Journal of Physics: Conference Series

PAPER • **OPEN ACCESS**

Design of a fluorescent tube antenna with defined copper wire coupling specifications

To cite this article: A M Alalade *et al* 2019 *J. Phys.: Conf. Ser.* **1378** 042095

Design of a fluorescent tube antenna with defined copper wire coupling specifications

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Abstract. In this paper, the performance of a fluorescent tube antenna is analyzed with respect to the dimensions of copper wire utilized in RF coupling. The fluorescent tube antenna in the study is implemented using a 58.5cm long fluorescent tube with a diameter of 2.7cm and four different copper wires with provided dimensions, wound at specific chosen lengths. RF signals are generated and output power measured using a Handheld RF Signal generator and Spectrum Analyzer respectively. The performance index used to evaluate the improved functionality of the design presented is the Received Signal Strength (RSS) and the gain. A peak RSS value of -34 dBm is obtained using a 1mm thick copper wire wound at 50cm of the fluorescent tube length and the gain of the antenna is 14.37 dBi derived with the Friis Transmission Equation. Research findings are presented and compared to previous similarly conducted studies, and seen to perform favorably better.
keywords. Fluorescent tube Antenna, Plasma, Copper wire, Received Signal Strength (RSS), Friis Transmission Equation, Antenna Gain.

1. Introduction

In telecommunications engineering, the major role to be fulfilled is the provision of exchange of communication or information over a distance between people, satellites or computers. This traditionally, is achieved with the use of metallic antennas which coupled with other technologies; make the reception and transmission of signals possible from different devices and in different regions of the world. A new technology of signal transference, which uses plasma, a mixture of inert gases ionized by an electric voltage capable of behaving like a conductor and thereby allowing for the passage of signals" was proposed as early as the 1970s in two patents [1], [2]. A group of researchers Dwyer et al., [3] successfully conducted an experiment for proof of principle using a laser-guided electric discharge (plasma) to set up a transceiver with a radio frequency (RF) of 112MHz. The efficiency of the antenna fell in the range of *-1 to +1dB* as compared to the results a corresponding metallic antenna. Subsequent research followed, solidifying plasma as an efficient substitute for metals in antennas for RF signal transference. The plasma used in the subsequent experiments was obtained from fluorescent lamps which are the most common form of man-made plasma as it can be found in majorly all buildings inhabited by man as a source of light. Fluorescent tubes are developed from insulating glass-type tubes filled with inert low-pressure gases such as argon, xenon, neon, or krypton and also mercury vapor which when ionized form a plasma column, are capable of conducting electricity and hence electric signals [4].In this study, a fluorescent tube antenna is designed using a 58.5cm long fluorescent tube with a diameter of 2.7cm with four different coupling sleeves. The aim of this study is to present an experiment set up and results to evaluate the performance of a fluorescent tube antenna with respect to the Received Signal Strengths (RSS) and gain at an RF of 435 MHz. This experiment set-up features the use of four different copper wires of thicknesses; 0.5mm, 1mm, 1.5mm and 2.0mm to evaluate which copper wire coupling produces the best results.

Hence, the major focus of this paper is to present experiment results, evaluating the effects of the copper wire dimensions used to couple a fluorescent tube antenna, on the performance of the antenna. The paper is organized in the following order: Section 2 presents background knowledge on fluorescent tubes antenna and related works that have been conducted. Section 3 presents the methodology utilized in achieving the research. Section 4 and 5 details the results and the discussion of results achieved respectively and Section 6 concludes the paper.

2. Background study and related works

The three fundamental states of matter commonly known to man are solids, liquids, and gases. Plasma is recognized as the fourth state of matter and can display some distinctive behaviors of these three more familiar states, depending on its density and temperature, with some apparent distinguishing features [5].According to Bittencourt [6], the word plasma describes a vast range of observably neutral substances comprising numerous interfaced free electrons and ionized atoms or molecules, which display collective behavior because of long-range Coulomb forces. Plasma can be found ubiquitously, in the cosmos and in about 99% of the seeable universe but aside from solid-state plasmas, like the ones found in metallic crystals, plasma is not a substance physically found on the Earth’s surface. This implies that in order to conduct experiments in the laboratory, or for applications in technology, plasma must be artificially manufactured. Usually, plasma is formed by applying heat to inert gases until the electrons attain enough energy to break free from the hold of the positively charged nuclei. After the molecular bonds break leading to atoms gaining or losing electrons, the formation of ions occurs thus allowing the plasma exhibit properties and characteristics of conductors [7].In other words, plasma occurs as a result of the addition of energy to a gas causing some of its individual atoms to break from their internal bonds thereby leading to the ionization of those atoms and letting loose of negatively charged electrons. When this occurrence has taken effect on a substantial amount of atoms, the collection of all the electrically charged particles produce a plasma [8]. The proposal for the utilization of fluorescent tubes as a conducting means in RF transmission and reception is not a new one. The initial production of plasma antennas involved the use of electrodes at either end of the fluorescent tube but this created very complex designs and techniques which were difficult to work with. Also because of the complexity, several elements and materials interfered with the antenna properties and radiating signal, thereby diminishing its properties [9]. Some of these interferences came in the form of higher radar cross section and very poor noise performance. Y. Burykin et al [10] and M. Moisan et al [11]counter proposed with experiments that the plasma in the fluorescent tube instead of being excited from the electrodes, can be excited from a plasma surface wave. By application of an RF wave to the surface of the column, the plasma in the column is driven from one end to the other, the greater the power of the RF wave, the greater the ionization level. This proposal has been the basis for subsequent application of fluorescent tubes in plasma antennas for RF transmission and reception. G. Borg et al [9]applied this technique in their research and utilized a cylindrical copper fitting to capacitively couple a 140MHz RF signal onto a fluorescent tube thereby causing excitement in the column. An oscilloscope is connected to this setup and readings indicate that fluorescent tubes produce high enough efficiencies to enable them feasible for the conduction of RF signals. Research works in more recent times that have been conducted on the validity of fluorescent tube antennas as effective substitutes to plasma antennas include, [12], [13], [14], [15], [16], [17], and [18]. The results obtained are in good agreement with the functionality of fluorescent tube antennas. Although, the results found in most of the reviewed literature existing on this topic point only to the characterization of fluorescent tube antennas with respect to parameters such as gain, radiation pattern and return loss. The glaring gap in all these studies is there is no clear definition of specifications chosen for selection of coupling materials with the major exception being the research conducted by N. Halili et al [19] [27] which talked about the effects of coupling sleeve on a fluorescent tube antenna with respect to the number of turns of copper wire on the fluorescent tube. The next sections of this paper build on the research by testing for various copper material dimensions and at different lengths of winding across the surface of the fluorescent tube so as to give a clear definition of the requirements for the implementation of a fully functioning fluorescent tube antenna.

3. Methodology

This section details the materials and methods used to realize this research. The implementation of the fluorescent tube as the transmitting end of the communication link is achieved by coupling RF signals from a signal generator via a coaxial cable and copper coil. Measurements and readings are consequently taken from a reference antenna and spectrum analyzer.

3.1. Design specifications of fluorescent tube antenna

The fluorescent tube antenna is comprised of two major components, a fluorescent tube, and a coupling mechanism. The specification for the design of the fluorescent tube antenna is described via the use of a commercial fluorescent tube 58.5 cm in length and 2.7 cm in diameter. The fluorescent tube dimensions selection is made over others because of its prevailing commonness in residential buildings, offices, and locations alike. The glass tube which consists of Argon gas and low-pressure mercury vapor has an operating frequency of 50Hz, is rated at 18W and powered by an AC supply of 220-240V. An electrical ballast is situated between the fluorescent tube and the power supply. The function of this electrical ballast is to regulate and stabilize the current supply into the fluorescent tube and also supply adequate enough voltage to bring the lamp into operation.

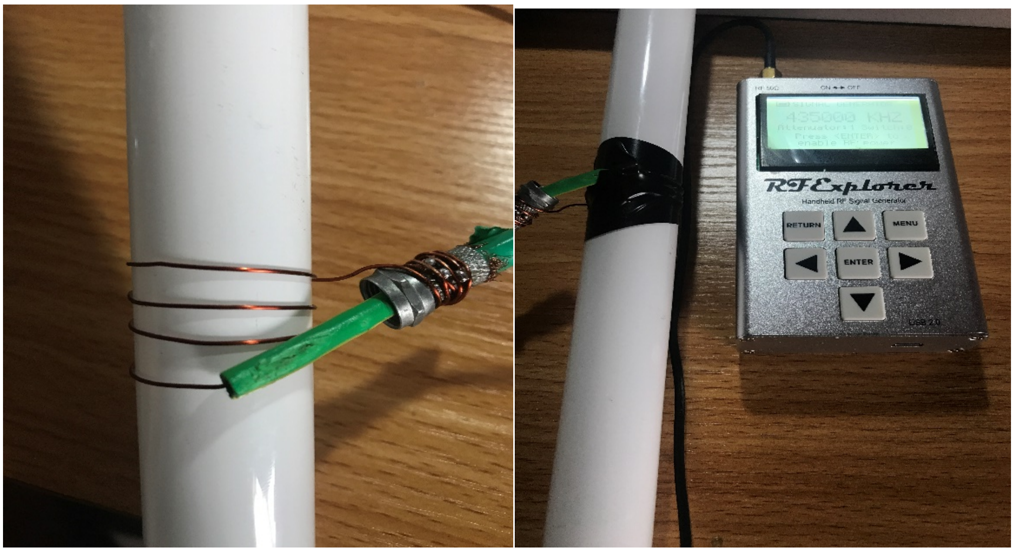
The second component is the coupler. For the various tests to be conducted, insulated copper wires are wound tightly around the fluorescent tube in such a way that the wound wires are parallel to the horizontal electromagnetic field (E-Field). Four different thicknesses of copper wires will be separately used to conduct four different sets of tests in a bid to discover the most effective copper wire for a fluorescent tube antenna. The thicknesses of the copper wires used in this study are; 0.5mm, 1mm, 1.5mm, and 2mm. These wound wires around the glass tube are responsible for the interaction of the RF signal and the plasma since there is no way to physically pass the signals into the fluorescent tube. The copper wire after being coupled is then fed to an SMA connector with a coaxial cable that is connected to an RF handheld signal generator. The hand-held RF signal generator and spectrum analyzer [20] on the other end, essentially are the devices that enable testing and measurement of the fluorescent tube antenna to be designed.

Table 1. Design specifications of the fluorescent tube antenna

Parameter	Description	Dimensions
Length of fluorescent tube	L_{FT}	58.5cm
Diameter of fluorescent tube	D_{FT}	2.7cm
Copper 1 thickness	C_{T1}	0.5mm
Copper 2 thickness	C_{T2}	1mm
Copper 3 thickness	C_{T3}	1.5mm
Copper 4 thickness	C_{T4}	2mm
Length at copper winding	Lcw	10cm, 20cm, 30cm, 40cm, and 50cm
No. of copper turns	n	4
AC Power Supply	V	220-240V

3.2. Experimental setup

Given all the parameters in table 1, the next step is to realize the fluorescent tube antenna. As researched and verified by N. Halili et al [19], the optimal number of turns of the copper wire on the fluorescent tube for best results is 4, this study also employs the same number of copper turns. The copper is wound tightly on the fluorescent tube ensuring only 4 turns are made, then connected to the handheld RF signal generator via the BNC connector of the coaxial cable. The two ends of the wound copper wire are soldered to the BNC connector, one end to the conducting copper wire of the coaxial cable and the other around the body of the connector. The coupling wires are taped down to the fluorescent tube using black electrical tape. This technique is illustrated in figure 1a. Shown in figure 1b is the other end of the coaxial cable, the SMA connector, directly connected to the handheld RF signal generator via the SMA port. To fully bring the antenna into operation, the 18W fluorescent tube is screwed into the electrical ballast which is fed an AC voltage of 220-240V. This causes ionization of the gases in the tube which brings about the creation of the plasma, the RF conducting medium. A RF of 435 MHz is produced by the signal generator and passing preferred frequency to the antenna, the coupled wires on the tube create the electromagnetic field [21]which allows for interaction between the RF signal and the plasma. Figure 2 shows the fluorescent tube brought to operation after connection to the electrical ballast and it represents the implemented fluorescent tube antenna design in this study as a transmitting fluorescent tube antenna in operation.



(a) (b)

Figure 1. (a) Coupling of a 1mm copper wire from the fluorescent tube to BNC connector; and; (b) Connection of fluorescent tube to handheld RF signal generator via the SMA port

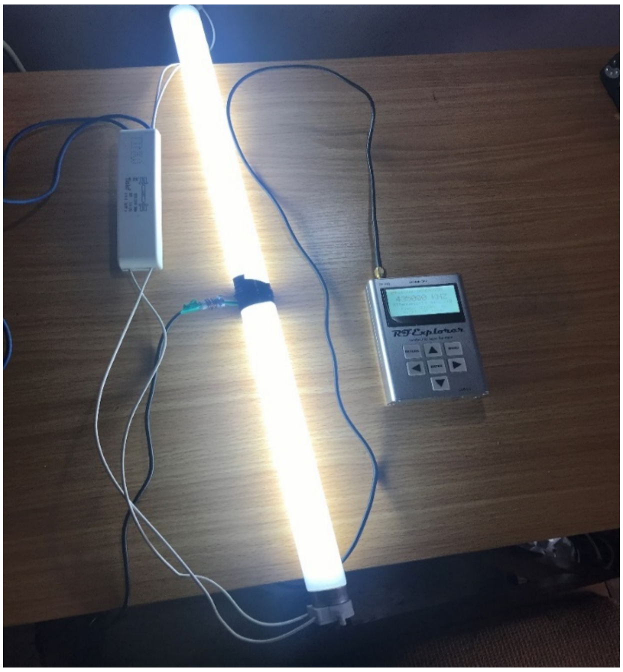


Figure 2. Implemented fluorescent tube antenna

On the receiving end of the communication link, the handheld RF spectrum analyzer in conjunction with a Nagoya NA-773 telescopic antenna capable of actively detecting all frequencies less than 1GHz is used to observe and take readings on the behavior of the fluorescent tube antenna. The distance between the transmitting fluorescent tube antenna and receiving Nagoya metallic antenna is 85cm.

3.2. Testing

Based on the research conducted in [19], it has been concluded that the optimal number of turns used for the coupling of the copper wire to the antenna is 4. In order to characterize the antenna with respect to most optimal output signal strength based on the coupling used, different copper wires with different thicknesses are wound simultaneously and at different lengths on the fluorescent tube. The four copper thicknesses to be utilized are 0.5mm, 1mm, 1.5mm and 2mm as values for C_{T1}, C_{T2}, C_{T3}, and C_{T4} respectively whereas the length at which the copper is wound on the antenna (L_{CW}) will be 10cm, 20cm, 30cm, 40cm and 50cm simultaneously. The RF signal utilized for tests in this study is the amateur radio frequency which lies in the UHF frequency band of 420-450MHz. This band is chosen over more common in-use bands because of the minimal interferences existent in it in this region of the world. To achieve this, the handheld RF signal generator is set to a Continuous wave (CW) frequency of 435MHz with a start frequency of 420MHz, and a stop frequency of 450MHZ. On the handheld spectrum analyzer, the readings are set to a center frequency of 435MHz, a start frequency of 420MHz, a stop frequency of 450MHz and a step size of 5MHz.

The copper wire (C_T) is wound around the fluorescent tube four times, with one end soldered to the BNC connector, and the other end around the body of the connector. After this, the coupling wires are taped down to the fluorescent tube using black electrical tape. For tests at other lengths (L_{CW}), this tape was removed and the coupler re-adjusted to the next length to be tested. The tape is then affixed again to give it stability and rigidity. The Received Signal Strength (RSS) values are taken via the spectrum analyzer software Touchstone [22] operated by means of a PC. The spectrum analyzer is connected to the PC via a USB cord and all readings displayed on the Touchstone software. These series of tests are conducted three times in the ON and OFF states of the fluorescent tube for each copper thickness (C_{T1-4}). Figures 3a and b show the implemented fluorescent tube antenna under test. The setup in Figure 3a is measured directly from the display of the spectrum analyzer while that in figure 3b is taken from the Touchstone software display.

(a) (b)

Figure 3. (a) Fluorescent tube antenna under test when 0.5mm is wound at a length of 10cm; and; (b) Fluorescent tube antenna under test when 1mm is wound at a length of 50cm

3.4. Antenna gain

After the antenna has been fully designed, implemented and readings obtained under several tests, the gain of the antenna is calculated to determine the ability of the implemented antenna to convert the input power received from the signal generator into radio waves and deliver it to specified directions. With the peak RSS value obtained from the spectrum analyzer readings, the Friis transmission equation is used to obtain the peak gain of the transmitting antenna. The antenna gain is a necessary parameter to determine because a higher gain indicates the antenna's capability to perform more efficiently and function over a farther range distance. The Friis Transmission equation which is used to calculate for the gain of the fluorescent tube antenna is expressed in equation 1.

Friis Transmission Equation;

$$\frac{P_{receiver}}{P_{transmitter}} = G_t G_r \left(\frac{\lambda}{4\pi R}\right)^2 \tag{1}$$

Where $P_{receiver}$ = *Received power (W)*
$P_{transmitter}$ = *Transmitted power (W)*
G_t = *Gain of transmitting antenna (dBi)*
G_r = *Gain of receiving antenna (dBi)*
R = *Distance between transmitting and receiving antennas (m)*
λ = *Wavelength (m)*

The power expressed in the Friis Transmission equation is in milli-watts (mW) and is converted to decibels with equation 2.

$$P(dBm) = 10 \times \log_{10}\big(P(W)\big) + 30 \tag{2}$$

The wavelength (λ) is calculated using the speed of light and the propagating frequency in the antenna via equation 3.

$$\lambda = \frac{c}{f} \tag{3}$$

Where *c =Speed of light (m/s)*
f = Transmitting frequency (Hz)

4. Results

This section presents all findings from the experiment setup and the tests conducted.

4.1. RSS values obtained from the spectrum analyzer

4.1.1. RSS values obtained for C_{T1} (0.5mm)

For a copper thickness of 0.5mm, the values obtained from the three sets of tests conducted can be seen in table 2. The values obtained indicate that the copper wire utilized is very inefficient. RSS for C_{T1} range from -86dBm to -96dBm indicating high losses in signal transmission from the copper wire.

Table 2. Readings obtained at C_{T1} for all lengths

LENGTH	1ST READING		2ND READING		3RD READING	
	OFF	ON	OFF	ON	OFF	ON
10cm	-86 dBm	-91 dBm	-95 dBm	-92 dBm	-93 dBm	-91 dBm
20cm	-89 dBm	-90 dBm	-87 dBm	-87 dBm	-94 dBm	-90 dBm
30cm	-96 dBm	-91 dBm	-89 dBm	-89 dBm	-87 dBm	-88 dBm
40cm	-87 dBm	-88 dBm	-90 dBm	-89 dBm	-91 dBm	-90 dBm
50cm	-89 dBm	-91 dBm	-91 dBm	-91 dBm	-89 dBm	-89 dBm

When plasma is on, the peak RSS value obtained is -87dBm at 20cm in the second test, this is captured in Figure 4. It is observed that irrespective of the plasma state, either OFF or ON, RSS values are very similar. C_{T1} is an inefficient copper wire utilized in coupling signals onto a fluorescent tube antenna.

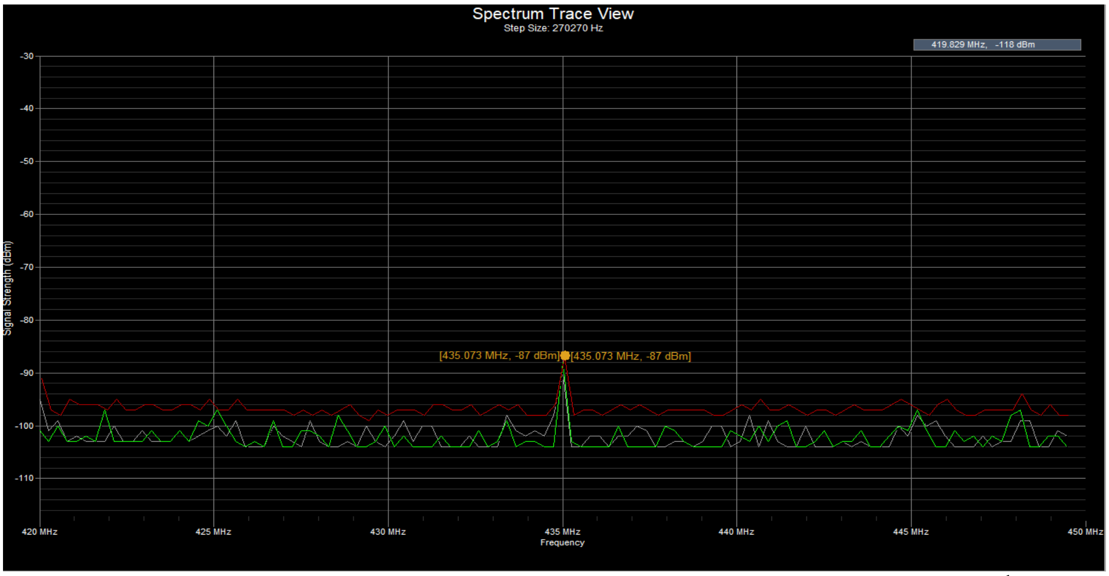


Figure 4. RSS reading of0.5mm copper coil at 20cm along the fluorescent tube (2^{nd} Test)

4.1.2. RSS values obtained for C_{T2} (1mm)

In the second sets of tests conducted, copper diameter used is 1mm and the RSS values received from the tests conducted are shown in table 3. The values obtained indicate that the copper wire utilized is very efficient. RSS values for C_{T2} range from -34dBm to -58dBm indicating high efficiency in RF coupling from the copper wire.

Table 3. Readings obtained at C_{T2} for all lengths

LENGTH	1ST READING		2ND READING		3RD READING	
	OFF	ON	OFF	ON	OFF	ON
10cm	-47 dBm	-58 dBm	-57 dBm	-52 dBm	-38 dBm	-41 dBm
20cm	-38 dBm	-43 dBm	-44 dBm	-49 dBm	-46 dBm	-48 dBm
30cm	-45 dBm	-53 dBm	-40 dBm	-47 dBm	-49 dBm	-51 dBm
40cm	-43 dBm	-47 dBm	-38 dBm	-49 dBm	-44 dBm	-49 dBm
50cm	-51 dBm	-41 dBm	-52 dBm	-34 dBm	-49 dBm	-38 dBm

Figure 5 shows readings obtained for the peak RSS at C_{T2} with coupling executed at 50cm in the second tests. In the ON state, an RSS value of -34dBm is observed and in the OFF state, an RSS value of -52dBm is observed. The received signal quality is very strong and can support any type of connectivity and service, therefore, it can be inferred that C_{T2} has very effective dimensions to be used for coupling signals onto a fluorescent tube antenna.

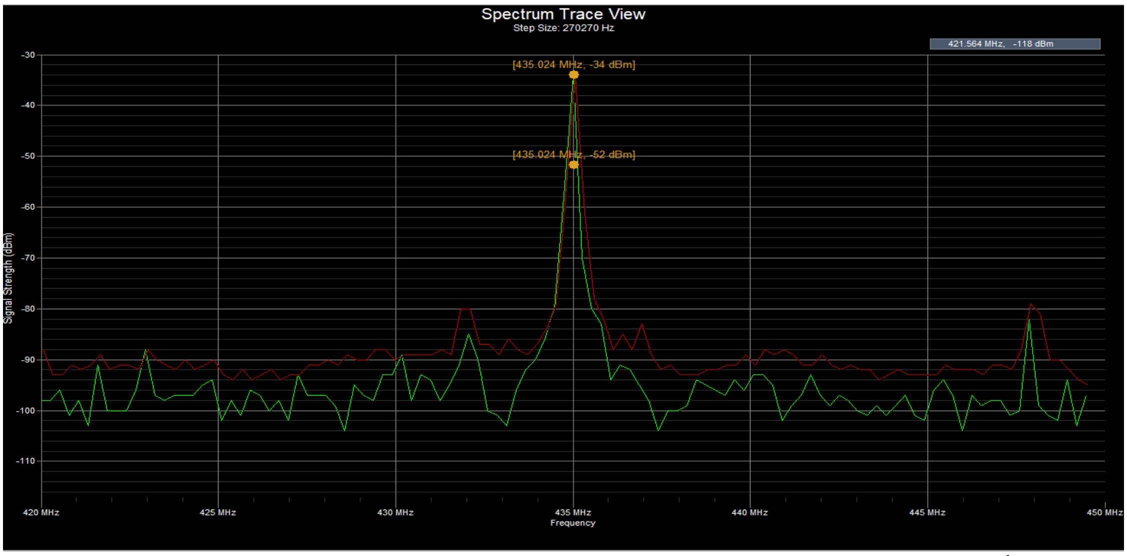


Figure 5. RSS reading of1mm copper coil at 50cm along the fluorescent tube (2nd Test)

4.1.3 RSS values obtained for C_{T3} (1.5mm)

In the third set of tests conducted, copper diameter used is 1.5mm and the RSS values obtained a range from -67dBm to -84dBm which fall under the category of fairly reliable signal strength to the minimum required signal strength for connectivity. These obtained values are shown in from the tests conducted are shown in table 4.

Table 4. Readings obtained at C_{T3} for all lengths

LENGTH	1ST READING		2ND READING		3RD READING	
	OFF	ON	OFF	ON	OFF	ON
10cm	-71 dBm	-82 dBm	-79 dBm	-72 dBm	-72 dBm	-70 dBm
20cm	-70 dBm	-84 dBm	-74 dBm	-73 dBm	-76 dBm	-77 dBm
30cm	-74 dBm	-67 dBm	-69 dBm	-71 dBm	-78 dBm	-70 dBm
40cm	-69 dBm	-76 dBm	-70 dBm	-74 dBm	-69 dBm	-70 dBm
50cm	-68 dBm	-74 dBm	-75 dBm	-71 dBm	-76 dBm	-69 dBm

Under the first set conducted, peak RSS value obtained in the ON state is -67dBm, which is observed at a copper winding length of 30cm as shown in figure 6.

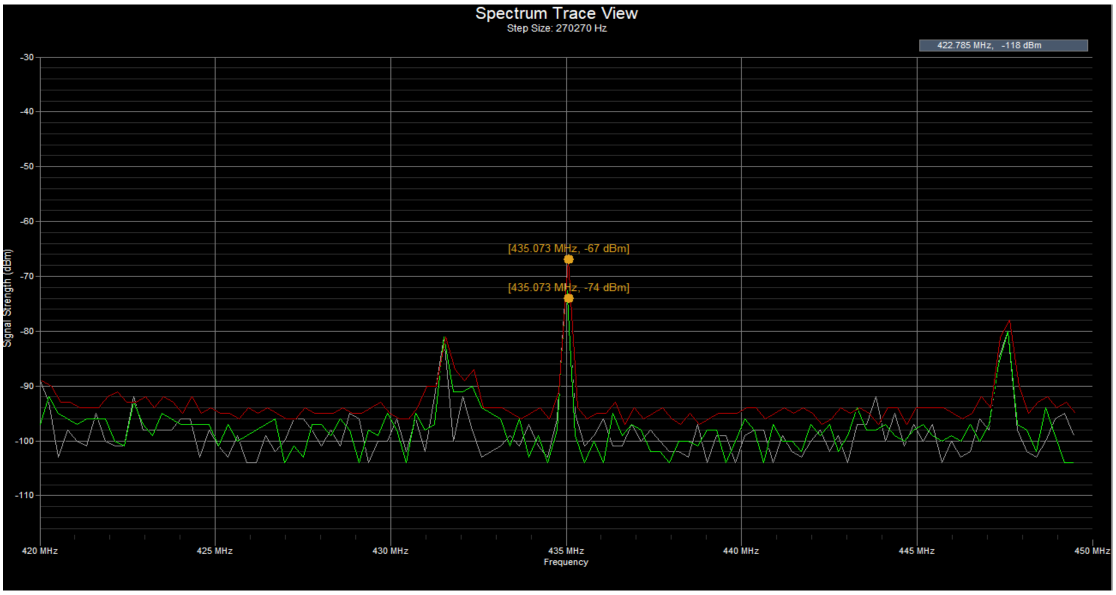


Figure 6. RSS reading of 1.5mm copper coil at 30cm along the fluorescent tube (1st Test)

4.1.4.RSS values obtained for C_{T4} (2mm)

Under tests using 2mm copper wire as the coupler, the peak RSS value received was -74dBm in the ON state at 50cm, and resulting values ranged from -74dBm to -83dBm. All values obtained are represented in table 5. This RSS range indicates that the copper wire utilized is inefficient and inappropriate for optimal coupling.

Table 5. Readings obtained at C_{T4} for all lengths

LENGTH	1ST READING		2ND READING		3RD READING	
	OFF	ON	OFF	ON	OFF	ON
10cm	-79 dBm	-77 dBm	-81 dBm	-79 dBm	-82 dBm	-80 dBm
20cm	-78 dBm	-81dBm	-80 dBm	-77 dBm	-78 dBm	-81 dBm
30cm	-79 dBm	-82dBm	-79 dBm	-81 dBm	-79 dBm	-83 dBm
40cm	-79 dBm	-81dBm	-78 dBm	-82 dBm	-77 dBm	-82 dBm
50cm	-80 dBm	-74dBm	-82 dBm	-77 dBm	-81 dBm	-78 dBm

4.2. Gain of the fluorescent tube antenna

From the tests conducted, peak RSS power (-34dBm) which is attained by our antenna, with a copper wire thickness of 1mm and at a winding length of 50cm on the fluorescent tube is thus used to calculate the gain of the fluorescent tube antenna using the Friis transmission equation expressed in equation 3.1. The values used and calculated to obtain the gain of the transmitting antenna (G_t) are shown in table 6.

Table 6. Values of parameters used in the Friis Transmission Equation

Parameter	Description	Value
Power received	P_r	-34dBm
Power transmitted	P_t	-40 dBm
Gain of receiving antenna	G_r	2.15 dBi
Speed of light	C	3×10^{-8} m/s
Transmitting frequency	f	435 MHz
Wavelength	λ	0.69 m
Distance between transmitting and receiving antenna	R	0.85 m

Inputting the values into equation 1, the calculated gain (G_t) is 14.37 dBi. This means the implemented fluorescent tube antenna a high gain antenna.

5. Discussion of results

After implementation and measurement of output RSS values, it is evident from tables 2-5 that a copper thickness of 1mm wound at 50cm across the fluorescent tube, is most optimal copper dimension for utilization in coupler winding of fluorescent tube antennas, for effective delivery of RF signals from a signal source to the fluorescent tube antenna. The result obtained compares favorably with other RSS values received from previous works such as [4] who obtained peak values of -77.92 dBm and -74.94 dBm in their tests at frequencies of 850.05 MHz and 850.17 MHz respectively. In [19], a peak RSS value of 30.63 dBm was achieved at an RF of 13.5 MHz which compares favorably with the results gotten from this study. Also, the calculated gain of 14.37 dBi for a frequency of 435MHz obtained from the use of the 1mm copper wire wound at 50cm shows how much this antenna effectively boosts the power from the generator to its destination. The gain of the fluorescent tube antenna designed compares favorably with other concluded designs. In the fluorescent tube antenna design conducted in [23], in the ON state a gain of -4.3 dBi was achieved at 490 MHz, [24] obtained a gain of 1.956 dBi at the Wi-Fi frequency 2.4 GHz from a fluorescent tube antenna of the same dimensions used in this study, [25] achieved a gain of their fluorescent tube antenna design of 6.691 dBi at 4.9 GHz and [26] who achieved a gain of 7.283 dBi from their design within a frequency band of 4.1 GHz – 4.7 GHz. The gain achieved in this study compared to previous works conducted illustrates that careful consideration of the copper dimensions used in the design of a fluorescent tube and appropriate selection of length at fluorescent tube at which the copper is wound, will provide more optimal results and the antenna will perform exceptionally better.

6. Conclusion

A plasma antenna designed with the use of a fluorescent tube 58.5cm in length and a diameter of 2.7cm was constructed. The received signal strength from the designed antenna was measured in a series of tests and results obtained were used to characterize the fluorescent tube antenna with respect to the best copper coupling dimensions to be executed on the antenna for the most optimal results attainable. Four dimensions of copper wires were wound and tested at five different lengths on the fluorescent tube and the received signal strength values obtained for each of the tests. The best result obtained from the tests was with a copper wire of 1mm thickness wound at 50cm across the length of the fluorescent tube. The results obtained generally under this copper wire falls under the exceptional signal quality to at worst very good signal quality category having a range of -34dBm to -58dB. A resulting peak RSS value of -34 dBm was reached with the plasma in the ON state conclusively demonstrating that it is the most optimal type of copper dimension that can be coupled onto the antenna. The Friis transmission equation

was used to derive the gain which resulted in 14.37 dBi and it compared favorably against the gains achieved in previous works. These results indicate the necessity for attention to be paid to the copper coupling dimensions executed on a fluorescent tube antenna.
Metallic antennas which can be very rugged and cumbersome to work with, and also take up more space, are quite expensive to implement and can be easily replaced with the more favorable fluorescent tube antennas. The measurement results of the fluorescent tube antenna showed that simple, commercial fluorescent tubes, found in homes, offices, and buildings alike, can be used as antennas in the transmission and reception of signals. These results obtained also prove that the antenna will function optimally as their metallic counterparts when implementing the specific coupling dimensions and technique used. It is also a more commercially viable and environmentally sustainable option going into the future for the transmission and reception of RF signals due to its ubiquitous nature.

Acknowledgments
Authors of this article would like to thank the management of Covenant University for financing the publication of this article.

References

[1] Tidman D A 1973 “Establishing highly conductive path in gas by thermal guidance of discharge
[2] Adewale A A, Adagunodo E R and John S N 2016 Improving Prioritized Handover Performance for Mobile WiMAX by Dynamic Guard Channel Allocation and RSS Quality Factor *Proc. of IEEE SAI Computing Conf. (IEEE)* pp 669-74
[3] Dwyer T J, Greig J R, Pechacek R E, Raleigh M, Murphy D P, and Perin J M 1984 On the Feasibility of Using an Atmospheric Discharge Plasma as an RF Antenna *IEEE Trans. Antennas Propag.*, **32(2)** pp 141–146
[4] Zali H M, Ali M T, Halili N A, Ja’Afar H and Pasya I 2012 Study of monopole plasma antenna using fluorescent tube in wireless transmission experiments *Int. Symp. Telecommun. Technol. ISTT* pp 52–55
[5] Gibbon P 2014 Introduction to Plasma Physics **1** pp 23–29
[6] Bittencourt J A 2004 *Fundamentals of Plasma Physics*, 3rd ed. Springer-Verlag
[7] Brucen K B, Kelley M C 2018 Plasma *Encyclopaedia Britannica* pp 19.
[8] Rogoff G L 2002 Lighting Plasmas *Coalit. Plasma Sci.*, pp. 1
[9] Borg G G, Harris J H, Miljak D G, and Martin N M 1999 Application of plasma columns to radiofrequency antennas,” *Appl. Phys. Lett.*, **74(22)** pp 3272–74
[10] Burykin Y I, Levitskiy S M, and Martynenko V G 1975 Establishing highly conductive path in gas by thermal guidance of discharge *Radio Eng. Electron. Phys*. **20** pp 86
[11] Moisan M, Shivarova A, and Trivelpiece A W 1982 Experimental investigations of the propagation of surface waves along a plasma column *Plasma Phys.* **24(11)** pp 1331
[12] Kumar V, Mishra M and Joshi N K 2011 Study of a Fluorescent Tube as Plasma Antenna *Prog. Electromagn. Res.* **24** pp 17–26
[13] Darvish P, Gorji A, and Zakeri B 2013 Design, simulation and implementation of a pre-ionized coupled plasma antenna at VHF band *Proc. Int. Symp. Electromagn. Theory*, pp. 452–55
[14] Charif M, Yaich M I, Khalladi M, Adraoui S E and Mounirh K 2015 Potentiality and performance of plasma antenna made from fluorescent tube for UHF applications *Int. J. Microw. Opt. Technol.*, **10(5)** pp 359–62
[15] Ja’afar H, Abdullah R, Omar S, Shafie R, Ismail N, and Rustam I 2017 Design and development of plasma antenna for Wi-Fi applicaion *J. Fundam. Appl. Sci.*, **9(5)** pp 1–11
[16] Ja’Afar H, Ali M T, Dagang A N, Ibrahim I P, Halili N A and Zali H M 2016 Reconfigurable plasma antenna array by using fluorescent tube for Wi-Fi application *Radioengineering* **25(2)** pp 276–82
[17] Barro O A, Himdi M, and Lafond O 2016 Performance of switchable patches array using plasma commercial fluorescent lamps *10th Eur. Conf. Antennas Propagation* pp 1–4

[18] Golazari S S, Amiri N, and Kashani F H 2016 Design, simulation and measurement of loop plasma antenna in UHF band *24th Telecomm Forum, TELFOR*
[19] Halili N A, Ali M T, Zali H M, Ja'Afar H, Pasya I and Dagang A N 2013 Effects of coupling sleeve designs on an RF charged plasma monopole antenna *IEEE Int. RF Microwave Conf. Proc.* **3** pp 467–70
[20] Nutsaboutnets 2019 RF EXPLORER *Nutsaboutnets* [Online] Available: http://rfexplorer.com/models/. [Accessed: 22-Feb-2019]
[21] Li K L, Liang T, Hong Y P, Yang F, Qin L, and Xiong J J 2012 Design of wireless coupling signal transmission antenna and impedance matching *Proc. Int. Conf. Comput. Meas. Control Sens. Network* pp 175–78
[22] NutsaboutNets 2019 Touchstone-RF Spectrum Analyzer Software *NutsaboutNets* [Online]. Available: http://rfexplorer.com/touchstone/. [Accessed: 01-Mar-2019].
[23] Barro O A, Rennes D E, Loire B, De D and Rennes D E 2016 Design and manufacturing reconfigurable antennas using plasma *Int. Conf. on Electromag. and Application* pp 545-48
[24] Hilmi M, Ali M T, Ya'Acob N, Zali H M and Ja'Afar H 2015 Development of fluorescent tube antenna array for Wi-Fi application," *IEEE Symp. Comput. Appl. Ind. Electron.*, **2(100)** pp 217–220
[25] Ja'Afar H, Ali M T, Dagang A N, Zali H M and Halili N A 2015 A reconfigurable monopole antenna with fluorescent tubes using plasma windowing concepts for 4.9-GHz Application *IEEE Transactions on Plasma Science* **43(3)** pp 815–20
[26] Binti H and Zali M 2015 Design of monopole plasma antenna using fluorescent tube for s wireless transmission applications Universiti Teknologi.
[27] Adewale A A, John S N and Adagunodo E R 2016 Performance Comparison of Dynamic Guard Channel with Buffered Prioritized Scheme for Mobile WiMAX Network", in the proceedings of the World Congress on Engineering (WCE) *Proc. of World Congress on Engineering (London)* **1** pp 566-70