notes:
1. This device can also be supplied in wafer form. Please contact your local Atmel sales office for detailed ordering information and minimum quantities.
 2. Pb-free packaging, complies to the European Directive for Restriction of Hazardous Substances (RoHS directive). Also Halide free and fully Green.
 3. For Speed vs. V_{CC} , see [Figure 28-1 on page 302](#).
 4. Tape & Reel

| Package Type | |
|--------------|--|
| 100A | 100-lead, 14 x 14 x 1.0mm, 0.5mm Lead Pitch, Thin Profile Plastic Quad Flat Package (TQFP) |

10. Packaging Information

10.1 64A



COMMON DIMENSIONS
(Unit of measure = mm)

| SYMBOL | MIN | NOM | MAX | NOTE |
|--------|----------|-------|-------|--------|
| A | - | - | 1.20 | |
| A1 | 0.05 | - | 0.15 | |
| A2 | 0.95 | 1.00 | 1.05 | |
| D | 15.75 | 16.00 | 16.25 | |
| D1 | 13.90 | 14.00 | 14.10 | Note 2 |
| E | 15.75 | 16.00 | 16.25 | |
| E1 | 13.90 | 14.00 | 14.10 | Note 2 |
| B | 0.30- | 0.45 | | |
| C | 0.09 | - | 0.20 | |
| L | 0.45 | - | 0.75 | |
| e | 0.80 TYP | | | |

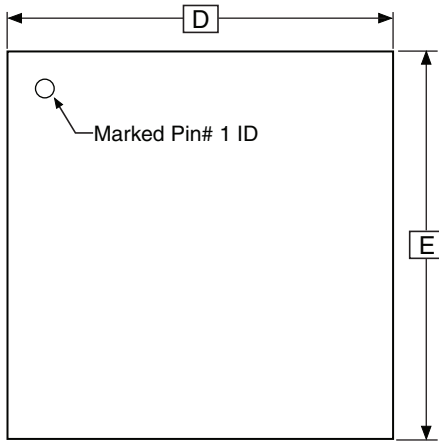
Notes:

1. This package conforms to JEDEC reference MS-026, Variation AEB.
2. Dimensions D1 and E1 do not include mold protrusion. Allowable protrusion is 0.25mm per side. Dimensions D1 and E1 are maximum plastic body size dimensions including mold mismatch.
3. Lead coplanarity is 0.10mm maximum.

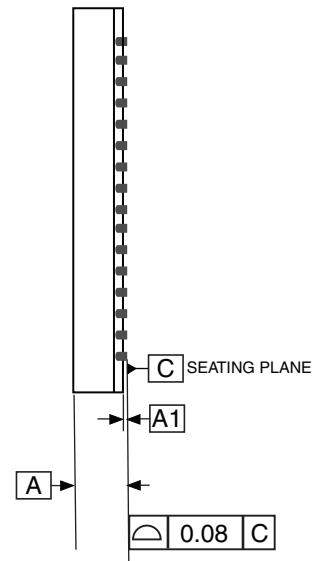
2010-10-20

| | | | |
|--|--|-------------|------|
| 2325 Orchard Parkway San Jose, CA 95131 | TITLE 64A, 64-lead, 14 x 14mm Body Size, 1.0mm Body Thickness, 0.8mm Lead Pitch, Thin Profile Plastic Quad Flat Package (TQFP) | DRAWING NO. | REV. |
| | | 64A | C |

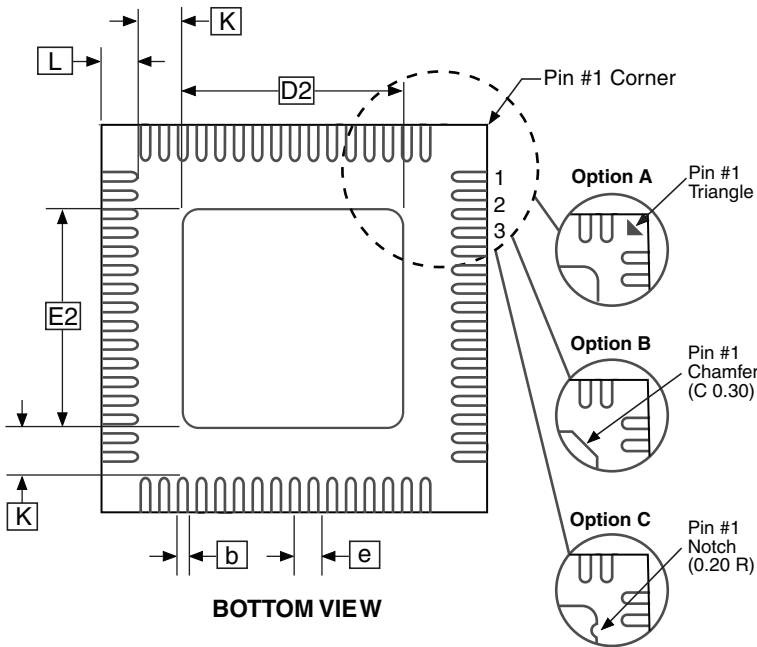
10.2 64M1



TOP VIEW



SIDE VIEW



BOTTOM VIEW

COMMON DIMENSIONS
(Unit of Measure = mm)

| SYMBOL | MIN | NOM | MAX | NOTE |
|--------|----------|------|------|------|
| A | 0.80 | 0.90 | 1.00 | |
| A1 | – | 0.02 | 0.05 | |
| b | 0.18 | 0.25 | 0.30 | |
| D | 8.90 | 9.00 | 9.10 | |
| D2 | 5.20 | 5.40 | 5.60 | |
| E | 8.90 | 9.00 | 9.10 | |
| E2 | 5.20 | 5.40 | 5.60 | |
| e | 0.50 BSC | | | |
| L | 0.35 | 0.40 | 0.45 | |
| K | 1.25 | 1.40 | 1.55 | |

Notes:

1. JEDEC Standard MO-220, (SAW Singulation) Fig. 1, VMMD.
2. Dimension and tolerance conform to ASMEY14.5M-1994.

2010-10-19

| | | | |
|--|---|--------------------|-------------|
| 2325 Orchard Parkway San Jose, CA 95131 | TITLE 64M1 , 64-pad, 9 x 9 x 1.0 mm Body, Lead Pitch 0.50 mm, 5.40 mm Exposed Pad, Micro Lead Frame Package (MLF) | DRAWING NO. | REV. |
| | | 64M1 | H |

10.3 64MC



COMMON DIMENSIONS
(Unit of Measure = mm)

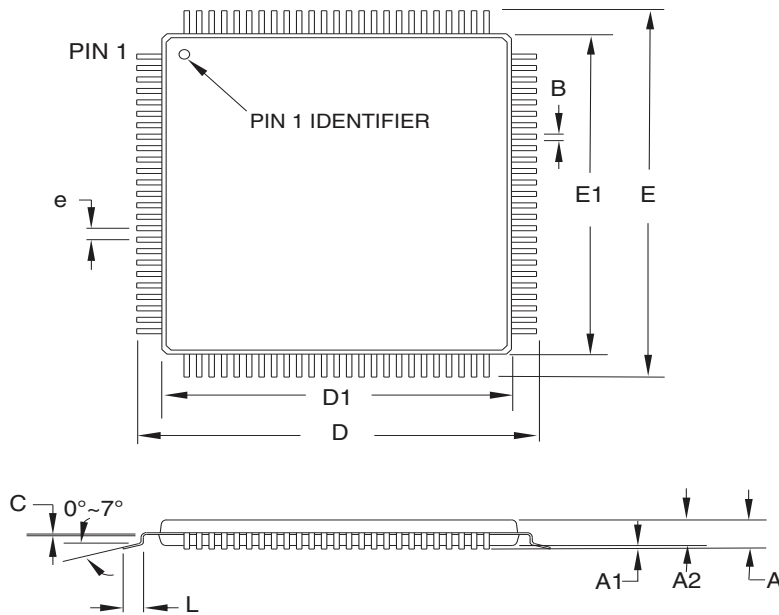
| SYMBOL | MIN | NOM | MAX | NOTE |
|--------|----------|------|-------|-------|
| A | 0.80 | 0.90 | 1.00 | |
| A1 | 0.00 | 0.02 | 0.05 | |
| b | 0.18 | 0.23 | 0.28 | |
| C | 0.20 REF | | | |
| D | 6.90 | 7.00 | 7.10 | |
| D2 | 3.95 | 4.00 | 4.05 | |
| E | 6.90 | 7.00 | 7.10 | |
| E2 | 3.95 | 4.00 | 4.05 | |
| eT | - | 0.65 | - | |
| eR | - | 0.65 | - | |
| K | 0.20 | - | - | (REF) |
| L | 0.35 | 0.40 | 0.45 | |
| y | 0.00 | - | 0.075 | |

Note: 1. The terminal #1 ID is a Laser-marked Feature.

10/3/07

| | | | | | |
|--|---|--|-----|-------------|------|
| | Package Drawing Contact: packagedrawings@atmel.com | TITLE | GPC | DRAWING NO. | REV. |
| | | 64MC, 64QFN (2-Row Staggered), 7 x 7 x 1.00 mm Body, 4.0 x 4.0 mm Exposed Pad, Quad Flat No Lead Package | ZXC | 64MC | A |

10.4 100A




COMMON DIMENSIONS
(Unit of Measure = mm)

| SYMBOL | MIN | NOM | MAX | NOTE |
|--------|----------|-------|-------|--------|
| A | – | – | 1.20 | |
| A1 | 0.05 | – | 0.15 | |
| A2 | 0.95 | 1.00 | 1.05 | |
| D | 15.75 | 16.00 | 16.25 | |
| D1 | 13.90 | 14.00 | 14.10 | Note 2 |
| E | 15.75 | 16.00 | 16.25 | |
| E1 | 13.90 | 14.00 | 14.10 | Note 2 |
| B | 0.17 | – | 0.27 | |
| C | 0.09 | – | 0.20 | |
| L | 0.45 | – | 0.75 | |
| e | 0.50 TYP | | | |

Notes:

1. This package conforms to JEDEC reference MS-026, Variation AED.
2. Dimensions D1 and E1 do not include mold protrusion. Allowable protrusion is 0.25mm per side. Dimensions D1 and E1 are maximum plastic body size dimensions including mold mismatch.
3. Lead coplanarity is 0.08mm maximum.

2014-02-05

| | | | |
|---|---|-------------|------|
|  Package Drawing Contact: packagedrawings@atmel.com | TITLE | DRAWING NO. | REV. |
| | 100A , 100-lead, 14 x 14mm Body Size, 1.0mm Body Thickness, 0.5mm Lead Pitch, Thin Profile Plastic Quad Flat Package (TQFP) | 100A | E |

11. Errata

11.1 ATmega165A/165PA/325A/325PA/3250A/3250PA/645A/645P/6450A/6450P Rev. G

No known errata.

11.2 ATmega165A/165PA/325A/325PA/3250A/3250PA/645A/645P/6450A/6450P Rev. A to F

Not sampled.

12. Datasheet Revision History

Please note that the referring page numbers in this section are referring to this document. The referring revisions in this section are referring to the document revision.

12.1 8285F – 08/2014

1. New back page from datasheet template 2014-0502
2. Changed chip definition in the text in [Section 9.6 "Low-frequency XTAL Oscillator" on page 32](#).

12.2 8285E – 02/2013

1. Applied partially the Atmel new template. New log, front page, page layout and last page changed.
2. Added ["Electrical Characteristics – TA = -40°C to 105°C" on page 308](#).
3. Removed sections 28.5 and 28.6, page 326.
4. Added ["Typical Characteristics – TA = -40°C to 105°C" on page 630](#).
5. Changed Input hysteresis (mV) to Input hysteresis (V) throughout the ["Typical characteristics – TA = -40°C to 85°C"](#).
6. Updated the typical characteristics to include Port H for all 100-pin devices: ATmega3250A/PA/6450/P. Port H has the same performance as Port A, C, D, E, F, G.
7. Updated ["Packaging Information" on page 28](#) to take into account the added the 105°C devices.

12.3 8285D – 06/11

1. Removed "Preliminary" from the front page.

12.4 8285C – 06/11

1. Updated ["Signature bytes" on page 267](#). A, P and PA devices have different signature (0x002) bytes.
2. Updated ["DC characteristics" on page 295](#) for all devices.

12.5 8285B – 03/11

1. Updated the datasheet according to the Atmel new Brand Style Guide
2. Updated ["Signature bytes"](#) , [Table 27.3 on page 267](#).
3. Updated the power supply voltage (1.5 - 5.5V) for all devices in ["Ordering Information" on page 18](#).
4. Added ["Ordering Information"](#) for Extended Temperature (-40°C to 105°C)

12.6 8285A – 09/10

1. Initial revision (Based on the ATmega165P/325P/3250P/645/6450/V).
2. Changes done compared to ATmega165P/325P/3250P/645/6450/V datasheet:
 - New EIMSK and EIFR register overview
 - New graphics in ["Typical characteristics – TA = -40°C to 85°C" on page 314](#).
 - Ordering Information includes Tape & Reel
 - New ["Ordering Information" on page 18](#).
 - QTouch Library Support Features



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