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Effective Coverage Area Enhancement of Ultrasound Pest Control Devices through Ultrasound Booster Design

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ABSTRACT

One of the drawbacks of ultrasound pest control devices is in terms of their reach, as ultrasound is easily attenuated by intervening media. Ultrasound booster was conceived as a way out of this quagmire. 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 the stand-alone device as input, process it and transmit it via its entire segment, resulting in a 360o horizontal spread and a bottom boost. Analysis of the designed and constructed booster system reveals that it enhanced the effective coverage area of the stand-alone device by a factor of five and nine when in isolated and contact placement methods respectively

Keywords: *Ultrasound, booster system design, stand-alone unit, booster unit, pest, weaver birds.*

1 INTRODUCTION

Ultrasound refers to sound frequency above 120 kHz (Novelline, 1997). It 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 and 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). 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). 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 ultrasound 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 an ultrasound generator to remote stations, here referred to as booster locations where it is processes and transmitted within the locations with a 360o 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 booster design and to determine the degree of success of such design.

2 METHODOLOGY

2.1 DESIGN DESCRIPTION

In this work, the entire ultrasound pest control system consists of two sub devices namely: the stand-alone unit and the booster unit. Each unit is made up of the device itself and other supporting parts working together to achieve same objective. The block diagram of the design connection between the stand-alone unit and its booster unit is shown in Figure 1.

The stand-alone device 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 bids away from the area of coverage. The booster device functions along with the stand-alone device from where it derives its electric power and ultrasound signal. It receives raw ultrasound signal from the stand-alone device, amplifies and transmits it in their booster location. The idea behind the booster device is to increase the area of coverage of the stand-alone device. The constituent section of the booster device is shown by the thick solid block line on the right hand side of Figure 1. While that of the stand-alone device is shown by the thick dash line on the left-hand side of Figure 1. The ultrasonic signal relay line showing electronic signal communication between both devices is shown by the faint and directed dash lines while the power line is shown by the slime continuous lines. The concern here is not on the stand-alone, but on booster unit. However, due to the interdependence between both devices, a few sections being shared by both devices shall be discussed.

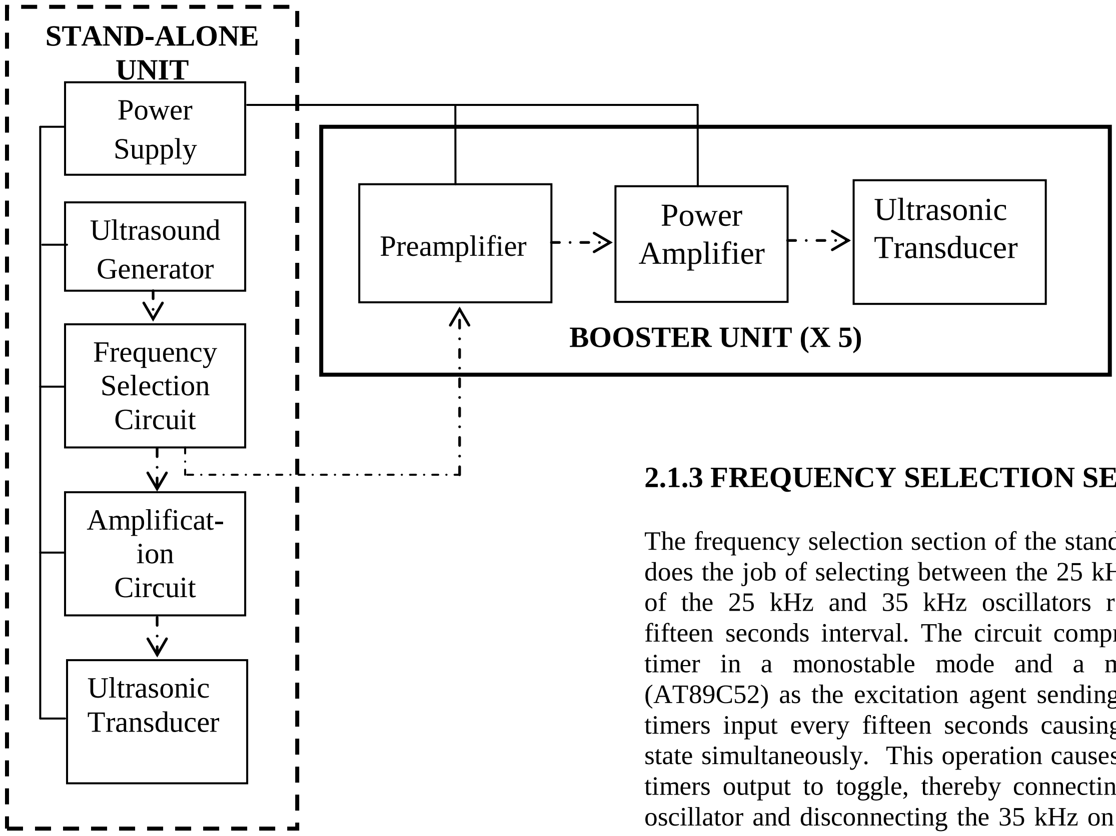

Figure 1: Block Diagram of the Booster System Design

2.1.1 POWER SUPPLY

The source of power for the booster system was conveniently derived from the stand-alone unit's 18 V solar panel and two 12 V batteries connected in parallel. The power requirement was tapped from the output of the tripping circuit to 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 sections inherent in the booster circuit. Connecting from the output of the stand-alone tripping circuit which is a photo sensitive circuit (Ibrahim, 2013a), ensures that both device shares the benefit of tripping ON and OFF at sunrise and sunset coinciding with the period of weaver bird pests activities.

2.1.2 ULTRASOUND GENERATOR

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.

2.1.3 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. The circuit comprises of a 555 timer in a monostable mode and a microcontroller (AT89C52) as the excitation agent sending 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 was tapped to each of the booster locations via the booster cables 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. Other successive sections of the booster system discussed below are located away from the stand-alone device and cased separately at a location (booster location) where it is expected to play its role of saturating the locations with ultrasound to deter the weaver birds.

2.1.4 BOOSTER PREAMPLIFIER SECTION

The preamplifier of the booster circuit is designed after that of the stand-alone circuit. The UR741 Integrated Circuit was used to raise the strength of the ultrasonic signal by 500. The circuit design and analysis is same as that of the preamplifier of the stand-alone device. The booster cable evacuating ultrasound signal from the stand-alone system terminates at the input of the UR741 of the preamplifier. The preamplifier and its ajoining sections constitute the booster circuit at a particular location. The circuit diagram of the preamplifier is shown in Figure 2.

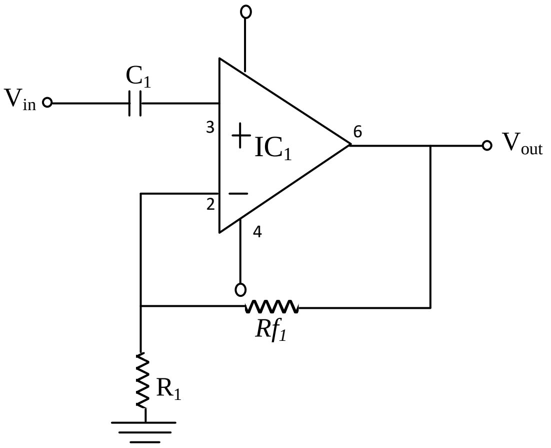

Figure 2: Preamplifier Circuit

The gain of the IC is given by (Usifo, 2004);

$$A = 1 + \left[\frac{Rf}{R}\right] \quad (1)$$

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

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

A similar gain of 500 was desired for the preamplifier as that of the standalone device. Therefore, from (2), a value of 1 K and 499 K was calculated for R_1 and Rf_1 respectively. 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.

2.1.5 BOOSTER POWER AMPLIFIER

The power amplifier circuit of the stand-alone system was replicated for the booster system. Same gain design of 200 was accomplished using the LM 386 Integrated Circuit

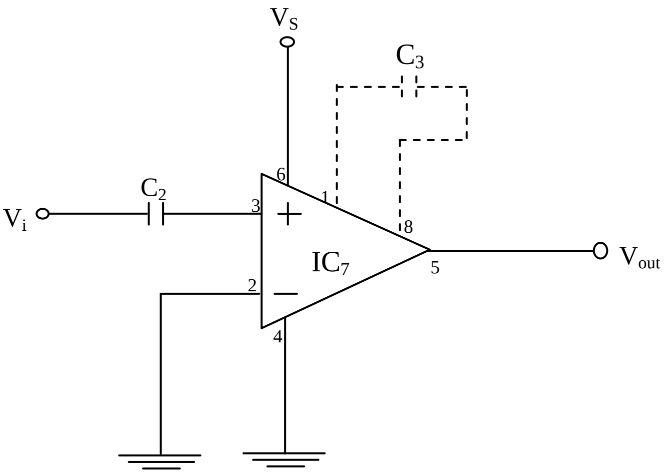

Figure 3: Power Amplifier Circuit

The power amplifier's input signal is the pre-amplifiers output signal. In order to obtain a higher gain from the IC, the circuit is moderated between pin 1 and pin 8. According to National Semi conductor 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 as shown in Figure 3. This simply means that the device's amplifier has been able to raise the voltage level of the ultrasound signal generated by the device's oscillators by one hundred thousand times. With this level of amplification, the ultrasound will propelled to penetrate deeper into the air and saturate the vicinity of broadcast to a reasonable distance. 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

Therefore, an overall amplification (preamplifier and power amplifier) gain of 100,000 in five segments for each of the five booster locations was maintained. The design has another 0.1 µF capacitor (C_2) at its input, to block electrical noise that may have been generated in the booster preamplifier from entering the booster circuit.

2.1.6 BOOSTER ULTRASONIC TRANSDUCER

For the ultrasonic transducers which will serve as the load in each direction, same dual diaphragm, dual outlet twitters (twin twitters) as used for the stand-alone was also used. A total of twenty of them are required for a 360^o coverage and a bottom boost at all the four booster locations (five for each booster location). Among the specifications of the ultrasonic twitters are that their frequency response should be beyond 35 kHz (Ibrahim *et al*., 2017). Coupling to the ultrasonic transducer was with a 220 µF capacitor, C_4.

The circuit diagram of the booster circuit in one of the five directions/segments at a booster location is shown in Figures 4. With the booster switch on the standalone device activated, the booster mode is enabled and the preamplifier, amplifier and ultrasonic transducers of the booster systems will automatically start operating in addition to those of the stand-alone device. In this mode, the stand-alone device will functions as the ultrasound generator and power house of the entire system.

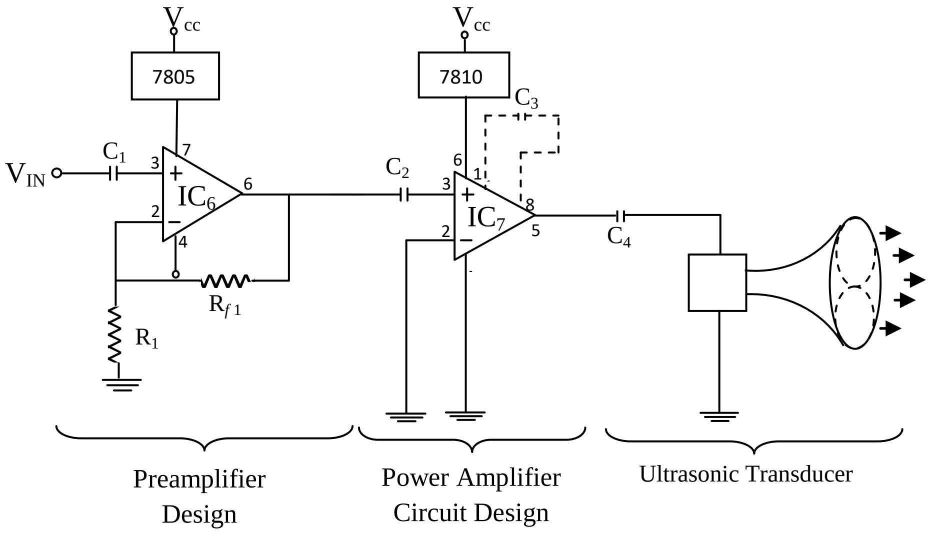

Fig. 4. Booster Preamplifier, Amplifier and Ultrasonic Transducer Circuit Design in One of the five Directions

2.1 ELECTRONIC CIRCUIT CONSTRUCTION

The booster circuit was physically realized using electronic construction technology. All components were sourced and assembled locally. The components were soldered on bread board to confirm their workability before being soldered on vero board in accordance with circuit designed. Plate I, shows the implemented circuitry along with the casing interior of the ultrasound booster.

2.2 CASING DESIGN

For the booster system’s casing, a dimension of 33 cm x 29 cm x 16 cm was chosen to adequately house the electronic panel and ultrasonic twitters. 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. The casing, together with its circuitry, is also referred to as the booster box. The sides, top and bottom of the casings were also sprayed with black paint from within, to absorb the heat generated by the components away from the circuitry. Picture of the circuitry with casing interior of the booster box is shown in Plates I.

2.2.3 FABRICATION OF ADJUSTABLE STAND

The design concept is such that the booster box will sit on a four-legged adjustable stand. It can be adjusted from a height of 1.2 meters to 5.5 meters. A detachable horizontal platform of dimensions 35 cm x 35 cm was mounted on the stand on top of which the booster devices will sit. 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. Plate II shows the picture of the adjustable stands, horizontal platform and a booster box which constitute a booster unit. The complete ultrasound booster system being put forward is made up of four booster units working in synergy with the stand-alone unit.

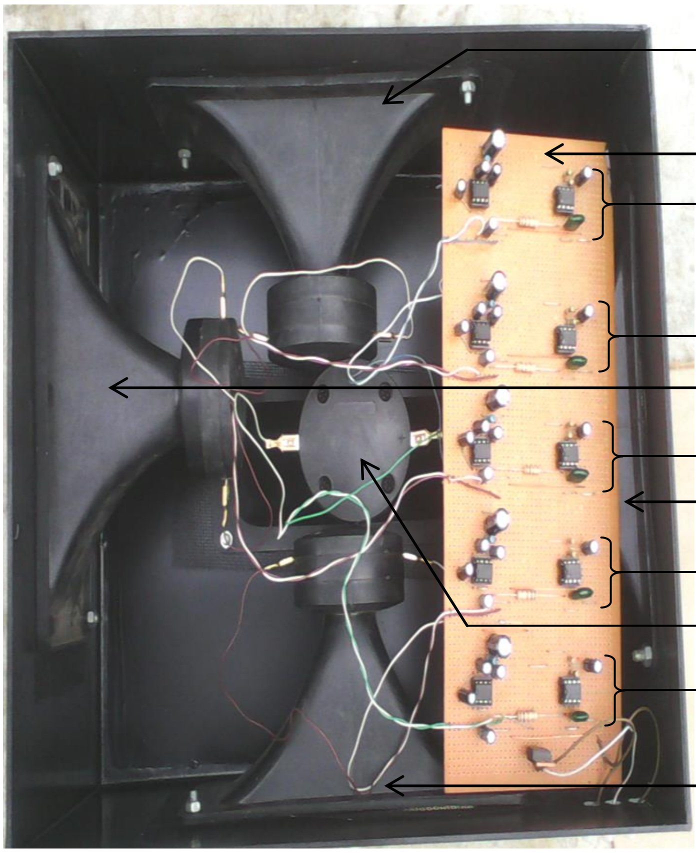

Plate I: Circuitry and Casing Interior of a Booster Box

3 RESULTS AND DISCUSSION

The conceived idea of a booster system and the implementation of the design concept give rise to the ultrasound pest control booster system shown in Plate III.

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

vi. The booster cords are plugged into the booster outlet on the stand-alone device and into the booster intlet of the booster box(es). This will make available to each booster location the needed power supply to boost the ultrasonic frequency signal to be supplied along the same cord when booster mode is enabled;

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

viii. The stands are adjusted to about the same height as the crop. This levelling is necessary for better

Plate III: The Ultrasound Pest Control Booster System

attaching the horizontal platforms;

ii. The stand-alone device and the booster boxes 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 III. In this position the panel is at the required angle of 10^o to the horizontal;

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

rops;

activating the booster akes the supply voltage on. 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 transmitted through the booster cords to booster locations for amplification and broadcasting.

Test result shows that the vicinity is kept saturated with ultrasound as all the twenty ultrasonic twitters of the booster units and five ultrasonic twitters of the stand-alone device were transmitting in their five respective directions.

To determine the distance and orientation of each of the booster locations from the central stand (stand-alone device), the effective distance of coverage of both devices need to be ascertained. To do this, the devices were evaluated in terms of ultrasound reach. An ultrasound detector (Seriki, 2015) was used to probe in all direction. The result shows that ultrasound from the device was sensed up to a distance of 35 meters, became faint on further probing and faded away beyond forty meters. This gave the result that the effective distance of coverage for the stand-alone device as 35 meters. Figure 5 can be used to depict the observation.

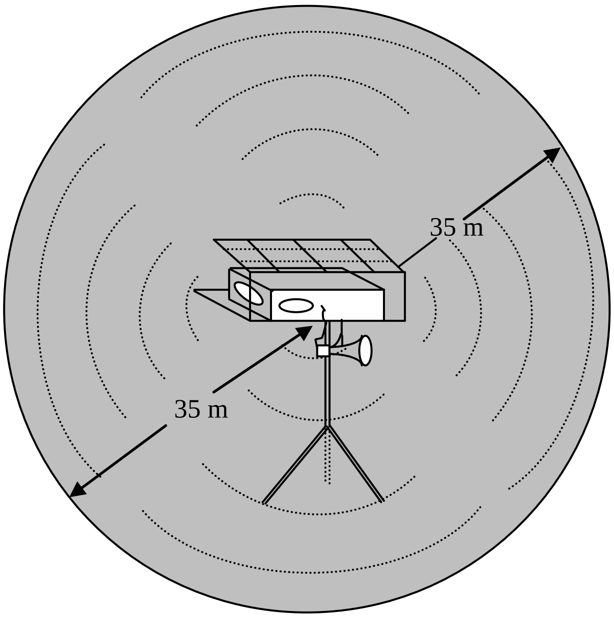

Figure 5: Effective Area of Coverage

For the effective area of coverage, the formula for the area of a circle was used (Stewart, 2003). That is:

$$A = \pi d_e^{\,2} \qquad (3)$$

where, A is the effective area of coverage, π is 22/7 and d_e is the radius, that is the effective distance of 35 m. Substituting into (3) yields:

$$A = \pi \text{ x } (35)^2 \qquad (4)$$

$$A = 3{,}850 \text{ m}^2 \qquad (5)$$

Thus, the stand-alone unit provides an effective weaver bird pest cover to an area of about three thousand eight hundred and fifty square meters.

The effective distance of thirty five meters radius for a stand-alone unit also holds for each of the booster units. This is because, same ultrasound twitters, preamplifier and amplifier design with uniform gain was implemented for both devices. This gave the idea of how to place the booster boxes in the field. In view of this, two placement methods were adopted: Placement in isolation and contact placement.

Placement in Isolation: In this placement method, each of the four booster units was positioned well apart from the effective distances of each other. Only favorite feeding spots of the weaver birds were covered. This placement method was informed by factors such as mixed cropping (where the pest selects preferred crops), different planting times leading to certain crops approaching the critical stage of vulnerability to pest attack differently and selective harvesting. In order to prevent wastage by saturating unnecessary areas with ultrasound, this placement method in which no definite angle of orientation or distance between booster stands is maintained was introduced. Figure 6 illustrates one of such placements in isolation.

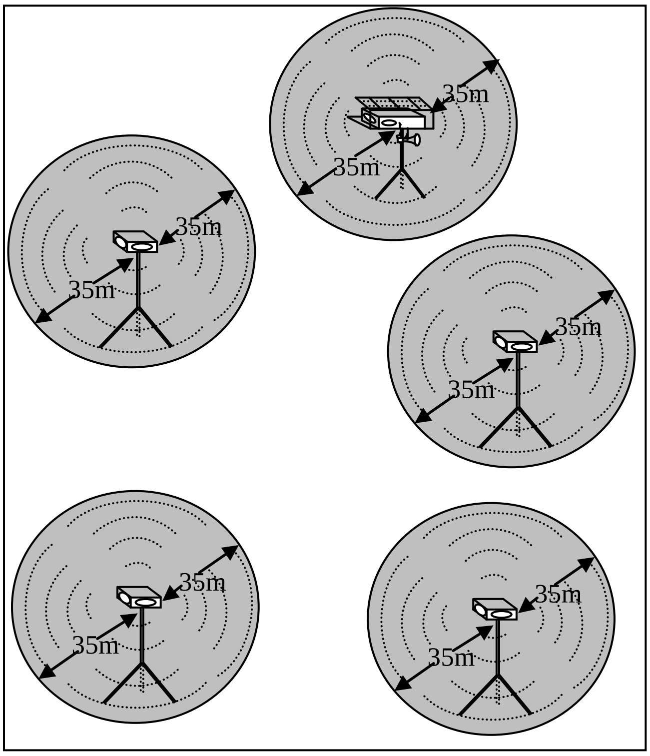

Figure 6: Placements in Isolation on a Farm

It can be observed that same effective distance of about 35 meters and effective area of 3,850 m2 was maintained for this placement method around each stand. Therefore, the total area of coverage achievable for this method was computed as nineteen thousand, two hundred and fifty square meters. This is five times the coverage area of the stand-alone device.

Contact Placement: In this placement method, the four booster units were kept close such that their distance of coverage overlaps with themselves and with that of the stand-alone unit. A definite orientation of 90o was each maintained by the booster units around the central stand-alone unit resulting to a 360^{o} spread. In this placement method, the booster units were positioned seventy meters away and ninety degrees around the now central stand-alone unit which will also function as the ultrasound generator and power house for the booster system. Therefore, the thirty five meters effective distance for the stand-alone device and another for the booster box will sum up to seventy meters. In addition to this distance is the other end (35 meter) of the booster transmission. This placement method is depicted in Figure 7.

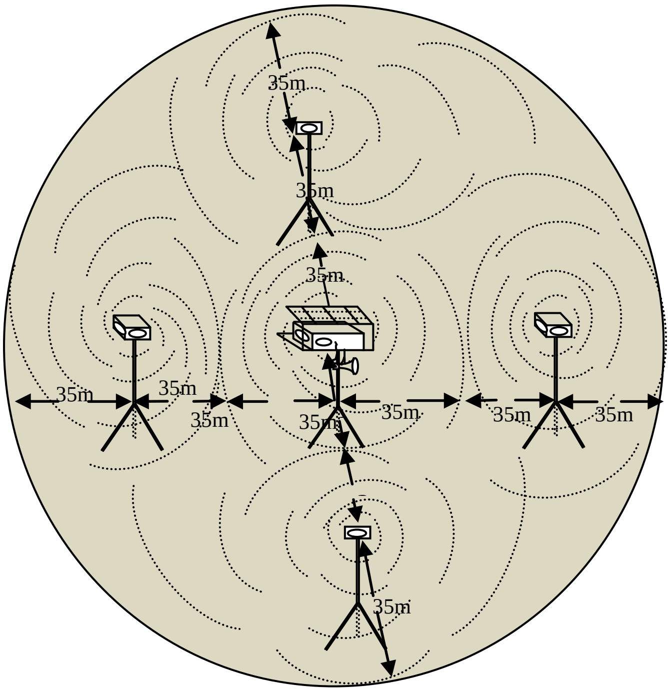

Figure 7: The Effective Distance/Area of Coverage in Contact Placement

It can be seen from figure 7 that the effective distance from the central ultrasound generator sum up to one hundred and five meters. From equation (3), the effective area of coverage of the device in contact placement type of booster was worked out as:

$$A = \pi \text{ x } (105)^2 \quad (6)$$

$$\text{A} = 34{,}650 \text{ m}^2 \quad (7)$$

Thus, a total area of thirty four thousand six hundred and fifty square meters of effective weaver bird pest deterrent is guaranteed using four booster boxes. This amounts to nine times the coverage area of the stand-alone device.

4 CONCLUSION

The booster system designed and placement method used in this work has enhanced the effective coverage area of the ultrasound pest control device by a factor of five and nine in the case of isolated and contact placement respectively. The maximum area of coverage of thirty four thousand six hundred and fifty square meters amount to an effective weaver bird pest cover on 3.465 hectares of farm land obtained using only four booster units. Hence, the ultrasound pest control system will make a considerable impact on the attainment of food sufficiency.

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