ULTRASOUND BOOSTER DESIGN AND IMPLEMENTATION FOR ELECTRONIC PEST CONTROL

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Abstract
In this work, an ultrasound booster was designed to increase the effective area of coverage of an existing stand-alone ultrasound pest control device designed to deter weaver bird away from farms. It is a five-segment device, each consisting of a preamplifier, power amplifier and an ultrasonic transducer section. It receives raw ultrasound signal generated by a stand-alone ultrasound device as input, processes and transmits it via its entire segments, resulting in a 360^o horizontal spread and a bottom boost. Implementation and testing reveals that, the effective coverage area of the stand-alone ultrasound pest control device was doubled with the aid of the ultrasound booster.

Keywords: Ultrasound, Integrated circuit (IC), ultrasound booster unit, stand-alone unit, weaver birds

Introduction
Ultrasound has a character of being inaudible to human ear but can be audible to certain animals such as bat, birds, insect and rodents (Cancel, 1998, Jones & Waters, 2000, Mann, 2001). When ultrasound is generated in an environment, such animals keep away from the vicinity (Brouwer et al., 1999). This idea has been applied in pest control with some level of success (Hangiandreou, 2003). In a previous work, an ultrasound pest control device was designed to improve the effectiveness of this method (Ibrahim *et al*., 2013a; Ibrahim *et al*., 2017). The said device was pest specific and environmental specific in the sense that, it targets only weaver birds in an endemic area of North central Nigeria (Ibrahim *et al*., 2016). Upon implementation and testing, it generates and transmit ultrasound of specific frequencies (25 kHz and 35 kHz) identified to be effective in repelling weaver birds (Ibrahim, 2015). In addition, the device when instructed is able to broadcast audio sounds of identified weaver birds predators through a mega phone in order to fortify it against habituation. However, one of the challenges encountered when the stand-alone device was deployed was in terms of its reach, as pests keep away from crops closer to the device and feeds on distant crops. The reason for this observation is because ultrasound is a short ranger (Berke, 2002), as it is easily attenuated by intervening media. As a way out of this quagmire, ultrasound booster was conceived. An ultrasound pest control booster is a device that is used to improve the signal strength of an electronically generated ultrasound for the purpose of pest control (Ibrahim, 2015). In this design concept, raw ultrasonic signal is transferred from a stand-alone ultrasound generator to a remote station, here referred to as a booster location where it is processed and transmitted within the location with a 360^o horizontal spread and a bottom boost. The aim of this work is to enhance the area of coverage of the stand-alone ultrasound pest control device through appropriate low-cost booster design.

Methodology
Circuit Design
The block schematic of the design concept is shown in Figure 1.

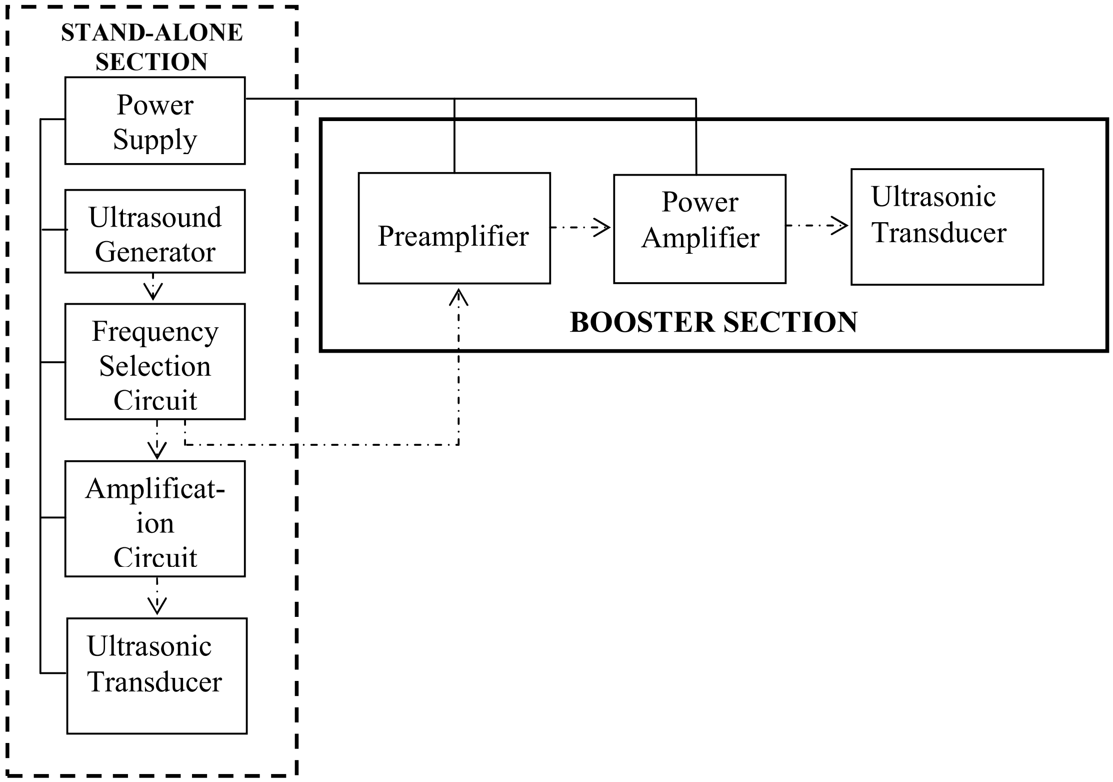

Figure 1: Block Schematic of the Ultrasound Booster Design

Figure 1 shows the two principal sections of the design namely: the stand-alone section and the booster section. The constituents of the booster section are shown by the thick solid block line on the right-hand side of Figure 1. While that of the stand-alone is shown by the thick dash line on the left-hand side of Figure 1. The stand-alone section has already been designed and implemented such that it is capable of independently generating its power and ultrasound requirements, selects a portion of the ultrasound signal for amplification and transmission in order to deter weaver birds away from the area of coverage. The booster section as evident from Figure 1 was designed to function along with the stand-alone section from where it derives its electric power and ultrasound signal. It will receive raw ultrasound signal from the stand-alone device for processing at its booster location. The ultrasonic signal relay line showing electronic signal communication between both sections is shown by the faint and directed dash lines while the power line is shown by the slime continuous lines.

The Stand-alone Section

The main thrust of this work is not on the stand-alone section, but on the booster section. However, due to the interdependence between both sections, few portions being shared shall be discussed.

The Power Supply Section: The power requirement was harnessed from the abundant solar energy of the study area using an 18 V solar panel and two 12 V batteries connected in parallel. This supply is available at the output of the tripping circuit and the booster outlets from where it is conveyed via booster cables to a booster location and from where it is regulated to meet the needs of various subsections inherent in the booster circuit. Connecting from the output of the stand-alone's tripping circuit, which is also a photo sensitive circuit (Ibrahim *et al.*, 2013a), ensures that both devices share the benefit of tripping ON and OFF at sunrise and sunset coinciding with the period of weaver bird pests activities in farms.

The Ultrasound Generator section: the 25 and 35 kHz ultrasound to be boosted by the booster device is generated by the 25 kHz and 35 kHz oscillators of the stand-alone device. Both oscillators were designed with 555 timer IC configured in astable mode (Ibrahim *et al*., 2017).

The Frequency Selection Section: The frequency selection section of the stand-alone system does the job of selecting between the 25 kHz and 35 kHz of the 25 kHz and 35 kHz oscillators respectively in fifteen seconds interval. This is to introduce some variability into the ultrasound signal, a necessary design consideration for delaying habituation of weaver birds to ultrasound stimulus (Ibrahim *et al*, 2013b). The circuit comprises of a 555 timer in a monostable mode and a microcontroller (AT89C52) as the excitation agent. It constantly sends pulses to the timers input every fifteen seconds causing it to change state simultaneously. This operation causes a relay at the timers output to toggle, thereby connecting the 25 kHz oscillator and disconnecting the 35 kHz on one hand and disconnecting 25 kHz and reconnecting the 35 kHz oscillators on the other hand (Ibrahim, 2015). The output of the frequency selection circuit was tapped to the booster outlet from where the ultrasound signal will be tapped via a booster cables to the booster section for further processing. This connection means that the signal to be boosted is also an intermittent selection of 25 kHz and 35 kHz every fifteen seconds.

The design descriptions given so far is housed separately inside the stand-alone device and executed in a single segment. Subsequent design to be described from the next subsection is referred to as the booster design and executed in five identical segments to be housed separately in the booster box. Only one of such segments will be discussed. Connection between the stand-alone device and booster box was established by means of a cable here referred to as the booster cord.

The Booster Section
This section is the major concern of this work. It comprises of sub-sections whose designs are described below.

The Booster Preamplifier Section
The essence of a booster circuit is to magnify or strengthen an in-coming signal. Ultrasound signal has the characteristics of travelling a short-range due to ease of attenuation by the intervening medium. The need to strengthen the signal for a wider reach necessitated the introduction of preamplifier circuit to amplify the in-coming signal to an appreciable level for further processing. The IC, UR 741 was considered appropriate for the preamplifier because of its high gain. The preamplifier circuit design is shown in Figure 2.

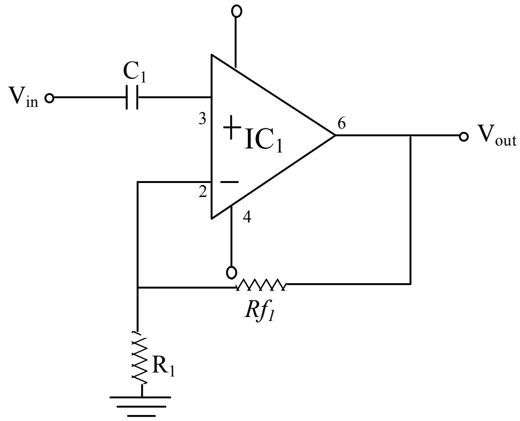

Figure 2: Preamplifier Circuit

The Voltage Gain, A_v equation of the IC is given by (Usifo, 2004);

$$A_v = \frac{V_{out}}{V_{in}} = 1 + \left[\frac{R_f}{R}\right] \quad (1)$$

where R_f is the value of the feedback resistor while R is the input resistor. Equation (1) can be modified as:

$$A_v = 1 + \left[\frac{Rf_1}{R_1}\right] \quad (2)$$

A gain of 500 was desirable for the preamplifier. Therefore, from (2), a choice of 1 K was made for R_1 and Rf_1 was calculated as 499 K. The design has a 0.1 μF capacitor (C_1) at its input, to block electrical noise that may have been generated in the stand-alone device and booster cord from entering the booster circuit. The preamplifier circuit so designed can raise the strength of the ultrasonic signal by 500. The booster cable evacuating electrical signals from the stand-alone system is a three in one cable which terminates at the input of the UR741 of the preamplifier. One of the cables transports ultrasound signal while the other two serves as the positive and negative power lines. The preamplifier and its adjoining sections constitute the booster circuit at a particular location.

The Booster Power Amplifier

The pre-amplifiers output signal serves as the input signal of the power amplifier. The preamplifier has boosted the ultrasound signal to an appreciable level to be complimented by the power amplifier. The IC, LM 386 notably applied as ultrasonic driver was adopted for the power amplifier design as shown in Figure 3.

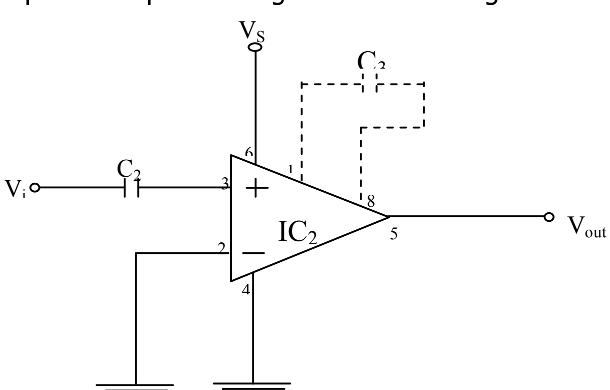

Figure 3: Power Amplifier Circuit

In order to obtain a higher gain from the IC, the circuit was modified between pin 1 and pin 8. According to National Semiconductor data sheet, to obtain the maximum gain of 200, a 10 μF capacitor is connected across pin 1 and 8. Therefore, a 10 μF capacitor (C_3) was connected across pin 1 and 8 (in dotted lines) to guarantee a gain of 200. Also, another 0.1 μF capacitor (C_2) was connected at its input to block electrical noise that may have been generated in the booster preamplifier from entering the booster circuit as shown in Figure 3. The power of the amplifier can be calculated using equation 3.

$$P = \frac{V^2}{R_L} \qquad (3)$$

where P is the power of the amplifier, V, the supply voltage and R_L is the impedance of the load. The succeeding section called the ultrasonic transducer section serves as the load on each segment and has impedance of 4 Ω. Equation (3) implies that raising the supply voltage of the power amplifier improves the power of the amplifier. But considering the fact that the device is solar powered via a 12 V battery and regulated by a 10 V regulator limits the maximum voltage required to power the amplifier to 10 V.
Equation (3) yields;

$$P = 25\ W$$

Therefore, a 25-Watt power amplifier with a gain of 200 was designed for each of the five segments of the device.

The gain in Decibel (dB) of the power amplifier is given by equation (4):

$$\text{Gain in dB} = 10\log (A_v) \qquad (4)$$

$$\text{Gain in dB} = 10\log (200) = 23.01\text{dB}$$

The total gain of the amplification section is given by the product of the preamplifier gain and the power amplifier gain. That is,

Total Gain = (Preamplifier Gain) x (Power Amplifier Gain) = 100,000

This simply means that the device's amplifier has been able to raise the voltage level of the ultrasound signal transmitted to it by one hundred thousand times. With this level of amplification, the ultrasound will be propelled to penetrate deeper into the air and saturate the vicinity of broadcast to a reasonable distance. This over-all amplification gain was achieved for each of the five segments.

The Booster Ultrasonic Transducer

The role of this section is to convert the ultrasonic frequency electrical signals generated by the stand-alone device and relayed to the booster device for preamplification and amplification into an equivalent frequency sound (Britanica, 2010). The booster ultrasonic transducers also serve as the load on each of the segments. Therefore, Ultrasonic twitters with band-width extending beyond the upper frequency of 35 kHz were employed for its advantage of not only converting to sound but further transmitting or broadcasting the sound over an area. A dual diaphragm, dual outlet twitters (twin twitters) was conventionally coupled via a 220 μF capacitor, C_4. The orientation of the ultrasonic transducers ought to be such that it allows for even spread of ultrasound in the booster location. Therefore, four out of the five segments were aligned 90^o horizontally to one another, and the fifth made 90^o to the horizontal arrangement. By this, a 360^o horizontal spread and a bottom boost is guaranteed. Figure 4 depicts this arrangement as illustrated using each segment's ultrasonic transducer.

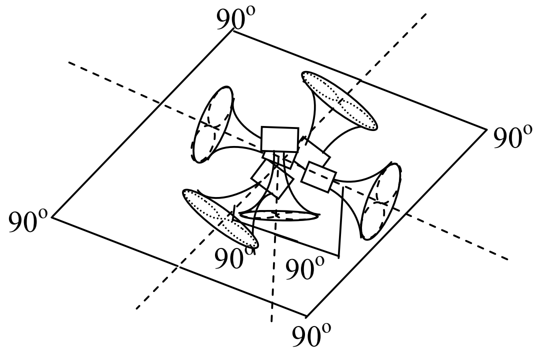

Figure 4. Orientation of each segment

Electronic Circuit Construction

Circuit Implementation

The implementation circuitry of the ultrasound booster is shown in Plate I.

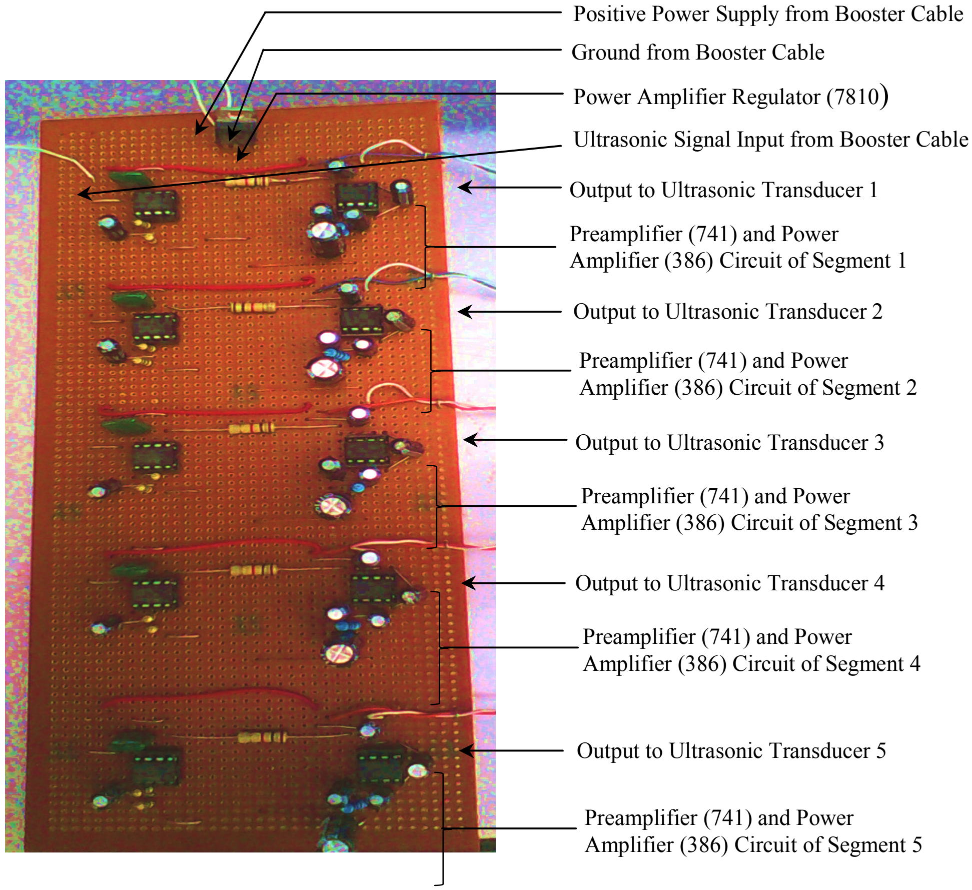

Plate I: Circuitry of the Ultrasound Booster

All components were sourced and assembled locally. The components were assembled on bread board to confirm their workability before being soldered on vero board in accordance with circuit design.

Casing Design

A wooden material was chosen to house the device because of its insulating property. Features on the casing include: Five broadcasting outlet (one on each side and one at the bottom); booster inlet and four clips at the base for fastening to the stand. A dimension of 33 cm x 29 cm x 16 cm was chosen to adequately house the electronic panel and ultrasonic twitters The casing, together with its circuitry, is also referred to as the booster box. Photograph of the casing interior of the booster box is shown in Plates II.

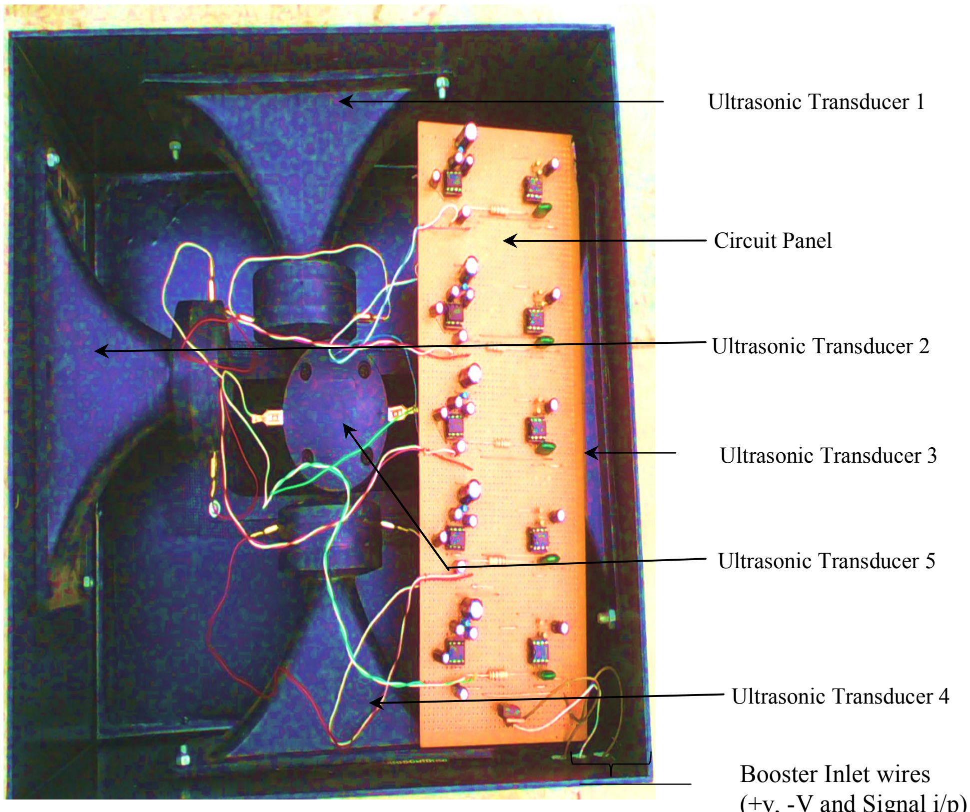

Plate II: Circuitry and Casing Interior of a Booster Box

Construction of Adjustable Support

An adjustable support of 1.2 meters to 5.5 meters high with a detachable horizontal platform of dimensions 35 cm x 35 cm on top of which the booster box will sit was implemented. A little portion of the platform having dimension 13 cm x 6 cm was opened to provide space for the bottom broadcasting outlet. These stand help to raise the device to the same height with the crops. Millet, sorghum and rice, for example, have their pest target points located at their topmost part. Therefore, the adjustable stands will help in achieving this leveling which allows for better interaction between the signal and the pest in different farm types and from trees housing them. Plate III shows the picture of the adjustable stands, horizontal platform and a booster box which constitute a booster unit.

Plate III: A Booster Unit

Results and Discussion

The outcome of this design concept consists of the booster unit working in synergy with the stand-alone unit as shown in Plate IV.

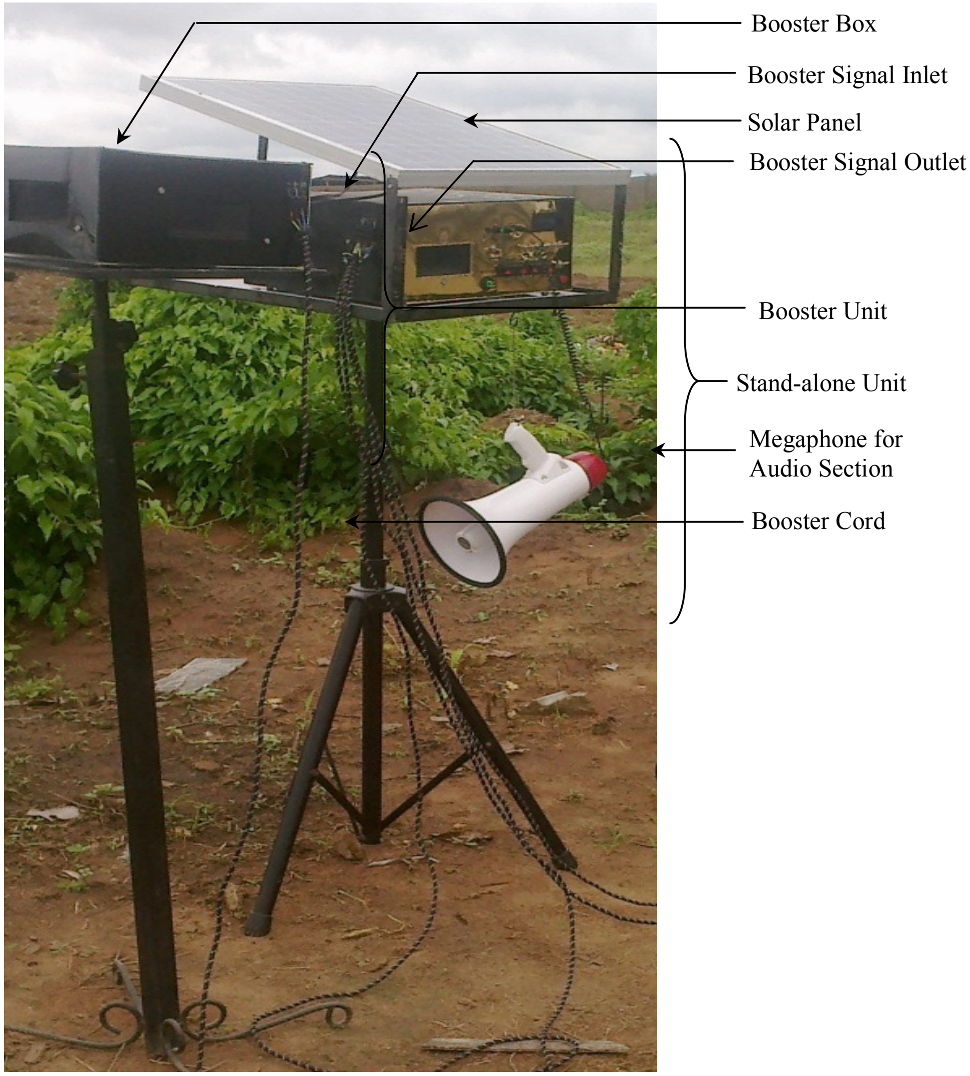

Plate IV: Set-up of the Booster mode of operation accomplished with the Stand-alone Device and a Booster

In this ultrasound booster mode, the stand-alone device functions as the ultrasound generator and power house of the entire system. With the booster switch on the stand-alone device activated, the booster mode is enabled and the preamplifier, amplifier and ultrasonic transducers of the booster device automatically starts operation in addition to those of the stand-alone device.

The following steps are followed while on the farm in order to operate the ultrasound booster system effectively:

(i) The stands of the stand-alone device and the booster box are coupled by adjusting the legs and attaching the horizontal platforms as shown in Plates IV;

(ii) The stand-alone device and the booster box are placed on their respective platforms and fastened;

(iii) The solar panel is placed above the stand-alone device by screwing the front to the platforms support and the rear is hooked to the stopper as shown in Plate IV. In this position the panel is at the required solar angle of 10^o to the horizontal. Solar angle is approximately equal to the latitude of the location;

(iv) The stand-alone unit is rotated such that the solar panel faces south. This provides the required direction for a direct exposure to the sun's rays;

(v) The solar panel's cable is plugged into the stand-alone device's power socket and the charging buttom is pressed to commence charging the battery;

(vi) The booster cord is plugged into the booster outlet on the stand-alone device and the other end into the booster inlet of the booster box. This will make available the needed power supply to boost the ultrasonic frequency signal to be supplied along the same cord at the booster location;

(vii) The booster box and stand are taken to desired booster location;

(viii) The stand is adjusted to about the same height as the crop. This levelling is necessary for better interaction with target part of the crops;

(ix) Pressing the power button of the stand-alone device and activating the booster switch makes the supply voltage (V_{CC}) available to the tripping section. If it is daytime, the section automatically clicks and feeds the supply line to power the other sections. But at evenings, this section trips OFF, disconnecting the other sections. When tripped ON, the timing section sets the frequency with which each of the oscillators will operate. The 25 and 35 kHz frequency signals generated by the oscillators are intermittently selected at 15 seconds interval by the frequency selection section and passed to the booster outlet and from where the signal is transported through the booster cords to the booster box for amplification and broadcasting throughout all its segments in its booster location;

(x) When habituation is observed to be setting in after about four weeks of operation, the audio section is activated by hanging the megaphone on its hanger located below the standalone horizontal platform and the input jack is slotted into the device's audio outlet as shown in Plate IV. The predator cry section (audio section) is activated by selecting the desired predator option to release the recorded predator sound for broadcasting by the megaphone.

Both the stand-alone device and the booster box simultaneously transmit ultrasound in five segments. A performance evaluation carried out on the stand-alone device using an ultrasound detector (Seriki, 2014) and by field inspection (Ibrahim *et al.*, 2017b) reveals that high intensity ultrasound was detected to a distance of thirty five meters (35 m), constituting an area of three thousand, eight hundred and fifty square meters (3850 m^2). Since the design parameters of the entire booster circuit was patterned after that of the signal propelling portion of the stand-alone design, it can be said that a similar distance and area of ultrasound coverage by the standalone device have been replicated for the booster box. Therefore, the booster system design employed (stand-alone working in synergy with the booster box) has doubled the ultrasound coverage of the stand-alone design. This advantage was reached at a reduced cost since the ultrasound generation section, solar panel, battery, charge controller, tripping section, frequency selection section, audio section and other peripherals of the stand-alone device were eliminated from the booster design.

Conclusion

The five-segment concept and the nature of transducer orientation used keeps the entire booster location and the stand-alone location saturated with ultrasound while in operation. With more area of land covered by ultrasound, the pest deterrent property of ultrasound is extended to more crops as they are brought under its protective cover, resulting in the availability of more food and the rapid attainance of food sufficiency. The design economics of having an ultrasound booster rather than replication of stand-alone device gives credence to the low-cost design concept. The focus of future research is on further enhancing the ultrasound coverage area by increasing the number of booster units, better booster configurations and modification of the stand-alone design to match-up these future design expansions.

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