DESIGN AND CONSTRUCTION OF A WIRELESS AUDIO LINK

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NOVEMBER, 2007

Declaration

I, Akangson Ekerete Ifiok declare that this work was done by me and has never been presented elsewhere for the award of a degree. I also hereby relinquish the copyright to the Federal University of Technology, Minna.

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DEDICATION

This project is dedicated to my dear mother. Mrs. U.E. Akangson. her support has been all I needed and my siblings; Ima Akangson . Mrs. Mfon Ekpeyong. and Elsie Akangson.

ACKNOWLEDGEMENT

I want to thank the Almighty creator of heaven and earth for keeping me alive. Special thanks and tribute to my mum, Mrs U.E. Akangson for all her support and encouragement. To my siblings for always being there for me irrespective of the situation. Also to Mr. Mike Onyianwu for getting me admission into this institution in the first place

I want to also acknowledge my supervisor in the person of, Engr. P.O. Attah for his painstaking advice and contribution.

I want to express recognition to my friends; our relationship has meant so much to me. I am also taking this opportunity to accredit YWAP (youth with a purpose) and Family Worship Center (FWC); my life has changed positively because of these ruling bodies.

TABLE OF CONTENTS

TABLE OF FIGURES

ABSTRACT

The wireless audio link is aimed at transmitting audio wirelessly using high power infrared beams frequency modulation. The modulation is done by a linear audio amplifier and drives two infrared diodes connected in series across a distance which is a function of power delivered to the diodes. The wireless audio link was designed and constructed. Distance covered is about 10m with a frequency of 100kHz.The project will consist of a headphone capable of picking up distant sound signals (encoded using analogue FM transmitted from a base unit), a high-gain pre-amplifier, a pre-emphasis circuit, an automatic gain control, limiting circuit and an FM pulse width modulator

CHAPTER ONE

INTRODUCTION

The use of infrared light to transmit a frequency modulated pulse wave has become a popular method for transmitting for communication systems. Data communication using light radiation can be traced back to Alexander Graham Bel in 1880 and did not become possible until the development of Light emitting diodes (LED) in 1963[1]. Since then, infrared technology has proven to be an efficient and economical method of audio transmission offering security from unwanted eavesdropping and permits multiple systems with the same building to operate on a single standard frequency.

1.1 OBJECTIVES

- Helping the current state of motion of a headphone user as he/she is limited in movement by the length of the cable connecting the headphone to a conventional receiver/amplifier. This limitation restricts the user's freedom of movement, endangers his safety as he may trip on the cable.
- Also with this invention, production of sound signals is done without disturbing surrounding individuals.
- An objective of the present invention is that this system can reliably pick-up and transmit voice and other desired sounds from both near and distant locations in the area of operation, while suppressing undesired background sounds.
- Also, it is capable of amplifying soft sounds to comfortable listening levels while reproducing loud sounds without overload distortion.

- Bearing in mind that since it is a low-power infrared listening system, it can be battery powered while maintaining a sufficient power output for reliable transmission.

1.2 METHODOLOGY

Most infrared communication systems operate on the same general principle. With reference to this project, audio is taken from its source(say: Cd-player, TV or any sound producing device), converted to a frequency modulated pulse wave, transmitted as light radiation by infrared LED emitters and is ultimately received by a receiver, that converts light radiation back to audio to be delivered to the listener's ear.

A high quality audio-in device is used, converting sound waves to electrical signals. Intelligibility is further increased by utilizing an equalization and pre-emphasis circuit. After passing through a high gain pre-amplifier the audio signal is boosted in the upper speech frequencies while under going a low frequency roll-off to eliminate undesired background noises. A limiting circuit which doubles as an automatic gain control circuit is advantageously employed to boost weak signals into a comfortable listening range and to reduce extremely strong audio signals so as to eliminate the possibility of distortion in the transmitted audio.

A better understanding of what has been said could be gleaned from the simple block diagrams shown in Fig 1 (a) & (b).

SIMPLE BLOCK DIAGRAMS

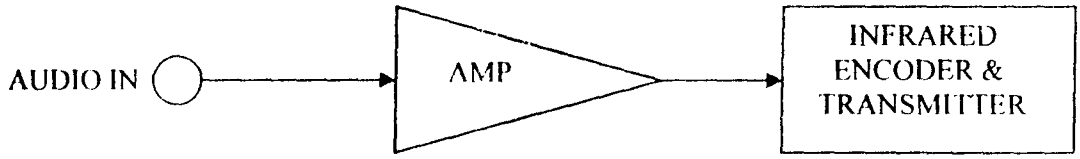

Fig 1.2(a) TRANSMITTER

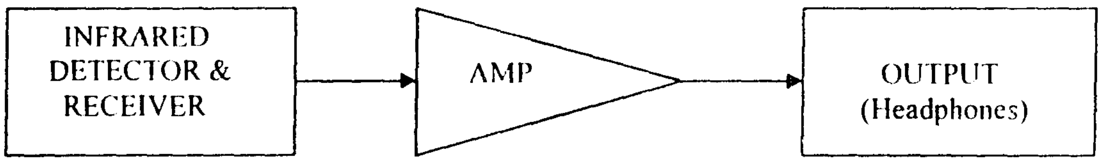

Fig 1.2(b) RECEIVER

CHAPTER TWO

LITERATURE REVIEW

2.1 HISTORICAL BACKGROUND

Infrared (IR) radiation is electromagnetic radiation of a wavelength longer than that of visible light, but shorter than that of radio waves. The name means "below red" (from the Latin infra, "below") [4], red being the color of visible light with the longest wavelength. Infra-Red is interesting because it is easily generated and doesn't suffer electromagnetic interference, so it is nicely used for communication and control though not absolutely perfect.

William Herschel, an amateur astronomer famous for the discovery of Uranus in 1781, made an important discovery in 1800[2]. Herschel was familiar with Newton's discovery that sunlight could be separated into separate chromatic components via refraction through a glass prism. Herschel thought that the colors themselves might contain different levels of heat, so he devised a clever experiment to investigate this. Herschel passed sunlight through a glass prism to create a spectrum (the rainbow created when light is divided into its color components) and measured the temperatures of the different colors. He used three thermometers with blackened bulbs and placed one bulb in each color while the other two were placed outside the spectrum as controls.

Herschel measured the temperature just beyond the red portion of the spectrum and found this area had the highest temperature of all and thus contained the most heat. Herschel's experiment was important not only because it lead to the discovery of infrared light, but because it was the first experiment that showed there were forms of light not visible to the human eye[2].

2.2 APPLICATIONS

The uses of infrared include military, such as: target acquisition, surveillance, homing and tracking and non-military, such as thermal efficiency analysis, remote temperature sensing, short-ranged wireless communication, meteorology, spectroscopy, and weather forecasting [2]. Infrared astronomy uses sensor-equipped telescopes to penetrate dusty regions, greater insight on some of the workings of infrared will be given below.

Night vision: Infrared is used in night-vision equipment when there is insufficient visible light to Night vision devices operate through a process involving the conversion of ambient light photons into electrons which are then amplified by a chemical and electrical process and then converted back into visible light

Thermography: Infrared thermography is a non-contact, non-destructive test method that utilizes a thermal imager to detect [3], display and record thermal patterns and temperatures across the surface of an object Thermography is widely used in industry for predictive maintenance, condition assessment, quality assurance, and forensic investigations of electrical, mechanical and structural systems.

Imaging: The result of infrared absorption is heating of the tissue since it increases molecular vibrational activity. Infrared radiation penetrates the skin further than visible light and can thus be used for photographic imaging of subcutaneous blood vessels.

Heating: Infrared radiation can be used as a deliberate heating source. For example it is used to remove ice from the wings of aircraft (de-icing) in extremely cold regions.

Infrared and health: Infrared radiation is also entirely harmless (bearing in mind that the heat we feel from the sun is infrared radiation) - as a matter of fact, just about everything radiates infrared waves, in more or less intense ways. When infrared rays hit your skin, it transfers heat energy to it. Your skin temperature goes up and you react by starting to sweat. The health benefits usually include improved blood circulation and hence a stronger cardiovascular system, a cleansing of the body, and finally loss of weight. This kind of health therapy is called *sauna* [3].

Locally administered infrared is used as treatment for some skin diseases and tissue traumas with varying success. The most successful use so far seems to be the application of infrared rays to help ease the joint pain and stiffness of arthritis patients[8]. This has become very beneficial for arthritis patients.

Communications: IR data transmission is also employed in short-range communication among computer peripherals and personal digital assistants. These devices usually conform to standards published by IrDA, the Infrared Data Association. IrDA devices use infrared light-emitting diodes (LEDs) to emit infrared radiation which is focused by a plastic lens into a narrow beam. The beam is modulated, i.e. switched on and off, to encode the data. The receiver uses a silicon photodiode to convert the infrared radiation to an electric current. IR does not penetrate walls and so does not interfere with other devices in adjoining rooms.

The utilization of this application can be seen in this project which consists of a simple communication system backed up by Infrared emission.

2.3 THEORETICAL BACKGROUND

Communication Systems

Communication systems consist of an input device, transmitter, transmission medium, receiver and output device; the input device may be a computer, sensor or oscillator depending on the application of the system, while the output device could be a speaker or computer. The source section produces two types of signal, namely the information signal, which may be speech, video or data, and a signal of constant frequency and constant amplitude called the carrier. The information signal mixes with the carrier to produce a complex signal which is transmitted; this combination is effected by a modulator (This stage produces an output carrier which varies in sympathy with the audio signals or signal, at this point the signal is low-level and must be amplified before transmission).

The destination section must be able to reproduce the original information, and the receiver block does this by separating the information from the carrier signal. The information is then fed to the output device. The transmission medium may be a copper cable, such as a co-axial cable, a fibre-optic cable or a waveguide.

Both the transmitter block and the receiver block incorporate many amplifier and processing stages, and one of the most important is the oscillator stage- The oscillator in the transmitter is generally referred to as the master oscillator [6] as it determines the channel at which the transmitter functions, also it generates a constant-amplitude and constant frequency signal which is used to carry the audio or intelligence signal. The receiver oscillator is called the local oscillator as it produces a local carrier within the receiver which allows the incoming carrier from the transmitter to be modified for easier processing within the receiver. The receiver amplifies the incoming signal, extracts the intelligence and passes it on to an output transducer such as a speaker. The local oscillator in this case causes the incoming (RF) signals to be translated to a fixed lower frequency, called the intermediate frequency (IF), which is then passed on.

2.4 THE PRINCIPLE OF OSCILLATION

The concept of oscillation cannot be properly inferred without mentioning operational amplifiers (usually called the Op-Amp). It is a device that is voltage controlled, voltage source with very high gain. Also, it's a five terminal, four port active element. The symbol of the op-amp is shown below

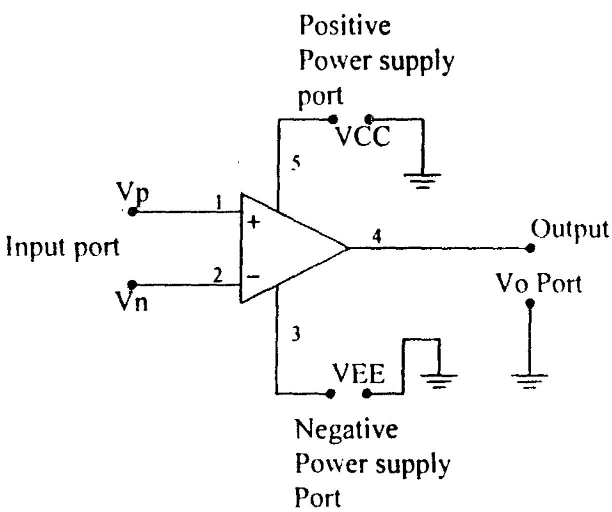

Fig 2.1 A Typical Operational Amplifier

The power supply voltages V_{CC} and V_{EE} power the operational amplifier and in general define the output voltage range of the amplifier. The terminals labeled with the "+" and the "-" signs are called non-inverting and inverting respectively. The input voltage V_p and V_n and the output voltage V_o referenced to ground.

. The gain parameter A is called the open loop gain [5], in the absence of any load at the output the output voltage is

$$V_o = AV_i = A(V_p - V_n) \qquad (2.1.1)$$

The operational amplifier has an extremely high gain under these circumstances and this leads to saturation within the amplifier. As saturation implies working in the non-linear section of the characteristics, harmonics are produced and a ringing pattern may appear inside the chip. As a result of this, a square wave output is produced for a sinusoidal input. The amplifier has ceased to amplify and we say it has become unstable. There are many reasons why an amplifier may become unstable, such as temperature changes or power supply variations, but in this case the problem is the very high gain of the operational amplifier.

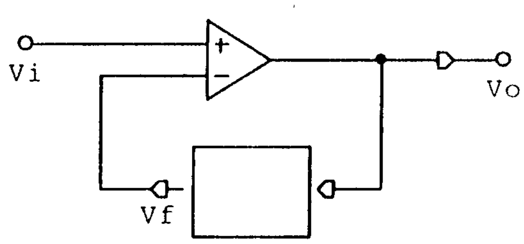

Fig 2.2 Diagram showing an Op-Amp with feedback block

Figure 2.2 above shows how this may be overcome by introducing a feedback network between the output and the input. When feedback is applied to an amplifier the overall gain can be reduced and controlled so that the operational amplifier can function as a linear amplifier. Note also that the signal fedback has a phase angle, due to the inverting input, which is in opposition to the input signal (V_i).

Negative feedback can therefore be defined as the process whereby a part of the output voltage of an amplifier is fed to the input with a phase angle that opposes the input signal. Negative feedback is used in amplifier circuits in order to give stability and reduced gain. Bandwidth is generally increased, noise reduced and input and output resistances altered. These are all desirable parameters for an amplifier, but if the feedback is overdone then the amplifier becomes unstable and will produce a ringing effect.

In order to understand stability, instability and its causes must be considered. From the above discussion, as long as the feedback is negative the amplifier is stable, but when the signal feedback is in phase with the input signal then positive feedback exists. Hence positive feedback occurs when the total phase shift through the operational amplifier (Op-Amp) and the feedback network is 360° (0°). The feedback signal is now in phase with the input signal (V_i) and oscillations take place [6].

Any oscillator consist of three sections as shown in Fig 2.3

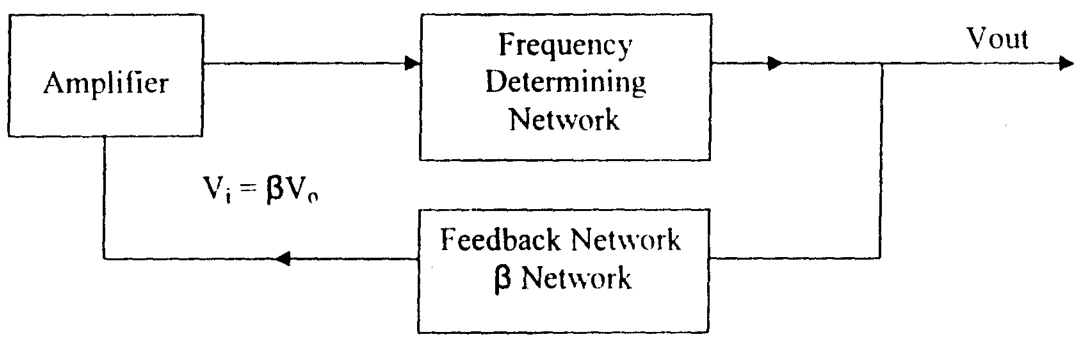

Fig2.3 Basic oscillator block diagram

The frequency-determining network is the core of the oscillator and deals with the generation of the specified frequency. The desired frequency may be generated by using an inductance–capacitance (LC) circuit, a resistance–capacitance (RC) circuit or a piezoelectric crystal. Each of these networks produces a particular frequency depending on the values of the components and the cut of the crystal. This frequency is known as the resonant or natural frequency of the network and can be calculated if the values of components are known.

Each of these three different networks will produce resonance, but in quite different ways.

In the case of the LC network, a parallel arrangement is generally used which is periodically fed a pulse of energy to keep the current circulating in the parallel circuit.

The current circulates in one direction and then in the other as the magnetic and electric fields of the coil and capacitor interchange their energies. A constant frequency is therefore generated.

The RC network is a time-constant network and as such responds to the charge and discharge times of a capacitor. The frequency of this network is determined by the values of R and C. The capacitor and resistor cause phase shift and produce positive feedback at a particular frequency. Its advantage is the absence of inductances which can be difficult to tune.

For maximum stability a crystal is generally used. It resonates when a pressure is applied across its ends so that mechanical energy is changed to electrical energy. The crystal has a large Q factor and this means that it is highly selective and stable.

The amplifying device may be a bipolar transistor, a field-effect transistor (FET) or operational amplifier. This block is responsible for maintaining amplitude and frequency stability and the correct DC bias conditions must apply, as in any simple discrete amplifier, if the output frequency has to be undistorted. The feedback factor (β) is derived from the output voltage. It is as well to note at this point that the product of the feedback factor (β) and the open loop gain (A) is known as the loop gain. The term loop gain refers to the fact that the product of all the gains is taken as one travels around the loop from the amplifier input [6], through the amplifier and through the feedback path. It is useful in predicting the behavior of a feedback system.

Note that this is different from the closed-loop gain which is the ratio of the output voltage to the input voltage of an amplifier.

There are many types of oscillator but they can be classified into four main groups:

2.4.1 RC Oscillators

There are three functional types of RC oscillator used in communication applications, they are;

1. Phase-shift oscillators: this uses a bipolar junction transistor (BJT). Each of the RC networks in the feedback path can provide a maximum phase shift of almost 60°. Oscillation occurs at the output when the RC ladder network produces a 180° phase shift. Hence three RC networks are required, each providing 60° of phase shift. The output of the feedback network is shunted by the low input resistance of the transistor to provide voltage feedback.

   Where the frequency, $F = 1/2\pi CR\sqrt{6}$ - - - (2.3.1.1)

2. Wien Bridge Oscillator: The circuit uses a balanced bridge network as the frequency-determining network and frequency is given by

   $F = 1/2\pi RC$ - - - - - - - (2.3.1.2)

   The following points should be noted about this oscillator:

(i) R and C may have different values in the bridge circuit, but it is customary to make them equal.

(ii) This oscillator may be made variable by using variable resistors or capacitors.

(iii) If a BJT or FET is used then two stages must be used in cascade to provide the 360° phase shift between input and output.

(iv) The amplitude of the output waveform is dependent on how much the loop gain Aβ is greater than unity. If the loop gain is excessive, saturation occurs. In order to prevent this, the zener diode network should be connected

(v) The closed loop gain must be 3.

3. The twin-T oscillator: it is used in problems where a narrow band of noise frequencies of a single-frequency component has to be attenuated. It consists of a low-pass and high-pass filter, both of which have a sharp cut-off at the rejected frequency or narrow band of frequencies. This type of oscillator provides good frequency stability due to the notch filter effect. There are two feedback paths, the negative feedback path of the twin-T network and the positive feedback path caused by the voltage divider in the circuit. One of the T-networks is low-pass and the other is high pass

2.4.2 LC Oscillations

These oscillators have a greater operational range than RC oscillators which are generally stable up to 1 MHz. Also the very small values of R and C in RC oscillators become impractical. In this section we discuss Colpitts, Hartley, Clapp and Armstrong oscillators in turn.

1. Colpitts: This oscillator consists of a basic amplifier with an LC Feedback circuit; the oscillator uses a split capacitance configuration. The approximate frequency is given by $F = 1/(2\pi\sqrt{LC_T})$ - - - - - - (2.3.2.1)

   where C_T is the total capacitance (two capacitors are effectively in series). As $A\beta = 1$ (for oscillation) and $A = C_1/C_2$

2. Hartley Oscillator: this oscillator is very similar to the Colpitts except that is has a split inductance. It is represented in a similar way to the Colpitts. It may be designed using a similar approach to the Colpitts but it has the disadvantages of mutual inductance between the coils, which causes unpredictable frequencies, and also the inductance is more difficult to vary.

   $F = 1/(2\pi\sqrt{L_TC})$ - - - - - - (2.3.2.2)

   where $L_T = L_1 + L_2 + 2M$ (with both coils in series and M is the Mutual inductance).$\beta = (L_1 + M)/(L_2 + M)$ and $A > (L_2 + M)/(L_1 + M)$

3. The Clapp Oscillator: the modified Colpitts,

   $F = 1/(2\pi\sqrt{LC_T}$ - - - - - - (2.3.2.3)

   Also, $A = C_1/C_2$; But frequency can be controlled by a fourth Capacitor, C_4 and $C_T = (1/C_1) + (1/C_2) + (1/C_4)$.The Clapp oscillator can be used as a test oscillator in a telephone system using frequency division multiplexing.

4. The Armstrong Oscillator: this uses transformer coupling to feed back a portion of the output voltage. The frequency can be found from the expression $F = (1/2\pi\sqrt{L_1C_3})$ - - - - - - - (2.3.2.4)

This oscillator is used in high-frequency, long-distance communications because of its power-handling capabilities. However, because of the transformer size and cost, it is not common as the other oscillators discussed earlier.

2.4.3 Crystal Oscillators

These are amongst the most stable of all oscillators and are generally used in broadcasting and telecommunication systems where high stability is required [6]. The crystal is generally made from quartz, it uses the piezo-electric principle whereby the application of a voltage across its axis causes the crystal to change shape. This property is useful because the properties of quartz are very stable with temperature. Every crystal has a maximum rating which might lie between 20 and 250 mA, overloading a crystal may cause temperature increase and change in frequency (although the common cause of overloading is excessive feedback) and frequency is determined by the crystal cut.

2.5 MODULATION SYSTEMS

The requirements for modulation are threefold [6]. First, all channels must be separated from one another to avoid interference in the form of inter-modulation distortion and crosstalk. Crosstalk occurs when one channel spills over into an adjacent channel, causing interference. Inter-modulation distortion occurs when two signals at frequencies f_1 and f_2 are amplified by a non-linear device. Second-order products ($2f_1$, $f_1 + f_2$ and $f_1 - f_2$) are produced. In order to achieve good channel separation and avoid interference data, audio and video are generally superimposed on a carrier signal.

Second, the physical size of half-wavelength antenna systems would be prohibitive if higher frequencies were not used. However, the point here is that the antenna has an electrical length of half the operating wavelength and is referred to as a $\lambda/2$ dipole. Thirdly, transmitting information in raw form, normally known as the base-band, would be impractical due to the low energy content. Losses between transmission and reception would soon attenuate the signals, with a resultant loss in reception. Modulating the signal by analogue or digital methods increases the power to the information and gives a higher signal-to-noise ratio. In this chapter the following modulation techniques will be discussed;

2.5.1 Analogue Modulation Techniques

1. **Amplitude Modulation:** When the amplitude of a carrier signal is varied in accordance with the information signal, amplitude modulation is produced. This method is mainly used where large power output is required for long-distance communications. The general expression for the waveform is

$$v_c = V_c \text{ Sin } (\omega_c + \theta) \quad - \quad - \quad (2.4.1.1)$$

where v_c is the instantaneous carrier voltage and V_c is the peak amplitude; and ω_c is the frequency of the carrier in radians. θ is the phase of the carrier. The modulating signal is given by

$$v_m = V_m \text{ Sin } \omega_m t \quad - \quad - \quad (2.4.1.2)$$

The amplitude modulated wave is given by

$$v = (V_c + V_m \sin \omega_m t) \sin \omega_c t \quad - \quad - \quad (2.4.1.3)$$

2. **Frequency Modulation**

In 1935 Major Armstrong announced that he had developed a system of frequency modulation that not only was free from frequency distortion but had marked advantages in its high signal-to-noise ratio. That is, the system had been made relatively insensitive to outside disturbances such as static [1]. With frequency modulation, the frequency of constant amplitude, constant-frequency sinusoidal carrier is made to vary in proportion to the amplitude of the applied modulating signal, this shows that a modulating square or sine wave may be used for this type of modulation. The frequency of the frequency-modulated carrier remains constant and this indicates that the modulating process does not increase the power of the carrier wave. The instantaneous frequency varies as

$$\omega = \omega_c + kV_m \sin \omega_m t: (kV_m = \Delta\omega) \quad - \quad - \quad (2.4.1.4)$$

$$\text{and } \theta = \{ \omega_c t - (\Delta f/f_m) \cos \omega_m t\} \quad - \quad - \quad (2.4.1.5)$$

$$v = V_c \sin \{\omega_c t - (\Delta f/f_m) \cos \omega_m t\} \quad - \quad - \quad (2.4.1.6)$$

The modulating index is given by

$$\beta = \Delta f / f_m \quad . \quad . \quad . \quad . \quad (2.4.1.7)$$

Where Δf is the peak frequency shift and f_m is the modulating frequency, Therefore

$$v = V_c \sin \{\omega_c t - \beta \cos \omega_m t\} \quad - \quad - \quad (2.4.1.8)$$

FM DEMODULATORS: they perform the reverse operation to modulation in that it converts variations in frequency into variations in amplitude. The frequency-to-voltage transfer may be non-linear over the operating range, and several methods are used in practice, the two common types are:

i. The Phase-locked loop demodulator: This is the simplest type of demodulator and is frequently used in data communications systems. It consists of a phase comparator which has two input signals, one from the voltage controlled oscillator (f_2) and the other being the FM signal (f_1). The phase comparator compares the phase of the VCO with the incoming FM signal, giving an output proportional to the difference in phase. This is then filtered to remove unwanted high-frequency components and the output from the filter is used to control the frequency of the voltage-controlled oscillator (VCO), locking it to the incoming signal. Hence the VCO should be capable of tracking the incoming FM signal within the frequency deviation of the system. The output from the low pass filter, i.e. the error voltage, is used to obtain the demodulated output.

ii. The Ratio Detector: Receivers which use this circuit generally have a band-pass limiter as the previous stage. This improves the filtering before demodulation takes place as ratio detectors have a low-input Q factor which causes the input voltage to change.

2.5.2 DIGITAL MODULATION TECHNIQUES

2.5.2.1 Frequency Shift Keying

In some situations data can be transmitted directly without any modulation technique being necessary. This is applicable over short distances where the baseband signal may be sent in a raw form. However, where distance is involved more sophisticated methods are required. One of the modulation methods most frequently used is frequency shift keying (FSK).

In FSK the transmitted signal is switched between two frequencies every time there is a change in the level of the modulating data stream. The higher frequency may be used to represent a high level (1) and the lower frequency used for the low level (0).

Generally the frequencies used in FSK depend on the system application. Most modems traditionally use frequencies within the voice range (300–3400 Hz), while much higher frequencies would be used for satellite or radio relay systems.

2.5.2.2 Binary Phase Shift Keying (BPSK)

This is also the preferred modulation method for satellite and space technology. Unlike FSK, phase shift keying uses one carrier frequency which is modulated by the data stream. It is a modulation system in which only discrete phase states are allowed. Usually 2n phase states are used, and when n = 1 this gives two-phase changes. This is sometimes called binary phase shift keying (BPSK). When n = 2, four phase changes are produced, and this is called quadrature phase shift keying (QPSK).

BPSK- two-phase modulation method in which a carrier is transmitted to indicate a mark (1) or the phase is reversed (shifted through 180°) to indicate a space (0). A balanced modulator is used with the carrier applied. The digital input passes through a unipolar–bipolar convertor to ensure that the digital signal passed to the balanced modulator is unipolar.

2.5.2.3 Quadrature Phase Shift keying (QPSK)

This type of modulation method has wide application in high-speed data transmission systems. It has two distinct advantages: it produces twice as much data with the same number of phase changes as BPSK, and this also means that the bandwidth is virtually decreased for the same amount of data being transmitted

In quadrature phase shift keying each pair of consecutive data bits in a data stream is considered a two-bit code called a dibit. This is used to switch the carrier at the transmitter between one of four phases, instead of two as was the case with BPSK. The phases selected are 45°, 135°, 225° and 315°, lagging relative to the phase of the original un-modulated carrier [6].

NOTE: It is important that the concept behind this project is perceived in meaning from the above stated and proper correlation is made.

CHAPTER THREE

PROJECT DESIGN AND CONSTRUCTION

The Infrared audio system comprises of the following sub-systems:

i. IR Audio Transmitter

ii. IR Audio Receiver

3.1 IR AUDIO TRANSMITTER:-

The IR audio transmitter sub-system uses a CD 4046 PLL/VCO as an FM carrier generator that is frequency modulated by the audio signal to be transmitted. The VCO section of the PLL was frequency modulated by the audio signal. A RC network fixed the VCO's center frequency at about 100 kHz.

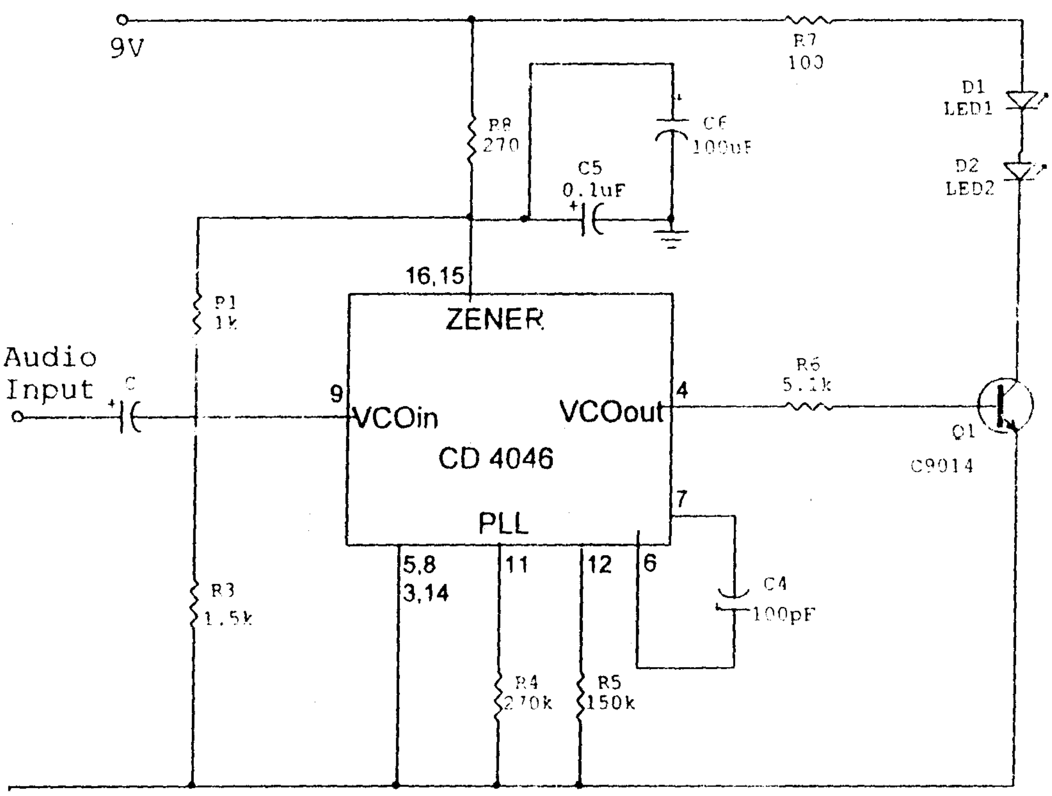

Figure 3.0 Transmitter Circuit

The PLL was powered by a 9V DC source. A 5V internal Zener diode was used to set the chips operating voltage. The 5V supply was stabilized by a 16V 220uF capacitor.

The two resistors biasing network biased the VCO control input at:

$$\frac{5 \times 1500}{2500} = 3V$$

Using Voltage Divider, i.e

$$\frac{R1 \times V}{(R1 + R2)} \qquad - \quad - \quad - \quad - \qquad (3.1.1)$$

The audio signal was superimposed in the control voltage: this caused the control voltage to vary in consonance with the audio signal, producing a frequency modulated output.

The square wave RF output was fed into the base emitter junction of a C9014 high frequency transistor

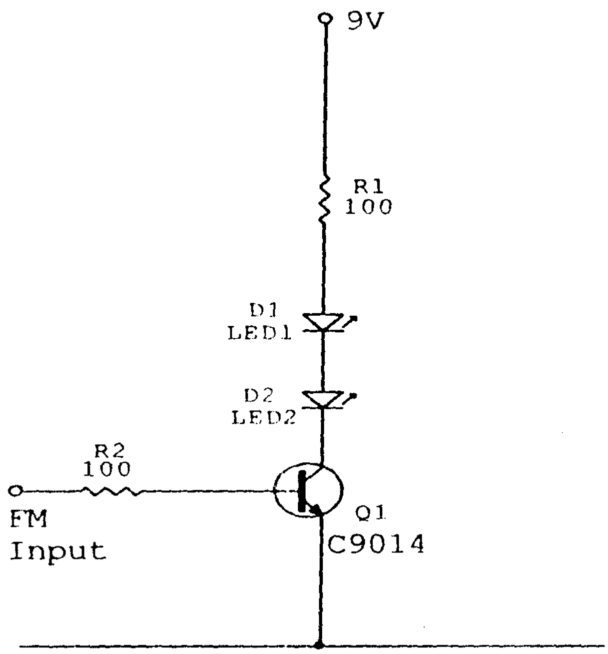

Fig 3.1 C9014 Transistor running at a high frequency

Two infrared emitters were used to radiate the generated FM wave. A current-limiting resistor of 100Ω was inserted in series with the emitters. The value of resistance was calculated for a diode peak current of 0.05A as shown below:

$$R_s = \frac{V_s - 2V_{led}}{I_{led}} \quad - \quad - \quad - \qquad (3.1.2)$$

Therefore, where the voltage in the LED = 2V

$$R_s = \frac{9 - 2(2)}{0.05} = 100\Omega$$

3.2 IR AUDIO RECEIVER:-

The audio receiver sub-system comprises three main blocks:

a. IR Pre-amplifier front-end

b. CD 4046 PLL FM detector

c. LM 386 audio power amplifier

3.2.1 Power Supply

The power supply for the receiver system was received from the 9v DC battery source. It was stabilized, decoupled and fed to the different sub-circuits as indicated in the fig below

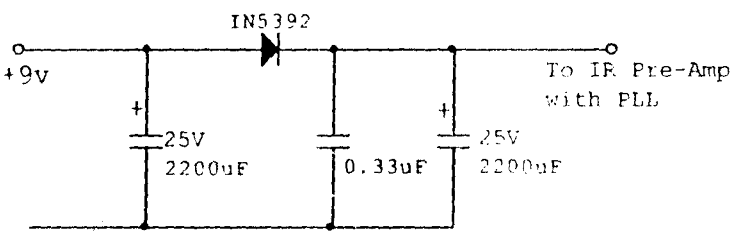

Fig 3.2 System Power Supply

A diode is used as the decoupling element on the power supply in place of the normal R-C elements because it has a higher apposition to signal flow through the power rail.

The 9V DC was stabilized by a 2200μF Capacitor and fed to the power amplifier section directly: a decoupled version of 8.3V (9V less $1V_f$) was supplied to the IR amplifier and PLL.

3.2.2 IR Amplifier

The IR amplifier front-end consists of an IR photodiode, an LM 358 dual operational amplifier and associated biasing gain-setting elements

3.2.3 Photodiode

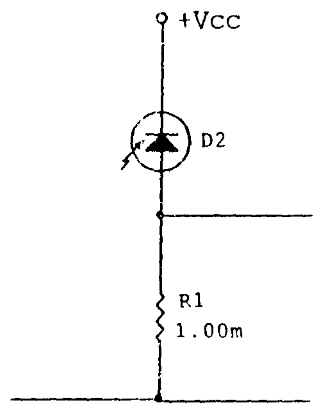

Fig 3.3 Photodiode connection

The photodiode was operated reversed biased as shown in fig 3.3. Its Cathode was connected to $+V_{cc}$ and its anode to ground through a 1MΩ resistance across which the output voltage was taken. The output voltage across the resistor is given by:

$V_R = IR$: $R = 1M\Omega$

I = Excitation Current through the diode.

Typically sensitivity of the order of 1μA for 1nw of incident light, the excitation current of the photodiode develops a voltage, V across the 1mΩ resistance. This voltage is amplified by a two-stage amplifier designed around the LM 358

3.2.4 The Pre-Amplifier

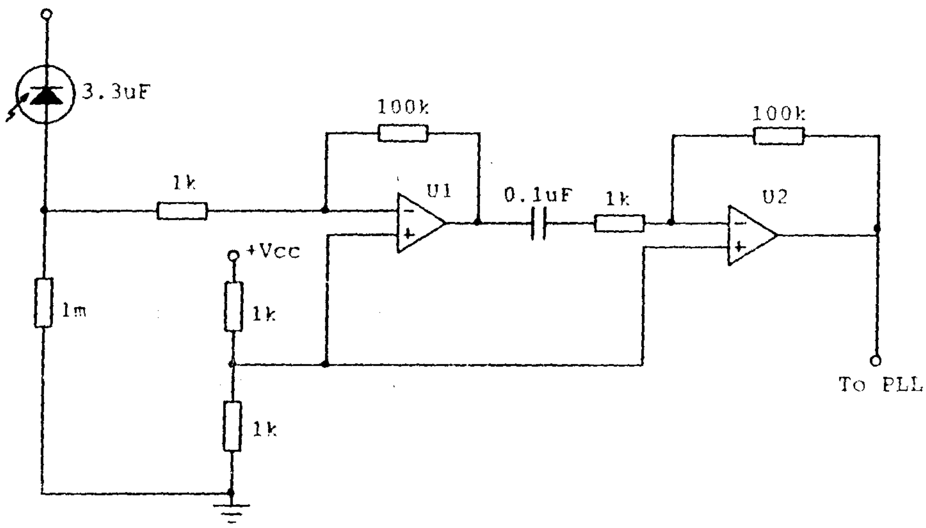

Fig 3.4 LM 358 –based IR audio amplifier

An LM 358 dual operational amplifier was configured as a two-stage non-inverting amplifier to amplify the microvolt of a signal across the 1MΩ resistance. Amplifier U1 has a gain given by (R_f/R_i) [7]: R_f was made 100kΩ and R_i = 1MΩ (for better noise performance and rejection). The gain was thus 100. The second stage of amplification also yielded 100, providing a total system gain of 10, 000.

3.2.5 Amplifier Biasing

Most Op-Amps are designed for operation on dual power supply. In single supply applications it is necessary to have a biasing arrangement that keeps quiescent output DC voltage centered on 0.5V (or some other desirable value). If the amplifier is intended for amplifying DC voltages, the biasing arrangement is not so often needed.

The amplifiers were biased by two 1kΩ resistance connected as shown below;

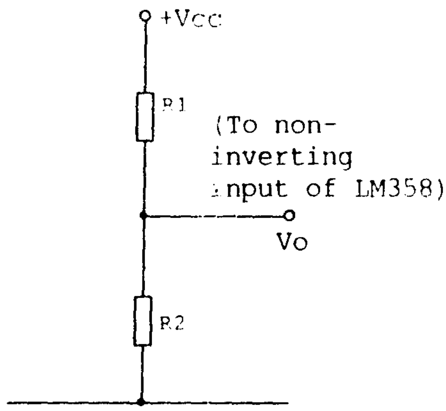

Fig 3.5 Biasing network for IR amplifier

The quiescent DC output voltage was fixed at 0.5Vcc, thus equal resistances were used on either side of the potential divider. The output voltage of the divider is given by:

$$V_o = \frac{Vcc \times R_2}{R_1 + R_2} \quad - \quad - \quad (3.2.5.1)$$

Since $V_o = 0.5Vcc$

$$0.5Vcc = \frac{Vcc \times R_2}{R_1 + R_2} \quad - \quad - \quad (3.2.5.2)$$

$$0.5Vcc\,(R_1 + R_2) = VccR_2$$

$$\frac{Vcc}{0.5Vcc} = \frac{R_1 + R_2}{R_2}$$

$$2 = \frac{R_1 + R_2}{R_2}$$

$$2R_2 = R_1 + R_2$$

$$\text{Therefore: } R_2 = R_1 \qquad - \qquad - \qquad (3.2.5.4)$$

A value of 1kΩ was chosen for R_1 and R_2 respectively to present minimal loading on the supply and also made low enough to supply the required DC operating current for the LM 358.

The amplified received FM audio signal was fed into the input of a CD4046 PLL/VCO where it was frequency demodulated to yield the original audio signal before amplification and reproduction over the headphones.

3.2.6 PLL FM Detector

An FM detector is required to produce an output voltage that is directly proportional to the instantaneous frequency of its input signal. A PLL detector was used in recovering the audio signal. The block schematic diagram of a PLL FM detector is shown in Fig 3.6. The free-running frequency, F_0 of the VCO is set to be equal to the not modulated carrier frequency, F_c of the signal to be demodulated. The analogue phase detector generates an output voltage that is directly proportional to the phase difference, or phase error, between the FM signal and the VCO voltage. This error voltage is passed through a low-pass filter and then amplified to produce both the output voltage and a control voltage for the VCO. The free-running frequency of the VCO is varied by the voltage applied to its control terminal. The polarity of the control voltage is always such that it varies with the frequency of the VCO in the direction that reduces the difference frequency, $\alpha F = F_c - F_0$ and hence reduces the phase error.

Assume that initially, the input signal is not modulated. The action of the PLL reduces the difference between the input carrier frequency, F_c and the F_0 of the VCO. Once the VCO frequency has moved very close to the carrier frequency, the loop attains lock. Then the VCO rapidly attains the same frequency as the input signal but there is always a difference between the two voltages. This phase error must always exist to maintain the VCO control voltage at the required value. This voltage, and hence the output voltage is a DC voltage.

When the input signal is frequency modulated a similar action takes place. As the input signal frequency deviates from the un-modulated carrier frequency, the error voltage also varies to ensure that the VCO tracks to minimize the phase error. As a result, the instantaneous frequency of the VCO is always approximately equal to the frequency or the incoming signal. The output of the LPF is the detected modulated signal voltage. The filter must have a cut-off frequency equal to the maximum modulating frequency, $F_{m\,(max)}$ of the FM signal to minimize noise and interference.

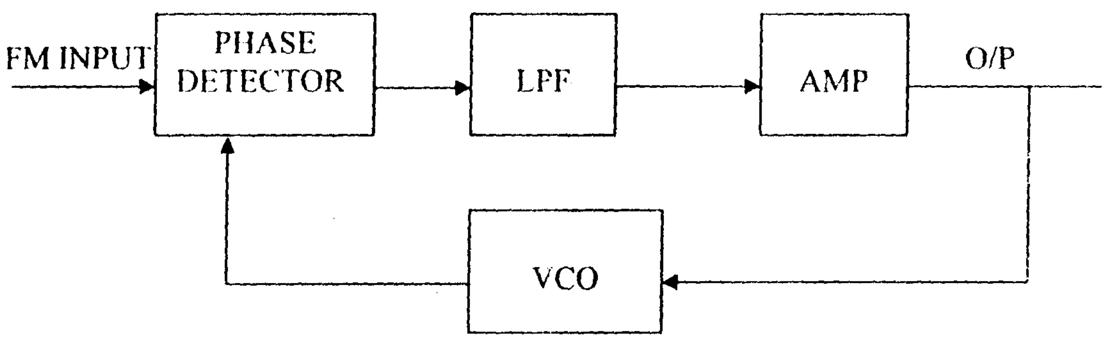

Fig 3.6 Block Diagram of a PLL FM Detector

3.2.7 ANALYSIS

When the loop is in lock. the frequency of the VCO is equal to the carrier frequency. The FM input signal is:

$$V_s = V_s \,\text{Sin}\left[W_c t + 2\pi k f_d \int V_m(t)\,dt\right] \quad - \quad - \quad - \quad - \qquad (3.2.7.1)$$

$$= V_s \,\text{Sin}\left[W_c t + K_s \int V_m(t)\,dt\right] = Vs \,\text{Sin}\left[W_c t + \theta_1(t)\right]$$

The output voltage of the VCO is:

$$V_c = V_o \,\text{Cos}\left[\, W_c t + \theta_2(t)\,\right] \quad - \quad - \quad - \quad - \quad - \qquad (3.2.7.2)$$

The two signals are the inputs to the phase detector which generates an output voltage. V_d that is directly proportional to their product.

Thus,

$$V_d = (\,K_d\, V_s V_o)\,\text{Sin}\left[W_c t + \theta_1(t)\right]\text{Cos}\left[\,W_c t + \theta_2(t)\,\right]$$

$$= (\,K_d\, V_s V_o/2)\,\text{Sin}\left[\theta_1(t) - \theta_2(t)\right] + \text{Sin}\left[\,2W_c\pi\,\theta_1(t) + \theta_2(t)\,\right] - \qquad (3.2.7.3)$$

Hence K_d is the gain factor in V rad^{-1} of the phase detector. The LPF will only transmit the lower frequency component of V_d so that the voltage appearing at the output of the circuit is:

$$V_d = (\,K_d\, V_s V_o/2)\,\text{Sin}\left[\theta_1(t) - \theta_2(t)\right]$$

Since the loop is locked, the phase error will be small and:

$$\text{Sin}\left[\theta_1(t) - \theta_2(t)\right] \approx \theta_1(t) - \theta_2(t), \text{ giving}$$

$$V_d = (\,K_d\, A_s V_s V_o/2)\left[\theta_1(t) - \theta_2(t)\right] \quad - \quad - \quad - \quad - \qquad (3.2.7.4)$$

The instantaneous angular velocity W'_o of the VCO output voltage is:

$$W'_o = W_o + K_o V_o(t) \qquad (3.2.7.5)$$

Where W_o, is the free-running angular velocity and K_o is the conversion gain of the VCO in rad s^{-1} v^{-1}. The conversion gain correlates the frequency of the VCO to its control voltage and is expressed in rad s^{-1} v^{-1} or in $KHzv^{-1}$.

Since $w = d\theta/dt$, $d\theta_2/dt = K_o V_o(t)$; also

$d\theta_1 / dt = K_s V_m(t)$

Equation (1) can be written as

$$V_o(t) = (K_d A_v V_s V_o/2)\left[\theta_1(t) - K_o \int V_o(t)\,dt\right] \qquad (3.2.7.6)$$

And differentiating with respect to time

$$dV_o(t)/dt = (K_d A_v V_s V_o/2)\left[d\theta_1(t)/dt - K_o V_o(t)\right] \qquad (3.2.7.7)$$

or

$$d\theta_1(t)/dt = \left[(2\,dV_o(t)/dt) / (K_d A_v V_s V_o)dt + K_o V_o(t)\right]$$

$$\approx K_o V_o(t) \qquad (3.2.7.8)$$

Therefore,

$K_s V_m(t) = K_o V_o(t)$, or

$$V_o(t) = K_s V_m(t) / K_o . \qquad (3.2.7.9)$$

The ratio K_s/K_o has dimensions of kHz kHz^{-1} v^{-1} or v so the output of the detector is the wanted modulating voltage $V_m(t)$

The CD4046 PLL was configured as shown below

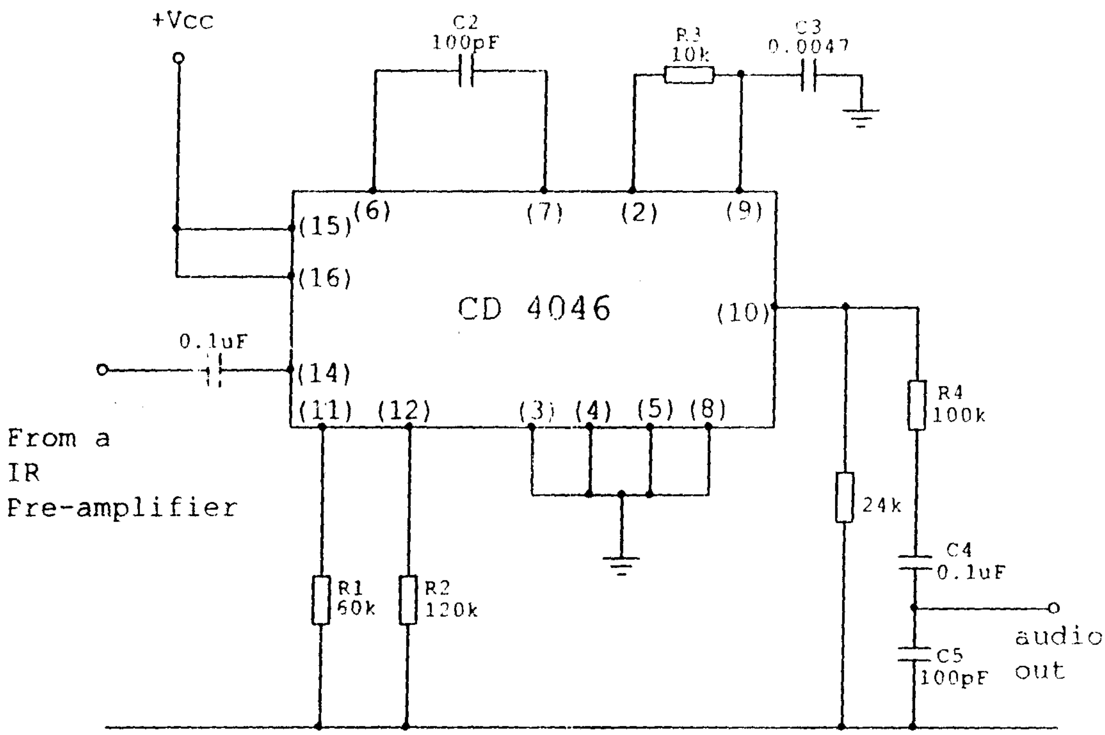

Fig 3.7 CD 4046 PLL configuration

C_1 is a DC-blocking capacitor for coupling the AC signal from the pre-amp into the demodulator. C_2 connected across pins 6 and 7 set the free-running frequency of the VCO. R_1 and R_2 also comprise the frequency determining network.

The frequency-modulated IR signal is fed into the PLL via pin 14 into the phase comparators (there are two comparators in the PLL)- The type1 comparator is used. Pin 9 is the VCO control voltage input and Pin 10, the VCO output (the recovered audio signal).

The recovered audio signal is fed via a 100kΩ variable resistance (volume control) into a single channel LM386 low power audio amplifier. The LM386 drives a stereo handset with the radiators wired in parallel.

3.2.8 Audio Power Amplifier

An LM 386 audio IC was used for the audio section. The LM 386 audio IC has an internally fixed gain of 20, expandable to 200 by connecting an R-C combination between Pins 1 and 8.

The LM 386 has inputs that are ground-referenced, with the output voltage centered on 0.5Vcc. The quiescent power drain is only 24mW on a supply voltage of 6v, making it ideal for battery operation.

The pin-out of the device is shown below:

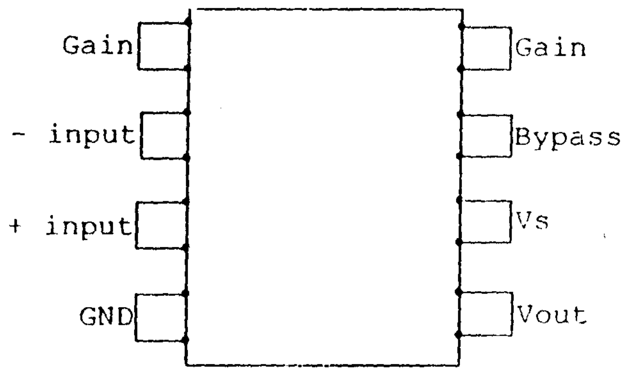

Fig 3.8 LM 386 Pin-Out

The amplifier was configured for the minimum gain of 20 according to the configuration shown in the diagram below

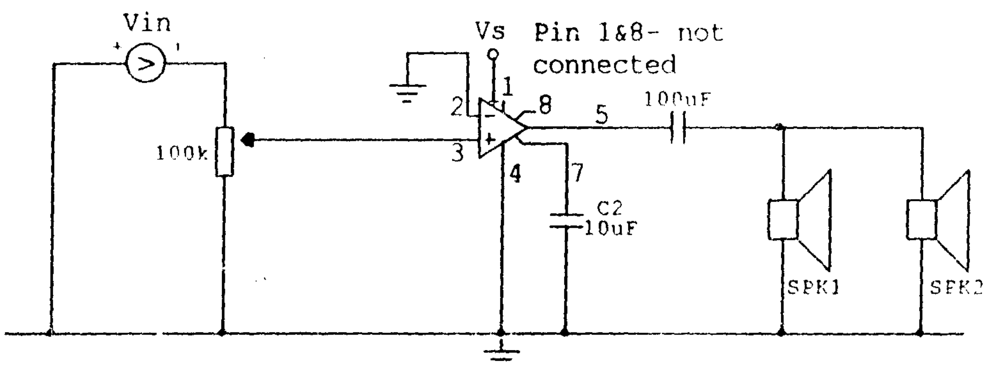

Fig 3.9LM 386 Audio Amplifier

CHAPTER FOUR

CONSTRUCTION, TESTING AND RESULT

4.1 CONSTRUCTION

The soldering of the circuits and coupling of the entire project to the casing was completed. The transmitter was soldered followed by the receiver, soldering was done on the Vero-board after testing the working on a breadboard.

Project coupled in a plastic/wooden casing and proper ventilation was ensured to guard against overheating. The position for the RF was perforated for audibility and clarity of sound.

Inter connection was made through earthen of the v-board and the use of insulated copper wire connected at the bottom of the v-board. While the components were mounted on the top of the v-board and then soldered underneath, thus giving the component good layout and space to give proper chances for trouble-shooting and subsequent replacement of faulty components. Long legs of transistors and resistors were reduced to prevent short circuiting.

Bench power supply, oscilloscope: (to observe the ripples wave and frequencies form of the power supply and oscilloscope was used). Digital multi-meter (used for measurement of quantities such as voltage, resistance, current and continuity measurement)

4.2 RESULTS OBTAINED

The table below shows the results obtained as the device was tested.

TABLE 4.0 Table of Results

TEST (DIST.)	OBSERVATION AND RESULT
0.5m distance of transmission	Sound too low, since the distance between is too close and hence did not help amplification
1m distance of transmission	Sound improved but is low
2m distance of transmission	Sound is clearer and louder but with static
4m distance of transmission	Sound is heard with a lot more static
6m distance of transmission	Static and noise disturbance are heard as audio is still diminishing
10m distance of transmission	Audio signal is completely taken over by static and noise

4.3 LIMITATIONS

Unable to achieve a longer range of infrared emission due to:

- Interference
- Electromagnetic interference(EMI)
- Improper oscillation of the PLL (CD 4046)

- Cross coupling between circuit components

4.4 DISCUSSION

The ranging (suppose to be for 10m) and quality of sound was forfeited but could be improve by Pulsing more current through the Light Emitting Diodes i.e Higher LED current , the greater the infrared emission.

Also, it is advised that for the use of a Phase locked loop (PLL), a higher grade is used For instance, the 74HC4046 PLL/VCO for better oscillation and hence better performance of the device.

The working of the device was successful as it showed achievements behind FM modulation and the use of the electrical components to establish a link from a source to a destination of audio signals.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

The Wireless audio linking system is a frequency modulated scheme hence, the received signal strength at the receiver is an inverse of the distance separating the receiver and the transmitter. This greater distance can be covered if two or more photodiodes are used or better photo transistor.

Problems faced: precise and exact values for components were not gotten so preferred values were used instead hence causing drifts in signal strength.

Components like the CD4046 PLL/VCO are hard to find and substitution affected the noise to signal ratio

5.2 RECOMMENDATIONS

- Additional Photodiode to the receiver to create higher distance range and good output reception.
- More LEDs in a circular array to the transmitter to enhance transmission at various direction and lines of sight
- Pulsing more current through the Light Emitting Diodes i.e Higher LED current, the greater the infrared emission.
- The use of a more effective IC i.e CD4046 for better oscillation

REFERENCES

[1] Microsoft Encarta Encyclopedia 2007 Edition

[2] www.electrophysics.com/A bit of history about infrared

[3] www.FLIRsystems.com/Why use infrared

[4] www.wikipedia.com/Infrared/

[5] Ron Mancini, Op Amps for Everyone- Texas instruments incorporated, 2002. pg 94

[6] Andrew Leven, Telecommunication Circuits & Technology- First published 225 Wildwood Avenue, Woburn, 2000. pg 3,4,24,50,73

[7] Paul Horowitz & Winfield Hill, The Art of Electronics, 2nd Edition- Cambridge University Press 1980.pg 232

[8] www.medindia.com/Consumer health/health information/ultra-violet radiation/

[9] www.google.com /Patent search/infrared audio transmitter system/

[10] www.freepatentsonline.com/20070155313.html/

[11] Charles A. Schuler, Electronics Principles and Applications- the McGraw-Hill companies, Inc 1999

APPENDIX

PRICING/ BILLING FOR ENGINEERING COMPONENTS

The tabular illustration below shows the financial clause to the project manufactured.

S/No	Description	Quantity	Unit price,₦	Total Amt,₦
1.	Resistors	32	20	640
2.	Capacitors	12	20	240
3.	CD4046 PLL	2	400	800
4.	IN 5392	1	30	30
5.	Amplifier-LM 358	1	250	250
6.	Light Emitting Diodes	2	20	40
7.	Audio jack	1	50	50
8.	Transistors	2	60	120
9.	Battery	2	90	180
10	Photodiode	1	220	220
11	Vero board	2	100	200
12	Headphones	1	200	200
	TOTAL	59	1460	2970

MANUAL OF OPERATION

(Wireless Audio Link)

- Connect a DC 9v battery to the transmitting end of the device to power the PLL CD4046 and the light emitting diodes. The sound to be transmitted is secured to using the RF audio-in cable
- At the receiver, a 9v is connected to power the PLL CD 4046 and the speaker/earphones affixed to receive the audio coming from the transmitter
- Place the transmitter and receiver in the same line of sight i.e. Photodiode facing the Light emitting diode
- The switch is toggled on the transmitter and sound is conveyed from one point to the other