AN2658

USART in One-Wire Mode

Features

- Explanation of half-duplex
- Explanation of why open-drain is needed
- A look at older tinyAVR® and megaAVR® one-wire solutions
- An introduction to the new solution on tinyAVR 0- and 1-series and megaAVR 0-series
- Three code examples for tinyAVR 0- and 1-series and megaAVR 0-series

Introduction

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The 1-Wire® protocol, sometimes referred to as Dallas 1-Wire or simply one-wire, is probably the most widely known form of one-wire half-duplex serial communication. 1-Wire is, however, not the only form of half-duplex serial communication over a single wire.

Using a single wire for communication can sometimes reduce the total cost of a product, where using multiple wires for serial communication would force a change to a higher pin count device.

In this document, the term *1-Wire* refers exclusively to the 1-Wire protocol. The term *one-wire* refers to any form of one-wire half-duplex communication including but not limited to the Dallas 1-Wire protocol.

In order to communicate over one-wire with a Universal Synchronous Asynchronous Receiver Transmitter (USART), an open-drain or open-collector circuit is needed. Older AVR® devices require external components and two pins to achieve this. On the new tinyAVR 0- and 1-series and megaAVR 0-series one pin is enough and no external components are needed. Before looking more closely at the old and new solution, some background information about half-duplex and open-drain is provided.

Table of Contents

1. Relevant Devices

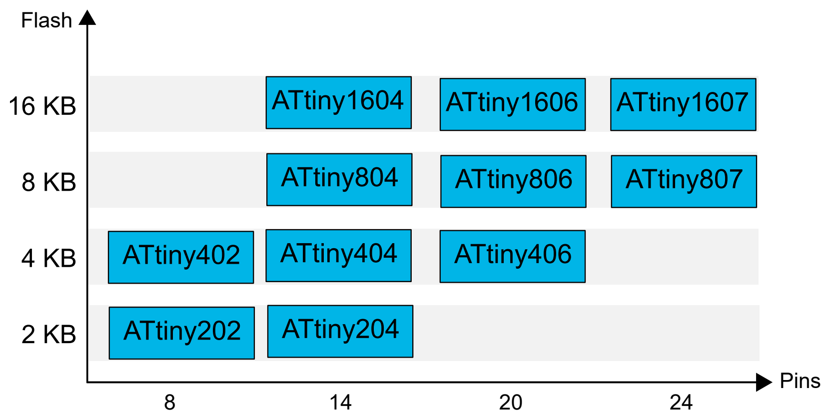
This chapter lists the relevant devices for this document.

1.1 tinyAVR® 0-series

The figure below shows the tinyAVR® 0-series, laying out pin count variants and memory sizes:

- Vertical migration is possible without code modification, as these devices are fully pin- and feature compatible.
- Horizontal migration to the left reduces the pin count and therefore, the available features.

Figure 1-1. Device Family Overview



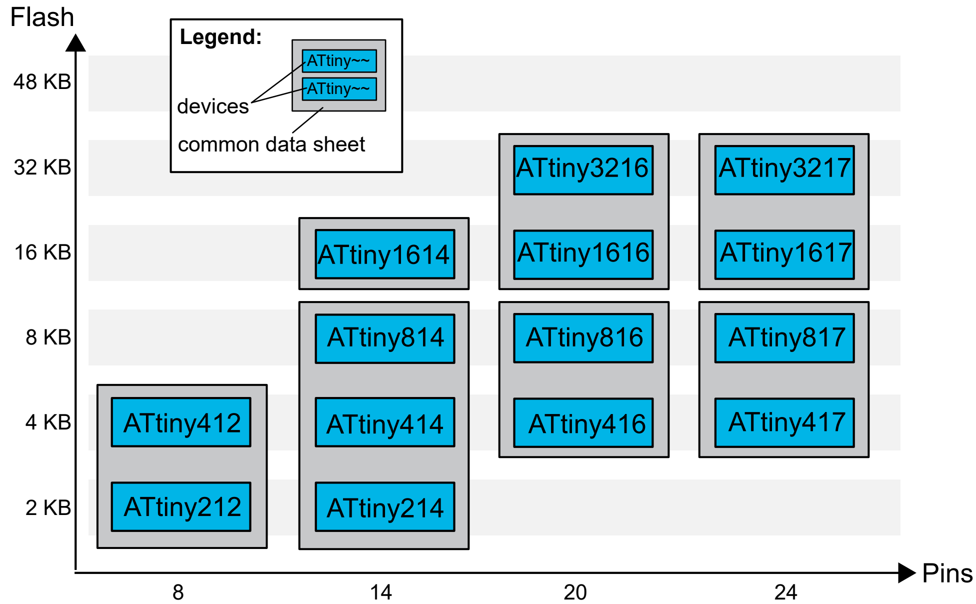
Devices with different Flash memory size typically also have different SRAM and EEPROM.

1.2 tinyAVR® 1-series

The figure below shows the tinyAVR® 1-series devices, laying out pin count variants and memory sizes:

- Vertical migration upwards is possible without code modification, as these devices are pin compatible and provide the same or more features. Downward migration may require code modification due to fewer available instances of some peripherals.
- Horizontal migration to the left reduces the pin count and therefore, the available features.

Figure 1-2. tinyAVR® 1-series Overview



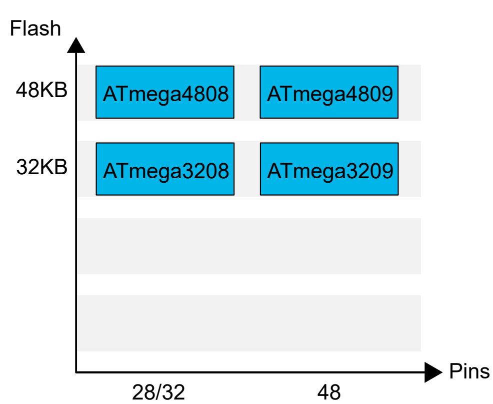
Devices with different Flash memory size typically also have different SRAM and EEPROM.

1.3 megaAVR® 0-series

The figure below shows the megaAVR® 0-series devices, laying out pin count variants and memory sizes:

- Vertical migration is possible without code modification, as these devices are fully pin and feature compatible.
- Horizontal migration to the left reduces the pin count and therefore, the available features.

Figure 1-3. megaAVR® 0-series Overview



Devices with different Flash memory size typically also have different SRAM and EEPROM.

2. Background Information

One-wire communication can be done in multiple ways. Here, the focus will mostly be on one-wire communication by using USART. USART is a communication peripheral which uses two pins; one for reception (RXD) and one for transmission (TXD). When the USART is used for one-wire communication, TXD and RXD need to be connected to each other.

Communication in electrical systems can be divided into three categories; simplex, half-duplex, and full-duplex. With simplex communication, data travel in only one direction. With half-duplex communication, data can travel in both directions, but not at the same time. With full-duplex communication, data can travel in both directions at the same time.

With most types of one-wire communication, simplex or half-duplex is used. Simplex is easiest to implement and does not require any special considerations for the USART, while half-duplex adds complexity as time-multiplexing of communication must be handled by software, and RXD and TXD will be connected together on the same device.

2.1 Half-Duplex with One-Wire

With half-duplex communication in a one-wire system, every device connected to the same line will need to be able to change the state of the line. The state of the line can either be high or low. When the line is high the measured voltage is usually the same as the supply voltage V_{CC}. When the line is low it will usually be pulled to ground, and zero volts will be measured on the input.

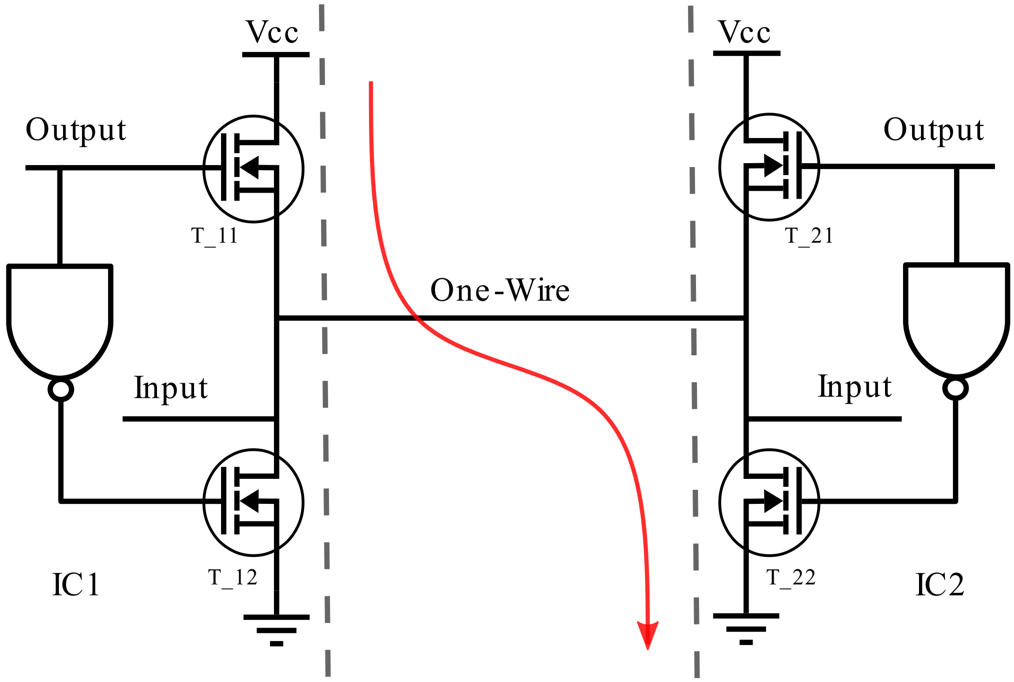
When there are no devices communicating, the line will be in a predefined state, usually high. When one device wants to send data it will have to pull the line low. As all devices are on the same line they can not all send data at the same time. The devices will have to share the line through some form of time multiplexing.

Because all devices are able to pull the line low when the line is high, a special output circuit is needed to protect against potential short circuits. The following chapter will discuss a solution for this, called open-drain.

2.2 Open-Drain

Open-drain and open-collector circuits allow multiple devices to safely connect to a wire which all connected devices can pull low. To better understand why open-drain or open-collector circuits are needed, consider the circuit below.

Figure 2-1. Two Simplified Output Circuits Connected to Each Other

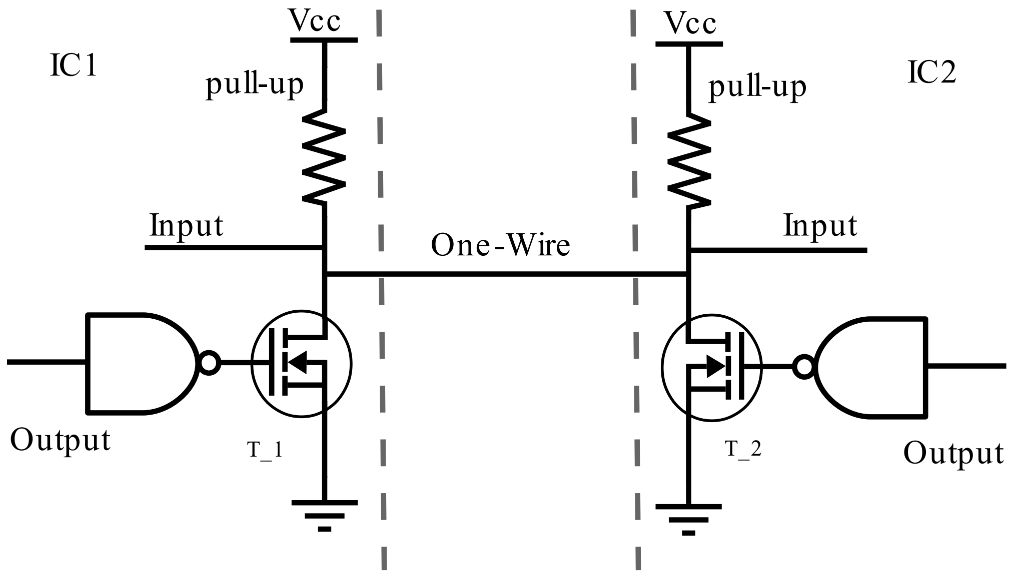


The figure above shows two simplified output circuits connected to each other. The problem in the circuit above occurs if, for example, IC1 tries to hold the line high while IC2 tries to pull the line low. Such a situation will create a low resistance path from V_{CC} to ground as both T_11 and T_22 will conduct current. This low resistance path is shown by the red line. If none of the circuits have any form of overcurrent protection, this will create a short circuit that can damage the devices. If the circuits do have such protection, it will be difficult to predict what the input will be on the devices.

The solution to this problem is to use an open-drain or open-collector circuit on the output with a pull-up resistor. This will avoid creating a low resistance path between V_{CC} and GND, and the inputs will be able to read the correct value from the bus.

The devices mentioned in chapter Relevant Devices feature open-drain functionality. Both the open-drain and the open-collector circuit are capable of having the line pulled low by another device and pulling the line low itself; the difference is that open-collector uses a BJT transistor to pull the line low, while open-drain does so by using a MOSFET transistor. The figure below shows two devices connected by an open-drain connection.

Figure 2-2. Two Devices Connected by Open-Drain with Pull-Up Resistor



When both devices' output is high, the transistors do not conduct current. The input will read the voltage over the transistors as V_{CC} (high) on both sides. If one or both devices pull the line low, the transistors will start conducting, and both inputs will read zero volts on the bus. The current will in any case flow through a pull-up resistor, which will limit the current between V_{CC} and ground. This circuit can never create a high current path from V_{CC} to ground, and the inputs will read the correct value.

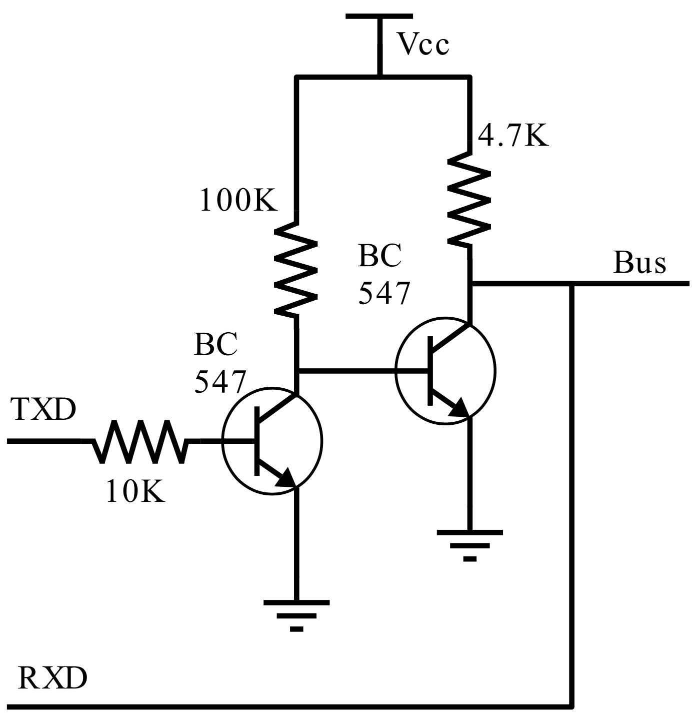
3. Older megaAVR and tinyAVR Solutions

When running one-wire communication with the USART peripheral on older tinyAVR and megaAVR devices, an external open-drain circuit is required. The USART will consume two GPIO pins for this solution. Alternatively, bit banging can be used to perform one-wire communication. This eliminates the need for external hardware and only requires one pin, at the cost of being highly CPU intensive.

3.1 USART with Hardware Modification

It is necessary to connect the RXD and TXD pins externally to use the USART for one-wire communication. Enabling other devices to pull the line low also require additional external circuitry. The circuit shown below is the recommended circuit for implementing one-wire on older tinyAVR and megaAVR devices.

Figure 3-1. megaAVR and tinyAVR Hardware Modification



This circuit is an open-collector solution. TXD, which is an output pin, is protected behind the open-collector circuit, while RXD, set as an input pin, can be connected directly to the bus.

When TXD is high, the leftmost transistor will conduct. This causes the rightmost transistor to see zero volts on its base and hence not conduct between the bus and ground, allowing the bus to be pulled high through the resistor. If a device on the bus pulls the line low while TXD is still high, current will flow through the rightmost pull-up resistor without creating a low resistance path between V_{CC} and the line that is pulled to zero volts.

If, on the other hand, TXD goes low, the leftmost transistor will stop conducting. The rightmost transistor will then see V_{CC} on its base and start conducting. The bus will go low, and the rightmost resistor will prevent a low resistance path between V_{CC} and ground. The input circuit in RXD is high impedance (high resistance) and will not impact the bus notably.

The circuit will ensure that no direct current path is created between V_{CC} and ground and that the USART can send and receive data on the same line.

3.2 Bit Banging

Bit banging refers to any implementation of serial communication which is directly driven by software. Instead of using a dedicated peripheral, software reads and writes the input and input pins and handles timing.

Delay routines can be used to handle bus timing. Delay routines are busy-wait loops which count a predefined number of CPU clock cycles. When a delay routine has finished, the CPU will take some action on the pin used for communication, such as sampling the pin, toggling the pin output, or changing the pin from an output to an input pin.

When executing delay routines, the CPU cannot do other tasks. Interrupt service routines (ISRs) will have to wait until the CPU is done with the bit banging. This is because the CPU cycles used by the ISR will not be correctly subtracted from the delay routine, and signal timing will not be correct. In the case of the 1-Wire protocol, this gives a worst case interrupt latency of almost 1 ms.

Arduino® implements the 1-Wire protocol on the AVR using bit banging. When bit banging 1-Wire, an open-drain or open-collector circuit is not necessary. Instead, the pin direction is switched from output to input dependent on if the protocol demands transmission or reception of data.

4. New Solution in tinyAVR 0- and 1-series and megaAVR 0-series

The USART peripheral supported by the tinyAVR 0- and 1-series and megaAVR 0-series has features that simplifies one-wire communication. TXD and RXD can be connected internally, eliminating the need for two pins. The TXD pin is used as both input and output. The pin supports open-drain mode and a configurable internal pull-up, eliminating the need for external hardware. Moreover, compared to the 1-Wire bit banging example, there is minimal need for CPU cycles, and interrupts can be enabled the whole time.

4.1 Implementation

In order to enable one-wire, two bits in the USART need to be written to `1`:

- The Loop Back Mode Enable (`LBME`) bit in the `CTRLA` register. This bit enables the internal connection between the TXD pin and the RXD pin.
- The Open-Drain Mode Enable (`ODME`) bit in the `CTRLB` register. This bit enables open-drain functionality for the TXD pin. The RXD pin will not be used by the USART.

As there needs to be at least one pull-up resistor connected to the bus, it may also be necessary to write to the respective pull-up enable bit (`PULLUPEN`) for the pin used. The code snippet below shows how the USART is configured as a 1-Wire master in a polled mode configuration.

```
// Enable internal pull-up
PORTB.PIN2CTRL = PORT_PULLUPEN_bm;
// Enable loop-back mode
USART0.CTRLA = USART_LBME_bm;
// Enable Open-drain mode. Enable TX and RX
USART0.CTRLB = USART_ODME_bm | USART_RXEN_bm | USART_TXEN_bm;
// Set 8-bit USART and 1 stop bit
USART0.CTRLC = USART_CHSIZE_8BIT_gc | USART_SBMODE_1BIT_gc;
// Set baud rate to 115200
USART0.BAUD = BAUD_115200;
```

If interrupts are going to be used, the interrupt flags for *data register empty* and *reception complete* will also have to be enabled. As TXD and RXD are connected together, data transmitted will also be received. Reading out the last byte that was sent can be used as part of error checking.

If the timing of the protocol does not allow for the overhead of reading the transmitted data, either the receive interrupt or the receiver itself can be disabled while transmitting. The receive interrupt can be disabled using the Receive Complete Interrupt Enable bit (`RXCIE`) in the Control A register (`CTRLA`), and the receiver using the Receiver Enable bit (`RXEN`) in the Control B register (`CTRLB`). When receiving, the receiver and receive interrupt must be enabled.

5. Protocols

When multiple devices are going to communicate over the same line, there is a need for a protocol. The complexity of such protocols depends on multiple factors of the one-wire system:

- Amount of devices connected
- Amount of masters
- Possibility for the devices to connect and disconnect
- Signal integrity in the environment that the bus is operating in
- Diversity of the clock speeds for the devices
- Data rate

The 1-Wire protocol provides a good solution in regards to almost all of the points above, but the data transfer rate is limited. Its maximum transfer rate is 14400, and some of the bus time and data is used for protocol overhead.

Section 7, *Get Source Code from Atmel | START* below provides a link to a simple example showing the USART communicating at higher speeds using one-wire. The example sets one device to listen for communication and another to initiate it. The data sent between the device is of fixed length. The device initiating the first transfer always expects to receive data in return from the other device, before sending new data.

6. Conclusion

On older megaAVR and tinyAVR devices, using the USART for one-wire communication will consume two pins, and it requires an external open-drain or open-collector circuit unless bit banging is used.

One-wire solutions on the new tinyAVR 0- and 1-series and megaAVR 0-series can be implemented with a lower bill of material (BOM) cost and with low CPU overhead thanks to the updated USART peripheral. With internal connection between RXD and TXD and open-drain mode on the pin, they introduce advantages that can be seen in the table below.

Table 6-1. Comparison of 1-Wire Techniques

	Old USART Solution	New USART Solution	Bit Banging
Interrupts	Active	Active	Disabled
Pins needed	2 (TXD and RXD)	1 (TXD)	1 (any)
CPU Load	Low	Low	High
BOM	External components needed	No extra cost	No extra cost

As can be seen from the table, the solution available on the new tinyAVR 0- and 1-series and megaAVR 0-series provides all the best aspects from the other solutions, except the fact that a dedicated TXD pin need to be used instead of being able to use any pin, such as with Bit Banging. These devices are a great platform to develop a one-wire application on.

7. Get Source Code from Atmel | START

The example code is available through Atmel | START, which is a web-based tool that enables configuration of application code through a Graphical User Interface (GUI). The code can be downloaded for both Atmel Studio and IAR Embedded Workbench® via the direct example code-link(s) below or the *BROWSE EXAMPLES* button on the Atmel | START front page.

Atmel | START web page: microchip.com/start

Example Code

One-wire in polled port mode

- http://start.atmel.com/#example/Atmel:one-wire:1.0.0::Application:One-wire_in_polled_port_mode:

One-wire in polled UART mode

- http://start.atmel.com/#example/Atmel:one-wire:1.0.0::Application:One-wire_in_polled_uart_mode:

Simple one-wire example

- http://start.atmel.com/#example/Simple/one-wire/example

Press *User guide* in Atmel | START for details and information about example projects. The *User guide* button can be found in the example browser, and by clicking the project name in the dashboard view within the Atmel | START project configurator.

Atmel Studio

Download the code as an .atzip file for Atmel Studio from the example browser in Atmel | START, by clicking *DOWNLOAD SELECTED EXAMPLE*. To download the file from within Atmel | START, click *EXPORT PROJECT* followed by *DOWNLOAD PACK*.

Double-click the downloaded .atzip file and the project will be imported to Atmel Studio 7.0.

IAR Embedded Workbench

For information on how to import the project in IAR Embedded Workbench, open the Atmel | START user guide, select *Using Atmel Start Output in External Tools*, and *IAR Embedded Workbench*. A link to the Atmel | START user guide can be found by clicking *About* from the Atmel | START front page or *Help And Support* within the project configurator, both located in the upper right corner of the page.

8. Revision History

Doc.	Date	Comments
A	04/2018	Initial document release.

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