Freescale Semiconductor
Application Note

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Ultrasonic Distance Measurer

Implemented with the MC9RS08KA2

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1 Introduction

Linear measurement is a problem that a lot of applications in the industrial and consumer market segment have to contend with. Ultrasonic technology is one of the solutions used by the industry. However, an optimized balance between cost and features are a must for almost all target applications. The ultrasonic distance measurer (UDM) is used mainly when a non-contact measurer is required. This is the type of solution this document explains using a simple robot toy implementation.

This demo is developed using Freescale's ultra low cost MC9RS08KA2.

Contents

2 Background

2.1 Sound and Ultrasound Principles

Sound is a mechanical vibration transmitted by an elastic medium. The range of frequencies that humans can hear are approximately between 20 Hz and 20,000 Hz. This range is by definition the audible spectrum and varies by individual and generally reduces with age. The ear is most sensitive to frequencies around 3,500 Hz. Sound above 20,000 Hz is known as ultrasound, and sound below 20 Hz as infrasound.

2.2 Speed of Sound

The speed which sound travels depends on the medium which it passes through. In general, the speed of sound is proportional (the square root of the ratio) to the stiffness of the medium and its density. This is a fundamental property of the medium. Physical properties and the speed of sound change with the conditions in the environment. The speed of sound in the air depends on the temperature. In the air speed is approximately 345 m/s, in water 1500 m/s and in a bar of steel 5000 m/s.

A common use of ultrasound is for range finding. This use is also called sonar. Sonar works similarly to radar. An ultrasonic pulse is generated in a particular direction. If there is an object in the way of this pulse, the pulse is reflected back to the sender as an echo and is detected. Measuring the difference in time between the pulse transmitted and the echo received, it is possible to determine how far away the object is. Bats use a variety of ultrasonic ranging (echolocation) to detect their prey.

2.3 Sound Reflection

To measure the distance of a sound signal transmitted, it needs to be reflected. This sound signal is a longitudinal sound wave that strikes a flat surface. Sound is then reflected, provided that the dimension of the reflective surface is large compared to the wavelength of the sound. See Figure 1.

Surface

An ideal target surface is hard and smooth. This surface reflects a greater amount of signal than a soft, rough surface. A weak echo is the result of a small or soft object. This reduces the operating distance of an ultrasonic sensor and decreases its accuracy.

Distance

The shorter the distance from the ultrasonic sensor to an object, the stronger the returning echo is. Therefore, as the distance increases, the object requires better reflective characteristics to return a sufficient echo.

Size

A large object has more surface to reflect the signal than a small one. The surface area recognized as the target is generally the area closest to the sensor.

Angle

The inclination of an objects' surface facing the ultrasonic sensor affects how the object reflects. The portion perpendicular to the sensor returns the echo. If the entire object is at a greater angle, the signal is then reflected away from the sensor and no echo is detected.

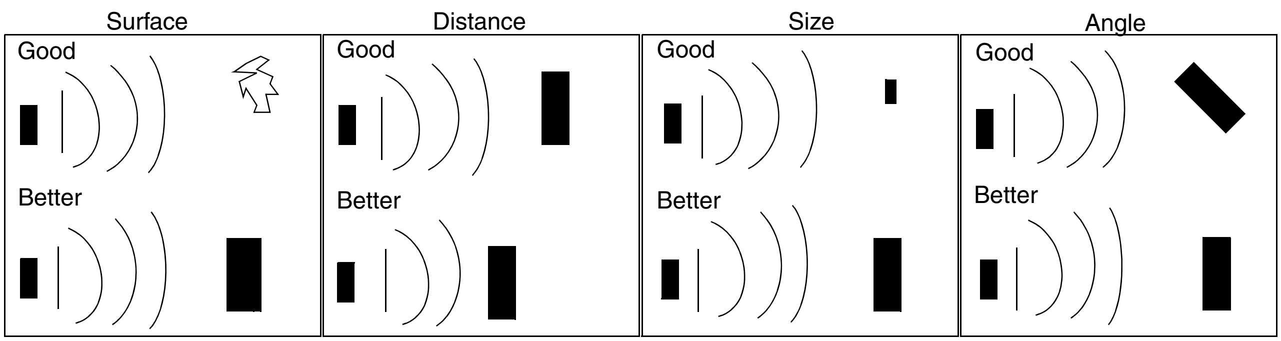

Figure 1. Sound Reflection Cases

2.4 General Description

The UDM is a demo that shows capability and performance of the MC9RS08KA2 and the ultrasonic sensor to build a distance measurer.

Figure 2 shows the basic building block of this project.

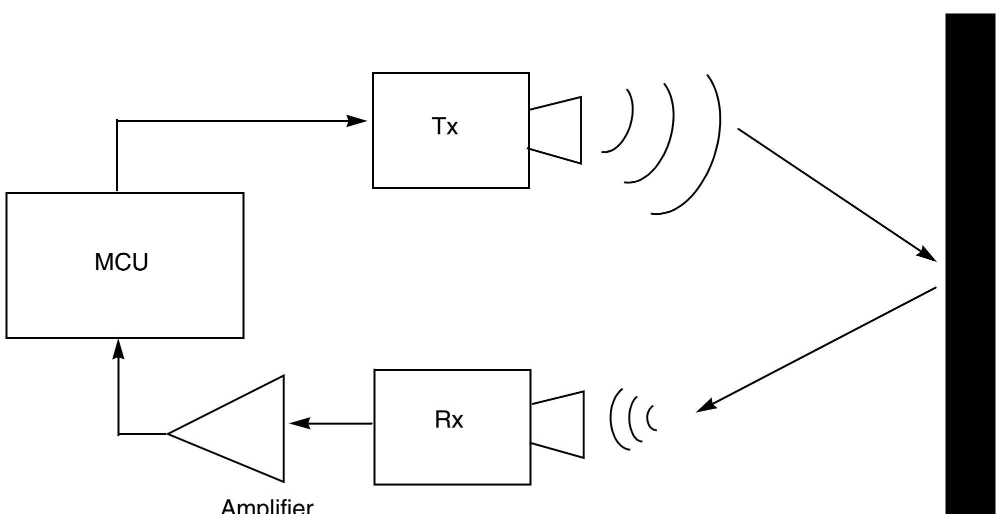

Figure 2. UDM Basic Building Block

The firmware generates a 40 kHz burst signal. After the 10 cycle burst is completed, a variable that measures the distance is activated. This variable measures the time sound takes to rebound and is used for distance calculation.

The burst signal goes to the ultrasonic transmitter (US Tx) and is transmitted as ultrasound through the air Figure 2. When the wave is reflected off an object, this wave is captured by the ultrasonic receiver (US Rx.) This received signal is amplified because it attenuates as it travels. Afterwards, the signal goes back to the microcontroller unit (MCU), filters it and calculates the distance.

A 40 kHz interrupt is generated by the timer in the MCU. To perform this, the keyboard interrupt (KBI) is enabled and detects the external signal. Every time the MCU is interrupted the counter is increased by three. And the variable used as a counter is decreased by one for the entrances to the modulus timer module (MTIM) interrupt service routine (ISR). When this variable is bigger than eight the ECHO signal is activated. The distance variable is then set to 0. Refer to Figure 3 for timing diagram.

For detailed information about the firmware see Figure 3.

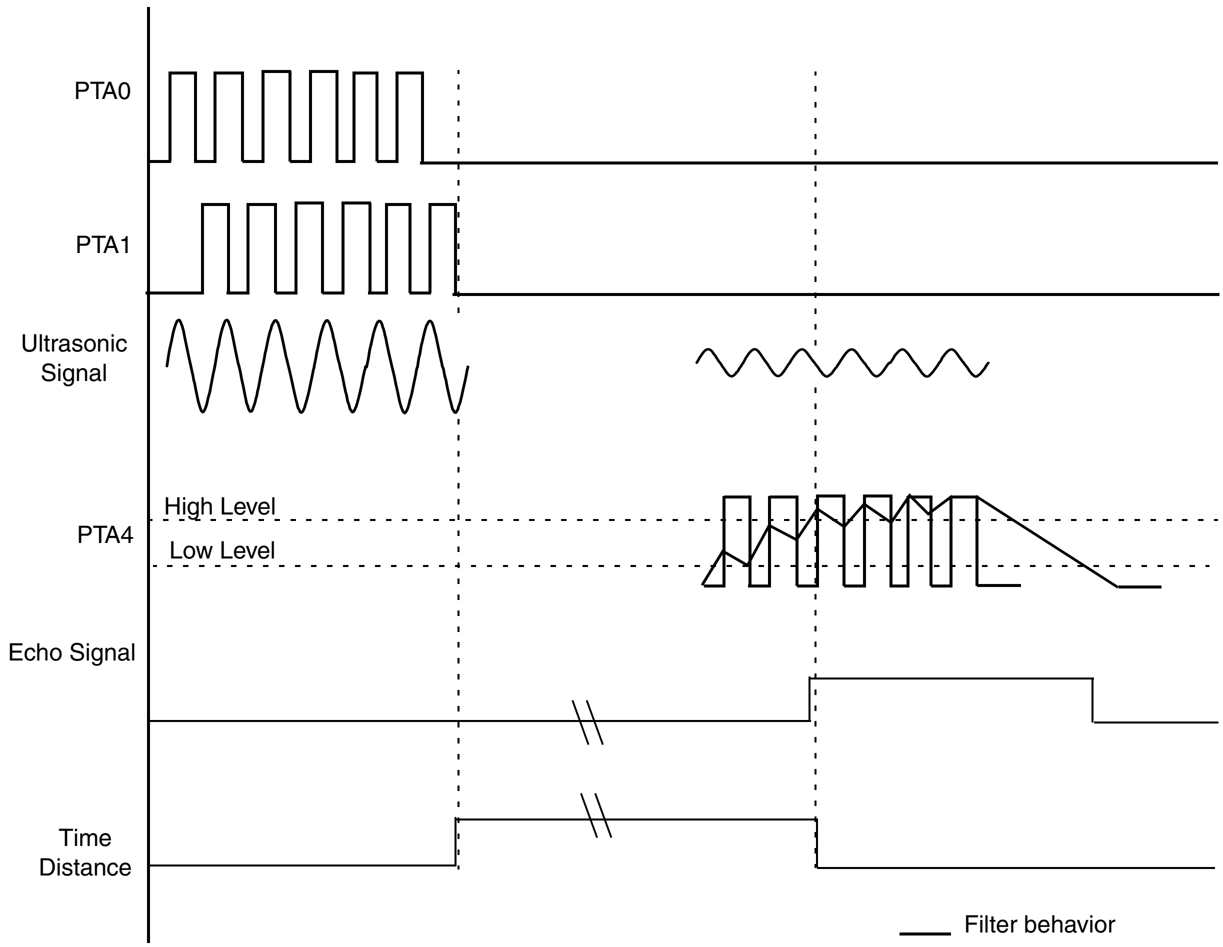

Figure 3. Timing Diagram

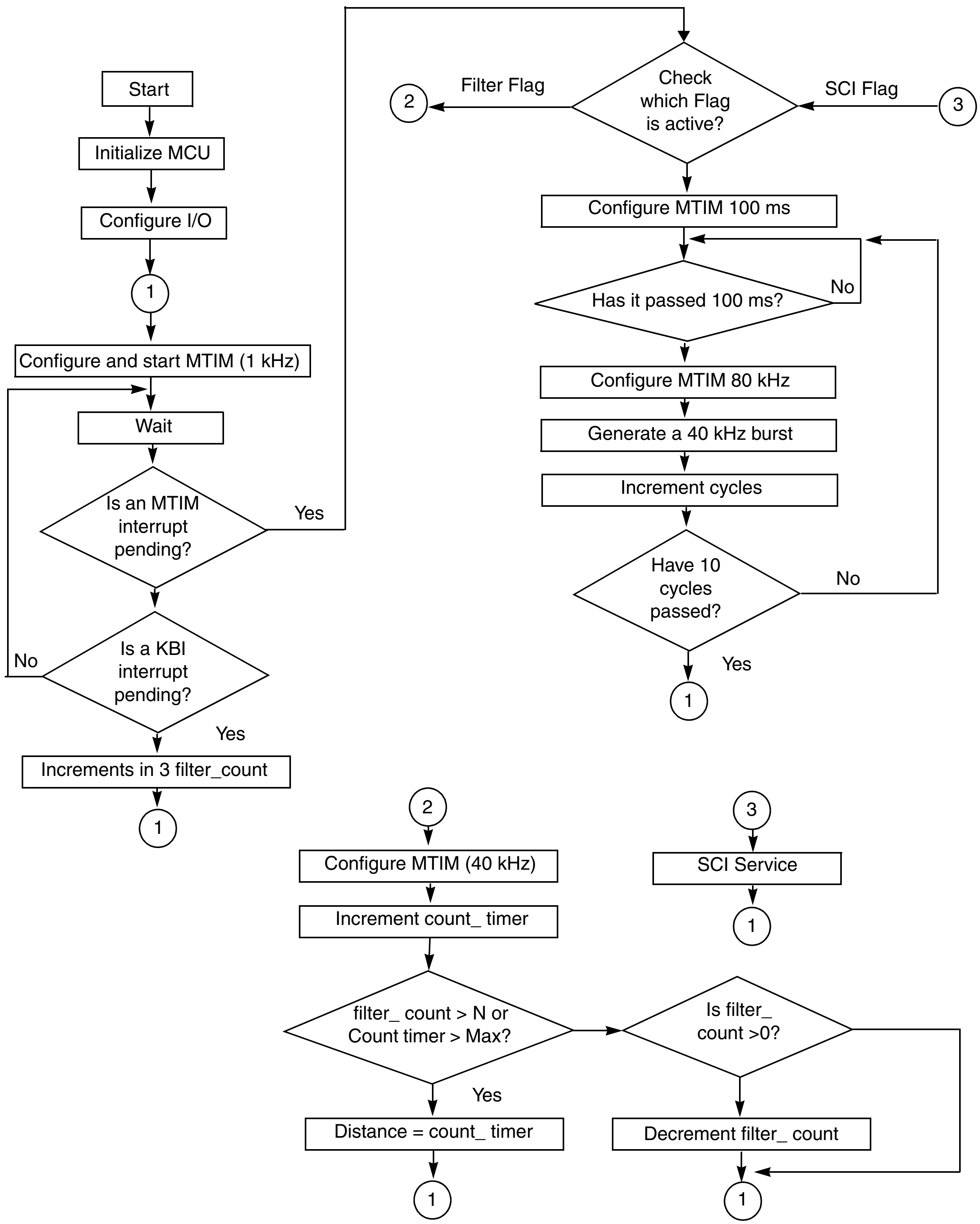

Figure 4. UDM Flow Chart Diagram

For detailed information refer to the software AN3481SW.

3 Freescale Tools Used

3.1 CodeWarrior

CodeWarrior is a professional integrated development environment (IDE) for fast and easy MCU development. This application is developed in assembly language using Freescale CodeWarrior Version 5.1.

4 Components Used

4.1 The MC9RS08KA2 Microcontroller

The MC9RS08KA21 MCU is a small pin count device at an extremely low cost. It has the ability for low voltage programming, system protection and analog control.

This device is composed of standard on-chip modules, including a very small and highly efficient RS08CPU. This is a list of some features of the device:

- 63 bytes of RAM
- 2 Kb of flash
- 8 bit module timer
- Keyboard interrupt (KBI)
- Analog comparator
- Real-time interrupt trigger with a 3-bit prescaler
- System protection with low voltage detection
- Background debugging system
- 4 bidirectional I/O pins

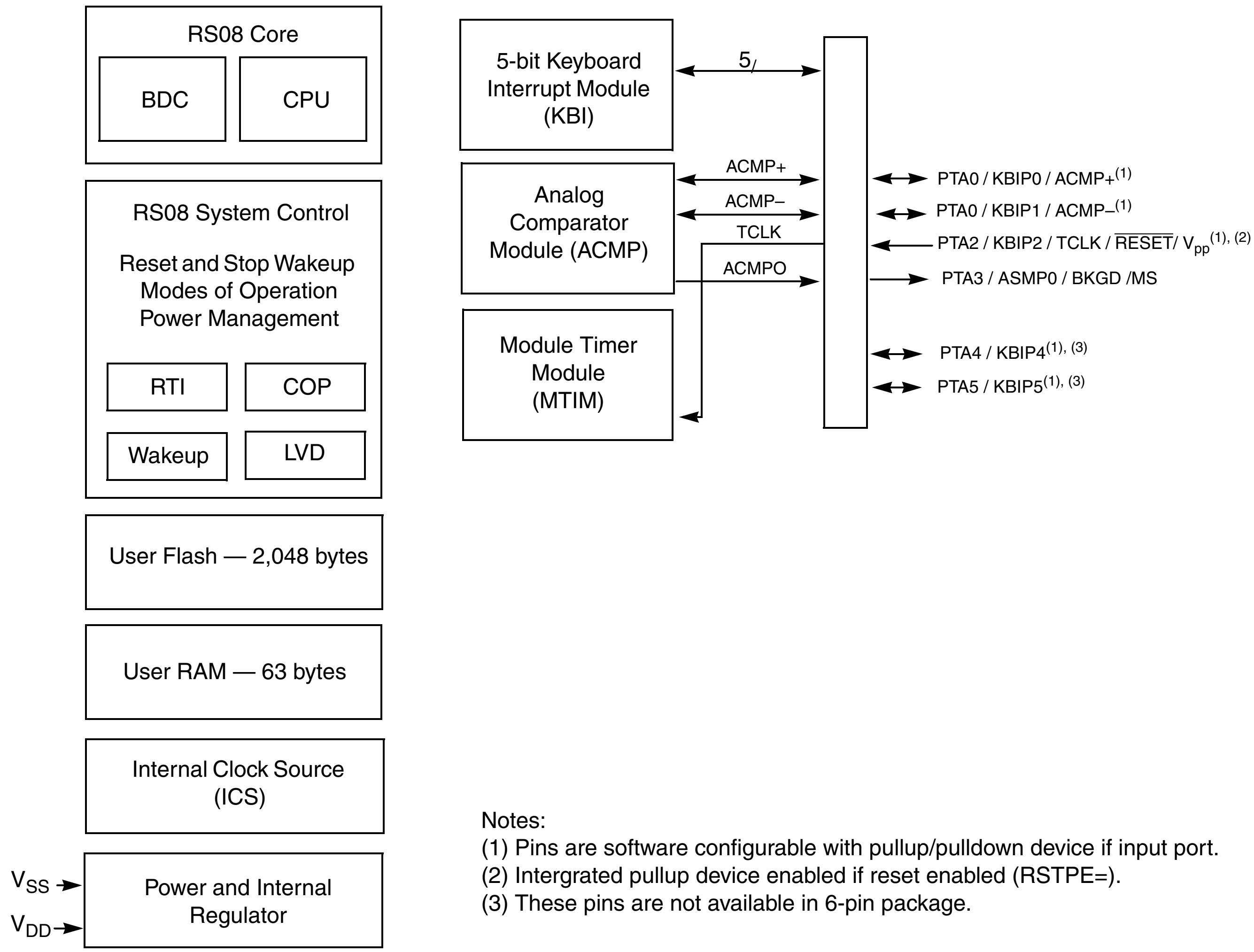

Figure 5. MC9RS08KA2 Block Diagram

4.2 Other Components

4.2.1 Ultrasonic Transducers

Ultrasonic transducers are devices that send and receive ultrasonic waves commonly used on many types of sensing. These devices include proximity counting, level measurement, and security applications.

For this demo, an ultrasonic sensor 2 (part number 255-400ET18-RO) is used.

- Center frequency: 40.0 kHz ± 1 kHz
- SPL 115 dB
- Bandwidth: 1.5 kHz (–6 dB)
- Input voltage: 20 V max

- Allowable input power: 0.2 W

5 Hardware Description

The ultrasonic distance measurer (UDM) is implemented with an MC9RS08KA2, a transmitter, receiver and an array of three operational amplifiers. These are used to amplify the wave signal and square it.

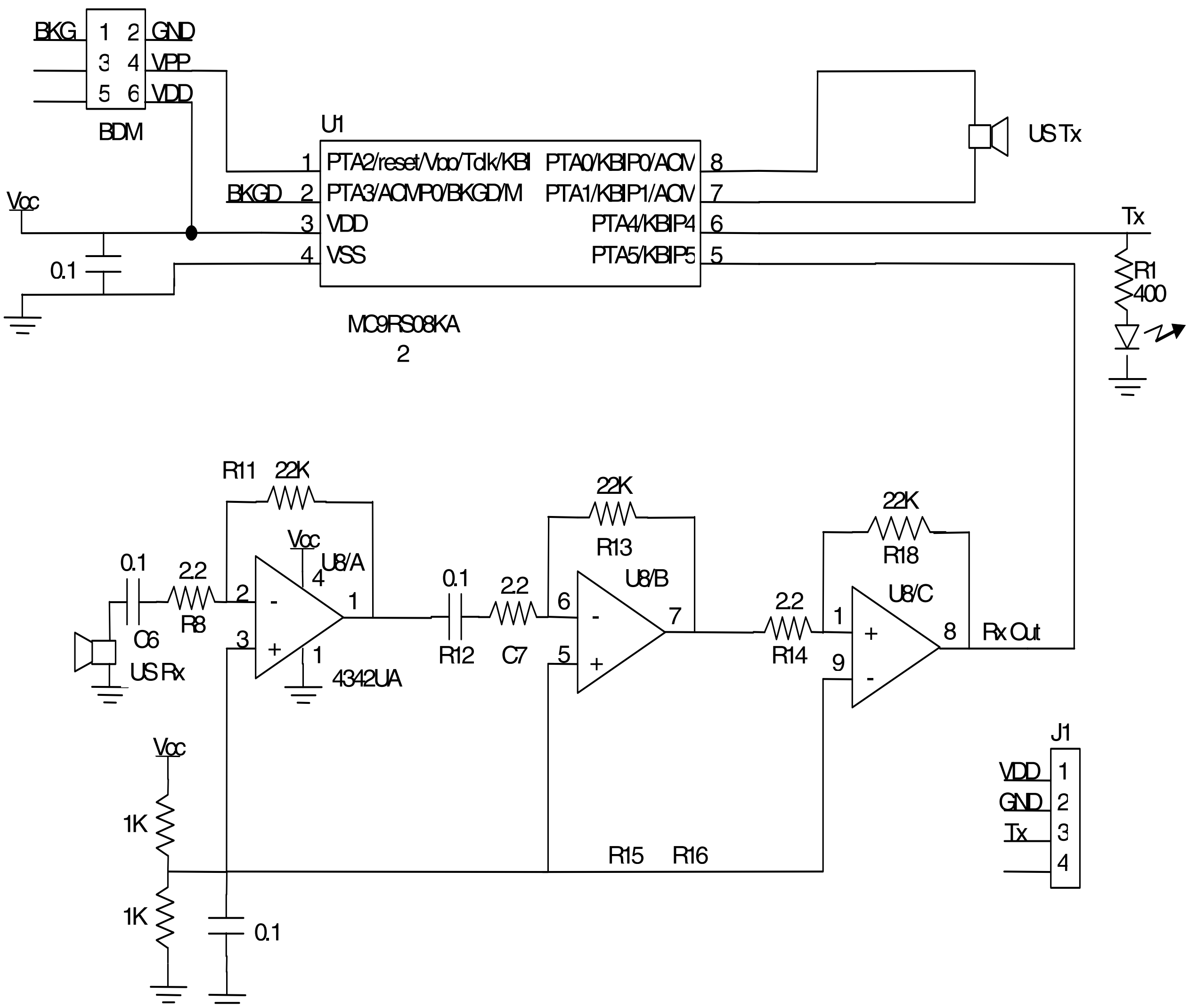

Figure 6. Ultrasonic Distance Measurer Schematic

Two signals from the MCU are used to produce an alternating current to generate a 40 kHz signal. These signals go to the US Tx which transmits the signal in the air. When the signal rebounds, it is received by the US Rx and amplified to obtain a logical signal. This signal goes to a KBI input of the MCU. Figure 2.

This system functions within a range of 3–5 V.

The system also has a background debug mode (BDM) connector. It is used for programming and debugging the MCU and the firmware code.

Because the MCU does not have an implemented Serial Communication Interface (SCI) module, an emulated SCI uses the port A pin 4 (PTA4) to output the distance value.

6 Software Implementation

The functions required to implement this UDM are:

- Time base of 1 millisecond
- 40 kHz 10 cycle burst is generated every 100 milliseconds. The MTIM is configured at 80 kHz to generate a signal at 40 kHz (80 kHz / 2).
- Filter of the reflected signal (echo signal)
- Measure the time (distance) between the burst Tx and the echo signal
- Conversion of time into distance
- Send the distance through an emulated SCI

6.1 Resources

Table 1 the resources used by the UDM are shown in this table.

Table 1. Resource Usage

	MC9RS08KA2	US Distance Measurer
I/O	6	6
Flash	2 Kbytes	623 bytes
RAM	63 bytes	14 bytes
Analog Comparator	1	
KBI	5	1
Bus Clock	Up to 10 MHz	8 MHz
MTIM	1	1
RTI	1	
Package	8 SOIC 6 DFN 8 DIP	8 SOIC

7 Test

The basic testing demo includes, taking time measurements vs. distance. Figure 7. The time period measured is displayed in the Hyper Terminal program of the computer.

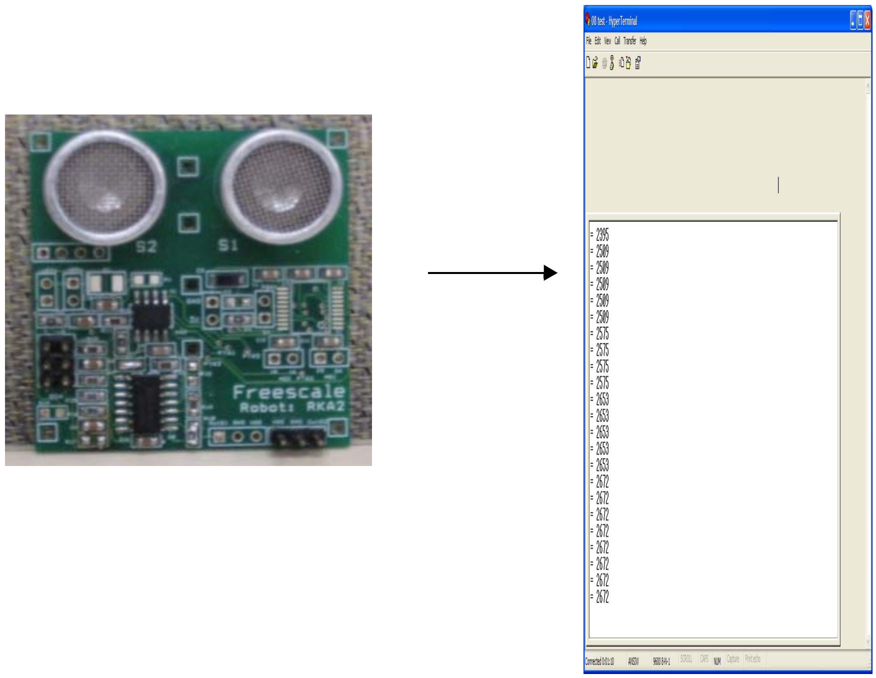

Figure 7. Distance Measurements

There are measurements taken using an oscilloscope to monitor the behavior of the signals before inputting them on the MCU, Figure 8. The plot on the top represents the 10 cycle 40 kHz burst. The echo response is the plot on the bottom view.

These results are plotted using a worksheet. This is done to understand the behavior on all the specified ranges. Figure 9 are the results obtained in the test plotted in the XY axis (time measured in timer counts vs. distance measured in cm).

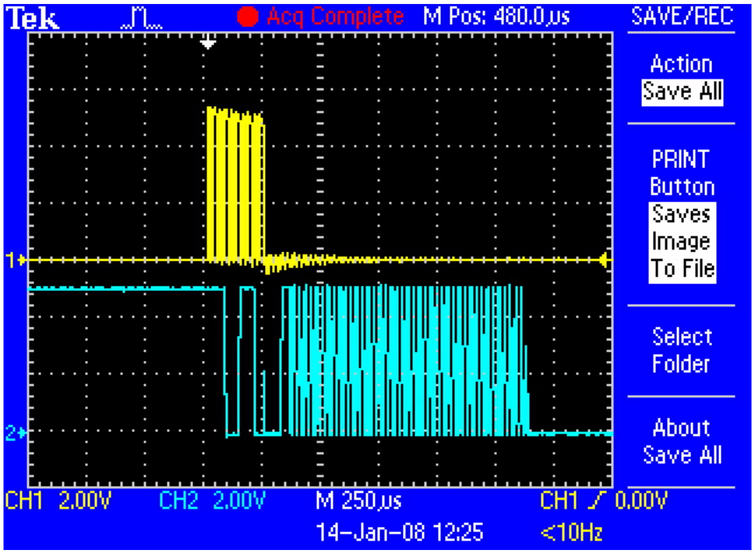

Figure 8. Behavior of Burst Signal and ECHO Signal

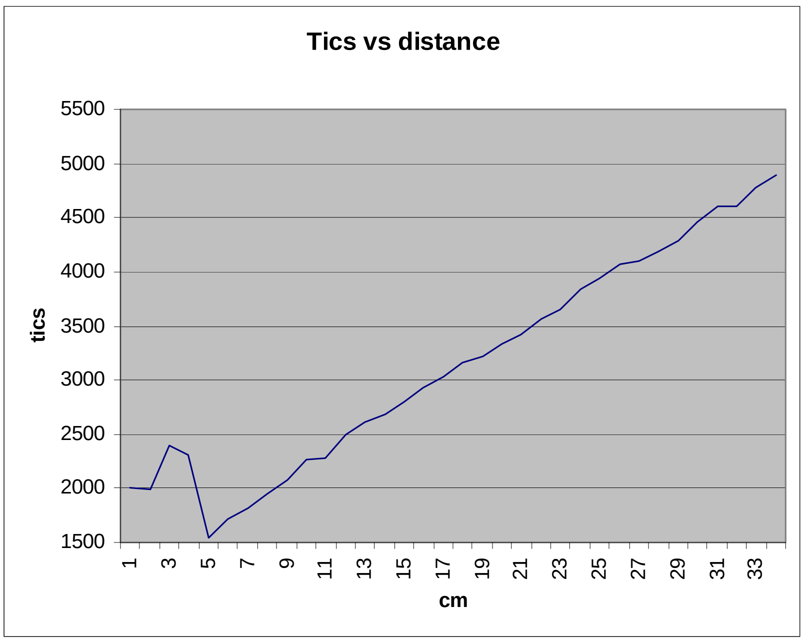

Figure 9. Tics vs. Distance

8 Conclusions

This demo shows the viability of implementing distance measurements using the MC9RS08KA2.

This type of implementation is optimized for reading distances above 5 cm. A hardware/software filter must be implemented when measuring distances shorter than 5 cm.

The time analysis is included in Appendix A. This section explains the restrictions that this demo has for time and cycles available to implement the filter.

The design uses a 3.3 V power supply. This limits the measurement up to 34 cm.

The transmitter is tested to a max of 20 Vrms. It is possible to drive it at a higher voltage to enable more distance.

This range of distance can be used for proximity sensors on all kind of consumer and industrial applications.

The scope of this document does not include temperature compensation. However; Appendix A can be used as a base for the conversions between tics and distances, at different temperatures.

9 References

Reference 1:

http://www.freescale.com/files/microcontrollers/doc/data_sheet/MC9RS08KA2.pdf. (MC9RS08KA2.pdf datasheet).

Reference 2:

http://www.mouser.com. 255-400ER18 Ultrasonic sensor datasheet.

Appendix A Time Analysis

The frequency of the ultrasonic sensor is 40 kHZ.

t = 25 microseconds,

Using a burst of 8 cycles

Tburst = 25*8 = 200 microseconds.

Table A-1. Speed of Sound vs. Temperature

Temperature of Air °C	Speed of Sound C in m/s	Density of Air in kg/m3	Acoustic Impedance of Air Z in N- s/m3
–10	325.4	1.341	436.5
–5	328.5	1.316	432.4
0	331.5	1.293	428.3
5	334.5	1.269	424.5
10	337.5	1.247	420.7
15	340.5	1.225	417.0
20	343.4	1.204	413.5
25	346.3	1.184	410.0
30	349.2	1.164	406.6

The speed of sound in the air is given approximately by:

$$c = 331 + 0.6\ g$$

Taken the speed of sound at 20°C = 343.4 m/s

Table A-2. Time Analysis

Frequency	40000	Hz	
Period	0.000025	Seconds	
Period (micro)	25	Microseconds	
Burst Cycles	8		
Burst Period	200	Microseconds	
Speed of sound in the air (20°C)	343.5	m/s	Speed of sound
Measured time	2.50E-02	sec	
Measured time (microseconds)	1.00E-04	Microseconds	
D	8.5875	m	
Rd	4.29375	m	
rd (centimeters)	429.375	cm	

Measured distances at different temperatures:

Table A-3. Time vs. Distance

Air Temperature	10	20	30
Speed of sound	337	343	349
Time (milliseconds)	Measured Distance (cm)	Measured Distance (cm)	Measured Distance (cm)
0.1	1.7	1.7	1.7
0.2	3.4	3.4	3.5
0.5	8.4	8.6	8.7
1	16.9	17.2	17.5
2	33.7	34.3	34.9
5	84.3	85.8	87.3
10	168.5	171.5	174.5
20	337.0	343.0	349.0
50	842.5	857.5	872.5
100	1685.0	1715.0	1745.0

As shown in Table A-3, 20 ms is the time needed to reach 345 cm (3.45 mts).

The minimum distance resolution depends on the time resolution required by the application. If a time resolution of 100 microseconds is selected, the minimum distance measured is 1.7 cm.

The filter has a time restriction of 1/ (2*40K), this means 12.5 microseconds. Therefore; if further time is needed to filter the signals, then a change in the overall algorithm is required.

If there is an 8 MHz bus clock frequency there are 125 nanoseconds by cycle.

12.5 micro/125 nanosec = 200 cycles to do the filter. This is the maximum number of cycles available to generate the filter in the MCU.

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