DESIGN AND CONSTRUCTION OF A MULTICHANNEL FREQUENCY MODULATION TRANSMITTER

PAPKA, DANIEL ANASILI

98/7201EE

DEPARTMENT OF ELECTRICAL ENGINEERING

SCHOOL OF ENGINEERING AND ENGINEERING TECHNOLOGY

FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA

NIGER STATE, NIGERIA

DESIGN AND CONSTRUCTION OF A MULTICHANNEL FREQUENCY MODULATION TRANSMITTER

PAPKA, DANIEL ANASILI

98/7201EE

A Project report submitted in partial fulfillment of the requirement for the award of Bachelor of Engineering (B.Eng) in the Department of Electrical/Computer Engineering, School of Engineering and Engineering Technology, Federal University of Technology, Minna, Niger State, Nigeria

NOVEMBER 2004

APPROVAL

This is to certify that this project titled **"Design and Construction of a Multichannel FM Transmitter"** was carried out by **Papka, Daniel Anasili** under the supervision of **Engr. J.G Kolo** and submitted to the Electrical/Computer Engineering Department, Federal University of Technology, Minna in partial fulfillment of the requirements for the award of Bachelor of Engineering (B.Eng) degree in Electrical Engineering.

....16/12/04......

Project Supervisor Signature and Date

.... 16/12/2004

Head of Department Signature and Date

....

External Examiner Signature and Date

Papka, Daniel A. 06/12/2004

Student Signature and Date

DECLARATION

I hereby declare that this project presented in partial fulfillment for the requirement of the award of Bachelor of Engineering (B.Eng) degree has not been presented before either wholly or partially for any other degree elsewhere. Information hereby obtained from published and unpublished work of others are acknowledged accordingly.

Ilagna, Daniel A.
....
Name of Student

06/12/2008
....
Signature and Date

ACKNOWLEDGEMENT

I use this medium to give thanks to God Almighty who has given me life to see such a time in my life and made me progress in all I put my hands to do.

My appreciation goes to:-

My Project Supervisor Engr. J.G. Kolo for all the time spared and the attention given when needed;

My Parents (Mr. and Mrs Papka) - You are the greatest parents anyone would ever wish to have. Thanks for giving me all I've asked or desired and your continued prayers which has kept me moving. I love you

My Sisters- Tina, Dzima and Joyce- My unbreakable love to you

My Spiritual Fathers- Bishop David Abioye and Bishop Dayo Olutayo- Thank you for everything Sirs

My Uncles- Mallam Hamidu Wathanafa, Mr. Alpha Papka, Alhaji Adamu Jafiya,Prince Ngama Papka, Mr. Frank Satumari, Dr. Musa Gashua, Barka Joel and Steve Birdling

My Cousins- Aaron, Nana, Minso,Janu, Patti and all others

The following Families- The Gambus',Wiafes', Yahayas', Douglass'

My Friends- Adeshina Adekunle, Abdulmalik Suleiman, Ozemela Ugochukwu, Skari Jagila, Ogbonna Keleci, Kpokpogiri Joy, Shuaibu Nazir, Douglas Inebi, Douglas Ayebaemi,Ahmad Umar, Mohammed Idris,Oyakhilome Emmanuel,Oyakilome David,Momoh Hauwa,Otsu Annette, Gana Yakubu, Okon Asuquo, Mogbo Obiekwe, and all those I can't mention due to space constraints – You guys are the greatest anyone would want to have around.

All those not mentioned- Gratitude in the heart is more than that on paper. You people are fantastic.

Finally, the staff of Federal University of Technology Minna, especially the departmental staff for their contribution in the development of my life.

DEDICATION

I hereby dedicate this work to the **HOLY SPIRIT** my teacher who teacheth me all things and bringeth it to my remembrance

AND

My Uncle, Late Mallam Ishyiaku Aliyu Jafiya (Galadima Uba)

ABSTRACT

The project report is on the Design and Construction of a Multi-Channel Frequency Modulation Transmitter.

The stages involved in the construction for proper performance are the Microphone, Reactance Modulator, Oscillator, Buffer amplifier, Frequency Multiplier, Driver amplifier and Power Output amplifier.

The main aim was to make the project miniature with coupling between the stages properly considered and having a good performance in the Commercial Band (88-108MHz).

The project report is divided into four chapters.

Chapter One covers the general introduction to communication systems, Literature review, FM theory and Technical background

Chapter Two and Three consist of System analysis and Design with emphasis on the appropriate values of components to be used.

Chapter Four is the Conclusion and recommendations for future area of research.

TABLE OF CONTENTS

CHAPTER ONE

1.0 INTRODUCTION TO COMMUNICATIONS SYSTEMS.

Communication can be said to be the transfer of information from one point to the other through a medium. This involves sending, processing and receiving the information.

The very first form of information to be transferred "electrically" was the Human voice which was coded (Morse code). This was done by Samuel Morse in 1837 by the invention of a Telegraph. The rapid rate of development then resulted in Telephone by Alexander Graham in 1876, then the first complete system of wireless communication by Guglielmo Marconi in 1894, Lee Deforests diode vacuum tube in 1908 which gave way to practical electronic amplification and in 1948 when transistors were invented by Shockley, Brattain and Bardeen.

Information cannot just be transmitted directly as human voice frequency has a range and if everyone's voice is transmitted at the same time and frequency, interference occurs and hence all communication becomes ineffective.

Modulation is a process of putting information onto a high frequency carrier for transmission. This implies that the transmission is done at high frequency but modified to carry the lower frequency information (also called Intelligence Signal). Once the information has been received, the intelligence signal will have to be removed from the high frequency carrier to get back your original information. The process which is called Demodulation.

Hence the only way to effectively carry out communication is through modulation which allows low frequency intelligence propagation with a high frequency carrier. The high frequency carrier chosen are done so that reasonable antenna size is used.

A high frequency carrier is represented by the mathematical expression of a sine wave

$$V = V_p \, \text{Sin}\, (\omega t + \Phi)$$

Where V- Instantaneous value

V_p - Peak value (Amplitude)

ω -Angular velocity ($2\pi f$)

Φ -Phase angle

The phase angle, Angular velocity or the Peak value can be varied in accordance with the low frequency information signal to produce a modulated signal which has the intelligence. If the amplitude term is varied, you have **AMPLITUDE MODULATION (AM)**, while if the frequency is varied you talk of **FREQUENCY MODULATION (FM)** and **PHASE MODULATION (PM)** when phase angle is varied.

Modulation is therefore important in communication for the following reasons

i. To reduce noise and interference

ii. For easy radiation

iii. For Multiplexing

iv. To use reasonable antenna length.

The block diagram of a simple communication system is shown below:

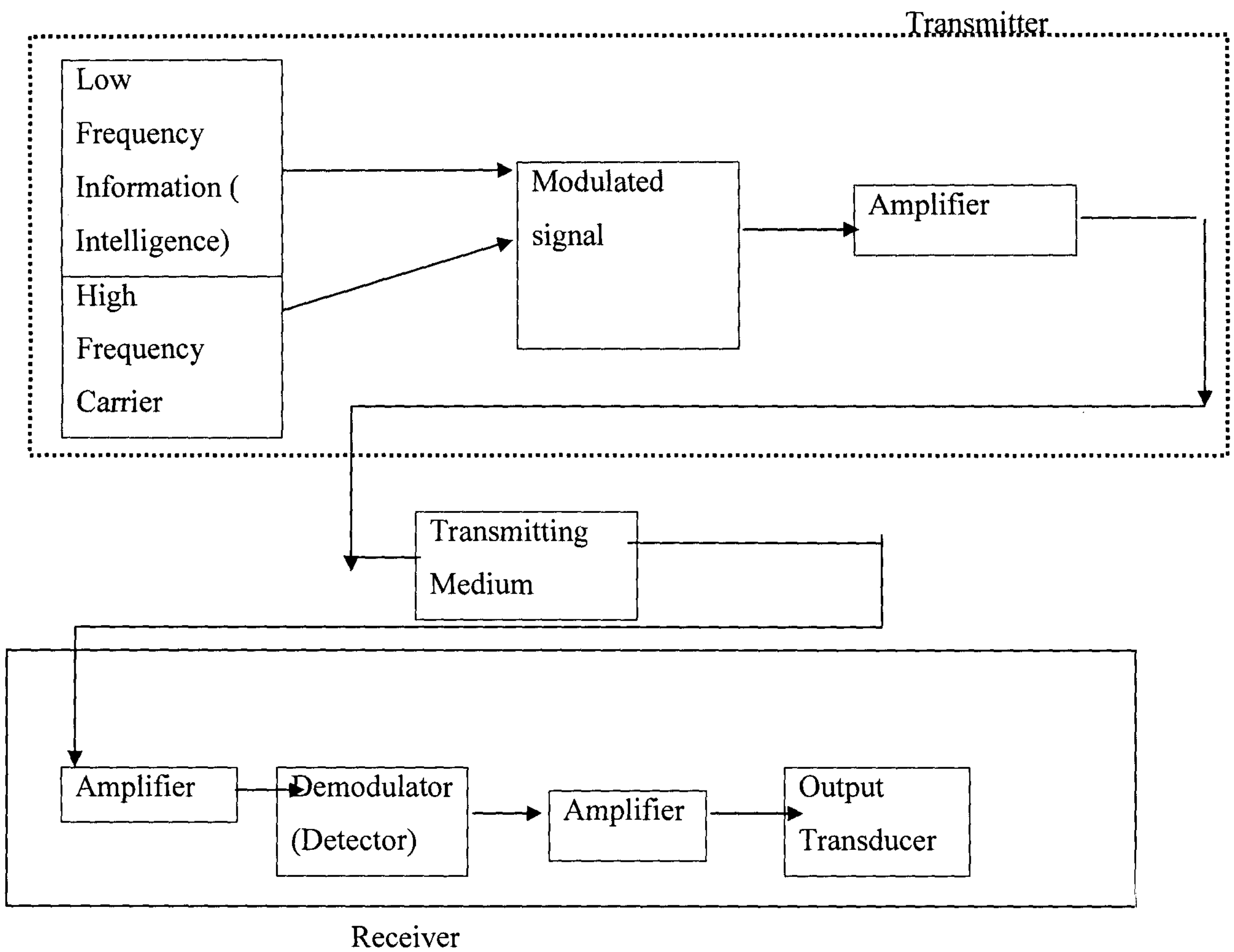


Fig 1.0 Communication Block System

From Fig 1.0 above

- The modulated stage accepts two inputs (the intelligence and carrier) producing the modulated signal which is amplified before transmission.
- Transmission of the modulated signal can be by antenna, waveguides, optical fibre or transmission lines
- The receiver takes up the transmitted signal and re-amplifies (due to attenuation along the transmission line) then fed into the demodulator/detector where the information is extracted from the carrier
- The demodulated signal is then fed into the amplifier and raised to a level which will enable it to drive an output transducer

1.1 LITERATURE REVIEW

Radio is a system communication using electromagnetic waves propagated through space. The radio waves have several areas of application such as telephone transmission, wireless telegraphy, radar, television, navigation system and Space communication.

Radio has no specific inventor but a series of attempts by several people. In 1873, James Clerk Maxwell (1831-1879) published the theory of electromagnetic waves hence predicting that electromagnetic waves exist. In 1884, Heinrich Rudolf Hertz (1857-1894) a German physicist clarified and expanded the electromagnetic theory which James Maxwell predicted. Hertz then proved that electromagnetic magnetic waves can be used to transmit electricity which travels at the speed of light. He then managed to create an oscillating electric discharge whose energy was radiated in the form of EM waves. But the problem of waves not traveling to great distances remained.

In 1896, Gugliemo Marconi (1874-1937) an Italian electrical engineer was able to transmit signals for a distance of more than 1 mile (1.6 KM). Within a year of 1st demonstration, signals were transmitted from shore to a ship at sea which was 18 miles away. By 1899, commercial communication between England and France was established. In 1901, simple message was sent across the Atlantic. This success was attributed in the development of a receiver and an oscillator which was connected to an antenna to transmit the radio waves over a good distance. In 1904, John Ambrose Fleming an English Electrical Engineer used the thermionic two electrode valve (also called Diode).

Reginald Fessenden in 1906 designed a system that transmitted both speech and music over a hundred miles out to sea from Massachusetts coast, earlier than that time only signals were transmitted but not sound.

The creation of vacuum tube oscillator provided the transition from signal transmission to sound transmission because it gave a continuous signal that was effective for speech transmission.

In 1906, De Forest Lee an American inserted a third electrode into the valve hence making a triode (called the audion by De Forest). This device was then able to amplify weak signals. The audion was used then in nearly all radio, television and computer systems until the early 1950 when transistors became available hence replacing vacuum tubes. By 1910 De Forest presented the first live opera radio broadcast and six years later announced the result of the presidential election in first radio news broadcast.

With all these developments, the first significant users of radio were the Coastal, Marine, Army and intelligence services of the British and German forces during World War I. The war led to large scale production of the thermionic valve and introduced a lot of people into the use of radios.

By 1920 the first time radio station (KDKA) began broadcasting in Pittsburg, Pennsylvania in the United States. By 1922 the radio stations were now in their hundreds. Radios then operate at different frequencies (ranging from Hertz to Giga Hertz) hence used for different purposes.

The essential components of a radio(also called radio transmitter) include an Oscillator generator (for converting electric power into oscillations of a predetermined radio frequency), amplifiers (for increasing the intensity of the oscillation while retaining the desired frequency), a transducer (for converting the information to be transmitted into varying electrical voltage), Modulator (which uses the proportionate voltages to control the variations in the oscillation intensity) and the antenna (which radiates a modulated wave).

Frequency Modulation (FM), which is a system of radio transmission in which the carrier wave is modulated so that its frequency varies with audio signal being transmitted was 1^{st} developed by Armstrong Edwin Howard in 1930.

In Armstrong's method of generating FM, the phase of a crystal oscillator's output is varied. Varying the phase of the signal also causes it's frequency to be changed. The modulating signal is pre-emphasized and applied to a frequency correcting network (low RC circuit) which makes the audio output amplitude inversely proportional to its' frequency. The Armstrong method of generating FM changes the phase of a crystal oscillator's output. The disadvantage of this method of generating FM is that it has very little frequency deviation hence cannot be used for commercial broadcasting.

In the Varactor diode method of generating FM, a varactor diode is constructed to exhibit characteristics such as the capacitance varying by the amount of reverse bias of the diode. A potentiometer is used to provide the variable capacitance which is needed for tuning. When the signal is applied to the varactor diode, its reverse bias is varied which then causes the diodes junction capacitance to vary in step with the signal. The frequency of the oscillator is then varied as required for FM. The disadvantage of this method is that the stability of the required frequency is not attained which is a very important factor in FM transmission (i.e. their frequency cannot be made to deviate reasonably to provide a workable wideband FM system).

In Voltage Controlled Oscillator (VCO), the output frequency is directly proportional or varied by a voltage applied to its control terminal. The VCO consist of linear frequency/voltage characteristics, free running (which is adjusted to a wanted figure) and good frequency stability. The VCO is considered as a functional block and not a complete transmitter. To make the VCO into a transmitter an audio amplifier will have to be inserted to interface with a microphone for modulation and an amplifier (usually class C) which is then terminated with impedance matched network before coupling into an antenna. The disadvantage of this method is that changing frequency would involve varying the resistor and changing the output frequency of the class C resonant tank.

In the Phase Locked Loop (PLL) method of generating FM, a closed feedback system in which the generated signal establishes synchronization with input signal used. The PLL consist of a Phase Detector, Low Pass Filter, Amplifier and VCO. The feedback divides the output frequency by a factor which makes it equal to the reference frequency such as a crystal oscillator and also minimizes interference from the crystal oscillator. The low pass filter prevents the feedback of the modulated frequencies and eliminates the possibility of the loop locking to a side band. The disadvantage of this method is its poor stability with respect to frequency drifts and the circuitry is always very large and complicated.

This method presently used for the generation of FM is the two transistor design which uses transistors (used as amplifiers or oscillators here) which give quite a stable frequency and can be made small in size. It is quite an effective transmitter which covers a reasonable range.

1.2 TECHNICAL BACKGROUND

Communication system depends on the frequency of the carrier. The various frequency ranges and their designation are shown in the Table 1.0. The frequency that is of interest for FM is 88-108 MHz with wave lengths of 3.4 and 2.77 meters.

i.e. $V = f\lambda$

Where $V = 3 \times 10^8$ m/s

Table 1.0 Radio Frequency Spectrum

FREQUENCY	DESIGNATION	ABRREVATION	WAVELENGHT
3- 30 k Hz	Very Low Frequency	VLF	100000-10000m
30-300kHz	Low Frequency	LF	10000-1000m
300- 3,000kHz	Medium Frequency	MF	1000-100m
3-30MHz	High Frequency	HF	100m-10m
30-300MHz	Very High Frequency	VHF	10-1m
300-3,000MHz	Ultra High Frequency	UHF	1m-10cm
3-30GHz	Super High Frequency	SHF	10cm-1cm
30-300GHz	Extremely High Frequency	EHF	1cm-1mm

1.3 FM THEORY

For a sine wave, 3 of the parameters associated with it can be altered to carry a low frequency intelligence signal. They are Amplitude, Phase and Frequency.

The phase and frequency are related in that altering one will also alter the position of the other. Hence they are categorized under Angle Modulation.

Angle modulation is said to occur when the angle of the sine wave is varied from its reference point or value.

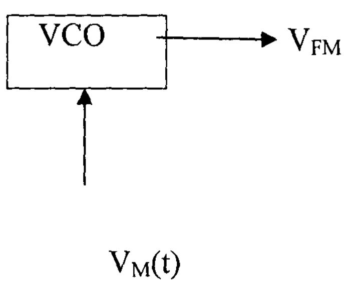
Hence it can be divided into 2 categories:-

i. **PHASE MODULATION (PM):** This is angle modulation where the phase angle of the carrier is caused to depart from its reference value by an amount proportional to the modulating signal amplitude

ii. **FREQUENCY MODULATION (FM):** This is angle modulation where the instantaneous frequency of a carrier is caused to vary by an amount proportional to the modulating signal amplitude.

1.4 DERIVATION OF FM EQUATION

Using a Voltage Controlled Oscillator with a running frequency F_C, a voltage source of $V_m(t)$ which makes the VCO to deviate from F_C by F , which is then multiplied by its sensitivity (K_O). The output is an FM voltage



V_{FM}=A *Cosθ (t) ....Equation 1

$F = F_C + \Delta f$ ....Equation 2

Where $\Delta f = K_O * V_m(t)$

$F = F_C + K_O V_m(t)$ ....Equation 3

These set of equations govern the VCO's output

$\omega = \frac{d\theta(t)}{dt} = 2\pi f$ ……………………………………Equation 4

Differentiating the angle θ(t) gives the angular velocity of the output and equating it to 2πf.

$\frac{d\theta(t)}{dt} = 2\pi F_C + 2\pi\Delta f$ ………………………………Equation 5

From $F = F_C + \Delta f$

Cross Multiplying

$d\theta(t) = (2\pi F_C + 2\pi\Delta f)dt$ ……………………………Equation 6

$\theta(t) = 2\pi F_C \int dt + 2\pi \int K_o V_m(t)$ ………………………Equation 7

$V_m(t) = V_{PK} \text{Cos}(2\pi F_M t)$ ………………………………………Equation 8

Substituting into θ (t) the equation becomes

$\theta(t) = 2\pi f_c \int dt + 2\pi \int K_o V_m(t) \text{Cos}(2\pi F_M t)$ ………………Equation 9

$\theta(t) = 2\pi f_c t + \frac{2\pi K_o}{2\pi F_M} V_{PK} \text{Sin}(2\pi F_M t)$ ………………………Equation 10

Hence $\theta(t) = 2\pi f_c t + \frac{K_o V_{PK}}{F_M} \text{Sin}(2\pi F_M t)$ ……………Equation 11

Where $M_F = \frac{K_o V_{PK}}{F_M}$

i.e $M_F = \frac{\Delta f}{F_M}$

Substituting into the FM equation

$V_{FM} = A\text{Cos}\,\theta(t) = A\cos(2\pi f_c t + M_F \text{Sin}(2\pi f_M t))$……………Equation 12

Hence the Standard FM equation becomes

$V_{PM} = A\cos\theta(t) = A\cos((2\pi f_c t + M_P \sin(2\pi f_M t))$ ....Equation 13

The equation for FM and PM are similar but the difference is seen at the modulation index and varying angle in the brackets.

1.5 DIFFERENCES BETWEEN FM & PM

i. Modulation Index: $M_p = \frac{\Delta f}{F_M}$

In PM M_F is constant while in FM it varies.

ii. In PM the amount of phase change is proportional to the intelligence amplitude while in FM it is the frequency change that is proportional to intelligence amplitude.

iii. FM can produce high index frequency modulation whereas PM requires multipliers to do so.

1.6 TECHNICAL TERMS ASSOCIATED WITH FREQUENCY MODULATION

Some of the important terms are stated as follows

i. **CAPTURE EFFECT:** It is said to occur when the FM receiver is able to pick up the stronger signal out of several transmitted signals while suppressing the weaker ones. This occurs mostly when transmission is done at the same or nearly the same frequency by several transmitting stations.
ii. **MODULATION INDEX:** It was known as modulation factor. It is a measure of the extent to which a carrier is varied by the intelligence (modulating signal).

$$M_F = \frac{\Delta f}{F_M}$$

iii. **FREQUENCY MODULATION:** It is defined as the increase or decrease by the carrier frequency around its reference value. The maximum departure of the instantaneous frequency of the FM wave from the carrier wave.

$$\Delta f = \frac{KV_M}{2\pi}$$

Where K - Phase sensitivity of the circuit

V_M - Peak Amplitude

iv. **CARRIER SWING:** This is always twice the instantaneous deviation from the carrier frequency also known as the difference between the highest and lowest frequencies attained by the FM signal.

$$F_{CARRIER\ SWING} = 2\Delta F_C.$$

The equation applies only for symmetrical modulating signal.

v. **CARSONS RULE:** The rule states that the bandwidth needed for transmission of FM signals should be twice the maximum carrier frequency deviation and instantaneous frequency of the base band.

$$\mathbf{BW \approx 2}\ (2\Delta F_C + F_M)$$

$$\mathbf{BW \approx 2}\ F_M\ (M_F+1)$$

Where F_M- Maximum Frequency component of the modulating signal

ΔF_C- Frequency Deviation

vi. **DEVIATION RATIO:** This is the largest allowable modulation index or the maximum possible frequency deviation over the maximum input frequency.

vii. **PERCENTAGE MODULATION:** This is a factor which describes the ratio of the instantaneous carrier deviation to the maximum carrier deviation (i.e. to say it gives the relationship between the relative amplitude of the carrier and intelligence signals) i.e.

$$\% \text{ Modulation} = \frac{\Delta F_C}{\Delta F_{MAX}} * 100$$

CHAPTER TWO

2.0 SYSTEM ANALYSIS

2.1 INTRODUCTION

The general view of an FM transmitter can be given as a block diagram with each block performing the actions that are required of it. The block diagram is shown below:

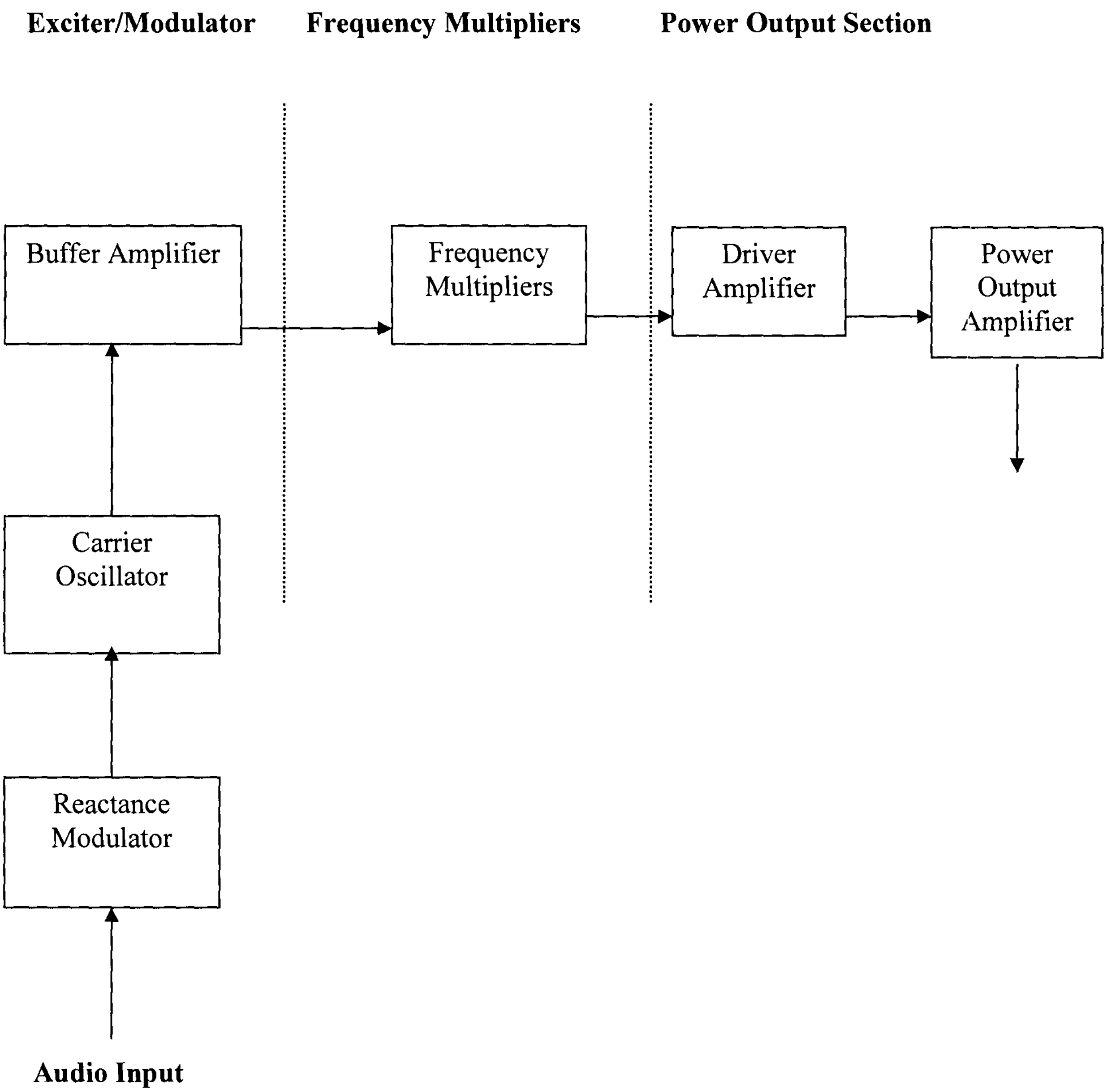


Fig 2.0 BLOCK DIAGRAM OF FM TRANSMITTER

The general functions of each of the sections and their general functions are given below:

i. Exciter/Modulator Stage

The modulator deviates the audio input about the carrier frequency. The carrier oscillator generates a stable sine wave for the carrier wave. The buffer amplifier acts as a high input impedance on the carrier oscillator which helps in stabilization of frequency.

ii. Frequency Multiplier Stage

The output here is always a multiple of the input signal.

iii. Power Output Section Stage

The final carrier power to be transmitted is developed here and it is also used as an impedance matching network: the output impedance is the same as that on the load (antenna).

2.2 MICROPHONE

This is a device that converts the variations in air pressure produced by voice or musical instruments into an electrical voltage (i.e. transform sound to electrical energy). Some types of available microphones used are Moving coil, Crystal, Piezo-electric and Capacitor (electret).

The Capacitor (electret) is most commonly used. In the Capacitor microphone, an electret element is used which acts as a special capacitor with one plate being a fixed diaphragm. Once a voltage is applied to the electret element, the capacitor is charged but no current flows apart from the leakage current which is negligible. The sound waves hitting the diaphragm change the amount of capacitance (which depends on the separation between the plates). The capacitance varies which in turn varies the voltage across the capacitor to maintain the constant charge of the capacitor.

The capacitor microphone has high impedance, but an IGFET pre-amplifier (built in the microphone module) can provide current and typical impedance. The output quality of sound is excellent but it needs a polarizing voltage to charge the capacitor which is done with a 1.5V battery. The output is coupled by an electrolytic capacitor to the next stage.

2.3 PRE-EMPHASIS AND DE-EMPHASIS

In FM, noise is a factor that has to be dealt with for good output. The higher the intelligence frequencies, the tendency of noise to be suppressed decreases.

Hence electrical amplitude of the higher frequencies will have to be given a boost (artificial).

Pre-emphasis is a process in FM transmission that amplifies high frequency more than low frequency audio signals to rescue the effect of noise (i.e. increasing the relative strength of high frequency components of the audio signal before being fed to the modulator).

The main reason for pre-emphasis is to prevent high frequency components of the transmitted intelligence from being degraded by noise that would have more effect on the higher than on the lower intelligence frequencies.

But as pre-emphasis is done, the natural balance (ratio) between the high and low frequencies are altered. Hence De-emphasis is carried out which is the process in an FM receiver that reduces the amplitudes of high frequency audio signals down to their original values to counteract the effect of pre-emphasis network in the transmitter. The circuits are as shown below:

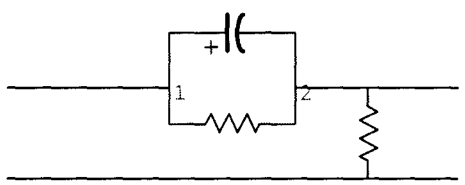


Fig 2.1a:Pre-emphasis

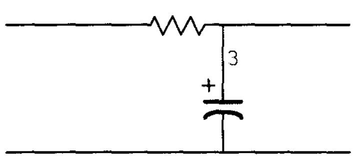


Fig 2.1b:De-emphasis

2.4 OSCILLATOR

This is a circuit that is used to generate waveforms that occur at some repetitive frequency. For an oscillator to be chosen for a particular application, some criteria have to be considered such as the output frequency required, the frequency stability required, whether the frequency to be variable, the allowable waveform distortion and the power output required. Some popular oscillators used are LC oscillator, Hartley oscillator, Colpitts oscillator, Clapp oscillator and Crystal Oscillator.

The carrier oscillator is used in FM to generate a stable sine wave at the carrier frequency when no modulating signal is applied to it. A parallel LC tank circuit found in the heart of oscillators should have positive feedback network which serves to increase or sustain the self generated output and an amplifier.

The criteria for oscillation is then given by the Barkhausen criteria which states that

i. Loop gain must be unity and

ii. Phase shift must be 0^o or 360^o

From the given criteria above, any impulse applied to the LC circuit is feedback and amplified; and it is sustained at a natural or resonant frequency

$$F_r = \frac{1}{2\pi\sqrt{LC}} \text{ Hz} \quad \text{.........................Equation 14}$$

However, for frequency higher than 1MHz, a Colpitts or Hartley's oscillator can be used.

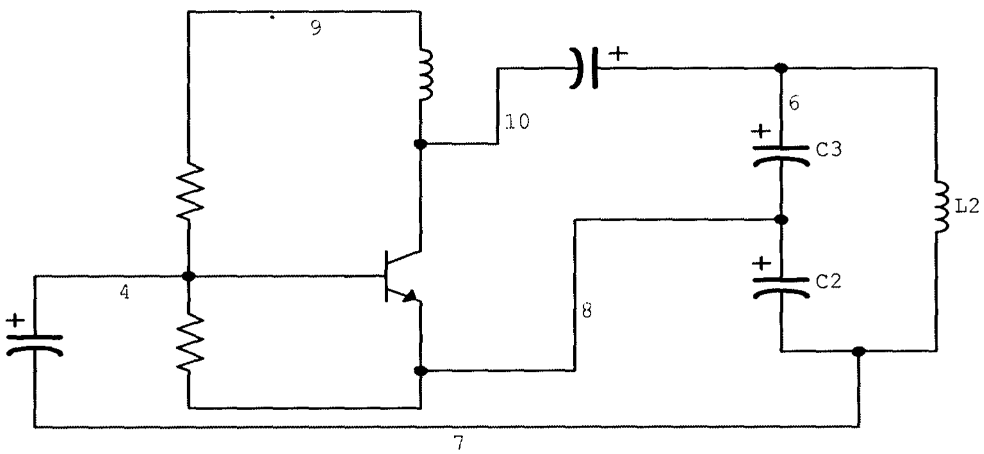


Fig 2.2: Colpitts Oscillator

Fig 2.2 is a Colpitts oscillator which has an LC tank (L2, C2, C3) helped by a common emitter amplifier and a feedback capacitor which sustains the oscillation

$$F = \frac{1}{2\pi\sqrt{L_1 C_{eq}}} \text{ Hz}$$

Where $C_{eq} = \frac{C_2C_3}{C_2+C_3}$

Hence $F = \frac{1}{2\pi\sqrt{L_1 \frac{C_2C_3}{C_2+C_3}}}$ ……._……..Equation 15

2.5 REACTANCE MODULATOR

In FM, when the base band signal is zero, the carrier is at its carrier frequency, and the carrier deviation is maximum when it is at its peak and vice versa. The deviation is either quickening or slowing down of the frequency around the carrier frequency by an amount proportional to the base band signal. In order to achieve this, the inductance or capacitance of the LC tank must be varied by a varactor diode.

The varactor diode when in reverse bias has a capacitance across it which is proportional to the magnitude of the reverse bias applied to it. From the formula given for instantaneous capacitance, as reverse bias is increased, the capacitance decreased.

$C_D = \frac{C_o}{\sqrt{(1 + 2|V_R|)}}$ ……………………………Equation 16

Where C_D- instantaneous capacitance about the diode's terminals

C_O- Capacitance at zero reverse bias voltage

When this is applied to an LC tank as the capacitance decreases, the frequency increases. When a fixed reverse bias is on the varactor diode, a fixed capacitance will be got which can be placed in parallel with a capacitor and Inductor. A bypass capacitor is then used to feed the base band voltage of the varactor diode, the sine wave base band voltage has the effect of varying the capacitance of the varactor up and down from the level set by the fixed reverse voltage bias.

The cases considered of maximum, minimum and nominal capacitance will give the frequencies as follows:-

$$F_{NOM} = \frac{1}{2\pi\sqrt{L}\,(C1 + C_{D\,NOM})} \text{ Hz}$$ i.e. No base band influence ....Equation 17

$$F_{MIN} = \frac{1}{2\pi\sqrt{L}\,(C1 + C_{D\,MAX})} \text{ Hz}$$ i.e. With peak negative base band influence...Equation 18

$$F_{MAX} = \frac{1}{2\pi\sqrt{L}\,(C1 + C_{D\,MIN})} \text{ Hz}$$ i.e. With peak positive base band influence...Equation 19

The circuit diagram is shown below:-

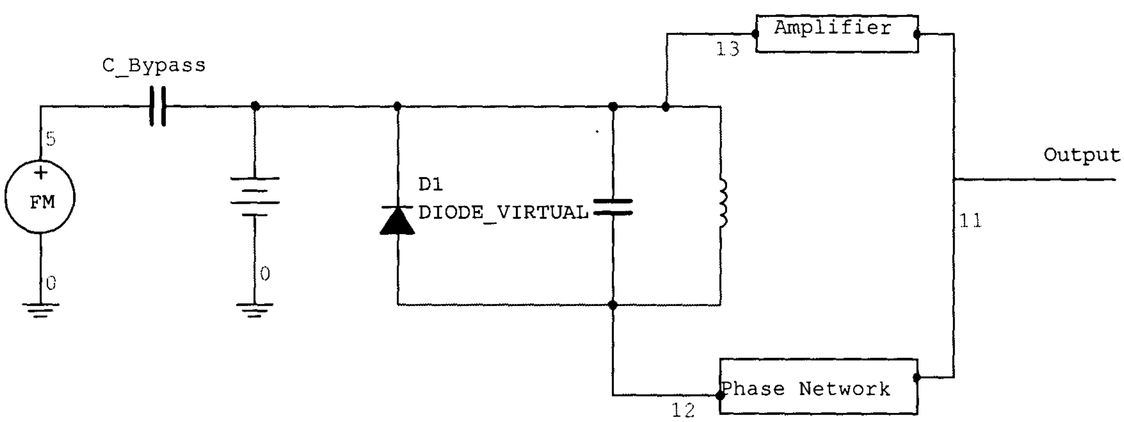


Fig 2.3: Reactance Modulator

2.6 BUFFER AMPLIFIER

This acts as a high input impedance with low gain and low output impedance. The high input impedance prevents the loading effects from the oscillator section. The high impedance can help in stabilizing the frequency. The buffer amplifier is a common emitter configuration with low voltage gain or an emitter follower transistor configuration.

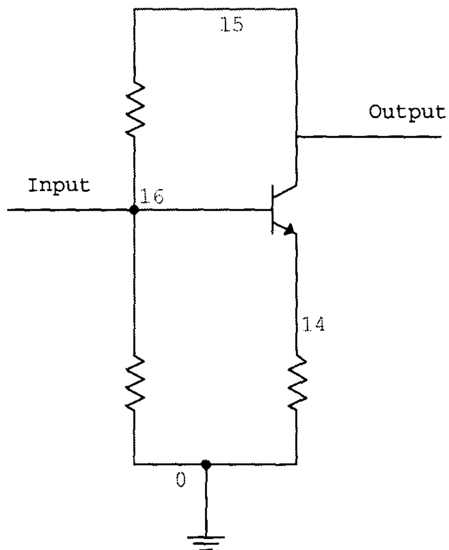


Fig 2.4: Buffer Amplifier

Increase in the input voltage increase the Base and Emitter current. As the Emitter Current $I_E \approx$ Collector Current I_C, then the current flowing through the emitter rises and voltage also rises.

The base voltage is always 0.6/0.7V greater than Emitter Voltage (i.e. the emitter voltage is always less than the base voltage (i.e. a voltage gain of less than 1). Hence since it has high input resistance and the output resistance is small, it is then used ideally in preventing loading of one circuit on another and feeding the next one with little voltage loss hence acting as a buffer between 2 circuits.

2.7 FREQUENCY MULTIPLIERS

Frequency Modulation of the carrier by the base band can be done at a high modulation index, but frequency drift of the LC tank is prone. For this to be avoided, modulation can take place at lower frequencies where the Q-factor of the LC tanks is high, and the carrier can be created by a crystal controlled oscillator. This oscillator is used when greater frequency stability than that provided by the LC oscillator is required. At low frequency deviation, the crystal oscillator can produce modulated signals that can keep audio distortion under 1%. The narrowband angle modulated wave can then be multiplied to the required transmission frequency. The deviation brought about by the base band is also multiplied which implies that the percentage modulation and Q-factor are not altered.

In frequency multipliers, the output of the resonant tank frequency is a multiple of the input frequency. The circuit diagram is shown below:

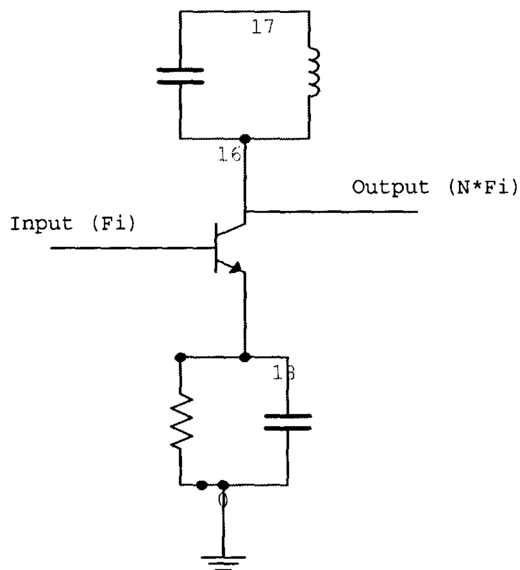


Fig 2.5: Frequency Multiplier

The circuit shown in Fig 2.5 above is good for multiplying factors (2, 3, and 4); current idlers are used to improve the efficiency. The series resonant LC's help in the output filtering of the input and also aid in circulation of harmonic currents to enhance the transistors non-linearity. The output of the tank is tuned to N* $F_i = F_o$. In respect of high efficiency transistor power amplifiers, most of the non-linearity is provided in the collector base junction and not base emitter in order to maintain a high current gain.

2.8 DRIVER AMPLIFIER

This does the same work as the buffer amplifier (i.e. high input impedance, low gain and low output impedance) between the frequency multipliers and power output stages of the transmitter. It has the same circuit as a Buffer amplifier.

2.9 POWER OUTPUT AMPLIFIER

This takes energy from the DC supply and converts to AC signal that is to be radiated. In order to generate good power output, the output power amplifier should be a Class C amplifier which can be used for high modulated systems. The efficiency of the Class C amplifier is 85%. The choice of amplifier type depends to a large extent on the output power and the intended range of the transmitter.

2.9.1 ANTENNA

This is a circuit element that converts the FM signal to EM waves which is then radiated into the atmosphere (i.e. a device that is used in transmission or reception of EM waves carrying some signal and are used to interface the transmitter or receiver to free space) hence making it the final stage of the transmitter.

The shape and number of antennas in a system depends on the types of waves being used and the frequency at which they are transmitted. The antenna's can be classified as being resonant or non-resonant.

Resonant antennas are those that are efficient propagator or receptor of EM energy at its designed wavelength.

For maximum power transfer by an antenna, some factors have to put into considerations which are:- Power Gain, Radiation Resistance, Polarization, Reciprocity, Power Transfer, and Radiation Pattern

i. POWER GAIN (G)

The power gain of an antenna is the ratio of its radiation intensity to that of an isotropic antenna radiating the same total power as accepted by the real antenna. An isotropic antenna is one that radiates power equally in all directions.

Since an isotropic antenna is hardly realizable, then the $\lambda/2$ dipole antenna is usually used as the reference antenna. It is measured in dBi (which indicates that the antenna gain is relative to an isotropic radiator).

ii. RADIATION RESISTANCE

This is the portion of the antenna's input impedance that results in power radiated into space. It is given by the pointing vector theorem

$\rho = E*H$

E- Electric Field Strength

H- Magnetic Field Strength

Which is multiplied by a certain area πr^2 and equated to the resulting power I^2R_r

Power = $I^2R_r = 80\pi 2\ I^2\ (dl/\lambda)$

$R_r = 80\ \pi^2\ (dl/\lambda)^n$ ....Equation 20

Where dl-length of antenna

λ -Wavelength

n- Exponent value that can be found by using (dl/λ) on the y-axis, the n can be found on the x-axis

iii. POLARIZATION

This is the alignment of the electric field vector of the plane wave relative to the direction of the plane wave relative to the direction of propagation (i.e. the plane in which the electric field lies).

It can also be the orientation of the electric field radiated from the antenna. e.g. a horizontally polarized antenna radiates a horizontally polarized EM wave and a circularly polarized antenna has the electric field rotating in a circular pattern.

iv. RECIPROCITY

The theorem states that if a voltage is applied to the terminals of an antenna A, and the current measured at the terminals of another Antenna B, then an equal current will be obtained at the terminals of Antenna A, if the same voltage is applied to Antenna B.

This means that any antenna will work well for transmitting and receiving, hence the theorem holds for any linear time-invariant medium.

v. POWER TRANSFER

In order to produce an efficient transmitter, maximum power transfer has to take place from the circuit to the antenna. If the impedance of the antenna of the receiver is Z_{in} and connected with the input terminal which is terminated with a resistance R_g; then maximum power transfer gives the current flowing in the receiver.

$$I = \frac{V}{Z_n + R_g} \quad \text{.....................Equation 21}$$

Gives an induced Voltage.

The power transferred is I^2R_g

Differentiating with respect to R_g and putting the derivate to zero for maximum power transfer

$$Z_n + R_g = 2\,R_g$$

$$Z_n = R_g \quad \text{.................. Equation 22}$$

vi. RADIATION PATTERN

This is the polar diagram representing the spatial distribution of the radiated energy.

2.9.2 HERTZIAN DIPOLE ANTENNA

This is also called the half-wave dipole and it is used mostly for frequencies above 2MHz. The impedance of a hertzian dipole is maximum at the open ends and minimum at the source end. (i.e. the impedance varies from a minimum at the source end to maximum at the open ends). The impedance given is normally 73Ω at the source and 2500Ω at the open end, which accounts for minimum voltage at the terminals and maximum voltage at the ends. This makes it possible accept electrical energy and radiate into space as EM waves.

2.9.3 MONOPOLE/MARCONI ANTENNA

This is used for frequencies below 2MHz. The Marconi antenna is usually a quarter-wave grounded antenna where the earth would act as the second quarter wave dipole antenna.

The difference between the vertical and half wave dipole is the need of a conducting path to ground for the vertical type of antenna. For the Marconi antenna, increase/decrease in height affects the power and area of coverage.

As regards this project the 2 factors considered in designing antenna's are:-

i. Frequency of transmission- For FM the frequency range is 88-108MHz. The mean frequency is given as

   $F= \sqrt{(88*108)}$ MHz

   $=100$MHz

ii. Coverage distance

   $V = f*\lambda$

V-Speed of light

F-frequency of operation.

CHAPTER THREE

3.0 SYSTEM DESIGN AND CONSTRUCTION

This chapter gives the final detailed circuit diagram of the transmitter and the construction process that made the project realizable. The different stages of the circuit are hence analyzed.

3.1 MICROPHONE

Microphone is a device that converts the variations in air pressure produced by voice or musical instruments into an electrical voltage. The capacitor microphone which is used for this project has high impedance (an IGFET preamplifier built in the microphone module). A polarizing voltage which is needed to charge the capacitor is done with a 1.5V battery. The output is then coupled by an electrolytic capacitor to the next stage (the purpose of which is to block any DC component in the input).

A 2 stage amplifier would be used because in designing circuits with the use of transistors as amplifiers, the circuit should always be divided into stages. The stages of the amplifier should consist be of

i. Low Signal which provides the drive requirements for the succeeding stages coupled to it
ii. Output stage which is mostly called the driver stage.

3.2 LOW SIGNAL STAGE (1ST STAGE)

The circuit configuration used for the low signal is the Common Emitter configuration for the following reasons:-

i. High power gain is established
ii. Less sensitive to temperature variations
iii. Has a stable DC operating point
iv. Control over stabilization by the designer

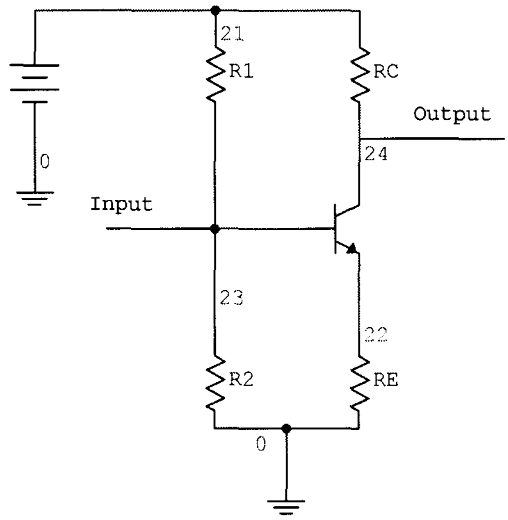


Fig 3.0:Common Emitter configuration

The performance of the transistor and amplifier always depends on the DC operating point (i.e. the values of I_C and V_{CE}).

There are various ways of biasing or setting the DC operating point of transistor or amplifier put in use. The most stable biasing network which is not affected by the variations in temperature is the Voltage Divider or Universal Bias method. The resistors R_1 and R_2 form a voltage divider network. The voltage across R_2 forward biases the emitter diode. When the bias terminal is on open circuit the following result is obtained.

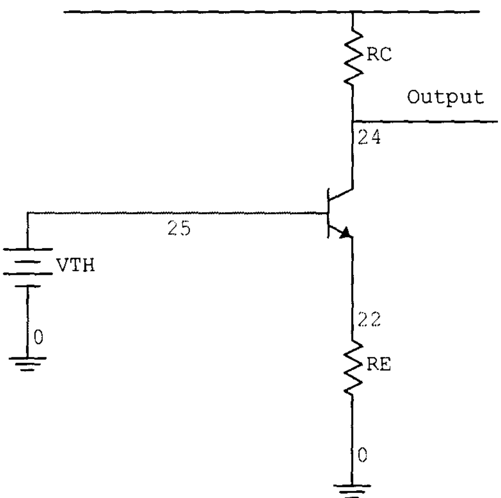


Fig 3.1:Open Circiut of Common Emitter configuration

The Thevenin voltage that drives the base is given as

$$V_{TH}= V_{CC} * \frac{R_2}{R_1+R_2}$$ ....Equation 23

The Emitter current $I_E= \frac{V_{TH}-V_{BE}}{R_E}$ ....Equation 24

But it should be noted that $I_C \approx I_E$ ....Equation 25

We should bear in mind that β_{DC} which is a consequence of temperature which affects all other biasing networks did not appear here hence making it to be stiff which makes for a good circuit design. The DC load line for the transistor can then be obtained by the following set of equations

$V_{CC}=V_{CE}$ $I_C=\frac{V_{CC}-V_{BE}}{R_C+R_E}$..............Equation 26

For the Common Emitter configuration above various values of R (R_1,R_2, R_C and R_E) are determined by the type of transistor used and its characteristics extracted from the transistor data sheet. The use of a Silicon transistor is advisable because it is relatively unaffected by temperature changes. The analysis of the above configuration can be deducted from the following set of equations which makes for use for the stability of the configuration. The equations for DC analysis are

$V_E = 0.1V_{CC}$...........Equation 27

$R_E = \frac{V_E}{I_E}$...................Equation 28

$R_C = 4R_E$ (approximately)...............Equation 29

$R2 \leq 0.1h_{FE}R_E$.....................Equation 30

$R_1 = R_2 * \frac{V_1}{V_2}$...........................Equation 31

Voltage at Base $V_B = V_{CC} * \frac{R_2}{R_1+R_2}$ ....Equation 32

Voltage at emitter $V_E = V_B - 0.7$ ....Equation 33

Emitter Current $I_C = \frac{V_E}{R_1+R_2}$.....................Equation 34

Collector Voltage $V_C = V_{CC} - I_C R_C$................Equation 35

Voltage across Collector and Emitter $V_{CE} = V_C - V_E$...........Equation 36

The biasing calculations are given thus

$V_{CC} = 9.0$ V

$h_{FE} = 800$ (From Transistor data sheet as attached)

$I_C = 2*10^{-3}$

$V_C = 0.5 * 9 = 4.5V$

$$R_C = \frac{V_C}{I_C} = \frac{4.5}{2*10^{-3}} = 2.25K\Omega$$

$V_E = 0.1V_{CC} = 0.1 * 9 = 0.9V$

$$R_E = \frac{V_E}{I_E} = \frac{0.9}{2*10^{-3}} = 450\Omega$$

$$h_{FE} = \frac{I_C}{I_B}$$

$$I_B = \frac{I_C}{h_{FE}} = 2*10^{-3} = 2.5 * 10^{-6}$$

For Silicon Transistors $V_{BE} = 0.7V$

$V_B = V_E + 0.7 = 0.9 + 0.7 = 1.6V$

$$I_{C(Sat)} = \frac{V_{CC}}{R_C+R_E} = \frac{9}{2.25K\ \Omega + 450\ \Omega} = 3.33*10^{-3}A$$

$$R_2 = \frac{V_B}{10I_B} = \frac{1.6}{10(2.5*10-6)} = 64K\ \Omega$$

$$R_1 = \frac{V_{CC}-V_B}{10I_B} = \frac{9-1.6}{10(2.5*10-6)} = 296K\ \Omega$$

Voltage across Collector and Emitter (V_{CE}) $=V_C-V_E = 4.5-0.9 = 3.6V$

Hence the circuit for the low signal stage becomes

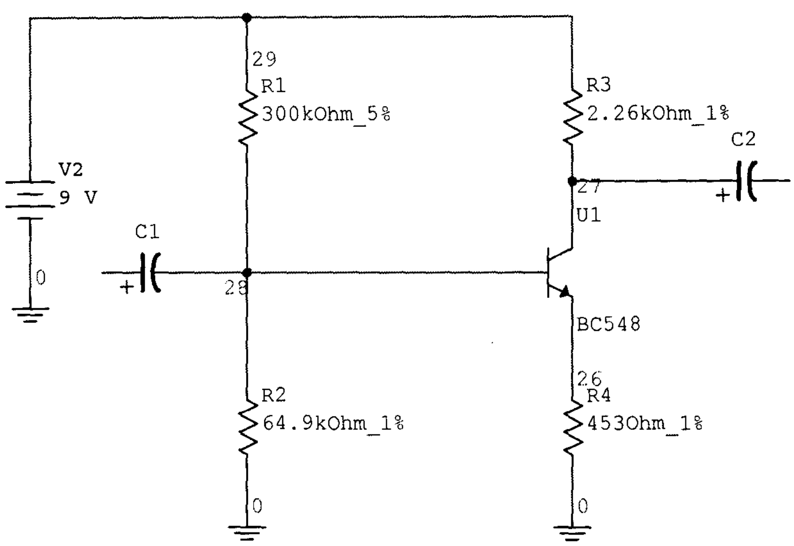


Fig 3.2:Low Signal Stage

As far as DC is concerned the capacitor appears as an open circuit to it, while a small input voltage (V_{IN}) drives the base and a corresponding amplified output voltage appears at the collector.

3.3 COUPLING

Whenever you need to couple a signal from one amplifier to the other you use a capacitor. A capacitor is used for this purpose to block any DC component in the input, which if allowed would interfere with the bias arrangements.

The signal is capacitively coupled to the base to cause the collector voltage to vary. Hence the value of C is chosen so that ALL frequencies of interest are passed by the High Pass Filter (HPF) it forms in combination with the parallel resistance of the base resistors.

$$\text{Hence } C \geq \frac{1}{2\pi f\,(R1//R2)} \qquad \text{.........Equation 37}$$

Where C- Capacitance required

f- Frequency at -3dB form to allow form a HPF; hence 200Hz for audio

An audio amplifier handles frequency from 20Hz to 20 KHz which the human ear can respond to.

The parallel combination of R_1 and R_2 becomes

$$\frac{R_1 * R_2}{R_1 + R_2} = \frac{296*10^3 * 64*10^3}{296*10^3 + 64*10^3} = 52.6K\Omega$$

$$C \geq \frac{1}{2\pi*200*52.6*10^3} = 0.015*10^{-6}F$$

$C \geq 0.02\mu F$

The capacitor used should be electrostatic in nature (i.e. polarity must be observed). The negative side of the inter-stage coupling capacitor is connected to the collector of the preceding transistor and the positive side to the base of the following transistor if a p-n-p type of transistor is used or vice-versa for n-p-n transistors.

It should be noted that where the capacitor forms part of a base-emitter network the negative side of the capacitor is connected to the base. The circuit with the capacitor values is shown in Fig 3.3 for the low signal stage.

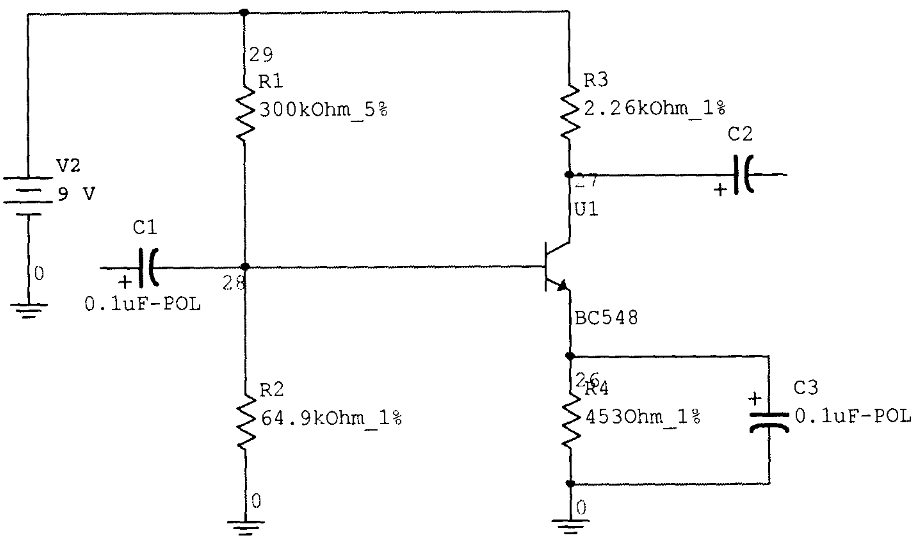


Fig 3.2:Low Signal Stage with Coupling Capacitors

3.4 OUTPUT STAGE (2^{ND} STAGE)

The 2^{nd} stage which is the output stage, a power amplifier circuit is connected to the low signal stage. The previous set of equations can still be used accordingly.

Power amplifiers are used for large signal amplification e.g. in RF application. The power required should be able to drive an antenna since it is used for transmission. We have 3 classes of power amplifiers and the classification depends on how long each conducts during one complete cycle of sinusoidal input signal.

The most efficient class is the Class-C operated device because it conducts for less than one-half cycle, but more than one-quarter cycle. The operation in Class-C puts the biasing point well beyond the cut-off region. Hence the output current is approximately 120° of the input signal cycle. For this description and efficiency this project has used the Class-C amplifier.

In order for the transistor to conduct and amplify, the base must be taken from 0 to 0.7V initially. The collector current then increases rapidly as the base become more positive. As the input decreases, the transistor will switch off before the half-cycle reaches 0V. On the negative half-cycle of the input, the transistor remains firmly off.

In Class-C transmitter, the collector load is replaced by a parallel tuned circuit. An amplifier is then created which will only amplify frequencies of a selected range. With the collector load replaced by the tuned circuit we now have

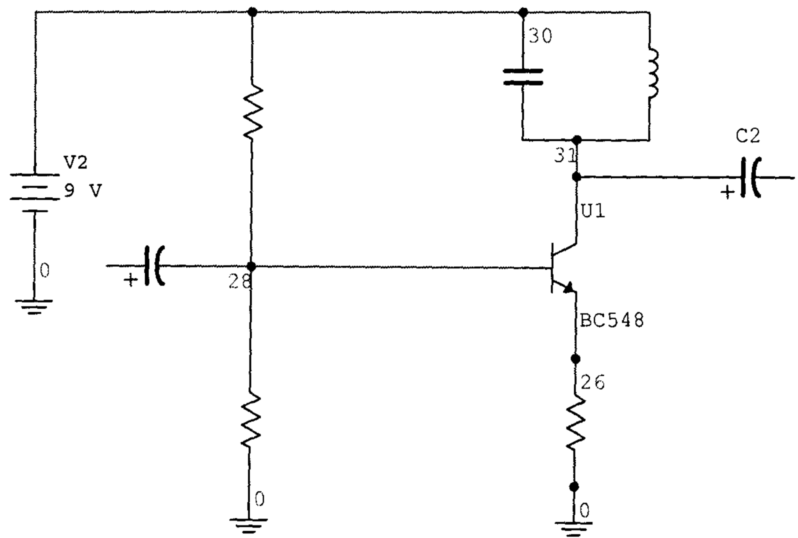


Fig 3.4:Output Stage

The maximum output of this circuit will be at the point of resonance (i.e. $X_L = X_C$)

To form a tuned circuit the inductor and capacitor should be connected either in series or parallel. At a particular frequency, the numerical values of the reactance of the inductor and the reactance of the capacitor will be equal.

i.e. $X_L = X_C$

$$2\pi F_R L = \frac{1}{2\pi F_R C}$$

$$F_R = \frac{1}{2\pi\sqrt{LC}}$$

Where L – Inductance in Henry's

C- Capacitance in Farads

F_R- Resonant frequency

Since the resonant frequency of a tuned circuit is fixed by the L * C, we have infinite number of values which will tune to give the frequency, this makes the values to be chosen using practical considerations.

The optimum choice of L/C ratio is difficult hence as a compromise, it is assumed that the value of C is 1.5pF per meter of wavelength. Since FM is from 88-108MHz, the capacitor value is as follows

$V = F\lambda$

Where $V = 3*10^8$m/s and $F = 100*10^6$Hz

$$\lambda = \frac{3*10^8}{100*10^6} = 3m$$

For the resistor values used for the power amplifier section we have the following

$I_C = 2*10^{-3}A$

$V_{CC} = 4.5V$

$V_E = 0.1V_{CC} = 0.1*4.5 = 0.45V$

$$R_E = \frac{V_E}{I_E} = \frac{0.45}{2*10^{-3}} = 225\Omega$$

$V_B = V_E + 0.7 = 0.45 + 0.7 = 1.15V$

$$R_2 = \frac{V_B}{10I_B} = \frac{1.15}{10\,(2.5*10^{-6})} = 46K\Omega$$

$$R_1 = \frac{V_{CC}-V_B}{10I_B} = \frac{4.5-1.15}{10\,(2.5*10^{-6})} = 134K\Omega$$

The coupling capacitance to the previous stage becomes

$$C \geq \frac{1}{2\pi f\,(R1//R2)}$$

$$(R1//R2) = \frac{134*10^3*46*10^3}{134*10^3+46*10^3} = 32.24K\Omega$$

$$C \geq \frac{1}{2\pi * 200* 32.24*10^3} = 0.02\ \mu F$$

The value of Inductance used for the tank will be

$$F_R = \frac{1}{2\pi\sqrt{LC}}$$

Since we earlier calculated the capacitance for the tank to be 4.5pF, the value of the inductance will be

$L = (1/2\pi*100*10^6)^2*(1/4.5*10^{-12})$

$= 0.56\mu H$

The detailed power amplifier circuit becomes

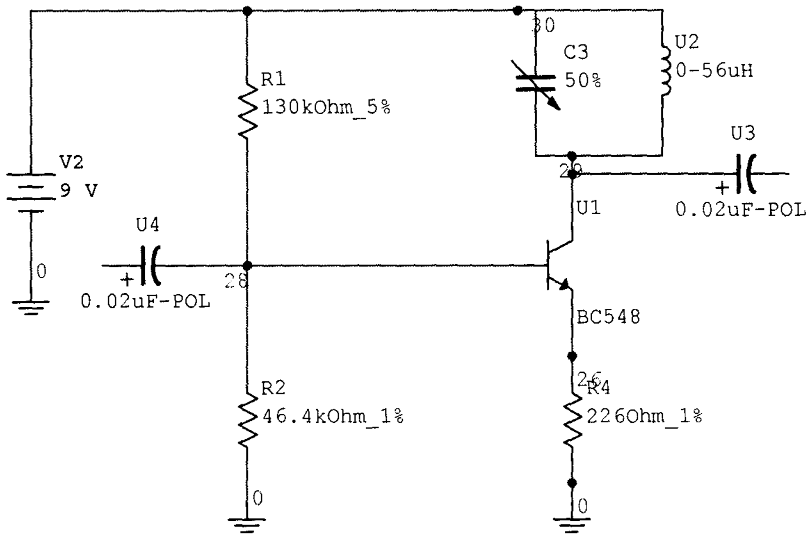


Fig 3.5:Output Stage with Coupling Capacitors

The final circuit diagram of the transmitter then becomes the cascade of the two stages as shown in Fig 3.6.

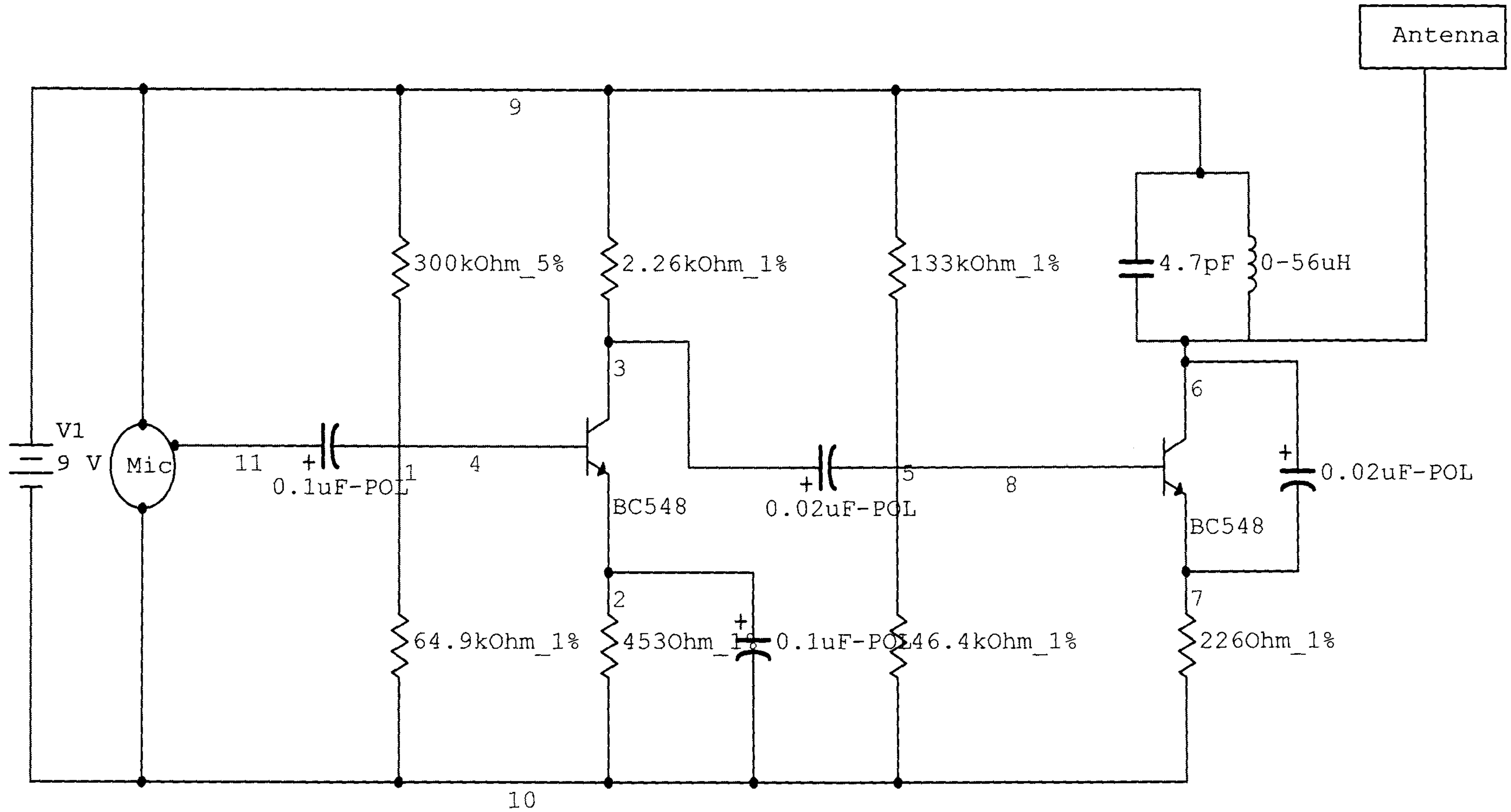


Fig 3.6 FM Transmitter Circuit

3.5 CONSTRUCTION

Construction in simple terms means the putting together of different parts to form a complete system. This always involves the assembly and testing of components.

After all calculations were carried out in the System Design section the components were sourced for and the ones not exactly found were replaced with very close values that could perform the same function.

The items used for the realization of the construction were

1. RESISTORS

RESISTOR VALUES	**QUANTITY**
296KΩ	1
65KΩ	1
2.26KΩ	1
453Ω	1
130Ω	1
46.4KΩ	1
226Ω	1

2. CAPACITORS

CAPACITOR VALUES	**QUANTITY**
0.1Mf	2
0.2 Mf	2
4.5pF	1

3. TRANSISTORS

TRANSISTOR VALUE	**QUANTITY**
BC548	2

4. INDUCTOR

INDUCTOR VALUE	**QUANTITY**
0.56 μ H	1

5. 1 No. Microphone

6. 1 No. Antenna

7. Connecting Wires

The other items used for the project are

i. Bread Board- The initial work was carried out here and tested before transferring to the Vero board
ii. Vero Board- The final construction work was done here
iii. Soldering Iron- used for soldering the components permanently to the Vero board
iv. Soldering Lead- used as a form of adhesive for the component to the Vero board
v. Lead Sucker- used to suck away all melted lead at the points not needed

One of the most important key in achieving the success of this project were

i. the parts were easily obtained
ii. leads of the devices used were made small and compact

The project before finally soldering to the Vero board was tested to see if it is functioning before the final stage of casing.

Utmost care was taken when the soldering work was done to ensure that the project was not problematic. The leads were properly checked after soldering to avoid short circuit and the polarity of the capacitors more especially at the inter-stage coupling were observed.

The problems encountered in this project were the construction and soldering as these were never taught during my stay in school. Some of the equipments that are used all over the World for standard test of Frequency Modulation such as the Frequency meter and Spectrum Analyzer were not available to be used hence the use of virtual instruments in simulation softwares.

CHAPTER FOUR

4.0 CONCLUSIONS AND RECOMMENDATIONS

4.1 CONCLUSIONS

The aim of this project was to design and construct a Multi-Channel Frequency Modulation transmitter which would be used for modulation across the commercial band (88-108MHz).

In Chapter 1, an introduction into the Communication Systems with the technical background, FM theory was covered. In Chapter 2, System Analysis with a generalized block diagram describing the function of each was covered. In Chapter 3, System Design was properly looked with all the values of achieving a working project then Conclusion and Recommendations in Chapter 4.

The whole aim is then to begin with the detailed description of the main topics with the initial approach to the final implementation.

Communication which can be defined as the sending of information from one place to another. With the growth of civilization and distance apart at which humans are, the need to communicate regularly at long distances has become so important.

For information to be transmitted from one place to another the transmitter is a very suitable form of doing so, hence making life to be comfortable.

For this project to be achieved a good knowledge of Analogue Design and Communication system had to be combined.

The final model was able to send information across in the Commercial Band when tested.

FM transmitters have been able to enhance information flow and can be used to enhance opportunities for developments in both rural and urban areas.

Hence this project was to transmit information on the Commercial Band which has become an effective way of communication.

4.2 RECOMMENDATIONS

I wish to recommend on how this project can be improved by the following:-

i. Impedance matching between the transmitter's antenna should be properly calculated for maximum transfer of power

ii. Analog output can be converted to digital as most systems are now digitalized

iii. Area of coverage can be increased

iv. Power of the transmitter can also be increased

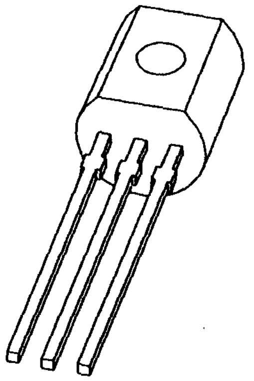
v. Stability of the oscillator part should also be considered

In conclusion, I would suggest that the Nigerian Universities Commission with the help of the Federal Government should always update the syllabuses used as most of what are taught is not of any relevance anywhere in the world where technology is fast developing. The University laboratories have to also be equipped with modern instruments, computers, and softwares to bring out a good combination of theoretical and practical aspects in the students who are always willing to learn and apply.

REFERNCES

1. ADEDIRAN, Y.A., Telecommunications: Principles and Systems, Finom Associates, Minna-Nigeria, 1997
2. BUGG,D.V., Electronics: Circuits, Amplifiers and Gates, Bath Press Avon, Great Britain, 1991
3. GEORGE, B. Radio Amateurs' Examination Manual,15th Ed, Radio Society of Great Britain,1995
4. GREEN,D.C. Radio Communication, 2nd Ed, Pearson Education, 2000
5. HOROWITZ,P., Art of Electronics,2nd Ed, Cambridge University Press,1980
6. MILLER,G.M., Modern Electronic Communication,7th Ed, Prentice Hall, UK, 2002
7. MICROSOFT ENCYCLOPEDIA 2003
8. RALPH,J,SMITH., Circuits, Devices and systems, 5th Ed
9. WATSON,J., Mastering Electronics,4th Ed, Macmillan Series,England,1996
10. WOLFENDALE.E., Transistor Circuit Design and Analysis, London Heywood Books,1966
11. www.dckits.com
12. www.dicovercircuits.com
13. www.lecrog.com
14. www.ele.uri.edu
15. www.nzart.org.nz
16. www.microelectronica.co.yu
17. www.electronics-tutorials.com
18. www.pcs-electronics.com
19. www.skynet.ie
20. www.ee.washington.edu/circuits
21. www.mitedu.freeserve.co.uk/circuits

DATA SHEET



BC546; BC547; BC548
NPN general purpose transistors

Product specification
Supersedes data of September 1994
File under Discrete Semiconductors, SC04

1997 Mar 04

Philips
Semiconductors

PHILIPS

NPN general purpose transistors | BC546; BC547; BC548

FEATURES

- Low current (max. 100 mA)
- Low voltage (max. 65 V).

APPLICATIONS

- General purpose switching and amplification.

DESCRIPTION

NPN transistor in a TO-92; SOT54 plastic package.
PNP complements: BC556, BC557 and BC558.

PINNING

PIN	DESCRIPTION
1	emitter
2	base
3	collector

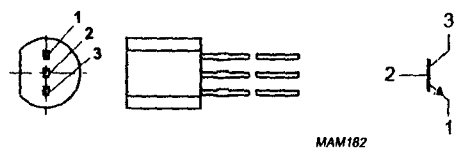


Fig.1 Simplified outline (TO-92; SOT54) and symbol.

QUICK REFERENCE DATA

SYMBOL	PARAMETER	CONDITIONS	MIN.	MAX.	UNIT
V_{CBO}	collector-base voltage	open emitter			
	BC546		–	80	V
	BC547		–	50	V
	BC548		–	30	V
V_{CEO}	collector-emitter voltage	open base			
	BC546		–	65	V
	BC547		–	45	V
	BC548		–	30	V
I_{CM}	peak collector current		–	200	mA
P_{tot}	total power dissipation	$T_{amb} \leq 25$ °C	–	500	mW
h_{FE}	DC current gain	$I_C = 2$ mA; $V_{CE} = 5$ V			
	BC546		110	450	
	BC547		110	800	
	BC548		110	800	
f_T	transition frequency	$I_C = 10$ mA; $V_{CE} = 5$ V; f = 100 MHz	100	–	MHz

LIMITING VALUES

In accordance with the Absolute Maximum Rating System (IEC 134).

SYMBOL	PARAMETER	CONDITIONS	MIN.	MAX.	UNIT
V_{CBO}	collector-base voltage	open emitter			
	BC546		–	80	V
	BC547		–	50	V
	BC548		–	30	V
V_{CEO}	collector-emitter voltage	open base			
	BC546		–	65	V
	BC547		–	45	V
	BC548		–	30	V
V_{EBO}	emitter-base voltage	open collector			
	BC546		–	6	V
	BC547		–	6	V
	BC548		–	5	V
I_C	collector current (DC)		–	100	mA
I_{CM}	peak collector current		–	200	mA
I_{BM}	peak base current		–	200	mA
P_{tot}	total power dissipation	$T_{amb} \leq 25$ °C; note 1	–	500	mW
T_{stg}	storage temperature		–65	+150	°C
T_j	junction temperature		–	150	°C
T_{amb}	operating ambient temperature		–65	+150	°C

Note

1. Transistor mounted on an FR4 printed-circuit board.

THERMAL CHARACTERISTICS

SYMBOL	PARAMETER	CONDITIONS	VALUE	UNIT
$R_{th\,j\text{-}a}$	thermal resistance from junction to ambient	note 1	0.25	K/mW

Note

1. Transistor mounted on an FR4 printed-circuit board.

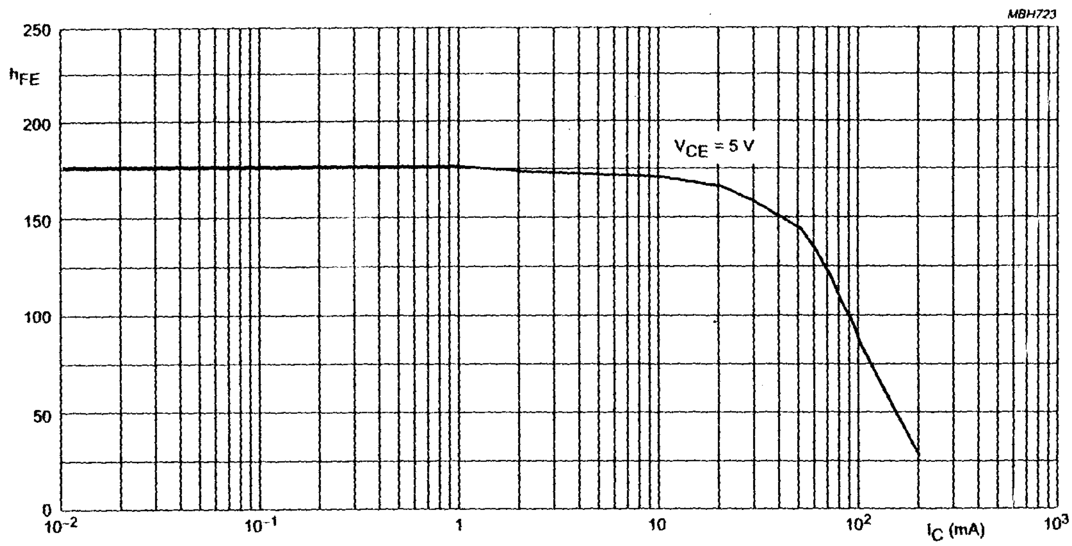
CHARACTERISTICS

T_j = 25 °C unless otherwise specified.

SYMBOL	PARAMETER	CONDITIONS	MIN.	TYP.	MAX.	UNIT
I_{CBO}	collector cut-off current	I_E = 0; V_{CB} = 30 V	–	–	15	nA
		I_E = 0; V_{CB} = 30 V; T_j = 150 °C	–	–	5	μA
I_{EBO}	emitter cut-off current	I_C = 0; V_{EB} = 5 V	–	–	100	nA
h_{FE}	DC current gain	I_C = 10 μA; V_{CE} = 5 V; see Figs 2, 3 and 4				
	BC546A; BC547A; BC548A		–	90	–	
	BC546B; BC547B; BC548B		–	150	–	
	BC547C; BC548C		–	270	–	
h_{FE}	DC current gain	I_C = 2 mA; V_{CE} = 5 V; see Figs 2, 3 and 4				
	BC546A; BC547A; BC548A		110	180	220	
	BC546B; BC547B; BC548B		200	290	450	
	BC547C; BC548C		420	520	800	
	BC547; BC548		110	–	800	
	BC546		110	–	450	
V_{CEsat}	collector-emitter saturation voltage	I_C = 10 mA; I_B = 0.5 mA	–	90	250	mV
		I_C = 100 mA; I_B = 5 mA	–	200	600	mV
V_{BEsat}	base-emitter saturation voltage	I_C = 10 mA; I_B = 0.5 mA; note 1	–	700	–	mV
		I_C = 100 mA; I_B = 5 mA; note 1	–	900	–	mV
V_{BE}	base-emitter voltage	I_C = 2 mA; V_{CE} = 5 V; note 2	580	660	700	mV
		I_C = 10 mA; V_{CE} = 5 V	–	–	770	mV
C_c	collector capacitance	I_E = i_e = 0; V_{CB} = 10 V; f = 1 MHz	–	1.5	–	pF
C_e	emitter capacitance	I_C = i_c = 0; V_{EB} = 0.5 V; f = 1 MHz	–	11	–	pF
f_T	transition frequency	I_C = 10mA; V_{CE} = 5 V; f = 100 MHz	100	–	–	MHz
F	noise figure	I_C = 200 μA; V_{CE} = 5 V; R_S = 2 kΩ; f = 1 kHz; B = 200 Hz	–	2	10	dB

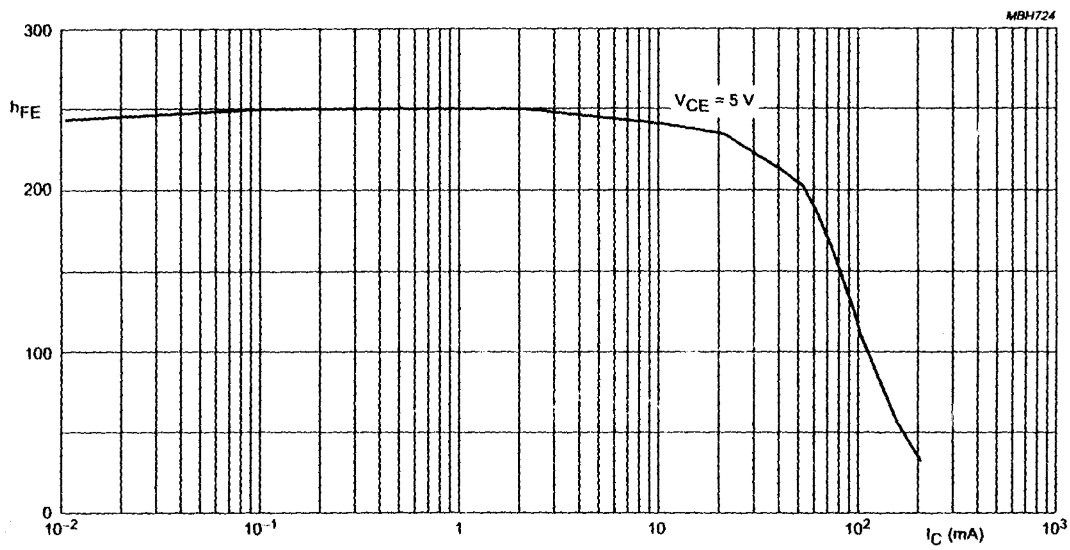
Notes

1. V_{BEsat} decreases by about 1.7 mV/K with increasing temperature.
2. V_{BE} decreases by about 2 mV/K with increasing temperature.



BC546A; BC547A; BC548A.

Fig.2 DC current gain; typical values.



BC546B; BC547B; BC548B.

Fig.3 DC current gain; typical values.