
Core Independent Ultrasonic Distance Measurement with the tinyAVR® 1-series

Introduction

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This application note describes a core independent method of measuring distance using an AVR® device and an ultrasonic transceiver. Many peripherals are configured to work together to perform measurements and present a result, independent of the CPU. The implementation is centered around the AVR Configurable Custom Logic (CCL) module and takes advantage of timer/counter Pulse Width Modulation (PWM) generation and uses timer/counter waveform generation for synchronized masking signals used for the transmit and receive lines of the ultrasonic transducer. The Analog Comparator (AC) and Digital-to-Analog Converter (DAC) are used to handle reception of the attenuated reflected signal. Timer capture is used to measure the ultrasonic burst's "time of flight" in order to measure proximity to a barrier.

Features

- Ultrasonic transceiver used for transmitting and receiving reflected bursts
- Core Independent operation using CCL module
- Timer/Counter Type D (TCD) used for synchronized masking signals
- Compact code size
- Ultrasonic Distance Measurement Field Engagement Board available

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1. Relevant Devices

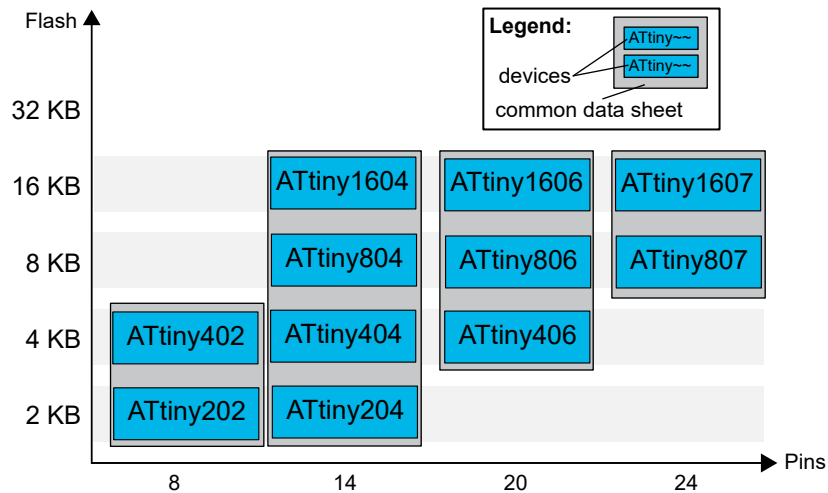
This chapter lists the relevant devices for this document.

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. tinyAVR® 0-series Overview



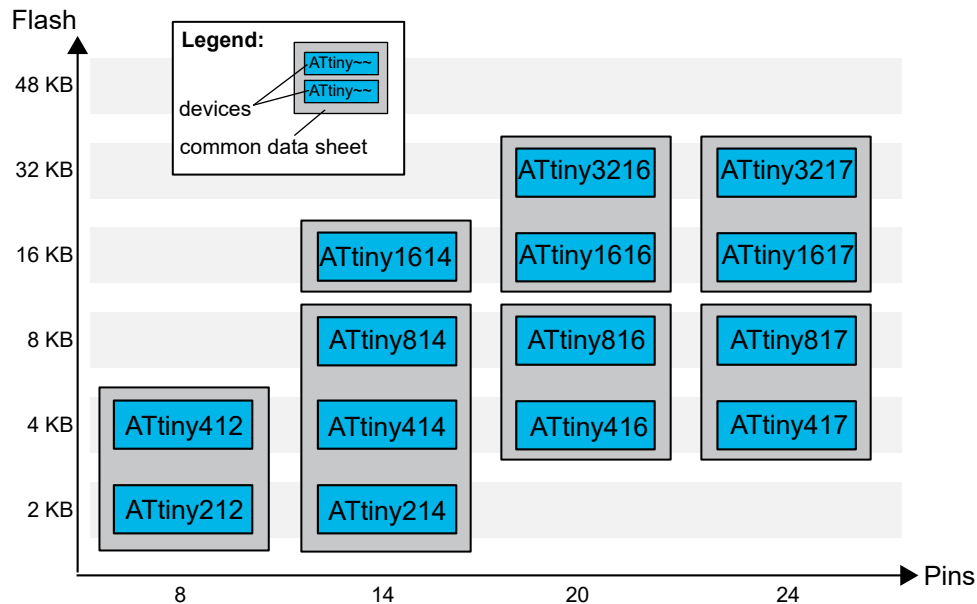
Devices with different Flash memory size typically also have different SRAM and EEPROM.

1.2 tinyAVR 1-series

The following figure 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



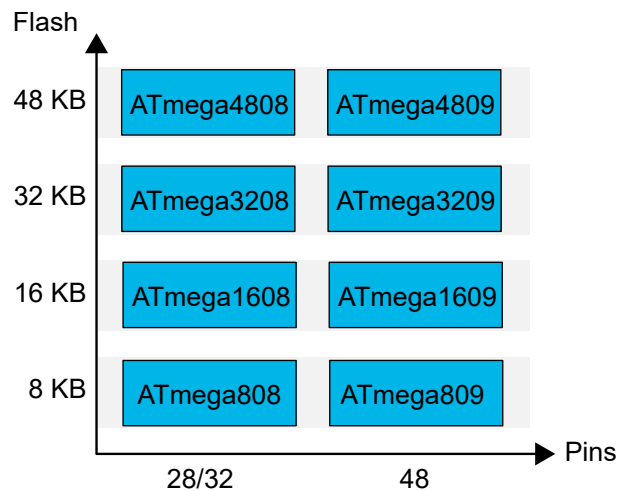
Devices with different Flash memory size typically also have different SRAM and EEPROM.

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.

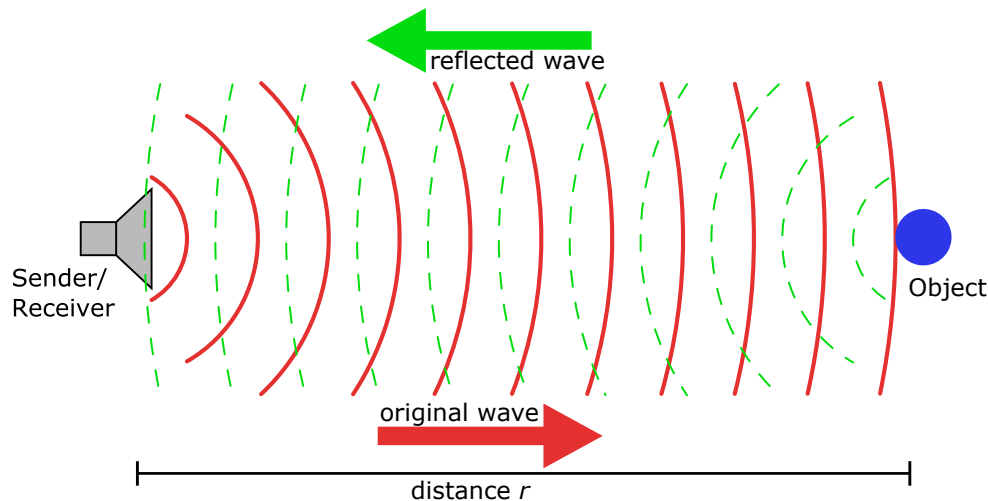
2. Ultrasonic Sensors

Ultrasonic transceivers are able to convert an electrical signal to an ultrasonic burst and receive the resulting reflected wave when directed at a barrier. Several property comparisons can be made between the transmitted and received bursts in order to determine different factors. For example, the time between transmitting a burst and receiving the reflected wave, termed "time of flight", can be used to determine distance, or if the distance is known, a material can be uniquely identified by calculating its sound attenuation coefficient. If directed at a moving object, the Doppler shift (frequency alteration due to velocity) between the transmitted and received bursts can be measured and used to determine speed. Other deductions are possible. However, these summarize the most common.

2.1 Measuring Distance with an Ultrasonic Transceiver

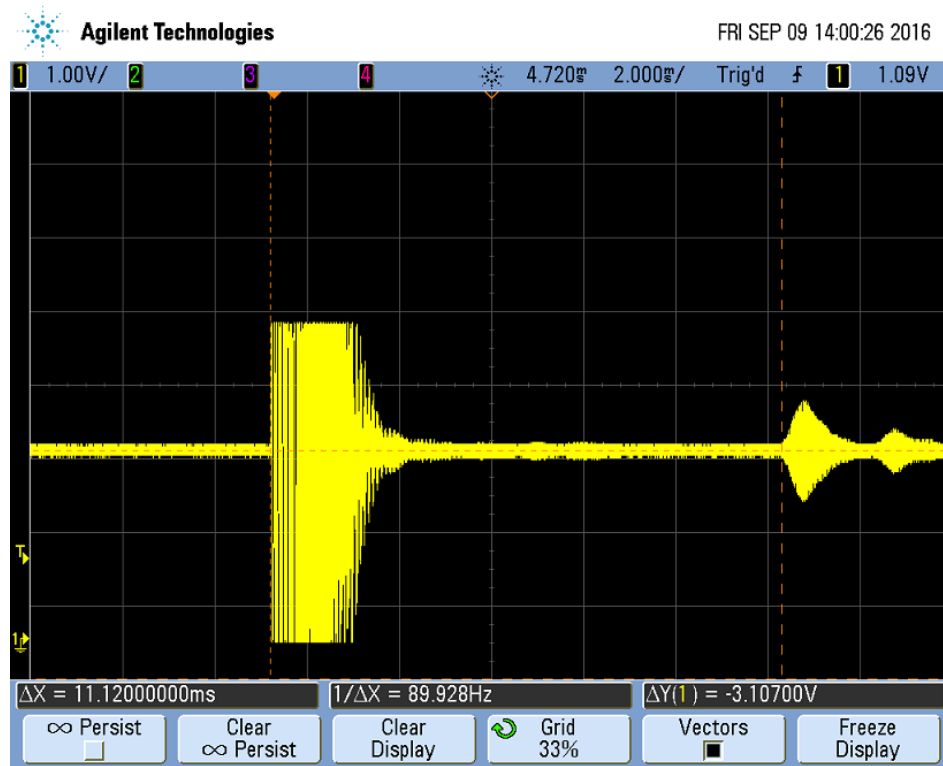
In this application note, an ultrasonic transceiver is used to measure the distance to a barrier, calculated from the "time of flight" between a transmitted ultrasonic burst and receiving its reflection. This process can also be referred to as "echo ranging". The first figure below illustrates the principle. The burst produced by the transceiver bounces off the barrier object and returns to be received after a time interval. The variation in distance traveled is proportional to the measured time interval, related by a factor of the speed of sound.

Figure 2-1. Ultrasonic Distance Measurement Principle



The signals transmitted and received by an ultrasonic transducer can be visually inspected via an oscilloscope. An example is depicted in the figure below. The dotted orange lines indicate the measurable "time of flight" mentioned above. It can be seen that the reflected wave is significantly attenuated; this should be kept in mind during application design in order to detect the received signal as soon as possible.

Figure 2-2. Ultrasonic Transducer "Time of Flight" Oscilloscope Screen Capture

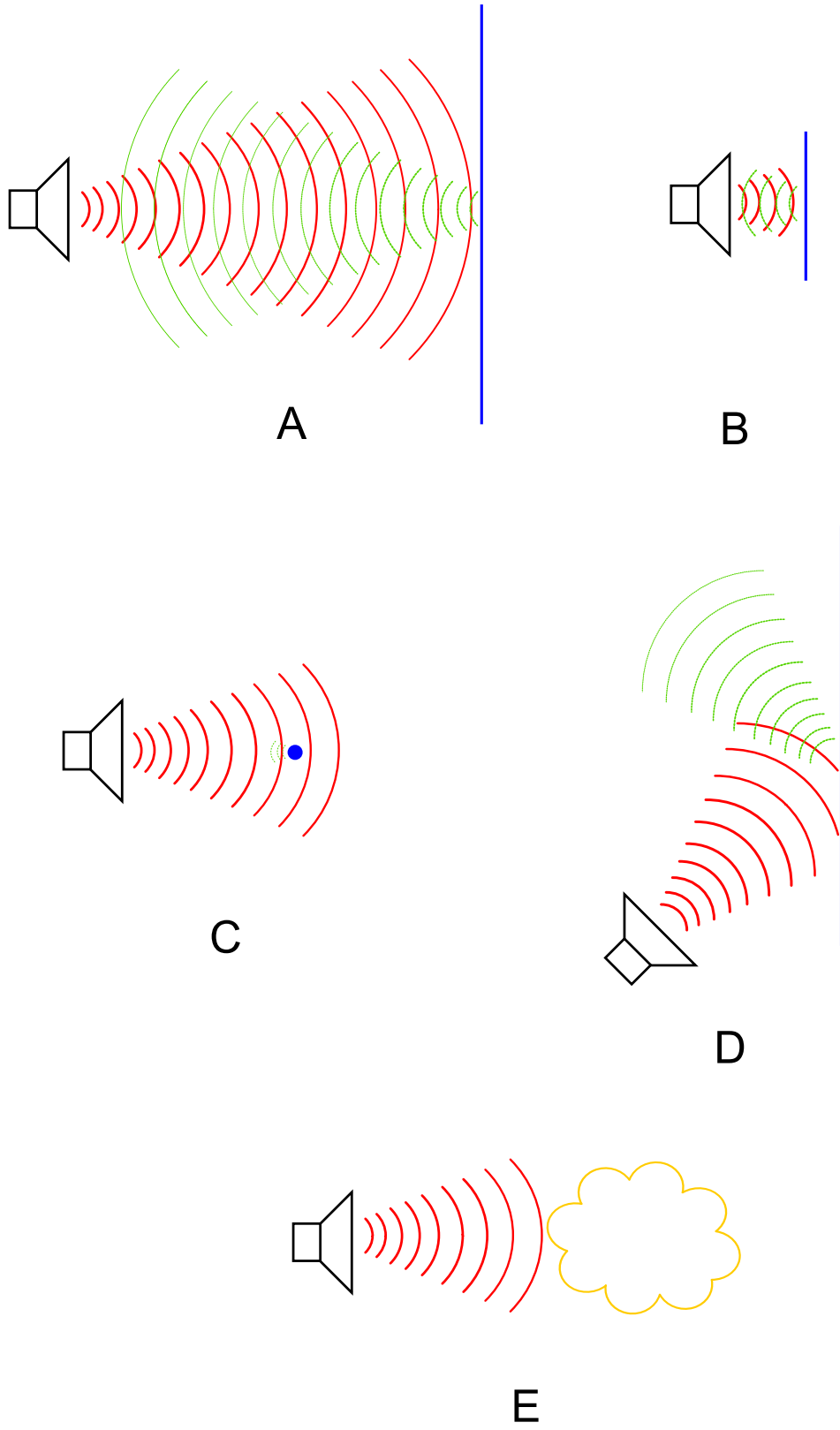


2.2 Limitations of Ultrasonic Distance Measurement

Situational Limitations

While measuring distance using an ultrasonic transceiver is quite effective, there are some situational requirements. Ideally, the barrier, the distance to which is to be measured, should be a solid, flat surface perpendicular to the ultrasonic beam. It should have a sufficiently different acoustic attenuation to that of air so that enough of the ultrasonic burst is reflected in order to be received by the transducer. It should also be within the operational range of the ultrasonic transceiver. The figure below (*Ineffective Ultrasonic Distance Measurement Situations*) depicts some situational limitations of ultrasonic distance measurement. In sub-figure A, the distance to the barrier is too far away and the reflected signal is too attenuated to be effectively received. Sub-figure B shows the barrier too close, meaning the transceiver is still in Transmission mode when the reflected signal should be received. In sub-figure C, the object is too small, and not enough of the ultrasonic burst is reflected. Sub-figure D shows the effect of an angle not perpendicular to the ultrasonic beam so that it is reflected away from the transceiver. In sub-figure E, the object is too soft and has an attenuation coefficient similar to that of air, so the ultrasonic beam is absorbed rather than reflected.

Figure 2-3. Ineffective Ultrasonic Distance Measurement Situations



Environmental Limitations

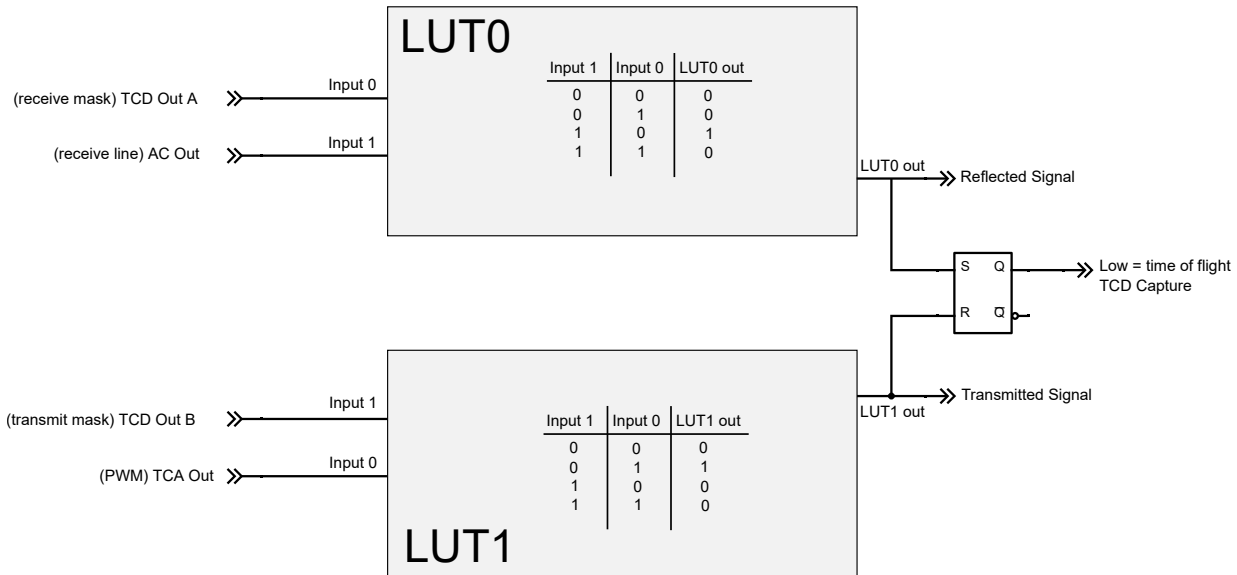
Additionally, ultrasonic distance measurement is highly affected by temperature and humidity, which changes the speed of sound in air. This, in turn, will contribute to large variations in measurements taken for the same distance, introducing substantial errors. Air currents can also contribute to error, in that they can act as invisible barriers that will reflect ultrasonic bursts.

It is possible to account for errors introduced by changing temperature to a certain degree. This can be done by taking a temperature measurement at the same time as a "time of flight" measurement and considering both in the distance calculation.

3. Implementation

The functionality of the Core Independent Ultrasonic Distance Measurement application is centered around the Configurable Custom Logic (CCL) module. It enables input MUXing to two Lookup-Tables (LUTs) with configurable logic. In this application, one LUT is used to control the transmit line of the ultrasonic transducer, and the other is used to filter the receive line. "Time of flight" can be measured by feeding both LUT outputs into a sequential control block, specifically an SR latch. The result is that the output of the latch indicates "time of flight". This setup can be seen in the figure below.

Figure 3-1. Ultrasonic Distance Measurement using Configurable Custom Logic Peripheral



The corresponding timing functionality is depicted in the figure below. The first three lines correspond to control of the ultrasonic transducer transmit line:

- Signal (1) is the output from timer/counter type A, which is set up to produce an approximate 40 kHz PWM
- Signal (2) is a mask produced by timer counter type D, set up to be low when an ultrasonic burst should be emitted, and the rest of the time high
- These two signals are the inputs to LUT1, the output of which (1 & !2) is connected to the transmit line of the ultrasonic transducer

The result is a specifically timed ultrasonic transmission at the PWM frequency. The initial edge of the output will also "reset" the SR latch, and start the timer/counter type D capture counter (the beginning of "time of flight").

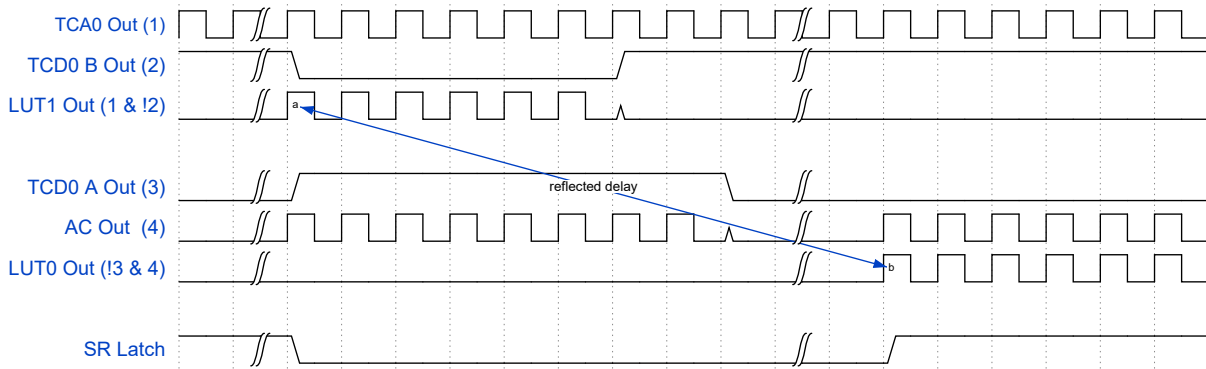
The next three lines correspond to the control of the ultrasonic transducer receive line:

- Signal (3) is a mask produced by timer counter type D, set up to be low when the receive line is enabled, and high when transmitting. The transmission will be picked up by the receive line of the ultrasonic transducer and needs to be masked because it will be erroneously detected as the reflected signal. It extends slightly past the transmission length to account for resonance. Because both masking signals (2 and 3) are produced by the same timer, they are synchronized and therefore the transmission is effectively masked from the receive line.
- Signal (4) represents the activity on the receive line, after being processed by the analog comparator

- These two signals are the inputs to LUT0, the output of which (!3 & 4) represents the filtered receive line, only containing pulse reflections

When the reflected signal is detected by the analog comparator, the first edge will "set" the SR latch, and timer counter type D capture will occur, thereby effectively measuring "time of flight" (SR Latch line in the figure).

Figure 3-2. Ultrasonic Distance Measurement Timing Diagram



3.1 Detecting the Attenuated Reflected Signal

As can be seen in figure *Oscilloscope Screen Capture Indicating Reflected Signal Attenuation* below here, the reflected signal is significantly attenuated compared to the transmitted PWM signal. To handle this, the receive line of the transducer is fed into the analog comparator, which has a compare value set just below the Idle state voltage (half of the supply voltage to the transducer). This value is very specifically generated by the Digital-to-Analog Converter (DAC) module. The result will be as indicated in figure *Functionality of the Analog Comparator in Detecting the Attenuated Reflected Signal*. This procedure enables the reflected signal to be detected as soon as it arrives, despite its attenuation.

Figure 3-3. Oscilloscope Screen Capture Indicating Reflected Signal Attenuation

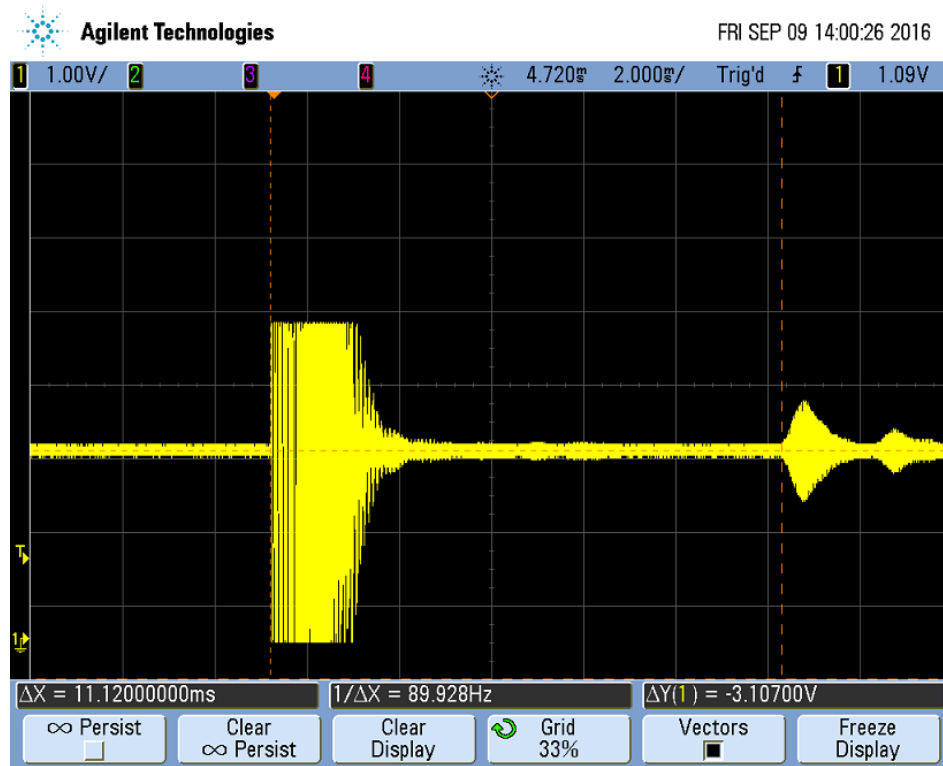
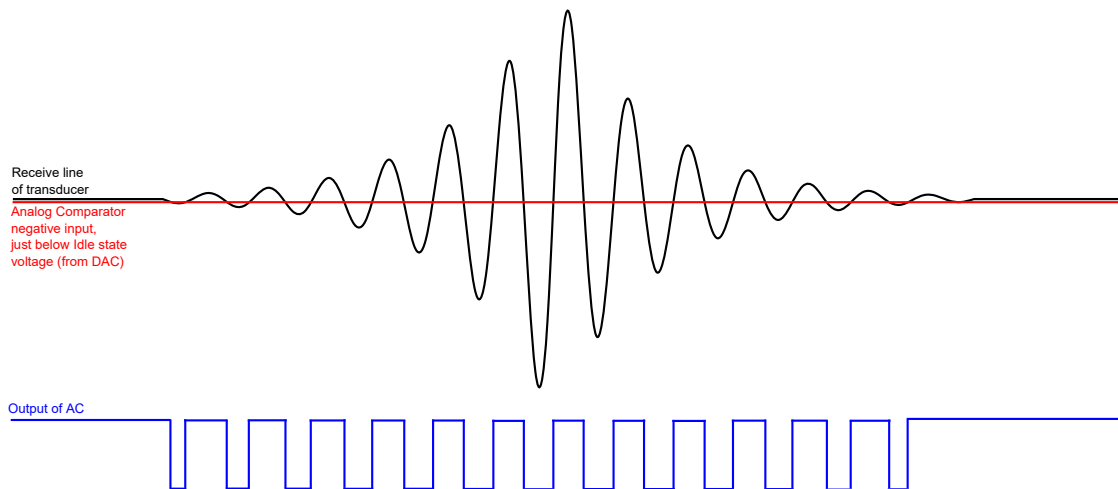


Figure 3-4. Functionality of the Analog Comparator in Detecting the Attenuated Reflected Signal



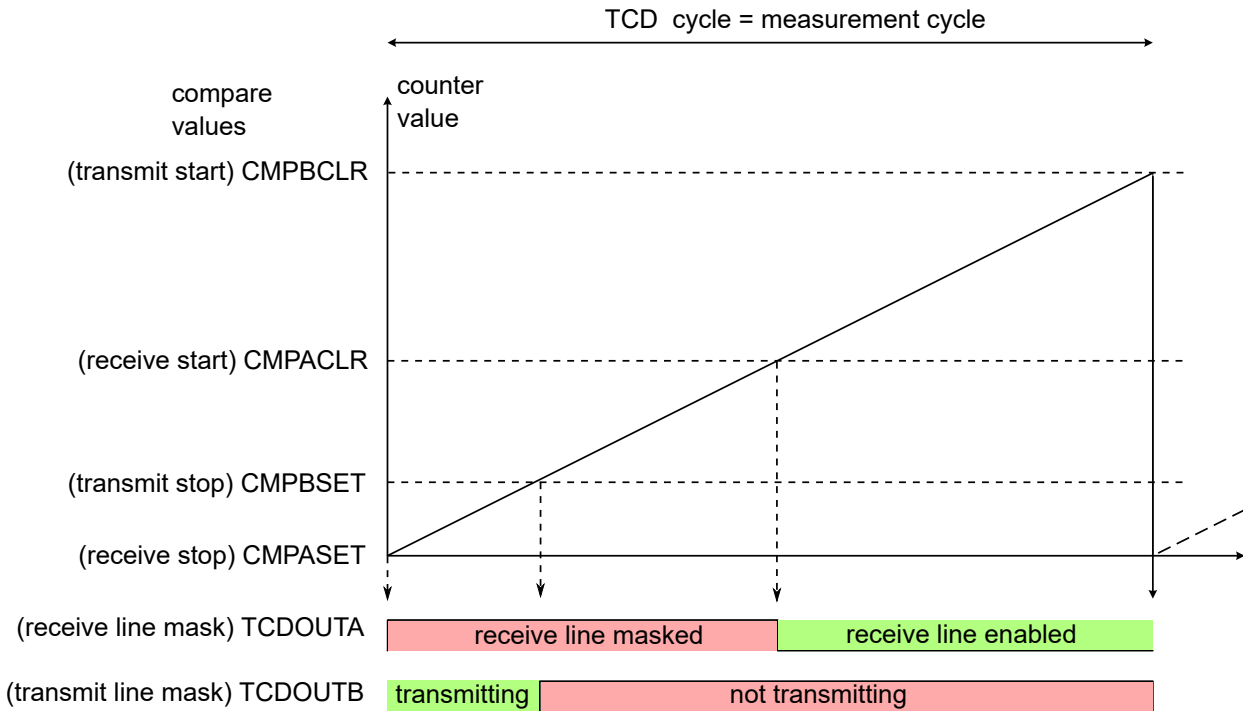
The DAC is set up to produce this value just below the idle voltage of the ultrasonic transducer. The DAC output value has to be configured to be close enough so that the reflected signal is detected as soon as it arrives despite its attenuation, but not so close that the AC picks up noise. To aid with filtering noise, the hysteresis setting of the AC can be enabled; this means the DAC value can be slightly closer to the idle voltage of the transducer, thereby increasing the accuracy of the distance measurements.

3.2 Synchronized Transmit and Receive Masking Signals with Timer/Counter Type D

In order to effectively mask the PWM transmission from the receive line, correct synchronization of the transmit and receive masking signals is necessary. This is possible by using the "One Ramp" Waveform

Generation mode of Timer/Counter Type D (for more information, refer to the device data sheet). As can be seen in the figure below, the compare values can be configured to generate two synchronized outputs able to be used as masks to control transmission and reception utilizing the transducer.

Figure 3-5. Generation of Synchronized Transmit and Receive Masking Signals using TCD One Ramp Mode



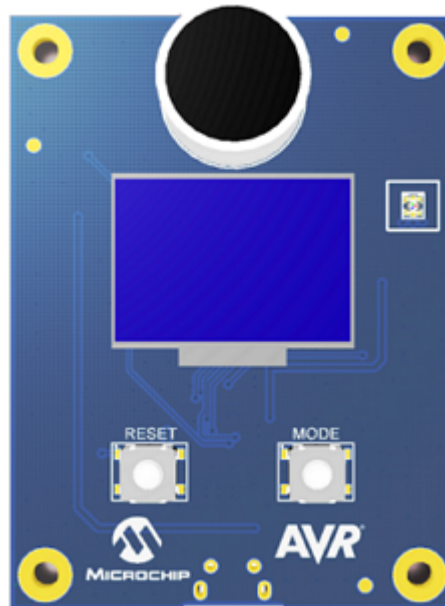
The different compare values have the following roles and should be customized according to the hardware being used:

- The CMPASET value is set to '0', indicating that the receive line should be disabled from the beginning of a measurement cycle (when an ultrasonic burst is being transmitted)
- The CMPBSET value indicates the length of a transmission. Decreasing this value will decrease both the minimum and maximum ranges. Increasing this value will increase the range to a certain point, however, once there is a part of the reflected burst with no attenuation, no advantage is gained from increasing transmission time.
- The CMPACLR value indicates when the receive line is enabled. This value should be customized according to the hardware being used, and the situational requirements. It should be long enough that resonance due to nonoptimal hardware is considered, and short enough that the reflected burst is not masked along with the transmission signal.
- The CMPBCLR value defines the length of a measurement cycle. This should be long enough that all reflected signals have been sufficiently attenuated (some signals can bounce back and forth between the sensor and the barrier several times). Decreasing this value will also decrease the resolution of measurement calculations (for example, CMPBCLR = 0xFFFF gives a distance measurement resolution of one cm).

4. Range Finder Field Engagement Board with ATtiny817

The Range Finder Field Engagement Board is functional hardware employing the implementation described in this application note. It is depicted in the figure below. Its firmware employs the peripheral setup described in this application note and includes an OLED driver to display the results onscreen. The hardware also includes an RGB LED to indicate proximity on a color scale and a temperature sensor in order to account for error introduced by temperature variation, however, this functionality is not implemented in the current firmware version. More information can be found in the ["Ultrasonic Range Finder with ATtiny817 Hardware User's Guide" \(DS40001902\)](#).

Figure 4-1. Range Finder Field Engagement Board



5. Hardware Considerations

If a custom hardware design is being used, there are some additional components which need to be considered. Depending on the characteristics of the ultrasonic transducer being used, there may be a need for additional circuitry between the AVR device and the transmit and receive lines of the sensor. For instance, the pins on the AVR may not have sufficient drive capability to initiate an ultrasonic transmission, meaning that a push-pull amplifier would be needed between the output pin of the AVR and the TX line of the transducer. Additionally, the transducer RX line signal will need some level of amplification and filtering before it can be effectively received by the AVR analog comparator. The design of these elements will depend on the application. For reference, see the *Ultrasonic Distance Measurement Field Engagement Board* schematic.

6. 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 below or the *Browse examples* button on the Atmel | START front page.

Atmel | START web page: <http://microchip.com/start>

Example Code

AVR42779 Ultrasonic Distance Measurement

- http://start.atmel.com/#example/Atmel:cip_ultrasonic_distance:1.0.0::Application:AVR42779_Ultrasonic_Distance_Measurement:

Click *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.

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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

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6.1 Code Configuration

The example code implements the setup described in this application note. It enables output either to an OLED display or via UART. This can be configured using the OUTPUT_USED hash-define at the top of the main file. It is designed for use with the Ultrasonic Distance Measurement Field Engagement Board, but can also be used with custom hardware.

7. Revision History

Doc. Rev.	Date	Comments
C	10/2018	- Updated megaAVR[®] 0-series family device - Added author - Minor editorial updates
B	02/2018	Chapter "Relevant Devices" has been updated to include also tinyAVR [®] 0-series and megaAVR [®] 0-series.
A	09/2017	- Converted to Microchip format and replaced the Atmel document number 42779B - Added "Relevant Devices" and "Get source code from Atmel START" topic
42779B	11/2016	Two images are updated: - Ultrasonic Distance Measurement using Configurable Custom Logic Peripheral - Range Finder Field Engagement Board
42779A	10/2016	Initial document release

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