

# Compiling Optiboot - ATmega328P at custom frequency

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This is a guide to use the ATmega328P (the microcontroller of an Arduino UNO) with a custom crystal, and run it at a different frequency than the standard 16 MHz.

## Downloading Optiboot

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The Arduino has a bootloader in order to be able to upload sketches over the UART (serial) connection. When running at a different clock speed, you have to recompile the bootloader. To do this, you need Optiboot. First, install git (if you haven't already):

```
$ sudo apt-get install git
```

Then clone Optiboot:

```
$ git clone https://github.com/Optiboot/optiboot.git
```

Next, go to the 'bootloaders' folder of your Arduino IDE installation, for example:

```
$ cd ~/opt/arduino-1.8.1/hardware/arduino/avr/bootloaders
```

Rename the old 'optiboot' folder:

```
$ mv optiboot optiboot.old
```

And replace it by the new version of Optiboot you just cloned:

```
$ cp -R ~/optiboot/optiboot/bootloaders/optiboot/ optiboot && cd optiboot
```

## Compiling the Optiboot bootloader

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Open the Makefile to add a new option with a custom frequency:

```
$ gedit Makefile
```

Then duplicate the atmega328 and atmega328\_isp options, and rename them, for example, atmega328\_12 and atmega328\_12\_isp. Change the CPU speeds, and save the file. The result could be something like this:

```
#Atmega328p @12MHz
atmega328_12: TARGET = atmega328
atmega328_12: MCU_TARGET = atmega328p
atmega328_12: CFLAGS += $(COMMON_OPTIONS)
atmega328_12: AVR_FREQ = 1200000L
atmega328_12: LDSECTIONS = -Wl,--section-start=.text=0x7e00 -Wl,--section-start=.version=0x7ffe
atmega328_12: $(PROGRAM)_atmega328_12.hex
atmega328_12: $(PROGRAM)_atmega328_12.lst

atmega328_12_isp: atmega328
atmega328_12_isp: TARGET = atmega328
atmega328_12_isp: MCU_TARGET = atmega328p
# 512 byte boot, SPIEN
atmega328_12_isp: HFUSE = DE
# Low power xtal (12MHz) 16KCK/14CK+65ms
atmega328_12_isp: LFUSE = FF
# 2.7V brownout
atmega328_12_isp: EFUSE = 05
atmega328_12_isp: isp
```

Now tell Optiboot to use the avr-gcc compiler that came with the Arduino IDE:

```
$ export ENV=arduino
```

And compile the firmware:

```
$ make atmega328_12
```

The output should look something like this:

```
avr-gcc (GCC) 4.9.2
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This is free software; see the source for copying conditions. There is NO
warranty; not even for MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE.

BAUD RATE CHECK: Desired: 115200, Real: 115200, UBRR1 = 15, Error=0.0%
../../../../tools/avr/bin/avr-gcc -g -Wall -Os -fno-split-wide-types -mrelax -mmcu=atmega328p -DF_CPU=12000000L -
DBAUD_RATE=115200 -DLED_START_FLASHES=3 -c -o optiboot.o optiboot.c
../../../../tools/avr/bin/avr-gcc -g -Wall -Os -fno-split-wide-types -mrelax -mmcu=atmega328p -DF_CPU=12000000L -
DBAUD_RATE=115200 -DLED_START_FLASHES=3 -Wl,--section-start=.text=0x7e00 -Wl,--section-start=.version=0x7ffe -Wl,--relax
-nostartfiles -nostdlib -o optiboot_atmega328_12.elf optiboot.o -lc
../../../../tools/avr/bin/avr-size optiboot_atmega328_12.elf
   text    data    bss     dec    hex filename
   464      0      0     464    1d0 optiboot_atmega328_12.elf
../../../../tools/avr/bin/avr-objcopy -j .text -j .data -j .version --set-section-flags .version=alloc,load -O ihex
optiboot_atmega328_12.elf optiboot_atmega328_12.hex
../../../../tools/avr/bin/avr-objdump -h -S optiboot_atmega328_12.elf > optiboot_atmega328_12.lst
```

## Adding the option in the Arduino IDE

The next step is to add a new option in the *Tools* menu in the Arduino IDE.  
Open the 'boards.txt' file for editing, for example:

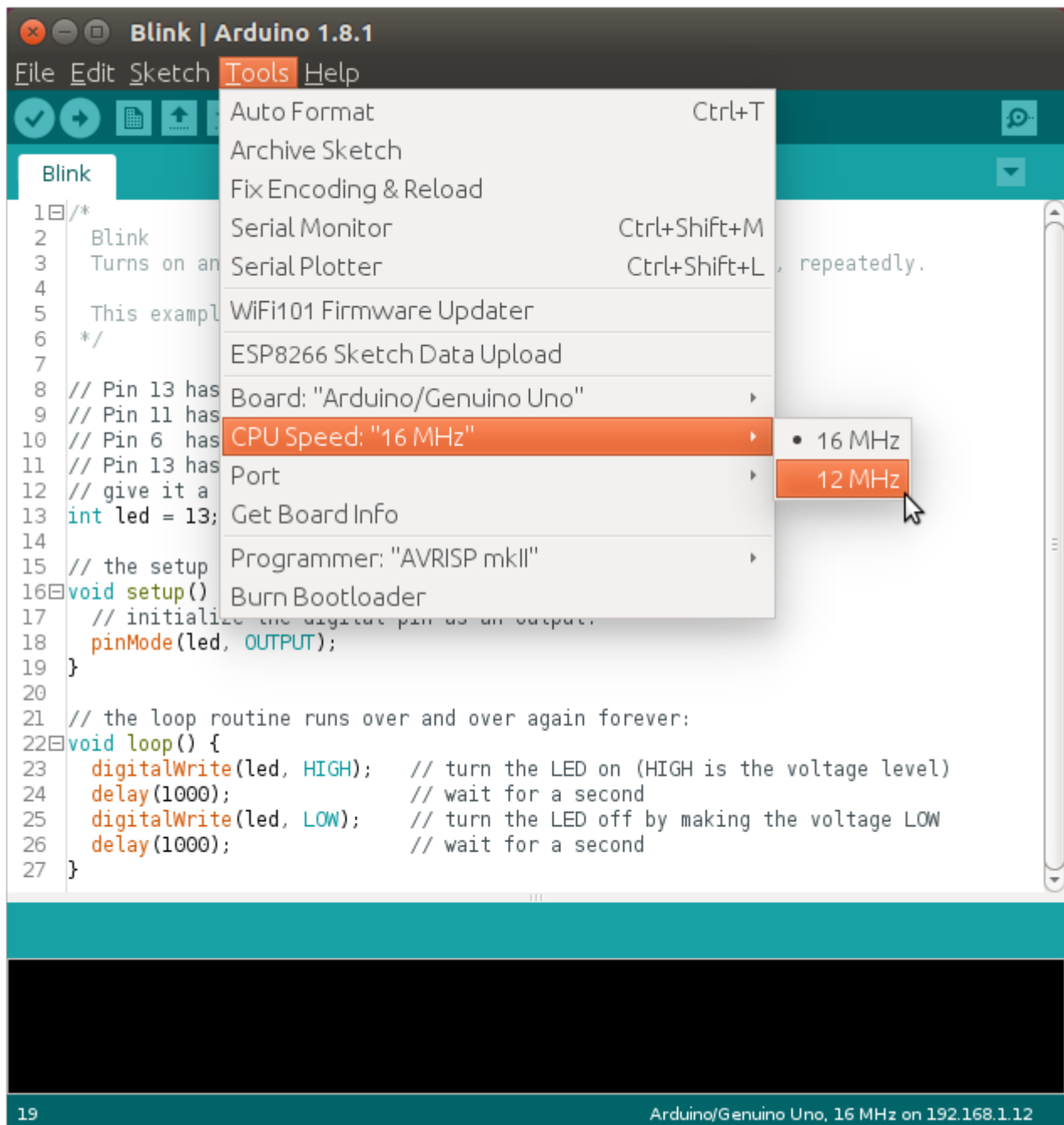
```
$ gedit ~/opt/arduino-1.8.1/hardware/arduino/avr/boards.txt
```

You have to add a menu entry to select the speed, change the `f_cpu` value, and point to the right bootloader. Edit the 'uno' entry, so it looks like this:

```
1  uno.name=Arduino/Genuino Uno
2
3  uno.vid.0=0x2341
4  uno.pid.0=0x0043
5  uno.vid.1=0x2341
6  uno.pid.1=0x0001
7  uno.vid.2=0x2A03
8  uno.pid.2=0x0043
9  uno.vid.3=0x2341
10 uno.pid.3=0x0243
11
12 uno.upload.tool=avrdude
13 uno.upload.protocol=arduino
14 uno.upload.maximum_size=32256
15 uno.upload.maximum_data_size=2048
16 uno.upload.speed=115200
17
18 uno.bootloader.tool=avrdude
19 uno.bootloader.low_fuses=0xFF
20 uno.bootloader.high_fuses=0xDE
21 uno.bootloader.extended_fuses=0x05
22 uno.bootloader.unlock_bits=0x3F
23 uno.bootloader.lock_bits=0x0F
24 # uno.bootloader.file=optiboot/optiboot_atmega328.hex
25
26 uno.build.mcu=atmega328p
27 # uno.build.f_cpu=16000000L
28 uno.build.board=AVR_UNO
29 uno.build.core=arduino
30 uno.build.variant=standard
31
32 menu.speed=CPU Speed
33
34 uno.menu.speed.16=16 MHz
35 uno.menu.speed.12=12 MHz
36 uno.menu.speed.16.bootloader.file=optiboot/optiboot_atmega328.hex
37 uno.menu.speed.12.bootloader.file=optiboot/optiboot_atmega328_12.hex
38 uno.menu.speed.16.build.f_cpu=16000000L
39 uno.menu.speed.12.build.f_cpu=12000000L
```

Note that the original `f_cpu` and `bootloader.file` lines are commented out. Also make sure that the speeds and bootloader filenames are the same as the ones in the Optiboot Makefile.

Restart the Arduino IDE for the changes to take effect. You should see the new options when opening the 'Tools' menu.



## Flashing the bootloader to the ATmega328P

You'll need an Arduino Uno (or a second ATmega328P with bootloader + USB-UART converter, or an AVR ISP programmer) to upload the bootloader to the ATmega328P.

### Uploading the ArduinoISP firmware

Open the ArduinoISP firmware in the Arduino IDE (File > Examples > 11.ArduinoISP), and upload it to the Arduino Uno that will be used for programming the target ATmega328P. Make sure that you have the right clock speed selected in the Tools > CPU Speed menu (16 MHz).

### Connecting to the Arduino

First, connect the power and crystal to the target ATmega328P. Pins 8 & 22 go to ground, pins 7 & 20 go to +5V. Connect the crystal oscillator to pins 9 & 10, with two 22pF capacitors from the 2 crystal pins to ground. Pull the reset pin (pin 1) high using a 10kΩ resistor. Add a 100nF bypass capacitor for stability. Connect the SPI pins for programming: pin D13 of the programmer Arduino to pin 19 of the target ATmega, D12 to pin 18, and D11 to pin 17. Connect pin D10 to the reset pin of the target ATmega. Check the result with the following image:

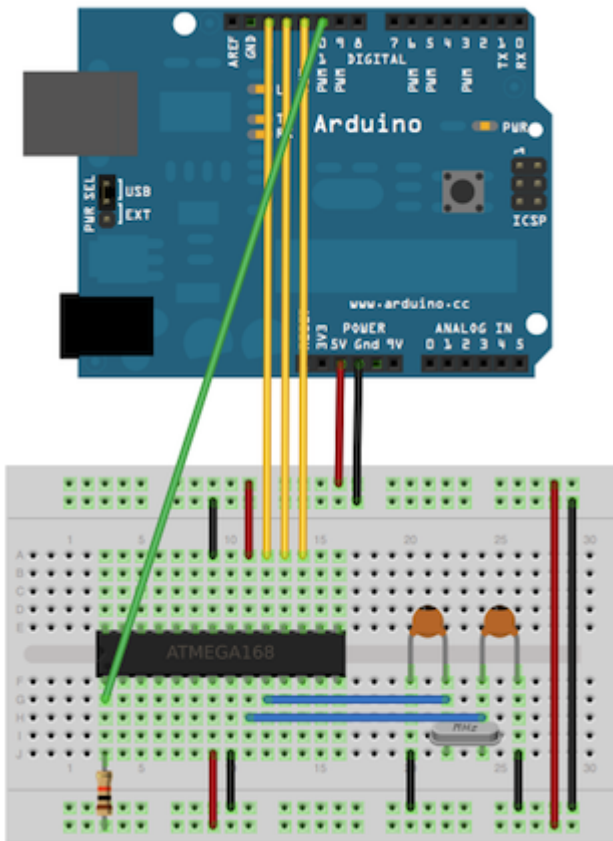


Image source: <https://www.arduino.cc/en/Tutorial/ArduinoISP>

Finally, add a 10µF capacitor between the reset pin of the programmer Arduino and ground, to prevent it from resetting while burning the bootloader.

### Burning the bootloader

Now go to the Tools menu in the IDE, and under CPU Speed, select the new custom frequency. Then select "Arduino as ISP" under Tools > Programmer. Select the serial port of the programmer Arduino, and click 'Burn Bootloader'.

The ATmega328P now has the bootloader installed, so you can upload sketches over UART.

### Testing

Connect the ATmega328P to a USB-to-Serial converter (an FTDI module, for example): TX (pin 3) to RX, and RX (pin 2) to TX. Connect the DTR pin of the FTDI to a 100nF capacitor, and connect the other lead of the capacitor to the reset pin of the ATmega. Add a diode with the anode to the reset pin, and the cathode to 5V.

Also add an LED (+ series resistor) between pin 19 (D13) and ground.

Connect the Arduino to your computer, select the right port and the custom frequency, and try uploading Blink.

The LED on D13 should start blinking.