



Design and Implementation of an Ultrasonic Insects Repellent

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ABSTRACT

The ultrasonic insect repellent circuit was designed and implemented using ultrasonic frequency generators and other electronics components. The developed circuit generates high frequencies (that is ultrasound) which are capable of repelling insects in homes, offices, hostels, hospitals, etc. The repelling circuit operates at a frequency higher than Human audibility (>20KHz). It was established that insects react at different frequencies, hence the design was made to operate at the established insects repelling frequencies (29 KHz and 33-43 KHz). Thus, to ensure effective operation, the frequency of ultrasonic oscillator was continuously varied within the established limits in a step wise manner automatically in these design. This was achieved using the output clock pulse of IC1 NE555 (which was used as a Square wave low-frequency oscillator in the design), and the high logic output of IC2 CD4017 (a decade counter) alternates from Q0 to Q9. Ten resistors R3 to R13 (each connected at Q0 to Q9 output pins) were fixed for alternate values and connected to pin 7 of IC3 (NE555) electronically. IC3 is an astable multivibrator operating at a frequency of about 44 KHz. Its output is then used to drive high-frequency piezo tweeter which in turn produce the ultrasonic sound that repelled the insect.

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INTRODUCTION

Electronic insect repellent was considered as a safer and efficient alternative to toxic insect repellents [1]. Electronic insects' repellents are Electronic devices that uses electromagnetic or ultrasonic waves to repel insects such as Mosquitoes, flies, spider, fleas, cockroaches etc. [2]. Even though the effectiveness of these devices has not been clearly established, numerous experimental studies have shown that these electrical devices are indeed effective in repelling or eliminating insects [3]. Some electronic insect's repellents are used as both ultrasonic transmitters and the electromagnetic lamps concurrently [4]. These electronic insects control devices have been around for more than two decades and they are very affordable.

However, they are acknowledged worldwide recently due to their environmentally friendly Claims, less noticeable and less cumbersomeness [5]. The absence of stinking spray repellents is also a true blessing by itself. Several methods have been used and are still being used for the control of insects in nature. Many of these methods have been proven to be ineffective in one way or the other [6]. The most commonly used method for insects control is the use of insecticides (chemicals) [7]. Insecticides are substances or a mixture of substances used for destroying, preventing, repelling or mitigating insects. They are commonly used due to their ease of application, fast-acting, and effectiveness against wide variety of insect. However, there is no any report or documentation which specifically refers to the use of insecticide

against insect's control which doesn't have potential hazard to man and the eco-system in general [8].

Chemical method of insects control is very effective but quite expensive to maintain. Also, the chemicals used are highly poisonous and harsh to humans due to their air pollution capabilities. Air pollution is one of the main courses of Respiratory diseases, particularly for bronchial asthma and chronic obstructive pulmonary disease (COPD) this makes chemical methods unsafe to be used in health care facilities [9].

Although the concentration and duration of exposure to air pollutants required for inducing an adverse pulmonary effect have not yet been determined. Moreover, it diversely affects the insects through genetic mutation of the internal make up of these insects. They produce offspring that are immune to these chemicals which were used on their predecessors [10]. This makes

chemical control methods ineffective hence, the need to explore other alternative control measures that are effective and secure such as electronic repellents (which uses Electromagnetic waves to repel insects).

MATERIALS AND METHODS

In this section, the details of the design, hardware and software materials used in the implementation are summarized.

Circuit Design

The design of the electronic insect repellent was carried out based on the available electronics component. The circuit design is segmented into five units, i.e. power supply unit, pulse generating unit, decade counter and voltage regulatory units, oscillator unit and output unit. A block diagram showing the various units and their relation to one another is given in Fig 1.

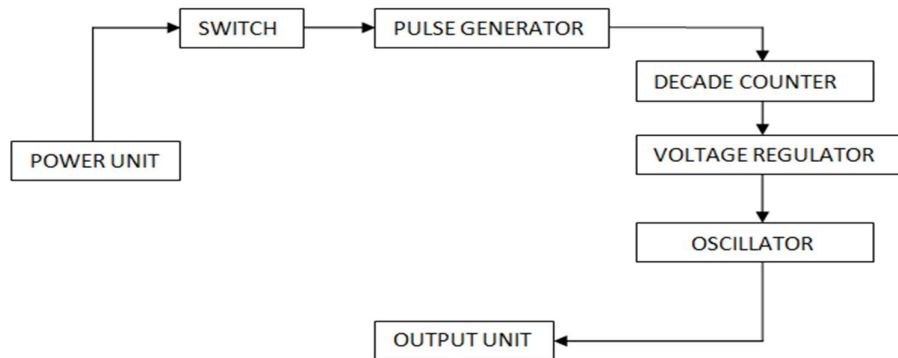


Figure 1: A Block Diagram of the Developed Electronic Insect Repellent.

Power Supply Unit

This unit is made up of the following Sections:

The Voltage Transformation Section: in this section, a 240V AC is stepped down to 12V AC by the used of transformer. The resultant output is given by equation (1)

$$V_{peak} = \sqrt{2} \times V_{rms}$$

(1)

Where $V_{rms} = 12V$

Hence $V_{peak} = \sqrt{2} \times 12$

$$V_{peak} = 16.97V$$

The Rectification Section: in this section, a IN4001 diodes were used to form a full wave bridge rectifier of 5A with a loading capacity of 2A, it is chosen for the capacity to a load up to 2A. The equation used is outline in equation (2)

$$V_{dc} = \frac{2}{\pi} \times V_{peak}$$

(2)

But $V_{peak} = 16.97V$

$$\text{Hence } V_{dc} = (2/\pi) \times 16.97$$

$$V_{dc} = 10.80V$$

Filter section: It is preferable to choose a filtering capacitor that will hold the peak-to-peak ripples at approximately 8% of the peak voltage. Therefore, using the values obtained, the value of the capacitor can be calculated as shown below.

$$I_{min} \approx I_{dc} = 300mA$$

$$\text{Where } V_{rms} = \sqrt{2} \times V_m$$

$$\text{Hence } V_m = 12v$$

$$V_{rms} = 16.9V$$

$$RF = 8\%$$

$$V_r = \frac{8}{100} \times 16.9 = 1.35v$$

$$C = \frac{I_{dc}}{4\sqrt{3} f V_r} = 111111 \mu f$$

$$C \approx 2200\mu f$$

Where; V_r = ruffle factor

I_{dc} = current taken by the load
 f = frequency of supply = 50Hz
 C = filtering capacitor

The Voltage Regulation section: A 9V voltage regulator (that is LM7809) is used in this section. LM7809 was chosen due to its 1A load current capacity and a heat sink which can prevent overheating. The percentage regulation is given in equation (3).

$$\% \text{ regulation} = [(V_{max} - V_{min})/V_{max}] \times 100 \quad (3)$$

Where; V_{max} = Max DC Output Voltage

V_{min} = Min DC Output Voltage

Alternatively,

$$\% \text{ regulation} = [(V_{no\ load} - V_{f_load})/V_{f_load}] \times 100$$

2. 1.2 Pulse Generating Unit

A pulse generator is needed to convert changes in resistance and capacitance to corresponding pulses. An astable multivibrator is used for pulse generation using 555 timer IC which is connected as shown in figure 2.

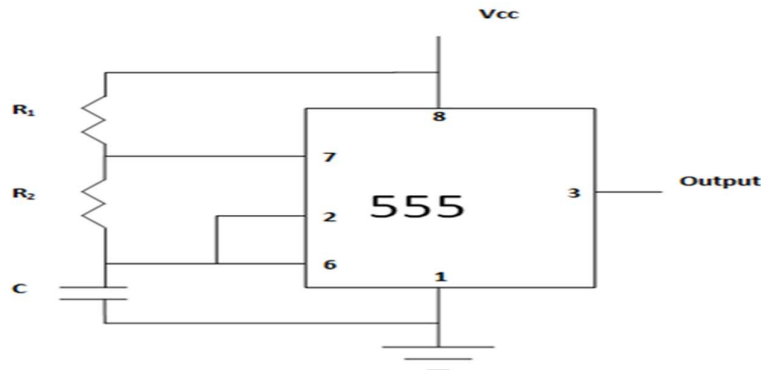


Figure 2: An Astable Multivibrator as a pulse generator

The free-running oscillating frequency F is given in equation (4)

$$F = \frac{1}{T} = 1.44 / (R_1 + 2R_2) C_1 \quad (4)$$

Selecting the values of R_1 , R_2 and C_1 to produce the frequency of 1.57Hz, resistance and capacitance range of R_1 , R_2 and C_1 are chosen as;

$$R_1 = R_2 = 470K\Omega$$

$$C_1 = 1\mu F$$

$$F = \frac{1}{T} = 1.44/1.41 = 1.02Hz$$

The Decade counter and Voltage Regulatory Unit.

The clock pulse is fed in as the input of the CD4017 decade counter, which yield 10 fully decade outputs of the same frequency but of specific time displacement, the introduction of the resistors forms the potentiometer (or potential divider), which varies the voltage output from the decade counter as shown in figure 3.

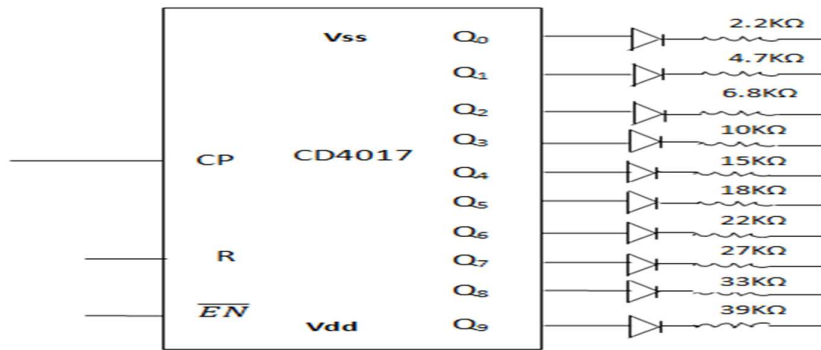


Figure 3: A Decade Counter and Voltage Regulating Unit

The oscillating unit

This is achieved by the used of 555 timer, which is basically a generator

of non-sinusoidal square waveforms its connection is shown in fig 4. Below.

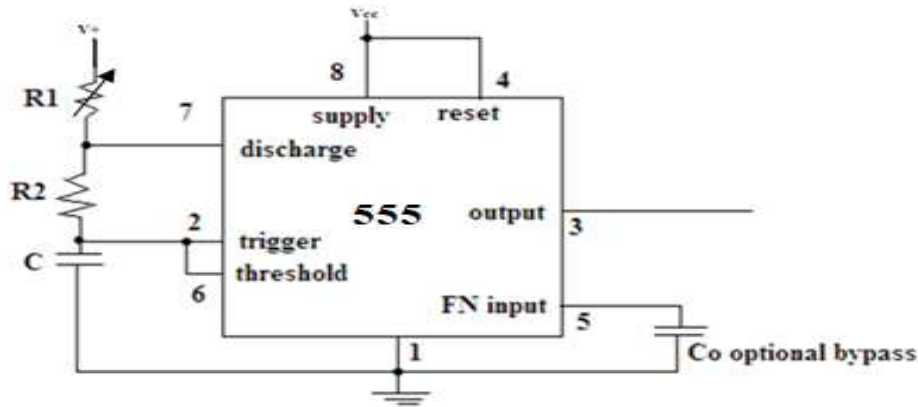


Figure 4: The Oscillating unit

The threshold and trigger inputs are connected to each other, in an astable mode. The timing capacitor C charges through $(R_1 + R_2)$ until $V(t)$ of the capacitor reaches, $\frac{2}{3}V_+$ where V_+ is the potential applied at the high output \bar{Q} of the flip flop. The discharging transistor then turn on and also the timing capacitor begin to discharges through "R₂". Its voltage kept on decreasing until it reaches $\frac{1}{3}V_+$. At this stage, the triggering comparator changes states and sends a low output Q which turn the discharge transistor off. The timing capacitor then begins to recharge until it reaches a

threshold level of $\frac{2}{3}V_+$. The cycle repeats itself. The analysis of the capacitor's voltage during the charging time of $0 < t < T_c$, is given by equation (5) to (7)

$$V(t) = V_+ + (V_i - V_+) e^{-t/\tau_c} \quad (5)$$

Where $\tau_c = (R_1 + R_2) C$ at time $t = T_c$, the voltage of the capacitor reaches the threshold level. The analysis below will be based on the assumption that V_+ is constant throughout the processes.

$$V(T_c) = \frac{2}{3}V_+ = \frac{1}{3}V_+ + \frac{2}{3}V_+ (1 - e^{-T_c/\tau_c}) \quad (6)$$

Solving the equation for timing capacitor during the time T_c yield

$$T_c = \tau_c \ln 2 = 0.693 (R_1 + R_2) C \quad (7)$$

During the discharging the time of $0 < t < T_d$, the timing capacitor capacitor's voltage given by equation (8) to (10)

$$V(t) = \frac{2}{3} V_+ e^{-t/\tau_d} \quad (8)$$

Where $\tau_d = R_2 C$ at time $t = T_d$, the time at which the capacitor voltage reaches the trigger level.

$$V(T_d) = \frac{1}{3} V_+ = \frac{2}{3} V_+ e^{-(T_d/\tau_d)} \quad (9)$$

Solving the equation for the timing capacitor discharge time yield

$$T_c = \tau_c \ln 2 = 0.693(R_2) C \quad (10)$$

The period T of the astable multivibrator's cycle is the summation of the period of charging T_c and discharging T_d . Hence the oscillator's frequency is given by equation (11).

$$F = \frac{1}{T} \quad (11)$$

The duty cycle as the ratio of the pulse width to the period, is given in equation (12).

$$\text{Duty cycle} = \frac{T_c}{T} * 100\% = \frac{R_1 + R_2}{R_1 + 2R_2} * 100\% \quad (12)$$

The duty cycle for the circuit is always greater than 50%.

Since, V_+ of the circuit is varying with respect to the output of the potential divider, the equation (6) and (8) which are for constant V_+ , are modified to suits the circuits varying nature in equation (13) and (14).

$$V(T_c) = \frac{2}{3} V_+ = \frac{1}{3} V_+ + \frac{2}{3} V_+ * (1 - e^{-(T_c/\tau_c)}) \quad (13)$$

$$V(T_d) = \frac{1}{3} V_+ = \frac{2}{3} V_+ * e^{-(T_d/\tau_d)} \quad (14)$$

Where T_c and T_d are given by equation (15) and (16)

$$T_c = \tau_c \ln \left[\left(\frac{2}{3} \right) - \left(\frac{V_+}{V_+} \right) \right] \quad (15)$$

$$T_d = \tau_d \ln \left[\left(\frac{3}{2} \right) - \left(\frac{V_+}{V_+} \right) \right] \quad (16)$$

Therefore, since V_+ is constantly being varied by the outputs of the potential divider the output frequency of the astable multivibrator will also vary within a certain range accordingly.

MATERIALS USED FOR THE IMPLEMENTATION OF THE DESIGNED CIRCUIT.

The hardware components used are: Resistors, Capacitors, IC NE555 Timer, decade Counter CD4017, Voltage regulator LM7809, and 240V/12V step down Transformer, Vero and Breadboard. The Software used for the design and simulation are: Circuit wizard and Multi Sim.

IMPLEMENTATION OF THE DESIGNED SYSTEM

The various units (that is, pulse generating, control, and oscillating unit) and the whole system are temporarily constructed on a breadboard. So as to test the workability and functionality of the components, the units and the system as a whole. The testing was carried out using a 9V D.C battery. It was found out that all the units and the system are operational as anticipated.

The Circuit was then implemented on a Vero-board permanently. During the layout process, spacing, wires (jumpers), shape, size and number of components used are all put in consideration. All the units (that is, the power supply, pulse generating, control, oscillating and output) were constructed on the same Vero-board. The ICs (NE555 Timers and CD4017) are fixed and soldered in position. Followed by the diodes, resistors, capacitors, wires (jumpers), switch and the piezo tweet. The output of the pulse generating unit is then connected to the counter, in which a special attention was given to the pin connections of the ICS (that is the NE555 Timer and CD4017). The power supply unit was connected to the pulse generating, decade counter and voltage regulator, and oscillating. The wires connecting switch were properly soldered. The circuitry was tested using a 220V AC supply and it was found to be operational. The whole circuitry is presented in figure 5.

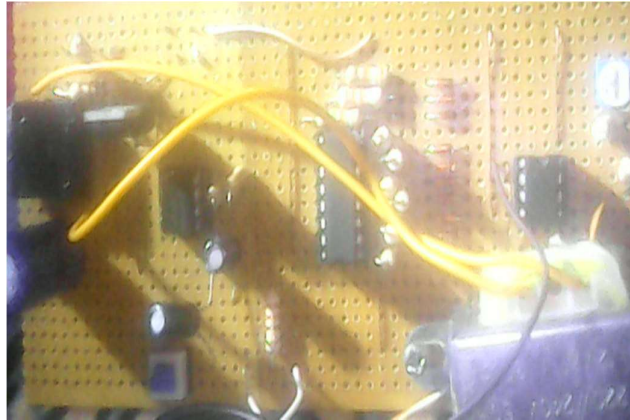


Figure 5: The Developed Electronic Insect Repellant Circuit

RESULTS AND DISCUSSION

Testing of the Designed Circuit and Components.

All the components used were tested to ensure workability before and after soldering to ensure that all contacts and connections were made properly. The tests used are divided into three namely; Software test, static and dynamic test.

Software Test

In this section the various designed units in section 2.1 (that is the

pulse generating, control, and oscillating) were simulated and tested so as to ensure workability and conformity with the designed requirements. The design was carried out in a circuit wizard software. The various units and the complete circuit simulation was carried out in multi sim. The simulation results and the design of the pulse generating unit is shown on figure 6. While that of the whole system is shown in figure 7.

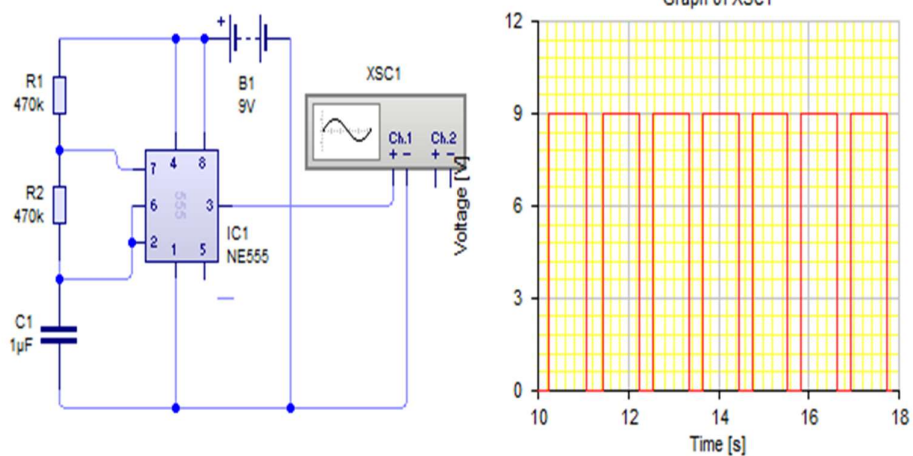


Figure 6: A simulation of the pulse generating unit and its output wave form.

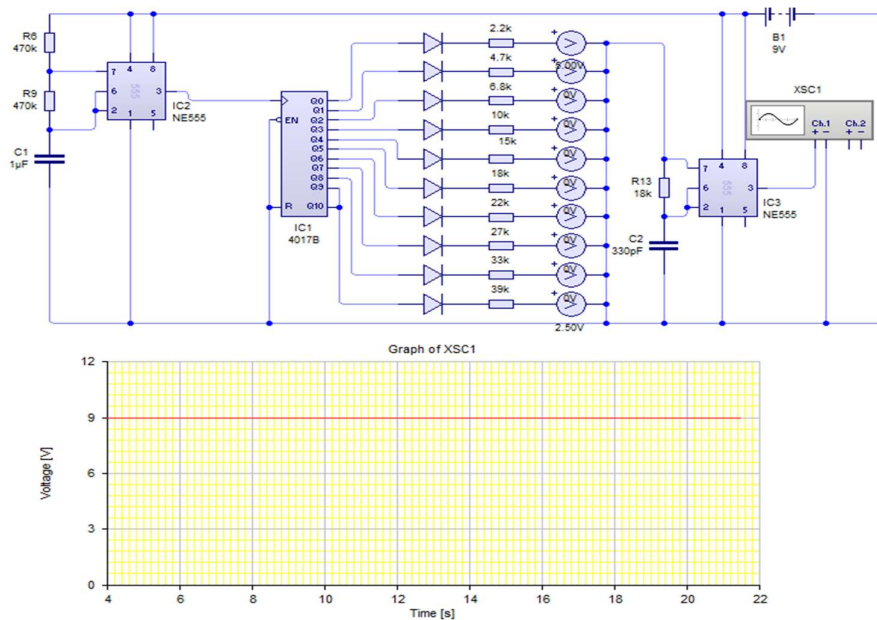


Figure 7: A Simulation of the Electronic Insect Repellent Circuit and it Output Wave Form

Static Test

Static test is a test that is carried out when the circuit is not powered. It involve the visual inspection of the circuitry to ensure all the connections and components were properly made. It was carried out by checking all the jumper wires and closed tracks, for short or open circuit. An ohmmeter was also used to test for resistance of the circuit. After obtaining a satisfactory performance, a dynamic test was then carried out.

Dynamic Test

In this test, the circuit was power for a transient time and then cut off. A finger is then used as a heat sensor to feel the temperature of all the components so as to ensure that components are not overheating. After obtaining a satisfactory performance the power switch was then turn on. A digital voltmeter was then used to carry out a voltage test, by measuring the voltage level at various considerate points on the circuitry, then used for comparison with the specifications.

Reliability Test

The test was carried out to ascertain the reliability of the developed ultrasonic insect repellent. The established stress failure rates of all the components used in the design of the device was considered. The process was carried out by listing all the components of the device and their failure rate from the standard tables of failure rate. The weighing factors due to temperature, environment, and operating stress were also considered. The overall failure rate estimation was then carryout using equation (17).

$$\lambda_{0i} = ni\lambda_i W_E W_T W_R (\%/10^3 \text{hr}) \quad (17)$$

where:

λ_{0i} denotes the *overall systems failure rate*.

ni is the number of components used in the system.

λ_i denotes the individual components failure rate.

W_E is the environmental weighing factor.

W_R is the operating stress weighing factor.

W_T is the temperature weighing factor

The system's reliability is calculated using the relation in equation (18)

$$R = e^{-\lambda t} \quad (18)$$

where; $\lambda = \sum \lambda_{0i}$ and t is the operation time of the device.

The number components used, their failure rates, weighing factors and the

overall device failure rate was given in Table 1.

The overall device failure rate was found to be 1.5315%/10³hr.

The one year operational reliability of the device is given as: (t = 24 x 365 =8760hr)

$$R = e^{-(0.01532 \times 10^{-3} \times 8760)} = e^{-(0.1342032)} = 0.874 = 87.4\%$$

Hence the device is 87.4% Reliable.

Table 1. Information of Components Failure Rates.

Component	Number used (ni)	Failure rate λ (%/10 ³ hr)	Weighing factor due to			Overall failure rate $\lambda_0 = ni\lambda_i W_E W_T W_R$ (%/10 ³ hr)
			Environ W_E	Tempt W_T	Rating W_R	
Integrated circuits (IC)	3	0.02	2.0	1.5	1.5	0.27
Resistors	13	0.01	2.0	1.5	1.5	0.585
Capacitors	2	0.001	2.0	1.5	1.5	0.009
Piezo tweet	1	0.001	2.0	1.5	1.5	0.0045
Diode	11	0.01	2.0	1.5	1.5	0.495
Soldered Joints	28	0.001	2.0	1.5	2.0	0.168
$\lambda = \sum \lambda_{0i} = 1.5315$						

The output of the 555timer IC in real life oscilloscope and the simulation oscilloscope are similar. Thus both produced square waves. The important of this result is to know the kind of wave fed into the counter section of the device and that obtained at the output of the

oscillating unit. Figure 8 shows the points at which the test was carried out. Also figure 9 shows the output wave form of the pulse generator while figure 10 (a & b) and figure 11(a, b, & c) shows that of the oscillator at different time interval.

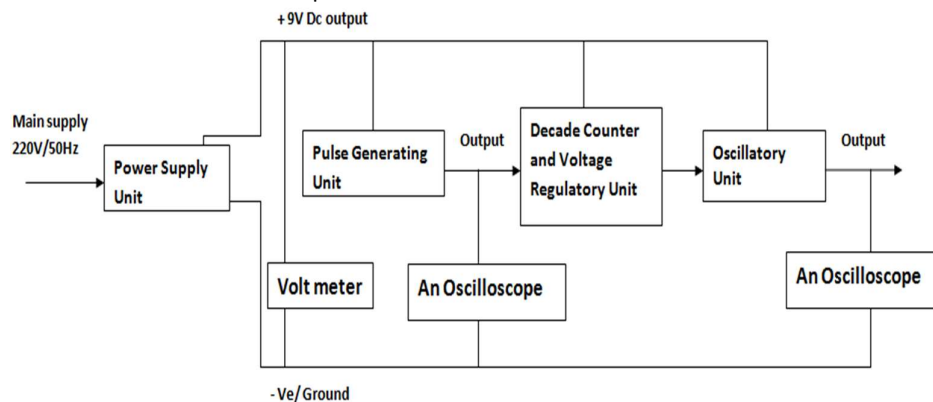


Figure 8: A Test Diagram

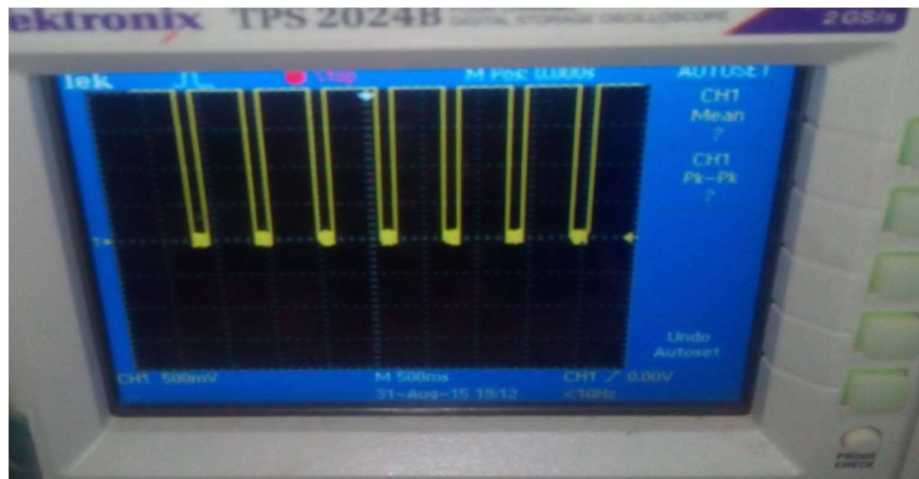


Figure 9: A Wave Form of the Pulse Generating Unit

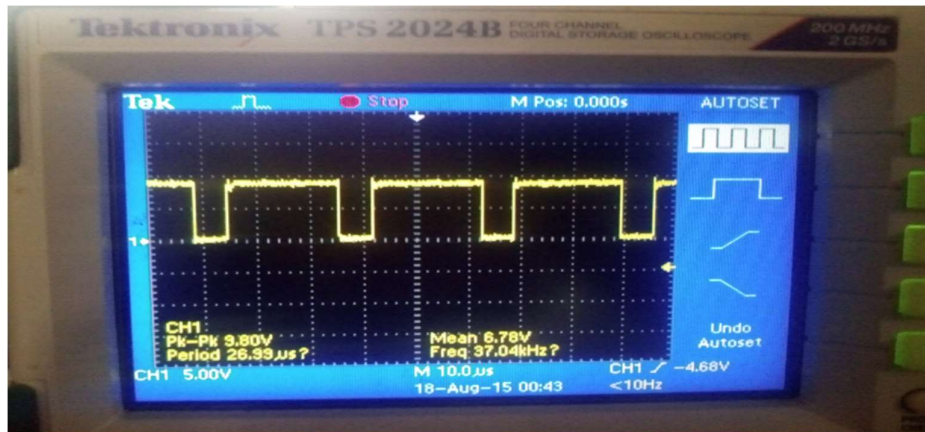


Figure 10(a): Wave Form and the Frequency Output of the Oscillating unit at 37.04KHz

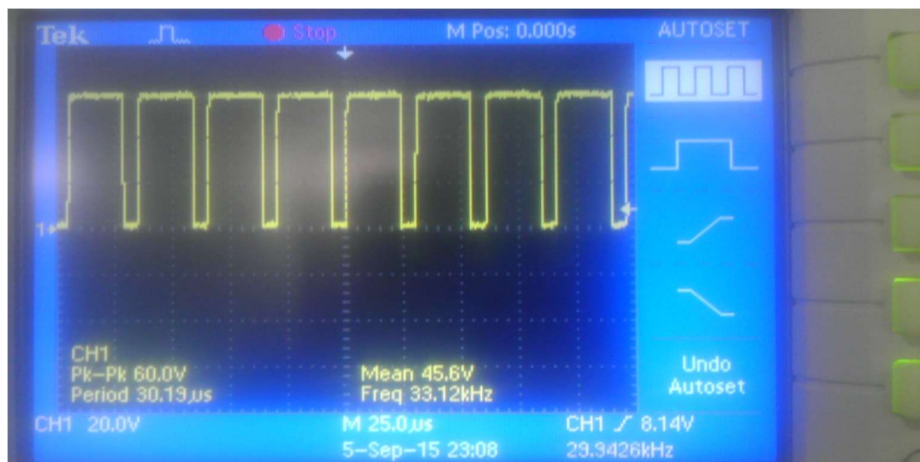


Figure 10(b): Wave Form and the Frequency Output of the Oscillating unit at 33.12KHz

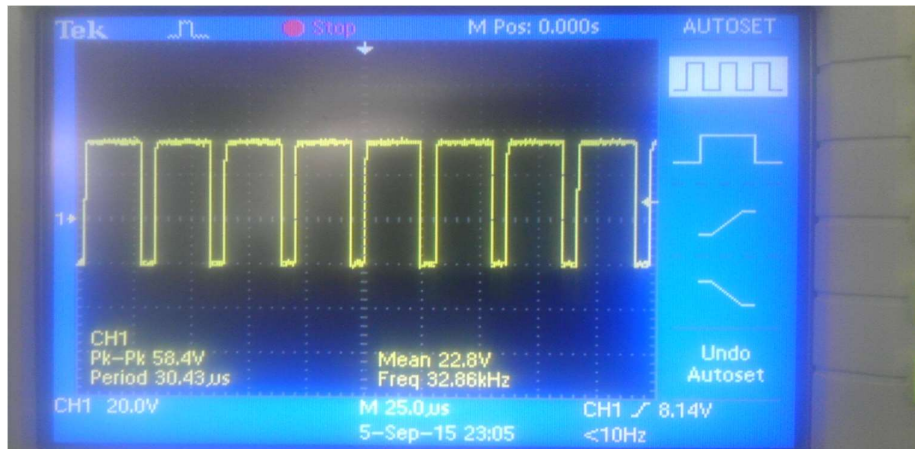


Figure 11(a): Wave Form and the Frequency Output of the Oscillating unit at 32.66KHz

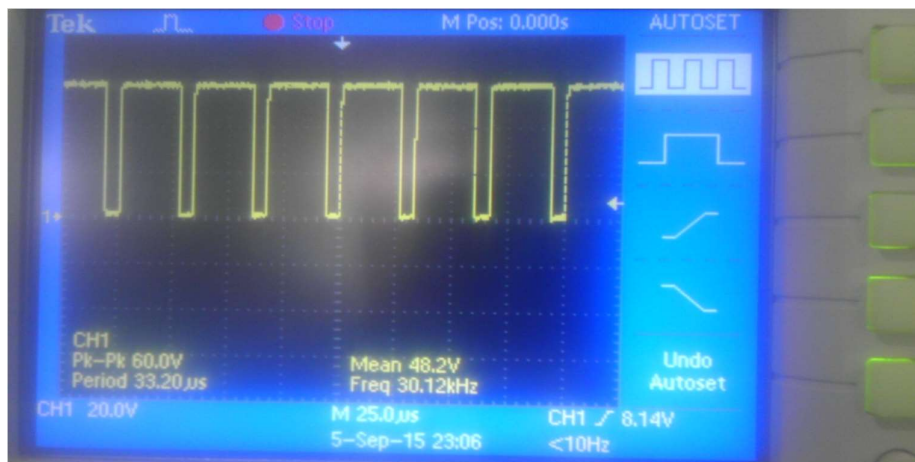


Figure 11(b): Wave Form and the Frequency Output of the Oscillating Unit at 30.12KHz

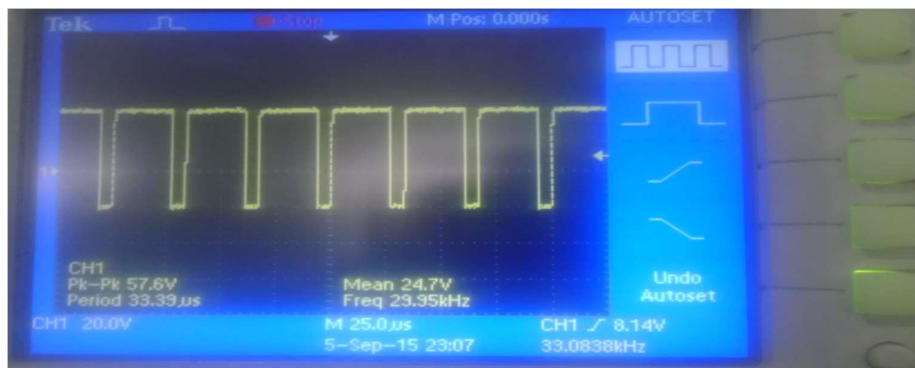


Figure 11(c): Wave Form and the Frequency Output of the Oscillating Unit at 29.45KHz



CONCLUSION

From the test carried out on the device and the test subjects using the device, the following results were obtained;

1. The devices developed is operating within the specified range of frequencies for insect repelling.
2. The result obtained from simulation and experimentation above, the wave forms obtained using oscilloscope in laboratory are both square wave.
3. When the device was place very close to the test subjects (flies and mosquitoes), the device repelled them up to a distance of 3meters.
4. Also, when the device was placed at about 4m (meters) away from the test subjects, the test subjects shows no any significant response.

The design, construction and testing of the system were satisfactory and successfully carried out. The system was found very effective and operates in accordance with the design specifications despite the little variations in the measured value. But when tested on the test subjects available (flies and mosquitoes) the test subject shows little or no response.

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