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DEVELOPMENT OF A MOSFET-BASED RADIO FREQUENCY AMPLIFIER FOR IMPROVED SIGNAL RECEPTION

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ABSTRACT

It is highly desirable that the information routed from a source reaches the audience or destination with little or no interference or distortion. In Radio wave propagation, at times, the signal received at the destination arrives with some form of noise; which makes the message unintelligible enough for the listener. And at some other times, the signal cannot even be picked up at the receiving end. Hence, a device that will obtain the maximum possible signal voltage from that available in the air with the minimum possible noise is desirable. In this research work, we designed a preamplifier using a Metal Oxide Semiconductor Field Effect Transistor (MOSFET) to filter noise and to produce clearer pictures and better sound quality with increased directivity or gain. The MOSFET - based preamplifier was analyzed in performance and compared with the usual Bipolar Junction Transistor (BJT) type. The result in analytical form showed a gain of 25.1dB in the MOSFET-type and a 7.93dB in BJT. The designs were simulated with a simulator package, Electronic workbench 5.0. The result obtained agrees with the analytical results. However, for better monitoring of antenna behavior, particularly over a band of frequencies, a network analyzer is suggested. And for a more accurate and stable preamplifier circuit, a microprocessor can be considered for future design.

INTRODUCTION

Antennas are fundamental components of an electrical system, which uses free space as the transmitting medium. They are used in the transmission or reception of electromagnetic waves carrying some signal and to interface the transmitter or receiver to free space [7]. However, in a layman's language it can be said that, antennas are passive devices that radiate or pick up Radio Frequency (RF) energy and focus the energy in a specific area or direction, thereby increasing the signal strength in that area or direction. They are made up of materials that conduct electricity arranged in such a way that it is in tune with the frequency of a radio signal [10]. A Radio wave acts as a carrier of information-bearing signals [6]; the information may be encoded directly on the wave by periodically interrupting its transmission (as in dot-and dash telegraphy) or impressed on it by a process called Modulation. In its most common form, radio is used for transmission of sounds (voice and music) and pictures (television). The sounds and images are converted into electrical signals by a microphone (sounds) or video camera (images), amplified, and used to modulate a carrier wave that has been generated by an oscillator circuit in a transmitter. The modulated carrier is also amplified, and then applied to an antenna that converts the electrical signals to electromagnetic waves for radiation into space. Such waves radiate at the speed of light and are transmitted not only by line of sight but also by deflection from the ionosphere. Thus, receiving antennas intercept part of this radiation, change it back to the form of electrical signals, and feed it to a receiver (Radio or Television set) after amplification.
The receiving antenna is made active by the amplifier circuit.

PROPERTIES OF ANTENNAS

Antennas have a number of important properties that vary according to their application. The properties of most interest include: the gain, receiving cross section, radiation pattern, bandwidth, polarization, impedance and size [4].

Gain

The power fed into an antenna is distributed with an angular pattern characteristic of the antenna. The actual power density however, is referred to the value it would have when related with a standard antenna, usually taken as an isotropic radiator or reference antenna [1]. The gain or directivity of an antenna is the ratio of the radiation intensity in a given direction to the radiation intensity averaged over all directions. Quite often, directivity and gain are used interchangeably. The difference is that directivity neglects antenna losses such as dielectric, resistance, and polarization. And since these losses in most classes of antennas are usually quite small, the directivity and gain will be approximately equal (disregarding unwanted pattern characteristics). Gain can be described again as that property of an antenna referenced when the Radio frequency energy is focused in a particular area or direction in order to increase the signal strength in that area or direction. It is specified in unit of dBi vis-à-vis, the gain with respect to an isotropic antenna in decibel (dB). For example, an antenna with 0dBi gain is one, which radiates in all directions especially (a practically unrealistic one). Whereas an antenna with 12dBi gain has a direction in which the signal is 12dB stronger than in another direction. In reception the antenna gain helps the antenna to pick up signal in one direction stronger than in other directions. This directivity is very important to receive weak signals in noisy environment

Bandwidth

The bandwidth is a description of the frequency range over which the antenna performs suitably for the given specifications. For example, a TV transmitting antenna must have at least the Bandwidth (BW) of all the frequency components of the TV signal that it must transmit and a TV receiving antenna must have sufficient BW to receive all the channels to which the receiving set can be tuned.

The designations for the frequency ranges of common waves are as shown below [6].

Frequency range	Destination
30 – 300Hz	ELF (Extremely Low Frequencies)
0.3 – 3KHz	VF (Voice Frequencies)
3 – 30KHz	VLF (Very Low Frequencies)
30 – 300KHz	LF (Low Frequencies)
0.3 – 3MHz	MF (Medium Frequencies)
3 – 30MHz	HF (High Frequencies)
30 – 300MHz	VHF (Very High Frequencies)
0.3 – 3GHz	UHF (Ultra High Frequencies)
3 – 30GHz	SHF (Super High Frequencies)
30 – 300GHz	EHF (Extremely High Frequencies)

VHF/UHF ANTENNAS

The VHF range is classed as 30 to 300 MHz and the UHF range is between 300 to 3000 MHz. These frequency ranges were chosen for television broadcasting. However, ***Yagi-Uda*** antenna is the most common VHF/UHF antenna used today. It is a traveling wave antenna and uses mutual coupling between standing wave current antennas to produce a traveling wave unidirectional pattern. It is possible to use them for frequencies up to 900MHz. The ***Yagi-Uda*** antenna is the most popular type used for the reception of UHF and VHF TV signals as well as for FM radio broadcast named after its inventor, Yagi, a Japanese Engineer [2]. It is designed using a central feed element called a half wave dipole and a couple of parasitic elements around it to produce an end-fire beam for increased directivity of signal and gain. The parasitic elements are of two types; a reflector and the other directors depending on the arrangements.

POTENTIAL PROBLEMS OF ANTENNA

Television waves travel in straight lines like light and do not bend much around obstacles. And then the earth is made up of different constituents like rain, sunlight, wind, air- based animals and landscape constituents like mountains, hills, trees, to mention but a few [8]. All these have their effects on the transmitted and received signals. Therefore, a study on antennas cannot be concluded without considering those and a good design cannot be proposed without putting these factors into consideration. Another major problem encountered is due to inappropriate installation.

DESIGN ISSUES

THE ACTIVE ANTENNA FOR GOOD RECEPTION IN THE VHF AND UHF

The design proposed here is a Yagi- type with a signal amplifier coupled within the antenna cabinet.

The antenna is made up of two reflectors, in the rear (one for signals in the VHF and the other, UHF), one driven element (a folded dipole), and four directors (in the direction of reception). The antenna design is as depicted below.

Table 1: Table showing the description of antenna elements.

VHF	UHF
LENGTHS	
$L_R = 150/F = 150/165 = 0.9091m \approx 0.91m$	$L_R = 150/F = 150/680 = 0.2206m \approx 0.22m$
$L_{DP} = 143/F = 143/165 = 0.87m$	$L_{DP} = 143/F = 143/680 = 0.21m$
$L_{D1} = 138/F = 138/165 = 0.84m$	$L_{D2} = 138/F = 138/680 = 0.20m$
LD2= 134/F = 134/165 = 0.81m	$L_{D3} = 130/F = 130/680 = 0.19m$ LD4 = 120/F = 120/680 = 0.18m
SPACING	
$S_{R\text{-}DP} = 45/F = 45/165 = 0.27m$	$S_{R\text{-}DP} = 45/F = 45/680 = 0.07m$
$S_{DP\text{-}D1} = 45/F = 45/165 = 0.27m$	$S_{DP\text{-}D1} = 45/F = 45/680 = 0.07m$
$S_{D1\text{-}D2} = 45/F = 45/165 = 0.27m$	$S_{D1\text{-}D2} = 45/F = 45/680 = 0.07m$
	$S_{D2\text{-}D3} = 60/F = 60/680 = 0.09m$

The preamplifier circuit that will amplify the signal received from the air is as depicted in Figure 1.

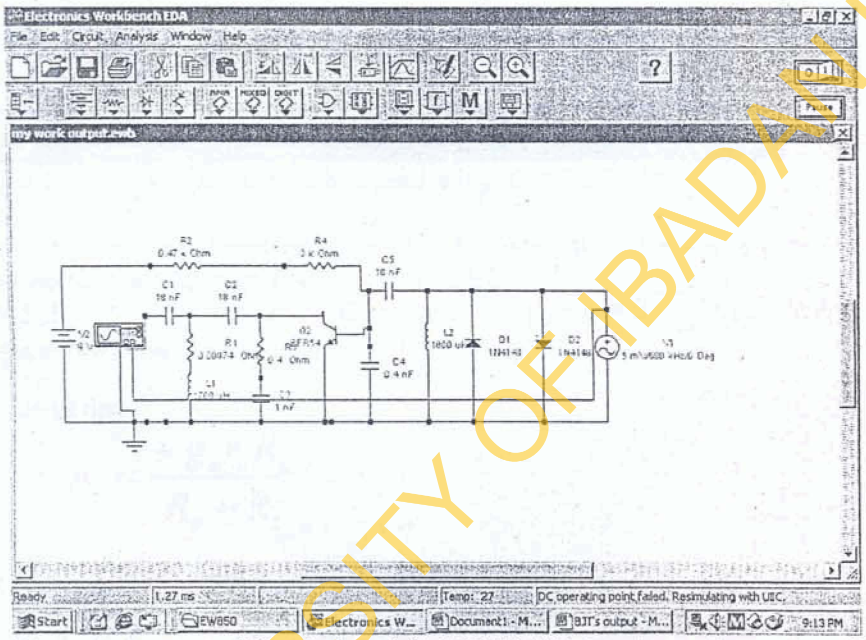

Figure 1: A preamplifier designed for VHF/UHF signal reception using a Bipolar Junction Transistor.

From the transistors characteristics the following values were obtained for the amplifier's components.
$F_0 = 907.5MHz$ $C_2 = 18nF$ $C_5 = 18nF$ $L_2 = 1.8nF$ $L_1 = 1.7pF$ $R_3 = 0.4\Omega$. $R_1 = 9.69 \times 10^{-3}\Omega$ $C_1 = 18nF$ $C_3 = 1.8nF$ $R_2 = 4.7k\Omega$ $R_4 = 29k\Omega$. $C_4 = 0.04pF$.
The gain of the transistor is therefore calculated as

$$A_V = \frac{R_C}{r_a + R_2}$$

$$A_V = \frac{2 \times 10^3}{10 + 4.7 \times 10^3} = \frac{2000}{4700.01} = 0.43$$

Current gain life = Ai = 70 dB.
Therefore the overall gain A_P is given by

$A_P = 10 \log A_i A_V$.
$A_P = 10 \log 70 \times 0.43$
$A_P = \underline{\underline{7.93dB}}$

And with the biasing resistor, the VHF/UHF preamplifier circuit using the Enhancement N-channel MOSFET is as depicted in Figure 2 [9].

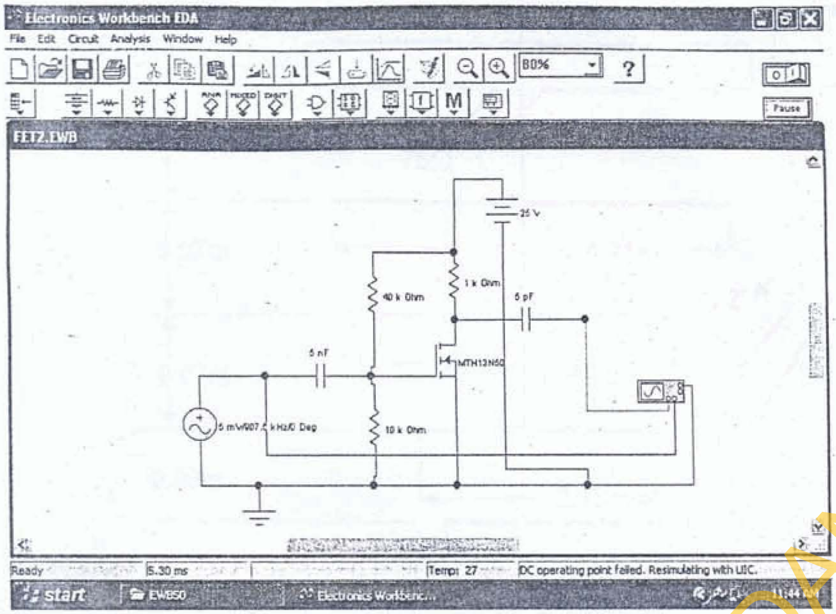

Figure 2:A preamplifier circuit designed using MOSFET.

Also from the transistors characteristics obtained from transistor data book the following values were obtained for the amplifier's components [5, 9].

$C_1 = 5nF$ $R_1 = 10k\Omega$ $C_2 = 50pF$ $R_2 = 40k\Omega$ $V_{DS} = 8.49v$

$I_{DS(ON)} = 21.2A$. $g_m = -9$

It follows that

$$A_v = \frac{-g_m r_d R_L}{R_d + R_L}$$

So,

$$A_v = \frac{-(-9)\times 40\times 10^3 \times 2}{40\times 10^3 + 2}$$

$$A_v = \frac{720000}{40002} = 18.0$$

or $A_v = 20\log_{10} 18 = 25.1dB$.

RESULTS AND DISCUSSION

The whole antenna picture is as shown in Figure 3.

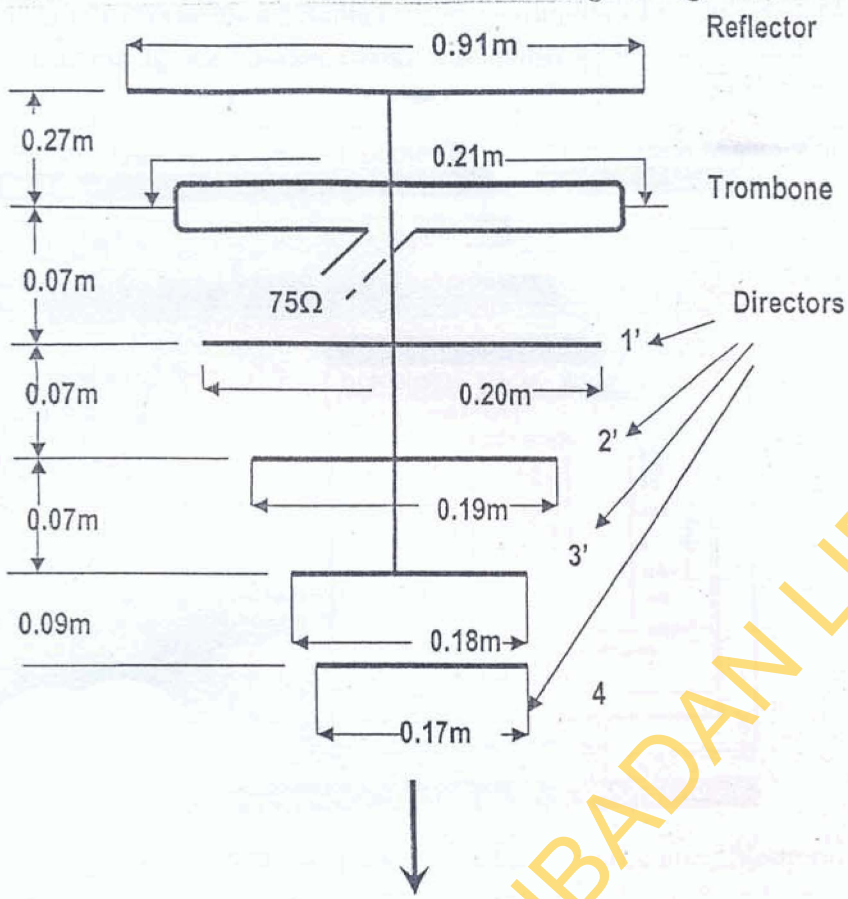

Figure 3: Yagi-Uda Antenna

From the design parameters analyzed in the Bipolar Junction Transistor-based amplifier, it has a gain of 7.93dB. However, this type of amplifier has a low immunity to radiations and with a low gain vis-à-vis, a high noise. So, to improve the performance of the radio wave reception, a more rugged, MOSFET transistor type was used which resulted in a gain of 25.1dB.

SIMULATION

The amplifier designed was set up and simulated with Electronic workbench 5.0 which translated the design into an experimental procedural routine. This is to ascertain that when the experiment is transferred or put into a real design, it will work as predicted.

For the Bipolar Junction Transistor-based amplifier, the Electronics workbench result is as placed in Figure 4.

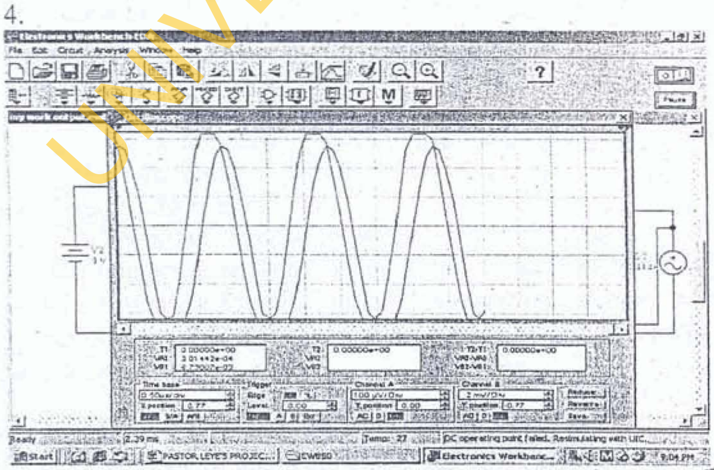

Figure 4: output of the Bipolar Junction Transistor Amplifier when simulated using Electronic workbench 5.0

Conversely, the simulator result obtained for the FET based transistor is as shown in Figure 5.

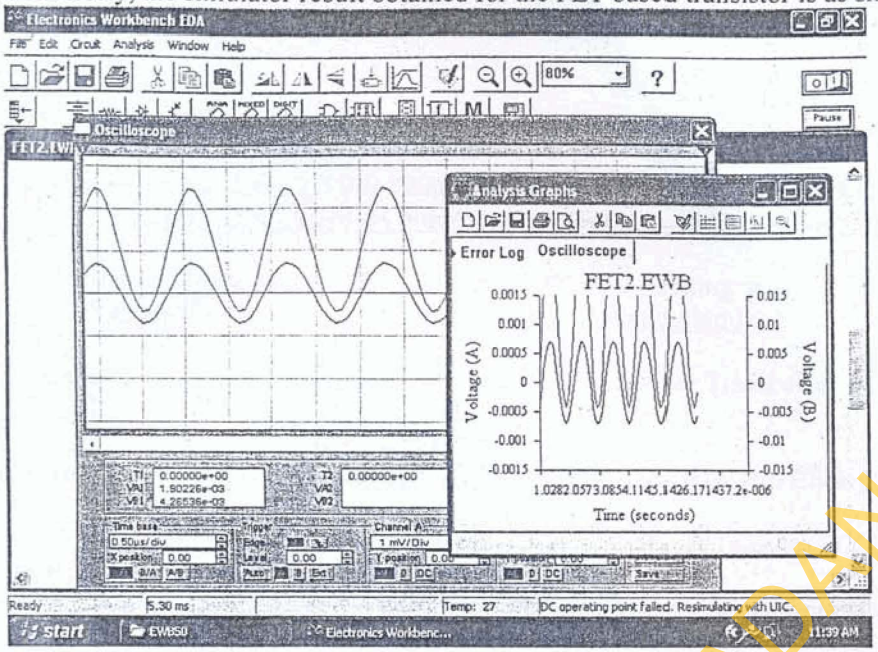

Figure 5: Output of the MOSFET based Amplifier when simulated using Electronic workbench 5.0

In both figures 4 and 5, the lower, black signal line represents the input to the Oscilloscope. That is the same signal from the aerial antenna (on the pole), which was fed into the Preamplifier or the booster. On the other hand, the upper, blue signal line showed the output from the Oscilloscope simulated as the gain coming out of the Preamplifier or booster to be fed into the TV. This describes the gain unto good reception.

CONCLUSION

One of the commonest types of antenna design of today is the Yagi-Uda antenna. Its design easily combines antenna elements for both VHF and UHF signal reception with little lengths and spacing between elements. And so the overall design is small in size, and pleasing to the eye when covered with plastic cabinet. This plastic cabinet also protects the elements from corrosion and other atmospheric constituents, the effect of which at times accounts for poor reception. Lightning is also a major destructor to antennas, but with a MOSFET-based amplifier or booster circuit, safety is guaranteed for this type of preamplifier design. How? MOSFET transistors have the following advantages over the other types of transistor. [3],[9].

* Low noise
* Long life
* High Frequency response
* Ruggedness
* Negative temperature coefficient hence better thermal stability
* High immunity to radiation
* High power gain.
* A low input impedance, which makes it capable to pick-up very low signals for amplification.

Also, the numerical analysis of the amplifier model (MOSFET- based) resulted in a gain of 25.1dB. Note that in reception the antenna gain (Properties of Antennas) helps the antenna pick up signals in one direction stronger than in other directions. Hence, this antenna will pick signals 25.1dB stronger at its destination than in any other place.

RECOMMENDATIONS

Since the number of elements employed in the antenna design is proportional to the directivity and hence gain, the design (real design) should be made with considerable number of elements. The MOSFET – based preamplifier has been judged to be better compared with the Bipolar Junction Transistor-based. Therefore, it is also recommended for booster circuits. Today, software is popularly used to accurately simulate antenna behaviour run on the model design. But it should be regarded as a rough guide to an antenna's behaviour in a real installation. A network analyzer, which monitors the reflection coefficient of the antenna over a band of frequencies, is necessary. Also, for a more accurate and stable preamplifier circuit, a microprocessor-based type can be looked into.

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