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EED3009 ENGINEERING DESIGN - II
THEORETICAL DESIGN REPORT
RANGE FINDER

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Abstract

Early societies measured distance with a variety of primitive tools, from basic paces to measuring rods and marked ropes.[1] Luckily, we've come a long way from the days of using belts, thumbs and cubits for measurement. Various methods have been developed over the years in order to increase the measurement accuracy and to be able to measure in various conditions. These devices, which have been developed by human beings step by step over the years and evolved with new technologies, have reached the level where they can measure without the need for physical contact or even light.

1 Introduction

This project focuses on measuring distances with no contact up to a meter. To realise this project a battery powered, handheld device will be designed. The device will utilise an ultrasonic speaker and microphone. It will send regular periodic ultrasonic bursts from the speaker and listen for the echoes. The necessary circuitry will measure the time between sent ultrasonic bursts and their respective echoes, following the time of flight (ToF) principle. This data will then be processed using necessary information such as the speed of sound on air, as a result of which, the distance data will be obtained. Finally, this distance value will be printed on a two digit display. The device will also employ a laser guide to assist proper alignment of the sensors, and also to provide a feedback to the user.

2 Objectives of the Project

The designed device must follow the above guidelines and accomplish these aims.

- Measure distances in the range of 0-99cm
- Have an accuracy of 1 cm
- Be battery powered and handheld
- Display the measured distance in real time on a two digit display.
- Not empoly an MCU or ASIC designed for this particular purpuse.

In terms of measurement accuracy and range, the given properties can evolve as the experiments and tests continue, and therefore are subject to change.

3 Overview of the Project

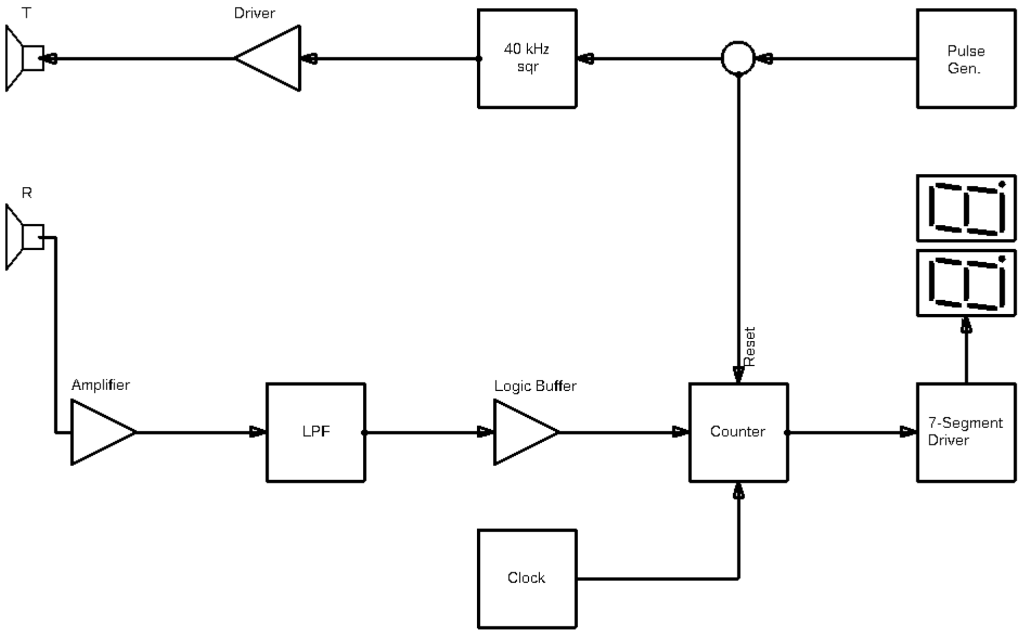

Figure 1: Revised Block Diagram

Guidelines of distance measurement using ultrasonic sensors is relatively straight forward. All the device should do is to send sound signals, wait for the echoes arrive and measure the time between. Since transmitting a continuous signal would produce a continuous echo, it is not possible to keep track of the time. Therefore the transmitter should emit bursts of sound waves, and the receiver should keep track of the time between.

Two ultrasonic transducers are needed, one for the transmitter and one for the receiver. The transmitter should be driven periodically with short pulses. The timing between these pulses is critical, such that the following pulse should not be transmitted before the echo of the previous pulse has arrived. This calculation should be made in consideration of the longest distance to be measured. Width of these pulses is also critical, as it should be short enough to ensure that the echo doesn't arrive before the pulse ends. This calculation should be made in considetation of the shortest distance of interest.

4 Design and Methodology

4.1 Ultrasonic Frequency Synthesis

Commonly available ultrasonic transducers work at frequencies near 40 kHz as tested and confirmed by the experiment in the feasibility report. Therefore the transmitter should send bursts of 40 kHz sound waves that fill the pulses. In order to provide a signal with these properties, two generators are needed. One to generate the 40 kHz signal, and another to generate the pulses.

Synthesizing sinusoidal waves is rather involved and hard. This is usually done digitally by the help of microcontrollers. Since this project does not allow the use of microcontrollers, and there are no readily available sinusoidal signal generator IC's, it has been decided that driving the transmitter with square waves will suffice. This is also how the HCSR04 module was operating. Refer to the feasibility report Section 4 Figure 5 .

4.2 Transmitter Driver

It is better to drive the transducer via a symmetrical wave, in order to use full swing range of the device. However, since the circuit will be powered via a 9V battery, there won't be a negative rail. To switch the polarity of voltage H bridge is used in our design.

After obtaining the power requirements of the transmitter, a separate driver IC may be concluded to be necessary. In such case, a simple power amplifier / audio opamp can be used to deliver the necessary power to the transmitter. This driver should be selected such that it is able to operate at the ultrasonic frequencies without distortion. Since the transmitter is driven via two separate timer circuits, two power amplifiers are needed.

4.3 Burst Generation

Since transmitting a continuous signal would produce a continuous echo, it is not possible to keep track of the time. Therefore the transmitter should emit bursts of sound waves, and the receiver should keep track of the time between.

To accomplish this, another 555 can be used in astable mode with adjustable duty cycle.

Assuming that the longest distance to be measured is 100 cm, and speed of sound is 343 m/s, the echo would arrive after:

$$\texttt{max}\ t_f = 2 \times \frac{1\,\mathrm{m}}{343\,\mathrm{m/s}} = 5.83\,\mathrm{ms} \tag{1}$$

Therefore the time between end of a pulse and start of the other should be around 6 ms minimum.
Assuming that the shortest distance to be measured is 1 cm,

$$\texttt{min}\ t_f = 2 \times \frac{0.01\,\mathrm{m}}{343\,\mathrm{m/s}} = 58.3\,\mathrm{\mu s} \tag{2}$$

Therefore the width of the pulse should not exceed about 50 µs.

$$t_h = 6.42\,\mathrm{ms} t_h = 250\,\mathrm{\mu s} \tag{3}$$

4.4 Receiver Amplifier

During the transmission of the signal, it gets weaker. On the receiver side, the received signal will most likely be small in amplitude, in order to compensate this loss, it must be amplified to be used in the following blocks.

This amplification should be made such that the lowest possible echo should not fall short of the limits of the next stage, and the highest possible amplitude echo should not exceed it. For this reason, it was deemed appropriate to use an instrumentation amplifier.

4.5 Low Pass Filter

Since the incoming echo signal will be a frequency modulated signal, where it consists of an ultrasonic burst filling a pulse, in order to obtain the actual waveform, it is necessary to pass the signal through a low pass filter. After this stage, the ultrasonic part will be discarded and following stages will see only the outlining pulse. This LPF which is used in our design is a simple passive RC LPF.

A passive first order RC low pass filter is designed with corner frequency fc $\hat{=}$ 5kHz. Where input signal consists of a 40kHz carrier and 150 Hz %0.3 duty pulses. Passing this signal through a LPF enables it to be further passed though a schmitt trigger and recover the digital pulse, resulting in clean fast rising and falling edges, sufficient to trigger the counter.

To encounter attenuation, a schottky diode is placed to prevent capacitor to be discharged over lower value programming resistor, whose value is fixed to get necessary corner frequency. Instead, a bigger bleeder resistor is added in parallel with the capacitor. This allows output signal to rise relatively quickly though the LPF resistor, during “on” times of the input signal, and prevents it discharge though the same resistor during “off” times, and therefore decrease the inevitable attenuation, increasing the voltage level sufficient enough to drive the input of 5V logic schmitt trigger.

After the amplification, the 40 kHz sound burst should be converted into a regular pulse with digital voltage levels. To accomplish this, firstly the signal should be passed though a lowpass filter with appropriate passband frequency. After which, the signal will resemble a single pulse, albeit with slow-rising edges. Feeding this signal into a logical buffer/schmitt-trigger, the pulse can be converted into a true digital pulse. APO YAZMIŞ BAK BUNA SONRA

4.6 Rectifier/Logical Buffer

After the LPF, even though the signal will resemble a pulse, it still will be an analogue signal, with slow rising/falling edges and an ambiguous amplitude value. To digitise the signal, it should be fed through a logical schmitt-trigger, output of which will be a truly digital signal. This is accomplished by using a generic schmitt-trigger IC which is 74HC14.

Even though the amplitude value does contain information about surface type and angle, these informations are beyond the scope of this project and therefore can be discarded without any problems in this stage.

4.7 Counter

After converting the echo burst into a digital pulse, timing measurements can be done. A counter that is to be started simultaneously with the first edge of the transmitted burst, should then be stopped by the first edge of the echo signal. Output of the counter is proportional to the distance, however, it is necessary to convert it into proper units. For which an arithmetic circuit should follow the counter.

5 Results

6 Needs of the Project / BOMList

7 Discussion

As mentioned in the Ultrasonic Frequency Synthesis section (section 4), HCSR04 drives the transducers with a symmetrical wave. The first design idea that came to our mind to accomplish this is to use two square waves with 180 degree phase difference to drive each pin of the transducer. Such that, one pin of the transducer will be kept on 0V where the other is kept at 5V. By alternating this process between the two pins, a differential symmetric 10V square wave can be obtained as shown in figure.

To implement this idea to the circuit, two 555 ICs will be driven on monostable mode with 0.25 duty cycle. To synchronise two pulse generators, each IC will be triggered by the falling edge of the other. As a result, a fully differential square wave with twice the frequency of individual pulse generators will be obtained.

The reason why this circuit, which we have already designed, is not realized is the trigger pulse must be shorter than the desired t_H . In our design, since the output of the first 555 comes to the trigger pin of the other 555, it does not comply with this condition.

Period Tuning

Since the frequency of the timer circuits will be programmed via passives, in order to avoid errors due to the tolerance of the passives, an adjustment is necessary. This can be achieved by placing trimpots into the programming circuitry, and manually fine-tuning the timing. It would be preferred to be able to adjust both of the individual timers simultaneously.

8 Conclusion

9 Gannt Chart

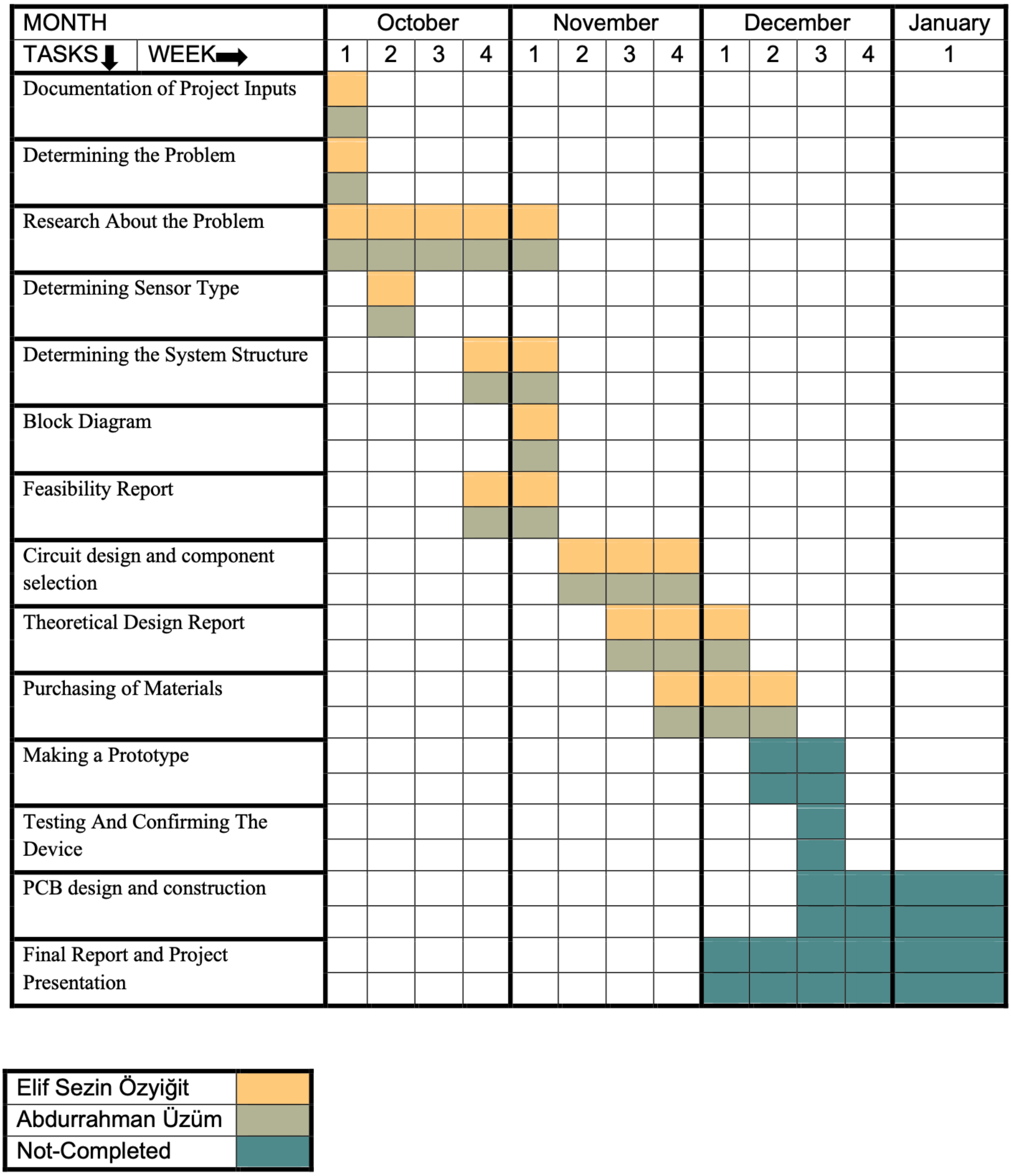

Figure 2: Gannt Chart

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