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ELECTRONIC DISTANCE MEASUREMENT

Group No: D8

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Abstract

The aim of the project is the contact less measurement of distance from a target. The basic principle is to project a signal (a pulse of some shape) onto the target and process the reflected signal to determine the distance of the target. We have taken the time of flight approach, wherein the delay between transmitted and received pulses (or the time of flight of the projected ultrasonic pulses) is measured to get the distance.

1. Issues

1.1 Conditions on the target

For contact less measurement of distance, the device has to rely on the target to reflect the pulse back to itself. The target needs to have a proper orientation that is it needs to be perpendicular to the direction of propagation of the pulses. Also if the reflectivity of the target is low, the signal received by the device may not be detectable. For example we cannot expect the device to work on a sound absorbing target.

Hence the target needs to be oriented perpendicularly and it should have high enough reflectivity.

1.2 Power and beam width

The power in the ultrasonic waves reduces exponentially with distance in the medium it travels. We used 40 kHz ultrasonic because of the easy availability of the corresponding transducers. Secondly, the beam width of typical ultrasonic sources is high, so that the waves diffuse in space. These two considerations greatly limit the range achievable by ultrasonic methods. We can do our best by transmitting pulses of high power, so that even after attenuation the signal is strong enough for detection. This would mean the use of a good drive circuit for the transducer.

To avoid the beam from spreading, we can enclose the transmitter and receiver in a sound absorbing material.

1.3 Resonance of transducer

The transducer resonates at 40khz.(It has a narrow bandwidth of about 4khz centered at 40kHz).The transmitted signal must hence be a pulse train of 40kHz, consisting of enough cycles to allow the transients to die down.

The very narrow bandwidth of the transducer requires us to generate 40 kHz pulse train of adequate number of cycles accurately and reliably. Rather than generating this pulse using hardware, for example by using the 555 timer, we would like to generate this pulse train using a microcontroller (in software).Since it operates from a crystal, the microcontroller is accurate and reliable.

1.4 Detection

Because of the resonance, the receiver must give a voltage of frequency 40 kHz across its terminals. But a lot of other noisy waveforms were also detected. For example when the transmitter was idle, some high frequency noise (in MHz) was detected at the receiver terminals. Also some noise in 80-90 KHz range was present when the receiver was operating. Since we need to detect the 40 kHz waveform, we must be frequency selective in our detection, and not send out false detections coming from the noisy range to the measuring circuit.

So the detection mechanism must ensure that it reports the measuring unit only when it detects a near 40 kHz component.

Once detected, the delay between the corresponding edges of the transmitted and received pulses needs to be measured, and using the velocity of sound, the distance can be estimated as

$$2d = \Delta t * v \qquad (1)$$

Where, d is the distance of the object, Δt is the time delay; v is the velocity of sound.

1.5 Atmospheric Influences

The velocity of sound is dependent on temperature. The variation is about 1% every 6° C around 20° C. Whether this is a critical problem or not depends on the accuracy the device achieves. For accurate measurements, or if the device requires to operate under diverse environments with similar results, then this must be taken into consideration. If not, it must be possible to include this later without too much change in the design and the components.

1.6 Hardware and Software

Considering all the issues, the hardware should consist of

1. The drive circuit and
2. The circuit for detecting the 40kHz received wave

And the software consists of

1. Generation of pulses
2. Time delay measurement
3. Display on an LCD
4. Calculation of distance given time delay and velocity

2. Block diagram

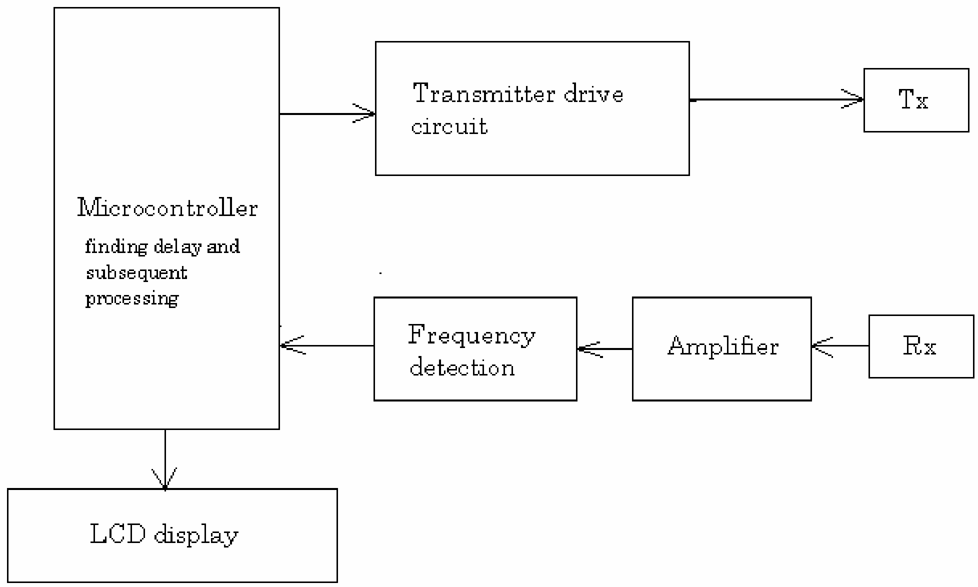

Figure 1 Block diagram of the distance meter

3. Circuit design

3.1 Choice of components

3.1.1 *Microcontroller*

In order to generate a 40 kHz pulse train, the microcontroller needs to act (say toggle a port pin) every 12.5 µs. Hence a microcontroller with speed and instructions adequate enough to switch every 12.5 µs had to be chosen. It should also have the requisite number of ports.

Since we must allow for the inclusion of temperature sensor in the design, it is better if the microcontroller has an A/D system built in it.

One of the microcontrollers that satisfies these requirements is the PIC 16F72. With a 16 MHz crystal, it has an instruction speed of 250 ns, which is adequate to generate 40 KHz. It also has three ports, of which one is used up by the LCD, one for the A/D (which we have not yet implemented) and another for user interface (for example a push button for distance measurement, interrupt when the 40 KHz waveform is detected at the receiver).

3.1.2 *The drive circuit*

The 40 kHz waveform is generated by the microcontroller. This cannot be given directly to the transducer because then the current being less, we wouldn't give enough power to the transducer. We need to use a power amplifier to drive the transducer.

Since 40 kHz is just outside the range of audio frequency, we can use an audio power amplifier to drive the ultrasonic transducer. We chose LM380 audio power amplifier.

To quadruple the power given to the transducer two LM380 audio power amplifiers have been used in bridge configuration.(See Fig 4 Circuit Diagram)

3.1.3 *Amplifier at the detector*

Because 40kz is near audio, an audio amplifier can be used at the receiver. We are using an LM386 audio amplifier. The gain of the amplifier is set to be 200.

3.1.4 *Detection of the 40 KHz waveform*

We need to look for the narrow band of signals in 38-42 KHz range. If any signal is detected in this band, the microcontroller needs to be reported to.

A tone detector is ideally suited for this. Its detection bandwidth is 10-20% of center frequency (which would be set to 40 KHz).There is no need for a rectifier (which would be required, for example if we use a notch pass filter).The microcontroller only needs to monitor the logic level of the tone detector output. We have used an LM 567 tone decoder.

The circuit diagram is attached (figure 4, page number 10).

Other settings

1. LM 380 must be given a higher power supply to increase power given to the transducer. We can operate from 12-18V.

2. Tone decoder settings:

The LM567 being an important component of the receiver circuitry, we put down the components used in the LM567.

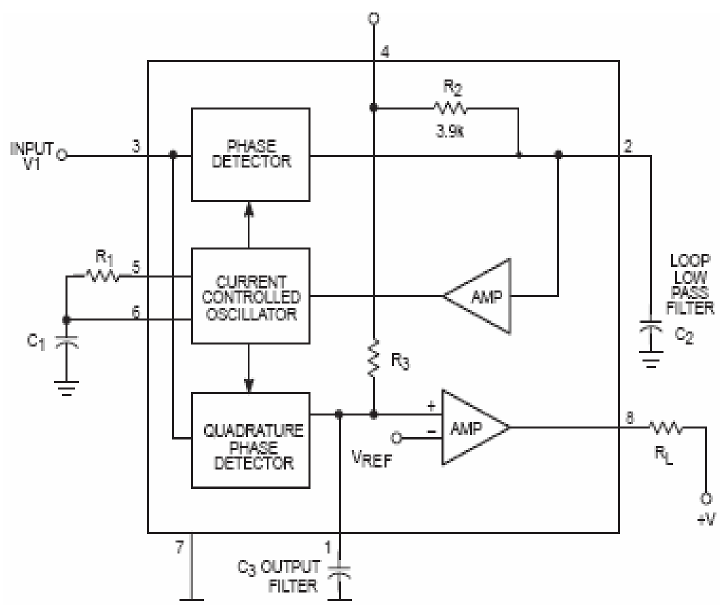

Figure 2 The block diagram of LM567 tone decoder

a) R1 and C1 have been selected to be 2.53k and 10nF for the desired center frequency of 40 kHz.
b) The loop filter C2 would decide the detection bandwidth, and more importantly, the speed of operation. For the optimum speed, a value of 3.3nF has been chosen.
c) The output filter C3 (to avoid out of band transitions) has been chosen to be 10nF.Smaller values were required to speed up the turn on time.
d) In order to decrease the sensitivity of the output stage, a resistor (100k) has been introduced from pin 1 to pin 4 (reference no 4).

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4. Explanation of the microcontroller code

4.1 The connections

The 40 kHz waveform is generated on the port A of the microcontroller. This waveform is given to the LM380 drive circuit. Port B is used for interface with the LCD. The output of the tone decoder (which is low level on detecting 40 kHz is connected to INT0 pin (edge triggered interrupt, on port B).

4.2 The software

On power on, the microcontroller goes through the initialization routines (that is configuring ports in input or output mode, timer and LCD initialization). Then it waits for the user's signal to measure distance which is to be provided using a push button.

Once asked to measure distance, a 40 KHz pulse train (comprising of 48 cycles) is transmitted, and a timer is started. The zero count of the timer corresponds to the leading edge of the transmitted pulse train. The microcontroller then should wait for an interrupt to occur. But, during the time of pulse transmission itself the detector detects a signal. (See figure 5, page number 11). This may generate a false interrupt. To avoid this problem the external interrupt is enabled short time after the transmission is over. This may limit the minimum measurable distance.

This interrupt is expected from the tone detector on reception of the reflected signal. It may happen that this interrupt does not arrive (which is the case when say the target is far, or an absorbing material, then the reflected signal is not detected).In such a situation, the microcontroller can be stranded in a loop. This situation can be avoided by enabling the timer overflow interrupt. When the timer count overflows, an interrupt is generated. In either case, in external interrupt service routine, the timer is stopped and its value is stored in memory. If the interrupt is due to timer overflow, the previous reading (previous count of the timer) is stored.

The readings are taken 16 times, and are averaged out to account for the minor fluctuations in the readings. Average count obtained is then multiplied with a constant which accounts for velocity of sound (taken to be 330 m/s) and other scaling factors (accounting for the timer speed of operation) to get the distance. The hexadecimal number so obtained is converted into BCD representation for display purpose. The obtained distance is then displayed on LCD screen in meters up to two decimal places.

The other routines are the ones used to drive the LCD and delay routines required in the code. Flow chart for the microcontroller code is attached. (Figure 3, page number 9)

5. Test results and discussions

The circuit has been implemented on the PCB with a single gain stage with a gain of about 200. This limits the maximum distance that can be measured and is observed to be about 4 meters with accuracy of about 3 cm. This can be increased further by better amplification at the receiver stage through cascading of amplifiers. With a gain of 900, a maximum range of 6m can be achieved. This has been done and verified on the bread board. But this also limited the minimum range because we had to increase the number of cycles transmitted. This was essential for proper decoding at the tone decoder.

The minimum distance that can be measured is about 60 cm. This limitation is caused by the fact that we have signal detection during transmission itself (See figure 5, page number 11). To avoid this, the external interrupt pin is disabled for some time during transmission period. This time approximately corresponds to the aforementioned distance.

When the transmission and reception was continuous, the current drawn from 18V source (with a 7805 regulator to give 5V to the microcontroller) was about 30mA. Since transmission and reception are only done for a short time, power consumption takes place only for a short time.

Nevertheless, a battery that can provide the required peak current needs to be chosen.
The transmitter and receiver have been enclosed in foam to improve directivity.

6. Further Improvements

6.1. Accounting for Temperature dependence

The variation in the velocity of sound can be accounted for by using a temperature sensor and taking the value of velocity according to the temperature. Or, we can also include a self calibration feature, which is that the device measures a standard distance and calculates the velocity and uses it for subsequent calculations. This can be included without too much change in the hardware.

6.2. Improvement of accuracy

One more method for determining the distance of a target is the phase shift method, wherein a continuous wave is transmitted, and the shift in phase of the received wave is measured to get the distance. In this method the maximum range is limited by the wavelength of the ultrasonic wave transmitted.

This means the maximum distance is very low (of the order of 7.5 mm), hence not good for long range applications.

But this method can be combined with the time of flight method to obtain very high accuracies at large range.

One recent method ("A high accuracy ultrasonic distance measurement system using binary frequency shift-keyed signal and phase detection" Huang et al REVIEW OF SCIENTIFIC INSTRUMENTS VOLUME 73, NUMBER 10 OCTOBER 2002) uses the above principle. Using this method, very high accuracies can be obtained.

6.3 Implementing circuit with a larger range on PCB

The range of the circuit implemented on PCB currently is small. This can be improved by including a higher gain receiver circuitry. This has been already tested on bread board.

7. References

1. "A high accuracy ultrasonic distance measurement system using binary frequency shift-keyed signal and phase detection" Huang et al REVIEW OF SCIENTIFIC INSTRUMENTS VOLUME 73, NUMBER 10 OCTOBER 2002
2. "The 8051 Microcontroller and Embedded systems" by M.A.Mazidi, Pearson education.
3. Datasheets of all the components involved (PIC 16F72 from Microchip, LM380, LM386, LM567 from Linear)
4. NE567/SE567 Tone decoder/phase-locked loop, Product data, Philips Semiconductors, 2002 Sep 25.

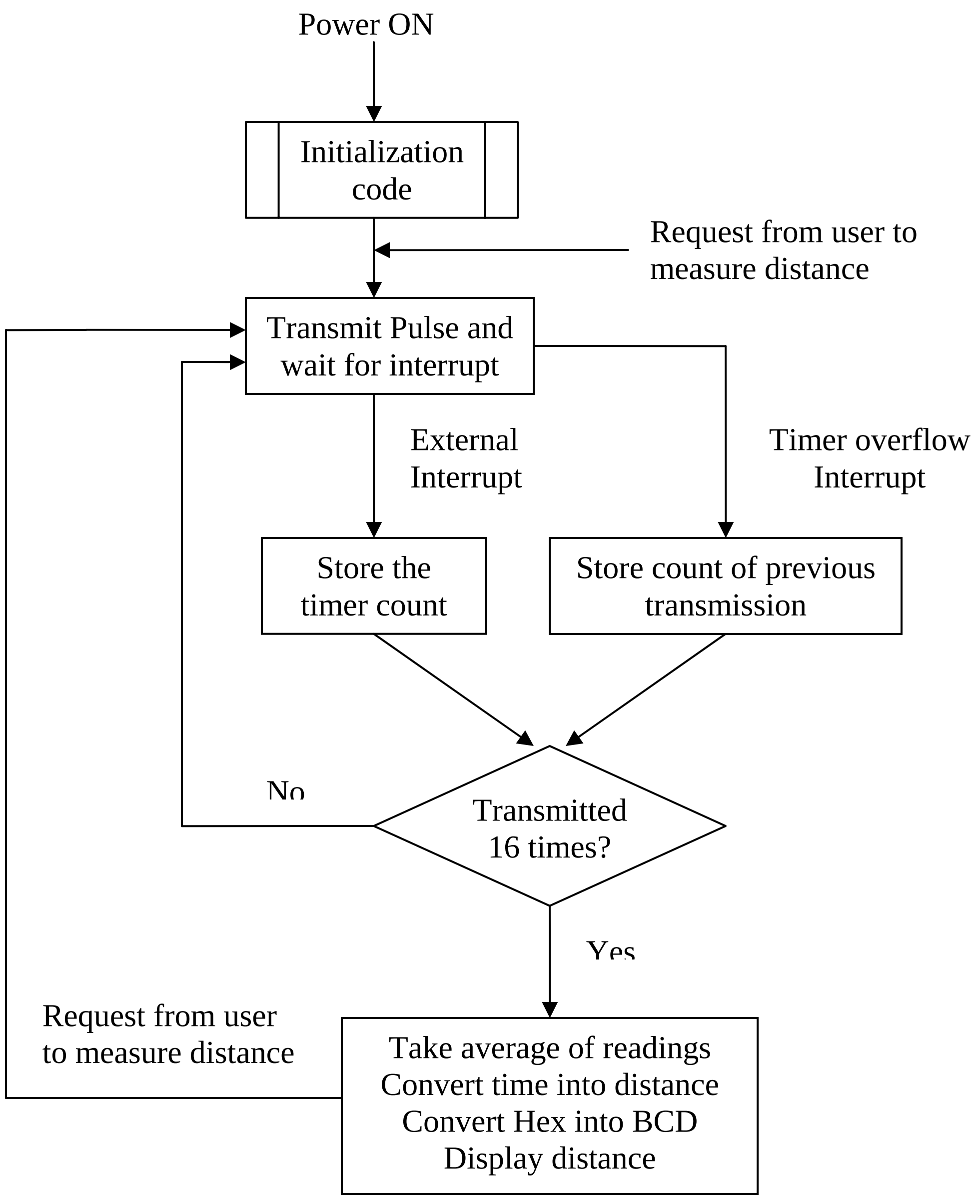

Figure 3 Flow chart for the code

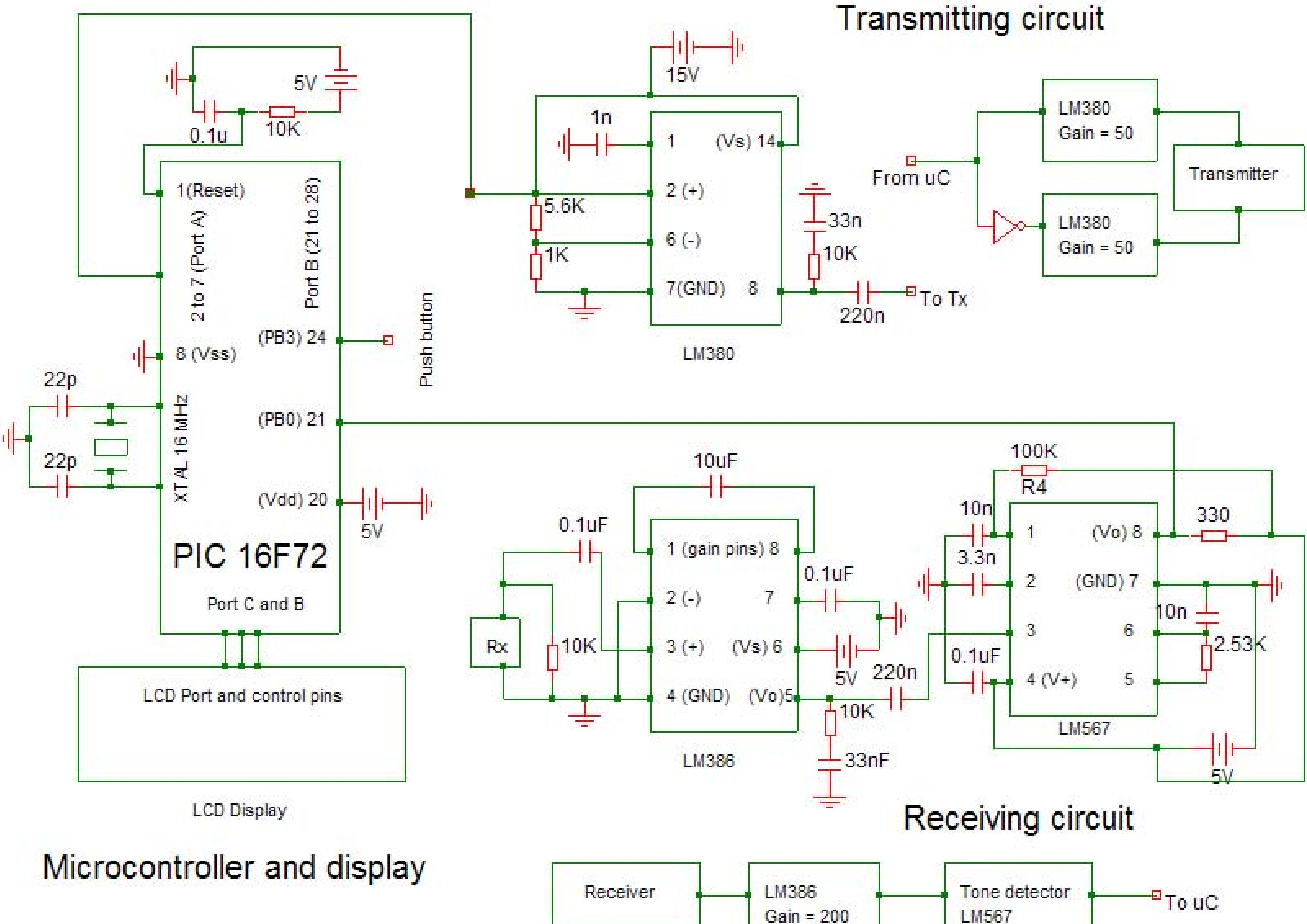

Figure 4 Circuit diagram

Figure 5 Waveform at the tone decoder output

Channel 1 represents the transmitted waveform, channel 2 the output of the tone decoder (the waveform that is given as interrupt to microcontroller).We can see that the receiver detects a signal during the time of transmission.The third detection should correspond to the wave after 2nd reflection.