DESIGN AND CONSTRUCTION OF A LOW POWER TELEVISION TRANSMITTER

BY

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A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF A BACHELOR OF ENGINEERING DEGREE (B.ENG) IN ELECTRICAL AND COMPUTER ENGINEERING
IN THE DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING
FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA

NOVEMBER, 2004

CERTIFICATION

This is to certify that I, **UGOCHUKWU OBINNA OZEMELA**, successfully carried out this project work on the design and construction of a television transmitter under the supervision of Engr. Paul Attah. This is in partial fulfillment of the requirement for the award of a Bachelor of Engineering degree (B.Eng) in the Electrical and Computer Engineering Department of the Federal University of Technology, Minna, Niger State, Nigeria.

Attah .... 10th Dec, 2004 ....

ENGR. PAUL ATTAH — DATE

(PROJECT SUPERVISOR)

.... 31/01/2005 ....

ENGR. M. D ABDULLAHI — DATE

(HEAD OF DEPARTMENT)

....

EXTERNAL EXAMINER — DATE

DECLARATION

I hereby declare that this project is an original work by UGOCHUKWU OBINNA OZEMELA under the supervision of Engineer Paul Attah and this is a record of a thorough research.

Information derived from published work of other distinguished engineers have been duly acknowledged in this text.

DEDICATION

This project is specially and particularly dedicated to GOD ALMIGHTY (THE ALPHA AND OMEGA, THE BEGINNING AND THE END, THE FIRST AND THE LAST) and to my Parents. Mr. & (Dr.)Mrs. C. Ozemela and the entire Ozemela family.

ACKNOWLEDGEMENT

TO GOD BE THE GLORY, HONOUR, POWER, MAJESTY, DOMINION, GREAT THINGS HE HAS DONE. THANK YOU GOD FOR THE PRIVILEDGE OF SEEING ME THROUGH MY UNIVERSITY EDUCATION.

My special and sincere thanks go to both of my parents, Mr. Chinedum Ozemela and Dr.(Mrs.) Chinenyem Ozemela. May God who made it possible for me to be a member of your family and who blessed you with the resources with which you took care of me and ensured my successful completion of my university education, continue to bless you all the days of your lives. May you live to enjoy the fruit of your labour in me in Jesus name, AMEN.

I wish to express my sincere appreciation to Engr. Paul Attah, my God given Supervisor for the assistance, support and encouragement you gave me in ensuring my completion of this project. Also to the entire staff and lecturers of the Electrical/Computer Engineering department. May God continue to go with you and remain with you all the days of your life, AMEN.

My special thanks also goes to my Head of Department, Engr. M. D. Abdullahi. God bless you sir.

My profound gratitude goes also to my sisters, Chinemerem, Ekelechi and Ngozi and my cousins, Blessing, Joy and Franka, who supported me both spiritually and financially and MY Aunty Onyekachi. May God continue to be your strength and shield in Jesus Name, Amen.

I will not forget you my family friends, Mr. & Mrs. Chika Egwoatu and family, Mr. & Mrs. Aghahowa and family, Mr. Christian Ohaneme and family, Mr. & Dr. (Mrs) Obinya, Mr. Okechukwu Iroegbu, Da Onyinye, Mummy, Gugo and Mama Lily.

My special thanks also go to my friends who supported me mentally, psychologically, spiritually, physically; Kelechi, Abdulkadir, Daniel, Becky, Joy, Afam, Funsho, Nwando, Emmanuel, Ramat, Kunle, Sule, Kemi, Samuel, Izika, Wale, Johnson, Bukky, Idongesit, Jolomi, Susan and all those who in one way or the other contributed to my success. God bless you all.

ABSTRACT

This project report deals with the design and construction of a wireless TV transmitter that works over the FM frequency and allows the transfer of a video/audio signal over a certain distance to a tuner (Television set). It is designed, with the use of various active components, such as transistors and diodes and passive components like resistors, capacitors, inductors to achieve the goal of transmitting video and audio signals. The sending or transmission of video/audio signal was designed in such a way that both the video and audio signals were transmitted at the same time due to the fact that the audio subcarrier frequency is 4.5MHz higher than the video carrier frequency.

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CHAPTER ONE

GENERAL INTRODUCTION

1.1 INTRODUCTION

The field of communications is highly dynamic, with constant advancement in technology and also improvement on the old systems. Communications was the basic origin of the electronics field and is simply referred to as the process of sending, processing and receiving information using electronic means. This information could be voice or data. The function of communication system is to transfer information from one point to another through some communication media. These media may be cables, fibre optics or a wireless link (free space). In communication, a radio or television transmitter can be used. This project work is based on the functions, applications and mode of operation of a low power TV Transmitter.

One of the most useful gadgets a Video/TV enthusiasts can have is a low power TV transmitter. The main function of the transmitter is to deliver sufficient high radio frequency (RF) power for transmission through the transmitting antenna. This process involves modulating a high frequency carrier with the message signal for ease of transmission, channel assignment, noise/interference reduction, multiplexing or to overcome equipment limitations.

Modulation is the process of impressing a low frequency message signal onto a higher frequency (carrier) signal.

While a radio transmitter can employ either amplitude or frequency modulation (AM or FM), a television transmitter employs both to achieve the desired signal transmission.

Communications systems are often categorized by the frequency of the carrier. The table below provides the names for various frequency ranges in the radio spectrum and their different areas of application:

TABLE 1.0: ELECTROMAGNETIC SPECTRUM

Frequency Band	Classification	Applications
3 – 30kHz	Very Low Frequency (VLF)	Long-range navigation, sonar
30 – 300kHz	Low Frequency (LF) or Long Wave (LW)	Navigational aids, radio beacons
300 – 3000kHz	Medium Frequency (MF) or Medium Wave (MW)	Maritime radio, direction finding, commercial AM sound broadcasting, coast guard communication
3 – 30MHz	High Frequency (HF) or Short Wave (SW)	Telephone, AM-SW radio broadcasting, search and rescue, aircraft communications with warships
30 – 300MHz	Very High Frequency (VHF)	VHF television broadcast, FM radio, police, private aircraft
300 – 3000MHz	Ultra High Frequency (UHF)	UHF television broadcast, radar, satellite communications
3 – 30GHz	Super High Frequency (SHF)	Microwave link, land mobile communication
30 – 300GHz	Extra High Frequency (EHF)	Railroad service, radar landing system, experimental

A TV transmitter is actually two (2) separate transmitters which transmit both video and audio signals from an input device to a television set over a wireless link. The sound or audio transmitter is a frequency modulated (FM) system, very similar to broadcast FM radio. The main difference between broadcast FM and TV audio systems is that TV uses a $\pm$25kHz low frequency deviation, while a broadcast FM uses a $\pm$75kHz higher frequency deviation. Thus, the TV audio signal has the same precision in reproduction of sound, but is less effective in canceling indirect noise effects. The video or 'picture' signal is amplitude modulated onto a carrier signal.

Thus, the composite transmitted signal is a combination of both AM and FM principles. This is done to minimize interference effects between the two at the receiver, since an FM receiver is relatively insensitive to amplitude modulation and an AM receiver has rejection capabilities to frequency modulation.

The TV transmitter is designed to accept video and audio base band signals from satellite receivers, video cameras, VCR's or any compatible input device. These devices are referred to as input transducers. The transmitter is very versatile due to its ability to accept signal from different types of input transducers.

The TV transmitter can be used to transmit satellite signal from one decoder to television sets situated in various offices, a radius of approximately 96m from its location.

Other uses of the TV transmitter include:

- wireless video camera for surveillance purposes
- wireless satellite/VCR transmission in household environments.

The uses of this device (TV transmitter) reduces the need to have multiple wires / cables used for the network installation.

The TV transmitter can be used for other practical purposes. With the continuous advancement of technology, many more uses will become a necessity.

1.2 COST/BUDGET

Most of the parts used in this project were common parts, but a few components had to be ordered specially. This increased the cost of the project. The total cost was N20,000.

A few colleagues of mine assisted in the design aspect of my project work. While I soldered the components onto the board during the construction, the board was held firm for neat and proper soldering. Others gave their little but appreciated inputs towards ensuring the success of this project.

1.3 AIM AND OBJECTIVE

To design and build a transmitter that can be used in the office premises of lecturers in the engineering department to transmit satellite (Video and Audio) signal within a range of transmission of up to 96m. using a power source of 12V DC supply during the alignment procedure.

1.4 DESIGN SPECIFICATION

The desired specifications are:-

- Input voltage of 220V
- Power voltage of 12V for the circuit
- Maximum stability of signal transmitted
- Maximum reliability
- Frequency range within NCC regulations.

1.5 PROJECT MOTIVATION

In the fast-paced world in which we live, there is virtually no time or space for inconveniences or irritants and a greater need for portability, simplicity, adaptability and cost effectiveness have arisen.

After stumbling over cables used for the installation of the DSTV satellite decoder at home, the idea to use a device that would require no use of cables for transmission of the signal to any television set in the house arose from this experience.

The desire to properly understand the mode of operation of a TV transmitter and enthusiasm in building one myself drove me to research, build and present a TV transmitter as my final year project.

1.6 LITERATURE REVIEW

Communicating over long distances has been a challenge throughout history. In ancient times, runners were used to carry important messages between rulers or other important people. Other forms of long-distance communication included smoke signals, chains of searchlights and flags to send a message from one tower to another, carrier pigeons, and horses.

Modern telecommunications began in the 1800s with the discovery that electricity can be used to transmit a signal. For the first time, a signal could be sent faster than any other mode of transportation. The first practical telecommunications device to make use of this discovery was the telegraph.

The idea of wireless radio communications arose in the mid-1800s from the theories of two English physicists, Michael Faraday and James Clerk Maxwell.

In 1873 the Scottish scientist James Clerk Maxwell predicted the existence of the electromagnetic waves that make it possible to transmit ordinary television broadcasts.

In 1888 German physicist Heinrich Hertz applied these theories to construct a spark-gap transmitter, a device that generated radio waves from an electric spark.

In 1895 Italian electrical engineer Guglielmo Marconi extended the range of such transmissions and adapted the technology to send and receive wireless telegraph signals. This began a revolution in wireless telegraphy that would later result in broadcast radios that could transmit actual voice and music.

In 1901 Marconi built the first transoceanic telegraph transmitter, which had a 3,400 km (2,100 mi) link from Poldhu, Cornwall, England, to St. John's, Newfoundland.

Developments in vacuum tube technology in the early 1900s by English physicist and engineer Sir John Ambrose Fleming and American inventor Lee De Forest made it possible to modulate and amplify wireless signals to send voice transmissions.

The range and clarity of voice transmissions increased as advancements in technology were made, and in 1915 the American Telephone & Telegraph Company transmitted a voice message by radio between the United States and France.

By the 1930s small two-way radio transmitters were in common use among law enforcement and civil emergency authorities. Improvements in technology have made two-way communications systems smaller and lighter, with extended range and capabilities.

Television got its start as a mass-communication medium shortly after World War II (1939-1945). The expense of television transmission prevented its use as a two-way medium, but radio broadcasters quickly saw the potential for television to provide a new way of bringing news and entertainment programming to people.

A television broadcasting boom began just after the war in 1946, and the industry grew rapidly. Signal transmission involves the use of both active and passive components. A brief discussion on these components is given thus:

CLAMPING

Below is a representation of a typical clamp application using a capacitor and a diode and showing the effect of the capacitor and clamp diode on the signal.

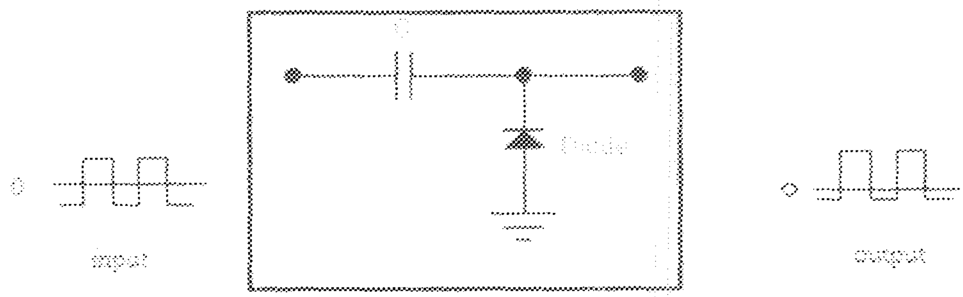

Figure 1.1: Dc Restoration

Without the diode clamp, the delicate input circuits are easily destroyed by static electricity discharges during handling. Clamping circuits are also needed to ensure proper DC video-level relationships because the sync pulses tips must always produce constant maximum transmitter RF output levels, regardless of the rest of the video waveform.

Variable resistors(also called volume controls, potentiometers, pots or trimmers) are useful as panel controls or internal adjustments in circuits. They are represented thus:

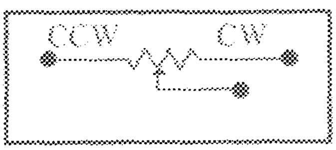

Fig 1.2: Potentiometer

They are handy for calibration adjustments.

TRANSISTORS

Transistors are active components, a devise that can amplify, producing an output signal with more power in it than the input signal. The additional power comes from an external source of power (the power supply to be exact). There are basically two main types of transistors, namely; The Bipolar Junction Transistors (BJT's), whose operation depends on the floor of both minority and majority carriers and The Field Effect Transistors (FET's) in which current flows due to majority carriers only (either electrons or holes).

A BJT transistor is a three terminal semiconductor device made up of two p-n junctions. Its three terminals are known as 'collector', 'base' and 'emitter'. The device is current controlled, ie the base current controls the amount of current flowing between the collector and emitter. The higher the base current, the greater the current flow between the collector and emitter and vice versa. It is available in two varieties: NPN and PNP. For proper operation of a transistor, it is essential to apply voltages of correct polarity across its two junctions. Transistors can be connected in various configurations:

Common - Base mode

Common - Collector mode

Common - Emitter mode

As a devise with power gain, it is distinguished by its ability to make amplifiers, oscillators or switches.

TRANSISTOR SWITCH

The Class amplifier leads straight into the use of the transistor as a switch. In this case the criterion becomes whether the transistor is conducting on not. This is the basis of digital circuits, ie ON or OFF; no intermediate state is wanted. Class A amplifier is also representative of a transistor switch circuit, as shown in Fig 1.3:

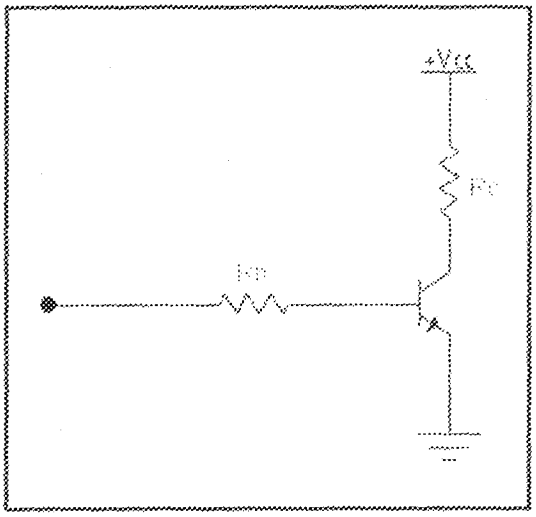

Fig. 1.3 Transistor switch

For the transistor configuration, since the transistor is biased to saturation,

$V_{CE} = 0$ when the transistor is ON which implies that

$V_F = I_cR_c + V_{CE}$ ---------------------- 2.1

$V_{in} = I_BR_B + V_{BE}$ ---------------------- 2.2

$\frac{I_c}{I_b} = h_{fe}$ ---------------------- 2.3

$R_b = \frac{V_{in} - V_{BE}}{I_b}$ ---------------------- 2.4

Where

I_c	=	collector current
I_b	=	base current
V_{in}	=	input voltage
V	=	supply voltage
V_{CE}	=	collector emitter voltage
h_{fe}	=	current gain

TRANSISTOR AMPLIFIER

The diagram below (Fig 1.4) shows a transistor operating as a common emitter amplifier, with a current source and a resistor as load.

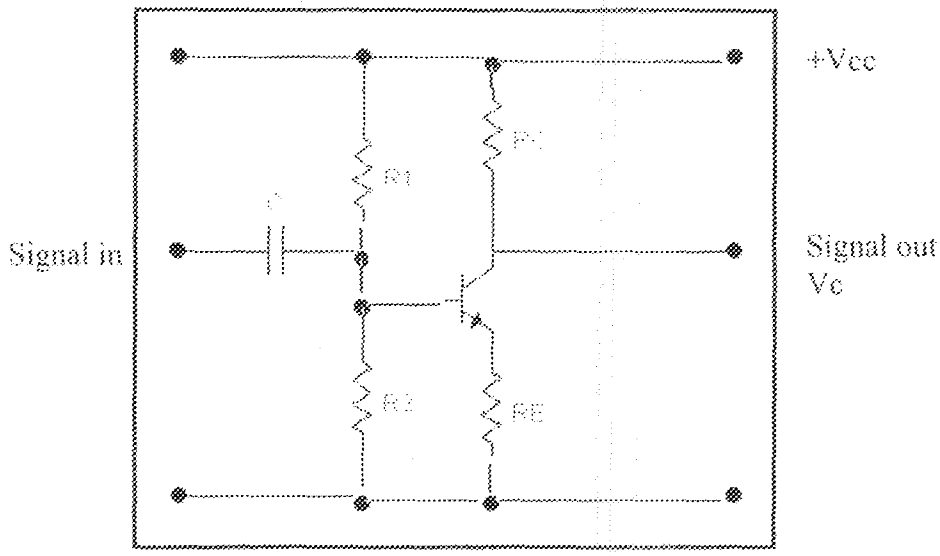

Fig 1.4 Transistor amplifier

The collector voltage is $V_C = V_{CC} - I_C R_C$ ---------------------2.5

A signal will be capacitively coupled to the base to cause the collector voltage to vary. C is chosen so that all frequencies of interest are passed by the filter it forms in combination with the parallel resistance of the base biasing resistors. It is obtained as ,

$$C \geq \frac{1}{2\pi f (R1 \| R2)}$$ ---------------------2.6

If a voltage is applied in the base, V_B, the emitter follows with $V_E = V_B$, which causes a change in emitter current

$$i_E = V_E / R_E = V_B / R_E$$ ---------------------2.7

and nearly the same change in collector current ($h_{fe} = I_C/I_B$).

Also, $R_C > R_E$.

Therefore, the initial change in base voltage causes a collector voltage change.

$V_C = -I_C R_C = -V_B (R_C/R_E)$ 2.8

This shows that it is a voltage amplifier with the voltage amplification given by

Gain = Vout / Vin = $-R_C / R_E$ 2.9

The minus sign means that a positive change at the input gets turned into a negative change at the output. This is called a common-emitter amplifier.

TRANSISTOR OSCILLATOR

At some point in a receiver or transmitter, it is necessary to produce a continuous sine wave. This is accomplished by a circuit known as an 'oscillator'. Fig 1.5 shows a basic circuit.

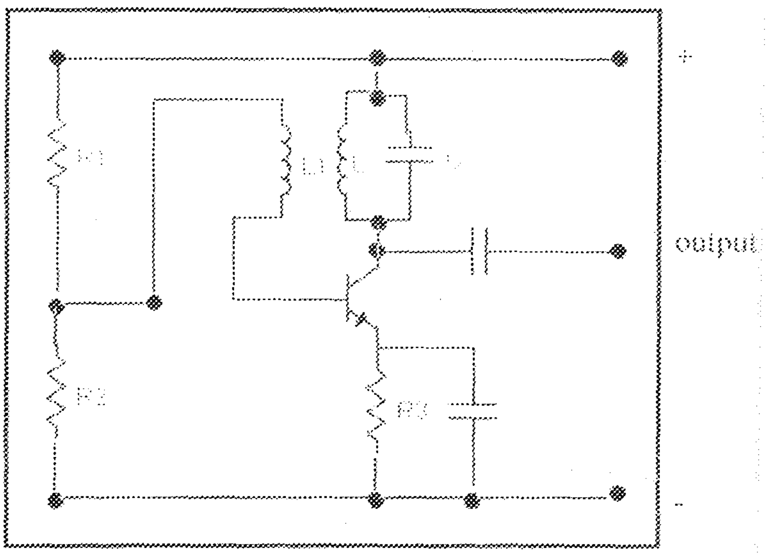

Fig 1.5 Basic oscillator circuit

The tuned circuit L – C determines the frequency of oscillation; the two coils L and L1 form the primary and secondary windings of a transformer; resistors R1, R2 and R3 set the bias conditions. The circuit is similar to the common emitter amplifier that produces a 180° phase shift between input and output.

When the circuit is switched ON there is a momentary surge which causes the circuit L-C to try to oscillate. This signal is fed back by the transformer action of L and L1. The phasing is such that this will cause a signal at the collector which adds to the original and so increases it. This is fed back again in the correct phase and so oscillations are maintained.

Oscillators are amplifiers in which there is intentional positive feedback from the output to the input. This feedback can be achieved in several ways, hence there are various oscillators, usually named after their originators, eg Colpitts, Hartley, Clapp-Gouriet, Vackar oscillators, etc. The first two are used in this project to generate different continuous sine waves.

TRANSISTOR BIASING

It is important to bias a transistor to obtain a good design that would operate properly.

DIODES

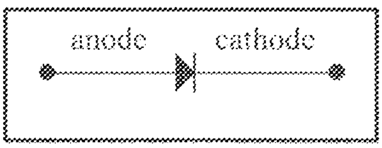

Fig 1.6: Diode

A diode is a pn crystal having a common region where p type and n type semiconductors meet. Hence, a diode of this type is called a semiconductor diode. The p-side has holes as its majority carriers, but the electrons are its minority carriers. A diode can be forward or reverse biased.

The diode is a very important and useful two-terminal passive non-linear device. It has a V-I curve shown in Fig 1.7

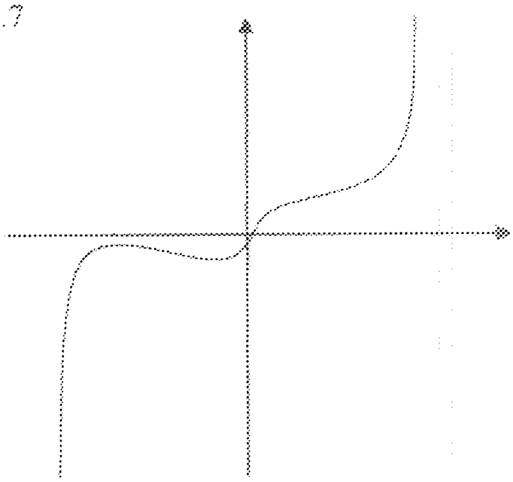

Fig 1.7: V – I curve for a diode

The diodes arrow (the anode terminal) points in the direction of forward current flow. If a forward current flow from the anode to the cathode, then the anode has a more positive voltage than the cathode: this is called the 'forward voltage drop'.

FREQUENCY DEVIATION: Frequency deviation is a measure of how much the carrier frequency varies under modulation. It must not be confused with the modulating frequency, which determines how often the carrier frequency is varied as a result of modulation. The ratio of the deviation to the modulation frequency is called the *modulation index* and is often designated by the Greek letter β (beta). The values of beta varies instantaneously.

$$\beta = \frac{\Delta f}{f_m} \qquad \text{..........3.0}$$

where β = modulation index
fm = modulating frequency
Δf = frequency deviation

OSCILLATOR

A good oscillator – as far as low-power transmitter use is concerned has the following characteristics:

1. *Good frequency stability:* Ideally, temperature and voltage variations, together with inevitable circuit component tolerances, should not have too serious an effect on the oscillator frequency. Only certain components should affect the frequency of oscillation. The load placed on the oscillator should not change the oscillator frequency.

2. *Adequate power output:* Signal output should be adequate to drive the load or following stage, even at the minimum expected supply voltage. The oscillator should start up reliably at low supply voltages and temperatures.

3. *Ability to be modulated:* Direct FM is often used, in which an audio or other modulating waveform is applied to the circuit, which is connected to the frequency-determining elements in the oscillator circuit.

4. *Simplicity:* To keep size and cost down, circuits with as few components as possible are preferred, but other performance requirements may dictate the exact circuitry needed.

Frequency-determining elements are those elements in an oscillator circuit that affect or are intended to determine the oscillator frequency, such as an LC tank circuit or a crystal. These elements must have as high a Q factor as possible.

Q Factor or Quality factor is a measure of the sharpness of the peak (a very sharp frequency characteristic). It equals the resonant frequency divided by the width.

TRANSMITTER/RECEIVER SYNCHRONIZATION

When the video signal is detected at the receiver, some means of synchronizing the transmitter and receiver is necessary:

1. When the TV camera starts scanning line 1, the receiver must also start scanning line 1 on the Cathode Ray Tube (CRT) output display. You do not want the top of a scene appearing at the centre of the TV screen.

2. The speed that the transmitter scans each line must be exactly duplicated by the receiver scanning process to avoid distortion in the receiver output.

3. The horizontal retrace or time when the electron beam is returned back to the left-hand side to start tracing a new line, must occur coincidentally at both transmitter and receiver. You do not want the horizontal lines starting at the center of the TV screen.

4. When a complete set of horizontal lines has been scanned, moving the electron beam from the end of the bottom line to the start of the top line or vertical retrace must occur simultaneously at both transmitter and receiver.

Visual transmissions are more complex than audio because of these synchronization requirements. At this point, voice transmission seems elementary because it can be sent on a continuous basis without synchronization. Thus, the other major function of the transmitter besides developing the video and audio signals is to generate synchronizing signals that can be used by the receiver so that it stays in step with the transmitter.

1.7 PROJECT OUTLINE

The outline for the design and construction of a TV transmitter is as listed below: Chapter one is an introduction of the project giving a brief review or an insight of what the project entails. It also gives the aims and objectives of undertaking the project, motivations, literature review (contains a brief history of transmitters and television inventions done by great scientists of the past) and outline. Chapter two is a detailed explanation of the design stages and the analysis of the various blocks of the circuit design. Chapter three encompasses the construction, testing, result and discussion of result. Chapter four gives the conclusion and recommendation of the project. Chapter five states the references.

CHAPTER TWO

DESIGN AND ANALYSIS OF TV TRANSMITTER

2.1 INTRODUCTION (GENERAL OPERATION)

The TV transmitter is an audio/video modulator operating in the VHF band which provides a low cost method of transmitting an audio-video signal. The device inputs are base band audio and base band video signals. The separate audio and video signals are fed into the base band modulator circuit. The modulator circuit AM modulates the video signals and the modulator circuit FM modulates the audio signals. These modulator circuits are then combined. The RF output of the modulator is then amplified, filtered and fed into the antenna. The transmitted signal can be received with any standard, unmodified television receiver. The block diagram of the transmitter can be seen in figure2.

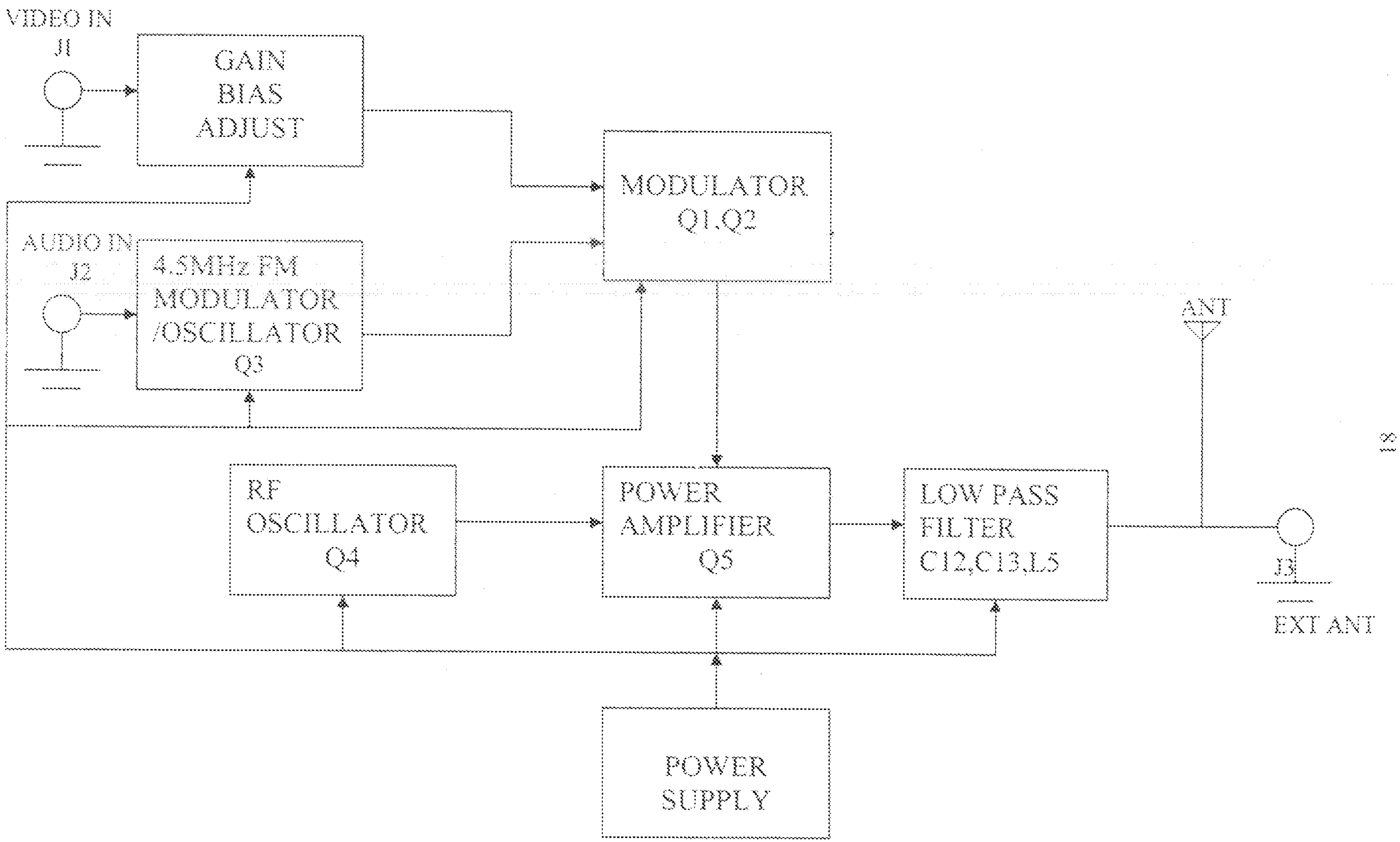

Fig 2.0 BLOCK DIAGRAM OF TV TRANSMITTER

The block diagram consists of the basic units:-

Video/Audio Input jacks:- this is the point at which the video and audio signals are imputed into the transmitter from the input transducer or the external device.

Gain bias adjust:- at this point, the video signal is amplitude modulated and set for mixing with the audio signal. This is achieved with the use of resistors/potentiometers capacitors and devices.

FM modulator- the audio signal is frequency modulated and transferred to the net modulator section for mixing or coupling with the audio signal. It is achieved with the use of capacitors, resistors, and a radio frequency (RF) transformer.

Modulator Stage:- the modulator circuit is used as a coupling circuit to couple the FM modulated audio signal with the AM modulated video signals. This requires the use of transistors (2N3904 NPN Transistor)

RF Oscillator Stage:- the audio and video signal requires a carrier signal. This RF signal is generated by the RF oscillator circuit. The circuit consists of coils, resistors, capacitors, inductors and a transistor (2N3866 NPN Transistor).

Power Amplifier Stage:- to transmit a signal that will be strong enough for a televison receiver to receive, the RF output signal must be amplified. This is also done through the use of transistors.

Low pass filter Stage:- Due to small signal errors or the presence of undesired signal frequencies in the amplified RF signal, a low pass filter is required on the output of the amplifier. Matching to the antenna is provided by the use of capacitors and an inductor in this stage.

Antenna:- After the transmitter amplifies the signal to the required level, it sends the signal to the antenna. Electromagnetic waves at the proper wavelength propagate out from the antenna as the electrical signal passes through it and is transmitted to receiving antennas.

Power supply unit:- This is the source of electrical energy to the entire circuit. Its proficiency cannot be overemphasized based on the fact that without it, the system will not work. The power unit supplies a 12V DC with a common ground.

2.2 SPECIFIC OPERATION OF BLOCKS

The block diagram of the TV transmitter is further explained below with various terms used in transmission briefly discussed.

2.2.1 GAIN, BIAS, ADJUST

The transmitter requires standard NTSC or PAL video. The video input requirement is standard 1-volt point to point 75 ohm, negative sync, i.e. the input impedance is 75 ohm and drive is a nominal 1-volt peak to peak negative sync which is fairly standard for most video devices. The video signal from J1 is suitably terminated by the 75 ohm resistor and coupled through capacitor C_1 of 100µF to the diode D_1. The combination of the capacitor and the diode produce a clamping effect whose application is "DC restoration" of a signal. The clamp forces the sync pulse on the video on the fixed DC level which will reduce "blooming" on some video scenes.

Video gain pot R3 permits you to adjust the amount of video applied to the modulator section of the transmitter, its function is similar to the contrast control on a TV receiver. The bias control R7 adjusts the black level of the transmitter. Ideally, it is desired for the transmitter to produce some level of signal even when a totally dark screen is presented. This is to allow the TV receiver to properly maintain synchronism and sound when no screen video is seen. This control is adjusted in conjunction with R3 for best all – around performance. This is shown in the circuit diagram of Fig 2.1.

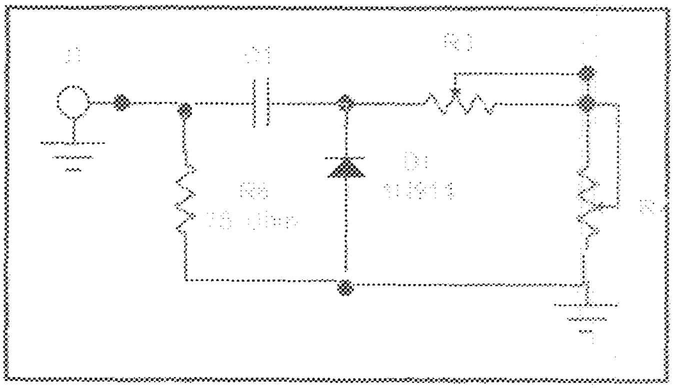

Fig 2.1 Gain Bias Adjust Circuit For Video Input

2.2.2 MODULATOR

Basic to the field of communications is the concept of modulation. **Modulation** is the process of impressing a low frequency message signal onto a high-frequency carrier for transmission. In essence, then, the transmission takes place at the high frequency (the carrier) which has been modified to carry the lower-frequency signal.

The process of modulation entails superimposing on the carrier wave the message or information signal. The relationship between the carrier and the message signal can be compared to that of a sheet of paper (message signal) containing vital information written on it and a stone (carrier signal). Based on the fact that a piece of paper, when thrown, would not travel a long distance due to its weight, can be wrapped around the stone, taking the shape of the stone and then thrown. It would then cover a longer distance. It should be observed that greater energy was used in transporting the stone (carrier), which did not contain any useful information, than the sheet of paper (modulating signal). This is the relationship between carrier and modulating signal.

Modulation process is employed in communication systems for the following reason:

1. For Channel Assignment
2. To reduce noise and interference, particularly at low frequencies
3. For easy radiation and reception of signals by using practically realizable antenna sizes
4. For multiplexing
5. To overcome Equipment limitations

Three different characteristics of a carrier can be modified so as to allow it to "carry" signal. Amplitude, frequency or phase of a carrier is altered by the message signal.

AMPLITUDE MODULATION: This is the modulation technique in which the modulating or message signal causes the amplitude of the carrier signal to vary.

There are two methods of achieving amplitude modulation:

i. Amplifier modulation
ii. Oscillator modulation

Here, the amplifier modulation method was used. The carrier and message signal are fed to an amplifier and the result of an AM output is achieved. The modulation process takes place in the active device used in the device. Transistors were used in the case of this project.

Let the carrier signal be represented by a sinusoidal voltage signal of amplitude Vc and frequency *fc*. That is,

$V_c = V_c\cos 2\pi f_c t = V_c\cos \varpi_c t$ ---------------------------- 3.1

Let the modulating signal of amplitude V_m and frequency f_m be represented by

$V_m = V_m\cos 2\pi f_m t = V_m\cos \varpi_m t$ ---------------------------- 3.2

From the definition of amplitude modulation, the amplitude of the amplitude modulated (AM) wave is

$V_{AM} = V_c + kV_m(t) = V_c + kV_m\cos \varpi_m t$ ---------------------------- 3.3

where k is the constant of proportionality and a parameter of the circuit.

Therefore the instantaneous voltage of the AM signal is

$$V_{AM}(t) = V_{AM}\cos \varpi_c t = V_c(1 + \frac{kV_m}{V_c}\cos \varpi_m t)\cos \varpi_c t$$

$$= V_c(1 + m.\cos \varpi_m t)\cos \varpi_c t \text{ ------------- } 3.4$$

where the ratio

$m = \frac{kV_m}{V_c}$ -- 3.5

is known as the MODULATION DEPTH of the AM signal. Its value lies between 0 and 1. The modulation depth, m, is usually expressed in percentage. That is

Modulation percentage = m 100 ---------------- 3.6

Modulation of the carrier signal at greater than 100% is undesirable as it causes distortion of the recovered audio signal at receiver. It should be less than 100%. The amount of modulation could be measured by modulation factor (M)

$M = \frac{B}{A}$ -- 3.7

Where

B = peak value of modulating signal

A = peak value of unmodulated signal

FREQUENCY MODULATION: This is the modulation technique in which the instantaneous frequency of the modulated or carrier signal is modulated with the modulating signal. The modulating waveform can be audio, video, digital pulses, or a combination of these methods. In most low-power work, audio is used and video is used for TV transmissions.

Modulators for AM are generally audio amplifiers that superimpose their output on the DC supply to the output amplifier or another amplifier in the transmitter signal path. The instantaneous voltage supplied to the stage by the modulator determines the output of that stage. In most cases, the DC supply to the RF stage is in series with the modulator output. The modulator must provide a power output (audio or video) equal to half of the DC input to the RF stage being modulated, for 100 percent modulation. For low power transmitters, powers of at most a few watts are needed, and simple transistors or IC audio amplifiers make good audio AM modulators. Video modulators for AM video need to handle bandwidths of up to 4 – 5 MHz, and most audio IC's will not handle this high of a frequency, so a discrete audio amplifier design using high-frequency transistors were used

2.2.3 FM OSCILLATOR/MODULATOR

An oscillator is a circuit capable of converting energy from a dc form to ac. In other words, an oscillator generates a waveform. The waveform can be of any type but occurs at some repetitive frequency. This frepency can be predicted using the following equation:

$$F_r = \frac{1}{2\pi\sqrt{(LC)}} \qquad \text{.......... 3.8}$$

where: F_r – resonant frequency

and the resonant frequency is chosen to be 4.5MHz.

For the TV transmitter, the internal capacitance can be calculated given the values of the inductor. Since we are using the IF can style adjustable RF transformer of No. 42IF122, the inductance of L1 is given to be 4.63pH.

Using the relation

$$F_r = \frac{1}{2\pi\sqrt{(LC)}} \quad \text{.......................................} \ 3.8$$

ie, $2\pi\sqrt{(LC)}\,F_r = 1$

$$\sqrt{(LC)} = \frac{1}{2\pi F_r}$$

$$LC = \left\{\frac{1}{2\pi F_r}\right\}^2$$

and

$$C = \frac{\left\{\frac{1}{2\pi F_r}\right\}^2}{L}$$

$$= \frac{\left\{\frac{1}{2\pi \times 4.5 \times 10^6}\right\}^2}{4.63 \times 10^{-9}}$$

$$= \frac{\{3.54 \times 10^{-8}\}^2}{4.63 \times 10^{-9}}$$

$$= \frac{1.25 \times 10^{-15}}{4.63 \times 10^{-9}}$$

$$= 270 \times 10^{-9}F$$

$$= 270pF$$

Therefore, for a well tuned oscillator, a 270pF capacitor is chosen.

The FM oscillator/modulator is all contained in one circuit. It consists of the free running oscillator collector to emitter feedback using External capacitors which contains an amplifier and a feedback network. The FM oscillator consists of an LC parallel resonance circuit, which acts as the oscillator of the free running oscillator. The LC circuit is designed to oscillate at 4.5MHz, which allows for a deviation of ±25kHz to be obtained. A frequency of 4.5MHz is used because the sound carrier is 4.5MHz above the video carrier.

The audio signal is FM (Frequency Modulation) modulated on the subcarrier oscillator. To understand the purpose of the subcarrier oscillator, think of it as another transmitter that operates on another frequency from the video transmitter. In actual practice, the audio subcarrier is 4.5MHz higher the video carrier frequency. Transistor Q3 (2N3904 NPN transistor) is a 4.5MHz oscillator which is FM modulated by having its bias voltage slightly varied. Audio signals are coupled into Q3's base through capacitor C2 and resistor R4, thus varying the bias voltage at an audio rate causing frequency modulation. The Coil L1 and its internal capacitor form the tank circuit of a Hartley oscillator which is tuned to the required 4.5MHz frequency.

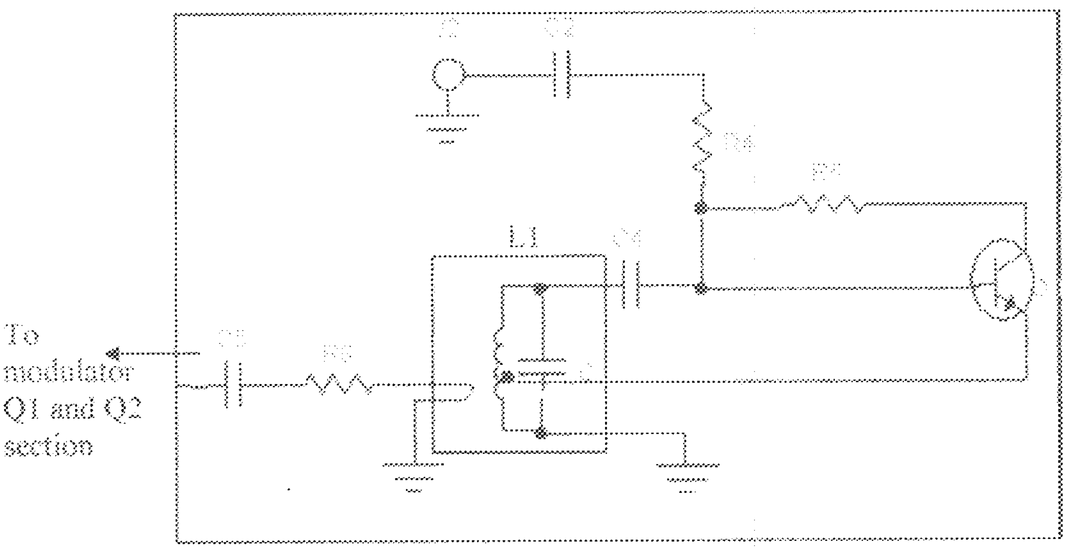

Fig 2.2 FM Oscillator/Modulator Circuit

The FM modulated, audio output signal, is coupled, through capacitor C5 and resistor R9 to the modulator section. Resistor R9 sets the proper amount of subcarrier signal in relation to video signal.

2.2.4 RF OSCILLATOR

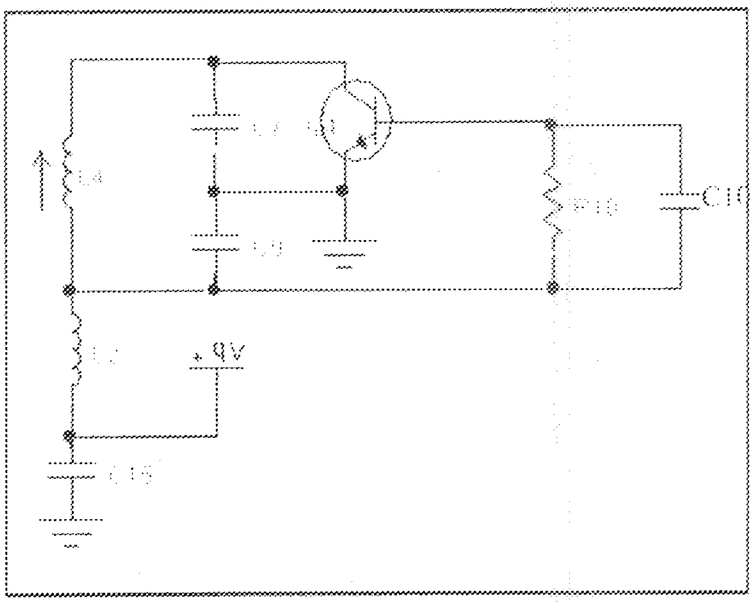

Fig 2.3: Circuit Diagram of an RF Oscillator

Oscillators are necessary in any low-power transmitter because they are a means for generating the necessary RF signal. Oscillators come in many forms but this project is mainly concerned with those suitable for RF signal generation at frequencies higher than 100kHz.

The different types of oscillators in use include:

- The Colpitts oscillator
- The Hartley oscillator
- Clapp oscillator

Some representative oscillator circuits that have application in low-power transmitters are as follows:

- Voltage Controlled Oscillator (VCO),
- Basic Overtone Crystal Oscillator,
- Free Running Oscillator collector to emitter feedback,
- Free Running Oscillator collector to emitter feedback using External Capacitors,
- Crystal Oscillator collector to emitter feedback using External Capacitors,
- Pierce Crystal Oscillator fundamental mode.

The free running oscillator collector to emitter feedback using external capacitors was used in this project, based on the fact that it is suitable in low-power transmitters and tolerates some frequency drift.

In the above circuit diagram, the transmitter operating frequency is set by coil L_4 (a plastic molded slug tuned coil of 5.5turns) which is part of a Colpitts tank circuit along with capacitors C_7 and C_9. The Colpitts oscillator is similar to the Hartley oscillator except that the tank circuit elements have interchanged their roles. The capacitor is now split, thereby making the two capacitors to be of the same value and the inductor is singe-valued with no tap. The details of circuit operation are identical with the Hartleys oscillator. The frequency of oscillation is given approximately by the resonant frequency of inductor L4 and capacitors C_7 and C_9 which are in series with the tank circuit:

$$F \simeq \frac{1}{2\pi\,[(C_7C_9/(C_7 + C_9)]} \qquad \text{---------- } 3.9$$

Assuming the operating frequency is 9MHz, since it is 4.5MHz higher than the FM, using the relation above, and $C_7 = C_9 = C$

$$9MHz = \frac{1}{2\pi\,[(C^2/(2C)]}$$

$$(9 \times 2\pi)MHz = \frac{1}{(C^2/(2C)}$$

therefore $$((2C/C^2) = (18\pi) \times 10^6$$

$$2C = (18\pi) \times 10^6 \times C^2$$

$$C = \frac{2}{(18\pi) \times 10^6}$$

$$= 3.54 \times 10^{-8}$$

$$= 35.4nF$$

But a preferred value of 39nF was chosen.

For proper channel adjust,

$C_7 = C_9 = 39nF$

Transistor Q_4 uses this tank circuit as its feedback network and oscillates at whatever frequency is selected.

2.2.5 POWER AMPLIFIER

The amplifier is used to amplify the low level signal from the modulator so it can be transmitted over a wireless link. The amplifier required to do this job must have a wide bandwidth and gave a very linear performance.

Amplifiers used for low-power transmitters may be either of IC or discrete transistor construction. For most small low-power transmitter applications, small-signal bipolar and FET discrete transistors of the appropriate type are adequate. Modern RF silicon NPN types come in both conventional plastic, metal, and surface-mount packages. Examples of usable types are the 2N918, 2N2857, 2N5179, and 2N2369. However, for amplifiers that must supply a little more power, the 2N3866 and 2N5109 are excellent.

The amplifier could either be class A, B, or C amplifier.

Class A Amplifier: It experiences little or no signal distortion. It has a maximum signal distortion of about 50% and a low efficiency.

Class B Amplifier: It is also called the push-pull amplifier. Its output is distorted and hence only used in circuits that can replace or restore the missing half cycle, i.e Tuned ratio circuit and also has a maximum efficiency of about 78.5%.

Class C Amplifier: The output are narrow pulses that is less than half the periodic time of the input signal waveform. It is used in radio frequency power amplifiers as well as in oscillator circuits.

The amplifier that was chosen for this task was the 2N3866 power amplifier. It is rated for higher power than the other devices, so it is housed in a metal case able to dissipate more heat. It is also an RF bipolar NPN transistor and the bias on the transistor is the Class C type.

For the transistor configuration, since the transistor is biased to saturation, $V_{CE} = 0$, when the transistor is ON. This implies that,

$$V_{+} = I_C R_C + V_{CE} \quad \text{..........................} \quad (4.0)$$

$$V_{in} = I_B R_B + V_{BE} \quad \text{..........................} \quad (4.1)$$

$$\frac{I_C}{I_B} = h_{fe} \quad \text{..........................} \quad (4.2)$$

$$R_B = \frac{V_{in} - V_{BE}}{I_B} \quad \text{..........................} \quad (4.3)$$

Where,

I_C = collector current

I_B = base current

V_{in} = input voltage

V_{+} = supply voltage

V_{CE} = collector – emitter voltage

V_{BE} = base – emitter voltage

h_{fe} = current gain

Since I_C = 400mA

$I_B = \frac{I_C}{h_{fe}}$ (where h_{fe} for 2N3866 = 25, obtained from data sheet)

$= \frac{400 \times 10^{-3}}{25}$

= 16mA

But

$V_{in} = I_B R_B + V_{BE}$

$V_{in} = 9V$

$V_{BE} = 3.5V$

$I_B = 16mA$

$$R_B = \frac{V_{in} - V_{BE}}{I_B}$$

$$= \frac{9 - 3.5}{16 \times 10^{-3}}$$

$= 344\Omega$

But a preferred value of 1KΩ was used for proper protection of the transistor.

Minimum device dissipation $P_D = 5W$

And the collector current is 400mA = 0.4A

But $P = IV = I^2R = I^2Z$ -------- 4.4

Where Z = minimum impedance of the load

Ie $$Z = \frac{P}{I^2}$$

$$Z = \frac{5}{(0.4)^2}$$

$= 31.25\Omega$

The diagram is shown below:

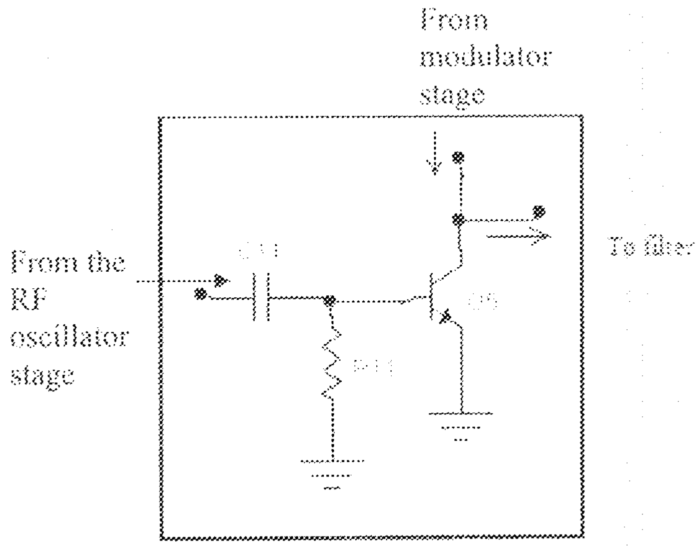

Fig 2.4 Power Amplifier circuit

RF output from the oscillator is amplified by transistor Q5 (2N3866 NPN transistor) whose supply voltage comes from the modulator section. This voltage is varying at a video and audio subcarrier rate, thus modulating the RF power output. The oscillator circuit is coupled to the amplifier circuit through capacitor C11.

2.2.6 FILTER/MATCHING

Filters are passive networks of capacitors and inductors which exhibit certain characteristics as the input frequency is varied. The filters of most interest in transmission are:

Low-pass filters: A low-pass filter passes all frequencies below a specified frequency but attenuates frequencies above it.

High-pass filters: A high-pass filter passes all frequencies above a specified frequency but attenuates frequencies below it.

The specified frequency referred to is the "cut-off frequency" (fc). The configuration of the simplest form ("single section") of each filter is shown in figure 2.5 which also shows the general shape of the characteristics

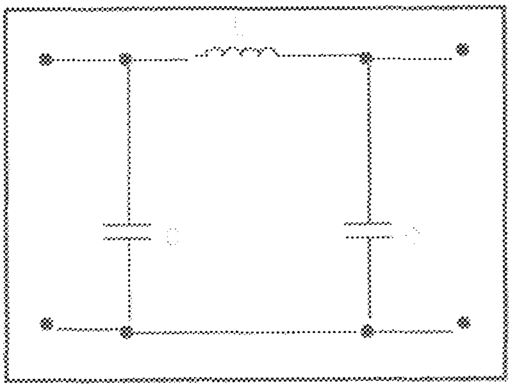

Fig 2.5a: Low-pass filter configuration

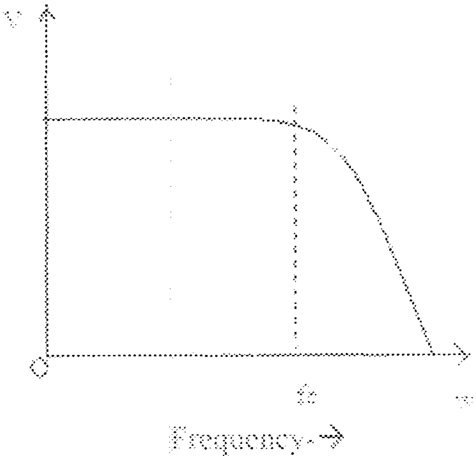

Fig 2.5b: Response curve

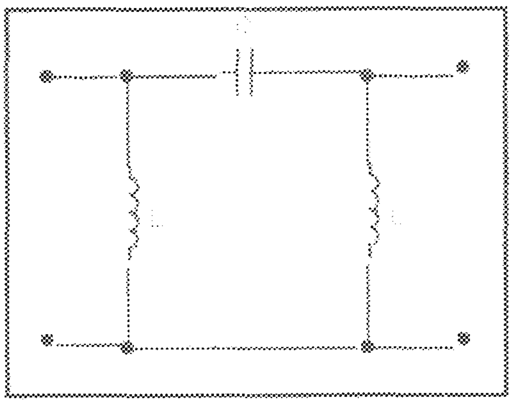

Fig 2.6a: High-pass filter configuration

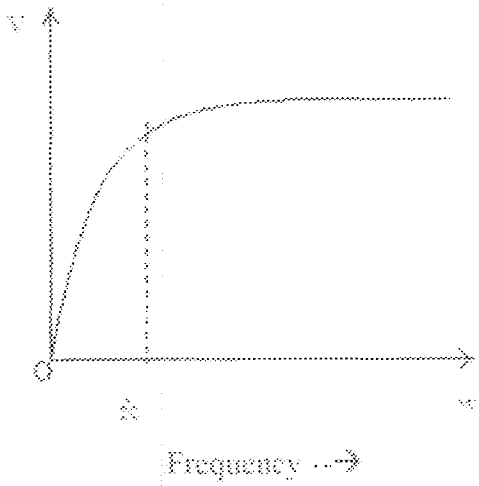

Fig 2.6b: Response curve

Filters have a number of important applications. Low-pass filters are used to attenuate unwanted frequencies in the output of the HF bands transmitter (transmitter-antenna matching unit connection). Another use is to limit the audio bandwidth of a telephony transmitter to the minimum necessary for intelligible communication. The

High-pass filter may be used in the antenna downlead (coaxial cable) of a television receiver in order to attenuate unwanted frequencies.

Due to small phase errors created within the modulating section, a low pass filter is required on the output of the modulator. The small phase errors create harmonic distortion in the RF output signal and the filter is used to remove this distortion.

It is necessary to match the output of a transmitter to the antenna feeder in order for maximum power to be transferred from the transmitter to the antenna. This is achieved by ensuring that the output stage current is resonant at the frequency of operation and the output impedance of the antenna feeder, when transformed by a coupling network, must be equal to the optimum load for the output stage.

The filter that is used is a low pass filter. The output matching network to the antenna and low pass filtering is a combination of inductors L3 and L5 and capacitor C12, C13 and C14. The 75Ω (R12) is added to help match the output signal to any kind of antenna. This is shown below:

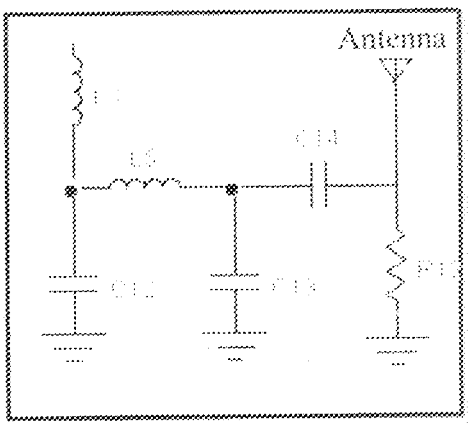

Fig 2.7: Filter/Matching circuit

2.2.7 ANTENNA

After the transmitter amplifies the video signal to the required level, it sends the signal to the Antenna.

An antenna is a circuit element that provides a transition from a guided wave on a transmission line to a free space wave and it provides for the collection of electromagnetic energy. In a transmitting system, a radio-frequency signal is developed, amplified, modulated and applied to the antenna. The RF currents flowing through the antenna produce electromagnetic waves that radiate into the atmosphere. To have adequate signal strength at the receiver, either the power transmitted must be extremely high or the efficiency of the transmitting and receiving antennas must be high because of the high losses in wave travel between the transmitter and the receiver.

All antennas have a gain factor expressed in decibels. Usually, this factor is relative to an isotropic radiator. An isotropic radiator radiates uniformly in all directions, as does a point source light. All the power that the transmitter produces ideally is radiated by the antenna; however, this is not generally true in practice because there are losses in both the antenna and its associated feedline. The transmitted power is effectively multiplied by the antenna system gain, which is the sum of the line losses and the antenna gain (or loss for many small simple antennas). The gains in decibels directly add and may be expressed as a numerical factor. The transmitter power and the antenna gain when multiplied equal the effective radiated power (ERP).

The antenna being used for this system is a whip antenna. It is an antenna with adjustable length. If more range is needed, the length of the whip antenna can be increased or an external antenna can be connected to J3. The diagram is shown in Fig. 2.8

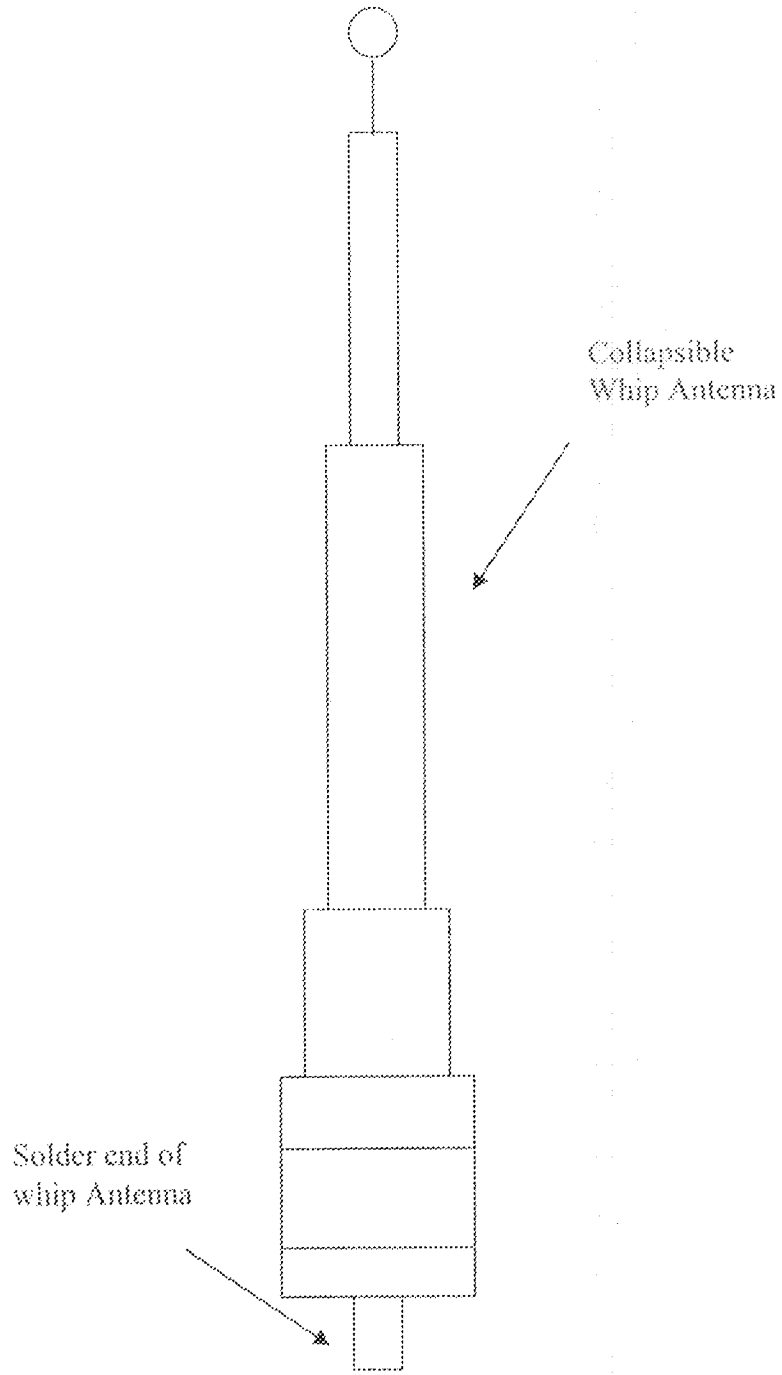

Fig 2.8: Collapsible Whip Antenna for Low Power Transmitters

For a whip antenna:

This design is for a whip antenna operating at 63MHz.

It is recommended that the length of the antenna be $l = 0.05\lambda$

l = antenna height (cm)

λ = wavelength

f = frequency (Hz)

v = speed of light = 3×10^8 m/s

$f = 63MHz$

$$\lambda = \frac{v}{f} = \frac{3 \times 10^8}{63 \times 10^6} = 4.76m$$

$l = 0.05\lambda = 0.05\ (4.76) = 0.238m = 23.8cm$

2.2.8 POWER SUPPLY STAGE

For the purpose of this design, power is supplied by an external 12 volt DC source. This is achieved using a 240V/12V converter, which converts the domestic supply mains voltage of 220V – 240V ac into the required 12 volt DC voltage.

All stages in this project use 9V. The power supply stage is a linear power supply type and involves the use of a step down transformer, filter capacitor and voltage regulators; to give the various voltage levels. The power supply circuit diagram is shown in Fig. 2.9:

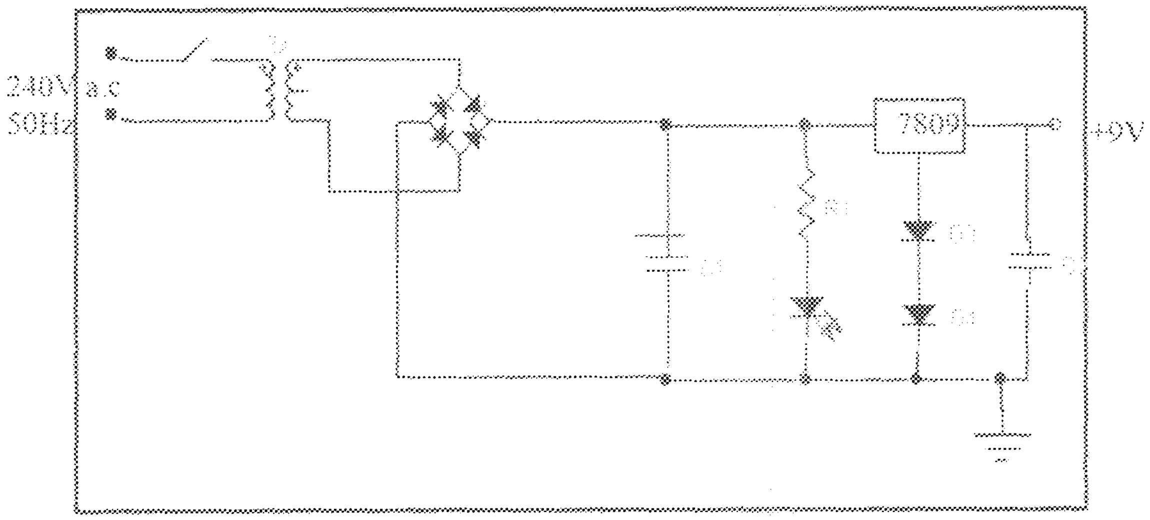

Fig 2.9 Circuit diagram of the Power Supply Unit

The rectifier is designed with four diodes to form a full wave bridge network. C1 is the filter capacitor and is inversely proportional to the ripple gradient of the power supply. The ripple gradient is shown in fig 2.10:

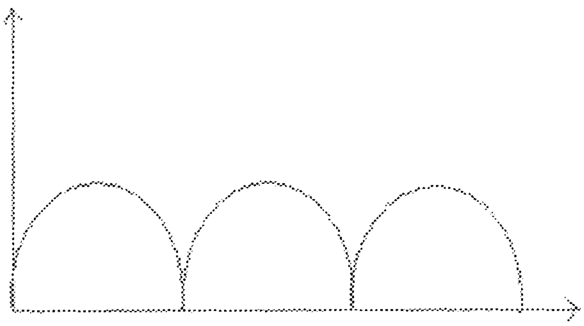

Fig 2.10 Ripple Gradient

Where dv is the ripple voltage for time dt, and dt is a dependent factor in power supply frequency.

$I = \frac{Cdv}{dt}$, $\frac{I}{C} = \frac{dv}{dt}$ But Io = 1A for silicon diode, ie

$\frac{1}{C} = \frac{dv}{dt}$ => $C = \frac{dt}{dv}$

But dt = 10ms for 50Hz transformer

& Vrms = 12V from the transformer

Vpeak = Vrms × √2 (ie, rms × √2)

= 12 × √2

= 16.97V

Assuming ripple factor of 15%,

$dv = \frac{15}{100} \times 16.97$

= 2.55V

Therefore

$C = \frac{dt}{dv} = \frac{10ms}{2.55}$

= 3.928mf

= 3928µf

A preferred value of 3300µf was used for the power supply stage.

But for the LED, $V_{in} = V_R + V_{LED}$ 4.5

$= I_F R + V_D$ 4.6

where I_F = diode forward current = 15mA

V_D = voltage drop across diode = 1.7V

$$\Rightarrow \quad R = \frac{V_{in} - V_D}{I_F} = \frac{12 - 1.7}{15mA}$$

$$= \frac{10.3 \times 1000}{15}$$

$$= 0.69Kohm$$

A preferred value of 1Kohm was used.

The voltage is regulated at approximately 9.4 volts by the 9 volt regulator, VR1 (7809 voltage regulator).

CHAPTER THREE

CONSTRUCTION, TESTING AND RESULT

3.1 CONSTRUCTION

The construction of the circuit for the TV transmitter for this project was done on a Printed Circuit board in phases. After the calculations were done to obtain the required values for the various components, the components were sourced for and assembled together.

First of all, the required components were identified and placed in a safe location to prevent loss or misplacement and to allow easy access to the parts while working.

Then, they were assembled on a bread board and tested to ensure they were in proper working condition using the required power source. After ensuring that they were functioning correctly, they were then transferred to the PC board and each component was inserted into the required location on the PC board and soldered firmly to it.

3.2 TESTING/ALIGNMENT AND OPERATION

To properly test the TV transmitter, the following basic tools and equipment were needed:

1. A TV set,
2. A source of video such as a VCD player,
3. A 12 volt DC power source
4. Plastic alignment tool for L1, L4, R3 and R7.

Alignment Procedure:

1. The TV set was tuned to an unused channel. It was also noted that due to the fact that we were transmitting locally, the TV set should also have a nearby antenna connected such as a pair of rabbit ears or a short dipole style antenna.
2. The R3 potentiometer was adjusted for video gain, then the bias pot R7 was also adjusted to mid rotation.
3. A properly regulated and stable 12 volt DC power source was connected to the external power jack J4. It was ensured that the power source could provide at least 100ma of current. The switch was then depressed to turn the transmitter on.
4. The channel adjustment coil L4 was adjusted with the plastic tuning tool until the TV screen went blank. The slug was slightly moved around the obtained point for the most blank picture. The sound was not producing noise because the sound section had not been adjusted yet.
5. The VCD player's video and audio output source was connected to the corresponding video and audio inputs (ie jack J1 and J2 respectively) of the TV transmitter. A VCD was inserted into the VCD player and the play button was pressed.
6. A resemblance was immediately seen of a picture on the screen of the television set. The coil L4 was adjusted for best picture.
7. The video gain pot R3 was adjusted for best 'brightness' in the picture and bias pot R7 for best overall picture. It was noticed that these two

adjustments interact and it was best to fiddle back and forth until best picture was obtained. When appropriate, the channel coil L4 was also touched-up for best performance.

8. The audio subcarrier coil L1 was adjusted for best sounding audio.

9. A steady picture was finally obtained.

3.3 RESULTS

The distance from the transmitting antenna at which the signal is received by a receiver and the field strength is given in the table below. Considering the fact that a whip antenna was used, the theoretical figures below were obtained using 1 meter of the whip antenna.

Table 3.1 DISTANCE FROM TRANSMITTER ANTENNA

METERS	FEET	FIELD STRENGTH (μV)	TOTAL RECEPTION AREA (FT)
3	10	100	314
6	20	50	1256
12	39	25	4800
24	78	12	19113
48	157	6	1.8 ACRES
96	315	3	7.2 ACRES

3.4 DISCUSSION OF RESULT

From the table above in the result section, it was observed that as the distance between the transmitter and the television receiver increased, the signal strength reduced proportionally. It was also observed during the operation of the transmitter that an increase in the length of the antenna above 1 metre also increased the reception distance from the transmitter

The reason why I translated the reception area into acres are due to the following reasons:

1. The numbers would get too cumbersome if I discussed the possible signal coverage terms in square feet or square metres.
2. It is easy to see that my signal can easily serve the school.

CHAPTER FOUR

CONCLUSION AND RECOMMENDATIONS

4.1 PROBLEMS ENCOUNTERED

1. Being an amateur in soldering components to the board, I realized that some of the soldered joints were not tightly done. This caused a distortion in picture quality.

2. I also experienced a hum in the audio. This was caused by the fact that the frequency generated by the RF oscillator was 4.5MHz and the frequency set on the receiver was 5.5MHz.

4.2 PRECAUTIONS

1. I ensured correct orientation of all the transistor flat sides

2. I ensured correct resistor, capacitor and inductor placements, ie, ensured that a 1K resistor was not placed in the place of a 10K resistor.

3. I ensured proper power source of 12 volts was supplied to the circuit.

4. I ensured that all solders were properly done.

4.3 CONCLUSION

The answer to transmitting both audio and video signals through a wireless link has been obtained in the use of the TV transmitter. The TV transmitter accepts normal video and audio signals from VCR's, VCD players or cameras and generates a low power TV signal that can be picked up by nearby TV sets.

The TV transmitter is thus suitable for use in the Engineering department premises.

4.4 RECOMMENDATIONS

I recommend that a TV transmitter be used in place of long span of cable wires for satellite installations and signal transmission from TV to video sets.

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APPENDIX

COMPONENTS LIST

<u>CAPACITORS</u>

- 7 .001µf disc [C3, C4, C5, C6, C11, C14, C15]
- 2 39pf disc [C7, C9]
- 1 100pf disc [C10]
- 2 68pf disc [C12, C13]
- 1 270pf disc [bottom of PC board]
- 1 2.2µf electrolytic [C2]
- 1 100µf electrolytic [C1]
- 2 1000µf electrolytic [C8, C16]

<u>SEMICONDUCTORS</u>

- 1 1N918 diode [D1]
- 2 1N4002 diode [D3, D4]
- 4 2N3904 NPN transistor [Q1, Q2, Q3, Q4]
- 1 2N3866 NPN transistor [Q5]
- 1 7809 voltage regulator [VR1]

<u>INDUCTORS</u>

- 1 .15µh miniature inductor (has brown and green bands) [L5]
- 2 2.2µh miniature inductor (green body with 2 red bands) [L2, L3]
- 1 5.5 turn slug tuned coil [L4]
- 1 IF can style RF transformer (marked 42IF122) [L1]

RESISTORS

- 3 1K ohm (brown-black-red) [R1, R2, R11]
- 2 4.7K ohm (yellow-violet-red) [R4, R8]
- 2 10K ohm (brown-black-orange) [R9, R10]
- 1 47K ohm (yellow-violet-orange) [R5]
- 2 75 ohm (violet-green-black) [R6, R12]
- 1 1K ohm trimmer potentiometer (yellow adjuster) [R7]
- 1 5K ohm trimmer potentiometer (yellow adjuster) [R3]

CONTROLS AND HARDWARE

- 1 Pushbutton switch [S1]
- 3 PC mount RCA phono jacks [J1, J2, J3]
- 1 DC power jack [J4]
- 1 Telescopic whip antenna [Ant 1]
- 1 Printed circuit board
- 1 Plastic tuning tool 'diddle stick'