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<p>Bats are found all around the world and study of bats is important as they are the part of the ecosystem we live in. For research and study, bats are to be located and for that, bat detectors are needed.</p> <p>The main target of this study was to build a prototype that would detect bat calls. This study aims to help scientists and researchers to study further about bats with the help of economical device for their detection.</p> <p>The transmitter circuit was used to imitate the bat call that produced ultrasonic sound and then, the receiver circuit was triggered as soon as the ultrasonic sound was detected. Different components including ultrasonic sensors were used. The final prototype detected the ultrasonic sound produced from the transmitter using a potentiometer to tune.</p> <p>The result showed that the ultrasonic sound could be detected using the components that are not so expensive which would help in saving money in research and study. The transmitter circuit worked in the beginning but showed some problems later on and the components were changed. However, the main focus was on building a detector which was a success.</p>	
Keywords	bats, detector, detection, ultrasonic, sound, wave, transducer, sensors, 555 timer, amplifier

Abbreviations

Hz	Hertz
kHz	Kilohertz
MHz	Megahertz
SONAR	Sound Navigation and Ranging
SHM	Simple Harmonic Motion
NDE	Non-destructive Examination

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1 Introduction

With the evolution of technology, mankind has always been curious in understanding their surroundings and the creatures living in it, from microscopic organisms to large mammals. One of the mammals that is living around us is Bat (***Chiroptera***).

There are around 1300 species of Bats worldwide among which 11 known species of bats are found in Finland. Some of them can survive extreme conditions and hence they are found almost in every corner of the world whether it is the desert of south western USA or far north of the Scandinavia. Their forelimbs are adapted as wings and they can fly. Some bats feed on fruits, some on nectars and some on insects, frog or lizard. [1]

Bats usually hunt in the dark and echolocation is the system that helps them fly and locate preys in dark. They make calls when they fly and as it reflects back, they listen the call and find out if there are obstructions ahead. This helps create a sonic map of the surrounding. The calls that bats make are non-audible to human ears as the frequency can range from around 20 Hz to 200 kHz. The frequency range can vary as different bats have different range. The range of human hearing is only 20 Hz to 20 kHz. Using echolocation, a bat can know what is ahead. If there is an object, it can even know its size, its exact position and if it is moving, to which direction it is moving. [2]

Since it is not possible to hear bats once the range crosses 20 kHz, the study focuses on making a device that can convert high frequency calls to audible sound and help locate the bats. So, basically it's a bat detector that can detect ultrasonic sound. The device shall help in research and study of bats in Finland.

The figure below shows how bats interact in the surrounding using ultrasonic sound and hearing back the echo from the obstacle in front of it.

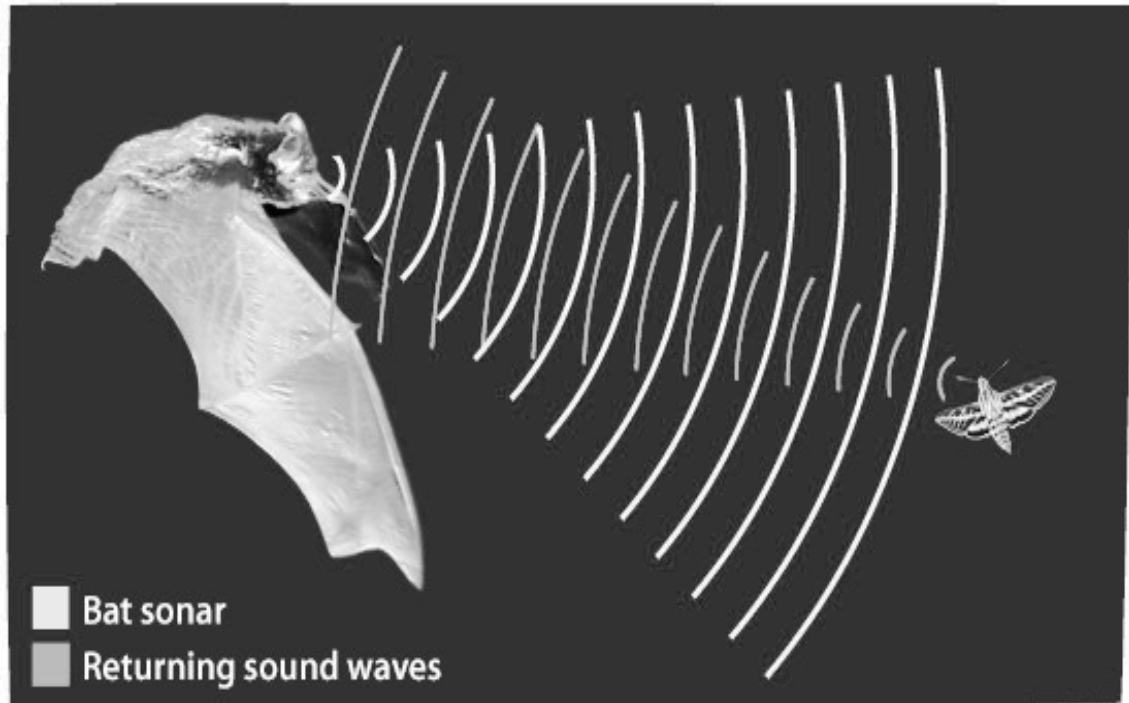


Fig 1. Echolocation [3]

In fig 1., the soundwave produced by the bat is transmitted and when it strikes the object, the soundwave reflected. The wave is then processed by the ears of bat after which the bat can find the exact position of the object and know whether the object is still or moving. [4]

2 Theoretical Backgrounds

2.1 Sound

Acoustics is a branch of physics that deals with the study of properties of sound. Sound is mechanical disturbances or vibrations that usually propagate as an audible wave of pressure. Sound waves use transmission medium to propagate such as solid liquid or gas. Hence, sound cannot travel in vacuum. Sound waves are longitudinal or transverse. Sound mostly is longitudinal but in solid it can also be transverse. Figure 2 shows the difference between longitudinal wave and transverse wave. Considering human psychology, ears perceive these waves which are processed by the brain using the acoustic nerve that provides the sensation of hearing to human ear. When a sound wave strikes the ear, it causes the ear drum to vibrate which is then transmitted by the acoustic nerve because of which sensation of hearing is produced. [5]

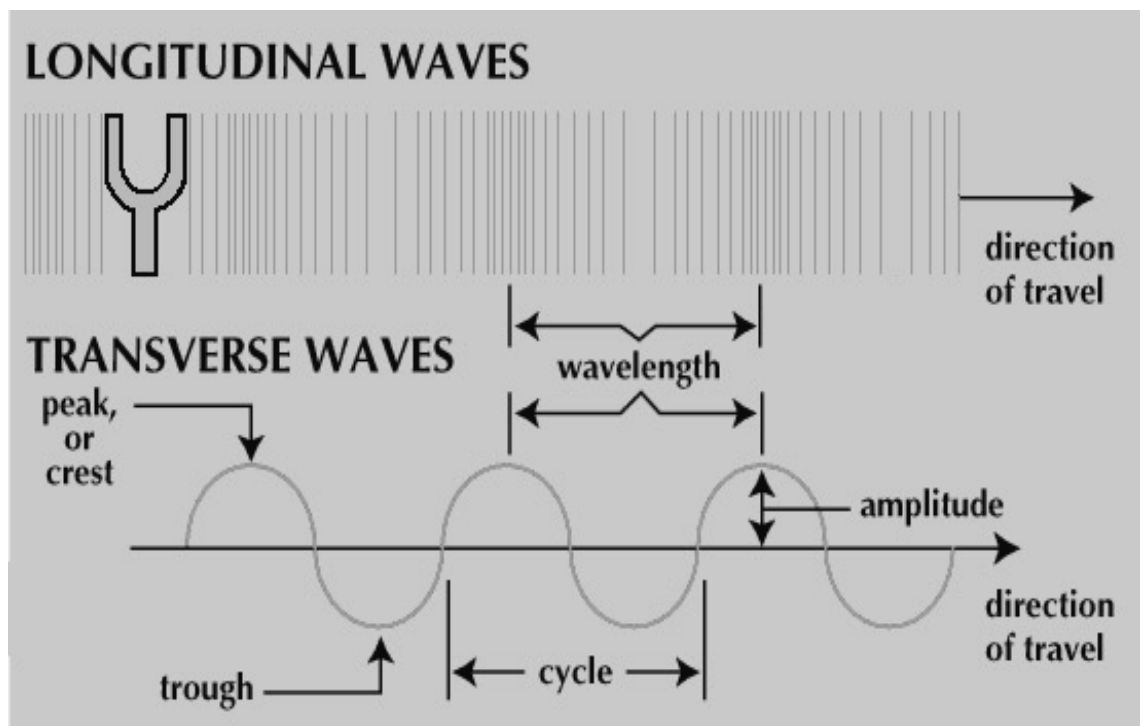


Fig 2. Waves

In fig. 2, the propagation of waves is shown. In longitudinal waves, the particles of the medium moves in a parallel direction compared to the direction of wave whereas in transverse waves, particle oscillation is perpendicular to the wave motion. The positive maximum positive displacement is called crest and the negative displacement is trough. Wavelength is the length of a complete cycle.

Sound fulfils all the properties of wave motion. It exhibits all the phenomenon including reflection, refraction and diffraction. It also has the same relations between frequency, wavelength and propagation speed and interference. The only property that sound lacks is the polarization. [5]

The speed of sound is determined by the density and temperature of the medium. If the density of a medium is high, the sound travels faster.

The sources of the production of sound wave can be a simple tuning fork or a very complex mechanism, for example human voice that is produced from the larynx with its vocal cords. Steady tone is produced from the turning fork and the energy at a single frequency of such tone is in simple harmonic motion (SHM). Frequency is number of oscillations with respect to time in seconds. The unit of frequency is Hertz (Hz) where 1 Hz is defined as one oscillation or cycle per second. The inverse of frequency is wavelength which is measured in meters and denoted by lambda (λ). [6]

Sound can be divided in three categories based on frequency – Infrasound, Acoustics and Ultrasound. [5]

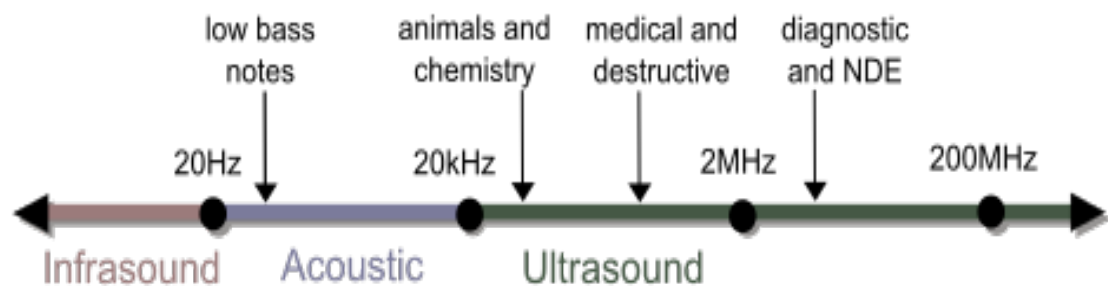


Fig. 3 Sound Ranging

Fig. 3 shows the ranging of sound measured in frequency (Hz). Below 20 Hz is infra-sound, 20 Hz to 20 kHz is acoustic. This is the sound that a normal human can hear. 20

kHz and more is ultrasound that very less beings can produce and hear. Medical and destructive testing is done from 20 kHz to 2 MHz whereas Non Destructive Examination (NDE) is done from 2 MHz to 20 MHz . [8]

Infrasound is the study of such sounds range from 20 Hz down to 0.1 Hz and very rarely to 0.01 Hz. Since the frequency is low, which means, wavelength is very high for infrasound. Hence, infrasound can cover long distances and even get around obstacles with little dissipation.

Infrasound can be produced by different animals including elephants, whales, hippopotamuses, giraffes and rhinoceros. They use infrasound to communicate although they are hundreds of kilometres away. Natural events such as earthquake, volcanoes, waterfalls, atmospheric lightning, etc. can also produce infrasound. Besides this, there are manmade equipment that can produce infrasound. Diesel engines, nuclear explosions, wind turbines etc. are some of the examples of manmade sources that produce infrasound.

Infrasound is used for atmospheric studies, earthquake and landslides detection, nuclear detonation detection etc. [9]

2.2 Ultrasonic Sound

Ultrasonics originally known as supersonics, is a specific branch of acoustics dealing with vibratory waves in different mediums including solids, liquids and gases above the hearing of human ranging 20 Hz to 20 kHz. There are many different uses of ultrasonic and the major applications are described below. [10]

2.2.1 Underwater Sound (SONAR)

Sound Navigation and Ranging (SONAR) uses ultrasonic sound waves to navigate, explore and map the underwater, as the waves from sound travel farther in water than that of radar or light waves. Originally, scientists used sonar to determine the underwater

hazards and find out what was there on sea floors including the wreckage of ships or airplanes. There are two types of sonar and they are Active Sonar and Passive Sonar. The figure below shows how a SONAR works. [11]

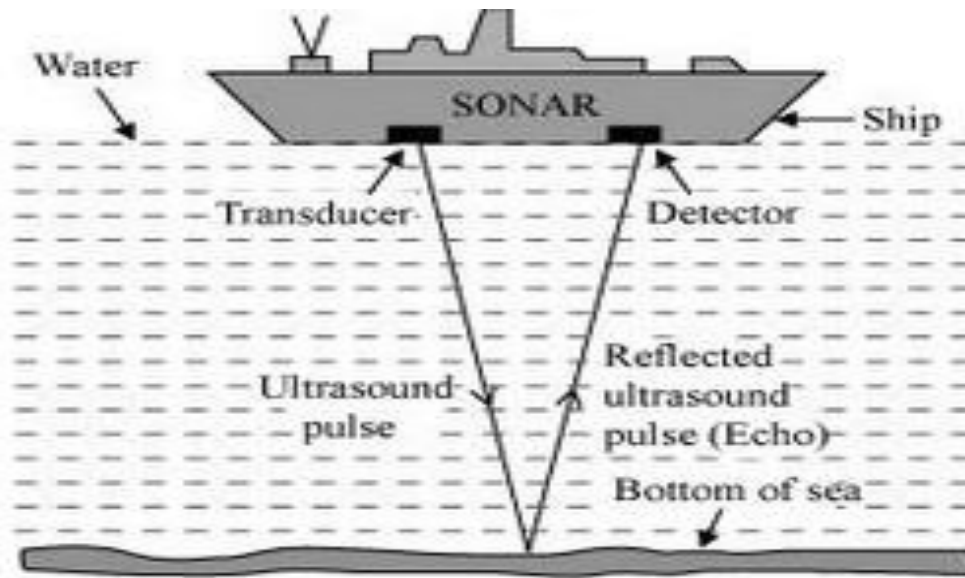


Fig. 4 Operation of a SONAR for the calculation of depth of sea

In Fig. 4, the ship is fitted with ultrasound transmitter and receiver. The transmitter sends a pulse of ultrasonic sound wave to the bottom of the sea. Once it reaches the bottom, it is then reflected which is then received by the receiver. The time taken to complete this whole process is then measured. When time is known, the depth of the sea can easily be measured by simple calculation.

$$d = (v \cdot t) / 2 \quad (1)$$

where,

d is the depth of the sea measured in meters (m)

v is the velocity of sound in water measured in meter per second (m/s)

t is the total time taken for the wave to reach the bottom of the sea and back to the ship which is measured in second (s)

a. Active Sonar

An acoustic signal or pulse of sound is emitted from the active sonar transducer which strikes with an object in the path and returns as an echo to the receiver. The receiver then measures the strength of the signal and by calculating the time between the emission and reception, the size and the distance of the object is measured. [11]

b. Passive Sonar

Passive sonar does not emit acoustic signal but it receives the signal coming from submarines or ships or the animals in the water. [12]

2.2.2 Industrial Ultrasonics

The use of ultrasonic in industrial field has increased from processing, non-destructive testing to measurements and control. It is widely used in echolocation of defects, material characterization, temperature measurements, flow and viscosity measurement, particle manipulation, soldering and welding etc.

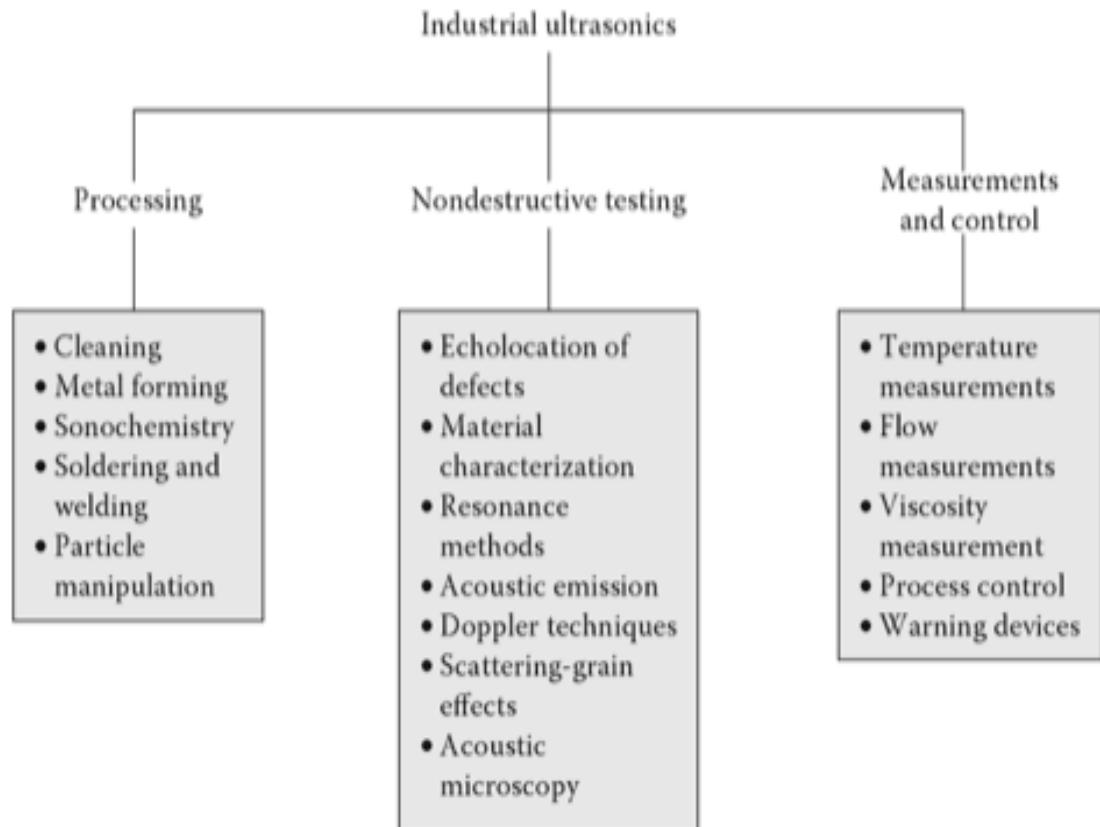


Fig. 5 Scope of Industrial Ultrasonics [10]

There are many different applications of ultrasound in industrial sector. The chart in fig. 5 shows its common usage in industrial sector including processing, non-destructive testing and measurements and control.

2.2.3 Ultrasonics in Electronics

Ultrasonic is closely related with the electronics through the circuits and the electronic systems. Different transducers and sensors are used in the system which is ultimately linked with electronics. With the use of modern technology linked with electronics, it has been possible to go deep in the field of ultrasonic.

2.2.4 Ultrasonics in Animals

Ultrasonic is used by different birds and animals to locate its prey, to communicate and to find the obstacles in front of them while flying or travelling. Bats, Oil birds, some species of frogs, mice, grasshoppers, moth, dolphins and whales are some of the animals that use ultrasonic sound. [13]

2.3 Technologies for Bat Detection

There are four different types of detectors that can be used for the detection of bats. The brief description of the detectors are as follows. [14]

2.3.1 The Heterodyne Class

This is the very basic class of detector for bats as it gives basic output. This detector produces an audible signal which is broadcasted through the speaker. The detector is set to 40kHz for echolocation and depending upon the frequency and the bat call, the output signal is heard. This shows the presence of bat around.

Since the device can catch only a portion of the original high frequency sound that is produced by the bat, it is quiet impossible to process the signals. It is difficult to know the frequency of the signal or the amplitude or any other data.

2.3.2 The Frequency Division Class

In this type of detector, the high frequency call of a bat is converted to a square wave which is then divided by a ration which is selected by a user usually 4, 8, 10, 16 and 32. This ratio helps in efficient processing of the calls. While making a call, the detector counts the wave cycles from the negative to the positive from the input giving the output of $1/4^{\text{th}}$, $1/8^{\text{th}}$, $1/10^{\text{th}}$, $1/16^{\text{th}}$ and $1/32^{\text{th}}$ respectively. This ratio helps in finding out whether the bat is producing a low frequency or a high frequency calls.

Frequency division class detectors can provide accurate data of a bat call including the shape, angle and the characteristic frequency which can later help in finding out the species of the bat. The results shown are in real time which helps in active monitoring of the bats. Since the output signal is lower than the original signal, display of duration of call and frequency time course in real time is possible.

2.3.3 Direct Recording Class

Generally, in direct recording class of bat detector, there is no audio output. It is simply a storing device that converts incoming bat call in a digital format. It has the capability to record up to 768,000 samples in a second. It has the ability to record every sound until the memory of the device is full in a WAV format. Through the use of different software programs, the sound can be studied later on. Every detail of the bat call is preserved.

Direct Recording Detector are helpful for long-term study of bats as the system is fully integrated. Numbers of files can be stored, compared and studied.

2.3.4 Time Expansion Class

Short portion of the bat call is recorded (usually 1 second) which is then listened in more than ten times slower rate. By doing this, for example 40 kHz frequency is lowered to 4 kHz which is audible to human ears. This is how a time expansion bat detector works. Different sound analysis software programs are then used to determine different species of bats.

The pros and cons of the different types of bat detectors are shown in the table 1. below.

Table 1. Advantages, Disadvantages and Uses of Different Types of Bat Detectors

Types	Advantages	Disadvantages	Best Use
Heterodyne	<ul style="list-style-type: none"> - Inexpensive - Good signal to noise ratio. - Real time analysis is possible. 	<ul style="list-style-type: none"> - Narrow band - Problem with sampling - Bat calls not preserved 	<ul style="list-style-type: none"> - Do it yourself projects - Real time survey
Frequency Division	<ul style="list-style-type: none"> - Displays time and frequency information - Real time analysis - Records files for later use. 	<ul style="list-style-type: none"> - Sensitivity is low - Strong bat calls are only recorded. - Full spectrum not preserved 	<ul style="list-style-type: none"> - Both Active and Passive Surveys. - Finding out the species of bats.
Direct Recording	<ul style="list-style-type: none"> - Full bat calls recorded in hard drive. - High sensitivity - Calls recorded in WAV format 	<ul style="list-style-type: none"> - Expensive and passive usage only. - Needs different software programs for further study. - Large size of files 	<ul style="list-style-type: none"> - Passive long term surveys. - Bat species detection
Time Expansion	<ul style="list-style-type: none"> - Active Monitoring - All spectral components preserved - High sensitivity and manual tuning not required. 	<ul style="list-style-type: none"> - Expensive - Different software programs required 	<ul style="list-style-type: none"> - Bat species detection. - Monitoring

3 Design of the System

3.1 Basic Design

Before the start of the actual design, the rough design of the prototype was done. The design consisted of a transducer to receive the ultrasonic sound which was then processed with the audio amplifier. Once the ultrasonic sound was received, the beeper would start to make a sound.

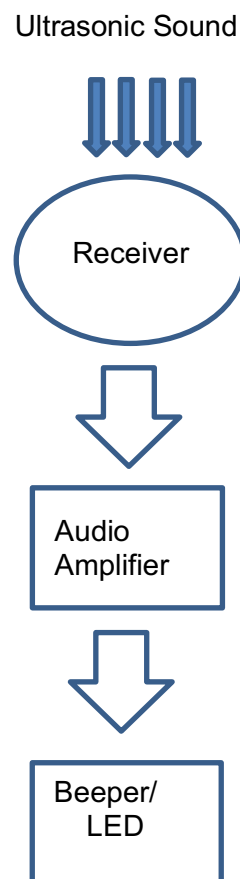


Fig. 6 Basic Design of the System

The fig. 6 shows the basic design of the system. A receiver receives the ultrasound from the surrounding and audio amplifier helps to amplify the power and finally the beeper is triggered.

3.2 Main System

The main system consisted of a transmitter circuit and a receiver circuit. The transmitter circuit would transmit the ultrasonic wave using the ultrasonic transmitter and similarly, the receiver would receive the ultrasonic wave using an ultrasonic receiver sensor.

3.2.1 Transmitter Circuit

Instead of using a real bat, the schematic shown in fig. 8 produces a pulse of ultrasonic wave.

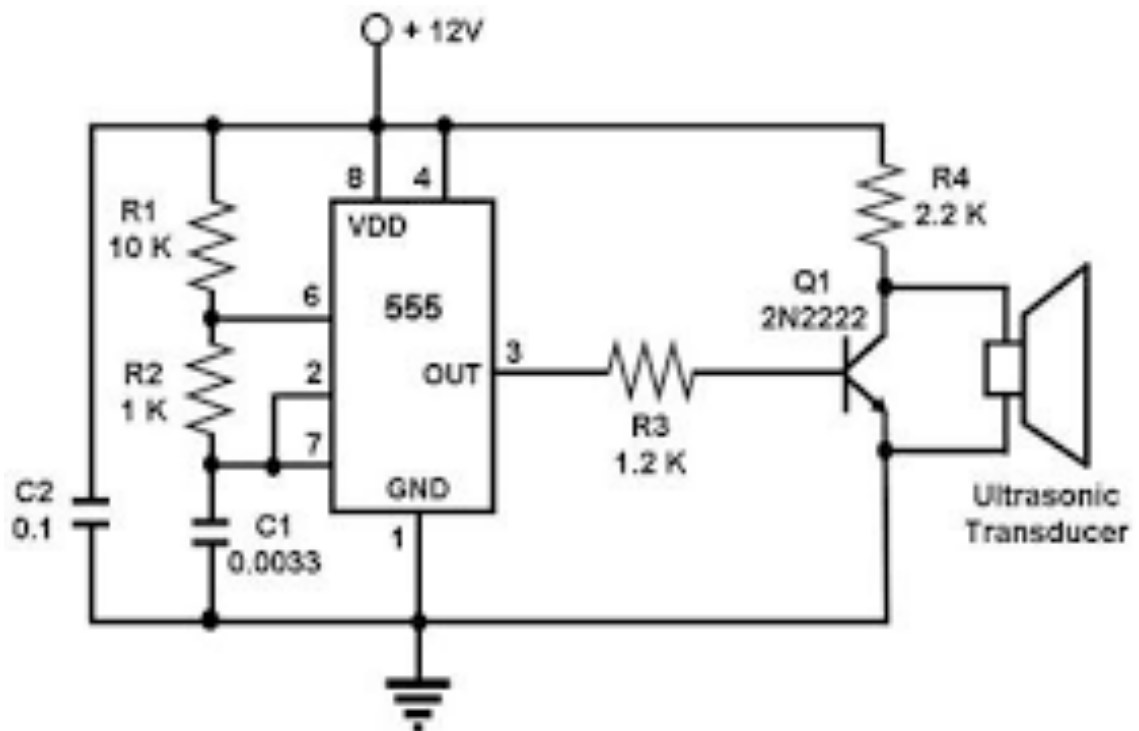


Fig. 8 Schematic of a Transmitter

The schematic for the generation of ultrasonic sound wave is illustrated in fig. 8. The circuit is operated in 12V dc supply where 555 timer is used. A 555 timer is an integrated circuit that is used for the pulse generation in this circuit. Capacitors C1 and C2 are used to block any dc voltage. R4 resistor is added for the safety of the circuit. [5]

3.2.2 Receiver Circuit

The receiver circuit is the detector circuit. It receives the ultrasonic wave produced from the transmitter which is processed by different amplifiers to detect ultrasonic sound.

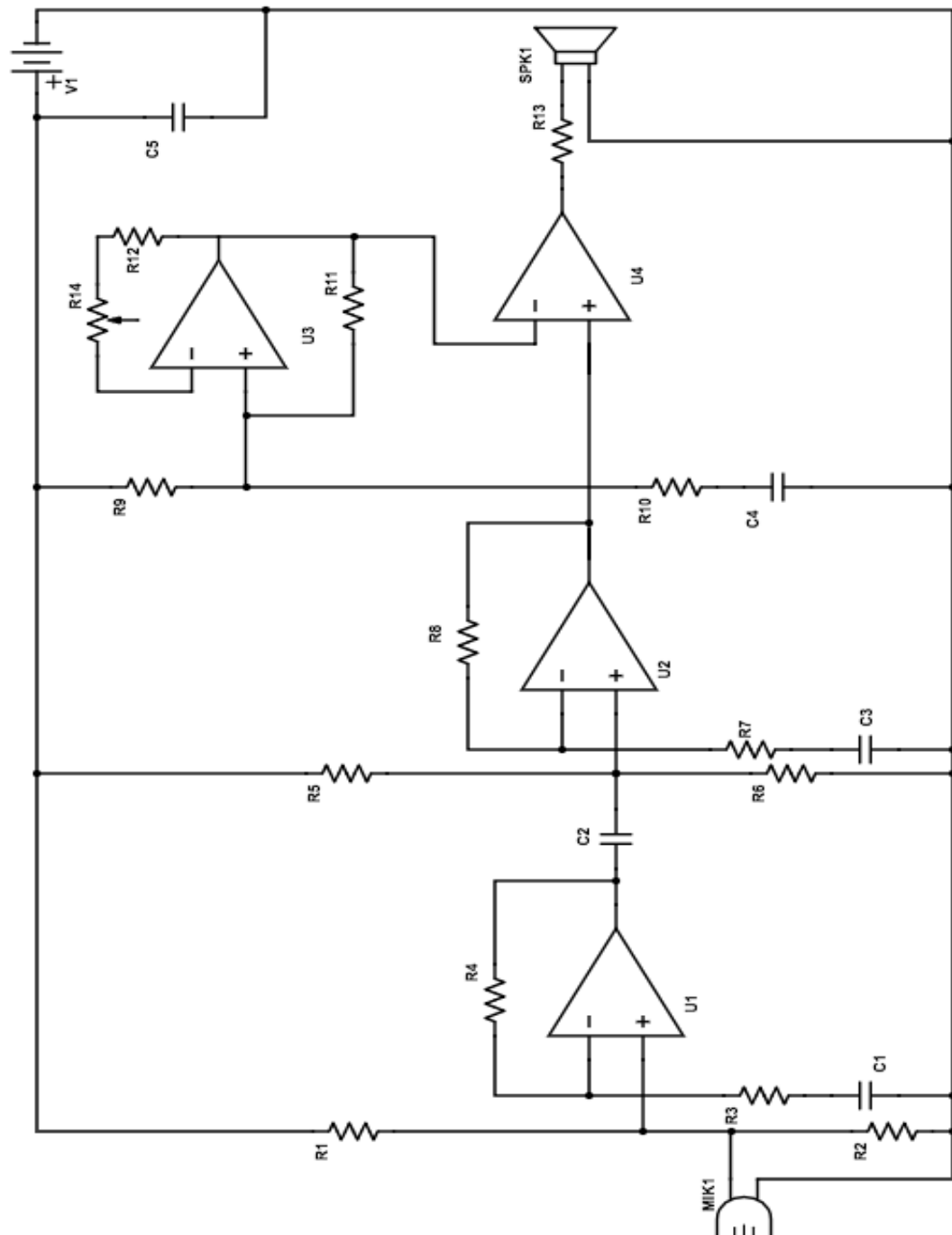


Fig. 9 Schematic of a Receiver Edited [15;19]

Fig. 9 shows the receiver circuit schematic. Instead of a complex circuit, a normal analogue circuitry comprising of operational amplifiers and passive components are used in the design of the bat detector. U1 and U2 are high gain audio pre-amplifiers. For high gain and low noise, Resistor R3 and R4 are selected which is connected to U1.

The capacitors C1 and C3 are selected so as to block audio band that are not within the range of ultrasonic frequency. These are used as high pass filters.

Similarly resistors R7 and R8 are selected for high gain as well. A variable resistor can also be used in place of R8 considering the specific ultrasonic receiver that is used during construction.

U3 is used as a conventional RC oscillator R14, R12 and C4 are responsible for the output frequency and that ranges from 15 kHz to 110 kHz. [15]

The main purpose of U4 is to act as a mixer. It combines the filtered and amplified input signal with the oscillator for the production of audio band signal. Besides this, it also helps in buffering the signal and driving it to the beeper.

3 volts of dc supply is used in the circuit. [15]

The values of the components in fig. 9 are given below.

$$R1 = R2 = R4 = R5 = R6 = 1M\Omega$$

$$R3 = 470\Omega$$

$$R7 = R12 = 1k\Omega$$

$$R8 = 62k\Omega$$

$$R9 = R10 = R11 = 220k\Omega$$

$$R13 = 240\Omega$$

$$C1 = C3 = 1.2nF$$

$$C2 = 100nF$$

$$C4 = 470pF$$

$$C5 = 47\mu F$$

3.3 Components Used in the System

There were different components that were used in the system which included resistors, capacitors, audio amplifier (LM386N), beeper, transducer, wires and bridgeboard. Each parts are described in brief below:

3.3.1 Resistors and Capacitors

Resistors and the capacitors are the very basic components of any electrical circuit. Resistors and capacitors of different values were used in constructing the prototype of the bat detector.

3.3.2 Transducer

Transducer is a device that converts one form of energy to the other form of energy. Ultrasonic transducers were used so as to convert the sound energy to electrical energy. Ultrasonic transducer receives the ultrasonic sound and hence convert it to the electrical energy. MCUST10P40B07RO was used as a transmitter whereas MCUSR10P40B07RO as a receiver.



Fig. 10 Transducer

Fig. 10 shows ultrasonic transducers.

3.3.3 Amplifier

Amplifier is a device that amplifies power of a signal in an electrical circuit. LM386N was used as an audio amplifier for this study. It is a low voltage power audio amplifier. It is commonly used as AM-FM radio amplifiers, portable tape player amplifiers, intercoms, TV sound systems, line drivers, small servo drivers, power converters and as ultrasonic driver. [16]

3.3.4 555 Timer

555 timer generates a time delay or oscillation. The time delay can be from microseconds through hours. The duty cycle is adjustable. The main applications of this component include precision timing, pulse and time delay generation, pulse position modulation and it is also used as a linear ramp generator. [16]

LM555 timer was connected to 2N2222 and then, to the ultrasonic transducer, for the generation of ultrasonic wave.

3.3.5 2N2222 Transistor

2N2222 is a low power bipolar transistor. It is used for low power amplifying or switching applications. [18]

3.3.6 Other Components

Other components included a beeper to produce sound whenever the ultrasonic wave was received, a breadboard where all the connections of the components were done and a battery to power the system.

4 Tests and Results

The schematics shown in fig. 8 was carried out first. It was the transmitter circuit which would produce the ultrasonic wave.

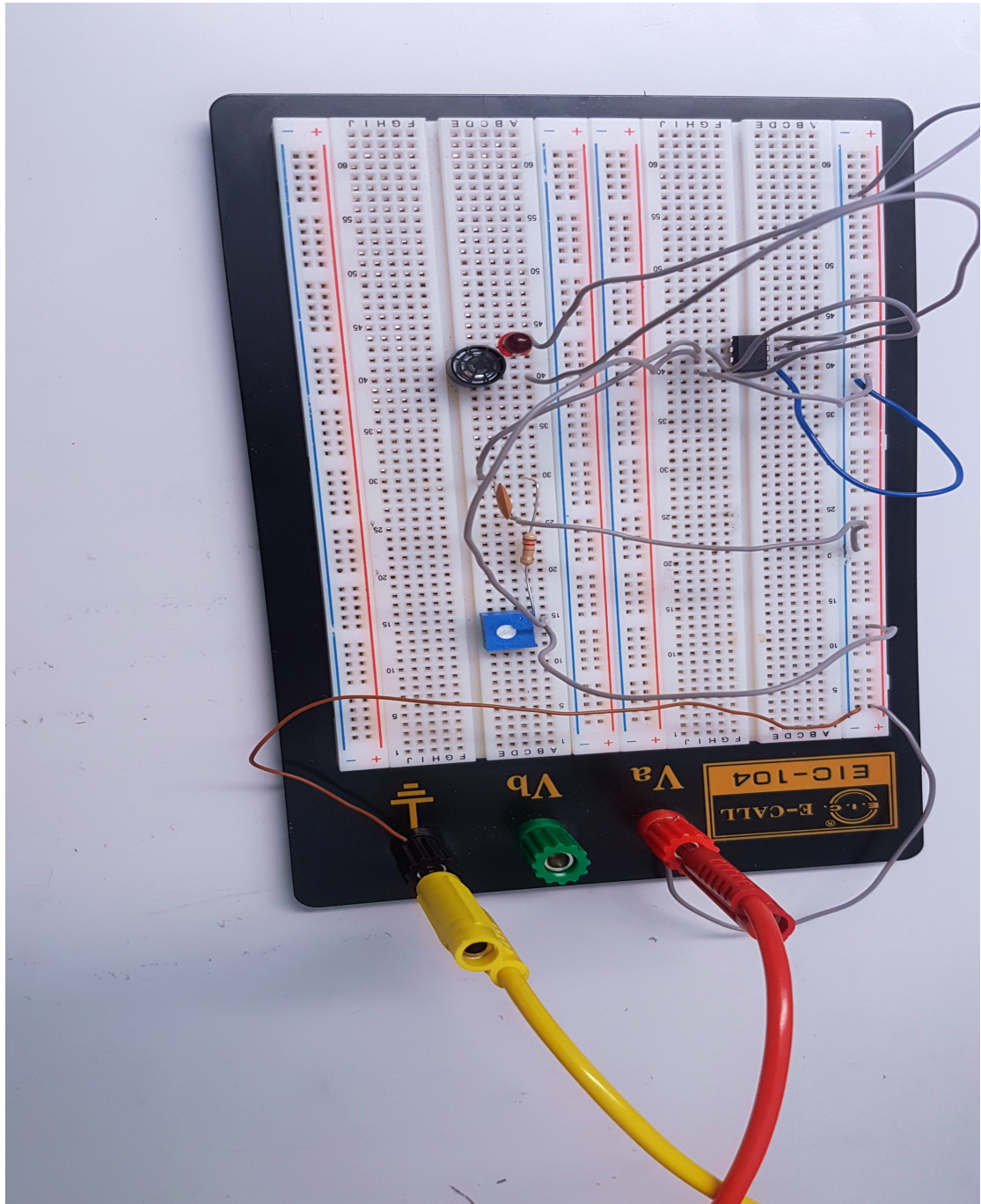


Fig. 11 The Transmitter

Fig. 11 shows the schematic in fig. 8 carried out in a board. The circuit was improvised and simplified. The resistor R4 and transistor from fig. 8 was removed. The circuit would still produce ultrasonic wave. A 200 kilo ohm trimmer was added to adjust the frequency of the ultrasonic transducer and an LED was attached to it just to check if the circuit was working.

The circuit worked at 12V dc supply. For some tests, oscilloscope was used to check different parameters. Later, a multi-meter was used across the ultrasonic sensor to check the voltage drop. There was sharp rise in the voltage and the voltage fell down repeatedly which was due to the fact that timer 555 was used. The timer sent ultrasonic pulse in regular interval.

The circuit did not work in the beginning as wrong pins were connected to the ultrasonic transmitter. Once the pins were corrected, the circuit started working.

Since the transmitter circuit started working, the receiver circuit was constructed in the breadboard. The fig. 12 is the ultrasonic receiver constructed with the help of the schematic in fig. 9.

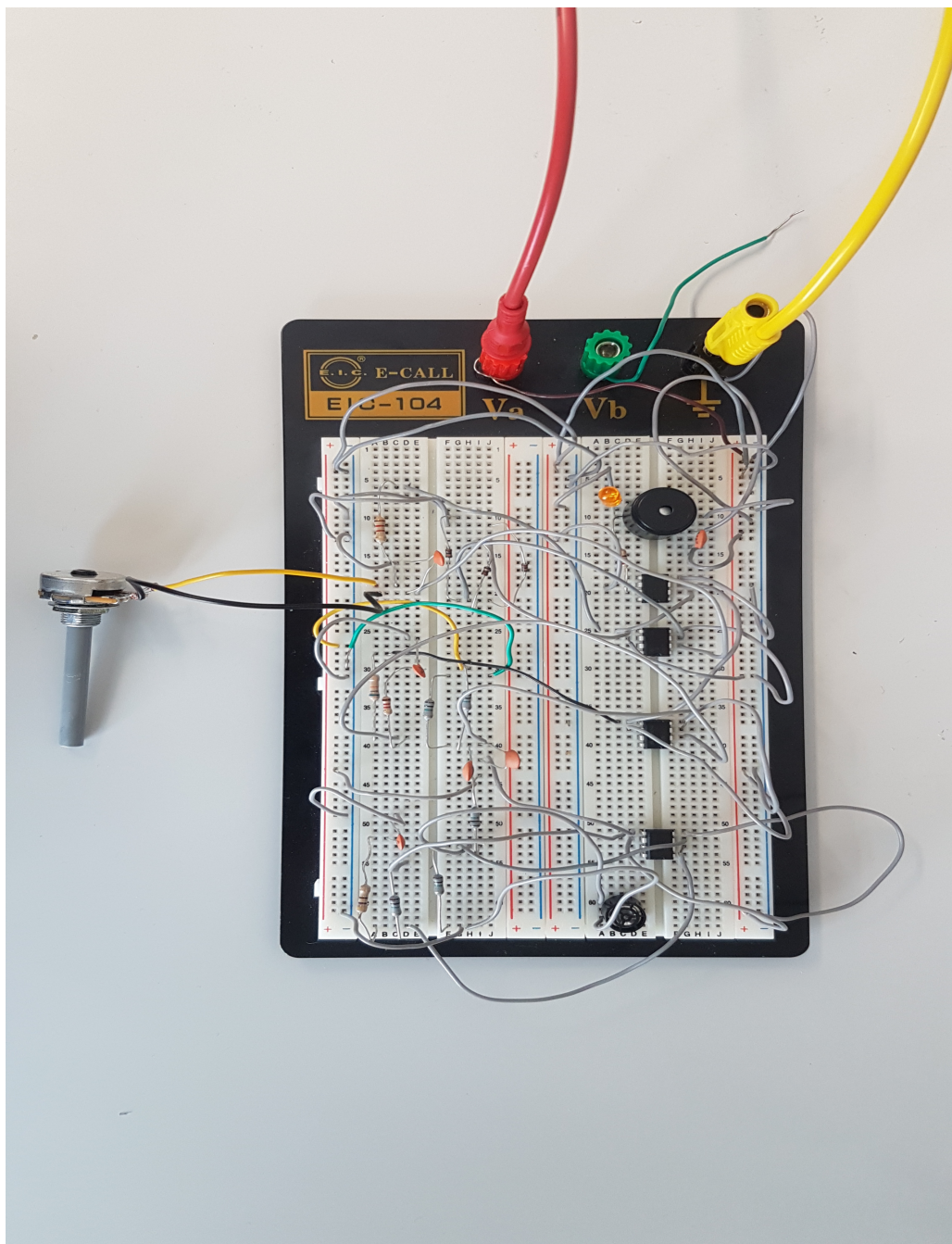


Fig. 12 The Receiver

Fig. 12 shows the receiver circuit where audio amplifiers were connected to different resistors and capacitors to finally make the circuit detect ultrasonic sound.

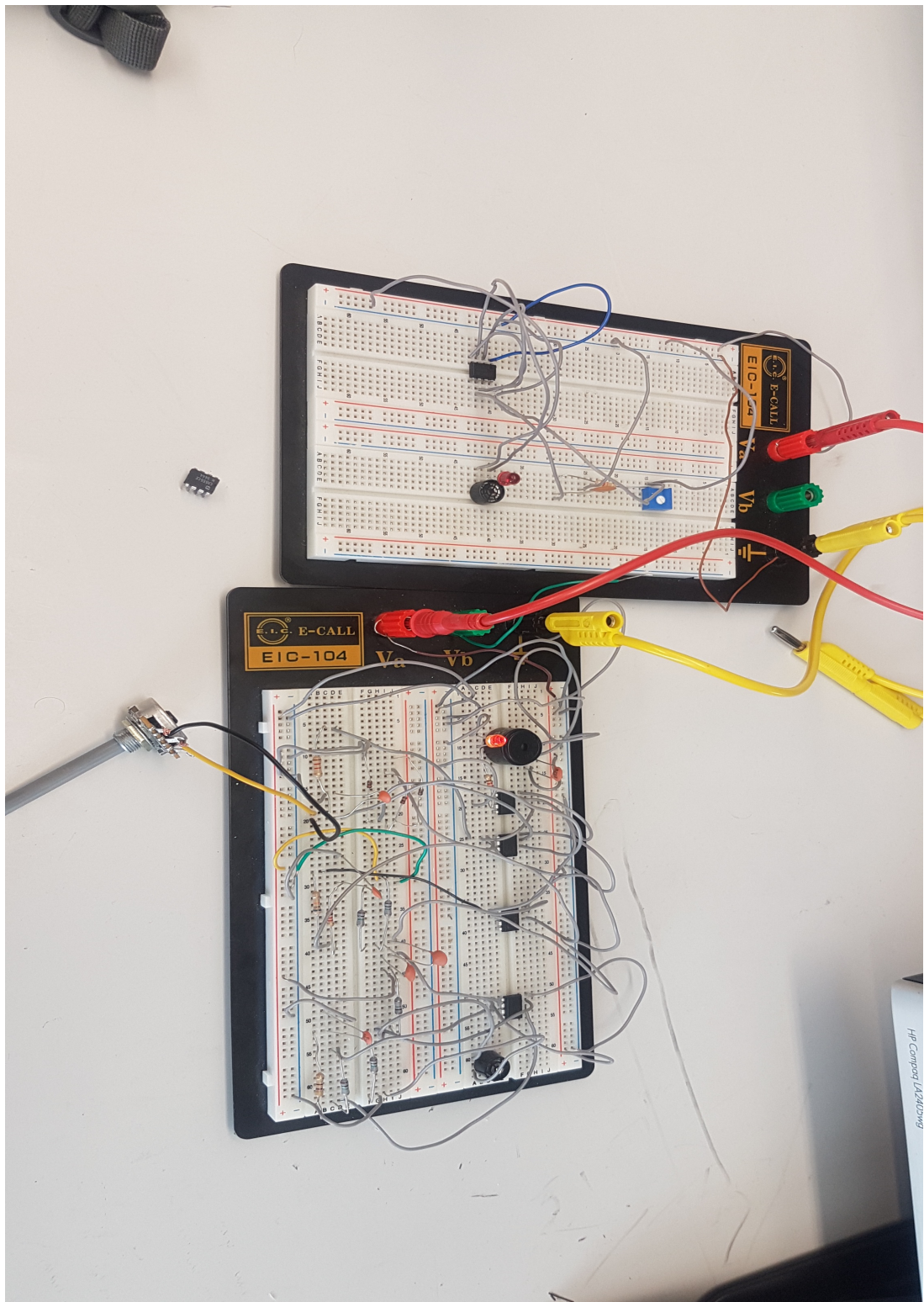


Fig. 13 A working ultrasonic transmitter-receiver

In fig. 13, both the transmitter and the receiver was tested. The transmitter produced the ultrasonic wave and the receiver received the ultrasound wave. The potentiometer helped tuning the frequency of the receiver to match the transmitter. Once the ultrasonic wave was detected the buzzer started producing sound.

5 Conclusion

The primary goal of this study was to build a detector based on ultrasonic sound that could detect bats. The prototype of bat detector was a success which could detect the incoming ultrasonic frequency but there were some problems with the transmitter which would work sometimes and stopped working. The problem might be on the circuit board or some connections were loose. However, primary goal of the study was fulfilled. The ultrasonic sensor detected the ultrasonic wave and the result was provided by the buzzer by making sound. The availability of all the sensors and other basic components made the bat detector easy to construct.

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