Construction and Empirical Study of Electronic Piezzo Buzzer Mosquito Repellent

Ikeri, H. I., Onyia, A. I., Chima A.I., Nwobodo A.N

Department of Industrial Physics, Enugu State University of Science and Technology
Corresponding Author: ifeanyihenry75@yahoo.com

Abstract: A successful construction and study of a 20 – 70 kHz Electronic Mosquito Repellent is here presented. The device has three compartments: a power unit which ensures a constant 5 V DC supply to the system, the oscillator which generates the ultra-frequencies that drive the buzzer and the piezo buzzer that converts the ultra-frequencies to ultrasounds. The ultrasonic device sweeps sound waves in the range of 20 – 70 kHz which are well above the upper human audible limit but nonetheless produces enough stress on the nervous system of mosquitoes to repel them. Experiments were carried out to obtain counts of mosquito bites on exposed observers with the repellants active as well as with the repellant inactive. The results showed that mosquitoes were repelled significantly by ultrasonic emission in the ranges of 40 – 55 kHz frequencies, the higher the intensity of the ultrasounds, the greater the repelling effect on mosquitoes. However, safety considerations limited our device to 60 – 70 dB. The device is cheap, reliable, non-toxic and can provide a better alternative to most of the traditional repellents. The device is also tunable to the optimum hearing frequencies for mosquito and other insects.

Index Terms: ultrasonic device, mosquito repellent, frequency ranges, sound waves and ultrasound.

1 INTRODUCTION

Growing concerns over diseases transmitted by mosquitoes as well as the negative health impacts associated with traditional mosquito repellents have led to researches for alternative repellents that is environmentally clean as well as cheap and efficient. Mosquito is a major transmitter of several diseases all over the world. Malaria is one major disease caused by mosquito, as a vector, which kills millions of people every year [1]. It is caused by a parasite called plasmodium which is transmitted by female anopheles mosquitoes [2]. These mosquitoes contact the parasite from infected people when they bite to collect blood needed for development of their eggs. When infected mosquitoes bite, they inject the tainted blood on their victims to thus effectively complete the transmission. [3] These mosquitoes usually bite during the night and the symptoms include fever, anemia, and in some cases coma and death [4]. Zika virus which causes several birth defects among children are transmitted by aggressive daytime biting mosquitoes [5]. Dengue diseases characterized by fever, painful headache, eye, joint and muscle pain among other ailments are transmitted also by mosquitoes [6]. The female mosquitoes are actually the ones that bite. They do so only after mating with the male in order to get the blood needed for maturation of their eggs [7].

Mosquitoes have sensory structures to transmit and receive ultrasounds [8] Male mosquitoes transmit ultrasound to attract the females. Females on the other hand have sensory structures to receive ultrasound [9] The ultrasound however produces stress on the nervous system of female mosquitoes once they are inseminated and hence causes them to quickly leave the source of ultrasound [10]. The best method hitherto of minimizing mosquito bites and hence mosquito borne diseases is by preventing the mosquito body contact using repellent solutions, and hence repellents have become practical tools for preventing the transmission of mosquito borne diseases [11] Various traditional repellents like coils, chemicals and creams have been used but they are known to have some serious disadvantages. Mosquito repellent creams cause allergic skin reactions [12] burning coils generate toxic fumes that cause breathing problems and chemical repellents are poisonous and cause air pollution which is an important risk factor for respiratory diseases [13]. In search of optimum solution devoid of severe side effects, scientists and engineers have sought ultrasonic repellents using various techniques [14] Here we present one such repellant which is a constructed piezzo buzzer-assisted device that is based on a 555 timer integrated circuit design that is stable, tunable, cheap, efficient and non-toxic. This device generates sound wave with frequencies well above 20 kHz human audible limit but which are yet adversely perceived by mosquitoes in a manner well explained by [15]. Only sound wave in the range of 20Hz to 20KHz lie in the audible range of normal humans [16]. For device such as ours that transmit ultrasound, care was taken not to exceed human safe intensity limit of about 60 – 70 dB.

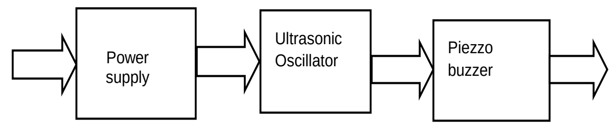
2 MATERIALS AND METHODS

We designed a 555 timer integrated circuit based astable multivibrator that generates ultra-frequencies in the ranges of 20 – 70 kHz. A piezo buzzer was used to convert these high frequencies into ultrasounds similar to that produced by male mosquitoes. We have used these ultrasounds to repel the female mosquitoes which actually are the ones that bite, based on the concept that non breeding female mosquitoes avoid the ultrasonic sound of the males, hence whatever mimics the male flight sounds will repel the females. The system design was in two sections: the software and hardware sections. A computer design software known as Proteus8 Professional was used to simulate the design prior to the hardware implementation on an experimental bread board. The hardware section comprised the power supply, ultrasonic oscillator and buzzer units as shown in the block diagram below (Fig. 3.1)

Figure 3.1: Block diagram of ultrasonic device.

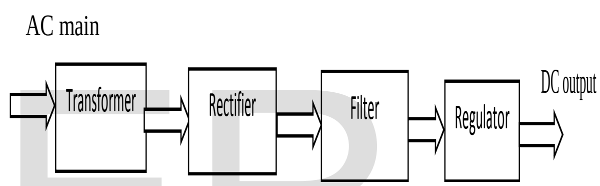
2.1 Design Analysis

There was a power supply unit the purpose of which



The power supply converts the AC mains to a desirable DC voltage, the oscillator converts this DC voltage into ultra-frequencies, and then the buzzer is used to convert these high frequencies into ultrasounds.

was to convert the high AC voltage into suitable DC voltage supply for electronic circuits. The power supply could be partitioned into series of blocks, as shown in the Fig. 3.2.



First, the transformer stepped down the high voltage AC mains to a low voltage AC, thereafter a rectifier circuit was then used to convert the low AC to pulsating DC voltage. This pulsating DC however contained a DC value and an AC ripple voltage. A filter circuit was appropriately used to smoothen such ripple and a regulator unit was applied to maintain a constant DC output voltage.

Figure 3.2: Block diagram of power supply.

2.1.1. Transformer

The choice of the transformer required for this design is gotten from the following calculations:

$$V_{dc} = \frac{2V_m}{\pi} \quad 1$$

Where, V_{dc} is the DC voltage after rectification and V_m is the maximum voltage at the transformer secondary. We required a 12 DC at the rectifier output, therefore equation 1 becomes:

$$12 = \frac{2\mathrm{V}_{\max}}{\pi} \quad 2$$

$$V_{max} = \frac{12\pi}{2} = 18.8V \quad 3$$

$$V_{rms} = \frac{V_{\max}}{\sqrt{2}} = \frac{18.8}{\sqrt{2}} = 13.2V \quad 4$$

A 220V /12V single phase step down transformer was chosen, since this was closest to the calculated value.

2.1.2 Filter Circuit Design

We used capacitor filter for this purpose. The reactance offered by the capacitor Xc is given by

$$X_c = \frac{1}{2\pi fc} \quad 5$$

where f was frequency and C was capacitance. For DC voltages, the frequency f was 0. Therefore,

$$X_c = \frac{1}{2\pi \times 0 \times c} = \infty$$

This means that the capacitor offered an infinite resistance to DC and hence when connected in parallel to the rectifier output would bypass the ripples but block the DC voltage entirely. The capacitance value required for the filtration was calculated as follows:

The charge Q removed from the capacitor during the discharge cycles is

$$Q = I_L T \quad 7$$

where I_L was the load current and T was the period of the AC voltage. The charge removed from the capacitor was expressed as:

$$Q = V_r C \quad 8$$

where V_r was the peak-to-peak ripple voltage and C was the capacitance. Equating equations 7 and 8, we get:

$$C = \frac{I_L T}{V_r} = \frac{I_L}{FV_r} \quad 9$$

Where $T = \frac{1}{F}$

For full-wave, the ripple frequency was twice the AC supply frequency, therefore,

$$C = \frac{I_L}{2FV_r} \quad 10$$

Where V_r = 1.0V, F = 50Hz, I_L = 0.25 A

Therefore, $C = \frac{0.25}{2} \times 50 \times 1.0 = 2500\mu F$ 11

Since $2500\mu F$ is not a standard value, then $22000\mu F$ was used. The voltage rating of the capacitor is usually twice the incoming dc supply. We therefore used $25V$, $2500\mu F$ capacitor for the filtering.

2.1.3. Rectifier Circuit Design:

A full-wave rectifier was used for this design. The peak inverse voltage P_{IV} of the diode to be used would be at least equal to:

$$P_{IV} = V_{max} - V_D \quad 12$$

where V_D was the voltage drop across the bridge rectifier diode, since silicon diodes were used for the bridge rectifier. The forward voltage drop was 1.4V, therefore, $P_{IV} = 18.8 - 1.4 = 17.4\ V$ 13

A full bridge rectifier 54001 was used because it had P_{IV} of $50V$ which was greater than the calculated value of 17. 4V, thus making it suitable for this design.

2.1.4 Regulator Unit:

A 5V DC stabilized power supply was required to drive the oscillator. We used a $5V$ Zener diode, the maximum power rating Pz_{max} of Zener diode according to the manufacturer data sheet was 2W. The maximum current flowing through the Zener diode, Iz_{max} is given as:

$$Iz_{max} = \frac{P_{z_{max}}}{V_z} \quad 14$$

Where V_z is the Zener voltage. Therefore,

$$Iz_{max} = \frac{2}{5} = 400mA \quad 15$$

The minimum value of the limiting resistor, R_s usually connected in series to the Zener diode is given as:

$$R_s = \frac{V_s - V_z}{Iz_{max}} \quad 16$$

$$R_s = \frac{12 - 5}{400mA} = 17.5\Omega$$

2.1.5 Indicator Unit:

A light emitting diode LED was used as an indicator to signify if there was power in the circuit. A limiting resistor R was connected in series to the LED to limit

IJSER

the amount of current entering it and was given as:

$$R = \frac{V - V_D}{I} \tag{17}$$

where V is the voltage supply, V_D is the operating voltage of LED and I is the allowable current through the LED. According to manufacturer data sheet, $V_D = 2V$ and $I = 30mA$, therefore:

$$R = \frac{5-2}{30 \times 10^{-3}} = 100\Omega$$

2.1.6 Oscillator Unit:

We used 555 timer IC astable multi-vibrator to generate the high frequencies required to drive piezo buzzer. According to 555 timer astable multi-vibrator theory, the time t_1 for which the output was high was:

$$t_1 = 0.693\,(R_1 + R_2)C_1 \tag{18}$$

and the t_2 for which the output was low was:

$$t_2 = 0.693\,R_2C_1 \tag{19}$$

The total period of oscillation T was:

$$T = t_1 + t_2 = 0.693(R_1 + 2R_2)C_1 \tag{20}$$

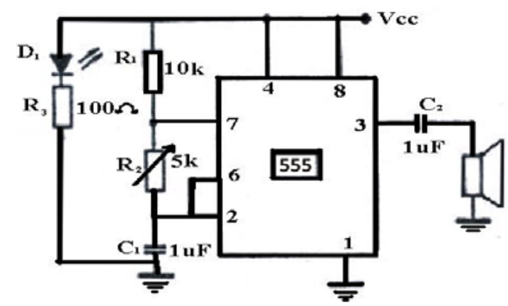
$$F = \frac{I}{T} = \frac{1.4}{(R_1 + 2R_2)c_1} \tag{21}$$

This frequency was set to the maximum value of 70 kHz required for this design. However, we could not use one equation to solve for three unknowns, so we chose $R_1 = 10k\Omega$ and $C_1 = 1\mu F$ and then we solved for R_2 using equation 21to obtain $R_2 = 5k\Omega$

A variable resistor has been chosen for R_2 so that the output frequencies could be fine-tuned between the ranges of 20 kHz to 70 kHz.

2.2. Circuit Description

This is a simple ultrasonic circuit based on astable multi-vibrator, specifically designed to sweep sound waves in the range of 20 kHz – 70 kHz frequencies.



In 555 timer based astable multi-vibrator, when the power supply is switched ON, the capacitor starts charging through the resistor R_1 and R_2, when the capacitor voltage exceeds $\frac{2}{3}V_{CC}$ it causes a change in the output. The duration of time for which the output is high is $t_1 = 0.693\left(R_1 + R_2\right)C$ *.Then the capacitor start discharging through the resistor R_2, when the capacitor voltage is less than $\frac{1}{3}V_{CC}$ it switches back to original state. The duration of the time t_2 for which the output is low is* $t_2 = 0.693R_2C$ *. This process continuously switches back and forth at a rate depending on the RC network of the circuit. The piezo buzzer converts the high frequencies* into ultrasounds that can be tuned between the ranges of 20 – 70 kHz simply by adjusting the variable resistor R_2.

Figure 3.3: Circuit Diagram of Electronic Mosquito Repellent

3 TESTS CONDUCTED

3.1 System Testing

After designing the system and making necessary calculations, it was simulated in a software environment of Proteus8 Professional to ensure it was working properly and also to ascertain if there was need to modify the design. Thereafter, the system was assembled in an experiment breadboard where testing of all components were carried out at various stages to ensure they are all in good working condition. The component which did not conform to the required output specifications were isolated and troubleshooted.

3.2 Repellency Testing

To ascertain the validity of repellency of ultrasonic emission on mosquitoes, a 3- night experiment for various device frequencies were conducted within a 4-room apartment, as shown in table 1, where four observers, similarly exposed for mosquito bites, obtained the bite counts each night (18.00 – 06.00 hrs). This enabled the comparison of mosquito bites in the rooms with ultrasound emission and that of rooms without emission. Another experiment was

IJSER

conducted within a highly populated mosquito environment to ascertain the repellency of ultrasonic emission in the ranges of 40 – 55 kHz on mosquitoes. The device was activated for a period of 30min and the number of mosquitoes that landed on a 4 m^2 exposed surface was obtained. The device was then turned off and the number of landing on the surface for same amount of time was also obtained. The experiment was repeated for three periods as shown in the table 2

4. RESULTS AND DISCUSSION

The simulation result carried out with the Proteus8 Professional showed that the circuit is functioning well. The frequencies generated from the simulation were approximately the same with the calculated result. A constant 5V DC supply was also verified on the multi-meter and the circuit was started. The output frequencies as observed in the oscilloscope varied from 20 kHz to 70 kHz as we tuned the circuit, which conformed to the design specification.

Table 1: The average mosquito bite for varying ranges of ultra sounds

Freq. Ranges (kHz)	**Average Mosquito Bite in the 1st Night**		**Average Mosquito Bite in the 2nd Night**		**Average Mosquito Bite in the 3rd Night**	
	Rooms With Ultrasonic Emission	*Rooms Without Ultrasonic Emission*	*Rooms With Ultrasonic Emission*	*Rooms Without Ultrasonic Emission*	*Rooms With Ultrasonic Emission*	*Rooms Without Ultrasonic Emission*
25 - 40	73	81	67	89	53	72
40 - 55	25	69	21	75	19	66
55 - 70	68	82	53	66	51	75

Repellency result showed that ultrasonic emission below 40 kHz and above 55 kHz had low repelling effects on mosquitoes. However, at frequencies in the ranges of 40 – 55 kHz. It was observed that the number of mosquito bites on the human participants in the rooms with ultrasonic emission was significantly low compared to those without emission.

Table 2: Average mosquito landing on the surface

Periods (30 minutes)	Number of mosquito landing during no emission	Number of mosquito landing during emission
Period 1	156	67
Period 2	93	32
Period 3	81	25

The results also indicated a significant landing rate of mosquitoes during period the device was off. Again, the repellency of ultrasounds was tested on rats which were confined in a cage to constrain their movement and to make observation easier. We activated the device and observed the reaction of each rodent simultaneously. There was a low response during the periods the device was below 55 kHz. As soon as the device was tuned above 60 kHz, there was an abrupt response; the rats abandoned their foods, stampeding each other in attempt to jump out of the cage.

5 CONCLUSION

An ultrasonic mosquito repellent has been constructed and its repellency on mosquitoes studied. The device consisted of three compartments; power which ensures a constant 5V DC supply to the system, the oscillator which generates the ultra-frequencies that drive the buzzer and the piezo buzzer that converts the ultra-frequencies to ultrasounds. The ultrasonic device sweeps sound waves in the range of 20 – 70 kHz, well above the upper audible limit of human but produces stress on the nervous system of mosquitoes. The experimental results showed that mosquitoes were repelled by ultrasonic emission in the range of 40 – 55 kHz frequencies. Results also showed that rats were repelled by ultrasounds in the ranges of 60 – 70 kHz. It was found that the higher the intensity of the ultrasounds, the greater the repelling effect on mosquitoes over a wider radius. The device is cheap, reliable and non-toxic and provides a better solution to most of the problems faced by the traditional repellents. The device is tunable to the appropriate hearing frequencies for other insects

IJSER

ISSN 2229-5518

References

[1] W.H.O. 2005. "Global Partnership to Roll Back Malaria World Malaria Report", Geneva: *World Health Organization*; 2005.

[2] R. Snow "The Global Distributor of Chemical Episodes of Plasmodium" *Falciparum Malaria. Nature* 434:314-217; 2005.

[3] C. Curtis, "Insecticide – Treated Bed-Nets for Malaria", *Mosquito Control Association* 22(3), 501 – 506 2006

[4] W. Guelbeogo "Seasonal Distribution of Anopheles Funestus Chromosomal Form Burkina Faso", *Malaria Journal*, 8: 239; 2009.

[5] A. Bomblis, "A Mechanical Approach for Accurate Simulation of Village Scale Malaria Transmission, *Malaria Journal*, 8: 223. 2009.

[6] S. Clement, "The Analysis of Mortality and Survival Rates in Wild Populations of Mosquitoes", *Journal of Applied Ecology* 20(2), 331 – 350, 2010.

[7] I. Cabrini "Evaluation of an electronic Mosquito Repelling Devices" *Neotropical Entomology*. 30(3) : 437 – 470, 2001.

[8] A.. Clement "The biology of mosquitoes sensory reception and behavior", Vol. 2. p. 73 – 78, 1999.

[9]. P. "Belton Sound of Insects in Flight" *Insects Flight Dispersal and Migration* p. 60 – 70, Springer Verlag, Berlin. 1986.

[10] R.D. Singleton, "Evaluation of Two Mosquito Repelling Devices" *Mosq. News* 37: 195 – 199; 1977.

[11] E. Anyanwu "Health Effects of Long Term Exposure to Insecticides-Treated Mosquito Nets", *The Science World Journal* 6, 1631 – 1641, 2006.

[12] L. Okell "Reduction of Transmission from Malaria Patients by Artemisisnin Combination Therapies", *Malaria Journal,* 7: 125; 2008.

[13] J. Gorham, "Test of Mosquito Repellents in Alaska. Mosquito News", 34: 409 – 415; 1974.

[14] D. J. Lewis, Evaluation of an Electronic Mosquitos Repeller Can", *Entomol.* 114: 699 – 702; 1982.

[15] F. Caro Review and History of Electronic Mosquito Repellers. *Wing Beats,* 11(2); p. 6 – 7, 2000.

[16] C. Shedreck, Evaluation of Electronic Sound Producing Devices. *Mosquito Noise* 37: 529 – 531; 1984.

IJSER