# ATTESTATION

This is to certify that this thesis titled "**Design and Construction of a Multichannel Frequency Modulation (FM) Transmitter**" was carried out by **Samaila Lassa** under the supervision of **Dr. E. N. Onwuka** and submitted to the Electrical / Computer Engineering Department, Federal University of Technology Minna, Niger State in partial fulfillment of the requirement for the award of Bachelor of Engineering (B. Eng.) degree in Electrical / Computer Engineering.

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# DECLARATION

I, SAMAILA LASSA hereby declare that this thesis entitled: "DESIGN AND CONSTRUCTION OF A MULTICHANNEL FREQUENCY MODULATION (FM) TRANSMITTER" is a product of my own research work under the supervision of Dr. E. N. ONWUKA.

--------------------------------------------------------------- 7/12/08

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MAT. NO: 99 / 9296EE

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Who is like unto thee, O' of Gods?

Thou giver of wisdom, without You even "without" can not be.

With every pulse of my being I bend knee in humble gratitude *Selah.*

**Mrs. Mariya Samaila:** Only one thing compare to you; NOTHING. So yours will be the Lions share, for the battle you fought on your knees on my behalf. May the labours or my life and the successes thereof be accommodated in your purse. O' mum.

**Late Major K. S. Lassa:** Thank you for bringing me into this world. Though I never got to know you much, you gave me a standing place from which I can move the world.

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# DEDICATION

This project is dedicated to the loving family of **(Late) Major K. S LASSA.**

# ABSTRACT

This thesis is base on the Design and Construction of a Multi-Channel Frequency Modulation (FM) Transmitter.

In chapter one an introduction to communication system with a view on the block diagram of a communication were covered. Chapter two and three literature review and design analysis elaborates on the history of radio broadcasting, frequencies and wavelength ranges giving emphasis on some equation and technical terms governing frequency modulation (FM) describing basic building blocks for an FM transmitter and designs under consideration of quantitative overview of some of the possible design that were considered in the progress of the project was given. In chapter four system design and construction the final design was discussed in full, stage by stage construction and assembling along with details of components and working principles.

Finally chapter five result and conclusion gives the result of the various tests used on the design with discussion and recommendation for improvement on design.

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# Chapter One

## 1.0 Introduction

### 1.1 Communication Systems

Communication, the process of transmitting and receiving ideas, information, and messages. The rapid transmission of information over long distances and ready access to information have become conspicuous and important features of human society, especially in the past 150 years, and in the past two decades, increasingly so[2].

With the growth of civilization and the development of written languages came the need to communicate regularly at longer distances as well, so as to conduct the trade and other affairs of nations and empires.

With the beginnings of modern understanding of the phenomenon of electricity in the 18th century, inventors started to search for ways in which electrical signals might be employed for the rapid relay of messages over long distances. The first practical telegraph system, however, was not produced until the 19th century, when two such inventions were announced in the same year of 1837: one, in Britain, by Charles Wheatstone and William F. Cooke, and the other, in America, by Samuel F. B. Morse. Morse also developed the code system of dots and dashes—Morse code—that was universally adopted for the new medium. Morse code was in worldwide use until February 1, 1999, when it was replaced by the Global Maritime Distress and Safety System, which uses satellite and terrestrial radio communication [1].

Although telegraphy marked a great advance in rapid long-distance communication, early telegraph systems could convey messages only letter by letter. The search was therefore also on for some means of voice communication by electricity as well. Early devices that appeared in the 1850s and 1860s were capable of transmitting sound vibrations but not true human speech. The first person to patent an electric telephone in the modern sense was the American inventor Alexander Graham Bell, in 1876. At the same time, Edison was also in the process of finding a way to record and then reproduce sound waves, paving the way for the invention of the record player [1].

The first radio broadcast was made in 1906, in the United States. The first broadcast of opera, from the Metropolitan Opera House in New York, was transmitted by De Forest in 1910. By 1920 several radio stations began transmitting in the United States, and by 1923 the British Broadcasting Corporation (BBC) was transmitting in the United Kingdom; by 1925 there were 600 radio stations worldwide. Nowadays almost every home has a radio [1].

Historically, the means of communicating have grown alongside the increased power of people to shape their physical world as well as with their increasing interdependence. With the telecommunications and data communications revolutions has been the evolution of the world as a "global village". The influence of the new communications media has increased the study of their effects. It is believed by some that the individual media tend to reinforce personal views rather than to convert people to other views, and by others that political conversion and influence, depending on who controls which medium of transmitting information, is prevalent. None the less, the changing communications media have proven to have long-term effects, which bring subtle but very important changes to views and perceptions of the audience [1].

In 1947 William Shockley, John Bardeen, and Walter Brattain invented the transistor. This enabled the electronics revolution to take place and provided the basis for a digitalized, rather than mechanical, telecommunications network.

In 1965 Charles Kao put forward the theory that information could be carried using optical fibres. These have subsequently been developed to provide a means of carrying huge amounts of information at very high speed. Optical fibres form the backbone of the global transmission network [1].

Audio-frequency waves must be combined with carrier waves in order to be transmitted over the radio. Either the frequency (rate of oscillation) or the amplitude (height) of the waves may be modified in a process called modulation. This accounts for the option on the radio dial for AM or FM stations; the signals are very different, so both kinds may not be received simultaneously [7].

There are several ways of carrying information between senders and users. The options chosen should reflect the type of communication required. For instance, humans compensate for noise and transmission errors when they talk to each other. Unexpected delays or echoes cause problems in understanding, however [3]. Computers have the reverse characteristics—being tolerant of short delays and less so of transmission errors.

Many older telecommunications systems are analogue; the electrical signals conveying information vary continuously in harmony with the sounds they represent. The quality of speech across analogue networks is determined by the amount of the speech spectrum that could be carried. Around 3 kHz was accepted as a reasonable compromise of cost and quality for normal telephone calls [1].

Most telecommunications networks today are "integrated" digital systems, ideally suited to computer networking and other multimedia applications such as speech (voice), data, text, fax, and video.

No one can predict with certainty exactly how telecommunications will develop, but certain trends can be noted. The cost of communication is falling in real terms, making advanced applications more affordable. Most of these have yet to evolve, but electronic commerce, mobile commerce, and various information-on-demand services are already being developed [1].

Some communication services currently provided by wire are migrating to radio means for greater convenience and flexibility; this includes not just cordless telephones in the home and the workplace but also connecting these telephones to the network. The short-range radio standard (known as Bluetooth) will be used to connect a range of devices into a fixed network. Conversely radio and television programmes, traditionally broadcast over the airwaves, are moving on to cable networks [1].

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 [7].

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** [2].

A high frequency carrier is represented by the mathematical expression of a sine wave; [8]

$V = V_p \text{ Sine } (wt + \Phi)$

Where, V – Instantaneous value

$V_p$ – Peak value (Amplitude)

w – Angular velocity ($2\pi f$)

$\Phi$ – 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, we have **amplitude modulation (AM)** and if the frequency is varied we have **frequency modulation (FM)** and **phase modulation (PM)** when the phase angle is varied [8].

Modulation is therefore important in communication for the following reasons:

1. For Channel Assignment
2. To reduce Noise and Interference, particularly at low frequency
3. For easy Radiation and Reception of signals by using practically realizable antenna sizes.
4. For Multiplexing
5. To overcome Equipment Limitations e.g. size and weight.

## 1.2 Block Diagram of a Communication System

A modern communication system [2] is shown in block diagram form in fig 1.0.

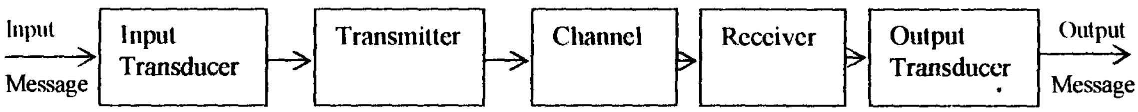


Fig. 1.0 Simple block diagram of a communication system

**Input Transducer:** The input message, which may be analogue or digital, must be converted from its original form into an electrical signal (message signal) to enable it to be processed by the necessary electrical/electronic equipment.

**Transmitter:** Essentially, the transmitter couples the message to the channel. It is at the transmitter that, if necessary, a carrier wave is modulated by the message signal.

**Channel:** This is the medium through which the transmitted signal gets to the receiver.

**Receiver:** Basically, the receiver in a communication system extracts and processes the desired signal from the various signals received at the channel output.

**Output Transducer:** This is an element or device that converts the electrical output signal of the receiver into the form desired by the user. For example, a loudspeaker convert electrical signal to sound waves for the user to hear.

# Chapter Two

## 2.0 Literature Review

### 2.1 History of Radio Broadcasting

Radio, system of communication using electromagnetic waves propagated through space [2]. Radio waves are used in wireless telegraphy, telephone transmission, television, radar, navigation systems, and space communication. They are also used in radio broadcasting; the term "radio" is therefore most popularly applied to sound broadcasting in general [1].

In the last quarter of the 19th century many scientists were attempting to transmit messages over distances without wires. They were not searching for a means of mass-communication, but simply exploring the possibility of using electromagnetic waves in order to communicate between two fixed points. Nevertheless, the history of "wireless" communication eventually became largely the history of broadcasting [1].

Radio had no single inventor, but grew out of several international developments. The pioneers of radio drew on the work of the British physicist James Clerk Maxwell, who published his theory of electromagnetic waves in 1873. However, it was the German physicist Heinrich Rudolf Hertz who first generated such waves electrically. Hertz managed to create an oscillating electric discharge, which radiated some of its energy in the form of electromagnetic waves. However, the waves produced were incapable of traveling great distances, and the problem of creating effective transmitters and receivers remained [1].

Guglielmo Marconi invented radio signaling and was the first person to send wireless signals across the ocean. His equipment played a vital role in rescuing survivors of sea disasters such as the sinking of the Titanic. He won the Nobel Prize for physics in 1909 for his work in wireless telegraphy [1].

It was the Italian electrical engineer and inventor Guglielmo Marconi who then took the most significant steps, combining technical inventiveness with business acumen. He succeeded in developing both a suitable receiver, or "coherer", and an improved spark oscillator, which was connected to a crude but effective antenna to transmit radio waves over significant distances. His transmitter was modulated with an ordinary telegraph key, and a crude amplification relay activated a telegraphic instrument at the receiving end [1].

In 1896 Marconi transmitted signals for a distance exceeding 1.6 km (1 mi) and applied for his first British patent. Within a year of his first demonstration he transmitted signals from shore to a ship at sea 29 km (18 mi) away. In 1899 he established commercial communication between England and France, and in 1901 he succeeded in sending a simple message across the Atlantic. He had demonstrated that radio waves could travel beyond the horizon, and had used his flair for the dramatic to bring the concept of radio to the attention of governmental agencies and business interests [1].

This was still only wireless telegraphy (the transmission of signals) rather than wireless telephony (the transmission of sound itself). However, on Christmas Eve in 1906 an American, Reginald Fessenden, managed to transmit both speech and music over several hundred miles out to sea from the Massachusetts coast. Over the next few years other demonstrations followed in the United States, Britain, and Europe [1].

The creation of the "vacuum tube oscillator" helped the steady transition from telegraphy to telephony, since it provided a continuous signal that was effective for transmitting speech, rather than just the short bursts of radio waves generated for early telegraphic messages.

It was, however, the development of the radio valve that proved to be crucial in advancing the transition from wireless to broadcasting. In 1904 the British electrical engineer John Ambrose Fleming experimented with the first thermionic two-electrode valve, or diode; a triode was created by the American Lee de Forest by inserting a third electrode into the valve. This device meant that a weak signal could be amplified. More sensitive wireless receivers could now be made, and radio-telephone messages picked up at far greater distances than had earlier been thought possible [1].

The combination of continuous signals being sent out from transmitters and more sensitive receivers laid the technical basis for more wide-scale listening, but there was in the pre-World War I years still little appreciation of the medium's social possibilities. Radio was thought of at this stage as a private means of point-to-point communication, rather than a more public means of mass communication: the very fact that signals were broadcast, reaching anyone with a receiver, rather than remaining confidential between the transmitter and the particular individual being addressed, was seen as a sign of the technology's primitiveness [1].

The first significant users of radio—coastal, marine, army, and intelligence services—were, however, content with this approach. Indeed, World War I, with both British and German forces using radio to communicate to naval forces from the outset, and governments commandeering all wireless stations, seemed to entrench this pattern. World War I also stimulated technical research, boosted large-scale production of the thermionic valve, and introduced many soldiers, sailors, and airmen to radio. When these people were demobilized after 1918, the small and scattered bands of home enthusiasts with primitive receivers of their own were joined by a new and bigger wave of wireless "amateurs", who began to show the social possibilities of radio as a medium of mass communication [1].

In 1920 the first true radio station (KDKA) began regular broadcasting in Pittsburgh, Pennsylvania, in the United States. Within two years the number of stations in America reached into the hundreds, concerts were being broadcast regularly in Europe from The Hague, and in Britain, Marconi stations broadcast from Chelmsford, Essex, and then London [1].

## 2.2 Radio Frequency and Wavelength Ranges

Radio waves have a wide range of applications, including communication during emergency rescues (transistor and shortwave radios), international broadcasts (satellites), and cooking food (microwaves). A radio wave is described by its wavelength (the distance from one crest to the next) or its frequency (the number of crests that move past a point in one second). Wavelengths of radio waves range from 100,000 m (270,000 ft) to 1 mm (.004 in). Frequencies range from 3 kilohertz to 300 gigahertz [1].

The various frequency ranges and their designation [2] are shown in Table 1.0. The frequency that is of interest for FM is **88-108 MHz** with wave lengths of **3.4** and **2.78 meters.**

i.e. $V = f*\lambda$

Where $V = 3*10^8$ m/s

**Table 1.0 Radio Frequency and Wavelength**

| FREQUENCY | DESIGNATION | ABBR. | WAVELENGTH |
|---|---|---|---|
| 3-30 kHz | Very low frequency | VLF | 100,000-10,000 m |
| 30-300 kHz | Low frequency | LF | 10,000-1,000 m |
| 300-3,000 kHz | Medium frequency | MF | 1,000-100 m |
| 3-30 MHz | High frequency (Short wave) | HF | 100-10 m |
| **30-300 MHz** | **Very high frequency** | **VHF** | **10-1 m** |
| 300-3,000 MHz | Ultrahigh frequency | UHF | 1 m-10 cm |
| 3-30 GHz | Super high frequency | SHF | 10-1 cm |
| 30-300 GHz | Extremely high frequency | EHF | 1 cm-1 mm |

KHz=kilohertz, or 1,000 Hz

MHz=megahertz, or 1,000 kHz

GHz=gigahertz, or 1,000 MHz

Because of their varying characteristics, radio waves of different lengths are employed for different purposes, and are usually identified by their frequency. The shortest waves have the highest frequency, or number of cycles per second; the longest waves have the lowest frequency, or fewest cycles per second.

Heinrich Hertz's name has been given to the cycle per second (hertz, Hz), with 1 kilohertz (kHz) being 1,000 cycles per second, and 1 megahertz (MHz) being 1 million cycles per second. Low and medium frequencies (30 to 3,000 kHz) are used by radio broadcasters transmitting on those parts of the spectrum traditionally described as long or medium wave, and most early transmissions in Europe and the United States were solely of this type. Because electromagnetic waves in a uniform atmosphere travel in straight lines and because the Earth's surface is approximately spherical, long-distance radio communication is made possible by the reflection of radio waves from the Earth's ionosphere. This allows programmes to be received both nationally and beyond national borders. However, these frequencies tend only to be able to use reflection from the ionosphere to bounce round the Earth's curvature under night-time atmospheric conditions, thus creating the possibility of each radio station covering a much wider area, but simultaneously contributing to increased interference between rival signals [3].

What people actually listened to was, and still is, crucially dependent, not just on what programme-makers construct but on the allocation of wavelengths and the distribution of transmitters. The discovery that electromagnetic waves could carry radio signals over the horizon had raised the prospect of broadcasting on an international scale, but governments and broadcasting organizations rapidly realized the inherent problems of the growth in the medium: if radio stations operated on the same or very similar wavelengths, listeners would suffer severe interference in reception [3].

In 1925 an international agreement over the allocation of wavelengths was reached in Europe in 1925 through the so-called Geneva Plan of the Union Internationale de Radiophonie, and in the United States, Congress passed the Radio Act in 1927 to create the Federal Radio Commission. Regulation of the world's electromagnetic spectrum has since been enacted largely by national governments through the International Telecommunication Union based in Geneva; however, from these earlier dates onward, transmission technology has been concerned primarily with the range and frequency of the signal being broadcast [1].

## 2.3 Radio Transmitter

Essential components of a radio transmitter include an oscillation generator for converting commercial electric power into oscillations of a predetermined radio frequency; amplifiers for increasing the intensity of these oscillations while retaining the desired frequency; and a transducer for converting the information to be transmitted into a varying electrical voltage proportional to each successive instantaneous intensity. For sound transmission a microphone is the transducer; for picture transmission the transducer is a photoelectric device [1].

Other important components of the radio transmitter are the modulator, which uses these proportionate voltages to control the variations in the oscillation intensity or the instantaneous frequency of the carrier, and the antenna, which radiates a similarly modulated carrier wave. Every antenna has some directional properties, that is, it radiates more energy in some directions than in others, but the antenna can be modified so that the radiation pattern varies from a comparatively narrow beam to a comparatively even distribution in all directions; the latter type of radiation is employed in broadcasting [1].

The particular method of designing and arranging the various components depends on the effects desired. The principal criteria of a radio in a commercial or military aircraft, for example, are lightness of weight and intelligibility; cost is a secondary consideration, and fidelity of reproduction is entirely unimportant. In a commercial broadcasting station, on the other hand, size and weight are of comparatively little importance; cost is of some importance; and fidelity is of the utmost importance, particularly for FM stations; rigid control of frequency is an absolute necessity. In the United States, for example, a typical commercial station broadcasting on 1,000 kHz is assigned a bandwidth of 10 kHz, but this width may be used only for modulation; the carrier frequency itself must be kept precisely at 1,000 kHz, for a deviation of one-hundredth of 1 per cent would cause serious interference with even distant stations on the same frequency [3].

## 2.4 AM and FM Broadcasting

"FM" stands for "frequency modulation", as opposed to "AM", or "amplitude modulation". Both terms apply to techniques for imposing a meaningful pattern of variations on an otherwise unvaried stream of energy during transmission, but they have also come to be applied to whole categories of broadcast radio [2].

AM modulates the carrier radio wave by varying the amplitude (strength of the wave) in accordance with the variations of frequency and intensity of a sound signal, such as a musical note. Such modulation is vulnerable to electrical interference, and the sound quality is variable. Throughout the first half of the century, most standard radio broadcasting was achieved using this technique, and today some music and a great deal of speech radio, which does not necessarily demand high-quality reception, is still found on the AM dial [2].

FM works by varying the frequency of the carrier wave within a narrowly fixed range at a rate corresponding to the frequency of a sound signal. It is used within the VHF band, so that the terms "VHF" and "FM" have become synonymous for most radio listeners. FM reaches only to the horizon, so a transmitter's remit is local rather than national in scale. This geographical restriction has the advantage of reducing interference, and coverage is therefore more stable, day or night. The signal itself is inherently static-free, unlike that for AM, and a suitable receiving-set can take advantage of its more generous frequency range and dynamic range to reproduce high-fidelity sound [7].

Frequency modulation has several advantages over the system of amplitude modulation (AM) used in the alternate form of radio broadcasting. The most important of these advantages is that an FM system has greater freedom from interference and static. Various electrical disturbances, such as those caused by thunderstorms and car ignition systems; create amplitude modulated radio signals that are received as noise by AM receivers. A well-designed FM receiver is not sensitive to such disturbances when it is tuned to an FM signal of sufficient strength. Also, the signal-to-noise ratio in an FM system is much higher than that of an AM system. FM broadcasting stations can be operated in the very-high-frequency bands at which AM interference is frequently severe; commercial FM radio stations are assigned frequencies between 88 and 108 MHz. The range of transmission on these bands is limited so that stations operating on the same frequency can be located within a few hundred miles of one another without mutual interference [7].

These features, coupled with the comparatively low cost of equipment for an FM broadcasting station, resulted in rapid growth in the years following World War II. Within three years after the close of the war, 600 licensed FM stations were broadcasting in the United States and by the end of the 1980s there were over 4,000. Similar trends have occurred in Britain and other countries. Because of crowding in the AM broadcast band and the inability of standard AM receivers to eliminate noise, the tonal fidelity of standard stations is purposely limited. FM does not have these drawbacks and therefore can be used to transmit music reproducing the original performance with a degree of fidelity that cannot be reached on AM bands. FM stereophonic broadcasting has drawn increasing numbers of listeners to popular as well as classical music, so that commercial FM stations draw higher audience ratings than AM stations [1].

FM's quality advantage over AM, exaggerated further with the development of stereo, has proved particularly suitable for the broadcasting of music and explains the rapid growth in the number of FM stations—often associated with rock and pop—in the 1960s, 1970s, and 1980s [1].

### 2.4.1 Analogue/Digital Broadcasting

Both AM and FM radio depends on traditional analogue technology, where the signal consists of a continuously changing pattern corresponding to the continuous flow of sound captured by a microphone. Such signals are inherently vulnerable to all sorts of distortions which restrict their ability to carry information without degradation. Digital processing, which breaks a signal down into a stream of individual energy pulses assigned a binary code, can resist distortion and convey far more information. Most large-scale radio broadcasters are now developing digital audio broadcasting, which promises a quality of sound equivalent to that of a Compact Discs (CD), and an increase in the number of radio services available within the existing electromagnetic spectrum [2].

# DESIGN AND CONSTRUCTION OF A MULTI-CHANNEL FREQUENCY MODULATION (FM) TRANSMITTER

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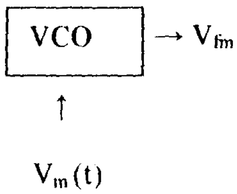
# Chapter Three

## 3.0 Design Analysis

### 3.1 Equation Governing FM

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






$$V_{fm} = A \times Cos\ \theta(t) \qquad (1)$$

$$F = F_C + \Delta f \qquad (2)$$

Where, $\Delta f = K_O \times V_m(t)$

$$F = F_C + K_O V_m(t) \qquad (3)$$

se set of equations govern the VCO's output

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

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

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

From $F = F_C + \Delta f$

Cross Multiplying

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

$$\theta(t) = 2\pi F_C \int dt + 2\pi \int K_O V_m(t) \quad (7)$$

$$V_m(t) = V_{PK} Cos\,(2\pi F_m t) \quad (8)$$

Substituting into $\theta(t)$ the equation becomes

$$\theta(t) = 2\pi F_C \int dt + 2\pi \int K_O V_m(t) Cos(2\pi F_m t) \quad (9)$$

$$\theta(t) = \frac{2\pi F_C + 2\pi K_O}{2\pi F_m V_{PK}\, Sine\, (2\pi F_m t)} \quad (10)$$

Hence,

$$\theta(t) = 2\pi F_C t + Mf Sine\,(2\pi F_m t) \quad (11)$$

Where, $Mf = \frac{K_O V_{PK}}{F_m}$

i.e. $Mf = \frac{\Delta f}{F_m}$

Substituting into the FM equation gives;

$$V_{fm} = ACos\,\theta(t) = ACos\,\{2\pi F_C t + Mf Sine\,(2\pi F_m t)\} \quad (12)$$

This gives the standard FM equation.

## 3.2 Technical Terms Associated With FM

Some of the important terms are stated as follows;

- **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.

- **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).

$$Mf = \frac{\Delta f}{F_m}$$

- **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

- **Carrier Swing:** This is always twice the instantaneous deviation from the carrier frequency also known as the difference between the highest and lowest frequency attained by the FM signal.

$F_{carrier\ swing} = 2\Delta F_C$.

The equation applies only for symmetrical modulating signal.

- **Carson's 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.

**$BW \approx 2\ (2\Delta F_c + F_m)$**

**$BW \approx 2F_m\ (Mf + 1)$**

Where $F_m$ – Maximum Frequency component of the modulating signal

$\Delta F_C$ – Frequency Deviation

- **Deviation Ratio:** This is the largest allowable modulation index or the maximum possible frequency deviation over the maximum input frequency.

- **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 the intelligence signals).

$$\text{Percentage Modulation} = \frac{\Delta F_C}{\Delta F_{MAX}} \times 100$$

## 3.3 System Description

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 as in Fig. 3.0 below:

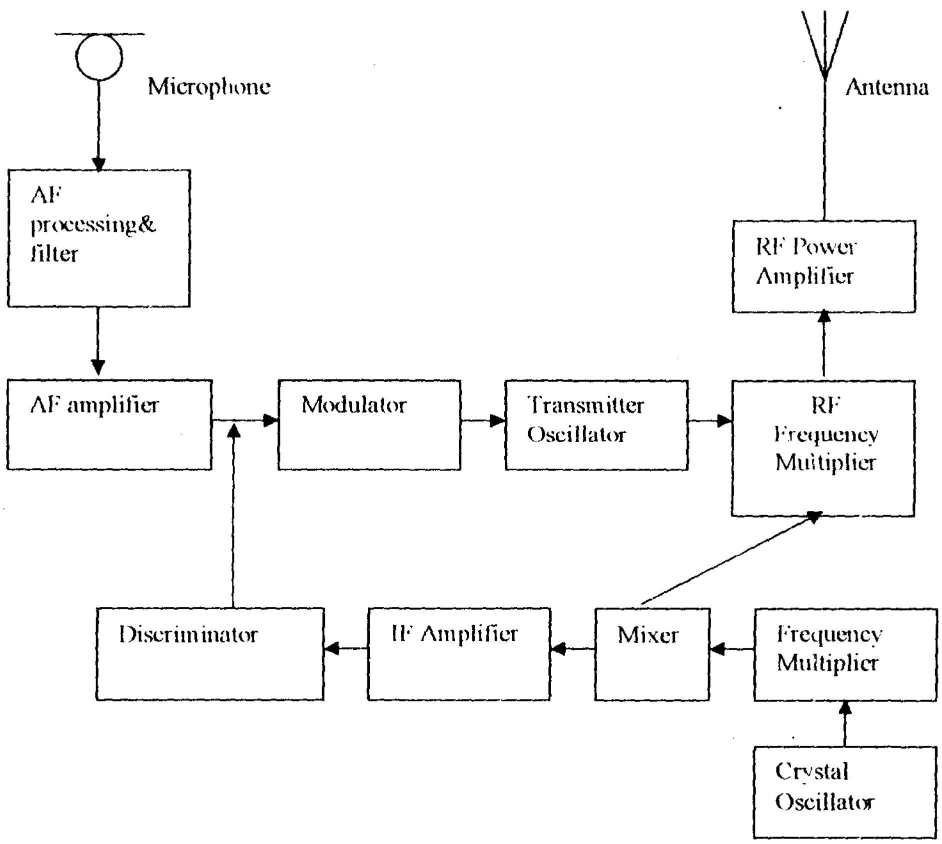



Fig. 3.0 Block diagram of FM sound transmitter

The microphone converts the voice information to a message signal which is processed, filtered, and amplified within the required voice bandwidth of about 4kHz. The FM modulator converts the changes in the message signal amplitude into frequency changes. The modulator may consist of a reactance modulator (e.g. varactor modulator) and an oscillator whose frequency is changed in accordance with the variation in the instantaneous value of the message signal. The resulting signal is then passed through a series of frequency multipliers that produce the required operating frequency. The final RF power amplifier boosts the power to a level high enough for radiation by the antenna.

The lower part of the circuitry constitutes the automatic frequency control (AFC) network. Broadcasting regulations require that the centre frequency of the carrier (i.e. unmodulated carrier frequency) be held constant within specified limits. The aim of the network is, therefore, to stabilize the centre frequency. The intermediate frequency signal is boosted in amplitude by the tuned IF amplifiers. The output voltage is finally applied to a phase-shift discriminator circuit which produces a fixed d.c voltage output as long as the input frequency is constant. Any variation in the input frequency leads to a change in the output voltage of the discriminator. This then serves as a reference potential for establishing the proper operating frequency of the transmitter.

Frequency-modulated (FM) transmitters are commonly used above the HF range, particularly for sound transmission e.g. the 88 – 108MHz band. Because of such high frequencies involved, it is difficult to obtain crystals that will oscillate well. Other oscillator types are also found to be very unstable at high frequency. One obvious method of circumventing this is to employ a low-frequency oscillator (e.g. crystal oscillator) and then multiply the output frequency as many times as to give the required high frequency. Such frequency multiplier may take the form of class C amplifiers tuned to the required frequency. A better alternative is to make use of frequency synthesizers which provide better frequency agility than the crystal-controlled oscillator. A frequency synthesizer basically accepts a single frequency of high stability which is processed to provide full frequency coverage. The figure below shows how FM can be generated using Voltage-Controlled Oscillator (VCO).

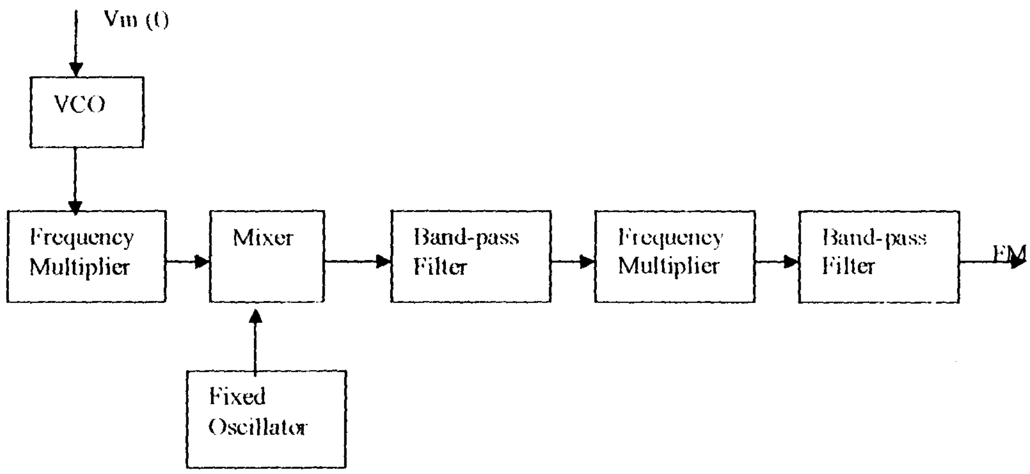



Fig. 3.1 Direct method of generating FM using VCO

The direct method of generating an FM wave can be accomplished by varying the frequency of the VCO. The VCO is followed by a series of frequency multipliers and mixers as shown in Fig. 3.1. This leads to a more stable oscillator design, constant proportionality between input-voltage and output-frequency changes, as well as adequate modulator bandwidth to achieve wideband FM.

### 3.4 Input Transducer (Microphone)

The input transducer employed in communication systems convert the audio input message (sound), which may be analogue or digital, into electrical current or voltage to give the message signal. In electrical communication of speech, the sound wave is converted to voltage variations by means of a microphone which is the transducer.

A microphone essentially converts acoustic signals i.e. sound waves, into electric signals. There are different types of microphones available for different applications ranging from, telephone handset transmitter, public address system, recording, and broadcasting to scientific measurements. Some factors to consider while choosing a particular microphone include amongst others, cost, robustness, frequency response, size, sensitivity, etc. Most microphones operate on one of the following principles:

- Variable contact resistance (e.g. carbon microphone)
- Piezoelectricity (e.g. crystal microphone)
- Electrodynamics (e.g. moving coil, moving-iron and ribbon microphone)
- Electrostatic (e.g. capacitor microphone)

The capacitor microphone (electret) is most commonly used. In the capacitor microphone, an electret element is used, which acts as a special capacitor with one fixed diaphragm. Once 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 tune 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 sound quality is excellent but needs a polarizing voltage to charge the capacitor which is done with a 1.5V battery.

## 3.5 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. The natural balance (ratio) between the high and low frequencies are altered, as pre-emphasis is done.

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:

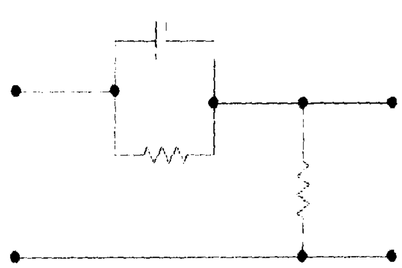


Fig 3.2a Pre-emphasis

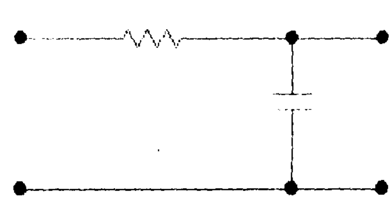


Fig 3.2b De-emphasis

## 3.6 Radio Frequency Oscillators (Generators)

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° or 360°

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

$$F_r = \frac{1}{2\pi\sqrt{LC}} Hz \qquad (13)$$

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

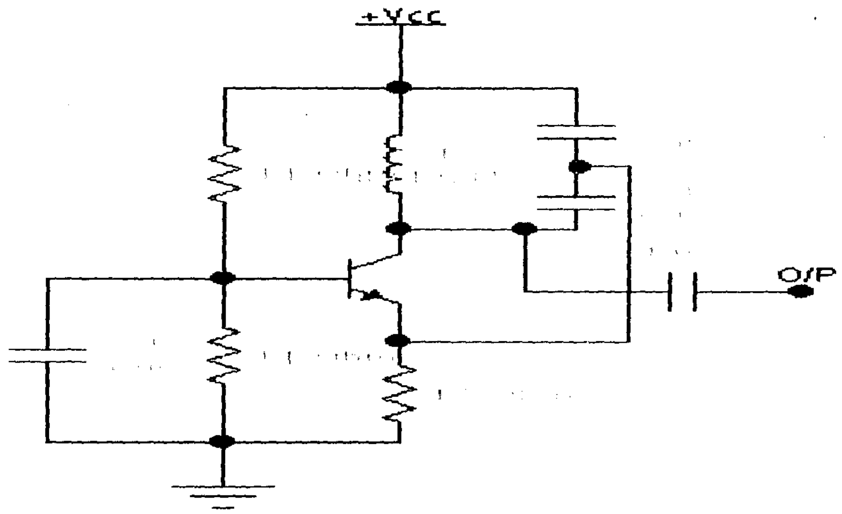



Fig. 3.3 Colpitts Oscillator

Fig 3.3 is a Colpitts oscillator which has an LC tank ($L_2$, $C_2$, $C_3$) helped by a common emitter amplifier and a feedback capacitor which sustains the oscillation

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

Where, $C_{eq} = \frac{C_2 C_3}{C_2 + C_3}(equivalent - capacitance)$

Hence,

$$F = \frac{1}{2\pi\sqrt{L_1\left(\frac{C_2 C_3}{C_2 + C_3}\right)}} \quad (14)$$

Radio frequency oscillators use tuned LC circuits consisting of a capacitor (C) and inductor (L). Every combination of an inductor and capacitor has resonant frequency. For oscillation to take place at the resonant frequency, transformer action is employed to provide the (180° phase shift) necessary positive (regenerative) feedback.

### 3.6.1 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 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.

$$C_D = \frac{C_O}{\sqrt{(1 + 2 \times V_R)}} \qquad (15)$$

Where $C_D$ - instantaneous capacitance about the diode's terminals

$C_O$ - Capacitance at zero reverses 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:-

$$F_{NOM} = \frac{1}{2\pi\sqrt{L(C_1 + C_{DNOM})}} Hz \text{ i.e. no base band influence.} \quad (16)$$

$$F_{MIN} = \frac{1}{2\pi\sqrt{L(C_1 + C_{DMAX})}} Hz \text{ i.e. with peak (-ve) base band influence} \quad (17)$$

$$F_{MAX} = \frac{1}{2\pi\sqrt{L(C_1 + C_{DMIN})}} Hz \text{ i.e. with peak (+ve) base band influence} \quad (18)$$

### 3.6.2 Signal 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 signal amplifier is a common emitter configuration with low voltage gain or an emitter follower transistor configuration.

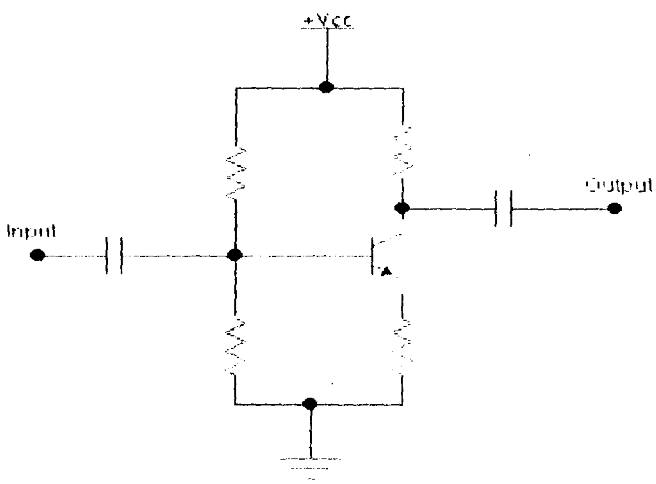



Fig 3.4 Common Emitter Amplifier

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

The base voltage is always 0.6 or 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.

## 3.7 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:

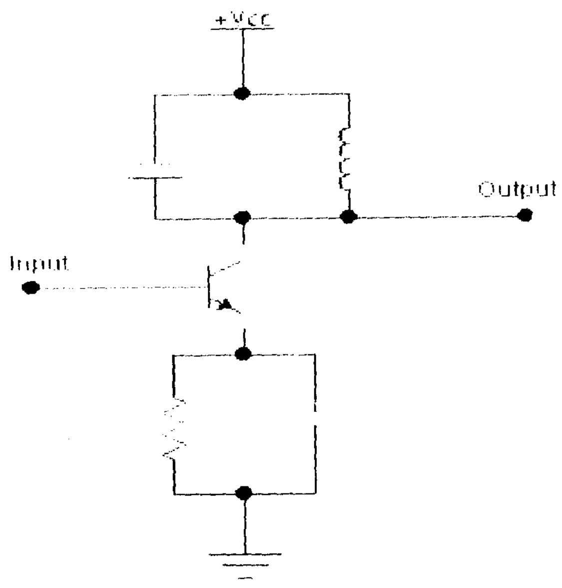



Fig 3.5 Frequency Multiplier Circuit

The circuit shown in Fig 3.5 above is good for multiplying factors (2, 3, and 4); current idlers are used to improve the efficiency. The series resonant LCs 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* Fi = Fo. 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.

## 3.8 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 modulation 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.

### 3.9 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 of a transmitter need not be close to the transmitter itself. Commercial broadcasting at medium frequencies generally requires a very large antenna, which is best located at an isolated point far from cities, whereas the broadcasting studio is usually in the heart of the city. FM, television, and other very-high-frequency broadcasts must have very high antennas if appreciably long range is to be achieved, and it may not be convenient to locate such a high antenna near the broadcasting studio. In all such cases, the signals may be transmitted by wires. Ordinary telephone lines are satisfactory for most commercial-radio broadcasts; if high fidelity or very high frequencies are required, coaxial cables are used.

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

- **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).

- **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 nr2 and equated to the resulting power $I^2R_r$

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

$$R_r = 80 \pi^2 (dl/\lambda)^n \qquad (19)$$

Where dl -Length of antenna

$\lambda$ -Wavelength

n - Exponent value that can be found by using (dI/A) on the y-axis, the n can be found on the x-axis.

- **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.

- **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.

- **Power Transfer**

In order to produce an efficient transmitter, maximum power transfer has to take place from the circuit to the antenna. If $Z_{in}$ is the impedance of the receiver antenna 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.

$$I = \frac{}{Z_{in} + R_g} \quad (20)$$

The power transferred is $I^2R_g$

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

$$Z_{in} + R_g = 2R_g$$

$$Z_{in} = R_g \quad (21)$$

For maximum transfer of power at an input, the output impedance of the transducer, such as a microphone, should be equal to the input impedance of the amplifier. Similarly for maximum transfer of power at the output, the output impedance of the amplifier should be equal to the impedance of the load, such as a loudspeaker. Making the input and output impedances equal is called **load matching** and is most desirable for efficient transfer of power.

Until recently, transformers were used for load matching in audio amplifiers, for example, from an amplifier of several hundred ohms output impedance to a loudspeaker of 4, 8, or 15-ohm impedance. Nowadays, transformers are seldom used because of their cost, bulk, and poor low frequency response.

The common-collector amplifier (emitter follower) has high input impedance and low output impedance. It is used as a 'buffer' to match an input transducer of high output impedance, such as a crystal microphone, to a low impedance load, such as the input of a common-emitter amplifier.

- **Radiation Pattern**

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

Now that a qualitative view of some of the characteristics of an antenna have been looked at, it is now time to look at some of the basic types of antenna that can be considered for this project.

### 3.9.1 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 at the terminals is high (typically 2500Ω) and at the open ends is low (73Ω), which accounts for minimum voltage at the terminals and maximum voltage at the ends. This makes it possible to accept electrical energy and radiate into space as Electro-Magnetic (EM) waves.

### 3.9.2 Monopole or Marconi Antenna

Gugliemo Marconi opened a whole new area of experimentation by popularizing the vertically polarized quarter wave dipole antenna, it was theorized that earth would act as the second quarter wave dipole antenna. Comparing the signal emanating from the quarter wave antenna in μV/m, it has been shown experimentally that for a reduction in the antenna from $\lambda/2$ to $\lambda/4$ a reduction of 40% (in μV/m) takes place, for a reduction λ4 to $\lambda/10$ a reduction of only 5% (in μV/m). This slight reduction of 0.05 in transmitted power for a decrease of 0.75 in antenna length seems impressive, but there is a decrease in the area of coverage.

## 3.10 Impedance Matching

Between the final power amplifier of the transmitter and the antenna, an impedance matching network may be considered. One of the possible surprises in power amplifier is that realization that output impedance matching is not based on the maximum power criteria. One reason for this is the fact that matching the load to the device output impedance results in power transfer at 50% efficiency.

An impedance matching system maybe merely a special wide-band transformer which is used for broadband matching (i.e. between 88 to 108MHz). The purpose of the impedance matching network is to transform load impedance to impedance appropriate for optimum circuit operation. Detailed description and calculations will be used latter on when evaluating the final design of the system.

# Chapter Four

## 4.0 System Design and Construction

The circuit of the transmitter is shown in figure 4.0 (a) and (b) as can be seen it is quite simple. Figure 4.0 (b) shows the drafted circuit and how it is being connected on the vero-board. The first stage of the transmitter circuit is the oscillator stage followed by the output stage. Although the entire circuitry comprises of a power supply, and an audio input stage coupled to first stage.

The circuit is analyzed into four (4) stages;

## 4.1 Power Supply Stage

The circuit of figure 4.1 shows the power supply. Although the circuit can be powered using a 9V or 12V battery. The power supply is converted from its A.C voltage (240V) to D.C voltage of approximately 12VDC after stepping down the A.C voltage supplied by PHCN (240V) to 12VAC by the use of a transformer.

This circuit achieves full-wave rectification without the use of a centre tapped transformer. It employs four (4) diodes connected in a fashion of arrangement that looks similar to the Wheastone Bridge circuit. The cathode leads of $D_1$ and $D_2$ are connected together to form the positive output terminal bridge circuit, while the anode leads of $D_3$ and $D_4$ are connected together to form the negative output terminal of the bridge circuit. The A.C voltage developed by $T_1$ is applied to point A and B while the combined output of the circuit is developed across the capacitor $C_1$ producing filtered rectified output (+ve

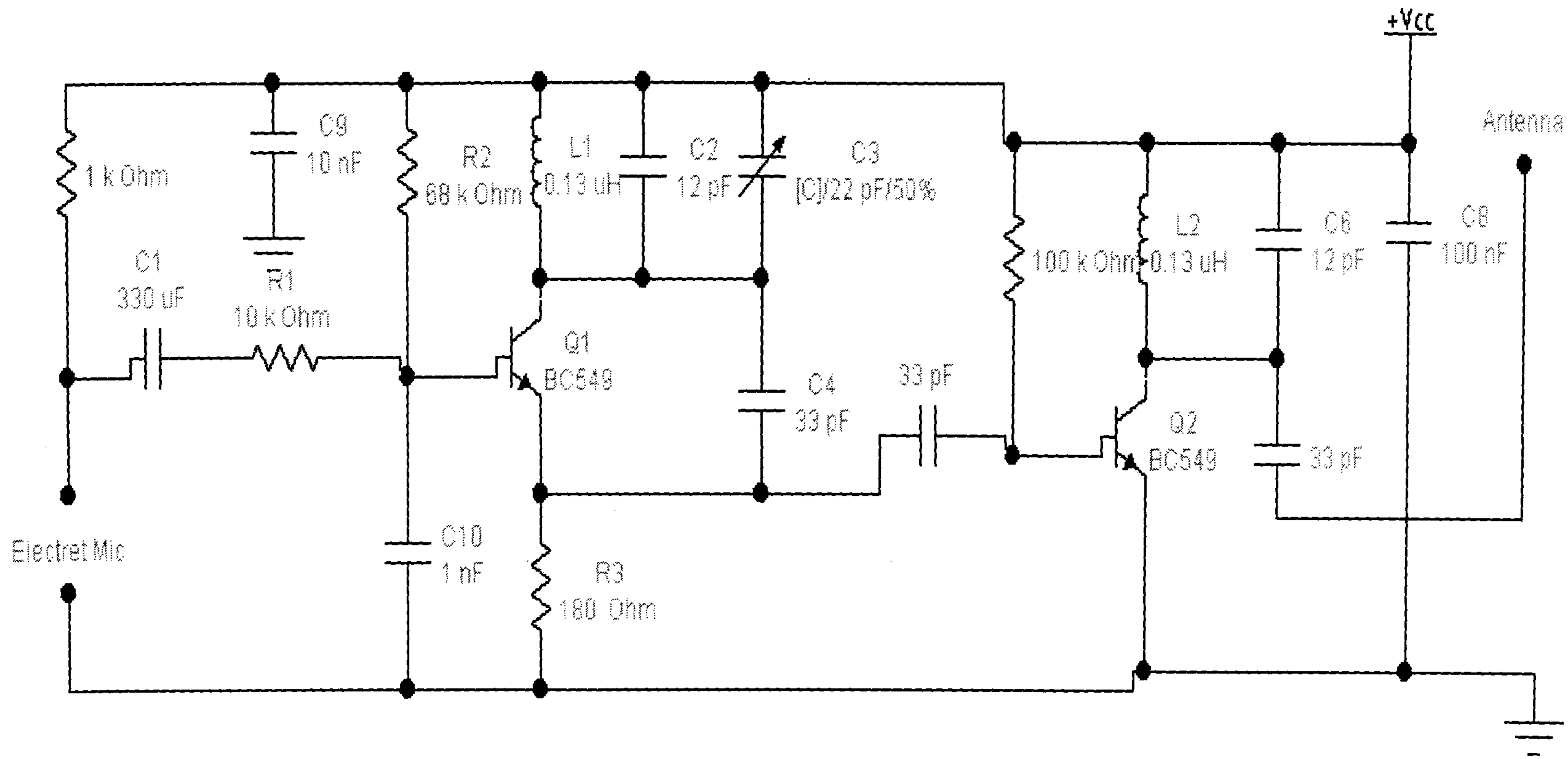
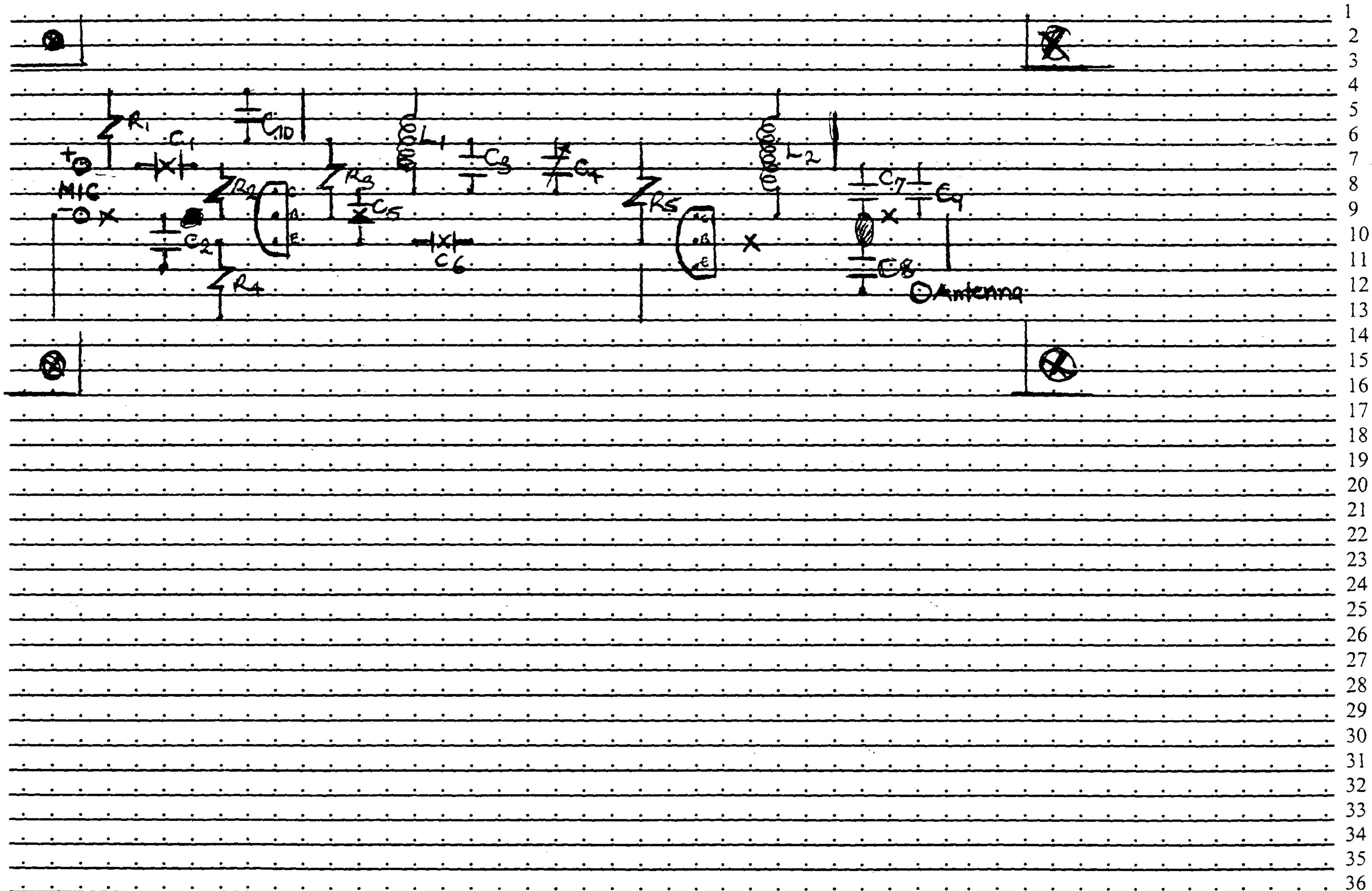



Figure 4.0 (a) Multi-Channel FM Transmitter Circuit Diagram


R1
C1
C10
MIC
R2
C2
R4
R3
C5
L1
C6
C3
C4
R5
L2
C7
C9
C8
Antenna
1
2
3
4
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and –ve) which is then developed across Resistor R1 through Zener Diode 12V to the collector of Regulator (7812) through capacitor $C_2$ to ground and across load resistor $R_2$, light emitting diode (LED).

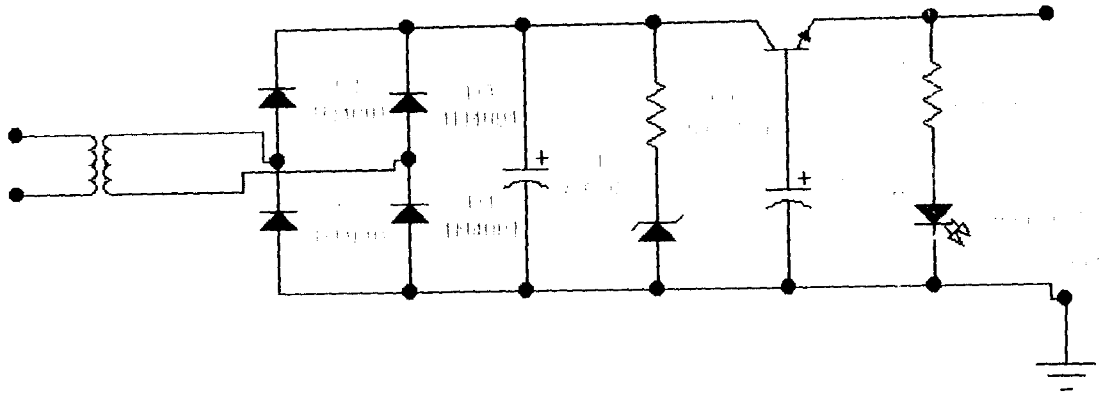

Figure 4.1 Power Supply Circuit

## 4.2 Audio Input Stage

This stage of the system comprises the Microphone in series with a 10kohms resistor R3 coupled to the next stage via a coupling capacitor $C_3$ in series with a 100Kohms resistor $R_4$.

The microphone is a condenser microphone (electret mic) which can be seen in figure 4.2 below. The 10Kohms resistor is provided for because of the type of microphone used in the circuit.

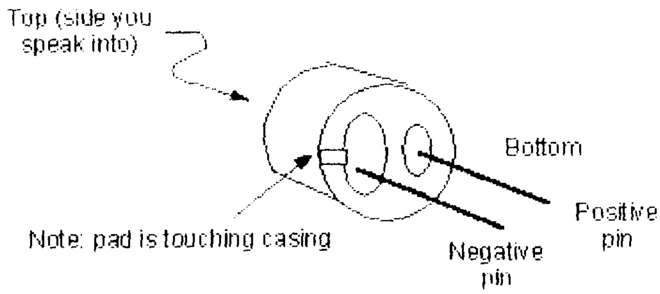


Figure 4.2 The Condenser Microphone (Electret Mic).

## 4.3 Low Signal Stage (oscillator stage)

This stage of the system amplifies the input voltage or signal detected.

The circuit built around transistor $Q_1$ (BC549) is a basic low power variable frequency VHF oscillator.

The circuit configuration used for the low signal is the Common Base amplifier configuration as can be seen in figure 4.3.

The performance of the transistor and amplifier always depends on the DC operating point (i.e. the value of $I_c$ and $V_{ce}$).

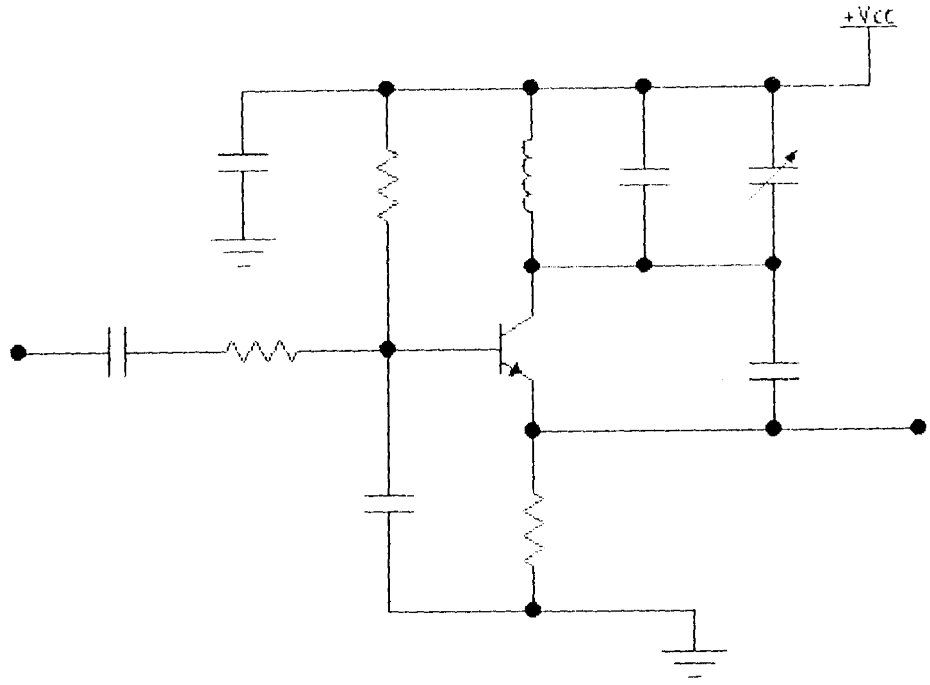


Fig 4.3 Common Base amplifier configuration of Low Signal Stage

The signal is applied between base and emitter. For the oscillator circuit of the common base amplifier above, the DC parameters was calculated and obtained as thus;

Applying KVL to the circuit above,

$$V_{CC} = I_C \times R_L + V_C$$

Where, $R_L$ is the load resistance of the LC tank circuit which gives the impedance of the circuit.

$$V_{CC} = I_B \times R_2 + V_{BE}$$

Using $V_{CC}$ = 9V

$V_{BE}$ = 0.7V (for silicon transistor)

But,

➢ $V_C = \frac{1}{2} \times V_{CC} = \frac{1}{2} \times 9 = 4.5V$

$V_E = 0.1 \times V_{CC} = 0.1 \times 9 = 0.9V$

Also, $I_C \approx I_E$

From the transistor manufacturers data sheet attached,

hfe = 400

$I_C$ = 1mA = $1 \times 10^{-3} A$

So that,

$$R_L = \frac{V_C}{I_C} = \frac{4.5}{1 \times 10^{-3}} = 4500\Omega = 4.5K\Omega$$

$$R_3 = \frac{V_E}{I_E} = \frac{0.9}{1 \times 10^{-3}} = 900\Omega$$

$V_B = V_E + V_{BE} = 0.9 + 0.7 = 1.6V$

$$hfe = \frac{I_C}{I_B}$$

➢ $I_B = \frac{I_C}{hfe} = \frac{1 \times 10^{-3}}{400} = 2.5 \times 10^{-6} A$

$$R_2 = \frac{V_{CC} - V_{BE}}{I_B} = \frac{9 - 0.7}{2.5 \times 10^{-6}} = 3.32 \times 10^{6}\Omega$$

$$I_C(sat) = \frac{V_{CC}}{R_L + R_3} = \frac{9}{4500 + 900} = 1.67 \times 10^{-3} A$$

The voltage across collector and emitter ($V_{CE}$) = $V_C - V_E = 4.5 - 0.9 = 3.6V$

And, the operating frequency of the oscillator can be estimated as thus;

Choosing the value of $C_2$ = 12pf so that it is far grater than $C_4$ = 5.6pf and the variable capacitor $C_3$ = 4 – 22pf, assuming the variable is varied to equal $C_2$ (12pf), the equivalent capacitance of the capacitors $C_{eq}$,

$$C_{eq} = \left\{\frac{C_2 \times C_3}{C_2 + C_3}\right\} + C_4 = \left\{\frac{(12 \times 12)}{12 + 12}\right\} + 5.6 = 6 + 5.6 = 11.6pf$$

From the equation, $F = \frac{1}{2\pi\sqrt{LC_{eq}}}$

If the frequency range of FM is 88 – 108MHz the average frequency of operation will be 98MHz. so that we can estimate the value of inductor;

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

$$L = \left\{\frac{1}{2\pi f}\right\}^2 \times \left\{\frac{1}{C}\right\} = \left\{\frac{1}{2 \times 3.142 \times 100 \times 10^6}\right\}^2 \times \left\{\frac{1}{11.6 \times 10^{-12}}\right\} = 0.23uH$$

## 4.4 The Output Stage

The second stage is a power amplifier circuit connected to the first stage (low power oscillator circuit). The succeeding equations used for the first stage holds.

The power amplifier used for this stage is simple but efficient enough to transmit the FM wave generated by the circuit to the free space. This is achieved by connecting the output of the biased transistor $Q_2$ (BC549) collector terminal to a matching antenna via coupling capacitor $C_7$ (33pf). The circuit is a frequency multiplier circuit as seen in figure 4.4 below.

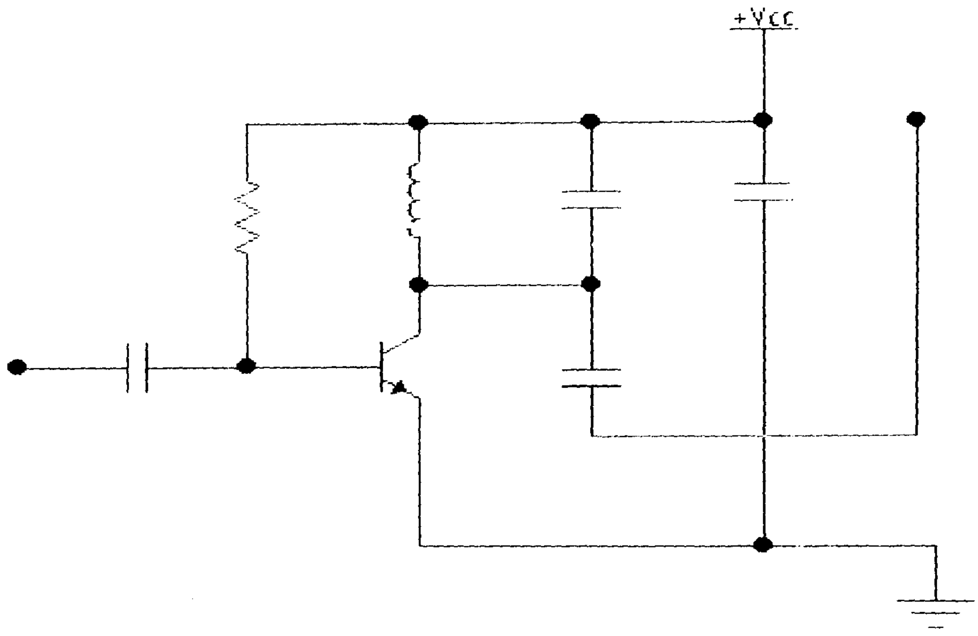


Figure 4.4 Frequency Multiplier Circuit of the Power Output Stage

The maximum output of the circuit will be at resonance frequency (i.e. $X_L = X_C$). The turned circuit can be achieved by either connecting the inductor and capacitor in series or parallel. Thus the nominal values of the reactances of the inductor and the capacitor will be equal.

- $X_L = X_C$
- $2\pi F_O L = \dfrac{1}{2\pi F_O C}$

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

Where, $F_O$ – Resonance 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.

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 selected range. With the collector load replaced by the tuned circuit as above, 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 the wavelength. Since FM is from 88 – 108MHz, the capacitor value is as follows;

$V = F * \lambda$

Where, $V = 3\times 10^{8} m/s$ (speed of light) and

F = 98MHz (average frequency)

$$\lambda = \frac{3\times 10^{8}}{98\times 10^{6}} = 3.06m$$

$$> C = 3.06\times 1.5 = 4.6pf$$

Only one (1) resistor was used for this part of the circuit, thus;

$I_C = 1\times 10^{-3} A$

$V_{CC} = 4.5V$

$V_E = 0.1\times V_{CC} = 0.1\times 4.5 = 0.45V$

$V_B = V_E + V_{BE} = 0.45 + 0.7 = 1.15V$

$$➢ \quad R_4 = \frac{V_{CC} - V_B}{I_B} = \frac{4.5 - 1.15}{1\times 10^{-3}} = 3.35K\Omega$$

The coupling of the circuitry is generally with the use of capacitor coupling. This can be obtained to be approximately;

$$C \geq \frac{1}{2\pi f\sqrt{R_4}}$$

$$C \geq \frac{1}{\left(2 \times 3.142 \times 98 \times 10^6 \sqrt{3.35 \times 10^3}\right)} = 0.24 \times 10^{-6} f$$

The value of inductance use for the tank will be

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

$$L = \left\{\frac{1}{2\pi f}\right\}^2 \times \left\{\frac{1}{C}\right\} = \left\{\frac{1}{2 \times 3.142 \times 98 \times 10^6}\right\}^2 \times \left\{\frac{1}{4.6 \times 10^{-12}}\right\} = 0.57uH$$

The combined circuits are what were obtained in figure 4.0 above.

## 4.5 Details of Components/Materials used

The following are list of components / material used for the practical construction of this project work.

- Transformer $T_1$ = 12 – 0 – 12V
- Silicon Diodes $D_1 - D_4$ (IN4001)
- Zener Diode 12V
- Condenser Microphone (Electret Mic)
- Light Emitting Diode (LED) Green
- Transistors, $Q_1$ and $Q_2$ = BC549

  $Q_3$ = IC Regulator 7812
- Resistors, $R_1 = R_5 = R_6 = R_7$ =10Kohms

  $R_2$ = 68Kohms

  $R_3$ = 180ohms

$R_4$ = 100Kohms

- Inductors, $L_1 = L_2 = 0.13uH$
- Capacitors, $C_1 = 330uf$

$C_2 = C_6 = 12pf$

$C_3 = 22pf$ (variable capacitor0

$C_4 = 5.6pf$

$C_5 = C_7 = 33pf$

$C_8 = 100nf$

$C_9 = 10nf$

$C_{10} = 1nf$

$C_{11} = 220uf$

$C_{12} = 350uf$

- Vero-Board and Bread Board
- Jumper Wires
- 1mm (20swg) Enameled Wire
- Soldering Iron/ soldering Lead
- Lead Sucker (for removing unwanted pail of solder)
- 3mm Drill Bit (for breaking off unwanted joints).

The detail for the construction of inductor $L_1$ and $L_2$ can be seen in figure 4.5 (a) and (b) below, showing

- N = Number of turns in inches
- R = Radius of winding in inches
- X = Length of coil in inches

- D = Diameter of winding
- L = Inductance in uH.

$L_1$ and $L_2$ are 9.5 turns 1mm enameled copper wire closed wound on a 3mm diameter former before it is then pulled out.

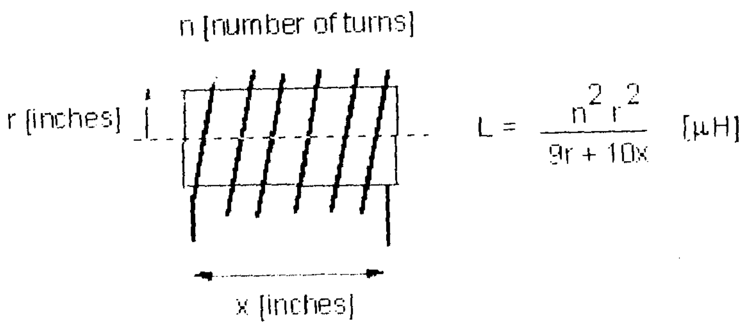


Figure 4.5 (a) Details of construction of inductor L1 and L2

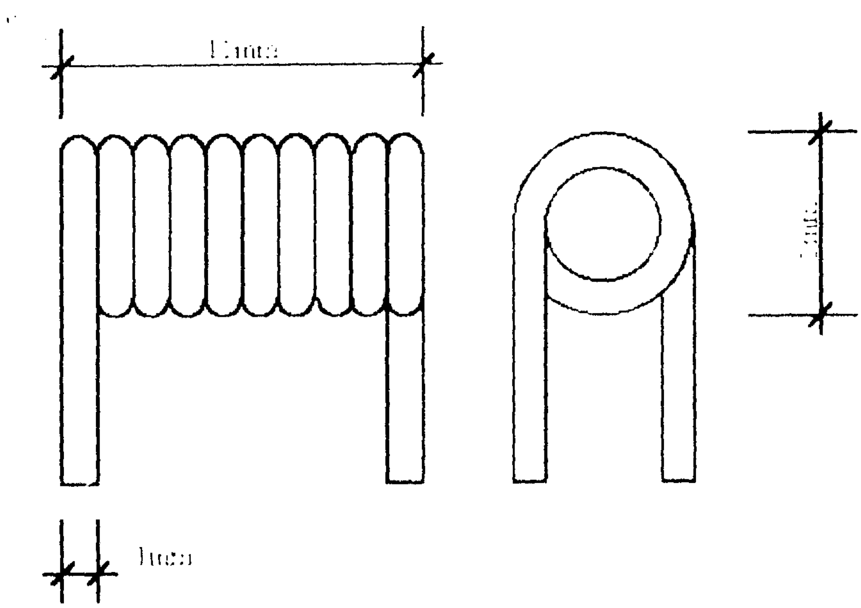

Figure 4.5 (b) Showing conductor closed wound to form an inductor.

## 4.6 Mode of Operation (Basic Working Principle)

From figure 4.0, when the circuit is supplied with source of power by switching it to its ON state the transformer $T_1$ steps down the AC source 240V to 12V-0-12V transformer voltage (AC).The four (4) diodes $D_1$- $D_4$ (bridge rectifier) will convert the output transformer voltage to a DC voltage (rectification process) where the output of the rectified AC source is connected across capacitor $C_{11}$ which act as a filter through $R_{11}$ and zener diode. It is then output through the IC regulator (7812) through load or limiting resistor $R_{12}$ and LED thereby indicating power ON.

The filtered DC is now connected to the next stage which is the transmitter. The first stage is the oscillator, and is turned with the variable capacitor. Select an unused frequency, and carefully adjust $C_3$ until the background noise stops (you may have to disable the FM receiver's mute circuit to hear this).

Because the trimmer capacitor is very sensitive, make the final adjustment on the receiver. A small piece of non copper-clad circuit board can be used to make the adjustment – this is so as not to alter the frequency.

$Q_1$ is the oscillator, and is a conventional Colpitts design. $L_1$ and $C_3$ (in parallel with $C_2$) turn the circuit to the desired frequency, and the output (from the emitter of $Q_1$) is fed to the Buffer and amplifier $Q_2$. This isolates the antenna from the oscillator giving much better frequency stability, as well as providing considerable extra gain. $L_2$ and $C_6$ form a tuned collector load, and $C_7$ helps to further isolate the circuit from the antenna, as well as preventing any possibility of short circuits should the antenna contact the grounded metal case that would normally be used for the complete transmitter.

The audio signal applied to base of $Q_1$ causes the frequency to change, as the transistor's collector current is modulated by the audio. This provides the frequency modulation (FM) that can be received on any standard FM band receiver. The audio input must be kept to a maximum of about 100mV, although this will vary somewhat from one unit to the next.

## 4.7 Trouble Shooting and Maintenance

| S/No: | SYMPTOMS | CAUSE | REMEDY |
|---|---|---|---|
| 1 | Power does not come ON | No supply from the mains | Plug in main cord into the mains outlet |
| 2 | Transformer heating | Bridging or short circuit between terminals | Clear the bridge or short circuit by opening appropriate places |
| 3 | Fuse out | High voltage<br><br>Filter capacitor short | Replace fuse<br><br>Replace capacitor and fuse |
| 4 | LED not lighting | No power supply to the terminals<br><br>High voltage across terminals | Check the source of power supply<br><br>Replace LED and check other faults |
| 5 | Signal not heard at the receiver | Frequency of operation not properly set<br><br>Microphone not properly connected or bad | Vary the variable capacitor $C_3$ and adjust the frequency of receiver until signal is heard<br><br>Check the terminals of the microphone or replace it |
| 6 | Variable capacitor not varying | Variable capacitor bad or terminals not properly connected | Check the terminals of the variable capacitor or replace it |
| 7 | Transistor heating no short circuit | Transistor bad | Replace the transistor |
| 8 | Transistor heating | Bridging or short circuit between terminals | Clear the bridge or short circuit by opening appropriate places |

# Chapter Five

## 5.0 Result and Conclusion

This chapter will discuss some of the more detailed tests carried out on the final circuit which was discussed in the previous chapter.

## 5.1 Result and Test

Due to lack of equipments used in analyzing circuitry (such as, spectrum analyzer, and frequency meter) so that the vital information that should have been provided about the advantages and disadvantages of the design could not be met. During the course of final test the equipment used were a digital multi-meter, an analogue and digital FM radio receiver was used.

**Radio Receiver:** An analogue (dial turn) and digital (push-button) receiver was used in demodulating the modulated carrier wave generated by the transmitter. The signal was clear at the receiver at a frequency of approximately 99-100MHz using a 9V battery.

At an open field the transmitter can transmit up to about 40-100m (although this value was not expertly measured).

## 5.2 Discussion

The design chosen was miniature, low powered and tunable to different frequencies. The parts used are very common and the circuit is very easily constructed. The circuit was first built on a bread board and worked rather well without applying any real effective RF techniques. The vero board, as expected performed equally well, all that had to be adhered to was to keep the leads short and compact the circuitry as possible but more of a better attempt had to be made in matching the antenna and shielding of the RF section from the output.

## 5.3 Conclusions

The Miniaturized Multi-Channel FM transmitter is essentially a Design and Implementation project. To approach a project like this a parallel path has to be taken in regards to the Theory and practical circuitry, for a successful conclusion in any project the paths must meet, and this only happens when they are fully understood. This is why a good grounding in the basics of Communication theory and Analogue design must be achieved before ever approaching a project like this. To start off looking at block diagrams of basic transmitter was a must, even if it seemed abstract and obscure the underlying meaning of each block can be found out one by one. This is what made the overall project challenging and rewarding.

## 5.4 Recommendations

The design used for this project is essentially quite simple, and it is this simplicity which partly brings it down when it comes to the overall reliable performance. The main area of instability is the oscillator part of the circuit. Shielding the oscillator should help in part to counteract this. After learning a lot from this project, there would have been a few things that could have been done to the final design to improve its performance.

- Rather than a simple single transistor amplifier, using an opamp gives better distortion figures and more predictable output impedance to the transmitter.
- Follow the oscillator with a buffer amplifier to reduce the effect of load change.
- Use negative temperature coefficients to compensate for typically positive temperature coefficient tuned circuit.
- Use of coaxial cable in matching the antenna should improve the distance and signal strength of the transmitter.
- Use foil paper to wrap the entire pre-amp unit and making sure it is well grounded or the shielding will make serve no purpose.

Finally, I would like to suggest to the appropriate authorities that small project (it can be a take home project) should be included as part of curriculum for Engineering Students most especially Electrical Electronics/Computer Engineering Department. This will definitely go a long way in improving the technical ability of students to approach constructive project thereby technically developing the Nation.

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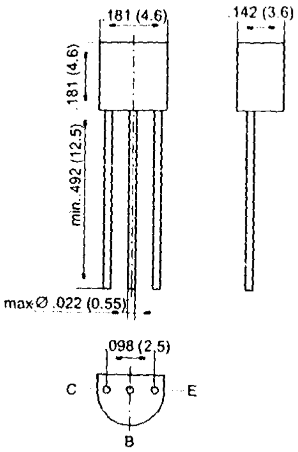
## Appendix A: BC549 (NPN)

## Appendix B: LM7812 (Regulator)

# BC546 THRU BC549

## Small Signal Transistors (NPN)

TO-92




*Dimensions in inches and (millimeters)*

### FEATURES

- NPN Silicon Epitaxial Planar Transistors
- These transistors are subdivided into three groups A, B and C according to their current gain. The type BC546 is available in groups A and B, however, the types BC547 and BC548 can be supplied in all three groups. The BC549 is a low-noise type and available in groups B and C. As complementary types, the PNP transistors BC556 … BC559 are recommended.
- On special request, these transistors are also manufactured in the pin configuration TO-18.

### MECHANICAL DATA

**Case:** TO-92 Plastic Package
**Weight:** approx. 0.18 g

## MAXIMUM RATINGS AND ELECTRICAL CHARACTERISTICS

ings at 25 °C ambient temperature unless otherwise specified

| | | Symbol | Value | Unit |
|---|---|---|---|---|
| Collector-Base Voltage | **BC546** | $V_{CBO}$ | 80 | V |
| | **BC547** | $V_{CBO}$ | 50 | V |
| | **BC548, BC549** | $V_{CBO}$ | 30 | V |
| Collector-Emitter Voltage | **BC546** | $V_{CES}$ | 80 | V |
| | **BC547** | $V_{CES}$ | 50 | V |
| | **BC548, BC549** | $V_{CES}$ | 30 | V |
| Collector-Emitter Voltage | **BC546** | $V_{CEO}$ | 65 | V |
| | **BC547** | $V_{CEO}$ | 45 | V |
| | **BC548, BC549** | $V_{CEO}$ | 30 | V |
| Emitter-Base Voltage | **BC546, BC547** | $V_{EBO}$ | 6 | V |
| | **BC548, BC549** | $V_{EBO}$ | 5 | V |
| Collector Current | | $I_C$ | 100 | mA |
| Peak Collector Current | | $I_{CM}$ | 200 | mA |
| Peak Base Current | | $I_{BM}$ | 200 | mA |
| Peak Emitter Current | | $-I_{EM}$ | 200 | mA |
| Power Dissipation at $T_{amb}$ = 25 °C | | $P_{tot}$ | 500[1] | mW |
| Junction Temperature | | $T_j$ | 150 | °C |
| Storage Temperature Range | | $T_S$ | –65 to +150 | °C |

[1] Valid provided that leads are kept at ambient temperature at a distance of 2 mm from case



GENERAL SEMICONDUCTOR

# BC546 THRU BC549

## ELECTRICAL CHARACTERISTICS

| | Symbol | Min. | Typ. | Max. | Unit |
|---|---|---|---|---|---|
| h-Parameters at $V_{CE}$ = 5 V, $I_C$ = 2 mA, f = 1 kHz, Small Signal Current Gain | | | | | |
| **Current Gain Group A** | $h_{fe}$ | – | 220 | – | – |
| **B** | $h_{fe}$ | – | 330 | – | – |
| **C** | $h_{fe}$ | – | 600 | – | – |
| Input Impedance **Current Gain Group A** | $h_{ie}$ | 1.6 | 2.7 | 4.5 | kΩ |
| **B** | $h_{ie}$ | 3.2 | 4.5 | 8.5 | kΩ |
| **C** | $h_{ie}$ | 6 | 8.7 | 15 | kΩ |
| Output Admittance **Current Gain Group A** | $h_{oe}$ | – | 18 | 30 | µS |
| **B** | $h_{oe}$ | – | 30 | 60 | µS |
| **C** | $h_{oe}$ | – | 60 | 110 | µS |
| Reverse Voltage Transfer Ratio | | | | | |
| **Current Gain Group A** | $h_{re}$ | – | $1.5 \cdot 10^{-4}$ | – | – |
| **B** | $h_{re}$ | – | $2 \cdot 10^{-4}$ | – | – |
| **C** | $h_{re}$ | – | $3 \cdot 10^{-4}$ | – | – |
| DC Current Gain at $V_{CE}$ = 5 V, $I_C$ = 10µA | | | | | |
| **Current Gain Group A** | $h_{FE}$ | – | 90 | – | – |
| **B** | $h_{FE}$ | – | 150 | – | – |
| **C** | $h_{FE}$ | – | 270 | – | – |
| at $V_{CE}$ = 5 V, $I_C$ = 2 mA | | | | | |
| **Current Gain Group A** | $h_{FE}$ | 110 | 180 | 220 | – |
| **B** | $h_{FE}$ | 200 | 290 | 450 | – |
| **C** | $h_{FE}$ | 420 | 500 | 800 | – |
| at $V_{CE}$ = 5 V, $I_C$ = 100 mA | | | | | |
| **Current Gain Group A** | $h_{FE}$ | – | 120 | – | – |
| **B** | $h_{FE}$ | – | 200 | – | – |
| **C** | $h_{FE}$ | – | 400 | – | – |
| Thermal Resistance Junction to Ambient Air | $R_{thJA}$ | – | – | 250[1] | K/W |
| Collector Saturation Voltage at $I_C$ = 10 mA, $I_B$ = 0.5 mA | $V_{CEsat}$ | – | 80 | 200 | mV |
| at $I_C$ = 100 mA, $I_B$ = 5 mA | $V_{CEsat}$ | – | 200 | 600 | mV |
| Base Saturation Voltage at $I_C$ = 10 mA, $I_B$ = 0.5 mA | $V_{BEsat}$ | – | 700 | – | mV |
| at $I_C$ = 100 mA, $I_B$ = 5 mA | $V_{BEsat}$ | – | 900 | – | mV |
| Base-Emitter Voltage at $V_{CE}$ = 5 V, $I_C$ = 2 mA | $V_{BE}$ | 580 | 660 | 700 | mV |
| at $V_{CE}$ = 5 V, $I_C$ = 10 mA | $V_{BE}$ | – | – | 720 | mV |
| Collector-Emitter Cutoff Current at $V_{CE}$ = 80 V **BC546** | $I_{CES}$ | – | 0.2 | 15 | nA |
| at $V_{CE}$ = 50 V **BC547** | $I_{CES}$ | – | 0.2 | 15 | nA |
| at $V_{CE}$ = 30 V **BC548, BC549** | $I_{CES}$ | – | 0.2 | 15 | nA |
| at $V_{CE}$ = 80 V, $T_j$ = 125 °C **BC546** | $I_{CES}$ | – | – | 4 | µA |
| at $V_{CE}$ = 50 V, $T_j$ = 125 °C **BC547** | $I_{CES}$ | – | – | 4 | µA |

[1] Valid provided that leads are kept at ambient temperature at a distance of 2 mm from case

GENERAL SEMICONDUCTOR®

# BC546 THRU BC549

## ELECTRICAL CHARACTERISTICS

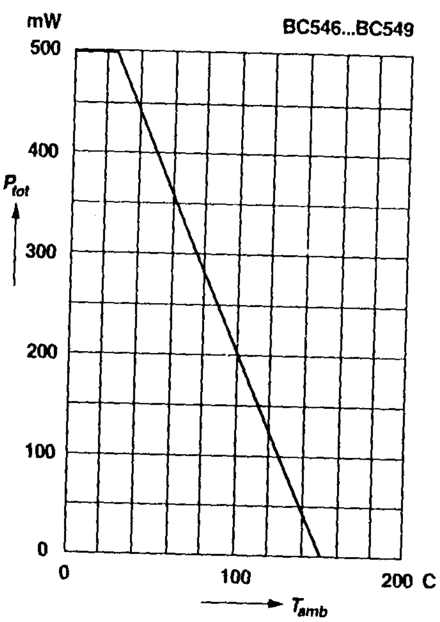
Ratings at 25 °C ambient temperature unless otherwise specified

| | Symbol | Min. | Typ. | Max. | Unit |
|---|---|---|---|---|---|
| at $V_{CE}$ = 30 V, $T_j$ = 125 °C **BC548, BC549** | $I_{CES}$ | – | – | 4<br>4 | µA<br>µA |
| Gain-Bandwidth Product<br>at $V_{CE}$ = 5 V, $I_C$ = 10 mA, f = 100 MHz | $f_T$ | – | 300 | – | MHz |
| Collector-Base Capacitance<br>at $V_{CB}$ = 10 V, f = 1 MHz | $C_{CBO}$ | – | 3.5 | 6 | pF |
| Emitter-Base Capacitance<br>at $V_{EB}$ = 0.5 V, f = 1 MHz | $C_{EBO}$ | – | 9 | – | pF |
| Noise Figure<br>at $V_{CE}$ = 5 V, $I_C$ = 200 µA, $R_G$ = 2 kΩ,<br>f = 1 kHz, Δf = 200 Hz **BC546, BC547** | F | – | 2 | 10 | dB |
| **BC548**<br>**BC549** | F | – | 1.2 | 4 | dB |
| at $V_{CE}$ = 5 V, $I_C$ = 200 µA, $R_G$ = 2 kΩ,<br>f = 30...15000 Hz **BC549** | F | – | 1.4 | 4 | dB |

## RATINGS AND CHARACTERISTIC CURVES BC546 THRU BC549

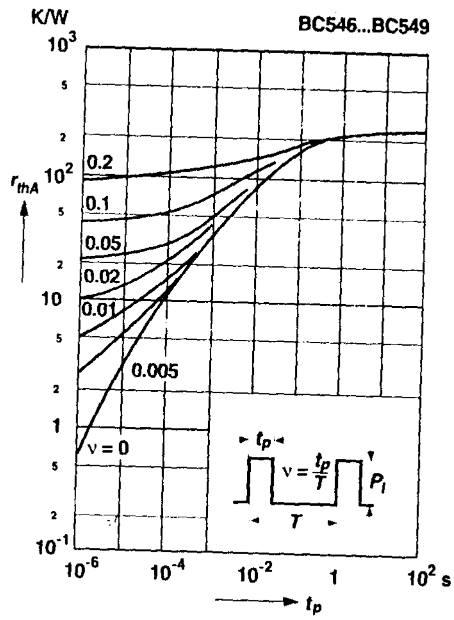
**Admissible power dissipation versus temperature**

Valid provided that leads are kept at ambient temperature at a distance of 2 mm from case




**Pulse thermal resistance versus pulse duration**

Valid provided that leads are kept at ambient temperature at a distance of 2 mm from case

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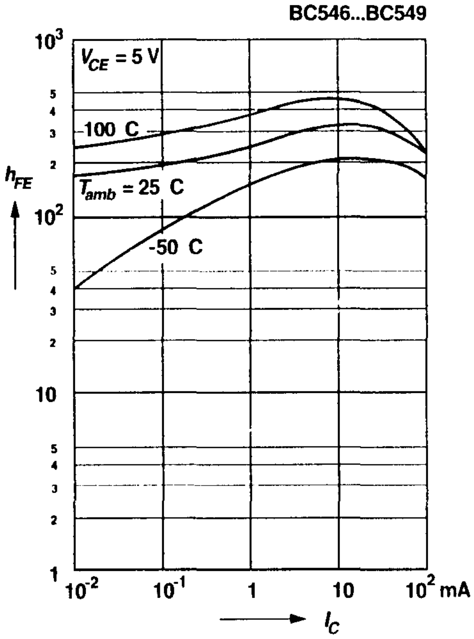
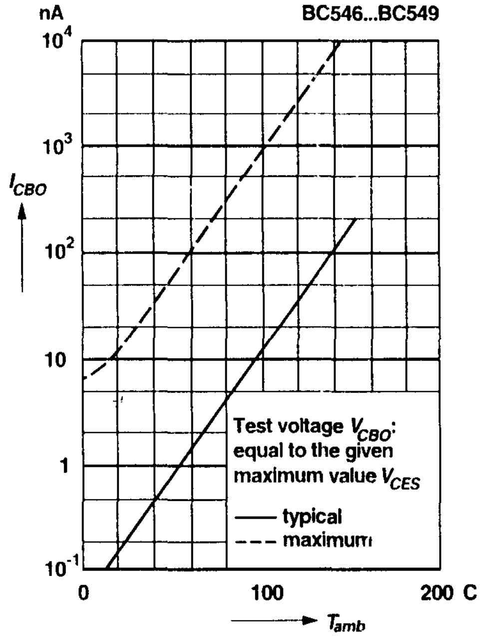
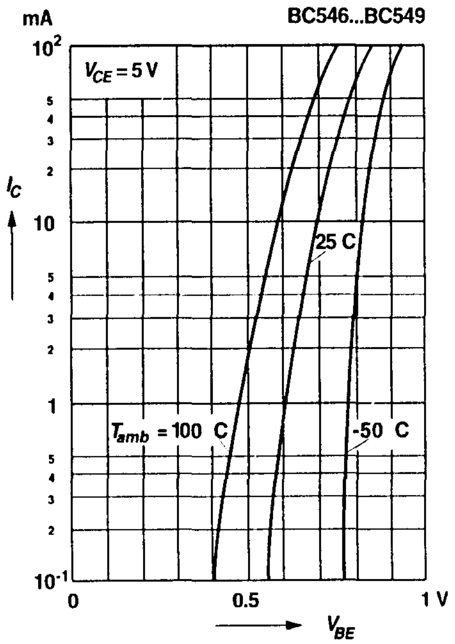
**DC current gain versus collector current**



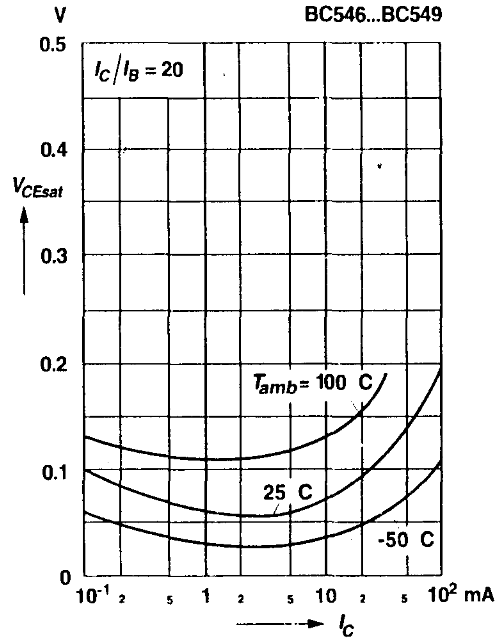

**Collector-base cutoff current versus ambient temperature**




**Collector current versus base-emitter voltage**




**Collector saturation voltage versus collector current**

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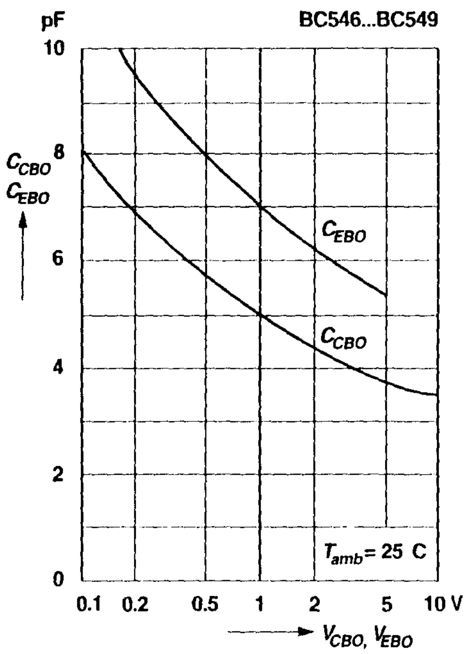
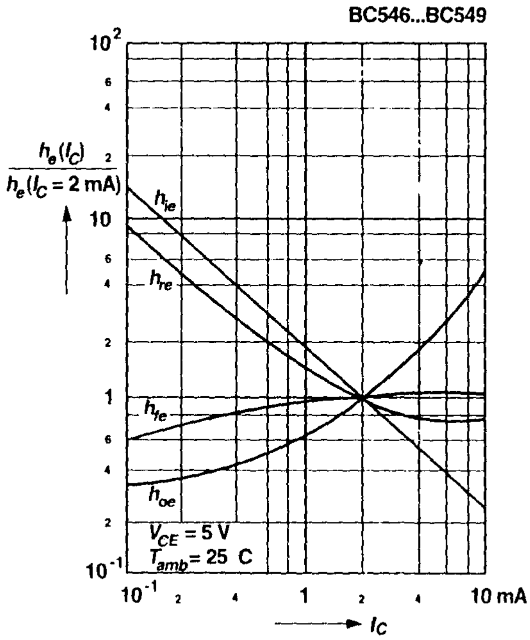
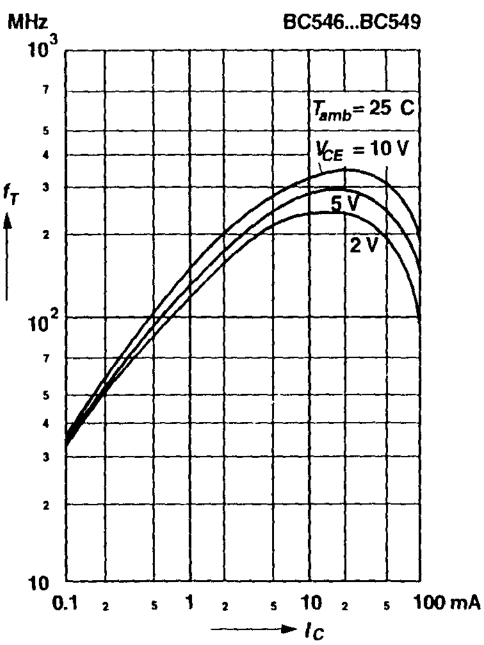
Collector-base capacitance,
Emitter-base capacitance
versus reverse bias voltage



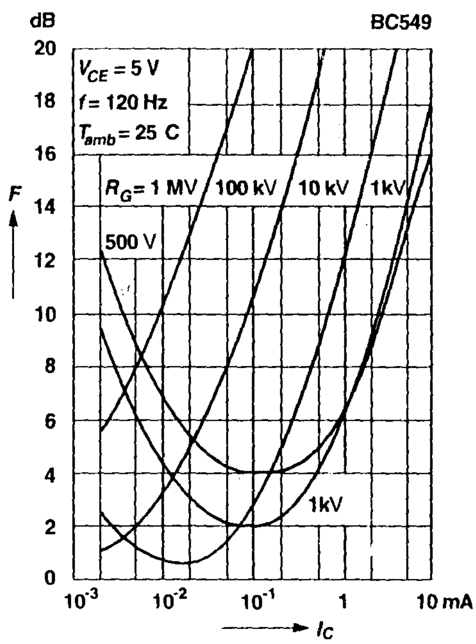

Relative h-parameters
versus collector current



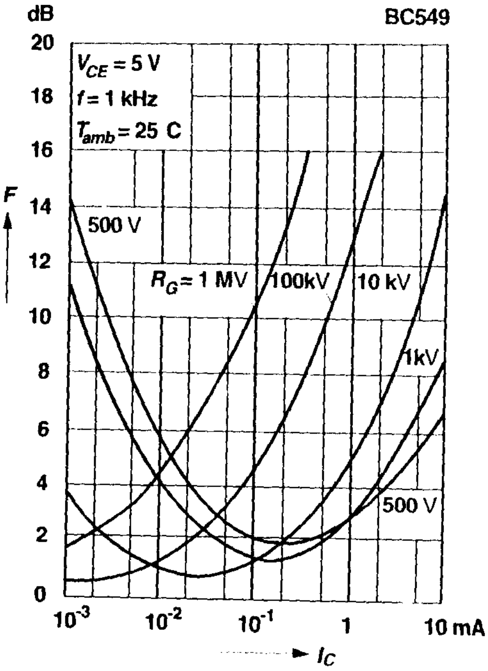

Gain-bandwidth product
versus collector current



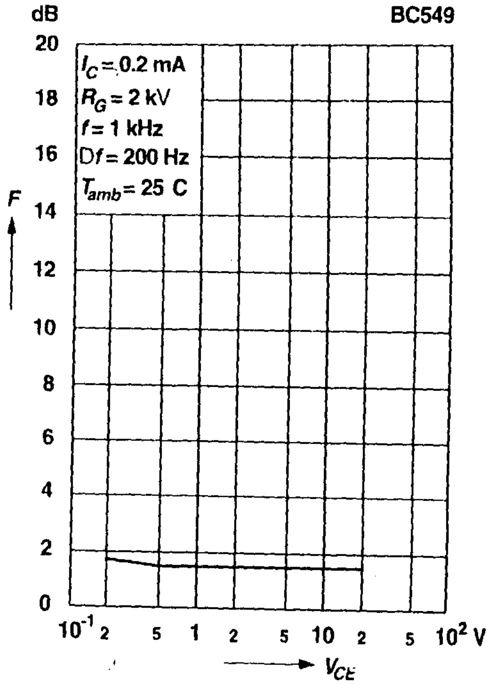

Noise figure
versus collector current



Noise figure
versus collector current




Noise figure
versus collector emitter voltage



May 2000

National Semiconductor

# LM78XX
# Series Voltage Regulators

## General Description

The LM78XX series of three terminal regulators is available with several fixed output voltages making them useful in a wide range of applications. One of these is local on card regulation, eliminating the distribution problems associated with single point regulation. The voltages available allow these regulators to be used in logic systems, instrumentation, HiFi, and other solid state electronic equipment. Although designed primarily as fixed voltage regulators these devices can be used with external components to obtain adjustable voltages and currents.

The LM78XX series is available in an aluminum TO-3 package which will allow over 1.0A load current if adequate heat sinking is provided. Current limiting is included to limit the peak output current to a safe value. Safe area protection for the output transistor is provided to limit internal power dissipation. If internal power dissipation becomes too high for the heat sinking provided, the thermal shutdown circuit takes over preventing the IC from overheating.

Considerable effort was expanded to make the LM78XX series of regulators easy to use and minimize the number of external components. It is not necessary to bypass the output, although this does improve transient response. Input bypassing is needed only if the regulator is located far from the filter capacitor of the power supply.

For output voltage other than 5V, 12V and 15V the LM117 series provides an output voltage range from 1.2V to 57V.

## Features

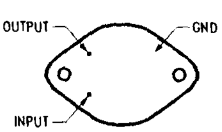
- Output current in excess of 1A
- Internal thermal overload protection
- No external components required
- Output transistor safe area protection
- Internal short circuit current limit
- Available in the aluminum TO-3 package

## Voltage Range

| | |
|---|---|
| LM7805C | 5V |
| LM7812C | 12V |
| LM7815C | 15V |

## Connection Diagrams

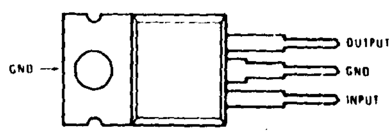
**Metal Can Package**
**TO-3 (K)**
**Aluminum**




DS007746-2

**Bottom View**
**Order Number LM7805CK,**
**LM7812CK or LM7815CK**
**See NS Package Number KC02A**

**Plastic Package**
**TO-220 (T)**

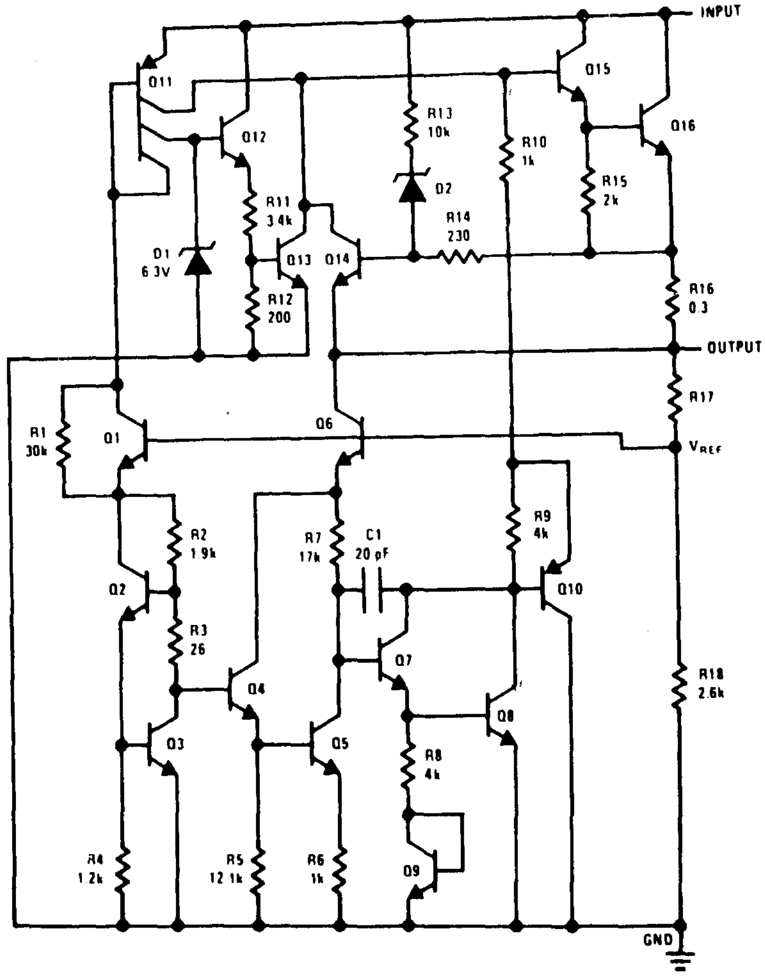



DS007746-3

**Top View**
**Order Number LM7805CT,**
**LM7812CT or LM7815CT**
**See NS Package Number T03B**

 DS007746

## Schematic




DS007746-1

## Absolute Maximum Ratings (Note 3)

**If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/ Distributors for availability and specifications.**

| | |
|---|---|
| Input Voltage | |
| ($V_O$ = 5V, 12V and 15V) | 35V |
| Internal Power Dissipation (Note 1) | Internally Limited |
| Operating Temperature Range ($T_A$) | 0°C to +70°C |
| Maximum Junction Temperature | |
| (K Package) | 150°C |
| (T Package) | 150°C |
| Storage Temperature Range | −65°C to +150°C |
| Lead Temperature (Soldering, 10 sec.) | |
| TO-3 Package K | 300°C |
| TO-220 Package T | 230°C |

## Electrical Characteristics LM78XXC (Note 2)

0°C ≤ $T_J$ ≤ 125°C unless otherwise noted.

| Output Voltage | | | | 5V | | | 12V | | | 15V | | | Units |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Input Voltage (unless otherwise noted)** | | | | **10V** | | | **19V** | | | **23V** | | | |
| **Symbol** | **Parameter** | **Conditions** | | **Min** | **Typ** | **Max** | **Min** | **Typ** | **Max** | **Min** | **Typ** | **Max** | |
| $V_O$ | Output Voltage | Tj = 25°C, 5 mA ≤ $I_O$ ≤ 1A | | 4.8 | 5 | 5.2 | 11.5 | 12 | 12.5 | 14.4 | 15 | 15.6 | V |
| | | $P_D$ ≤ 15W, 5 mA ≤ $I_O$ ≤ 1A | | 4.75 | | 5.25 | 11.4 | | 12.6 | 14.25 | | 15.75 | V |
| | | $V_{MIN}$ ≤ $V_{IN}$ ≤ $V_{MAX}$ | | (7.5 ≤ $V_{IN}$ ≤ 20) | | | (14.5 ≤ $V_{IN}$ ≤ 27) | | | (17.5 ≤ $V_{IN}$ ≤ 30) | | | V |
| $\Delta V_O$ | Line Regulation | $I_O$ = 500 mA | Tj = 25°C | | 3 | 50 | | 4 | 120 | | 4 | 150 | mV |
| | | | $\Delta V_{IN}$ | (7 ≤ $V_{IN}$ ≤ 25) | | | 14.5 ≤ $V_{IN}$ ≤ 30) | | | (17.5 ≤ $V_{IN}$ ≤ 30) | | | V |
| | | | 0°C ≤ Tj ≤ +125°C | | | 50 | | | 120 | | | 150 | mV |
| | | | $\Delta V_{IN}$ | (8 ≤ $V_{IN}$ ≤ 20) | | | (15 ≤ $V_{IN}$ ≤ 27) | | | (18.5 ≤ $V_{IN}$ ≤ 30) | | | V |
| | | $I_O$ ≤ 1A | Tj = 25°C | | | 50 | | | 120 | | | 150 | mV |
| | | | $\Delta V_{IN}$ | (7.5 ≤ $V_{IN}$ ≤ 20) | | | (14.6 ≤ $V_{IN}$ ≤ 27) | | | (17.7 ≤ $V_{IN}$ ≤ 30) | | | V |
| | | | 0°C ≤ Tj ≤ +125°C | | | 25 | | | 60 | | | 75 | mV |
| | | | $\Delta V_{IN}$ | (8 ≤ $V_{IN}$ ≤ 12) | | | (16 ≤ $V_{IN}$ ≤ 22) | | | (20 ≤ $V_{IN}$ ≤ 26) | | | V |
| $\Delta V_O$ | Load Regulation | Tj = 25°C | 5 mA ≤ $I_O$ ≤ 1.5A | | 10 | 50 | | 12 | 120 | | 12 | 150 | mV |
| | | | 250 mA ≤ $I_O$ ≤ 750 mA | | | 25 | | | 60 | | | 75 | mV |
| | | 5 mA ≤ $I_O$ ≤ 1A, 0°C ≤ Tj ≤ +125°C | | | | 50 | | | 120 | | | 150 | mV |
| $I_Q$ | Quiescent Current | $I_O$ ≤ 1A | Tj = 25°C | | | 8 | | | 8 | | | 8 | mA |
| | | | 0°C ≤ Tj ≤ +125°C | | | 8.5 | | | 8.5 | | | 8.5 | mA |
| $\Delta I_Q$ | Quiescent Current Change | 5 mA ≤ $I_O$ ≤ 1A | | | | 0.5 | | | 0.5 | | | 0.5 | mA |
| | | Tj = 25°C, $I_O$ ≤ 1A | | | | 1.0 | | | 1.0 | | | 1.0 | mA |
| | | $V_{MIN}$ ≤ $V_{IN}$ ≤ $V_{MAX}$ | | (7.5 ≤ $V_{IN}$ ≤ 20) | | | (14.8 ≤ $V_{IN}$ ≤ 27) | | | (17.9 ≤ $V_{IN}$ ≤ 30) | | | V |
| | | $I_O$ ≤ 500 mA, 0°C ≤ Tj ≤ +125°C | | | | 1.0 | | | 1.0 | | | 1.0 | mA |
| | | $V_{MIN}$ ≤ $V_{IN}$ ≤ $V_{MAX}$ | | (7 ≤ $V_{IN}$ ≤ 25) | | | (14.5 ≤ $V_{IN}$ ≤ 30) | | | (17.5 ≤ $V_{IN}$ ≤ 30) | | | V |
| $V_N$ | Output Noise Voltage | $T_A$ = 25°C, 10 Hz ≤ f ≤ 100 kHz | | | 40 | | | 75 | | | 90 | | μV |
| $\frac{\Delta V_{IN}}{\Delta V_{OUT}}$ | Ripple Rejection | f = 120 Hz | $I_O$ ≤ 1A, Tj = 25°C or | 62 | 80 | | 55 | 72 | | 54 | 70 | | dB |
| | | | $I_O$ ≤ 500 mA 0°C ≤ Tj ≤ +125°C | 62 | | | 55 | | | 54 | | | dB |
| | | $V_{MIN}$ ≤ $V_{IN}$ ≤ $V_{MAX}$ | | (8 ≤ $V_{IN}$ ≤ 18) | | | (15 ≤ $V_{IN}$ ≤ 25) | | | (18.5 ≤ $V_{IN}$ ≤ 28.5) | | | V |
| $R_O$ | Dropout Voltage | Tj = 25°C, $I_{OUT}$ = 1A | | | 2.0 | | | 2.0 | | | 2.0 | | V |
| | Output Resistance | f = 1 kHz | | | 8 | | | 18 | | | 19 | | mΩ |

## Electrical Characteristics LM78XXC (Note 2) (Continued)

0°C ≤ $T_J$ ≤ 125°C unless otherwise noted.

| Output Voltage | | | 5V | | | 12V | | | 15V | | | Units |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Input Voltage (unless otherwise noted) | | | 10V | | | 19V | | | 23V | | | |
| Symbol | Parameter | Conditions | Min | Typ | Max | Min | Typ | Max | Min | Typ | Max | |
| | Short-Circuit Current | Tj = 25°C | | 2.1 | | | 1.5 | | | 1.2 | | A |
| | Peak Output Current | Tj = 25°C | | 2.4 | | | 2.4 | | | 2.4 | | A |
| | Average TC of $V_{OUT}$ | 0°C ≤ Tj ≤ +125°C, $I_O$ = 5 mA | | 0.6 | | | 1.5 | | | 1.8 | | mV/°C |
| $V_{IN}$ | Input Voltage Required to Maintain Line Regulation | Tj = 25°C, $I_O$ ≤ 1A | | 7.5 | | 14.6 | | | 17.7 | | | V |

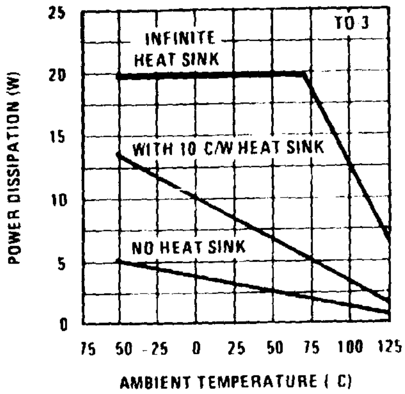
**Note 1:** Thermal resistance of the TO-3 package (K, KC) is typically 4°C/W junction to case and 35°C/W case to ambient. Thermal resistance of the TO-220 package (T) is typically 4°C/W junction to case and 50°C/W case to ambient.

**Note 2:** All characteristics are measured with capacitor across the input of 0.22 µF, and a capacitor across the output of 0.1µF. All characteristics except noise voltage and ripple rejection ratio are measured using pulse techniques ($t_w$ ≤ 10 ms, duty cycle ≤ 5%). Output voltage changes due to changes in internal temperature must be taken into account separately.

**Note 3:** Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. For guaranteed specifications and the test conditions, see Electrical Characteristics.

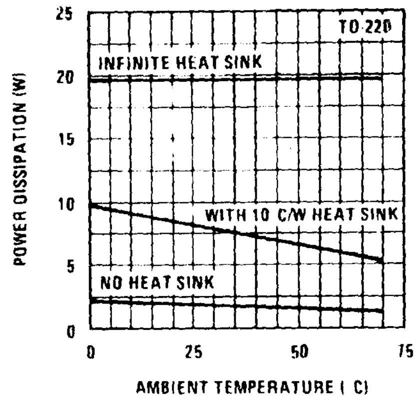
## Typical Performance Characteristics

**Maximum Average Power Dissipation**



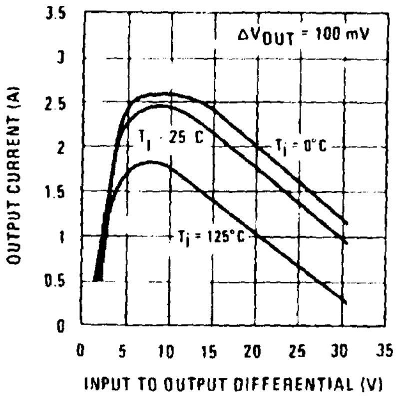

DS007746-5

**Maximum Average Power Dissipation**



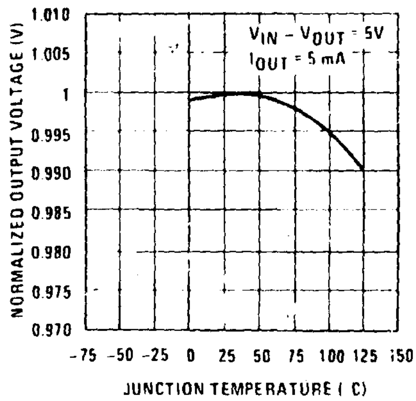

DS007746-6

**Peak Output Current**



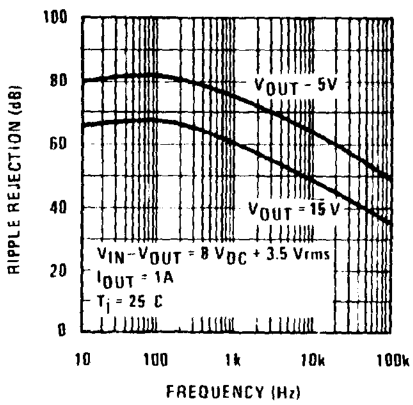

DS007746-7

**Output Voltage (Normalized to 1V at $T_J$ = 25˚C)**



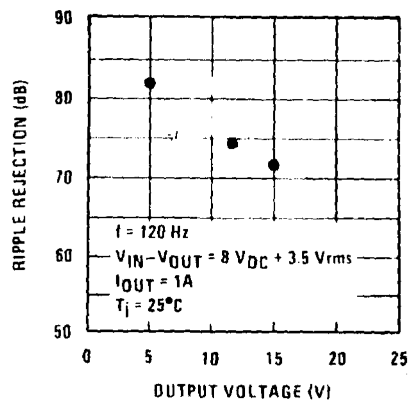

DS007746-8

**Ripple Rejection**




DS007746-9

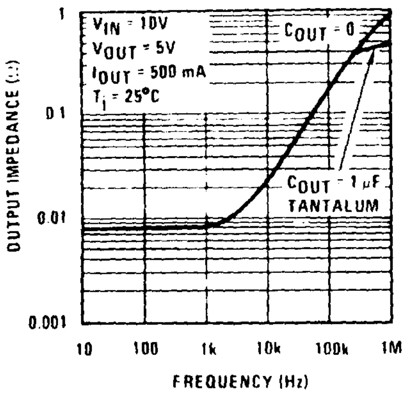
**Ripple Rejection**




DS007746-10

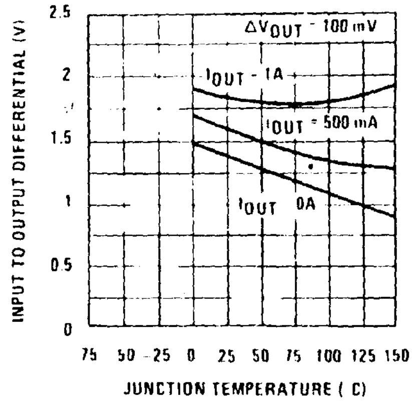
## Typical Performance Characteristics (Continued)

### Output Impedance



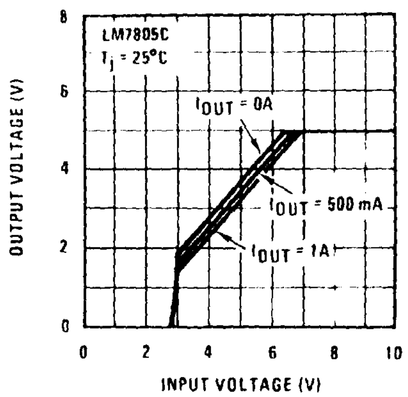

DS007746-11

### Dropout Voltage



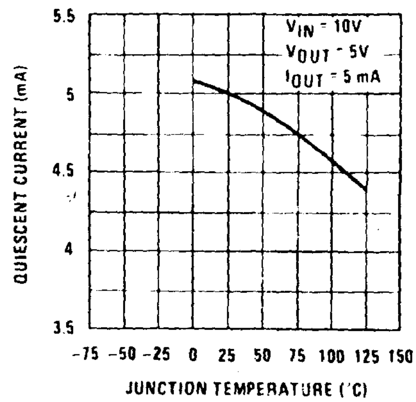

DS007746-12

### Dropout Characteristics



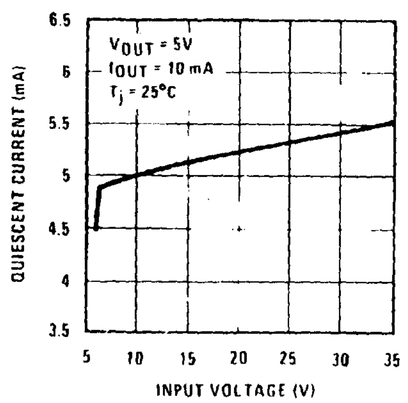

DS007746-13

### Quiescent Current



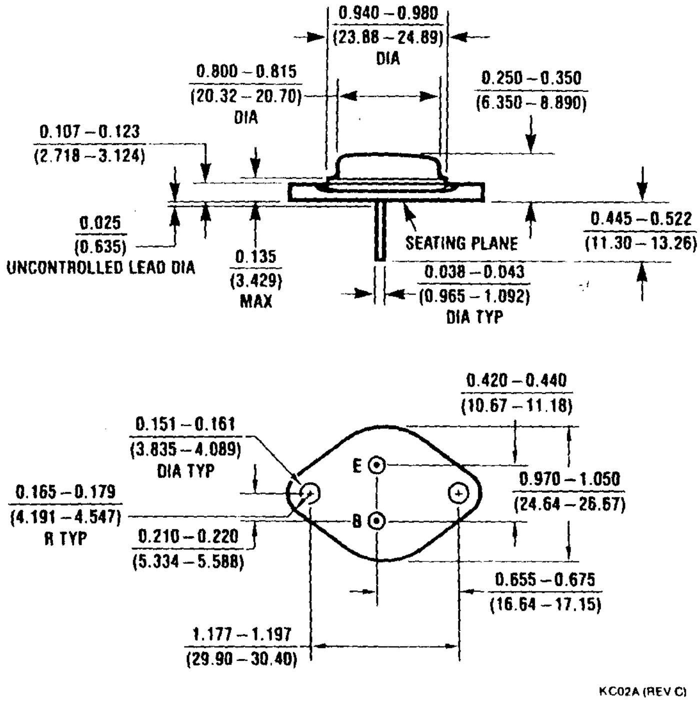

DS007746-14

### Quiescent Current



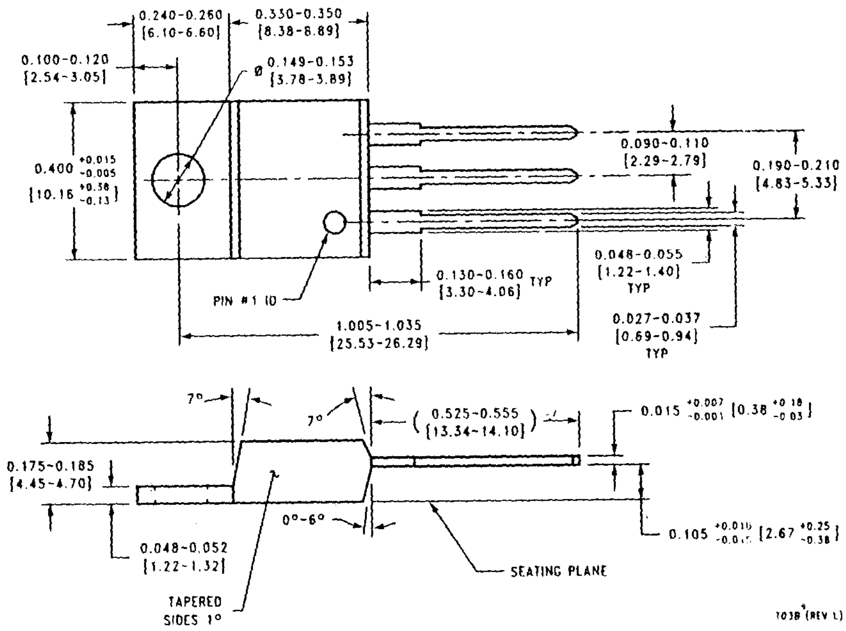

DS007746-15

## Physical Dimensions inches (millimeters) unless otherwise noted




**Aluminum Metal Can Package (KC)**
**Order Number LM7805CK, LM7812CK or LM7815CK**
**NS Package Number KC02A**

## Physical Dimensions inches (millimeters) unless otherwise noted (Continued)



**TO-220 Package (T)**
**Order Number LM7805CT, LM7812CT or LM7815CT**
**NS Package Number T03B**

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2. A critical component is any component of a life support device or system whose failure to perform can be reasonably expected to cause the failure of the life support device or system, or to affect its safety or effectiveness.

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