dw-link

An Arduino-based debugWIRE debugger

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1. Introduction

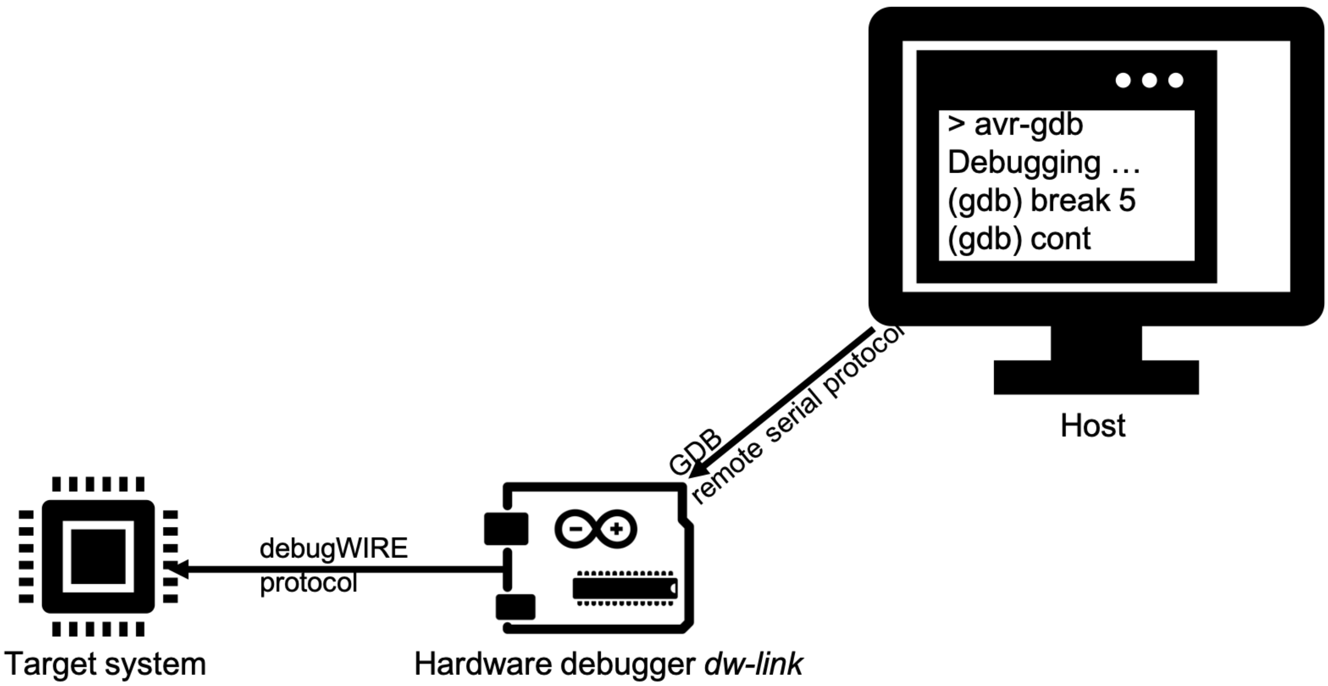
The Arduino IDE is very simple and makes it easy to get started. After a while, however, one notes that a lot of important features are missing. In particular, neither the old nor the new IDE supports any kind of debugging for AVR chips. So what can you do when you want to debug your Arduino project on small ATmegas (such as the popular ATmega328) or ATtinys? The usual way is to insert print statements and see whether the program does the things it is supposed to do. However, supposedly one should be able to do better than that because the above mentioned MCUs support on-chip debugging via debugWIRE.

When you want hardware debugging support, you could buy expensive hardware-debuggers such as the Atmel-ICE or the MPLAB Snap and you have to use the propriatery development IDE Microchip Studio (for Windows) or MPLAB X IDE (for all platforms). The question is, of course, whether there are open-source alternatives? Preferably supporting `avr-gdb`, the GNU debugger for AVR MCUs. With *dw-link*, you have such a solution. It turns an Arduino UNO into a hardware debugger that implements the GDB remote serial protocol.

For your first excursion into the wonderful world of debugging, you need an Arduino UNO (or something equivalent) as the hardware debugger (see Section 3.1) and a chip or board that understands debugWIRE (see Section 3.2), i.e., a classic ATtiny or an ATmegaX8. Then you only have to install the firmware for the debugger on the UNO (Section 4.1) and to set up the hardware for a debugging session (Section 4.2).

Finally, you need to install a debugging environment. I will describe two options for that. The first one, covered in Section 5, is the easiest one. In addition to installing new board definition files, it requires you to download `avr-gdb`. The second option, described in Section 6, involves downloading the PlatformIO IDE, setting up a project, and starting your first debug session with this IDE. There are numerous other possibilities, which you might try out. In the guide to debugging with *avr_debug*, there is an extensive description of how to setup Eclipse for debugging with *avr_debug*, which applies to *dw-link* as well. Another option may be Emacs. Unfortunately, so far, I have not been able to get avr-gdb to work under gdbgui.

If you have performed all the above steps, then the setup should look like as in the following picture.



The connection between *dw-link* and the target is something that might need some enhancements. Instead of flying wires, which we use in the initial example, you may want to have a more durable connection. This is all covered in Section 7. Finally, possible problems and trouble shooting are covered in Section 8 and Section 9, respectively.

1.1 Other debugging approaches for classic ATtinys and ATmegaX8s

While *dw-link* is probably the best open source solution for debugging classic tiny AVRs and ATmegaX8s, there are a number of other possible approaches.

There exists a software simulator called SIMAVR and there is a GDB remote stub for some ATmegas, called avr_debug. Both are integrated into PlatformIO as debuggers. However, both tools come with a lot of restrictions and using them is not the same as debugging on the hardware where your firmware should finally run.

Based on RikusW's work on reverse engineering the debugWIRE protocol, you can find a few attempts at building debuggers using debugWIRE. First of all, there is an implementation called dwire-debug for host systems that use just the serial interface to talk with a target using the debugWIRE interface. This program implements GDB's remote serial protocol. However, only one breakpoint (the hardware breakpoint on the target system) is supported and the particular way of turning a serial interface into a one-wire interface did not work for me. This approach has been further developed resulting in an interesting solution for debugging Arduino UNOs using a CH552 board which works even with the Arduino IDE 2.

Additionally, there exists a similar implementation in Pascal called debugwire-gdb-bridge that appears to be more 'complete'. However, I was not able to install it. That is probably based on the fact that my knowledge of Pascal is rusty and I have no experience with the Lazarus IDE. Finally, there is the Arduino based hardware debugger called DebugWireDebuggerProgrammer. Unfortunately, it is not able to program flash memory and it does not provide an interface for GDB's remote serial protocol.

I took all of the above ideas (and some of the code) and put it together in order to come up with a cheap debugWIRE hardware debugger supporting GDB's remote serial protocol. Actually, it was a bit more than just throwing the things together. I developed a new library for single wire serial communication that is much more reliable and robust than the usually employed SoftwareSerial library. Further, I fixed a few loose ends in the existing implementations, sped up communication and flash programming, supported super-slow MCU clocks (16 kHz), implemented an interrupt-safe way of single-stepping, and spent a few nights debugging the debugger. Along the way, I also made a number of interesting discoveries. And I tested the debugger on almost all MCUs supported by ATTinyCore and MiniCore.

Warning

Read Sections 3.3 & 3.4 about the requirements on the RESET line carefully before trying to debug a target system. You might very well "brick" your MCU by enabling debugWIRE on a system which does not satisfy these requirements.

2. The debugWIRE interface

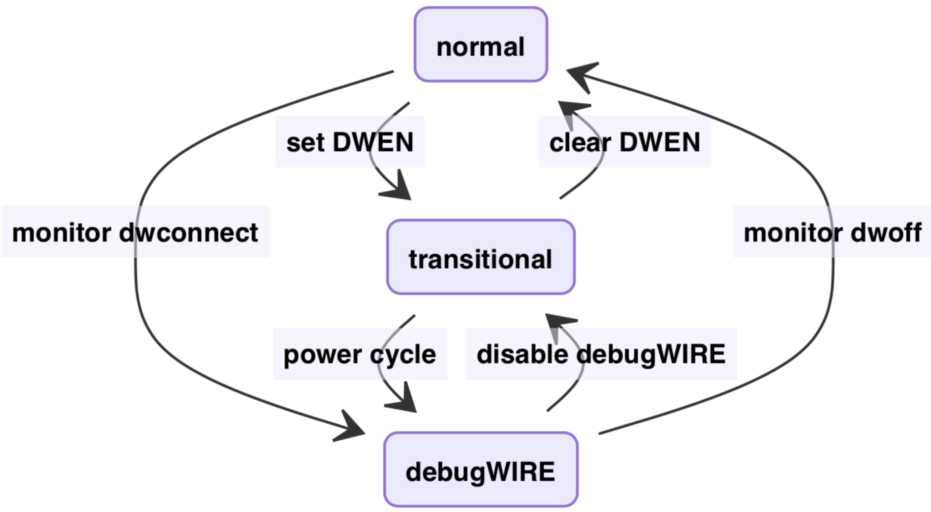
The basic idea of ***debugWIRE*** is that the RESET line is used as a communication line between the ***target system*** (the system you want to debug) and the ***hardware debugger***, which in turn can then communicate with the development machine or ***host***, which runs a debug program such as `gdb` or in our case `avr-gdb`. The idea of using only a single line that is not used otherwise is very cool because it does not waste any of the other pins for debugging purposes (as does e.g. the JTAG interface). However, using the RESET line as a communication channel means, of course, that one cannot use the RESET line to reset the MCU anymore.

Furthermore, one cannot any longer use ISP programming to upload new firmware to the MCU or change the fuses of the MCU. Firmware uploads are possible over the debugWIRE interface, they are a bit slower, however.

Do not get nervous when your MCU does not react any longer as you expect it, but try to understand in which state the MCU is. With respect to the debugWIRE protocol there are basically three states your MCU could be in:

1. The **normal state** in which the DWEN (debugWIRE enable) fuse is disabled. In this state, you can use ISP programming to change fuses and to upload programs. By enabling the DWEN fuse, one reaches the **transitional state**.
2. The **transitional state** is the state in which the DWEN fuse is enabled. In this state, you could use ISP programming to disable the DWEN fuse again, in order to reach the **normal state**. By *power-cycling* (switching the target system off and on again), one reaches the **debugWIRE state**.
3. The **debugWIRE state** is the state in which you can use the debugger to control the target system. If you want to return to the **normal state**, a particular debugWIRE command leads to a transition to the **transitional state**, from which one can reach the **normal state** using ordinary ISP programming.

The hardware debugger will take care of bringing you from *normal* state to *debugWIRE* state when you connect to the target by using the `target remote` command or when using the `monitor dwconnect` command. The system LED will flash in a particular pattern, which signals that you should power-cycle the target. Alternatively, if the target is powered by the hardware debugger, it will power-cycle automatically. The transition from *debugWIRE* state to *normal* state will take place when you terminate GDB. It can also be achieved by the GDB command `monitor dwoff`. If things seemed to have not worked out, you can simply reconnect the target to the hardware debugger and issue `monitor dwoff` again.



3. Hardware requirements

There are a few constraints on what kind of board you can use as the base for the hardware debugger and some requirements on how to connect the debugger to the target system. Furthermore, there is only a limited set of AVR MCUs that can be debugged using debugWIRE.

3.1 The hardware debugger

As a base for the debugger, in principle one can use any ATmega328 based board. The clock speed must be 16MHz. Currently, the sketch has been tested on the following boards:

- Arduino UNO,
- Arduino Nano,
- Arduino Pro Mini.

If you intend to use *dw-link* on a board with an MCU different from ATmega328P, you should be aware that *dw-link* makes heavy use of the particular hardware features of the ATmega328P and operates close to the limit. I tried it out on the Leonardo and on the Mega256, but was not successful.

The most basic setup is to use the UNO board and connect the cables as it is shown in the Fritzing sketch further down. If you want to use the debugger more than once, it may pay off to use a prototype shield and put an ISP socket on it. The more luxurious solution is a shield for the UNO as described further down in Section 7.

3.2 MCUs with debugWIRE interface

In general, almost all "classic" ATtiny MCUs and some ATmega MCUs have the debugWIRE interface. Specifically, the following MCUs that are supported by the Arduino standard core, by ATTinyCore, and/or by MiniCore can be debugged using this interface:

- **~~ATtiny13~~**
- **ATtiny43U**
- **ATtiny2313(A)**, **ATtiny4313**
- **ATtiny24(A)**, **ATtiny44(A)**, **ATtiny84(A)**
- **ATtiny441**, **ATtiny841**
- **ATtiny25**, **ATtiny45**, **ATtiny85**
- **ATtiny261(A)**, **ATtiny461(A)**, **ATtiny861(A)**
- **ATtiny87**, **ATtiny167**
- **ATtiny828**
- **ATtiny48**, **ATtiny88**
- **ATtiny1634**
- **~~ATmega48~~**, **ATmega48A**, **ATmega48PA**, ATmega48PB,
- **~~ATmega88~~**, **ATmega88A**, **ATmega88PA**, Atmega88PB,
- **ATmega168**, **ATmega168A**, **ATmega168PA**, ATmega168PB,
- **ATmega328**, **ATmega328P**, **ATmega328PB**

I have tested the debugger on MCUs marked bold. The untested PB types appear to be very very difficult to get. I excluded the ATtiny13 b because it behaved very strangely and I was not able to figure out why. The two ATmegas that are stroke out have program counters with some bits stuck at one (see Section 8.9). For this reason, GDB has problems debugging them and *dw-link* rejects these MCUs.

Additionally, there exist a few more exotic MCUs, which also have the debugWIRE interface:

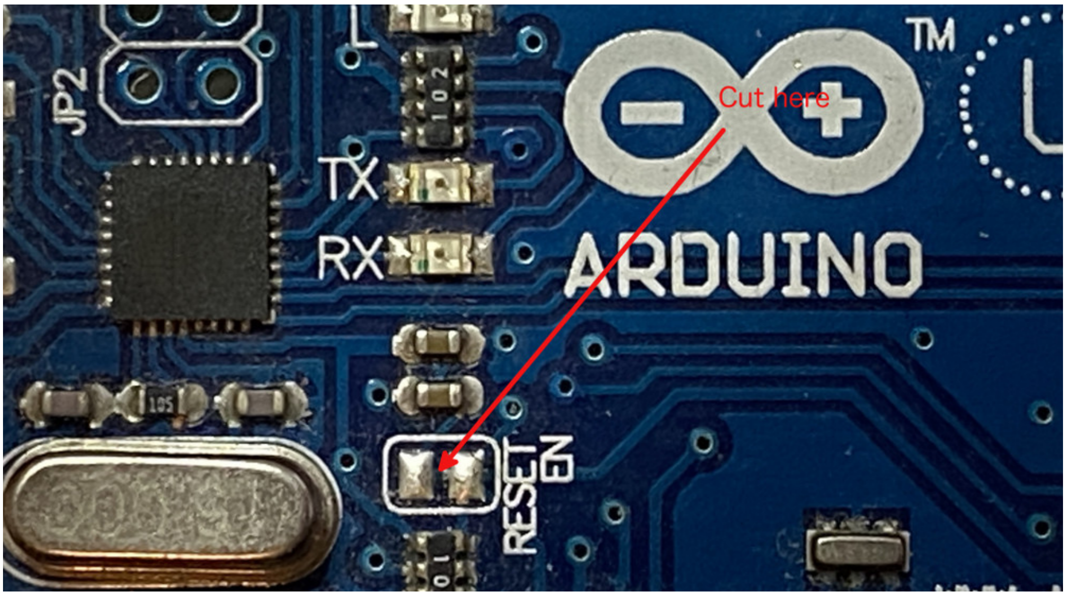
- ATmega8U2, ATmega16U2, ATmega32U2
- ATmega32C1, ATmega64C1, ATmega16M1, ATmega32M1, ATmega64M1
- AT90USB82, AT90USB162
- AT90PWM1, AT90PWM2B, AT90PWM3B
- AT90PWM81, AT90PWM161
- AT90PWM216, AT90PWM316
- ~~ATmega8HVA~~, ~~ATmega16HVA~~, ~~ATmega16HVB~~, ~~ATmega32HVA~~, ~~ATmega32HVB~~, ~~ATmega64HVE2~~

The debugger contains code for supporting all listed MCUs except for the ones stroke out, which are obsolete. I expect the debugger to work on the supported MCUs. However, there are always surprises. If you are able to debug such an MCU using *dw-link*, please drop me a note.

3.3 Requirements concerning the RESET line of the target system

Since the RESET line of the target system is used as an open-drain, asynchronous half-duplex serial communication line, one has to make sure that there is no capacitive load on the line when it is used in debugWIRE mode. Further, there should be a pull-up resistor of around 10 kΩ. According to reports of other people, 4.7 kΩ might also work. And the RESET line should, of course, not be directly connected to Vcc and there should not be any external reset sources on the RESET line.

If your target system is an Arduino UNO, you have to be aware that there is a capacitor between the RESET pin of the ATmega328 and the DTR pin of the serial chip, which implements the auto-reset feature. This is used by the Arduino IDE to issue a reset pulse in order to start the bootloader. One can disconnect the capacitor by cutting the solder bridge labeled *RESET EN* on the board (see picture), but then you cannot use the automatic reset feature of the Arduino IDE any longer.



A recovery method is to put a bit of soldering on the bridge. Alternatively, you could always manually reset the UNO before the Arduino IDE attempts to upload a sketch. The trick is to release the reset button just when the compilation process has finished.

Other Arduino boards, such as the Nano, are a bit harder to modify. A Pro Mini, on the other hand, can be used without a problem, provided the DTR line of the FTDI connector is not connected. In general, it is a good idea to get hold of a schematic of the board you are going to debug. Then it is easy to find out what is connected to the RESET line, and what needs to be removed. It is probably also a good idea to check the value of the pull-up resistor, if present.

3.4 Worst-case scenario

So, what is the worst-case scenario when using debugWIRE? As described in Section 2, first the DWEN fuse is programmed using ISP programming. Then one has to power-cycle in order to reach the debugWIRE state, in which you can communicate with the target over the RESET line. If this kind of communication fails, you cannot put the target back in a state, in which ISP programming is possible. Your MCU is *bricked*. It still works with the firmware programmed last time. However, the only way to reset the MCU is now to power-cycle it. Further, it is impossible to reprogram it using ISP programming.

There are two ways out. First you can try to make the RESET line compliant with the debugWIRE requirements. Then you should be able to connect to the target using the hardware debugger. Second, you can use high-voltage programming, where 12 volt have to be applied to the RESET pin. So you either remove the chip from the board and do the programming offline or you remove any connection from the RESET line to the Vcc rail and other components on the board. Then you can use either an existing high-voltage programmer or you build one on a breadboard.

4. Installation of firmware and hardware setup

There are only a few steps necessary for installing the *dw-link* firmware on the hardware debugger, most of which you probably already have done. For the hardware setup, you need a breadboard or a development board with one of the chips that speak debugWIRE.

4.1 Firmware installation

Since the firmware of the hardware debugger comes in form of an Arduino sketch, you need to download first of all the Arduino IDE, if you have not done that already. Note that for some of the later software components (e.g., ATTinyCore), a reasonably recent version of the IDE is required, i.e. 1.8.13+. It is probably best when you upgrade your installation now. As an alternative, you can also use PlatformIO.

Second, you need to download this repository somewhere, where the IDE is able to find the Arduino sketch. If you use PlatformIO, note that the repository is already prepared to be opened as a PlatformIO project, i.e., it contains a `platformio.ini` file.

Third, you have to connect your future hardware debugger, i.e., the ATmega328 board, to your computer, select the right board in the Arduino IDE and upload the *dw-link.ino* sketch to the board. Similarly, in PlatformIO, you have to choose the right board and choose the `Upload` menu entry.

Usually, it should not be necessary to change a compile-time constant in *dw-link*. I will nevertheless document all these constants here. If you want to change one of them, you can do that when using `arduino-cli` by using the `--build-property` option or by changing the value in the source code.

Name	Default	Meaning
VERSION	current version number	Current version number of *dw-link*; should not be changed, except when one generates a new version
HOSTBPS	115200	Communication speed for host interface
HIGHSPEEDDW	0	If 1, the speed limit of debugWIRE communication is 300 kbps, otherwise it is 150kbps
NOAUTODWOFF	0	If 1, disables the feature that debugWIRE mode is automatically disabled when leaving the debugger (makes startup of consecutive sessions a bit faster)
STUCKAT1PC	0	If this value is set to 1, then *dw-link* will accept connections to targets that have program counters with stuck-at-one bits; one can then use the debugger, but GDB can get confused at many points, e.g., when single-stepping or when trying to produce a stack backtrace.

4.2 Setting up the hardware

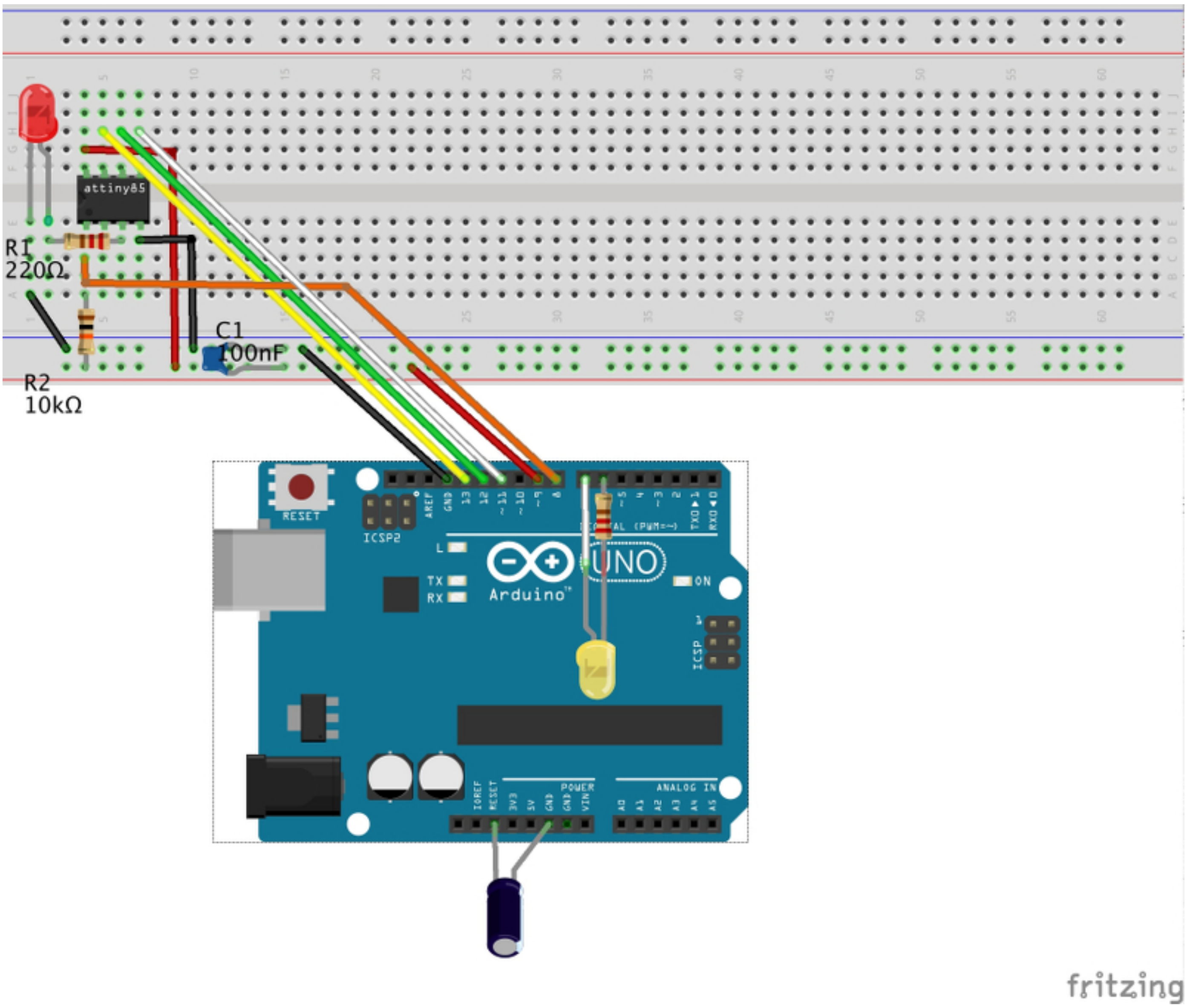
Before you can start debugging, you have to setup the hardware. I'll use an ATtiny85 on a breadboard as the example target system and an UNO as the example debugger. However, any MCU listed above would do as a target. You have to adapt the steps where I describe the modification of configuration files in Section 5 accordingly, though. And one could even use an Arduino UNO, provided the modification described in Section 3.3 are done.

4.2.1 Debugging an ATtiny85

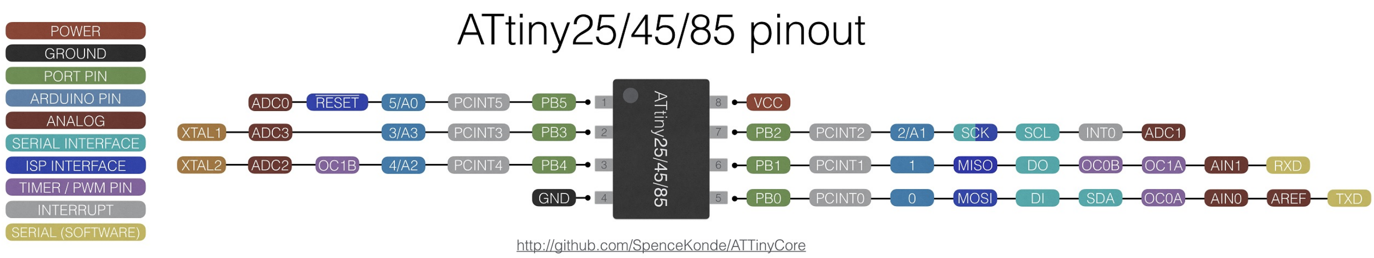
In order to debug an ATtiny85, we will assume it is completely "naked" and plugged into a breadboard as shown below.

First of all, notice the capacitor of 10 µF or more between RESET and GND on the UNO board. This will disable auto-reset of the UNO board. Second, note the LED and resistor plugged in to pin 7 and 6. This is the system LED which is used to visualise the internal state of the debugger (see below). This is optional, but very helpful.

If you do not have a solder iron at hand in order to solder a series resistor to the system LED, you can instead put an ordinary LED without resistor into pin D6 (-) and D5 (+). It will not be very bright since the internal pull-up resistor is used, which is around 20 kΩ, but it should be enough.



Third, as you can see, the Vcc rail of the breadboard is connected to pin D9 of the Arduino UNO so that it will be able to power-cycle the target chip. Furthermore, pin D8 of the Arduino UNO is connected to the RESET pin of the ATtiny (pin 1).   Note the presence of the pull-up resistor of 10kΩ on the ATtiny RESET pin. The remaining connections between Arduino UNO and ATtiny are MOSI (Arduino UNO D11), MISO (Arduino UNO D12) and SCK (Arduino UNO D13), which you need for ISP programming. In addition, there is a LED connected to pin 3 of the ATtiny chip (which is PB4 or pin D4 in Arduino terminology). The pinout of the ATtiny85 is given in the next figure (with the usual "counter-clockwise" numbering of Arduino pins).

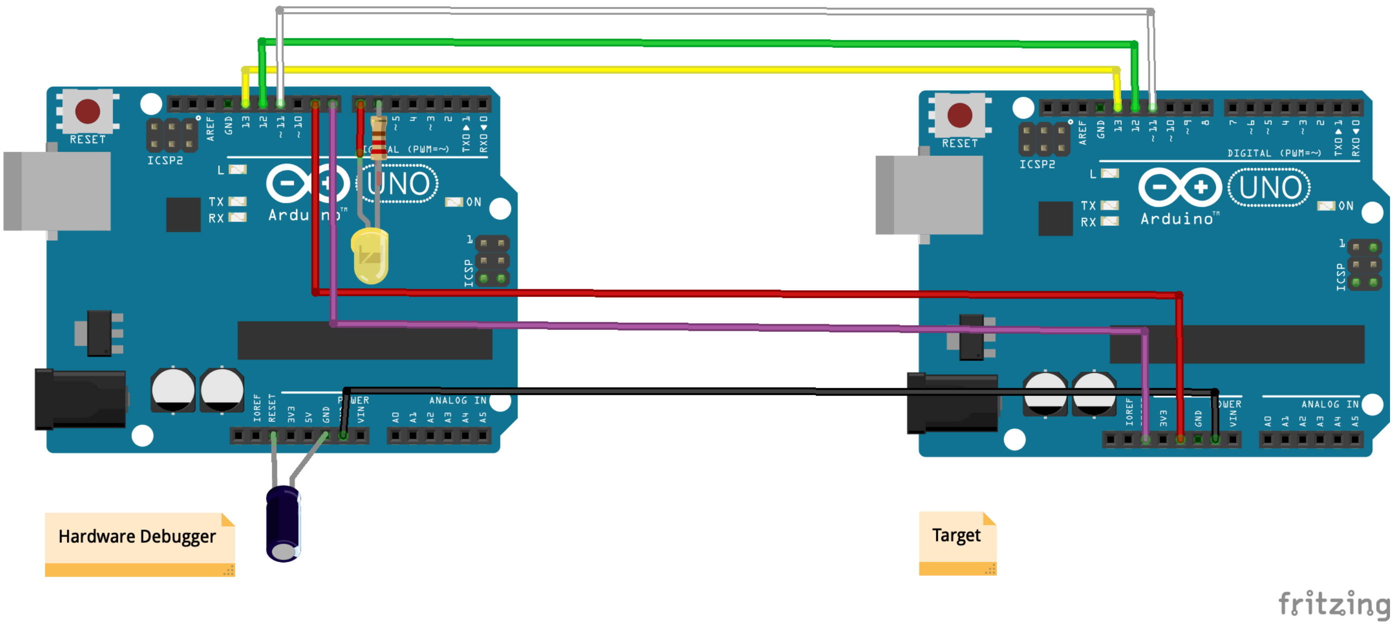


Here is a table of all the connections so that you can check that you have made all the connections.

ATtiny pin#	Arduino UNO pin	component
1 (Reset)	D8	10k resistor to Vcc
2 (D3)		
3 (D4)		220 Ω resistor to LED (+)
4 (GND)	GND	LED (-), decoupling cap 100 nF, blocking cap of 10μF (-),
5 (D0, MOSI)	D11	
6 (D1, MISO)	D12	
7 (D2, SCK)	D13	
8 (Vcc)	D9	10k resistor, decoupling cap 100 nF
	RESET	blocking cap of 10 μF (+)
	D7	system LED (+)
	D6	200 Ω to system LED (-) (or possibly dark LED(-) without resistor)
	D5	(possibly dark system LED (+))

4.5.2 Debugging an UNO

If instead of an ATtiny85, you want to debug an UNO board, everything said above applies here as well. The Fritzing sketch below shows you the connections. Remember to cut the `RESET EN` solder bridge on the target board (see Section 3.3)! When you first establish a connection with the UNO as a target, the target will be completely erased (including the boot loader), because the lock bits have to be cleared.



When after a debugging session you want to restore the target so that it behaves again like an ordinary UNO, you have to execute the following steps:

1. Exit the debugWIRE state as described in Section 2. This should happened automatically when exiting GDB.
2. Reestablish the `RESET EN` connection by putting a solder blob on the connection.
3. Burn the bootloader into the UNO again, as described on the Arduino website.

We are now good to go and 'only' need to install the additional debugging software on the host. Before we do that, let us have a look, in which states the hardware debugger can be and how it signals that using the system LED.

4.3 States of the hardware debugger

There are four states the debugger can be in and each is signaled by a different blink pattern of the system LED:

- not connected (LED is off)
- waiting for power-cycling the target (LED flashes every second for 0.1 sec)
- target is connected (LED is on)
- error state, i.e., not possible to connect to target or internal error (LED blinks furiously every 0.1 sec)

If the hardware debugger is in the error state, one should try to find out the reason by typing the command `monitor lasterror`, study the error message table at the end of the document, finish the GDB session, reset the debugger, and restart everything. If the problem persists, please check the section on trouble shooting.

5. Arduino IDE and avr-gdb

Assuming that you are working with the Arduino IDE and/or Arduino CLI, the simplest way of starting to debug your code is to use the GNU debugger. You only have to install the avr-gdb debugger and the appropriate board manager files. Note that this works only with Arduino IDE versions at least 1.8.13.

5.1 Installing avr-gdb

Unfortunately, the debugger is not any longer part of the toolchain integrated into the Arduino IDE. This means, you have to download it and install it by yourself:

- macOS: Use **homebrew** to install it.
- Linux: Use your favorite packet manager to install it.
- Windows: You can download the AVR-toolchain from the Microchip website or from Zak's Electronic Blog~*. This includes avr-gdb. I noticed that the most recent versions, i.e., >10.X, have a problem interacting with dw-link. So, use an earlier version. You have to copy `avr-gdb.exe` (which you find in the `bin` folder) to some place (e.g., to C:\ProgramFiles\bin) and set the `PATH` variable to point to this folder. Afterwards, you can execute the debugger by simply typing `avr-gdb.exe` into a terminal window (e.g. Windows Powershell).

5.2 Installing board manager files

In order to be able to debug the MCUs mentioned in the indroduction, you need to install 3rd party cores. For the classic ATtiny family, this is [ATTinyCore]() and for the ATmegaX8 family (including the Arduino UNO), it is [MiniCore](). In fact, in order to be able to generate object files that are debug friendly, you need to install my fork of the board manager files. You first have to add URLs under the `Additional Board Manager URLs` in the `Preference` menu:

- ATTinyCore: `https://felias-fogg.github.io/ATTinyCore/package_drazzy.com_ATTinyCore_index.json` (for all the classic ATtinys)
- MiniCore: `https://felias-fogg.github.io/MiniCore/package_MCUdude_MiniCore_index.json` (for all the ATmegaX8 MCUs)

After that, you can download and install the board using the `Boards Manager`, which you find in the Arduino IDE menu under `Tools/Board`. Currently, choose the versions that have a `+debug` suffix in its version number! I hope the capability of generating debug-friendly binaries will be incorporated in future versions of these board manager files, in which case you can rely on the regular board manager files by MCUdude and SpenceKonde.

5.3 Compiling the sketch

Now we need to compile a sketch. Let us take `varblink.ino` from the `examples` folder of the *dw-link* package as our example sketch. First select the board you want to compile the sketch for under the `Tools` menu. In particular, you should select an `328P` (with 16MHz clock) from the `MiniCore` when debugging an UNO board.

Then set additional parameters for the board. Most importantly, you need to select `Debug` for the `Debug Compiler Flags` option. The other possibilities for this option can be chosen when the debugger should create code that more closely mirrors the source code, as described in [Section 8.11](). Now compile the example `varblink.ino` with debugging enabled by requesting to `Export compiled Binary` in the `Sketch` menu. This will generate the file `varblink.ino.elf` in the sketch or build directory, depending on which version of the IDE or CLI you are using.

5.4 Example session with avr-gdb

Open a terminal window, and change into the directory where the Arduino IDE/CLI has copied the ELF file to. After that, we start the debugging session by connecting the hardware debugger to the host computer and start avr-gdb. All the lines starting with either the **>** or the **(gdb)** prompt contain user input and everything after # is a comment. **<serial port>** is the serial port you use to communicate with the hardware debugger.

```
> avr-gdb -b 115200 varblink.ino.elf
GNU gdb (GDB) 10.1
Copyright (C) 2020 Free Software Foundation, Inc.
...
Reading symbols from varblink.ino.elf...
```

```
(gdb) target remote <serial port>               # connect to the serial port of the
debugger
Remote debugging using <serial port>            # connection made
0x00000000 in __vectors ()                      # we always start at location 0x0000
(gdb) monitor dwconnect                         # show properties of the debugWIRE
connection
Connected to ATtiny85
debugWIRE is now enabled, bps: 125736
(gdb) load                                      # load binary file
Loading section .text, size 0x714 lma 0x0
Loading section .data, size 0x4 lma 0x714
Start address 0x00000000, load size 1816
Transfer rate: 618 bytes/sec, 113 bytes/write.
(gdb) list loop                                 # list part of loop and shift focus
6       byte thisByte = 0;
7       void setup() {
8         pinMode(LED, OUTPUT);
9       }
10
11      void loop() {
12        int i=random(100);
13        digitalWrite(LED, HIGH);
14        delay(1000);
15        digitalWrite(LED, LOW);
(gdb) break loop                                # set breakpoint at start of loop
function
Breakpoint 1 at 0x494: file ..., line 12.
(gdb) br 15                                     # set breakpoint at line 15
Breakpoint 2 at 0x4bc: file ..., line 15.
(gdb) c                                         # start execution at PC=0
Continuing.

Breakpoint 1, loop () at /.../varblink.ino:12
12        int i=random(100);
(gdb) next                                      # single-step over function

13        digitalWrite(LED, HIGH);
(gdb) n                                         # again
14        delay(1000);
(gdb) print i                                   # print value of 'i'
$1 = 7
(gdb)  print thisByte                           # print value of 'thisByte'
$2 = 0 '\000'
(gdb) set var thisByte = 20                     # set variable thisByte
(gdb) p thisByte                                # print value of 'thisByte' again
$3 = 20 '\024'
(gdb) step                                      # single-step into function
delay (ms=1000) at /.../wiring.c:108
108             uint32_t start = micros();
```

```
(gdb) finish                                    # execute until function returns
Run till exit from #0  delay (ms=1000)
    at /.../wiring.c:108

Breakpoint 2, loop () at /.../varblink.ino:15
15        digitalWrite(LED, LOW);
(gdb) info br                                   # give inormation about breakpoints
Num     Type           Disp Enb Address    What
1       breakpoint     keep y   0x00000494 in loop()
                                           at /.../varblink.ino:12
        breakpoint already hit 1 time
2       breakpoint     keep y   0x000004bc in loop()
                                           at /.../varblink.ino:15
        breakpoint already hit 1 time
(gdb) delete 1                                  # delete breakpoint 1
(gdb) quit                                      # quit debugger, which will
automatically disable debugWIRE
A debugging session is active.

  Inferior 1 [Remote target] will be killed.

Quit anyway? (y or n) y
>
```

5.4 Disabling debugWIRE mode explicitly

Exiting GDB should disable debugWIRE mode. However, if something went wrong or you killed the debug session, the ATtiny MCU might still be in debugWIRE mode and the RESET pin cannot be used to reset the chip and/or you cannot use ISP programming. In this case, you can explicitly disable debugWIRE, as shown below.

```
> avr-gdb
GNU gdb (GDB) 10.1
...

(gdb) set serial baud 115200            # set baud rate
(gdb) target remote <serial port>       # connect to serial port of debugger
Remote debugging using <serial port>
0x00000000 in __vectors ()
(gdb) monitor dwoff                     # terminate debugWIRE mode
Connected to ATtiny85
debugWIRE is now disabled
(gdb) quit
>
```

5.5 GDB commands

In the example session above, we saw a number of relevant commands already. If you really want to debug using gdb, you need to know a few more commands, though. Let me just give a brief overview of the most relevant commands (anything between square brackets can be omitted, a vertical bar separates alternative forms, arguments are in italics). For the most common commands, it is enough to just type the first character. In general, you only have to type as many characters as are necessary to make the command unambiguous. You also find a good reference card and a very extensive manual on the GDB website. I also recommend these tips on using GDB by Jay Carlson.

command	action
help [*command*]	get help on a specific command
step [*number*]	single step statement, descending into functions (step in), *number* times
next [*number*]	single step statement without descending into functions (step over)
finish	finish current function and return from call (step out)
continue [*number*]	continue from current position and stop after *number* breakpoints have been hit.
run	reset MCU and restart program at address 0x0000
break *function* | [*file*:]*number*	set breakpoint at beginning of *function* or at line *number* in *file*
info breakpoints	list all breakpoints
delete [*number* ...]	delete breakpoint(s) *number* or all breakpoints

In order to display information about the program and variables in it, the following commands are helpful. Further, you may want to change the value of variables.

command	action
list [*function* | [*filename*:]*number*]	show source code around current point, of *function*, or around line *number* in *filename*
print *expression*	evaluate expression and print
set var *variable* = *expression*	set the variable to a new value
display[/*f*] *expression*	display expression using format *f* each time the program halts
info display	print all auto-display commands
delete display [*number* ...]	delete auto-display commands(s) or all auto-display commands

In addition to the commands above, you have to know a few more commands that control the execution of `avr-gdb`.

command	action
set serial baud *number*	set baud rate of serial port to the hardware debugger (same as using the `-b` option when starting `avr-gdb`); only effective when called before establishing a connection with the `target` command
target [extended-]remote *serialport* |	establish a connection to the hardware debugger via *serialport*, which in turn will set up a connection to the target via debugWIRE; if extended is used, then establish a connection in the *extended remote mode*, i.e., one can restart the program using the `run` command
run	reset MCU and restart program, which works only if we are in extended remote mode
file *name*.elf	load the symbol table from the specified ELF file
load	load the ELF file into flash memory (should be done every time after the `target remote` command; it will only change the parts of the flash memory that needs to be changed)
quit	exit from GDB

Finally, there are commands that control the settings of the debugger and the MCU, which are particular to *dw-link*. They all start with the keyword `monitor`. You can abbreviate all keywords to 2 or 3 characters, if this is unambiguous.

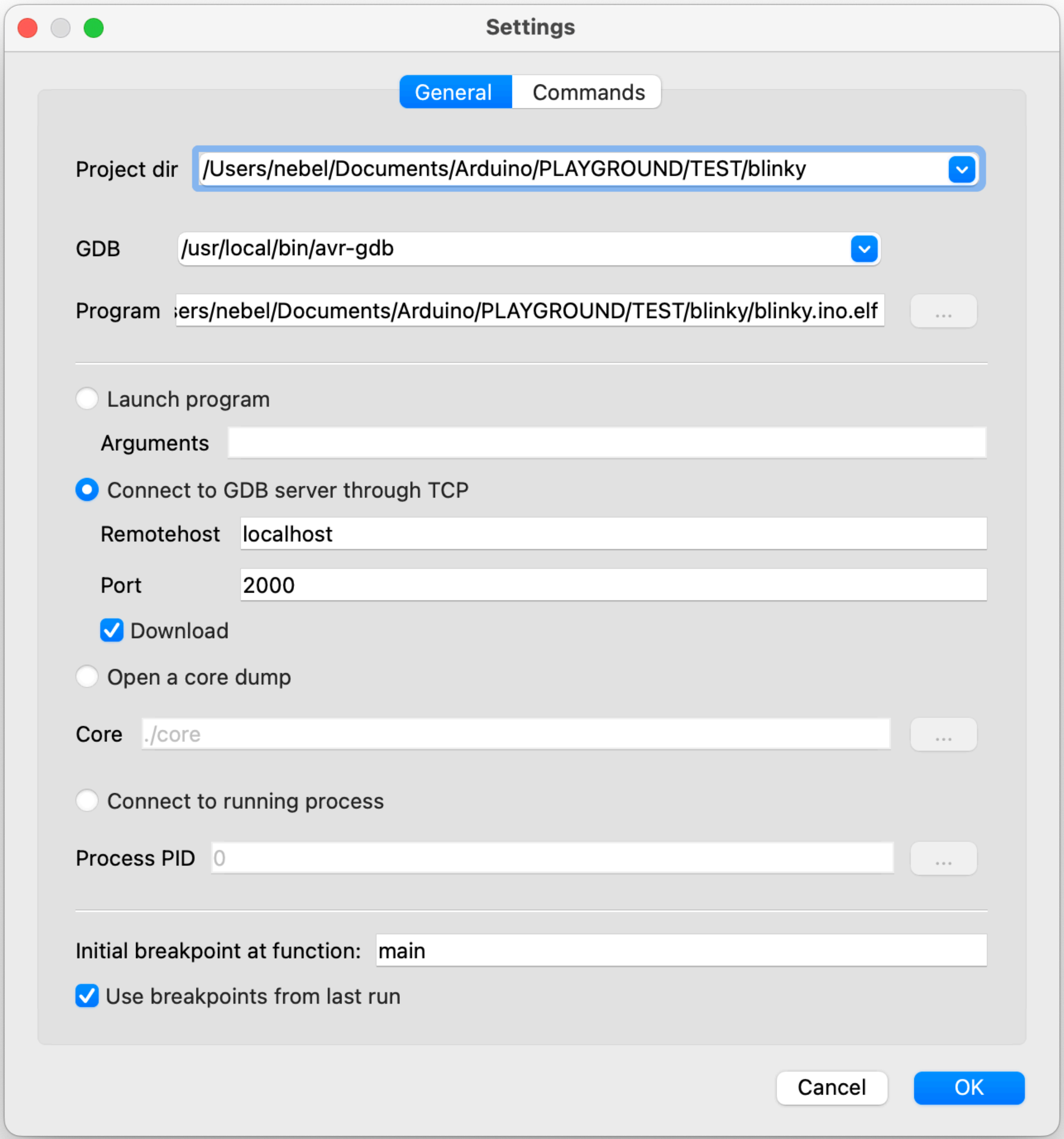
command	action
monitor help	give a help message on monitor commands
monitor dwconnect	establishes the debugWIRE link to the target (is already executed by the `target remote` command); will report MCU type and communication speed (even when already connected) (*)
monitor dwoff	disable debugWIRE mode in the target (which is executed when leaving GDB, or when executing the `kill` or `detach` command) (*)
monitor reset	resets the MCU (*)
monitor ck8prescaler	program the CKDIV8 fuse (i.e., set MCU clock to 1MHz if running on internal oscillator) (*)
monitor ck1prescaler	un-program the CKDIV8 fuse (i.e., set MCU to 8MHz if running on internal oscillator) (*)

monitor rcosc	set clock source to internal RC oscillator (*)
monitor extosc	set clock source to external clock (*)
monitor xtalosc	set clock source to crystal oscillator (*)
monitor slowosc	set clock source to internal low frequency oscillator (125 kHz) (*)
monitor hwbp	set number of allowed breakpoints to 1 (i.e., only HW BP)
monitor swbp	set number of allowed user breakpoints to 32 (+1 system breakpoint), which is the default
monitor speed [l|h]	set communication speed limit to **l**ow (=150kbps) or to **h**igh (=300kbps); without an argument, the current communication speed and limit is printed
monitor lasterror	print error number of last fatal error
monitor flashcount	reports on how many flash-page write operation have taken place since start
monitor timeouts	report number of timeouts (should be 0!)
monitor safestep	single-stepping is uninterruptible and time is frozen during single-stepping, which is the default
monitor unsafestep	single stepping is interruptible and time advances during single-stepping
monitor version	print version number of firmware

All of the commands marked with (*) reset the MCU.

5.6 A graphical user interface: *Gede*

If you believe that GDB is too much typing, then you are probably the type of programmer who wants a graphical user interface. As it turns out, it is not completely trivial to come up with a solution that is easy to install and easy to work with. Recently, I stumbled over *Gede*, which appears to be just the right solution. It has been designed for Linux, but after a few small changes it also works under macOS. There was a slight hiccup with the old version of avr-gdb that is the standard version in Debian, but that was also solved. Making a long story short, you can download the modified source from a [Github repository]() and compile it by yourself. Or you just use the binary in the `gui` folder that I compiled for you. I would recommend to copy it to `/usr/local/bin`. The `gui` directory contains also a Python script called *dw-server.py*. If you now start *dw-server.py*, it will try to discover a dw-link adapter connected to a serial line. After that it starts *Gede*, and then it forwards the serial connection over TCP/IP to *Gede*, which will present you with the following window.



`Project dir` and `Program` are specific to your debugging session. The rest should be copied as it is shown. And with clicking on OK, you start a debugging session. Johan Henriksson, the author of the GUI, has written up two short tutorials about using the GUI.

I have added an additional command to the interface that re-downloads the binary to the target. This means that after a small change to the program, you do not have to fire the thing up again, but you simply reload the modified ELF file.

Unfortunately, there is no Windows version yet. However, I will look into it when time permits.

6 PlatformIO

PlatformIO is an IDE aimed at embedded systems and is based on Visual Studio Code. It supports many MCUs, in particular almost all AVR MCUs. And it is possible to import Arduino projects, which are then turned into ordinary C++ projects. Projects are highly configurable, that is a lot of parameters can be set for different purposes. However, that makes things in the beginning a bit more challenging.

The main differences to the Arduino IDE are:

1. You do not select the MCU and its parameters using a dropdown menu, but you have to write/modify the INI-style file `platform.ini`.
2. Libraries are not global, but they are local to each project. That means that a new library version will not break your project, but you have to update library versions for each project separately.
3. There is no preprocessor that generates function declarations automagically. You have to add the include statement for the arduino header file and all function declarations by yourself. In addition, you need to import `Arduino.h` explicitly.
4. There is already a powerful editor integrated into the IDE.
5. Most importantly, the IDE contains ways to configure the debugging interface, which makes it possible to integrate dw-link easily. Note that this is still not possible for the Arduino IDE 2.X!

So, moving from the Arduino IDE to PlatformIO is a significant step and I have not done it yet completely.

6.1 Installing PlatformIO

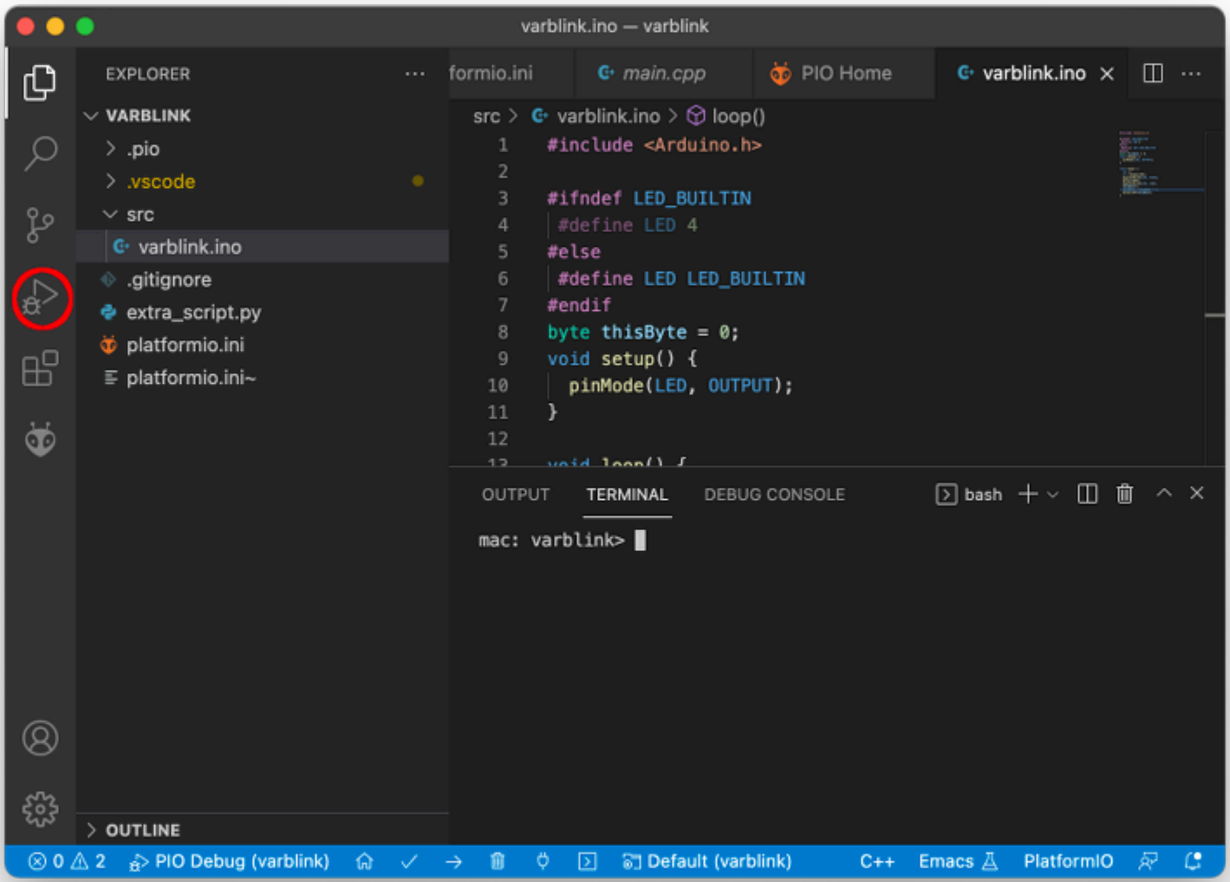
Installing PlatformIO is straight forward. Download and install Visual Studio Code. Then start it and click on the extension icon on the left, search for the PlatformIO extension and install it, as is described here. Check out the quick start guide. Now we are all set.

6.2 Import an Arduino project into PlatformIO

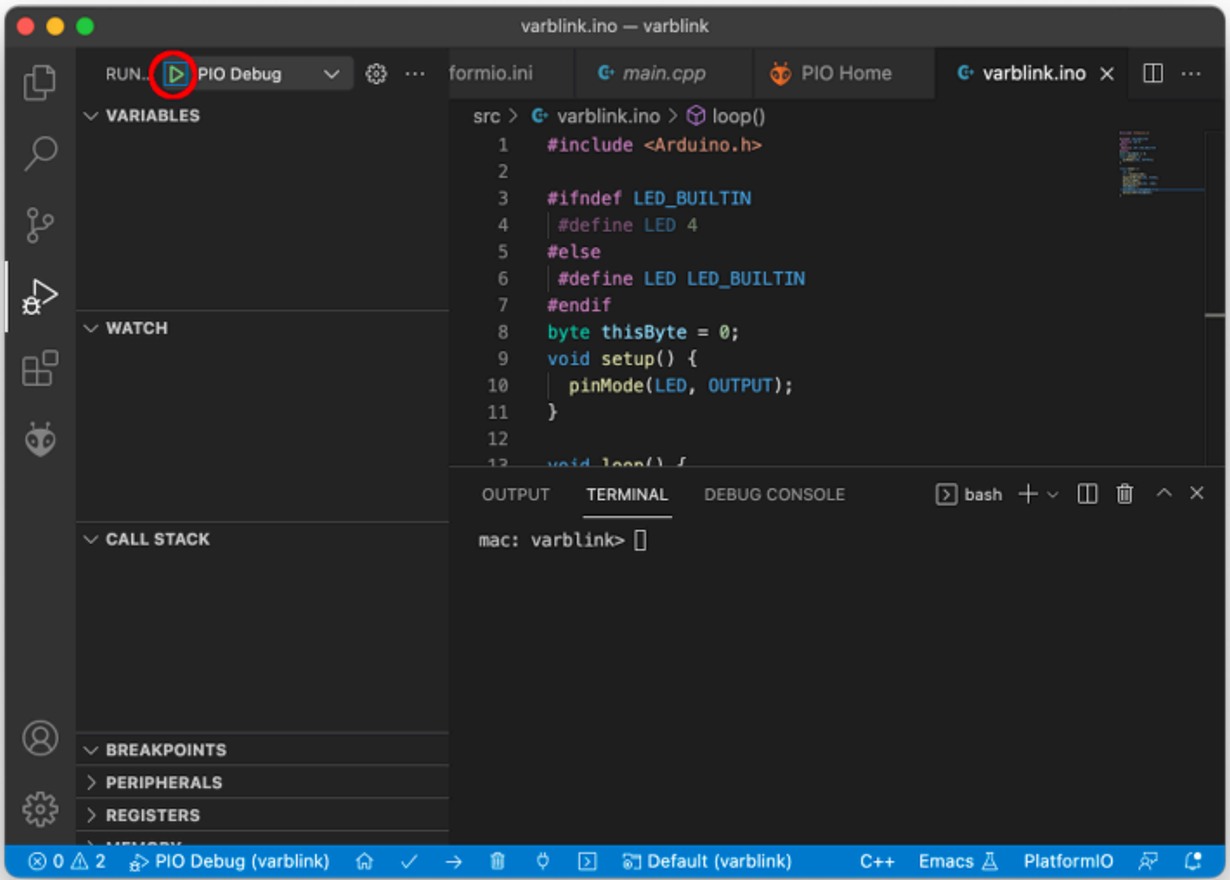
Now let us prepare a debugging session with the same project we had before. Startup Visual Studio Code and click on the home symbol in the lower navigation bar. Now PlatformIO offers you to create a new project, import an Arduino project, open a project, or take some project examples. Choose **Import Arduino Project** and PlatformIO will ask you which platform you want to use. Type in **attiny85** and choose **ATtiny85 generic**. If you have a different board, you can, of course, select a different board. After that, you can navigate to the directory containing the Arduino project and PlatformIO will import it. It will also tell you to convert your INO sketch into a well-formed C++ program. This is something we can do later, though.

6.3 Debugging with PlatformIO

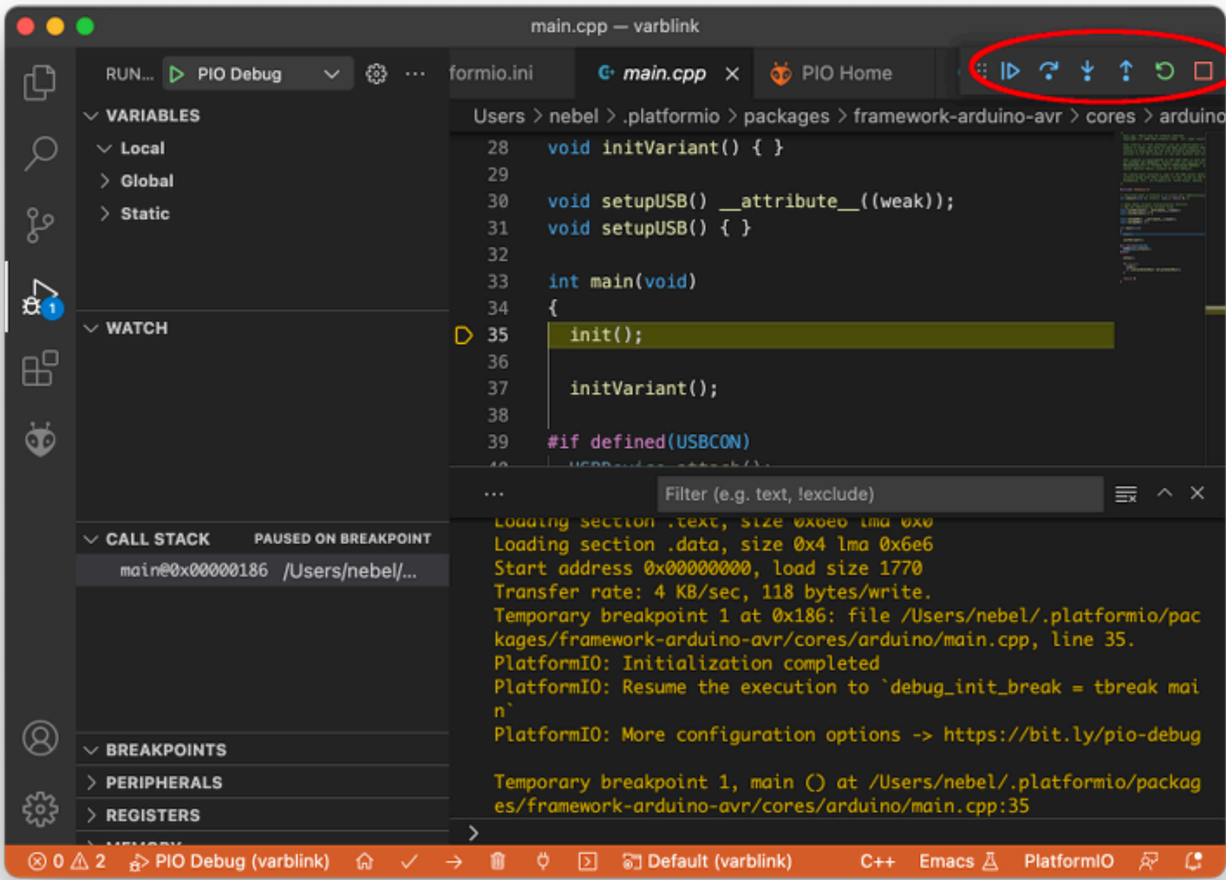
If you now click on the debug symbol in the left navigation bar (fourth from the top), PlatformIO enables debugging using **simavr**, the default debugger for this chip.



You can now start a debug session by clicking the green triangle at the top navigation bar labeled **PIO Debug**.



On the right, the debug control bar shows up, with symbols for starting execution, step-over, step-in, step-out, reset, and exit. On the left there are a number of window panes giving you information about variables, watchpoints, the call stack, breakpoints, peripherals, registers, memory, and disassembly. Try to play around with it!



On a Mac, unfortunately it does not work out of the box, because the gcc-toolchain PlatformIO uses is quite dated and avr-gdb is not any longer compatible with recent macOS versions. Simply install avr-gdb with homebrew and copy the file (`/usr/local/bin/avr-gdb`) linto the toolchain directory (`~/.platformio/packages/toolchain-atmelavr/bin/`).

6.4 *Dw-link* setup

But, of course, this is not the real thing. No LED is blinking. So close the window and copy the following file from `examples/pio-config` to the project directory of your new PlatformIO project:

- `platformio.ini`
- `discover-dw-link.py`

Both files need to be present in any project you create. The first one is an INI-style configuration that you can adapt to your wishes. You can find an extensive description of what can be configured in the [PlatformIO documentation](). Note one important point, though. PlatformIO debugging will always choose the *default environment* or, if this is not set, the first environment in the config file. The second file is a Python script that discovers the dw-link adapter by probing all connected serial devices. If one of them identifies itself as a dw-link adapter, GDB connects to it.

After having copied the file into the project directory and having set up the hardware as described in Section 4, you should reopen the project window. Now you should be able to debug your project as described above. Only you are debugging the program on the target system, i.e., the LED really blinks (if it is connected to the right pin).

A very readable introduction to debugging using PlatformIO has been written by Valerii Koval. It explains the general ideas and all the many ways how to interact with the PlatformIO GUI. Part II of this introduction covers embedded debugging.

6.5 Disabling debugWIRE mode

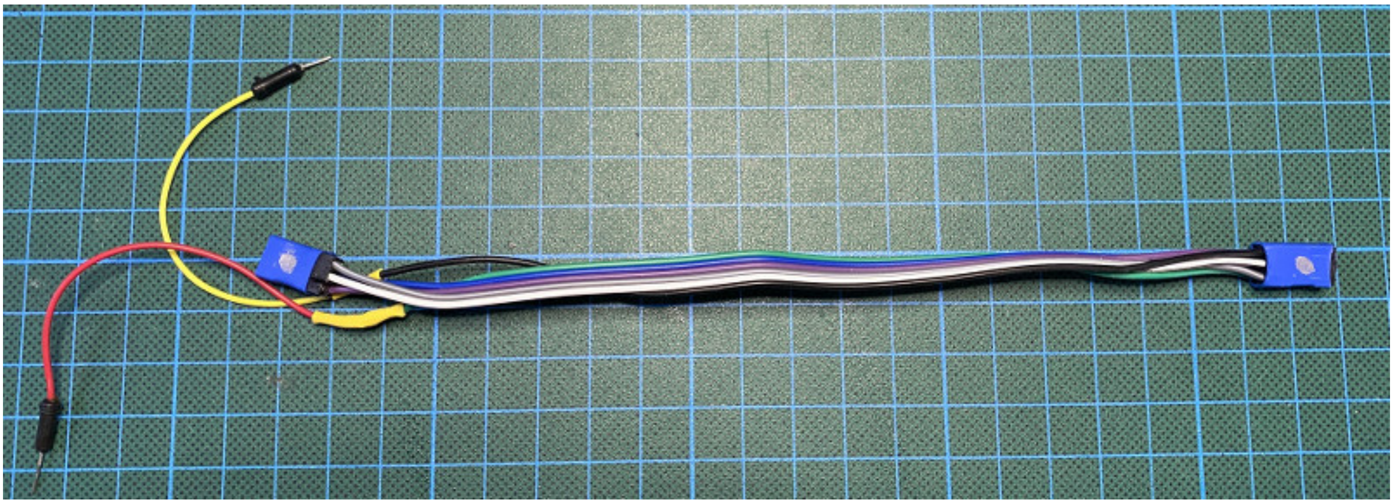
There are two ways of switching off the debugWIRE mode. It happens automatically when you terminate the debugger using the exit button. Alternatively, you should be able to bring back your MCU to the normal state by typing `monitor dwoff` in the debugging terminal window after having started a debugging session in PlatformIO IDE.

7. A "real" hardware debugger

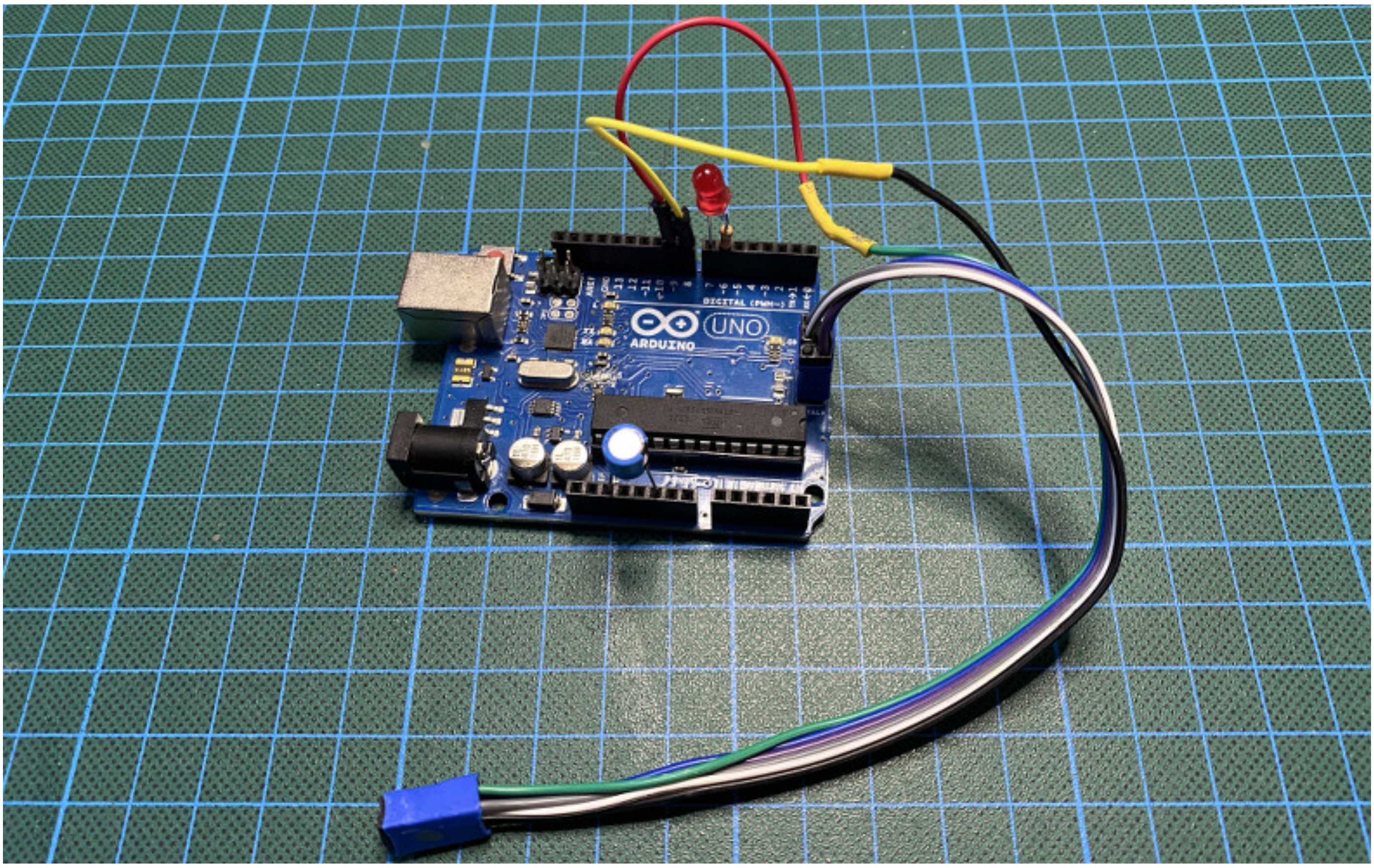
The hardware part of our hardware debugger is very limited so far. You can, of course, use 6 jumper wires to connect *dw-link* to your target as described in Section 4.2. However, if you want to use this tool more than once, then there should be at least something like a ISP cable connection. Otherwise you might scratch your head which cable goes where every time you start a debugging session.

7.1 The basic solution

For most of the wires, we use the same pins on the debugger and the target. So, it makes sense to think about something similar to an ISP cable people use when employing an Arduino UNO as an ISP programmer. Such cables can be easily constructed with some Dupont wires and a bit of heat shrink tube as, for example, demonstrated in this instructable. In contrast to such a programmer cable, it makes sense to also break out the Vcc wire. And you definitely do not want to integrate a capacitor between RESET and GND in such a cable as described in the instructable!



As argued in my blog post on being cheap, with such a wire we have sort of constructed a hardware debugger for less than 10 €, which can be considered as semi-durable. Just add the optional system LED and a capacitor between RESET and GND.

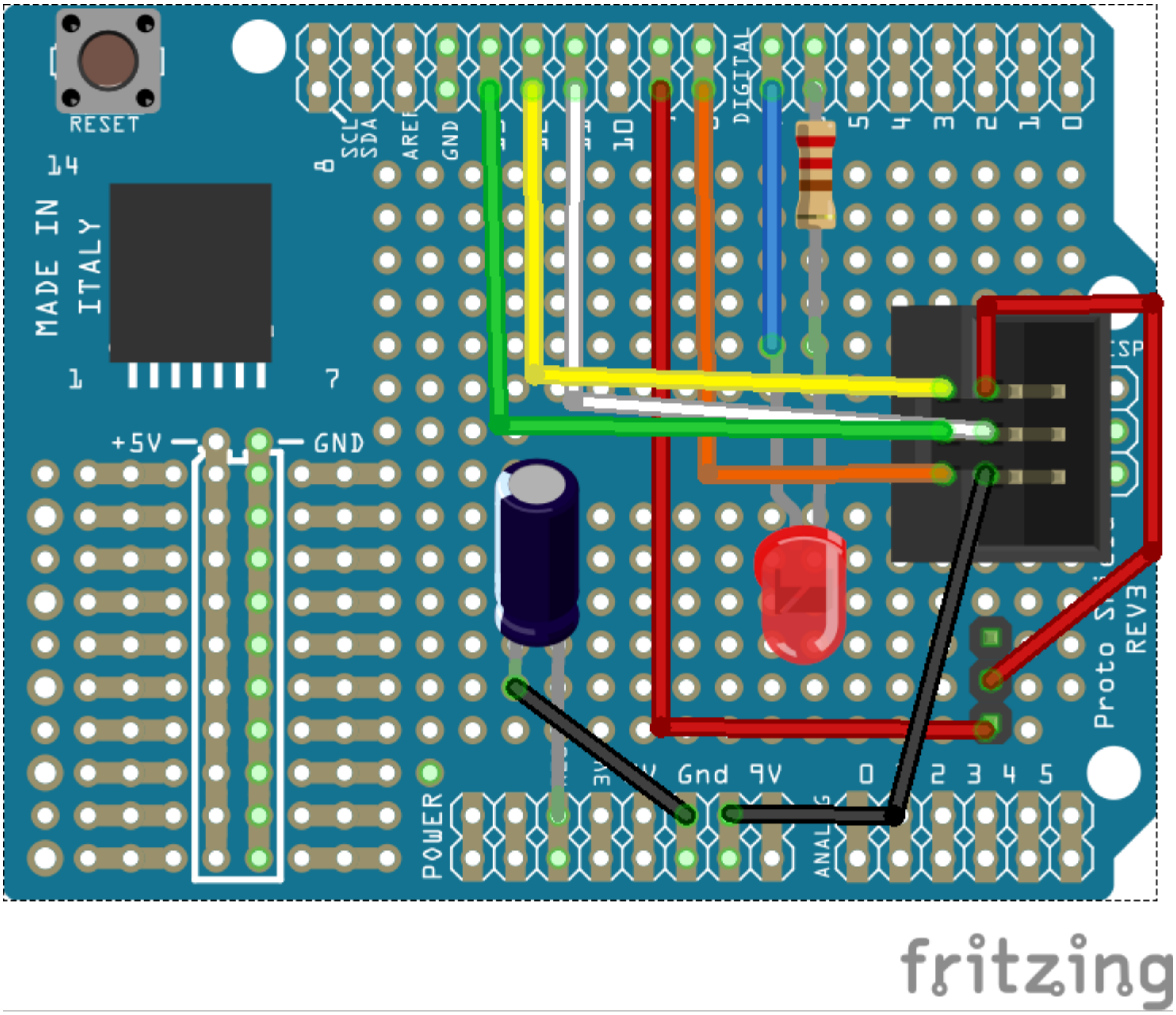


The relevant pins are therefore as defined in the following table. The pins in italics are not used in this basic version, but have its use for a more complex adapter board.

Arduino pin	ISP pin	Function
D13	3	SCK
D12	1	MISO
D11	4	MOSI
D9 (or Vcc)	2	VTG
D8	5	RESET
GND	6	GND
D7		System LED+
D6		System LED-
D5		System LED+ without series resistor
D4		ISP enable (active low)
D3		Debug TX
D2		Power enable (active low)

7.2 A simple shield

Taking it one one step further, one might think about a prototype shield for an UNO or adapter board for an Arduino Nano. It is actually very straightforward to build a basic hardware debugger that can be used without much preparation. Just take a prototype shield for an UNO, put an ISP socket on it, and connect the socket to the respective shield pins. You probably should also plan to have jumper pins in order to be able to disconnect the target power supply line from the Arduino pin that delivers the supply voltage. And finally, you probably also want to place the system LED on the board. So, it could look like as in the following Fritzing sketch.



You can also do a similar thing with the Arduino Nano. Note, however, that the maximum communication speed of a Nano is 115200.

7.3 Adapter board/shield with level-shifter and switchable power supply

So, it would be great to have a board with the following features:

- switchable target power supply (supporting power-cycling by the hardware debugger),
- offering 5 volt and 3.3 volt supply at 200 mA,
- a bidirectional level-shifter on the debugWIRE line,
- an optional pull-up resistor of 10 kΩ on this line,
- unidirectional level-shifters on the ISP lines, and
- tri-state buffers for the two output signals MOSI and SCK.

I have designed an UNO shield with these features. You only have to set jumpers, then plug in a USB cable on one side and an ISP cable on the other side, and off you go. The following picture shows the version 2.0 dw-probe board in action. It all works flawlessly.

The Eagle design files of the Version 2.0 board are in the pcb directory. This design is currently untested but should work.

You have to set three different jumpers.

Label	Left	Middle	Right
Supply	**3.3V** are supplied to the target	**no**: target needs to its own supply and power cycling has to be done manually	**5V** are supplied to the target
Pullup	A **10kΩ** pull-up resistor is connected to the RESET line of the target		There is **no** pull-up resistor connected
Cap	A **10µF** cap disables the auto-reset feature of the debugger		There is no cap connected to the RESET line of the debugger

8. Problems and shortcomings

dw-link is still in ***beta*** state. The most obvious errors have been fixed, but there are most probably others. If something does not go according to plan, please try to isolate the reason for the erroneous behaviour, i.e., identify a sequence of operations to replicate the error. The most serious errors are *fatal errors*, which stop the debugger from working. With the command `monitor lasterror` you can get information what the cause is (check the error table at the end).

One perfect way to document a debugger error is to switch on logging and command tracing in the debugger:

```
set trace-commands on
set remote debug 1
set logging on
...
set logging off
```

I have prepared an *issue form* for you, where I ask for all the information necessary to replicate the error.

Apart from bugs, there are, of course, shortcomings that one cannot avoid. I will present some of them in the next subsections.

8.1 Flash memory wear

Setting and removing *breakpoints* is one of the main functionality of a debugger. Setting a breakpoint is mainly accomplished by changing an instruction in flash memory to the BREAK instruction. This, however, implies that one has to *reprogram flash memory*. Since flash memory wears out, one should try to minimize the number of flash memory reprogramming operations.

One now has to understand that gdb does not pass *breakpoint set* and *breakpoint delete* commands from the user to the hardware debugger, but instead it sends a list of *breakpoint set* commands before execution starts. After execution stops, it sends *breakpoint delete* commands for all breakpoints. In particular, when thinking about conditional breakpoints, it becomes clear that gdb may send a large number of *breakpoint set* and *breakpoint delete* commands for one breakpoint during one debug session. Although it is guaranteed that flash memory can be reprogrammed at least 10,000 times according to the data sheets, this number can easily be reached even in a few debug sessions, provided there are loops which are often executed and where a conditional breakpoint has been inserted. Fortunately, the situation is not as bad as it looks since there are a number of ways of getting around the need of reprogramming flash memory.

First of all, *dw-link* leaves the breakpoint in memory, even when gdb requests to remove them. Only when gdb requests to continue execution, the breakpoints in flash memory are updated. Well, the same happens before loading program code, detaching, exiting, etc. Assuming that the user does not change breakpoints too often, this will reduce flash reprogramming significantly.

Second, if there are many breakpoints on the same flash page, then the page is reprogrammed only once instead of reprogramming it for each breakpoint individually.

Third, when one restarts from a location where a breakpoint has been set, gdb removes this breakpoint temporarily, single steps to the next instruction, reinserts the breakpoint, and only then continues execution. This would lead to two reprogramming operations. However, *dw-link* does not update flash memory before single-stepping. Instead, if the instruction is a single-word instructions, it loads the original instruction into the *instruction register* of the MCU and executes it there.

For two-word instructions (i.e., LDS, STS, JUMP, and CALL), things are a bit more complicated. The Microchip documents state that one should refrain from inserting breakpoints at double word instructions, implying that this would create problems. Indeed, RikusW noted in his reverse engineering notes about debugWIRE:

> Seems that its not possible to execute a 32 bit instruction this way.
> The Dragon reflash the page to remove the SW BP, SS and then reflash again with the SW BP!!!

I noticed that this is still the case, i.e., MPLAB-X in connection with ATMEL-ICE still reprograms the page twice for hitting a breakpoint at a two-word instruction. The more sensible solution is to simulate the execution of these instructions, which is at least as fast and saves two reprogramming operations. And this is what *dw-link* does.

Fourth, each MCU contains one *hardware breakpoint register*, which stops the MCU when the value in the register equals the program counter. *Dw-link* uses this for the breakpoint introduced most recently. With this heuristic, temporary breakpoints (as the ones GDB generates for single-stepping) will always get priority and more permanent breakpoints set by the user will end up in flash.

Fifth, when reprogramming of a flash page is requested, *dw-link* first checks whether the identical contents should be loaded, in which case it does nothing. Further, it checks whether it is possible to achieve the result by just turning some 1's into 0's. Only if these two things are not possible, the flash page is erased and reprogrammed. This helps in particular when reloading a file with the GDB `load` command after only a few things in the program have been changed.

With all of that in mind, you do not have to worry too much about flash memory wear when debugging. As a general rule, you should not make massive changes of the breakpoints each time the MCU stops executing. Finally, Microchip recommends that chips that have been used for debugging using debugWIRE should not been shipped to customers. Well, I never ship chips to customers anyway.

For the really paranoid, there is the option that permits only one breakpoint, i.e., the hardware breakpoint: `monitor hwbp`. In this case, one either can set one breakpoint or on can single-step, but not both. So, if you want to continue after a break by single-stepping, you first have to delete the breakpoint. By the way, with `monitor swbp`, one switches back to normal mode, in which 32 (+1 temporary) breakpoints are allowed.

In addition, there is the debugger command `monitor flashcount`, which returns the number of how many flash page reprogramming commands have been executed since the debugger had been started. This includes also the flash reprogramming commands needed when loading code.

8.2 Slow responses when loading or single-stepping

Sometimes, in particular when using a clock speed below 1 MHz, responses from the MCU can be quite sluggish. This shows, e.g., when loading code or single-stepping. The reason is that a lot of communication over the RESET line is going on in these cases and the communication speed is set to the MCU clock frequency divided by 8, which is roughly 16000 bps in case of a 128 kHz MCU clock. If the CKDIV8 fuse is programmed, i.e., the MCU clock uses a prescaler of 8, then we are down to 16 kHz MCU clock and 2000 bps. The [Atmel AVR JTAGICE mkII manual] states under [known issues]:

> Setting the CLKDIV8 fuse can cause connection problems when using debugWIRE. For best results, leave this fuse un-programmed during debugging.

"Leaving the fuse un-programmed" means that you probably have to change the fuse to be un-programmed using a fuse-programmer, because the fuse is programmed by default. In order to simplify life, I added the two commands `monitor ck8prescaler` and `monitor ck1prescaler` to the hardware debugger that allows you to change this fuse. `monitor ck8prescaler` programs the fuse, i.e., the clock is divided by 8, `monitor ck1prescaler` un-programs this fuse. In addition to changing the CKDIV8 fuse, you can also change the clock source with monitor commands, whereby always the slowest startup time is chosen. Be careful about setting it to *XTAL* or *external clock*! Your MCU will get unresponsive if there is no crystal oscillator or external clock, respectively. Note that after executing these commands, the MCU is reset (and the register values shown by the GDB `register info` command are not valid anymore).

With an optimal setting, i.e., 250 kbps for the debugWIRE line and 230400 bps for the host communication line, loading is done with 500-800 bytes/second. It should be 3-5 KiB/second when the identical file is loaded again (in which case only a comparison with the already loaded file is performed). For the default setting (115200bps to host, 125000bps for debugWIRE), it is probably half the speed.

8.3 Program execution is very slow when conditional breakpoints are present

If you use *conditional breakpoints*, the program is slowed down significantly. The reason is that at such a breakpoint, the program has to be stopped, all registers have to be saved, the current values of the variables have to be inspected, and then the program needs to be started again, whereby registers have to be restored first. For all of these operations, debugWIRE communication takes place. This takes roughly 100 ms per stop, even for simple conditions and an MCU running at 8MHz. So, if you have a loop that iterates 1000 times before the condition is met, it may easily take 2 minutes (instead of the fraction of a second) before execution stops.

8.4 Single-stepping and interrupt handling clash

In many debuggers, it is impossible to do single-stepping when timer interrupts are active since after each step the program ends up in the interrupt routine. This is not the case with `avr-gdb` and *dw-link*. Instead, time is frozen and interrupts cannot be raised while the debugger single-steps. Only when the `continue` command is used, interrupts are serviced and the timers are advanced. One can change this behavior by using the command `monitor unsafestep`. In this case it can happen that control is transferred to the interrupt vector table while single-stepping.

8.5 Limited number of breakpoints

The hardware debugger supports only a limited number of breakpoints. Currently, 32 breakpoints (+1 temporary breakpoint for single-stepping) are supported by default. You can reduce this to 1 by issuing the command `monitor hwbp` (see above). If you set more breakpoints than the maximum number, it will not be possible to start execution. Instead one will get the warning `Cannot insert breakpoint ... Command aborted`. You have to delete or disable some breakpoints before program execution can continue. However, you should not use that many breakpoints in any case. One to five breakpoints are usually enough.

8.6 Power saving is not operational

When you activate *sleep mode*, the power consumed by the MCU is supposed to go down significantly. If debugWIRE is active, then some timer/counters will never be stopped and for this reason the power reduction is not as high as in normal state.

8.7 MCU operations interfering with debugWIRE

There are a few situations, which might lead to problems. The above mentioned list of known issues mentions the following:

- The PRSPI bit in the power-saving register should not be set
- Breakpoints should not be set at the last address of flash memory
- Do not single step over a SLEEP instruction
- Do not insert breakpoints immediately after an LPM instruction and do not single-step LPM code

Since the debugWIRE communication hardware uses the SPI machinery, it is obvious that one should not disable it by setting the power-saving bits. Otherwise the communication will not work any longer. The latter three situations may lead to problems stopping at the breakpoint or executing the instructions, respectively.

The list of known issues mentions also the following four potential problems:

- BOD and WDT resets lead to loss of connection
- The OSCCAL and CLKPR registers should not be changed during a debug session
- The voltage should not be changed during a debug session
- The CKDIV8 fuse should not be in the programmed state when running off a 128 kHz clock source

However, I had no problems reconnecting to the target when the target had been stopped asynchronously or by a breakpoint. The only problem was that the target will not stop at the hardware breakpoint after a reset, since this hardware breakpoint will be cleared by the reset. So, if you want to be sure to stop after a reset, place two different breakpoints in the startup routine. Changing the clock frequency is also not a problem since at each stop the debugger re-synchronizes with the target. Further, changing the supply voltage can be done, if you have level-shifting hardware in place. Finally, debugging at very low clock frequencies (128 kHz/8 = 16 kHz) is not impossible, but communication is extremely slow.

8.8 BREAK instructions in your program

It is possible to put the BREAK instruction, which is used to implement breakpoints, in ones program by using the inline assembly statement asm("break"). This does not make any sense since without the debugger, the MCU will stop at this point and will not do anything anymore. Such a BREAK instruction may also be in the program because a previous debugging session was not terminated in a clean way. If such a BREAK is detected, one may want to issue the `load` command again.

When running under the debugger, the program will be stopped in the same way as if there is a software breakpoint set by the user. However, one cannot continue execution from this point with the `step`, `next`, or `continue` command. Instead, the debugger gets an "illegal instruction" signal. So, one either needs to reload the program code or, set the PC to a different value, or restart the debugging session.

8.9 Some MCUs have stuck-at-one bits in the program counter

Some debugWIRE MCUs appear to have program counters in which some unused bits are stuck at one. ATmega48s and ATmega88s (without the A-suffix), which I have sitting on my bench, have their PC bits 11 and 12 or only PC bit 12 always stuck at one. In other words the PC has at least the value 0x1800 or 0x1000, respectively (note that the AVR program counter addresses words, not bytes!). The hardware debugger can deal with it, but GDB gets confused when trying to perform a stack backtrace. It gets also confused when trying to step over a function call or tries to finalize a function call. For these reasons, debugging these MCUs does not make much sense and *dw-link* rejects these MCUs with an error message when one tries to connect to one of those (see also [this blog entry](#)).

The only reasonable way to deal with this problem is to use a different MCU, one with an A, PA, or PB suffix. If you really need to debug this particular MCU and are aware of the problems and limitations, you can recompile the sketch with the compile time constant `STUCKAT1PC` set to 1.

8.10 The start of the debugger takes two seconds

The reason is that when the host establishes a connection to the debugger, the debugger is reset and the bootloader waits two seconds. You can avoid that by disabling the auto-reset feature putting a capacitor of 10 µF or more between RESET and GND.

8.11 Code optimization reorganizes code and makes it impossible to stop at a particular source line or to inspect or change values of local variables

The standard setting of the Arduino IDE and CLI is to optimize for space, which is accomplished by using the compiler option **-Os**. In this case, it may be difficult to stop at some source lines and single-stepping may give strange results. When you choose `Debug` as the value for the option `Debug Compile Flags`, then the compiler optimizes the code in a debugger-friendly way (using the compiler option **-Og**). And this is actually what the GDB people recommend.

I have encountered situations [when it was impossible to get the right information about C++ objects](#). This can be avoided by disabling *link-time optimization* (LTO). Choose `Debug (no LTO)` in this case. Finally, if there are still discrepancies between what you expect and what the debugger delivers, you can try `Debug (no LTO, no comp. optim.)`, which effectively switches off any optimization (corresponding to **-O0 -fno-lto**).

In PlatformIO, you can set the options for generating the debug binary in the `platform.ini` file.

9 Trouble shooting

Problem: After changing optimization options, the binary is still too large/very small

You switched optimization option from **-Og -fno-lto** back to normal and you recompiled, but your program still looks very big. The reason for that can be that the Arduino IDE/CLI does not always recompile the core, but reuses the compiled and linked archive. In the Arduino IDE 1, you can force a recompile of the core by exiting the IDE. In IDE 2, this is not longer an option. You need to look at where the files are compiled and stored and delete them manually.

Problem: When starting the debug session in PlatformIO, you get the message *pioinit:XX: Error in sourced command file*

Something in the `platformio.ini` file is not quite right. Sometimes an additional line of information is given that identifies the problem. If you see also see the message `"monitor" command not supported by this target` then the dw-link adapter could not be found.

One other common problem is that the debug environment is not the first environment or the default environment. In this case, the wrong environment is used to configure the debug session and probably some environment variables are not set at all or set to the wrong values. So, you need to edit the `platformio.ini` file accordingly.

Problem: When connecting to the target using the *target remote* command, it takes a long time and then you get the message *Remote replied unexpectedly to 'vMustReplyEmpty': timeout*

The serial connection to the hardware debugger could not be established. The most likely reason for that is that there is a mismatch of the bit rates. The Arduino uses by default 115200 baud, but you can recompile dw-link with a changed value of `HOSTBPS`, e.g., using 230400. If GDB is told something differently, either as the argument to the `-b` option when starting `avr-gdb` or as an argument to the GDB command `set serial baud ...`, you should change that. If you did not specify the bitrate at all, GDB uses its default speed of 9600, which will not work!

My experience is that 230400 bps works only with the UNO boards that use the ATmega32U2 chip as the USB interface. The Arduino Nano as well a Chinese clones using the CH320 chips cannot communicate at that speed. You have to fall back to 115200 bps.

A further (unlikely) reason for a failure in connecting to the host might be that a different communication format was chosen (parity, two stop bits, ...).

Problem: In response to the `monitor dwconnect` command, you get the error message *Cannot connect: ...*

Depending on the concrete error message, the problem fix varies.

- *Cannot connect: Check wiring*: The debugger can neither establish an ISP nor a debugWIRE connection. Check wiring. It could also be a problem with the RESET line (see Section 3.3).
- *Cannot connect: Unsupported MCU*: This MCU is not supported by *dw-link*. It most probably has no debugWIRE connectivity.
- *Cannot connect: PC with stuck-at-one bits*: dw-link tried to connect to an MCU with stuck-at-one bits in the program counter (see Section 8.9). These MCUs cannot be debugged with GDB.
- *Cannot connect for unknown reasons:* This error message should not be shown at all. If it does, please tell me!

Problem: You receive the message *Protocol error with Rcmd*

This is a generic GDB error message that indicates that the last `monitor` command you typed could not be successfully executed. Usually, also a more specific error message is displayed, e.g., *debugWIRE could NOT be disabled*. These messages are suppressed in some GUIs, though.

Problem: You get the message *Connection to target lost*, the program receives a `SIGHUP` signal when you try to start execution, and/or the system LED is off

The target is not responsive any longer. Possible reasons for such a loss of connectivity could be that the RESET line of the target system does not satisfy the necessary electrical requirements (see Section 3.3). Other reasons might be that the program disturbed the communication by changing, e.g., the MCU clock frequency (see Section 8.7). Try to identify the reason, eliminate it and then restart the debug session. Most probably, there are still BREAK instructions in flash memory, so the `load` command should be used to reload the program.

Problem: When stopping the program with Ctrl-C (or with the stop button), you get the message *Cannot remove breakpoints because program is no longer writable.*

The reason is most probably that the communication connection to the target system has been lost (see above).

Problem: The debugger responses are very sluggish

One reason for that could be that the target is run with a clock less than 1 MHz, e.g. at 128 kHz. Since the debugWIRE communication speed is MCU clock/8 or clock/16, the communication speed could be 8kbps. If the CKDIV8 fuse is programmed, it could even be only 1kbps. Unprogram CKDIV8 and if possible choose a higher clock frequency (see Section 8.2).

Problem: The debugger does not start execution when you request *single-stepping* or *execution* and you get the warning *Cannot insert breakpoint ... Command aborted*

You use more than the allowed number of breakpoints, i.e., usually 32 (+1 for a temporary breakpoint for single-stepping). If you have executed the `monitor hwbp` command, this number is reduced to 1. In this case, you can either set a breakpoint or you can single-step, but not both! In any case, you need to reduce the number of breakpoints before you can continue.

Problem: When single stepping with `next` or `step` , you receive the message *Warning: Cannot insert breakpoint 0* and the program is stopped at a strange location

The problem is similar to the one above: You used too many breakpoints and there is no temporary breakpoint left for gdb. The program is probably stopped somewhere you have not anticipated. You may be able to recover by deleting one or more breakpoints, setting a breakpoint close to where you wanted to step, and then using the `continue` command. If this is not possible, restart and use fewer breakpoints.

Problem: While single-stepping, time seems to be frozen, i.e., the timers do not advance and no timer interrupt is raised

This is a feature, not a bug. It allows you to single-step through the code without being distracted by interrupts that transfer the control to the interrupt service routine. Time passes and interrupts are raised only when you use the `continue` command (or when the `next` command skips over a function call). You can change this behavior by using the command `monitor unsafestep`, which enables the timers and interrupts while single-stepping. In this case, however, it may happen that during single-stepping control is transferred into an interrupt routine.

Problem: When single stepping with `next` or `step` , the program ends up at the start of flash memory, e.g., 0x0030

This should only happen when you have used the command `monitor unsafestep` before, which enables interrupts while single-stepping. In this case an interrupt might have raised which has transferred control to the interrupt vector table at the beginning of flash memory. If you want to continue debugging, set a breakpoint at the line you planned to stop with the single-step command and use the `continue` command. If you want to avoid this behavior in the future, issue the debugger command `monitor safestep`.

Problem: The debugger does not start execution when you request *single-stepping* or *execution*, you get the message *illegal instruction*, and the program receives a `SIGILL` signal

The debugger checks whether the first instruction it has to execute is a legal instruction according to the Microchip specification. Additionally, a BREAK instruction (which has not been inserted by the debugger) is considered as illegal since it would halt the MCU. Such a BREAK instruction might have been inserted as part of the program code or may be a leftover from a previous debugging session that has not been terminated in a clean way.

Check the instruction by using the command `x/i $pc`. If the BREAK instruction is a leftover from a previous debug session, you can remove it using the `load` command. Note that the program counter is set to 0x0000 and you should use the `monitor reset` command to reset your MCU before restarting.

If you simply want to continue, you can set the PC to another value, e.g., one that is higher by two or four. Do that by using the command `set $pc=...`.

Problem: The debugger does not stop at the line a breakpoint was set

Not all source lines generate machine code so that it is sometimes impossible to stop at a given line. The debugger will then try to stop at the next possible line. This effect can get worse with different compiler optimization levels. For debugging, **-Og** is the recommended optimization option, which applies optimizations in a debug-friendly way. This is also the default for PlatformIO. In the Arduino IDE, you have to select the `Debug` option. You can also disable all possible optimizations (choose `Debug (no comp. optim.)` in the Arduino IDE).

Problem: The debugger does things that appear to be strange

The debugger starts execution, but it never stops at a breakpoint it should stop, single-stepping does not lead to the expected results, etc. I have seen three possible reasons for that (apart from a programming error that you are hunting).

Often, I had forgotten to load the binary code into flash. Remember to use the `load` command ***every time*** after you have started a debugging session. Otherwise it may be the case that the MCU flash memory contains old code! Note that after the `load` command the program counter is set to zero. However, the MCU and its registers have not been reset. You should probably do that by using the command `monitor reset`. Alternatively, when you initiated your session with `target extended-remote ...`, you can use the `run` command that resets the MCU and starts at address zero.

Second, you may have specified a board/MCU different from your actual target. This happens quite easily with PlatformIO when you work with different targets. In this case, some things appear to work, but others do not work at all.

Another possible reason for strange behavior is the chosen compiler optimization level. If you have not chosen **-Og** (or **-O0**), then single-stepping may not work as expected and/or you may not be able to assign values to local variables. If objects are not printed the right way, then you may consider disabling LTO (by using the compiler option **-fno-lto**). Have a look into the Section about compiler optimization flags.

So, before blaming the debugger, check for the three possible causes.

Problem: You have set the value of a local variable using the `set var <var>=<value>` command, but the value is still unchanged when you inspect the variable using the `print` command

This appears to happen even when the optimization level is set to **-Og**, but not when you use **-O0**. So, if it is important for you to change the value of local variables, you should use the latter optimization level (see the preceding problem).

Problem: In PlatformIO, the global variables are not displayed

I have no idea, why that is the case. If you want to see the value of a global variable, you can set a `watchpoint`.

Problem: The disassembly cannot be displayed

Older versions of avr-gdb had a problem with disassembly: https://sourceware.org/bugzilla/show_bug.cgi?id=13519. In the current version the problem has been fixed, though. So, you might want to get hold of a current version.

Problem: The system LED blinks furiously and/or the program receives an `ABORT` signal when trying to start execution

In this case some serious internal error had happened. You have to stop the current debug session and restart.

The reason for such an error could be that the connection to the target could not be established or that there was an internal debugger error. It may be that the corresponding error message has already been displayed. If it is a connection error that happened when you tried to establish a connection, you may get the error message by typing `monitor dwconnect`. You can find out what kind of error happened by typing the following command:

```
monitor lasterror
```

If the error number is less than 100, then it is a connection error. Errors above 100 are serious internal debugger errors (see below).

If you have encountered an internal debugger error, then please try to reproduce the problem and tell me how it happened. Please try to distill a minimal example leading to the problem and fill out the *issue form*. By the way: `monitor dwoff` can still be executed, provided there is still a functioning connection to the target. So you should still be able to disable debugWIRE on the target MCU even if a fatal error has happened.

Error #	Meaning
1	Connection error: No response to ISP and debugWIRE communication; check wiring
2	Connection error: MCU type is not supported
3	Connection error: Lock bits are set
4	Connection error: MCU has PC with stuck-at-one bits
5	Unknown connection error
101	No free slot in breakpoint table
102	Packet length too large
103	Wrong memory type
104	Packet length is negative
105	Reset operation failed
106	Memory address in flash read operation does not point to page start
107	Could not complete flash read operation
108	Could not complete RAM read operation
109	Memory address in flash write operation does not point to page start
110	Could not complete flash page erase operation
111	Could not load data into the flash buffer for writing
112	Error when programming flash page from buffer

113	Assignment of hardware breakpoint is inconsistent
114	BREAK inserted by debugger at a point where a step or execute operation is required
115	Trying to read flash word at an uneven address
116	Error when single-stepping
117	A relevant breakpoint has disappeared
118	Input buffer overflow
119	Wrong fuse
120	Breakpoint update while flash programming is active
121	Timeout while reading from debugWIRE line
122	Timeout while reading general register
123	Timeout while reading IO register
124	Could not reenable RWW
125	Failure while reading from EEPROM
126	Bad interrupt

Revision history

V 1.1

Initial version

V 1.2

- Changed pin mapping. The default is now to use ISP pins on the debugger so that a simple ISP cable with broken out RESET line is sufficient. System LED is pin D7, GND for the system LED is provided at pin D6. In order to use the pin mapping for shields/adapters, one has to tie SNSGND to ground, whereby the pin number of SNSGND depends on the Arduino board dw-link is compiled for (see mapping described in Section 7.3.3).
- Added wording to recommend optimization level -O0 instead of -Og, because otherwise assignments to local variables will not work. Single-stepping works now with -Og after dw-link hides all inserted BREAK instructions.

V 1.3

- Removed Arduino Mega boards from the set of boards that can be used as hardware debuggers

V 1.4

- New error messages
- System LED with fewer modes
- Some screen shots added to PlatformIO description

V 1.5

- New error message (126)
- default DW speed is now 250 kbps

V 1.6

- New example: Debugging Uno board as target

V 1.7

- Changes in 8.7
- Section 9, Problem 'vMustReplyEmpty': timeout - explanation of what problems I encountered
- Section 5.1-5.3 have been reworked, in particular concerning ATTinyCore 2.0.0 and the new Python script for extending the boards.txt files.

V 1.8

- New help command for monitor commands in 5.7

V 1.9

- Additional trouble shooting help when lockouts are set

V 1.10

- Pointed out in Section 4.2 that when debugging an Uno the first time you try to debug it, you need to erase the chip in order to clear the lock bits.
- Added similar wording under trouble shooting

V 2.0

- Removed „lock bit“ error
- Added explanation that lock bits are automatically removed by erasing the entire chip
- Added extra part how to restore UNO functionality
- Restructured Introduction
- Removed instructions how to modify board and platform files. Now the board definition files are downloaded from my fork.
- Added section 8.11
- More explanation how to start a debugging session using the Arduino IDE
- Reorganized and simplified as much as possible

- Corrected wrong placement in the table about the connections between UNO and ATtiny85
- new monitor command: lasterror
- deleted monitor commands: eraseflash, serial
- added comment about dark system LED
- changed Section 7 in order to describe the V2.0 design
- have thrown out ATtiny13 since it behaves strangely
- added that disabling debugWIRE is now done automatically
- added connect.py