Arduino / ATmega 328P fuse settings

Posted on **August 16, 2014**

Part of programming stand-alone ATmega chips is setting the fuse bytes, these are special settings that can be used to change how the ATmega chips operate.

Some of the things you can do by changing the value of the fuses include;

- select different clock sources and change how fast the chip runs,
- set the minimum voltage required before the chip works.
- set whether or not a boot loader is used,
- set how much memory is allocated to the boot loader,
- disable reset.
- disable serial programming
- stop eeprom data being erased when uploading a new sketch.

There are many articles online but I could not find a single source that brought all the information together and fully explain what the fuses actually do.

It is important to remember that some of the fuse bits can be used to lock certain aspects of the chip and can potentially brick it (make it unusable). However, with a bit of care it is fairly straight forward to understand and use the fuse settings.

Disclaimer, I am relatively new to programming fuses and these are notes I wrote to help me remember things. The information is based on the data sheet for the ATmega chip, internet searches, and questions I asked on forums (especially the Arduino forum).

There are 3 bytes in total:

- low byte fuse,
- high byte fuse,
- extended fuse

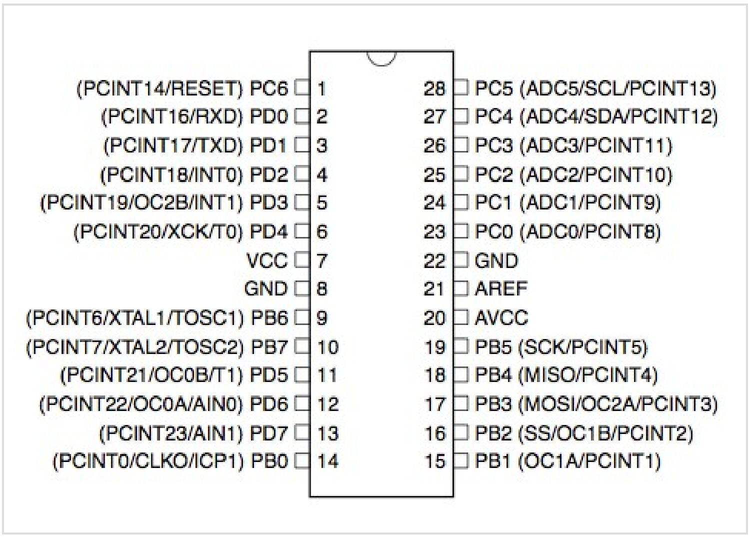
There is also a forth byte that is used to program the lock bits. Lock bits are not covered by this article.

Each byte is 8 bits and each bit is a separate setting or flag. When we talk about setting/not setting, programmed/not programmed fuses we are actually using binary. 1 means not set/not programmed and a 0 (zero) means set/programmed.

When programming the fuses you can use binary notation or more commonly hexadecimal notation. For 8 bits (1 byte) we can use B11111111 or 0xFF. Both are the same value.

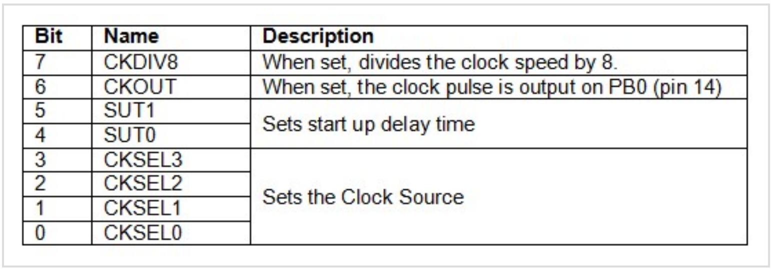
Note: For all fuses, a value of 1 means not set and a value of 0(zero) means set.

ATmega 328P 28 PDIP diagram



Low Byte Fuses

The low byte fuse deals with the clock source, how fast the chip will run, and how long it waits at startup.

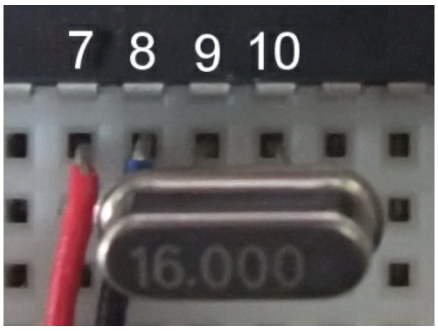


Bit	Name	Description
7	CKDIV8	When set, divides the clock speed by 8.
6	CKOUT	When set, the clock pulse is output on PB0 (pin 14)
5	SUT1	Sets start up delay time
4	SUT0	
3	CKSEL3	Sets the Clock Source
2	CKSEL2	
1	CKSEL1	
0	CKSEL0	

The ATmega chips can be run at different speeds or frequencies and the frequency is determined by the clock source that is used. The clock source is set by using the CKSEL fuse bits.

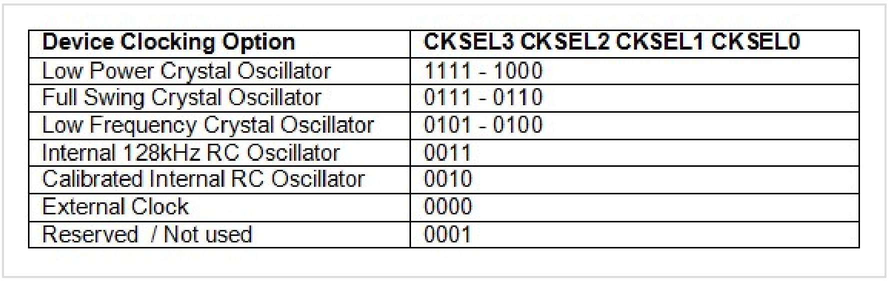
CKSEL (Clock Sources / Clock Selection)

The clock signal can come from an internal oscillator, an external crystal/resonator, or an external signal. Arduinos normally use an external 16MHz crystal.



Here is a 16 MHz crystal used on a bread board Arduino connected to XTAL1 and XTAL2. The ATmega chip has to be told to use the external crystal and this is done by setting the CKSEL bits. A common mistake is to have the crystal correctly connected in the circuit but forget to tell the chip to use it.

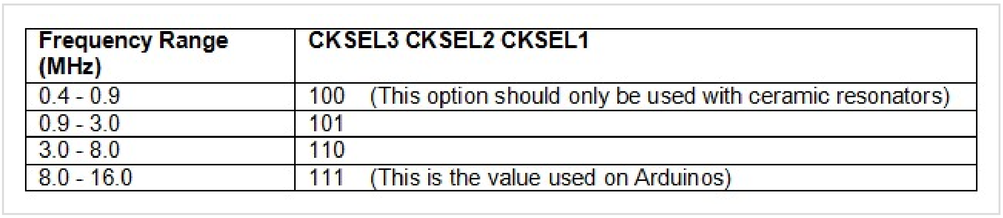
The different options for CKSEL are:



Device Clocking Option	CKSEL3 CKSEL2 CKSEL1 CKSEL0
Low Power Crystal Oscillator	1111 - 1000
Full Swing Crystal Oscillator	0111 - 0110
Low Frequency Crystal Oscillator	0101 - 0100
Internal 128kHz RC Oscillator	0011
Calibrated Internal RC Oscillator	0010
External Clock	0000
Reserved / Not used	0001

Arduinos normally use a low power crystal oscillator.
The ATmega has 2 built in oscillators, a 128kHz RC oscillator and a calibrated RC oscillator.
The external clock option allows the chip to use an external square wave clock signal. This is used when you have a circuit with its own clock that you want to sync the ATmega with or if you want to use a separate clock chip. The external clock signal needs to be connected to the CLOCK-IN pin

Crystal Oscillator Options



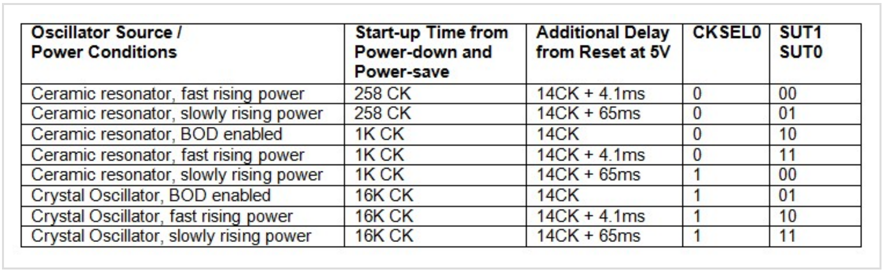
Frequency Range (MHz)	CKSEL3 CKSEL2 CKSEL1
0.4 - 0.9	100 (This option should only be used with ceramic resonators)
0.9 - 3.0	101
3.0 - 8.0	110
8.0 - 16.0	111 (This is the value used on Arduinos)

CKSEL3=1 CKSEL2=1 CKSEL1=1 CKSEL0=1 selects a crystal any where from 8MHz to 16MHz and is the normal setting for Arduinos.
If you want to use a slower crystal, for example 6MHz, then you would use CKSEL3=1 CKSEL2=1 CKSEL1=0 CKSEL0=1 (the 3.0 to 8.0 range).

To use the internal RC oscillator at 8MHz, the settings are CKSEL3=0 CKSEL2=0 CKSEL1=1 CKSEL0=0

SUT1/SUT0 (Start Up Time)
Crystals and oscillators require sufficient voltage to operate correctly. When you start the ATmega chip it can take a brief period of time for the voltage to get to its maximum value. While the voltage is rising the clock source may not be working at the correct speed or frequency. To allow the clock to stabilise a startup delay can be set.

CKSEL0 is used together with SUT1 and SUT0 to set the start up delay time.



Oscillator Source / Power Conditions	Start-up Time from Power-down and Power-save	Additional Delay from Reset at 5V	CKSEL0	SUT1 SUT0
Ceramic resonator, fast rising power	258 CK	14CK + 4.1ms	0	00
Ceramic resonator, slowly rising power	258 CK	14CK + 65ms	0	01
Ceramic resonator, BOD enabled	1K CK	14CK	0	10
Ceramic resonator, fast rising power	1K CK	14CK + 4.1ms	0	11
Ceramic resonator, slowly rising power	1K CK	14CK + 65ms	1	00
Crystal Oscillator, BOD enabled	16K CK	14CK	1	01
Crystal Oscillator, fast rising power	16K CK	14CK + 4.1ms	1	10
Crystal Oscillator, slowly rising power	16K CK	14CK + 65ms	1	11

BOD is Brown Out Detection and discussed later.

The Arduino uses the maximum startup delay of 14CK + 65ms (CKSEL0=1, SUT1=1, SUT0=1) which are also the default settings for new ATmega 328/328P chips.

CHDIV8 (Clock Divide)
ATmega 328/328P chips have a built in RC oscillator which has a 8.0MHz frequency. New chips are shipped with this set as the clock source and the CKDIV8 fuse active, resulting in a 1.0MHz system clock. The startup time is set to maximum and time-out period enabled. (CKSEL = “0010”, SUT = “10”, CKDIV8 = “0”). This setting is used so that all users can make their desired clock source setting using any available programming interface.

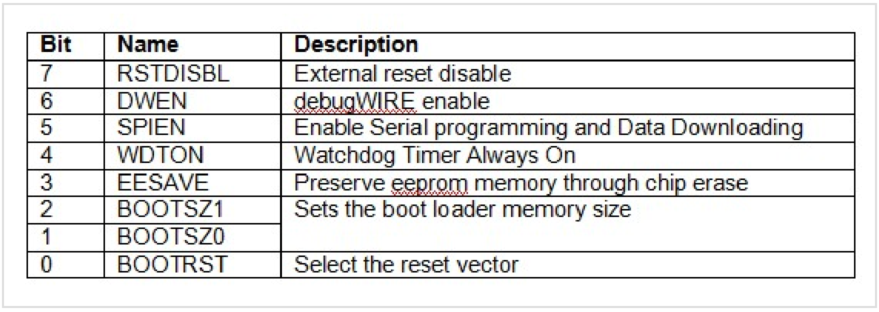
CKDIV8 should be used if the selected clock source has a higher frequency than the maximum frequency of the ATmega chip.

The ATmega chips can be used at very low voltages, however, the lower the voltage the slower they need to work at. The CHDIV8 can be used to set a slow clock speed to match a low voltage.

CKOUT (Clock Out)
The clock signal can be routed to PB0. This is useful if you need the clock signal to drive other circuits. This works for all clock sources and the default setting for new chips is CKOUT=1 (not set).

High Byte Fuses

The high byte fuse has several different settings. The ones of normal interest (to me as a hobbyist at least) are the watchdog timer, preserving or erasing eeprom and the boot loader attribute settings.



Bit	Name	Description
7	RSTDISBL	External reset disable
6	DWEN	debugWIRE enable
5	SPIEN	Enable Serial programming and Data Downloading
4	WDTON	Watchdog Timer Always On
3	EESAVE	Preserve eeprom memory through chip erase
2	BOOTSZ1	Sets the boot loader memory size
1	BOOTSZ0	
0	BOOTRST	Select the reset vector

RSTDISBL (External reset disable)
PC6 is a reset pin, hold it low (to ground) and the chip will reset. This is how the switch on the Arduino works. When you press the reset button it connects PC6 to ground and resets the chip.

PC6 can also be used as a regular IO pin but this means disabling the reset function which in turns means the chip can no longer be inline programmed (in line programming requires a reset). This is one of the options it is better not to change.

I imagine RSTDISBL is implemented for security reasons to stop the chip being reprogrammed or the firmware being downloaded.

When RSTDISBL is programmed the start up time (SUT1 SUT0) is increased to 14CK + 4.1ms to ensure the programming mode can be entered.

By default, the setting is RSTDISBL=1 (not set).

DWEN (debugWIRE enable)
ATmega chips have built in debugging tools which are by default turned off. The DWEN fuse is used to turn them on.

DWEN uses the same pin as reset (PC6) and when DWEN is enabled (and the lock bits are not set) the reset pin becomes a communication pin and normal reset no longer works. For example, if you enable DWEN on an Arduino the reset button no longer works.

To use the on-chip debugging you need a compatible programmer such as the AVR Dragon. Since I have never used AVR studio and do not have a suitable programmer I have never used and do not know how to use debugging. If you would like to know more then there is a good article at http://www.hilltop-cottage.info/blogs/adam/debugging-arduino-using-debugwire-atmel-studio-and-an-avr-dragon/ to get you started.

This is one of the fuses you should take care with. If you enable DWEN and also enable the lock bits you can no longer program the chip in the normal way.

If you are just starting then leave DWEN to not set. After all, reset is very useful.

SPIEN (Enable Serial programming and Data Downloading)
ATmega chips can be programmed using serial programming. Serial programming is used for on board programming using a serial protocol via an ISP (inline serial programmer) or UART (universal asynchronous receiver/transmitter).

The normal method of programming the ATmega chips is via the SPI interface using the SCK (clock), MOSI (input) and MISO (output) pins. If you disable serial programming then you can no longer use the SPI to program the chip. You can also disable serial programming using the lock bits.

For normal use and development leave SPIEN enabled, however, if you have a device that is final and no further programming is required then you can use this option to stop people accessing the chip through serial communication.

The default setting is SPIEN enabled, SPIEN=0.

The RSTDISBL, SPIEN and DWEN fuses have the potential to brick the ATmega chip, or at least make the chip very very difficult to use again. For general use, and especially if you are just starting out with programming stand-alone chips, you should not change these fuse settings. You should also double check that you are not changing them when you re-write the other fuse settings.

WDTON (Watchdog Timer Always On)
The watchdog is basically a timer that will cause the chip to reset if it does not receive an OK signal at specific times.

This can be useful when you have unstable code or have a system that must not be allowed to permanently lock up.

When the watchdog timer is enabled, should a sketch crash or freeze then the timer will time out and reset the chip causing a restart similar to pressing the reset button an a running Arduino.

The Watchdog Timer can be activated in software so the fuse settings doesn’t really need to be used. By default, the watchdog timer is off, WDTON=1.

There is a nice mini guide on the Watchdog timer by za_nic on the Arduino forum at ttp://forum.arduino.cc/index.php/topic,63651.0.html
Paul Martinsen has a guide on how to use the watchdog timer to detect lockups at http://www.megunolink.com/how-to-detect-lockups-using-the-arduino-watchdog/

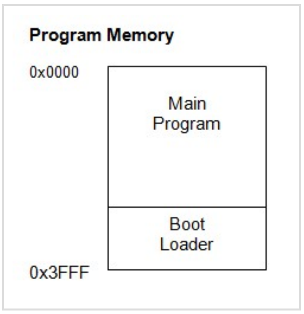
EESAVE (Preserve EEPROM memory)
When the ATmega chip is programmed the memory is erased just before the new code is uploaded. Under normal circumstances the eeprom memory is erased as well as the program memory. The EESAVE fuse can be used to tell the chip not to erase the eeprom. This is useful when you want to upgrade code but keep user settings that are stored in eeprom.

The default value is EESAVE=1, not set and eeprom memory is erased during the chip erase cycle when programming.

I have got into the habit of setting this fuse; eeprom has a limited life cycle so the less you write to it the better. Erasing the eeprom has no effect on uploading new code and the majority of my projects don’t use the eeprom memory so not erasing it is not a problem. The dropController stores settings and drop times in eeprom and so I set EESAVE to preserve the data when I upload new versions of the code.

BOOTSZ1 & BOOTSZ0 (Boot loader Size)
The ATmega chips have the ability to use a boot loader, this is a small program that runs when the chip is first started or when it is reset. Boot loaders are normally used to initialize the device and check for external communication. The Arduino uses a boot loader to talk to a connected computer to see if there is a new program to be uploaded. This is the reason the Arduino resets when you upload new code, the reset runs the boot loader, the boot loader checks to see if you have new code.

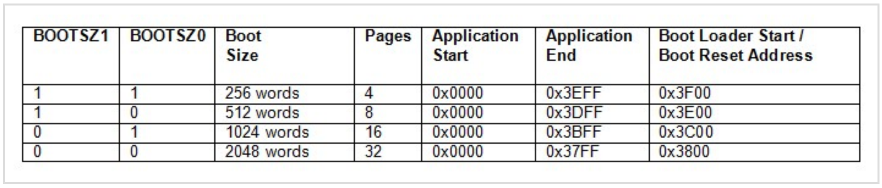
The boot loader is stored in program memory, the same memory used for the user application and since the boot loader can be different sizes you can tell the ATmega chip how much space to reserve. The regular (older) Arduino boot loader is 2 kilobytes (KB) but the newer Optiboot (used on the UNO) is only 0.5KB (512 bytes). If using Optiboot and setting the boot loader size accordingly you gain an extra 1.5KB for your own program. 1.5KB can be a lot of space, running out of program space is why I started programming stand alone ATmega chips in the first place. The code for the dropController became too large for the regular Arduino so I removed the boot loader.



The boot loader is stored at the top of the program memory

If you have a boot loader then BOOTSZ has to be used in conjunction with BOOTRST. BOOTRST tells the ATmega chip the memory address where the boot loader starts. If BOOTRST is not set then the user application can use the whole of the memory regardless of the BOOTSZ settings.

Boot Size Configuration for the 328/328P



BOOTSZ1	BOOTSZ0	Boot Size	Pages	Application Start	Application End	Boot Loader Start / Boot Reset Address
1	1	256 words	4	0x0000	0x3EFF	0x3F00
1	0	512 words	8	0x0000	0x3DFF	0x3E00
0	1	1024 words	16	0x0000	0x3BFF	0x3C00
0	0	2048 words	32	0x0000	0x37FF	0x3800

Note that the above sizes are in words (a word is 2 bytes) and 256 words is 512 bytes.
The default for new chips is BOOTSZ1=0 BOOTSZ0=0 which means they have 4KB reserved for a boot loader.

BOOTRST Select reset vector
ATmega chips can use a boot loader, this is a small program that runs when the chip is reset. If you have a boot loader then you need to inform the MCU and this is done by using the BOOTRST fuse setting. When the BOOTRST Fuse is set, on reset the device will jump to the Boot Loader address. If not set, the chip will jump to the program start address at 0x0000.

The default value is BOOTRST = 1 (not set).

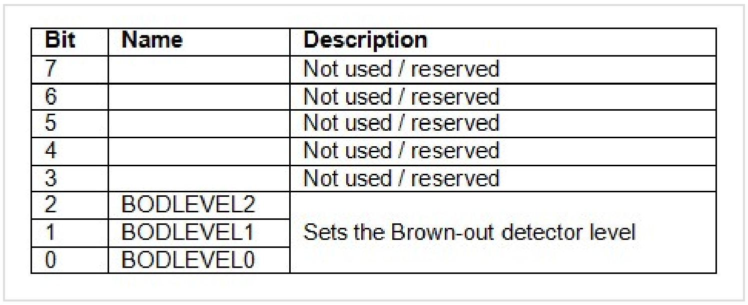
If BOOTRST is not set (no boot loader) then the BOOTSZ fuses are ignored.

Extended Fuse Bits

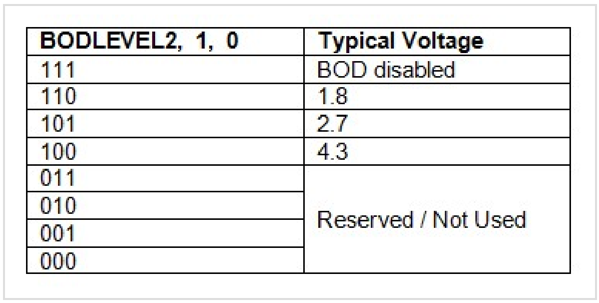
The extended fuses are only used to set the brown-out detection level (BOD).

The ATmega chips can become unstable or unreliable when used with insufficient voltage. For example, the 328/328P can run safely at 16MHz if it has at least 4V. Anything below 4V means the chip is likely to misbehave. This would be a problem if the device were being used with sensors to take measurements or relied on accurate timings.

To ensure the chip has sufficient input voltage a minimum voltage level can be set. If the voltage falls below this level then the chip will reset itself. This is called the brown-out detector level. Basically, if the supplied voltage is below the BOD the chip keeps reset low.



Bit	Name	Description
7		Not used / reserved
6		Not used / reserved
5		Not used / reserved
4		Not used / reserved
3		Not used / reserved
2	BODLEVEL2	Sets the Brown-out detector level
1	BODLEVEL1	
0	BODLEVEL0	



BODLEVEL2, 1, 0	Typical Voltage
111	BOD disabled
110	1.8
101	2.7
100	4.3
011	Reserved / Not Used
010	
001	
000	

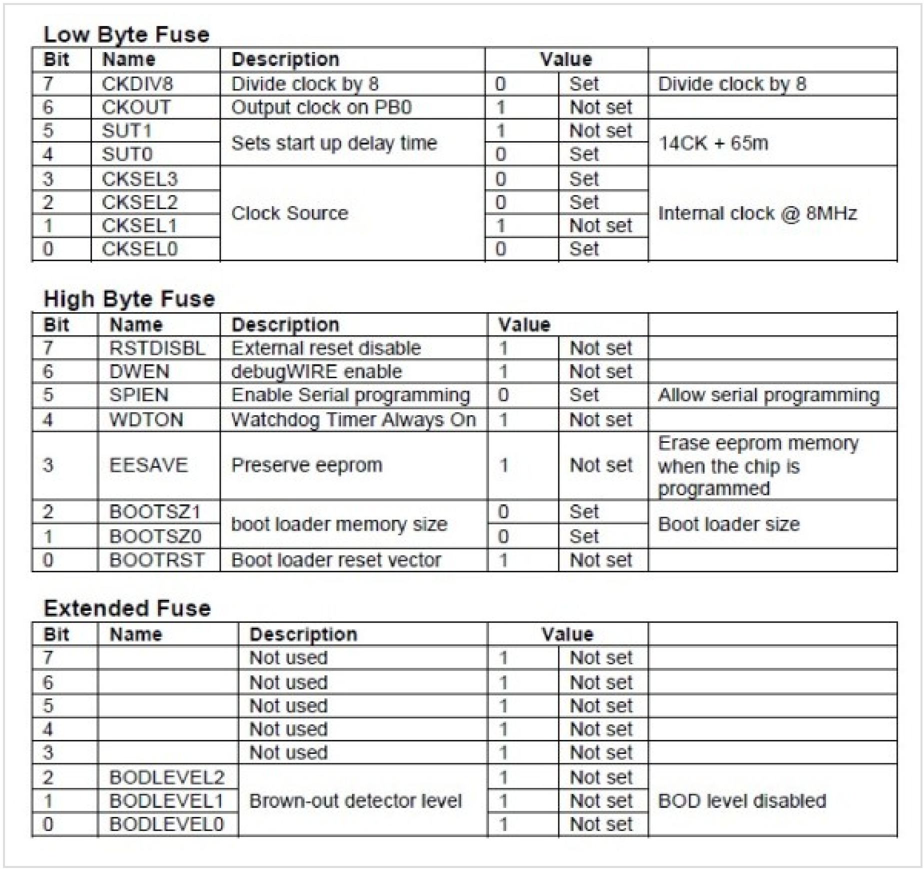
The default values for new chips are; BODLEVEL2=1 (not set), BODLEVEL1=1 (not set), BODLEVEL0=1 (not set).

Default Fuse Settings

New ATmega 328P Chip.

New 328/328P chips generally have the following fuse settings:

Low fuse = 0x62 (B01100010)
High fuse = 0xD9 (B11011001)
Extended fuse = 0xFF (B11111111)



Low Byte Fuse

Bit	Name	Description	Value		
7	CKDIV8	Divide clock by 8	0	Set	Divide clock by 8
6	CKOUT	Output clock on PB0	1	Not set	
5	SUT1	Sets start up delay time	1	Not set	14CK + 65m
4	SUT0		0	Set	
3	CKSEL3	Clock Source	0	Set	Internal clock @ 8MHz
2	CKSEL2		0	Set	
1	CKSEL1		1	Not set	
0	CKSEL0		0	Set	

High Byte Fuse

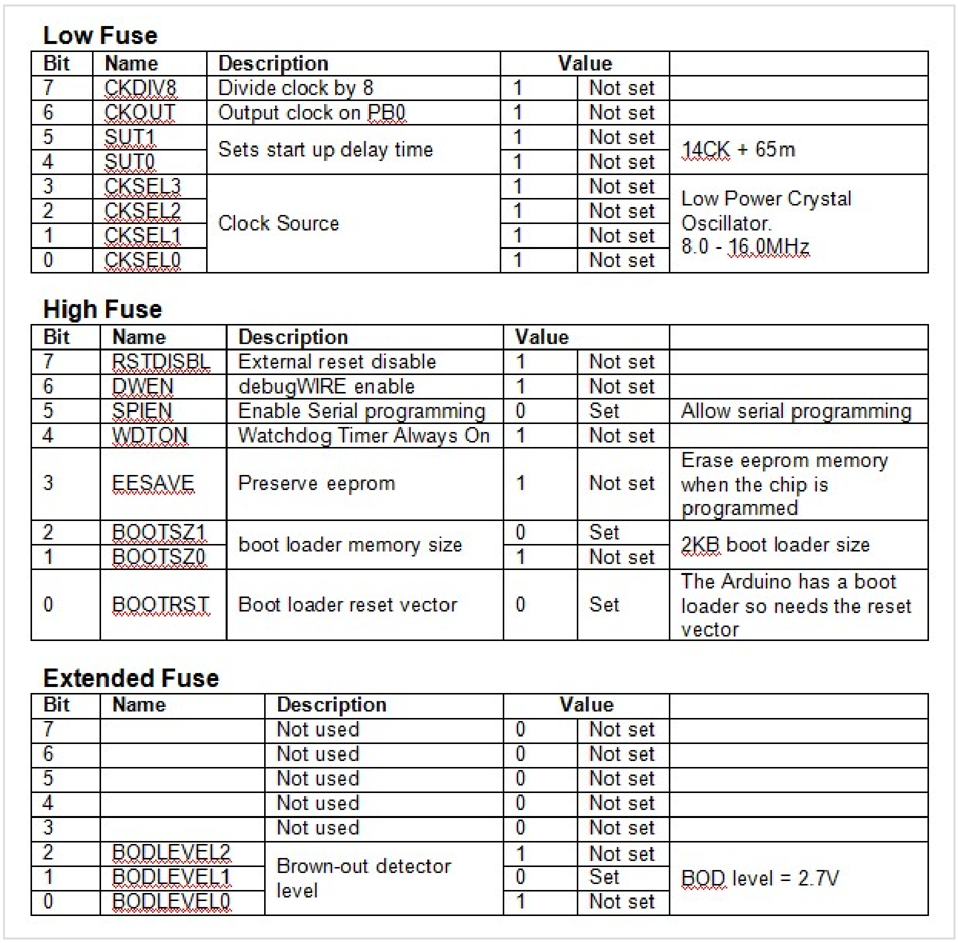
Bit	Name	Description	Value		
7	RSTDISBL	External reset disable	1	Not set	
6	DWEN	debugWIRE enable	1	Not set	
5	SPIEN	Enable Serial programming	0	Set	Allow serial programming
4	WDTON	Watchdog Timer Always On	1	Not set	
3	EESAVE	Preserve eeprom	1	Not set	Erase eeprom memory when the chip is programmed
2	BOOTSZ1	boot loader memory size	0	Set	Boot loader size
1	BOOTSZ0		0	Set	
0	BOOTRST	Boot loader reset vector	1	Not set	

Extended Fuse

Bit	Name	Description	Value		
7		Not used	1	Not set	
6		Not used	1	Not set	
5		Not used	1	Not set	
4		Not used	1	Not set	
3		Not used	1	Not set	
2	BODLEVEL2	Brown-out detector level	1	Not set	BOD level disabled
1	BODLEVEL1		1	Not set	
0	BODLEVEL0		1	Not set	

Arduino Duemilanove or Nano w/ ATmega328 Default Fuse Settings

Low fuse = 0xFF (B11111111)
High fuse = 0xDA (B11011110)
Extended fuse = 0x05 (B00000101)



Low Fuse

Bit	Name	Description	Value		
7	CKDIV8	Divide clock by 8	1	Not set	
6	CKOUT	Output clock on PB0	1	Not set	
5	SUT1	Sets start up delay time	1	Not set	14CK + 65m
4	SUT0		1	Not set	
3	CKSEL3	Clock Source	1	Not set	Low Power Crystal Oscillator. 8.0 - 16.0MHz
2	CKSEL2		1	Not set	
1	CKSEL1		1	Not set	
0	CKSEL0		1	Not set	

High Fuse

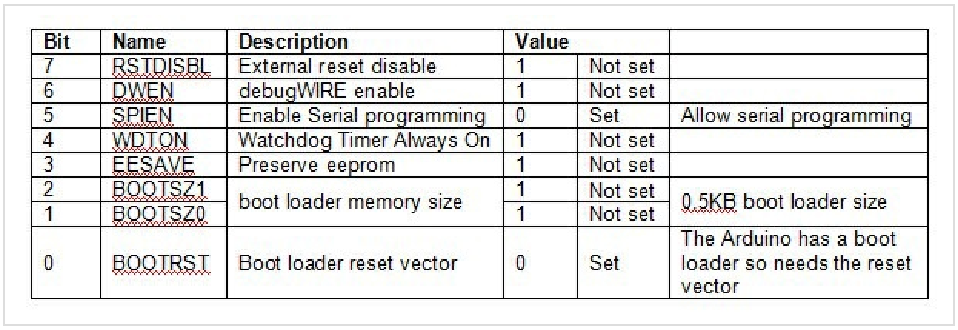
Bit	Name	Description	Value		
7	RSTDISBL	External reset disable	1	Not set	
6	DWEN	debugWIRE enable	1	Not set	
5	SPIEN	Enable Serial programming	0	Set	Allow serial programming
4	WDTON	Watchdog Timer Always On	1	Not set	
3	EESAVE	Preserve eeprom	1	Not set	Erase eeprom memory when the chip is programmed
2	BOOTSZ1	boot loader memory size	0	Set	2KB boot loader size
1	BOOTSZ0		1	Not set	
0	BOOTRST	Boot loader reset vector	0	Set	The Arduino has a boot loader so needs the reset vector

Extended Fuse

Bit	Name	Description	Value		
7		Not used	0	Not set	
6		Not used	0	Not set	
5		Not used	0	Not set	
4		Not used	0	Not set	
3		Not used	0	Not set	
2	BODLEVEL2	Brown-out detector level	1	Not set	BOD level = 2.7V
1	BODLEVEL1		0	Set	
0	BODLEVEL0		1	Not set	

Optiboot Boot Loader

If you load the Optiboot boot loader then the high byte fuse should be set as 0xDE (B11011110). The only difference is the space allocated to the boot loader.



Bit	Name	Description	Value		
7	RSTDISBL	External reset disable	1	Not set	
6	DWEN	debugWIRE enable	1	Not set	
5	SPIEN	Enable Serial programming	0	Set	Allow serial programming
4	WDTON	Watchdog Timer Always On	1	Not set	
3	EESAVE	Preserve eeprom	1	Not set	
2	BOOTSZ1	boot loader memory size	1	Not set	0.5KB boot loader size
1	BOOTSZ0		1	Not set	
0	BOOTRST	Boot loader reset vector	0	Set	The Arduino has a boot loader so needs the reset vector

For a comprehensive list of the default fuse settings for the various Arduinos have a look at Coding with Cody's Arduino Default Fuse Settings page.

Lock Bits

Lock bits can be used to restrict read/write access to the program memory. The boot section and the application section have their own lock bits and access for each area can be controlled separately.

You can brick the ATmega chip if you enable the lock bits and you should not change them.

I will try to cover lock bits in more detail in a later post.

Actually Programming The Fuses

To program stand-alone ATmega chips I used an Arduino Nano as programmer, see Arduino Nano as an ISP Programmer and found the easiest way to set the fuses was to burn a boot loader (the fuses are set as part of the process). The boot loader can then be written over later when you upload a sketch. By editing the boards.txt file in the Arduino installation folder you can use any values you desire for the fuses.

Here is the entry I added to boards.txt for use with bread board Arduinos. This has the low byte fuse at 0xFF, the hight byte fuse at 0xDF, the extended fuse at 0x05, and uses the Optiboot boot loader. The values for the lock bits were copied from the Arduino Uno entry.

```
atmegasa16.name=ATmega328P Stand Alone (Arduino as ISP)
atmegasa16.upload.protocol=stk500
atmegasa16.upload.maximum_size=32768
atmegasa16.upload.speed=115200
atmegasa16.upload.using=arduino:arduinoisp
atmegasa16.bootloader.low_fuses=0xff
atmegasa16.bootloader.high_fuses=0xdf
atmegasa16.bootloader.extended_fuses=0x05
atmegasa16.bootloader.path=optiboot
atmegasa16.bootloader.file=optiboot_atmega328.hex
atmegasa16.bootloader.unlock_bits=0x3F
atmegasa16.bootloader.lock_bits=0x0F
atmegasa16.build.mcu=atmega328p
atmegasa16.build.f_cpu=16000000L
atmegasa16.build.core=arduino
atmegasa16.build.variant=arduino:standard
```

Useful links

Nick Gammon’s site has a lot of really good information about building your own Arduino and uploading boot loaders:
How to make an Arduino-compatible minimal board (similar to mine).
Solving problems with uploading programs to your Arduino
ATmega bootloader programmer.

My own Arduino on a breadboard explains how to set up a stand-alone ATmega chip and Using an Arduino Nano to program a ATmega328P chip explains how to use an Arduino as an ISP programmer.

The ATmega 328P data sheet can be down loaded from the Amtel website at http://www.atmel.com/Images/doc8161.pdf

http://eleccelerator.com and http://www.engbedded.com both have a fuse calculator where you select what options you want and the page gives you the fuse settings to use. I prefer not to use the calculators as I think it may be easy to make mistakes but this is my personal opinion only.

NIck Gammon also has a useful sketch that detects ATmega chip types. The sketch can be found at http://www.gammon.com.au/forum/?id=11633. The sketch displays the fuse settings, the lock bits and gives information about the boot loader if one is present. I found this sketch very useful when I first started programming chips directly.

This entry was posted in **Arduino**, **ATmega** and tagged **arduino**, **ATmega**, **fuse**, **fuses** by **Martyn**. Bookmark the **permalink**.

18 THOUGHTS ON “ARDUINO / ATMEGA 328P FUSE SETTINGS”