Ultrasonic Switch

Third Year Project Report

Final Report

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In this life, human cannot live without other people, and this is for better achievement of the work, because no one knows everything, but he can think and work hardly.

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Abstract:

It is required to design, analyze and simulate an ultrasonic switch. The Ultra-Sonic system consists of a transmitter and receiver. The expected range of the transceiver is around 10 meters. The purpose of this project is to gain more details about the different types of transducers.

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Chapter 1

1. Introduction

Ultrasonic transducers can utilize sound waves to detect the presence of an object or to measure the distance of the object from a reference point.

1.1 The basic ranges of sound spectrum

The sound spectrum is divided into three basic ranges:

(i) The infrasonic range: consists of very low frequencies (i.e. below 20 Hz), which we generally cannot hear. Examples of infrasonic sound include volcanoes, earthquakes and vibrations from heavy machinery. [6]

(ii) The audible range: includes those frequencies that can be detected by the human ear. The audible range is typically from about 20 Hz to 20 kHz but this can vary from person to person. [6]

(iii)The ultrasonic range: includes frequencies above 20 kHz. You cannot hear these frequencies but certain instruments and some animals can detect them. Bats, for example can hear frequencies up to 100 kHz.

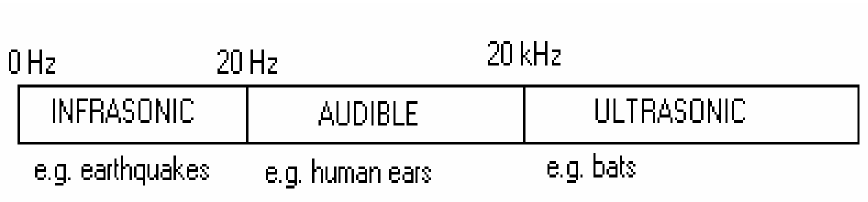


Figure 1: Sound ranges

Ultrasonic transmitters and receivers are transducers that perform the same basic functions as the loudspeaker and the microphone but the sound waves are in the ultrasonic range. [6]

1.2 Types of Transducers

There are two basic types of ultrasonic transducers**:**

(i) Electrostatic transducer.

(ii) Piezoelectric transducer, which will be covered in more depth.

The piezoelectric transducer consists of three main parts, the housing, two metal plates and piezoelectric crystal, which is made of quartz. [6]

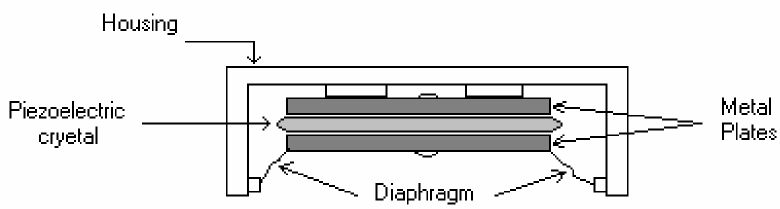


Figure 2: Cross-sectional view of the piezoelectric transducer.

Figures (3a) and (3b) show that the transducer can be used as either an ultrasonic transmitter or an ultrasonic receiver, depending on how it is configured. [6]

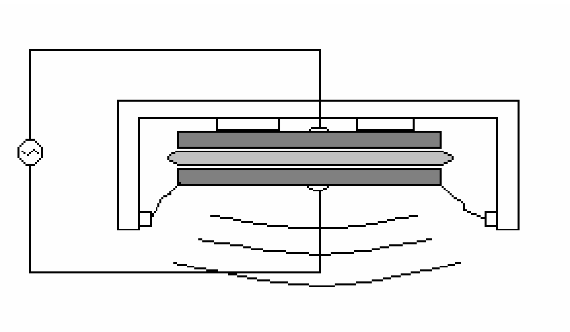


Figure 3a: Piezoelectric transmitter.

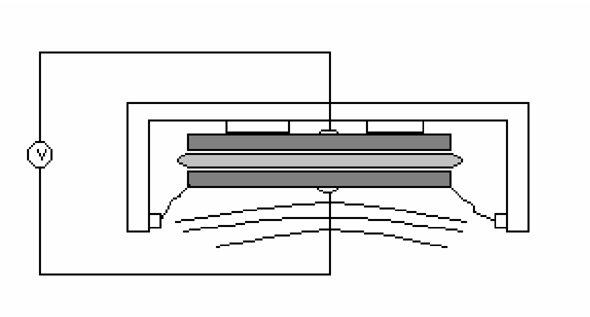


Figure 3b: Piezoelectric receiver.

1.3 Transducer Configuration

The Ultrasonic transducer can be configured in two main ways:

1.3.1 Ultrasonic Transmitter

The ultra-sonic transmitter is a transducer that converts electrical energy into Ultrasonic sound energy. [6]

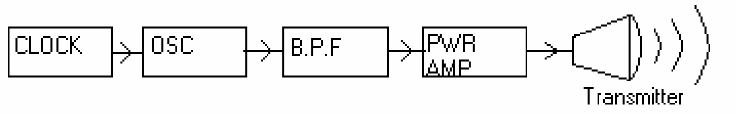


Figure 4 Ultra-sonic transmitter

1.3.2 Ultrasonic Receiver

The ultra-sonic receiver is a transducer that converts Ultrasonic sound waves into electrical energy. [6]

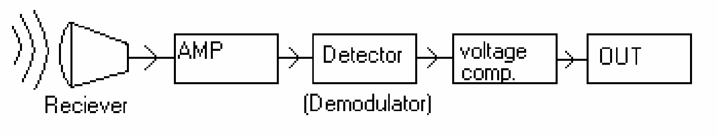


Figure 5 Ultra-sonic receiver

1.4 Applications of Ultrasonic Transducers:

1.4.1 Automatic Door Openers

A remote control device is used to send a specific frequency to be relieved by the receiver at the door, which will respond to the sent signal and open the door.

1.4.2 Fish Finders

Ultrasonic fish finder devices send Ultrasonic waves through the water and receive the reflected signal by the fish and therefore compute the location of the fish. The distance is measured by computing the time required for the signal to travel back to the receiver.

1.4.3 Other examples

There are many other applications for an ultra-sonic transceiver, such as reverse car sensors, alarm systems and range finders.

Chapter 2

1. Ultra-Sonic Transmitter

The ultrasonic transmitter is used to transmit frequencies above 20 KHz that is in the ultrasonic range where human cannot hear it. The ultrasonic receiver can detect these frequencies.

1.1 Ultra-Sonic Transducer

The ultrasonic transmitters are transducers that perform the same basic functions as the loudspeaker, but the sound waves are in the ultrasonic range. There are two basic types of the ultrasonic transducers, the electrostatic transducer and the piezoelectric transducer. These two types are differing in their internal construction and operation characteristics, as shown in table 1.

	Piezoelectric	**Electrostatic**
Transduction element	Quarts or ceramic crystal	Thin metal foil
Bandwidth	Narrow (high Q)	Wide (low Q)
Ringing	Yes	No

Table 1: Piezoelectric Vs Electrostatic Ultrasonic Transducers.

In the ultrasonic transmitter circuit designed, the piezoelectric transducer is used although it has the ringing problem, but a narrow Bandwidth with high Q is needed to transmit the exact selected frequency, which is required for the receiver. [6]

This is a cross-sectional view showing in figure 6 the construction or the transmitter's transducer.

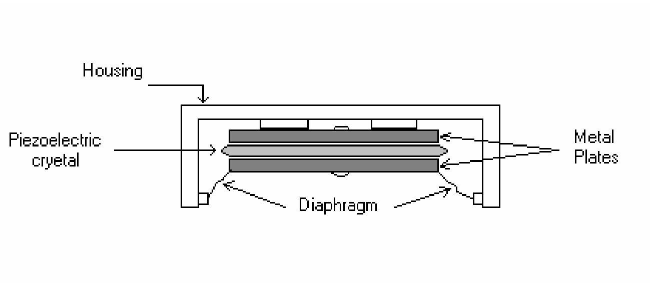


Figure 6: Cross-sectional view of the piezoelectric transducer.

As it is shown in figure 6, the piezoelectric crystal is sandwiched between two metal plates. The upper plate is mechanically anchored to the device's cyhindrical housing, and the lower plate is attached to a vibrating diaphragm. [6]

When an AC voltage of ultrasonic frequency is applied, the crystal rapidly expands and contracts. This vibration is transferred to the diaphragm, which, in turn, emits sound waves in the ultrasonic range. [6]

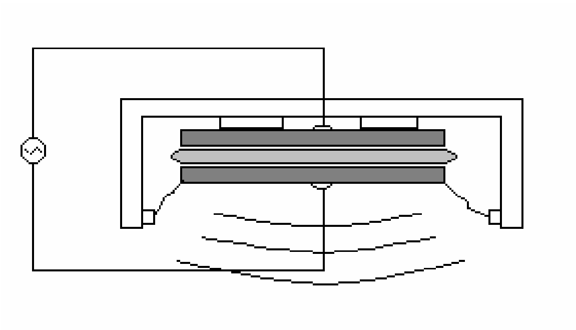


Figure 7: Piezoelectric transmitter.

The ringing is caused because of the vibration of the diaphragm causing continues small vibration.

In this part, the explanation of how does the ultrasonic circuit works would be covered.

In the ultrasonic transmitter, these steps should be followed in order to transmit the exact signal needed to the receiver.

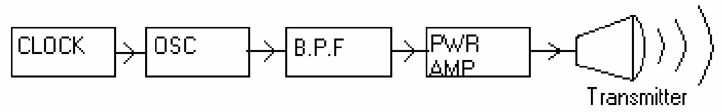


Figure 8: Ultra-Sonic Transmitter

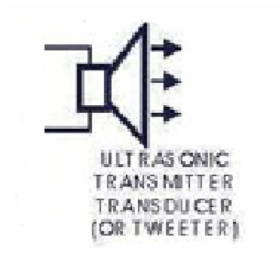


Figure 12: Tweeter

This is the transmitter block that should be connected to the transducer, which has been introduced before:

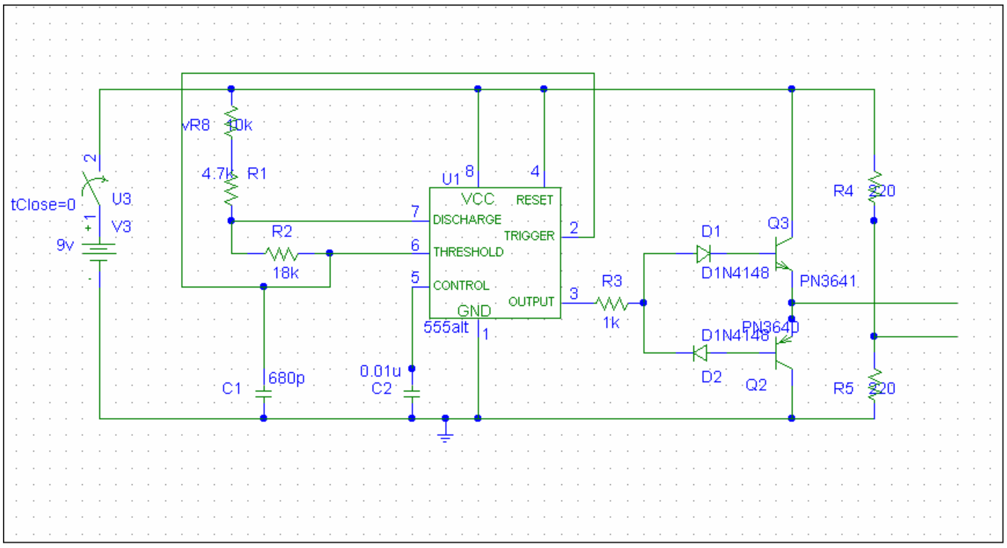


Figure 11: Transmitter block

The graph shown below gives a more detailed and accurate tracing of the output with a delayed triggering of 2milliseconds:

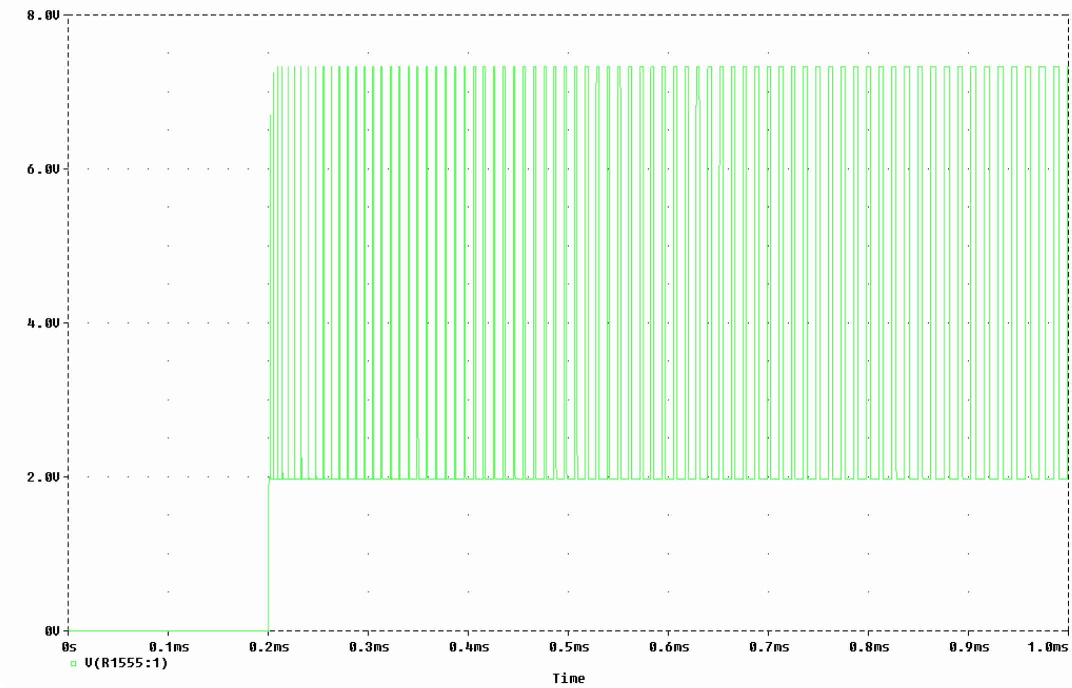


Figure : Detailed trace of the transmitter's output

The IC, which would generate the ultrasonic signal, is called the 555 timer.

1.2 The 555 timer:

This IC is designed to generate accurate and stable C-R defined timing periods for use in a variety of as table square – wave generator applications. [4]

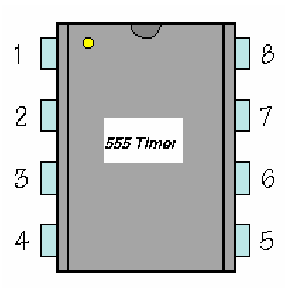


Figure 9: 555 timer

There are two packages of the 555 timer, the bipolar package, which are available in both single (555) and dual (556), and the CMOS packages, which forms 7555 and 7556. In the transmitter circuit, the 555 timer of the bipolar type is used because a higher supply current is supplied and higher output current is needed. [4]

1.3 How the 555 timer works

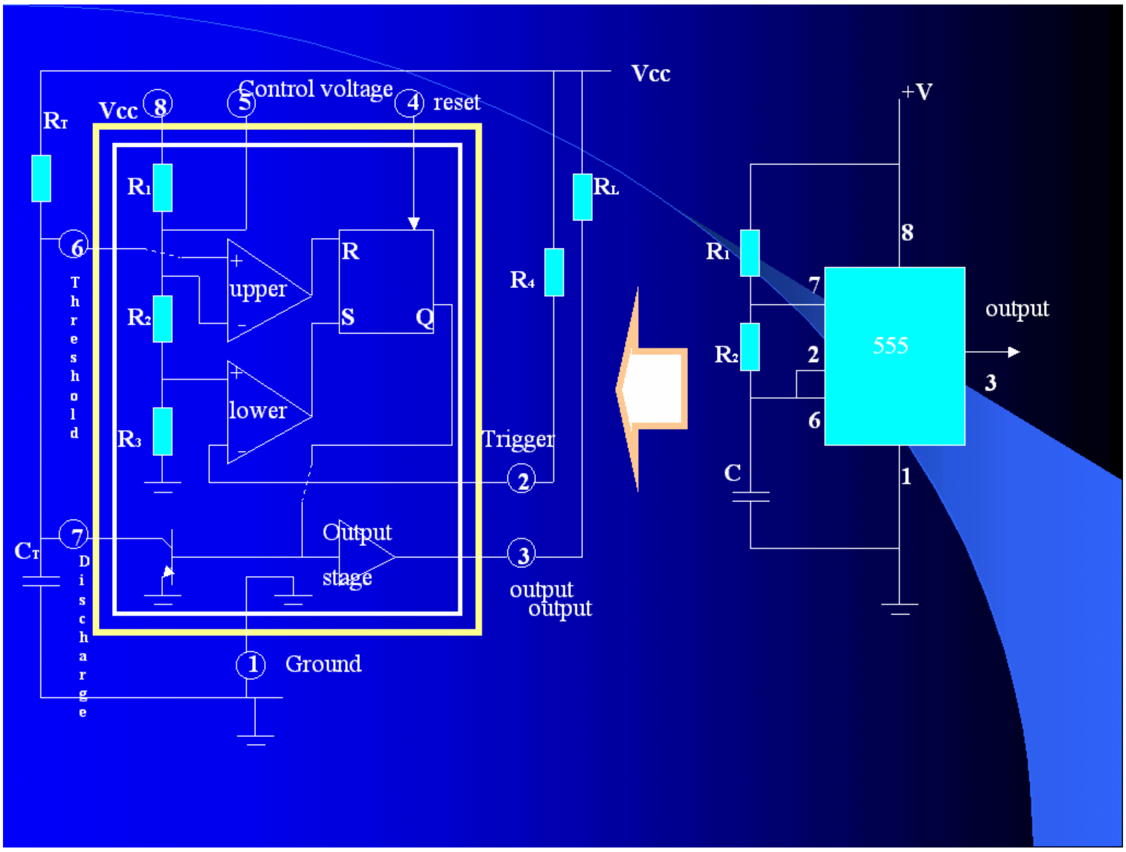


Figure 10: 555 Timer circuit diagram

As shown in figure 10, the functional diagram of the basic 555 timer IC, which is internally arranged in the form of two voltage comparators, one R-S flip flop, a low-power complementary output stage, a slave transistor, and a supply-driven three resistors of 5k0 potential divider that generates a 1/3 Vcc reference voltage that is fed to the non-inverting input of the lower comparator and a 2/3 Vcc reference that is fed to the inverting input of the upper comparator. The outputs of these comparators control the R-S flip-flop, which in turn controls the states of the output stage and the slave transistor. [4]

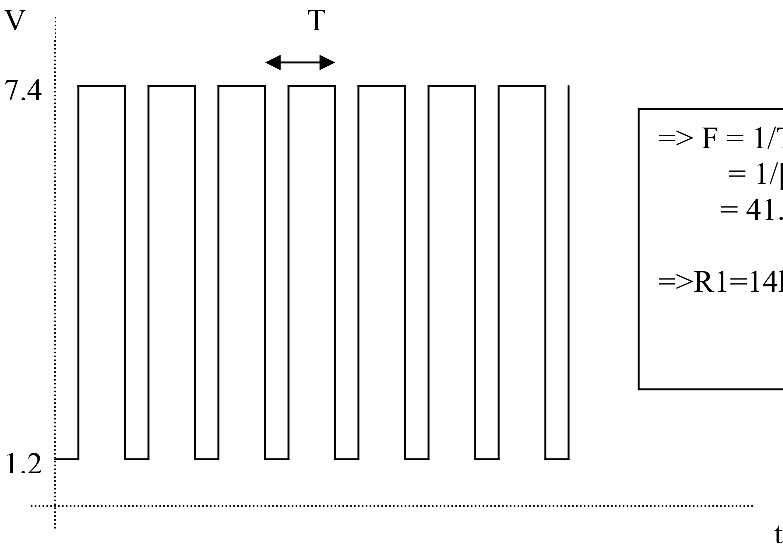
The flip-flop state can also be controlled via the IC's pin 4 reset. When the timer circuit is in its quiescent state the pin 2 trigger terminal is held high via R4, Q1 is saturated and forms a short across timing capacitor Ct and the pin 3 output terminal is driven low. The timer action is initiated by feeding a negative-going trigger pulse to pin 2, and as this pulse falls below the internal 1/3 Vcc reference value the output of the lower voltage comparator changes state and makes the R-S flip flop switch over, turning Q1 off and driving the pin 3 output high. [4]

As Q1 turns off it removes the short from Ct, so Ct starts to charge exponentially via Rt until eventually the Ct voltage rises to 2/3 Vcc. At this point the IC's upper voltage comparator changes state and switches the R-S flip-flop back to its original state, turning Q1 on and rapidly discharging Ct and simultaneously switching output pin 3 low again, thus completing the operating sequence. [4]

The timing period of the circuit, in which the pin 3 output is high, is given as:

$$T = 1.1 \; Rt \; Ct$$

The output of this transmitter is:



$$\Rightarrow F = 1/T$$
$$= 1/[\,0.693 \times C \times (R1 + 2R2)]$$
$$= 41.855 \text{ kHz}$$

=>R1=14k7 R2=18k0 C=680p

Graph 1: Sketch of the transmitter's output

2. Ultra-sonic Receiver

The second part of the ultra-sonic transceiver is the receiver block. It is the part that receives the signal sent by the transmitter through the ultra-sonic transducers mentioned previously. The receiver will *only* work if the received frequency meets the assigned receiver frequency in order to operate according to the designers needs.

The receiver's circuit block was harder in designing than the ultra-sonic transmitter. First of all, a complex design was chosen to represent the receiver's block, which is shown in figure :

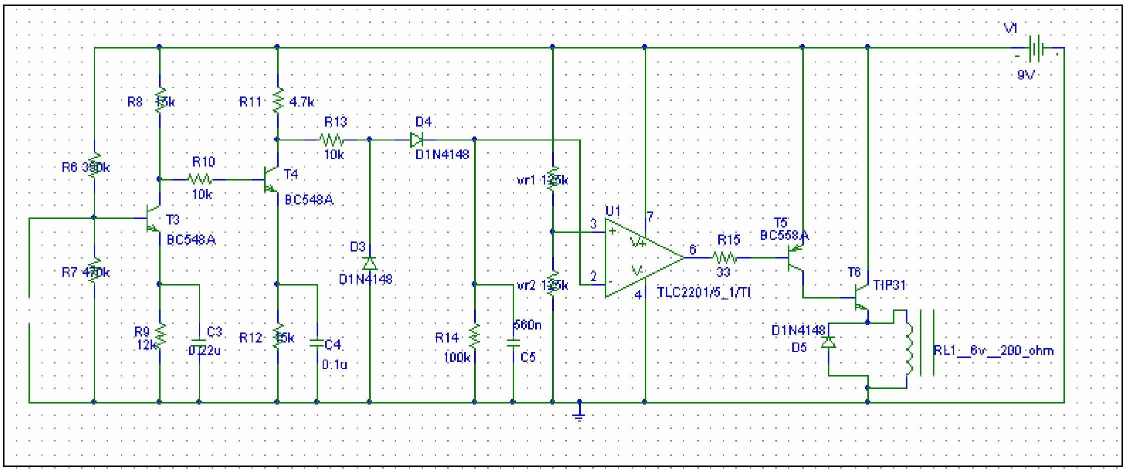


Figure 13: Receiver block

2.1 Receiver Design

This receiver consists mainly of the following:

(i) An ultrasonic transducer, that receives the signal sent by the transmitter and converts it into an ac current.

(ii) An amplifying system, that consists of an n-p-n transistor, resistor and a capacitor. Its job is to amplify the signal that comes from the receiver and filter out the unwanted frequencies through the capacitor.

(iii) A second amplifying system, that also consists of an n-p-n transistor, resistor and a capacitor. Its job also is similar to the first amplifying system mentioned above.

(iv) Two diodes, the first one (D3) is to bypass the negative signals to the ground and the second diode (D4) is to let only the positive part of the signal pass through.

(v) A low pass filter, which grounds the higher frequencies, and let the lower ones pass through.

(vi) An op-amp (operational amplifier) that acts as an amplifier and amplifies the signal that passes through the diode (D4). It also acts as a comparator that compares the received voltage signal to a constant reference voltage. When the received signal becomes higher that or equal to the reference constant voltage, the output will be high. If the received signal is lower that the reference constant voltage, the output will be low. The op-amp which was used in the circuit can be seen in the next page:

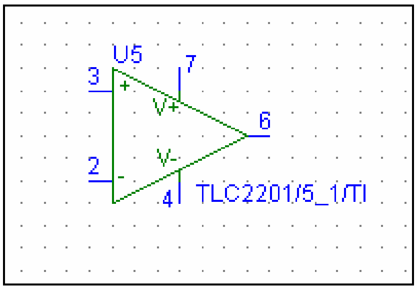


Figure 14: Operational Amplifier

(vii) The Darlington switch that works as a current amplifier.

(viii) An output relay that will be fed the amplified current from the Darlington switch.

When the receiver was first built, some components such as the transistors at the end of the Op-Amp were not available, but those were replaced with similar parts from the library of the design manager software. The whole circuit was tested by directly connecting the transmitter to the receiver's input terminal and turning-on the transmitter.

The output of the receiver should be a constant DC voltage that will then be fed to a relay or an opto-coupler (Isolator) that will in turn, run a desired circuit or device such as the motor of a remote gate opener for example.

The results and output obtained from the receiver were incorrect. The receiver seemed to work by itself without the signal of the transmitter. After checking the voltage at different nodes throughout the circuit, it was thought that the wrong power supply was connected to the receiver.

The power supply was switched with a floating-point voltage but this made the situation even worse; this time, the receiver didn't work at all. It seemed that the previous voltage supply is correct where the floating voltage didn't provide any voltage because its not connected to ground.

After measuring the voltage at different nodes through the receiver, it was noticed that as soon as the receiver is turned-on, the voltage starts to build up at the input of the op-amp; this resulted in giving an output at the receiver although the was no signal sent from the transmitter itself.

To test the circuit, the voltage at the nodes (without connecting the transmitter) was measured as shown in (figure 15):

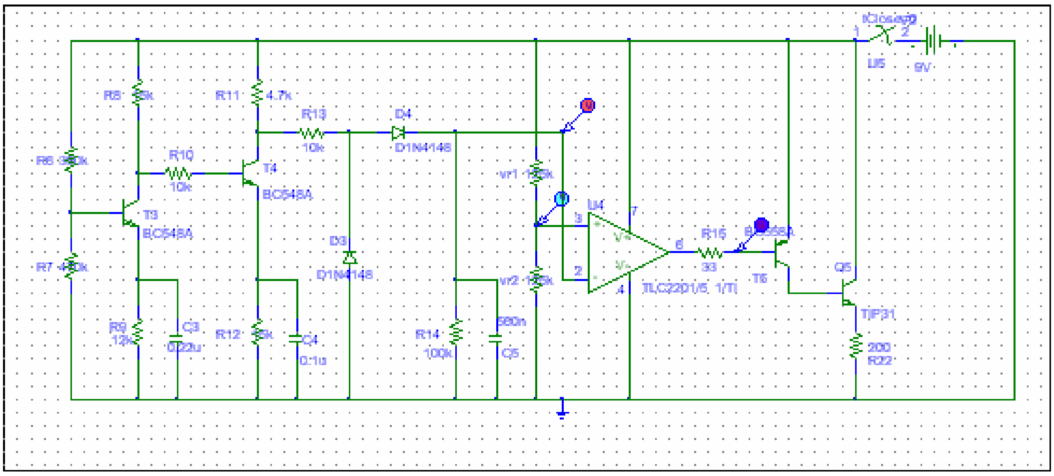


Figure 15: Voltage nodes in specific locations on the receiver

The output of the receiver (without connecting the transmitter) is shown in (graph 3) below:

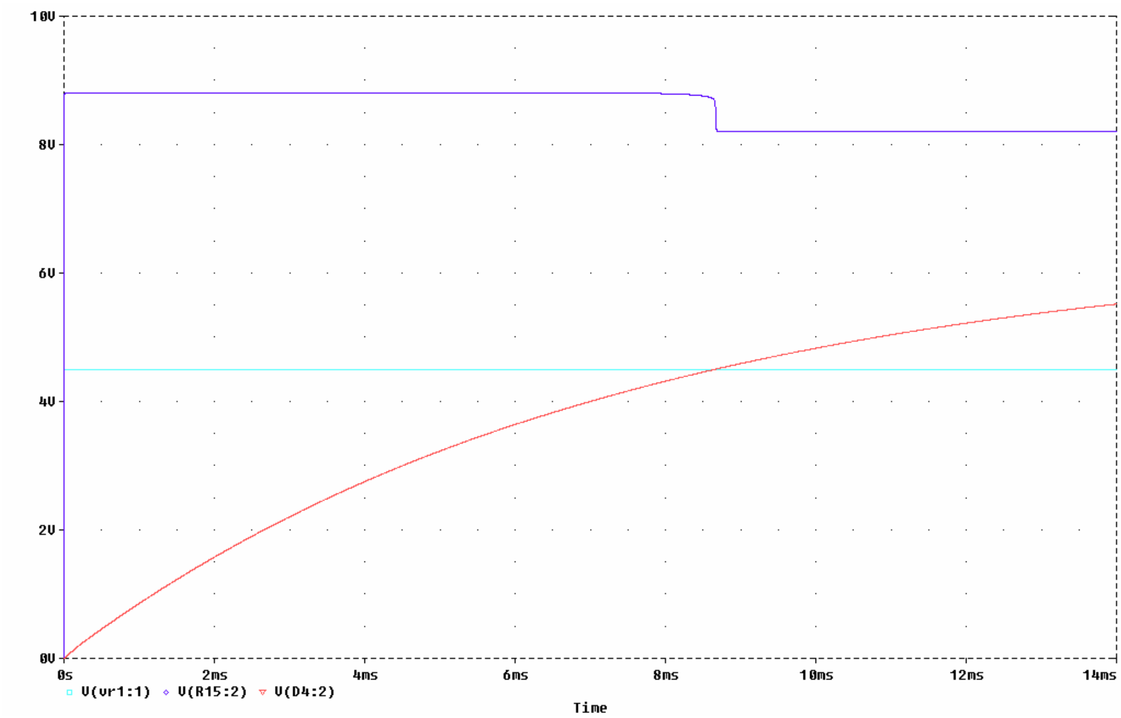


Figure 3: Incorrect output of the receiver

It can be clearly seen that the compared voltage (red line) keeps increasing although there is no signal from the transmitter to trigger this increase. On the other hand, the output voltage of the receiver (purple line) shots up to its maximum value although there is no input signal. The light blue line is the constant reference voltage of the op amp, fixed at 4.5 volts.

2.2 New Receiver Circuit Diagram

The receiver's block shown in Figure () wouldn't be easily modified in order to make it work in conjunction with the transmitter, that's why another receiver block was designed instead of the previous one.

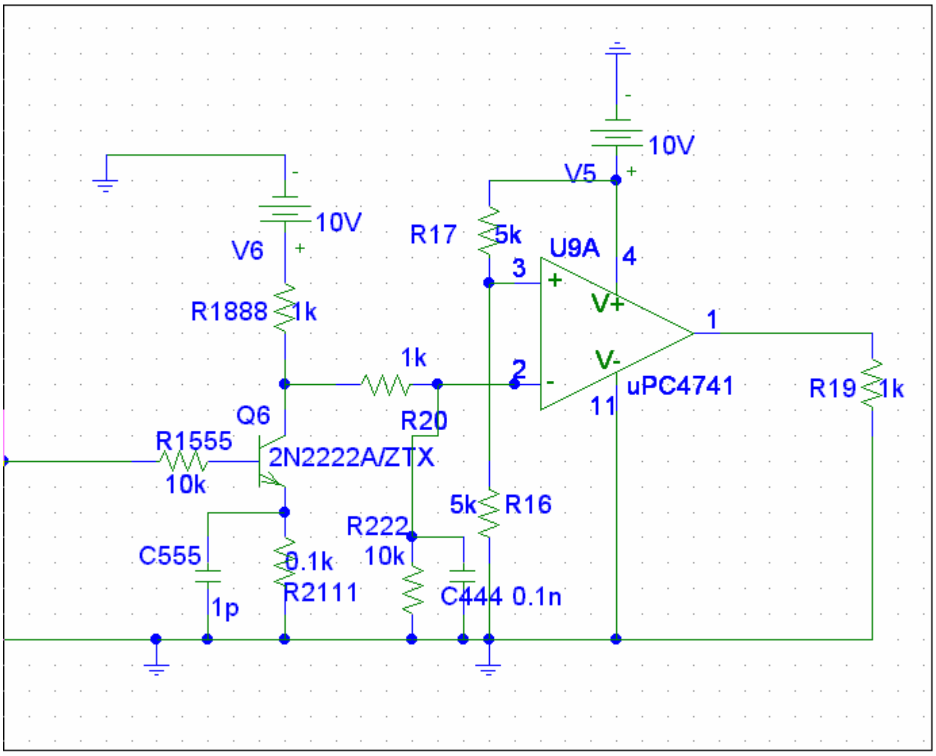


Figure 16: New receiver's circuit diagram

As shown in (figure 16) in the previous page, the new receiver block consist of much less parts than the previous one, which are:

(i) An amplifying system, that consists of an n-p-n transistor, resistor and a capacitor. Just like the previous block, this part is used to amplify the signal that comes from the receiver and filter out the unwanted frequencies through the capacitor.

(ii) A second stage low-pass filter in order to increase the complexity of the filter and achieve a higher Q factor.

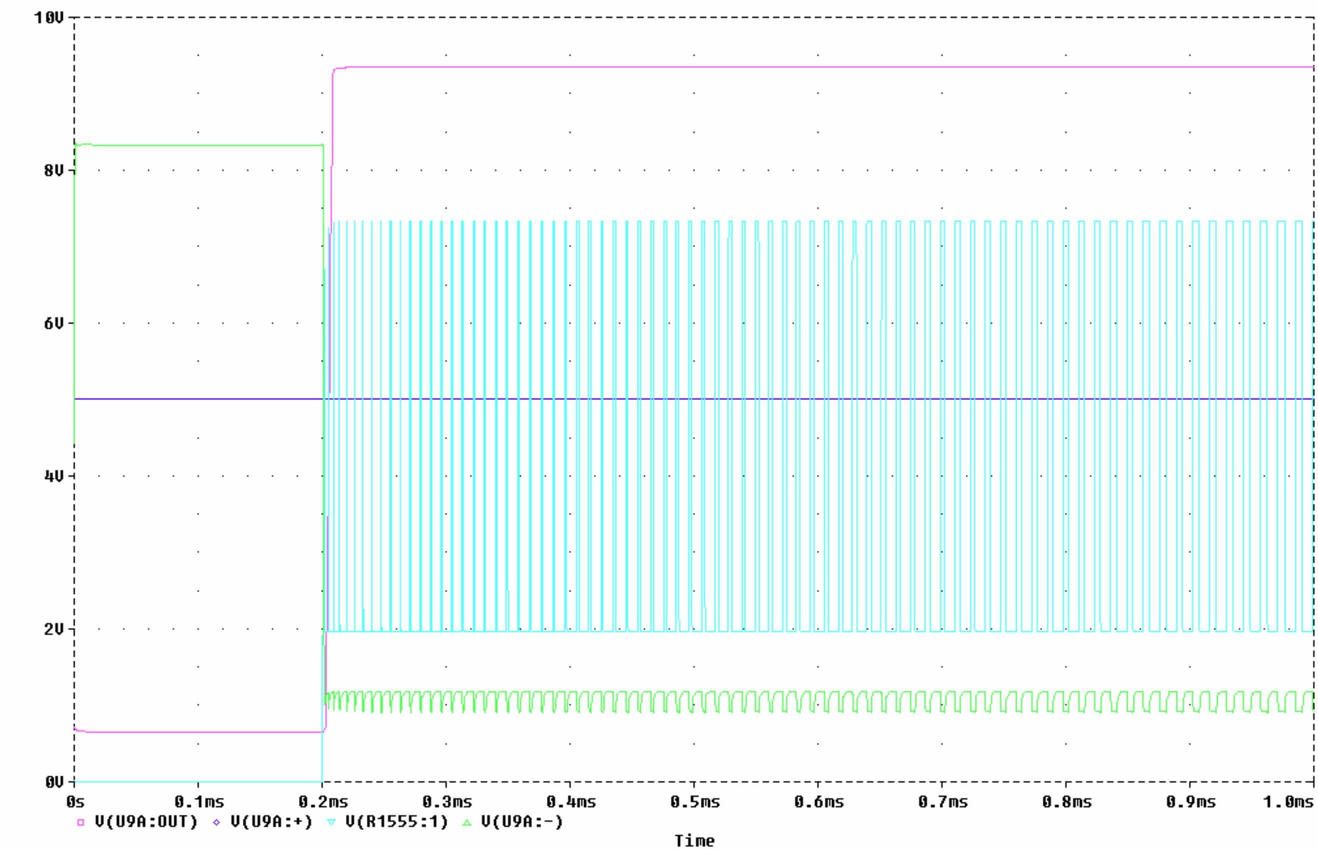
(iii) An op-amp than will compare the resulted received signal with the constant reference voltage. In this case, the value of the voltage in stand-by is always more than the reference voltage, but because the compared voltage is connected to the negative terminal of the op-amp, the output will be (V-) which is connected to ground, thus the output of the op-amp is always zero at stand-by. So, when a signal is received, the transistor shorts the voltage to ground making it lower than the constant reference voltage; thus this gives an output of (V+) which is connected to the +10v voltage supply, and the receiver is turned-on. [1]

(iv) An output resistor R4 that will be replaced by a relay in order to run another device or system.

2.3 Output of New receiver

The receiver was tested using a signal generator in order to guarantee a correct signal and voltage source. This time, the receiver worked exactly as desired where before applying an input signal, the receiver's output was zero, and at the instance the signal source was connected to the block, an output voltage of 9 volts shoots up at the output terminal of the op-amp.

This can be more clearly seen from Figure (4) in the next page:



Graph 4: Output of the new receiver at different nodes

Graph 4 in the previous page, shows the value of the voltage at four different locations, which are:

(i) The purple voltage line that represents the value of the constant reference voltage at the input terminal of the op-amp. It can be seen that it holds a constant value of 5 volts.

(ii) The light blue voltage line that represents the input signal, coming from the transmitter, with a frequency of 41.885 kHz.

(iii) The green voltage line that represents the input compared voltage at the other input terminal of the op-amp. [1]

(iv) The pink voltage line that represents the output voltage at the op-amp output terminal.

This will be more clearly seem from the circuit block below with the specified colored voltage nodes:

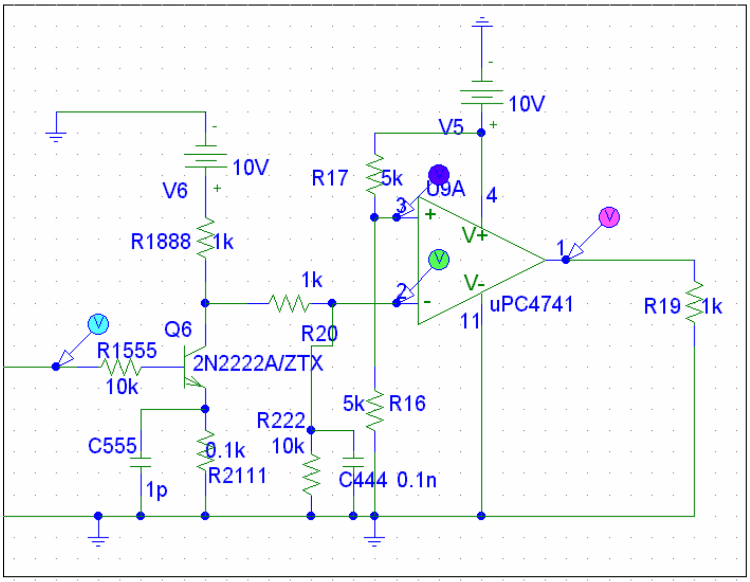


Figure 17: Voltage nodes at specified locations on the receiver's block

2.4 Transceiver Circuit Diagram

After connecting the two circuits, which are the transmitter and the new receiver, they will look like this:

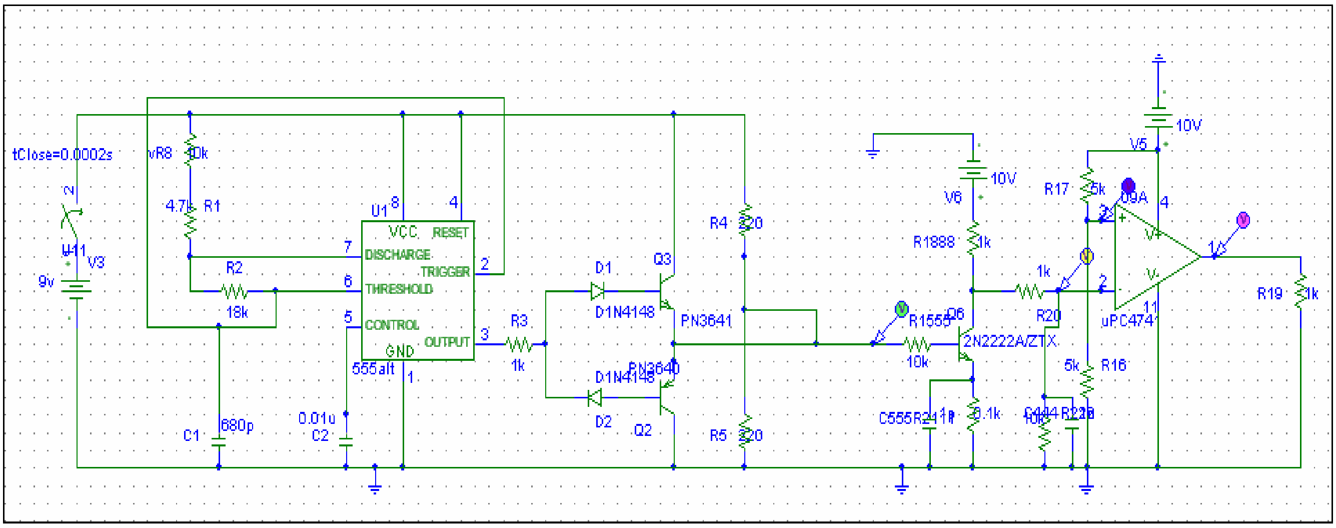


Figure 18: Transceiver Block

3. Conclusion

- This project is to design an ultrasonic switch. The purpose of using Ultrasonic devices is to maintain a wireless communication between a transmitter and a receiver to make it portable and handy to use.

- The transducers can convert the sound energy into electrical energy and vise versa.

- The most common type of ultrasonic transducers s the piezoelectric transducer. [6]

- There are some other application for the ultrasonic transducers such as:
  - Car sensors
  - Alarm systems

- A person can also measure the distance of an object with an ultrasonic transceiver the time it takes for the signal pulses to reach the object and echo back to the receiver.

- The ultrasonic wave gets weaker as it travels further away. [6]

- The Ultrasonic wave is strongest in the area directly in the front of the transmitter. [6]

- The maximum measuring distance is limited by the transducers sensitivity and also by the period of the triggered pulses. [6]

- The velocity of the wave depends on the temperature and the transmission medium, it can be measured by this equation:

$$V = (331 + 0.6\ T)\ m/s$$

Where V: the velocity

T: any temperature in (°c)

- Applications of an operational amplifier: [2]

  - Amplifiers: they are to amplify the signal and also can be made to be frequency selective.

  - Oscillators: the basic op-amp can be connected to operate as an oscillator.

  - Regulators: they used to improve the regulation in power supplies.

  - Rectification: used to build a half-wave rectifier.

  - Computer interfaces: used to convert the digital devices (motors, lights).

References

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