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DEVELOPMENT OF AN ACTIVE VHF-UHF ANTENNA FOR TELEVISION RECEPTION IN A FRINGE COVERAGE AREA

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Abstract

An active antenna for the reception of television signals in those area of relatively weak signals has been designed and constructed, and was also tested to be more efficient compared to the available ones in the market. This was accomplished through a careful design of filter stage and proper selection of electronic components and materials that formed the antenna elements, as well as the pre-amplification stage. A gain of 73.2 ± 0.1dB was obtained.

Introduction

For ages man has dreamt of transmitting picture and sound from one place to another. Over the years the transmitting and receiving signal in picture and sound have greatly improved with the advent of different electronic devices capable of doing the work. Video technology of which television forms an integral part is one of the means in which the technology is gaining tremendous breakthrough.

A focus on the development in television technology is much centered on antenna with pre-amplifier. The antenna is designed for both the transmission and reception of television signals. Due to the limitation of TV signals by the line- of- sight transmission, the receiving antenna is properly designed such that the quality, gain, signal strength and faithfulness of the signal being received provide better and satisfactory reception on the television receiver screen. Although the problem of proper TV signals reception is being addressed by the use of different kind of active antenna, the problem necessitates the use of active antenna, which will produce a gain at the construction of yagi antenna. The gain is large enough to greatly boost up the signal reception of areas that suffer poor TV signal reception, due to long distance or poor location from the transmitting station. The antenna is aimed at receiving signal situated within the VHF and UHF bandwidth.

The aim of this work is to design and construct an active Yagi antenna with booster or a pre-amplifier to greatly improve the TV signal reception as indicated by the block diagram in Figure 1. The VHF and UHF antenna are to be constructed separately and hinged together on the same mast for easy directivity adjustments. The elements for both the VHF and UHF are dipole, the reflector and the directors with proper spacing between them. This is to ensure proper signal reception.

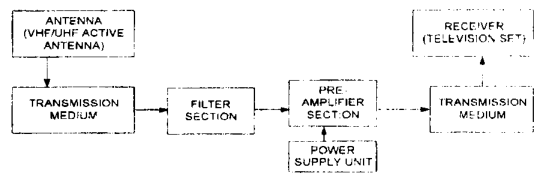

Figure 1: Block diagram of an active VHF –UHF antenna.

This work was embarked upon so as to solve the problems in area with poor television signal reception anywhere in Nigeria. The active antenna was designed so as to have a high gain and in order to improve on the already existing antenna efficiency.

Literature Review

Radio Wave Propagation Principle

Electromagnetic wave is classified by frequency and wavelength. The propagated radio waves, as one of the electromagnetic waves, can be transmitted or received by the antenna. The receiving antenna for the VHF and the UHF bands are generally designed similar to the transmitting antenna. Transmitting antenna radiates electromagnetic energy. The energy radiated gets induced into the receiving antenna and generates both current and voltage signals, which serve as the input signal to the pre- amplifier circuit via the signal cable. The output of the pre-amplifier goes into the television receiver. In the television signals, electromagnetic waves are propagated between the transmitting and the receiving antenna by the space waves depending on the magnitude of the frequency. The transmitted waves are produced at the frequency band of VHF at 30MHz to 300MHz while the frequency band of UHF is within the range 300MHz to 3GHz. The corresponding wavelengths are calculated from the electromagnetic waves equation given by

$$c = f \times \lambda \qquad (1)$$

where the speed, c has a constant numerical value of 3×10^8 m/s. f and λ are the frequency and wavelength, respectively.

The frequency spectrum of this band is used to provide services for radio communication, telephone communication and television signal transmission. However the bandwidth spectrum for the television signal at VHF and UHF is considered in the project (Richard, 1987).

Radiation Patterns of the Antenna

Whenever an electric current flows across a conductor, such conductor is surrounded by a magnetic field, the direction of which depends on the direction of the current flow according to the Lenz's law. When the current changes, there is also a corresponding increase in the electric field produced or induced by the magnetic field. The changing magnetic field produced also, in turn, produces a changing electric field. Hence a conductor carrying alternating current is always surrounded by a continuous changing magnetic and electric fields that is completely dependent on one another (Theraja and Theraja, 2000).

The energy radiated from the conductor supplied by an alternating current is in the form of electromagnetic wave. In this electromagnetic wave, the electric and magnetic fields are at right angles to each other and they are both mutually at right angles to the direction of propagation. This radiated energy increases with increase in the frequency of the supplied energy. The radiation pattern of a typical radiating antenna is shown in Figure 2.

Antenna Principles

A receiving antenna in practice has a length that is a sizeable portion of the wavelength of the transmitted signals. The most popular antenna used for the reception of television signal in the VHF and UHF band is known as the Yagi –Uda (A name derived from the scientists that invented the antenna). This antenna consists of a dipole, a reflector and a system of directors. The half- wavelength antenna is known as a DIPOLE. A reflector is generally larger than the folded dipole and placed at appropriate distance behind the dipole and the directors in front of the same dipole to receive extra gain compared to the dipole alone.

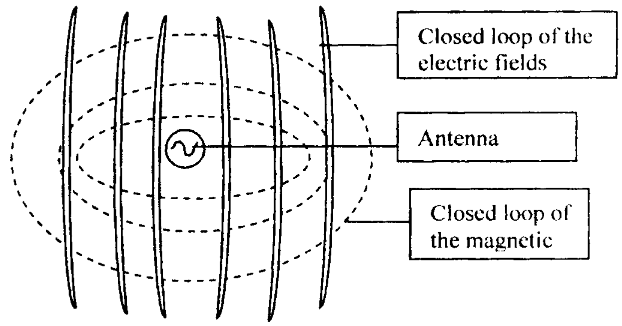

Figure 2: Radiation pattern of an antenna

These directors are normally shorter than the dipole and with appropriate spacing, which will narrow the main beam further, making the antenna to be more directional and thus giving a higher gain. The elements are clamped on the self-supporting rod with and insulator in-between the contacting point to avoid absorption or losses of radiation though the driving poles as shown in Figure 3 (Richard, 1987).

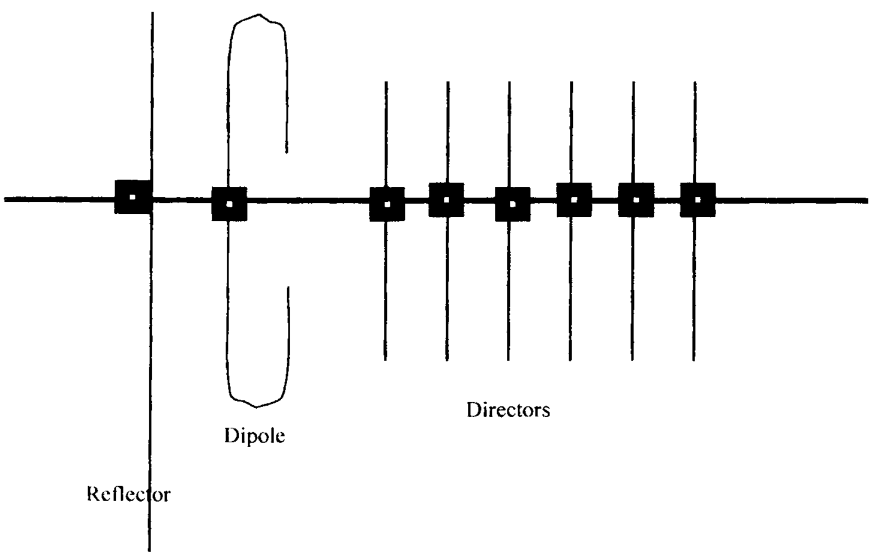

Figure 3: A system of dipole antenna

Dipole Antenna

The half wave dipole

The half wave dipole forms the basis for VHF / UHF signal reception. It is in conjunction with a number of parasitic elements. These parasitic elements are the REFLECTOR and the DIRECTORS. They are essentially for increasing the directivity of the antenna, thereby increasing the gain. A purely resistive dipole has a length of about 5% less than λ/2.It is cut into equal pieces and mounted on an insulator with a gap of about 3cm. It offers a resistance of about 75Ω. Figure 4 shows a typical half-wave dipole (Alade et al., 2004).

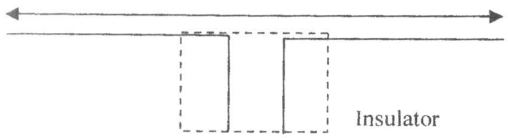

Figure 4: Half wave dipole

Folded Dipole

The folded dipole is designed with the aim of increasing the center impedance of a half wave dipole while the overall length is retained. As shown in Figure 5, when the dipole of the same dimension is brought very close to the dipole, which is energized, a signal of equal current and voltage is induced in the same phase. By joining the top and bottom of the dipoles, the conditions with regards to the current and voltage are not all altered; this means that the available signal current is divided and subsequently, the impedance at the centre of the energized dipole is increased by four times. Suppose we have the same power supplied to the dipoles, the folded input current will be one-half that of the half – wave dipole with the same input voltage. Therefore, the impedance of folded dipole is four times that of the dipole as provided in equations 2. Figure 5 shows the diagram of a folded dipole (Richard, 1987).

$$R_{FD} = 4R_D = 4 \times 75 = 300\Omega \qquad (2)$$

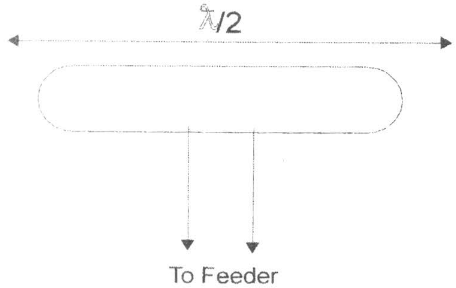

Figure 5: Folded dipole

This implies that the nominal impedance of 75Ω has increased to 300Ω by designing a folded dipole. In VHF and UHF frequencies, single fold dipole is generally used alongside with the parasitic elements known as reflectors and directors.

Reflectors

This is one of the parasitic elements placed behind the dipole with respect to the television transmitting station. It is approximately 5% longer than the folded dipole and mounted on the side of the antenna away from the direction in which maximum radiation was directed to. The reflector affects the radiation of the driven elements because the electromotive force is induced into it and causes it to radiate energy. The exact effect produced depends upon the length of the reflector and the distance from the active element. The reflector, therefore, has an inductive reactance. Since the reflector is reactive, the element is therefore lossless and re-radiates the energy that falls on it thereby increasing the directivity in the forward direction. The effective spacing from the dipole is 0.15λ to 0.25λ (Alade et al., 2004).

Directors

As one of the parasitic element of VHF/UHF antenna, the director is approximately 5% shorter than the folded dipole. It is usually spread in the range 0.125λ - 0.15λ. However, the director to – director spacing is taken to be 0.10λ - 0.12λ.

A director is a conducting rod with approximately 5% shorter than length of the folded dipole, that is, λ/2. It is mounted on the side of the antenna at which maximum radiation or reception is desired. The addition of further directors gives extra gain to the antenna but the increase must be rejected because of its effect on the bandwidth (Alade et al., 2004).

Antenna Properties

Polarization

The plane of polarization of the wave determines the placement of the antenna for maximum response. A horizontal polarization is said to occur when the lines of electric field are horizontal with respect to the orientation of the antenna. The two systems of polarization (i.e. vertical polarization and horizontal polarization) are used by television system for the transmission of the TV signal. This is to be able to discriminate between signals from different transmitters sharing common channel frequency. The energy radiated from the transmitter antenna is in the form of electromagnetic wave (Richard, 1987).

Bandwidth

The bandwidth for the television channel is 6.0MHz and this is the bandwidth in which its operation becomes satisfactory. The antenna performance can be considered to be dependent on the bandwidth of the TV channel. The bandwidth of a dipole antenna is directly proportional to the length of the element and the corresponding diameter (Richard, 1987).

Antenna Gain and Directivity

This indicates the extent in which radiation of the antenna is concentrated in a particular direction. That is, the directional properties of the antenna. This property accounts for antenna efficiency, since the power radiated by the transmitting antenna is always less than the power received due to space loss in the atmosphere (Alade et al., 2004).

Antenna Pre-Amplifier

The power level of the TV signal transmitted from the TV station becomes very weak at greater distance due to the signal attenuation before it reaches the receiving antenna. The power level of the receiving antenna will just be a few milliwatts (Richard, 1987). This power level may not be enough to drive the TV power amplifier; hence there is need for a booster to increase the level of the signal for good reception. Such a preamplifier may also be useful due to the following conditions of signal reception:

- When raster are noticed on the receiver station on the TV receiver.
- If the picture contrast is not sufficient or weak
- Poor audio output.
- When more than one TV set is connected to the antenna system.

The amplifiers (or boosters) are in two stages. The first stage is a pre amplifier stage to raise the received signal directly from the antenna while the second stages further raise the signal level for higher gain.

The pre-amplifier is a transistor circuit, which is built around an a.c signal applied to its input. It is called a voltage amplifier if the magnitude of the output voltage from the amplifier is greater than the input of signal. The ratio of the output voltage to the input voltage is referred to as amplification or gain.

Antenna Cable

In the design of the active VHF/UHF antenna, a 75Ω coaxial cable is selectively chosen. This is to ensure proper impedance matching with the pre-amplifier circuit. This also helps to produce undistorted signal received at the receiver end.

Designing a Transistor Amplifier (Single Stage)

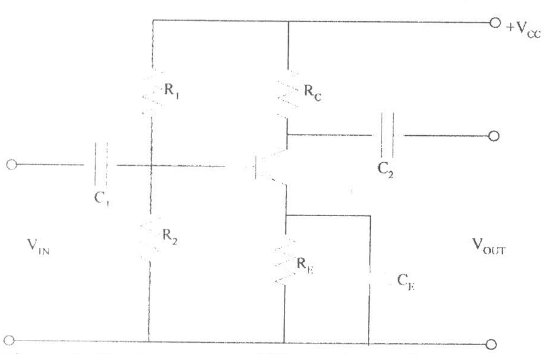

Figure 7: Single stage amplifier with coupling

In designing a transistor amplifier circuit, it is necessary to take the following into consideration.

- An appropriate operating point selected (i.e. Ic, I_B and V_{CE}) from the manufacturer's data book. The P_D is also obtained.
- It must be assumed that $V_E = I_E R_E \approx I_C R_E$.
- Necessary values of V_{CE} and R_C selected.

If the V_{CE} is specified, then R_C can be obtained as (Theraja and Theraja, 2000):

$$R_C \approx \frac{V_{CC} - V_{CE} - I_C R_E}{I_C} \quad (3)$$

If I_C is specified then

$$V_{CC} \approx I_C R_E + V_{CE} + I_C R_E. \quad (4)$$

- V_{BB} is also calculated as:

$$V_{BB} = I_B R_B + V_{BE} + R_E (I_B + I_C) \quad (5)$$

Then the values of the resistors are obtained.

$$R_1 = \frac{V_{CC} R_{BB}}{V_{CC} - V_{BB}} \quad (6)$$

$$R_2 = \frac{V_{CC} R_B}{V_{BB}} \quad (7)$$

Other transistor parameter (**Emitter Input Impedance**) To obtain the transistor input, emitter a.c resistance, the resistance r_e is obtained as

$$r_e = \frac{25\text{mV}}{I_E} \quad (8)$$

The input impedance as seen by a.c source looking in at the base requires the r_e parameter determined at room temperature (Alade et al., 2004).

$$R_{in} = \beta (I_E (r_e + R_E)) \quad (9)$$

- Output impedance:
  The output impedance R_{out} is approximately RC when it is on no load connected.
- Current gain
  The current gain from the base to collector is I_C to I_B.

$$\beta = \frac{I_C}{I_B} \quad (10)$$

- Coupling capacitor.
  The capacitor is reactive component. This means that the opposition it offers to the alternating signal is dependent upon two things:

(a) The capacitance of the capacitor.
(b) The frequency of the signal.

Analysis of Pre - Amplifier Circuit

Consider the equivalent RC coupled Amplifier in Figure 8, the effective input capacitance and the collector. Base junction capacitance with r_e (small signal input resistance) is considered important for the transistor devices and is found to be significant (Theraja and Theraja, 2000).

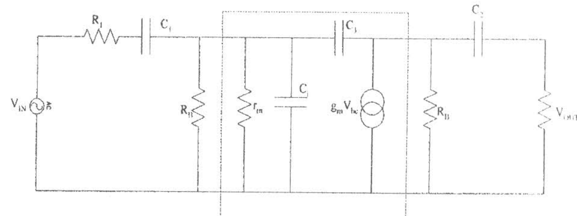

Figure 8(a): Equivalent circuit for RC coupled amplifier.

A typical frequency versus gain curve is shown in Figure 8(b). The analysis of the curve indicates three important values of frequencies. They are:

(a) The Mid-frequency Region.
The gain is independent of frequency variation in this region.
The capacitance (coupling and bypass) can be neglected because they are assumed large with negligible reactance. But the transistor internal capacitances are small so that their reactances are large. Thus a voltage divider may be created by the transistor- input resistance (Theraja and Theraja, 2000).

The mid – frequency voltage gain

$$A_{vm} = \frac{V_0}{V_S} \quad (11)$$

(b) Low – frequency Region

The coupling capacitances are significant and must be retained in the circuit so that the voltage gain is

$$A_{v2} = \frac{1}{\sqrt{2}} A_{vm} \quad (12)$$

(c) High – frequency response

At high – frequency, the reactances of the coupling and bypass capacitors are negligibly small, but the other capacitances (inter-electrode and capacitance) become significant.
The high frequency voltage is also

$$A_{VH} = \frac{1}{\sqrt{2}} A_{vm} \quad (13)$$

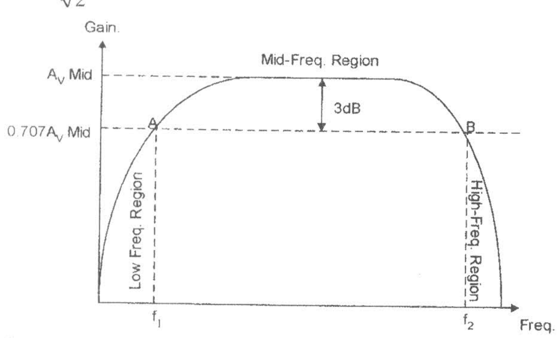

Figure 8(b): Graphical illustration of operating stage of the amplifier

Filter Section

The type of filters involved for this project is passive filters. In a low pass filter design network, if all the zeros of the system were assumed to be at infinity, the magnitude function takes the general form (Kuo, 1998)

$$M_{(w)} = \frac{K_0}{\left[1 + f(w^2)\right]^{\frac{1}{2}}} \quad (14)$$

Where K_0 is the d.c gain constant

$f(w^2)$ is the polynomial to be selected to give the desired amplitude response.

There are two bands for which filters are to be designed. They are the UHF and the VHF bands. Low pass filter is to be designed for the VHF band while high pass filter for the UHF band. In this design, the Butterworth approximation is used because of its maximally flat property (Kuo, 1998).

(a) Low pass filter
The low pass filter is designed for VHF band. The band ranges from 30MHz to 300MHz, thus the cut – of frequency for the low pass filter is 300MHz.

(b) High pass filter
The high pass filter is designed for the UHF band. This band ranges from 300MHz to 3000MHz. Thus the cut off frequency for the UHF band is 3000MHz.

The illustration for coupling of these two filters is as shown in Figure 9.

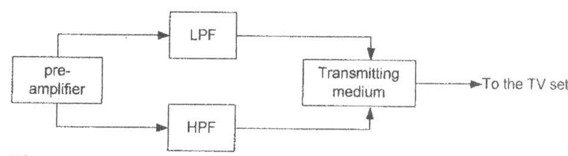

Figure 9: Illustration of the coupling of low pass and high pass filters.

Summary of Operation of the Active Antenna

When the incoming signal energy reached the directors, all the conducting elements get excited into resonance. The re-radiation energy from the parasitic elements adds constructively at the folded dipole for an overall power gain and passed through the signal cable to the pre-amplifier circuit.

The RF signal enters through the filter section of the pre-amplifier circuit. The filter section traps the bandwidth of the frequency range for the VHF and UHF band in which the required signals are present. The trapped signal then enters into the single stage transistor pre-amplifier which magnifies the signal for final reception at the output on the TV receiver.

Design of Yagi Antenna
VHF Antenna

The VHF antenna is constructed with six elements: one dipole, one reflector and four directors. The frequency range of the VHF band ranges from 30MHz to 300MHz. therefore the length spacing of the element can be calculated as follows.

$$\text{Mid frequency} = \frac{30+300}{2} = 165\text{MHz}$$

From electromagnetic equation (equation 1)

$$C = f\lambda$$

$$\lambda = \frac{C}{f} = \frac{3\times10^8}{165\times10^6} = 1.82\text{m}$$

Where C = velocity of light
f = mid frequency
λ = wavelength

The designed values for each item of the antenna are as presented in Table 1.

Table 1: Designed values for VHF antenna elements

Item	Calculated Value (m)	Designed Value (m)
Length of Dipole, L	0.91	0.82*
Length of Reflector, L_R	0.96	0.96
Length of Director, L_D	0.86	0.43**
Distance between Reflector and Dipole D_{RD} (0.2λ)	0.364	0.10***
Distance between Director and Dipole D_{RD} (0.2λ)	0.364	0.05****
Distance between Director and another Director D_{DD} (0.2λ)	0.364	0.05*****

*The length of a purely resistive dipole must be about 10% less than the calculated value.
**For compatibility, the length of the director would be taken as half of the calculated value. Hence, the remaining length of the directors would continually decrease by 5%.
***For compatibility, the distance between the reflector and the dipole could be taken as 10cm.
****For compatibility, the distance between the director and the dipole could be taken as 5cm.
*****For compatibility, the distance between directors to another director could be taken as 5cm.

UHF Antenna

The UHF antenna would have seven elements: One dipole, one reflector and five directors. The frequency range of the UHF band is 300MHz and 3000MHz. it covers channels 14 to 83. The length of the element for the UHF band and the spacing between the elements are calculated as shown below.

$$\text{Mid freq} = \frac{300+3000}{2} = 1650\text{MHz}.$$

$$\lambda = \frac{C}{f} = \frac{3\times10^8}{1650\times10^6} = 0.1818\text{m}$$

The designed values for each item of the antenna are as presented in Table 2.

Table 2: Designed values for UHF antenna elements

Item	Calculated Value (M)	Designed Value (M)
Length of Dipole, L	0.09	0.82*
Length of Reflector, L_R (5% longer than L)	0.86	0.86
Length of Director, L_D (5% less than L)	0.78	0.39**

*To obtain purely resistive impedance for the antenna, the dipole length must be less than $\frac{\lambda}{2}$ by 10% and to obtain a realizable length for the dipole, we multiply the value obtained by 10.

**For compatibility, the length of the directors could be taken as 39cm. (i.e. L_D/2).

Design of the Pre-amplifier Stage

A well-regulated power supply was designed for the amplifier stage; with an LED to indicate whether the power is ON or NOT.

A C3355 BJT transistor was used as the main amplifying element. The operating characteristics of the transistor were:

$V_{cc} = 12V,\ V_c = 8V,\ V_{CE} = 5V,\ V_E = 2V,\ I_{CQ} = 0.01A,\ h_{FE} = 40dB.$

The designed parameters for Pre-amplifier stage as calculated are as shown in Table 3.

Table3: Designed parameters for pre-amplifier stage

Item	Calculated Value	Designed Value
R_B	2000 Ω	2000 Ω
R_C	800 Ω	800 Ω
R_E	195 Ω	200 kΩ
R_1	2.7 kΩ	3 kΩ
R_2	7.5 kΩ	8 kΩ
Coupling Capacitor	3.1pF	3pF
By-pass Capacitor	265.3pF	200pF
R^1_C	555 Ω	600 Ω

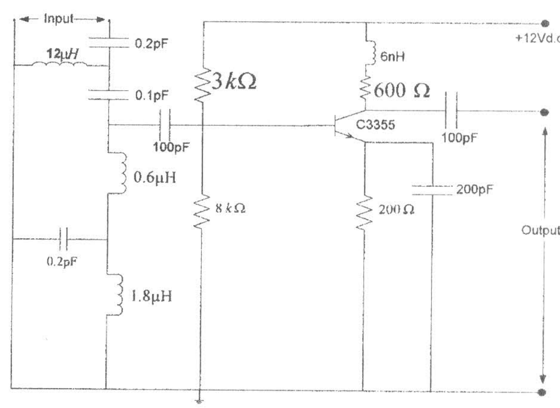

Figure 10(a): Antenna pre-amplifier circuit

Design calculation for power gain

$$A_V = \frac{R^1_C}{r_e + R_E} \quad (21)$$

$$A_V = \frac{555}{2.44+200} = 2.74$$

Recall A_i = 40dB (=100), A_v = 2.74, and

$A_P = 10 \log A_V A_i$ = 24.40dB (Where A_p is the power gain)

Three stage of this amplifier was connected in cascaded form to get a higher gain of 73.2dB.

Design of Low Pass and High Pass Filters

Selecting a three - pole filter design with an impedance functions:

$$Z(s) = \frac{1}{S^3+2S^2+2S+1}$$

$$Z(s) = \frac{\frac{1}{S^3+2S}}{\frac{S^3+2S}{S^3+2S}+\frac{2S^2+1}{S^3+2S}}$$

$$Z_{22}^{(s)} = \frac{2S^2+1}{S^3+2S}$$

$$S^3+2S\overline{)2S^2+1}\ \overline{)0}$$

$$\frac{0}{2S^2+1\overline{)S^3+3S}\ \overline{)S/2}}$$

$$\underline{S^S+S/2}$$

$$\frac{3S}{2}\overline{)2S^2+1}\;\overline{)4S/3}$$
$$2s^2$$
$$1\overline{)3S/2}\;\overline{)3S/2}$$
$$\frac{3S}{2}$$

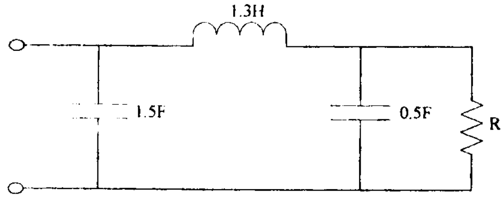

Figure 11(a): Normalized filter circuit

Denormalizing the circuit

$R_{in} \quad = \quad R_o = 1.72k\Omega$

For low pass filter the cut off frequency is 300MHz

$$C_{LP} = \frac{C_n}{R_o W_o}$$

$$C_{LP1} = \frac{0.5}{1.72\times10^3\times20\times300\times10^6} = 0.048\text{pF}$$

$$C_{LP2} = \frac{1.5}{1.72\times10^3\times2\pi\times300\times10^6} = 0.15\text{pF}$$

$$L_{P1} = \frac{R_0 L_0}{W_0} = \frac{1.72\times10^3\times1.3}{2\pi\times300\times10^6} = 12\mu H$$

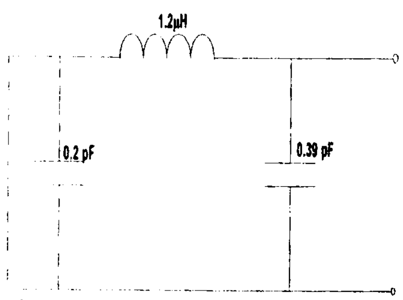

Figure 11(b): Low pass filter for VHF Band.

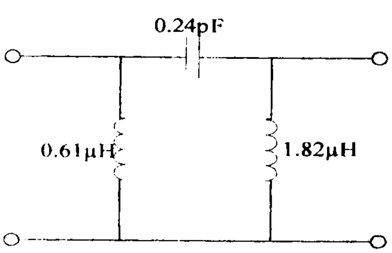

Figure 11(c): High pass filter for UHF band

For high pass filter,

Cut off frequency $\Rightarrow 470 \times 10^3$ Hz

$W_o = 2\pi \times 300 \times 10^6 = 1.88 \times 10^9$.

$$CH_{P1} = \frac{1}{W_0 R_0 L_n} = \frac{1}{1.88\times10^9\times1.72\times10^3\times1.3} = 2.38 \times 10^{-12} \approx 0.24\text{pF}.$$

$$L_{HP1} = \frac{R_0}{W_0 C_0} = \frac{1.72\times10^3}{1.88\times10^9\times0.5} = 0.61\mu H$$

$$L_{HP2} = \frac{R_0}{W_0 C_0} = \frac{1.72\times10^3}{1.88\times10^9\times1.5} = 1.82\mu H$$

Results and Observation

Results

The constructed antenna with pre - amplifier was tested with a television receiver and it was able to pick few desired stations. Stations like NTA Ilorin and NTA Ibadan both which are in the VHF band were considered. Kwara state Television broadcasting stations situated in Ilorin and the Osun state Television broadcasting station both of which transmit in the UHF band were also received by the antenna.

With a favorable weather conditions, the picture and audio quality was greatly improved.

Observation

It was observed that with the increase in the length of the antenna more than the available ones, the quality of signal received was improved. Also in some cases it was necessary to turn the antennas to a particular direction (i.e the major lobe) in order to receiver a purer signal.

Summary

The design and construction of this active antenna was an interesting but a challenging project. One of the beauties of the project is the ability of television signal reception at fringe coverage area of some of the transmitting station where the signal strength is very weak. The gain obtained (73.2dB) was an improvement on available design (66.82dB of Alade, et al, 2004). Another distinguishing feature of this design is the careful design for the filters; this was not common in other designs available.

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