60Hz to 16kHz AUDIO GRAPHIC EQUALIZER DESIGN, CONSTRUCTION AND TEST

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Project submitted in Partial Fulfillment of the Requirements
For the Award of the Degree of Bachelor of Engineering in
Electrical and Computer Engineering.

March, 2000

CERTIFICATION

This is to certify that this project titled "Design and Construction of a 60Hz to 16kHz Audio Graphic Equalizer" was carried out by Amba Anwana under the supervision of Mr. P. Attah and submitted to Electrical and Computer Engineering Department, Federal University of Technology, Minna in partial fulfillment of the requirements for the award of Bachelor of Engineering (B. ENG.) degree in Electrical and Computer Engineering.

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DEDICATION

This project is dedicated to my parents, Dr. and Dr. (Mrs) E. A. Amba; and my brother and sisters, Ikpeme, Eme, Ekanem and Keteh.

ACKNOWLEDGMENTS

I give God all the glory for His countless blessings on my life. He has been by my side, through thick and thin, may His name be praised for all eternity.

I am thankful to my Lord and Saviour Jesus Christ, for he has set me free, giving me, life, and life more abundantly.

I cherish the in-dwelling presence of the Holy Spirit, my Teacher, Comforter, Counselor and Guide.

To my parents, who have supported me in every ramification, I am filled with gratitude and appreciation. May God highly reward you in all your endeavours.

To my brother and sisters, thank you for being there.

I am highly grateful to my project supervisor, Mr. Paul Attah, for his guidance and motivation during the period of undertaking this project. I appreciate his knowledge and experience which was of immense benefit to me.

A big thank you to my good friend and colleague, Mark Adzege, sharing facts and working together as a team on this project topic was a lot of fun.

I appreciate the professional expertise of Engr. Abanyam of the Benue Cement Company (BCC) Plc., Gboko, which was of great assistance.

To all the present and past Lecturers and Staff of the Electrical & Computer Engineering Department, FUT, Minna, especially Engr. (Dr.) Y. A. Adediran , Mr. Danjuma, Prof. S. Ajose, Mr Kolo, Engr. Aduloju, Mal. S. Ahmed, Engr. Raji (Shiroro Power Station), Mr. Raji, Mal. Adamu and Mr. Audu. I am full of gratitude for the time and energy you have spent imparting knowledge, imbibing technical skills and sharing with us valuable experience acquired over the years. You have all highly contributed to national development by moulding credible engineers, thereby putting this country on the path of technological advancement.

I remain highly appreciative & indebted to Professor Adefolalu , Dr (Miss) A. Okhimame, Dr. Usman and Dr. Sadauki of the Geography Department, FUT Minna, who have been of tremendous help to me on this campus from the onset.

Cheers to all the men in the house; Mark-1, Mike Kwaplong, Steve Ogirima, Gerald Fumbial, Arch. Abiodun Fasasi, Peter "Don Pedro" Olom, Cax, Bertram "Mac 10" Madu, Yonenge Patrick, James Longkwang, Dase, Tunde "TQ" & Chidi; and Wale, Michael and Sola of Christ Embassy.

TABLE OF CONTENTS

CHAPTER 1

GENERAL INTRODUCTION

1.1 Introduction

The McGraw Hill Dictionary of Scientific and Technical Terms defines an *equalizer* as "a network designed to compensate for an undesired amplitude-frequency or phase-frequency response of a system or component." It also defines equalization as "the effect of all frequency-discriminating means employed in transmitting, recording, or other signal-handling systems to obtain a desired overall frequency response." In essence, equalizers are used to shape the gain versus frequency spectrum of a given signal.

An audio graphic equalizer is an electronic control circuit that compensates by means of circuitry, for the manufacturer's alterations in frequency characteristics on discs or tapes used in sound recording and reproduction systems. Its tone controls serve the useful purpose of compensating for other frequency-response deficiencies such as highly sound-absorptive listening rooms and also, of course to satisfy personal preferences. For example, the dynamic spectrum equalizer boosts low frequencies at low level and the 2 to 8kHz range at high level to make typical home listening more like a concert hall.

A familiar application of gain equalizers occurs in the recording and reproduction of music on phonograph records. It alleviates the problem of high frequency background-hiss noise associated with the recording of sound by a method known as preemphasis. It is a means whereby the amplitude of the high frequency signal is increased. Another problem associated with phonograph recording is that, for normal levels of sound, the low frequencies require impractically wide excursions in the record grooves. These excursions can be reduced by attenuating the low frequency band with an equalizer. In the playback system which consists of a turntable and equalizer, the high frequencies must be deemphasized and the low frequencies boosted. After this equalization, the reproduced sound possesses the same frequency as that of the original source generated in the recording studio. To allow for different recording schemes, some high quality phonograph amplifiers are equipped with variable shape equalizers.

The frequency range for the audio graphic equalizer designed here, is between 60Hz to 16kHz, which falls well within the audible frequency range that lies roughly between 20Hz to 20kHz. It is thus used to modify strictly the amplitude-frequency response characteristics of audio signals as the human ear is insensitive to phase variations. It can be adjusted at various frequency bands to give a "flat" or linear response (i.e. all frequencies reproduced equally), for speech waves that are affected inadvertently by electronic circuit performance deficiencies or limitations. Furthermore, it will compensate for the tendency of magnetic tape or discs, used in high fidelity[1] equipment, to be more sensitive to one range of frequencies, by electronic modification of their respective audio output signals.

1.2 Aims and Objectives

The main aim of this project is to design and construct a low cost, wideband audio graphic equalizer. The system is to function as a stand-alone unit with audio input and output terminals respectively.

To realize this goal, the following objectives have to form the basis of the system design and development:

(i) The amplitude-frequency response of the audio signal at various frequency bands between 60Hz to16kHz, should be capable of adjustment, i.e. deemphasis and preemphasis for high frequencies, as well as attenuation and boost for low frequencies; in order to achieve the desired sound effect.

(ii) The acquired and reproduced sounds must possess high quality and fidelity.

(iii) It should be easy to set up, reliable, and should require minimum maintenance.

(iv) It should be relatively inexpensive.

[1] High fidelity, commonly called "hi-fi", may be defined as sound reproduction that is faithful to the original sound or to the master recording that serves as a primary source.

This project will in no small way, enhance the sound quality, and thus, the listening pleasure that people derive from their high fidelity stereo equipment.

1.3 Methodology

The basic network employed in the systematic design of an audio graphic equalizer is an *electric filter.* Essentially, an electric filter is a network that transforms an input signal in some specified way into a desired output signal. Although many applications exist where filter requirements are set in terms of time domain specifications, the majority of filters are designed to specify certain frequency-domain criteria. Hence, a filter can be described as a network used to shape the frequency spectrum of an electrical signal; of which the most common objective is to pass certain frequencies while rejecting others.

A basis for classification of filters considered here, is that of their respective components. *Passive filters* consist of combinations of resistors, capacitors, and inductors. Passive RLC structures are capable of achieving relatively good filter characteristics in applications ranging from the audio frequency range to the upper limit of the lumped parameter range. However, at the lower end of the audio frequency range, the inductance values increase as the required frequency decreases, creating several problems. First, inductors are somewhat imperfect devices due to internal losses, but these losses increase markedly in the very large inductance range required at lower frequencies. These heavy losses degrade significantly the quality factor (Q) for each coil, and the associated filter responses have large deviations from their desired forms. Second, the actual physical sizes of the large inductance values limit their usefulness. Third, the cost of such inductors are certainly not trivial considerations.

Active filters consist of combinations of resistors, capacitors, and one or more active devices such as operational amplifiers (for low frequency applications), or operational transconductance amplifiers (for high frequency applications), with both amplifier types employing feedback. They are theoretically capable of achieving the same responses as passive RLC filters with the difficulties associated with them at low frequencies eliminated as inductors are not required. Hence, active filter frequency response characteristics can be made to approach ideal forms very closely. The devices used in active RC filters can all be integrated, thus providing the following advantages:

(i) A reduction in size and weight.

(ii) Increased circuit reliability, because all the processing steps can be automated.

(iii) In large quantities the cost of an integrated circuit can be much lower than its equivalent passive counterpart.

(iv) Improvement in performance because high quality components can be realized readily.

(v) A reduction in the parasitics, because of the smaller size.

Other advantages of active RC realizations that are independent of the physical implementation are:

(i) The design process is simpler than that for passive filters.

(ii) Active filters can realize a wider class of functions.

(iii) Active realizations can provide voltage gains; in contrast, passive filters often exhibit a significant voltage loss.

While active filters are capable of circumventing most of the low frequency limitations of passive filters, they introduce a few disadvantages of their own:

(i) Since they are active, power is required to make them operate properly.

(ii) The sensitivity[2] of passive realizations, thus making active components generally less reliable than passive circuits.

(iii) Active filters employ feedback and there is always a possibility of instability.

(iv) The finite bandwidth of the active devices places a limit on the highest attainable pole frequency. This high frequency limitation bars the use of active filters much above 30kHz unlike passive filters that can be used up to approximately 500MHz.

The economic and performance advantages of active RC realizations far outweigh the above-mentioned disadvantages and the modern engineering trend is to use active filters in most voice and data communications systems which represent a large

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[2] Sensitivity is the measure of deviation of the filter response due to variations in the elements, caused by environmental changes.

percentage of all filter applications. Thus, in this project design, active RC filters are being used.

A classification scheme that applies to both passive and active filters is in terms of the amplitude-response. Most filters can be classified as *low-pass*, *high-pass*, *band-pass* or *band-rejection*. In this project, band-pass active filters are being employed. The band-pass amplitude response is shown in Figure 1-1. Band-pass filters pass frequencies with very little attenuation, while rejecting frequencies on either side of this band. Figure 1-2

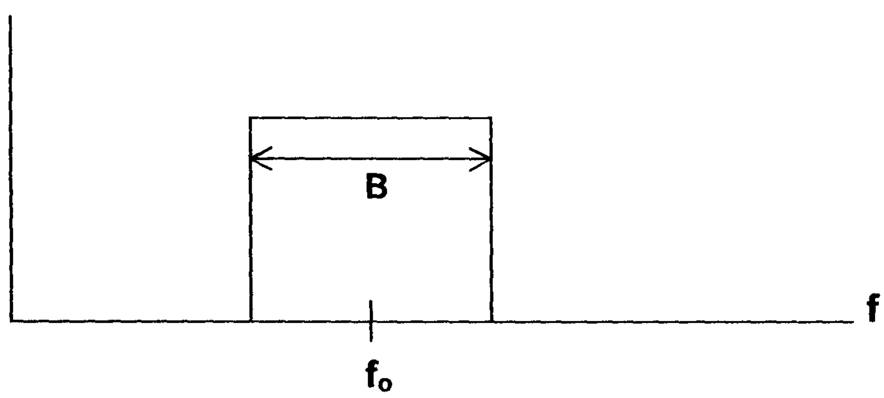

Figure 1-1 Ideal block form of the amplitude response for band-pass filters

shows a typical band-pass requirement. The pass-band from ω_1 to ω_2 has a maximum attenuation of A_{max} dB; the two stop-bands from dc to ω_3 and ω_4 to ∞ have a minimum attenuation of A_{min} dB.

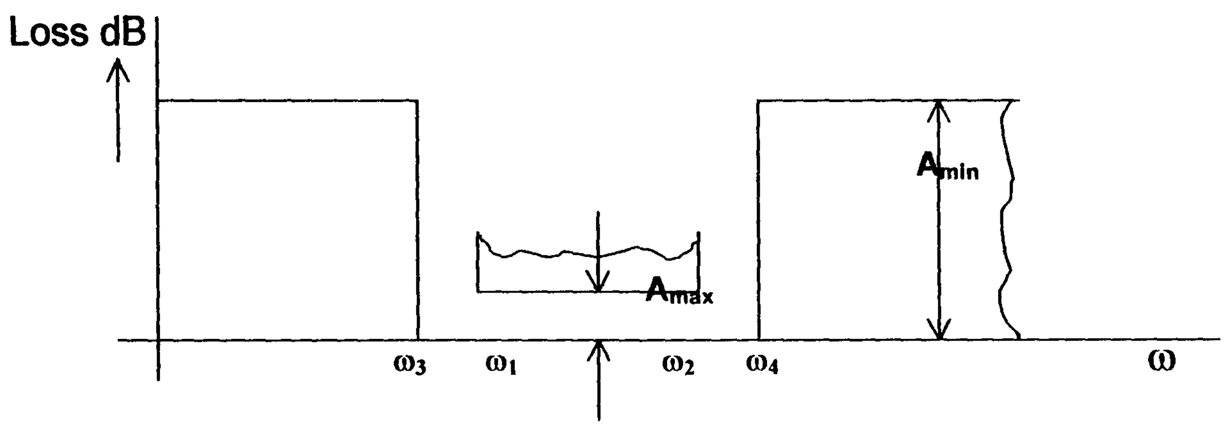

Figure 1-2 Typical band-pass requirements

A common parameter used in specifying filters is the *order* of the filter. In Laplace transform terminology, the term order is synonymous with the number of *poles*. The order or number of poles will be the number of non redundant reactive elements in the circuit. Both inductors and capacitors are reactive elements in the circuit but since active filters contain no inductors; the order or number of poles will be the number of *non-redundant capacitors*. (This does not include capacitors external to the filter network, such as power supply bypass capacitors, op amp compensating capacitors and so on).

For a given filter type, the performance generally becomes closer to the ideal block characteristic as the number of poles increases. Thus, a higher order filter will have a flatter pass-band response and a lower stop-band response (more attenuation) as compared with one of lower order. However, the ideal block characteristic can never be attained.

The band-pass active filters that are being utilized in this project design are the two-pole forms; and are significantly superior to passive forms for low frequency applications.

The two-pole forms are mathematically equivalent to certain configurations involving series or parallel RLC resonant circuits. Hence, active RC circuits can perform operations equivalent to passive RLC circuits, for example, parallel resonance. Resonance is important in circuits designed to emphasize one single frequency over all others. And this is applicable in the aspect of audio signal equalization.

Basically, the specified frequency range for the equalizer considered here, being 60Hz to 16kHz, is divided into four bands; and therefore, four two-pole band-pass active RC filters are used. Their respective amplitude responses overlap, as the shape of the gain versus frequency spectrum of a typical gain equalizer is not characterized by rejected bands within its frequency range. Hence, we have an *equalization curve*, where various bands within that range can have their gain versus frequency shape modified.

In addition , each of the four filter networks in the equalizer circuitry has a tuning circuit at the output, consisting of resistors and a potentiometer for gain enhancement/adjustment. This enables manual adjustment of the gain at various

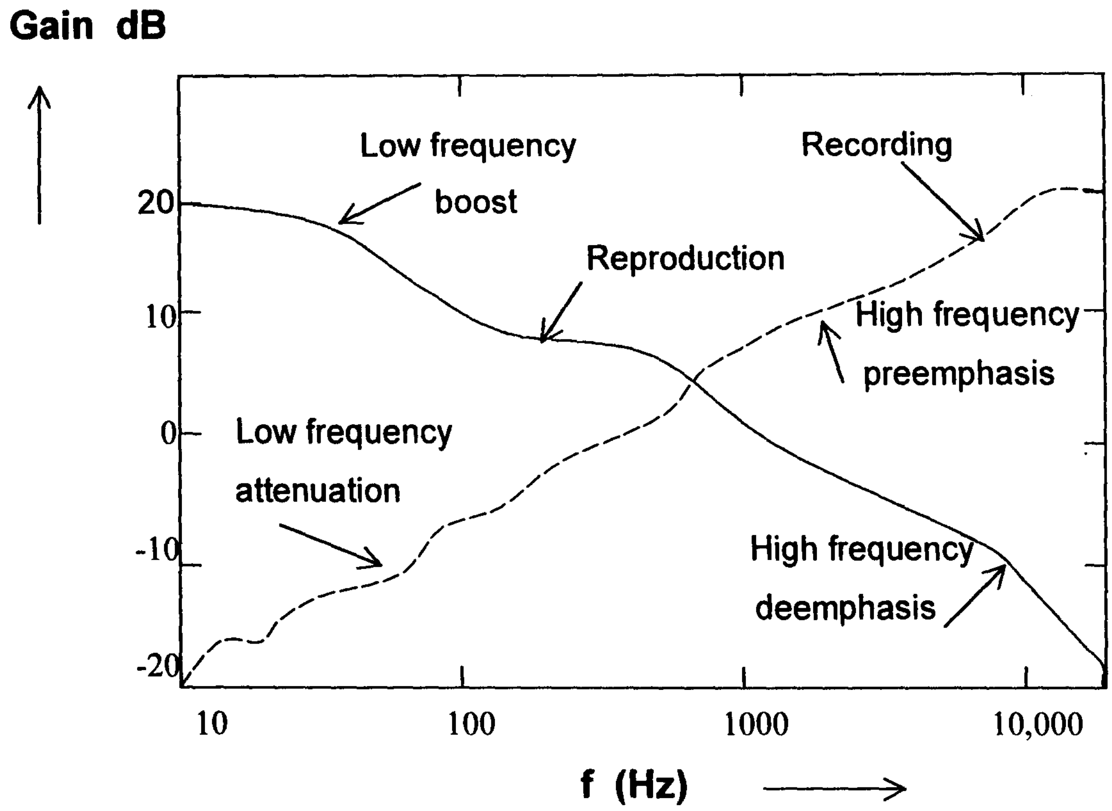

Figure 1-3 Equalization curves for phonograph recording and playback

frequency bands. Implying that, the Q of the circuit can be adjusted independent of the geometric center frequency, f_o from the knowledge of the active filter as a negative impedance converter.

1.4 Literature Review

The early forms of sound recording were considered miraculously lifelike. This was true from the first successful recording –Thomas Edison's recitation of *Mary had a Little Lamb*, inscribed on a tin foil cylinder in 1877. In time, it became clear that a more faithful reproduction would increase the usefulness and impact of sound.

Little progress was made in efforts to attain high fidelity in sound reproduction until the introduction of electrical recording in 1925. Amplification of the electrical signal at all stages was the key to a vast new expansion of recording. The electrical home reproducer was introduced to playback the electrically made recordings, and the new sound was recognized as the beginning of an era.

Sporadic advances was made in the 1930's but the general technical level of the reproduced sound was held back by the limitations of the phonograph and the shellac disc.

After World War II, sound reproduction developed rapidly. The development of high fidelity home systems involved many forms, with three basic elements. These include the signal source or *input*, e.g. record player, tape deck, and radio; the *preamplifier* and *power amplifier*, which process the electrical signal; and the loudspeaker system, which converts the final electrical product into actual sound waves. Most weak input signals were built to a standard level by the preamplifier before enlargement by the power-amplifier. Processing and mixing of the signals took place in the preamplifier stage. Specific circuitry was incorporated into the preamplifier to provide for *fixed equalizations* compensating for the differing emphases on lower and higher frequencies provided by different program sources. However, tone controls were provided for further adjustments.

The introduction of transistors and other solid-state devices into sound equipment during the 1960's began a revolution affecting the design of all types of sound reproduction equipment. And by the 1970's, the audio graphic equalizer became an integral part of the home hi-fi system.

Nevertheless, minimum standards have been drawn up for the construction and performance of hi-fi equipment. The internationally agreed standard of performance for disc recording and replay equalization characteristics is the RIAA (Record Industry Association of America) standard. Tape equalization standard are either the CCIR (International Radio Consultative Committee) standard or that determined by the NARTB (also called NAB; the National Association of Radio and Television Broadcasters in the U.S.). RIAA equalization increases the playing time of records and reduces the high frequency noise levels emanating from them. Tape equalization also serves to reduce noise.

1.5 Project Outline

The systematic design and development for the equalizer is treated in chapter two. The transfer function synthesis, and frequency response analysis for each biquad[3] of the cascaded filter network, as well as other related parameters employed in the equalizer design are also treated in detail.

Chapter three deals with the design concept implementation, i.e. construction; test, and results.

In chapter four, drawn up conclusions, recommendations for further work, as well as references are presented.

[3] Biquad – the basic circuit block that is cascaded to realize a general transfer function, used in the synthesis of a large class of active filters.

or

$$\alpha_{dB}(\omega) = -20\log_{10}\left[M(\omega)/M_O\right]$$

(1.8b)

Note that this attenuation is related to the maximum level of transmission in the pass-band.

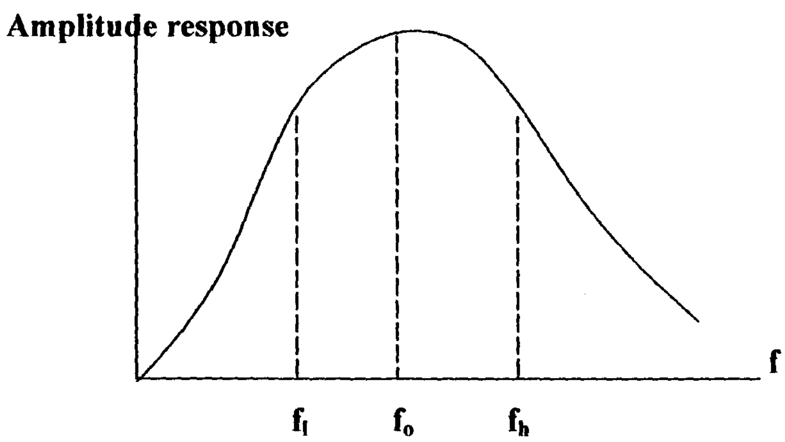

Figure 2-2 The illustration of band-pass filter response.

Let f_l and f_h represent frequencies on low and high sides, i.e. lower and upper frequencies respectively, at which the response is $1/\sqrt{2}$ times the peak response (-3.01 dB down). The bandwidth, B is defined as

$$B = f_h - f_l \qquad (1.9)$$

The frequencies, f_l and f_h have geometric symmetry about the center frequency f_O. Thus,

$$f_O = \sqrt{(f_l f_h)} \qquad (1.10)$$

The parameter Q is related to the center frequency and bandwidth by

$$Q = \frac{f_O}{B}$$

(1.11)

The upper and lower frequencies can be expressed as

$$f_l = \frac{1}{2\pi R_i C_i}$$

(1.12)

$$f_h = \frac{1}{2\pi R_f C_f}$$

(1.13)

where R_i and C_i are the resistor and capacitor on the low pass side; R_f and C_f being the resistor and capacitor on the high pass side respectively.

The filter design specifications

During the design process, the given frequency range of 60Hz to 16kHz was systematically divided into four approximately equal bands, thus requiring four cascaded two-pole active band-pass filters.

In order to ensure that there are no rejected bands within the frequency range, the respective amplitude response from the band-pass filters virtually overlap at the upper and lower ends of their respective pass-bands within the spectrum.

The lower frequency of the first filter at the input of the cascaded network is fixed at 60Hz; and the upper frequency of the fourth filter is fixed at 16kHz, thus meeting the desired range.

Hence, appropriate resistor and capacitor values were used in obtaining the upper and lower frequencies for each biquad in the network. From Equations 1.11 and 1.12, we have

1st band-pass filter

$$f_l = \frac{1}{2\pi R_1 C_1} = \frac{1}{2\pi \times 8.0 \times 10^3 \times 330 \times 10^{-9}} \approx 60Hz$$

$$f_h = \frac{1}{2\pi R_2 C_2} = \frac{1}{2\pi \times 390 \times 100 \times 10^{-9}} \approx 4.095kHz$$

2nd band-pass filter

$$f_l = \frac{1}{2\pi R_5 C_4} = \frac{1}{2\pi \times 400 \times 100 \times 10^{-9}} \approx 3.995kHz$$

$$f_h = \frac{1}{2\pi R_6 C_5} = \frac{1}{2\pi \times 730 \times 27 \times 10^{-9}} \approx 8.08kHz$$

2nd biquad

$$T(s)=\frac{V_O}{V_{IN}}=\frac{-\dfrac{1}{R_5C_5}s}{s^2+s\left(\dfrac{1}{R_5C_4}+\dfrac{1}{R_6C_4}\right)+\dfrac{1}{R_5R_6C_4C_5}}$$

$$=\frac{-\dfrac{1}{(400\times 27\times 10^{-9})}s}{s^2+s\left(\dfrac{1}{400\times 100\times 10^{-9}}+\dfrac{1}{730\times 100\times 10^{-9}}\right)+\left(\dfrac{1}{400\times 730\times 100\times 10^{-9}\times 27\times 10^{-9}}\right)}$$

$$\approx\frac{-92592.6s}{s^2+38698.6s+1.2684\times 10^9}$$

The gain, $|K| = 92592.6$

And the pole frequency, $\omega_p = \sqrt{(1.2684 \times 10^9)} \approx 35614$ radians

The pole Q, $Q_p = 35614/38698.6 \approx 0.92$

3rd biquad

$$T(s)=\frac{V_O}{V_{IN}}=\frac{-\dfrac{1}{R_9C_8}s}{s^2+s\left(\dfrac{1}{R_9C_7}+\dfrac{1}{R_{10}C_7}\right)+\dfrac{1}{R_9R_{10}C_7C_8}}$$

$$=\frac{-\dfrac{1}{(2\times 10^3\times 4.7\times 10^{-9})}s}{s^2+s\left(\dfrac{1}{2\times 10^3\times 10\times 10^{-9}}+\dfrac{1}{2.8\times 10^3\times 10\times 10^{-9}}\right)+\left(\dfrac{1}{2\times 10^3\times 2.8\times 10^3\times 10\times 10^{-9}\times 4.7\times 10^{-9}}\right)}$$

The gain, $|K| = 106383$

And the pole frequency, $\omega_p = \sqrt{(3.7994 \times 10^9)} \approx 61639.2$ radians

The pole Q, $Q_p = 61639.2/85714.3 \approx 0.72$

$$\approx\frac{-106383s}{s^2+85714s+3.7994\times 10^9}$$

4th biquad

$$T(s) = \frac{V_O}{V_{IN}} = \frac{-\frac{1}{R_{13}C_{11}}s}{s^2 + s\left(\frac{1}{R_{13}C_{10}} + \frac{1}{R_{14}C_{10}}\right) + \frac{1}{R_{13}R_{14}C_{10}C_{11}}}$$

$$= \frac{-\frac{1}{(6\times10^3\times560\times10^{-12})}s}{s^2 + s\left(\frac{1}{6\times10^3\times2.2\times10^{-9}} + \frac{1}{17.8\times10^3\times2.2\times10^{-9}}\right) + \left(\frac{1}{6\times10^3\times17.8\times10^3\times2.2\times10^{-9}\times560\times10^{-12}}\right)}$$

$$\approx \frac{-297619s}{s^2 + 101293.9s + 7.6\times10^9}$$

The gain, $|K| = 297619$
And the pole frequency, $\omega_p = \sqrt{(7.6 \times 10^9)} \approx 87178.4$ radians

The pole Q, $Q_p = 87178.4/101293.9 \approx 0.86$

The large gain values obtained from the computations bear close correspondence to the general assumption that an ideal op amp possesses an infinite gain.

2.1.2 The tuning circuit

The tuning circuit is connected to the coupling capacitor at the output of the filter network. It consists of a potentiometer of relatively high resistance in series with another resistor of lower resistance. A load resistor is connected across the potentiometer as shown in figure 2-1b. The manual movement downwards of the sliding contact of the potentiometer increases the resistance at the filter output, and thus reduces the output gain from the network. However, when the contact is subsequently moved upwards, the resistance to the network's output is reduced, and hence, an increase in the amplitude response is obtained.

The gain/amplitude response spans a range of 20dB. Thus, each of the four bands have their tuners calibrated from –10 to +10dB.

List of electronic components for the audio graphic equalizer circuitry in figure 2-3

Resistors	Capacitors	IC's
$R_1 = 8$ K	$C_1 = 330$ nF	2 dual op-amp IC's
$R_2 = 390$ ohms	$C_2 = 100$ nF	(No. MC1458CPI)
$R_3 = 120$ ohms	$C_3 = 10$ nF	
$R_4 = 1$ K	$C_4 = 100$ nF	
$R_{V1} = 10$ K potentiometer	$C_5 = 27$ nF	
$R_5 = 400$ ohms	$C_6 = 2.2$ nF	
$R_6 = 730$ ohms	$C_7 = 10$ nF	
$R_7 = 120$ ohms	$C_8 = 4.7$ nF	
$R_8 = 1$ K	$C_9 = 1$ nF	
$R_{V2} = 10$ K potentiometer	$C_{10} = 2.2$ nF	
$R_9 = 2$ K	$C_{11} = 560$ pF	
$R_{10} = 2.8$K	$C_{12} = 0.47$ nF	
$R_{11} = 120$ ohms		
$R_{12} = 1$ K		
$R_{V3} = 10$ K potentiometer		
$R_{13} = 6$ K		
$R_{14} = 17.8$ K		
$R_{15} = 120$ ohms		
$R_{16} = 1$ K		
$R_{V4} = 10$ K potentiometer		

2.2 The power supply unit

The op amps in the active filter network are fed with 12 V DC from the power supply unit. The unit consists of a 240 – 12 V step down transformer with the output connected to a bridge rectifier to provide full wave rectification. Parallel connected capacitors and resistors serve as smoothening filters that reduce the ripple effect of the rectified output waveform. A pair of zener diodes are used to regulate the voltage supply for both polarities.

The resistor and capacitor values for the power supply circuit shown in figure 2-4 are given below:

Resistors	Capacitors
$R_1 = 39$ ohms	$C_1 = 1000$ μF/35V
$R_2 = 39$ ohms	$C_2 = 1000$ μF/35V

CHAPTER 3

CONSTRUCTION, TESTS AND RESULTS

3.1 CONSTRUCTION

In the absence of computer simulation software, the design concepts were implemented by practical construction of the equalizer system with the discrete circuitry inserted on to a veroboard.

This method of discrete circuit wiring otherwise known as *point-to-point* or *harness* wiring being employed requires minimum engineering effort and equipment. It has advantages over printed circuit (PC) wiring in many applications, the following are:

(i) Layout and design (of printed circuit wiring) are difficult.

(ii) Small quantity of printed circuit boards (PCB's) are more expensive to produce.

(iii) Circuit design of PC's is usually restricted to one plane.

(iv) More labour costs are involved for PC changes and repairs.

(v) Subcontracting of PCB's is more difficult and costly.

The audio graphic equalizer circuitry and that of the power supply unit are inserted on a 58 X 144 mm veroboard. The veroboard and the 240 –12V step-down transformer are subsequently mounted and screwed on a 186 X 101mm synthetic plastic material providing adequate insulation support. Appropriate audio input and output terminals are provided, as well as an extension cord to plug into an a.c. power supply socket.

The two dual low-noise JFET op-amp IC's (MC1458CPI) constitute the "heart" of the system to which the various components of the main circuit, e.g. resistors, and capacitors, were connected to.

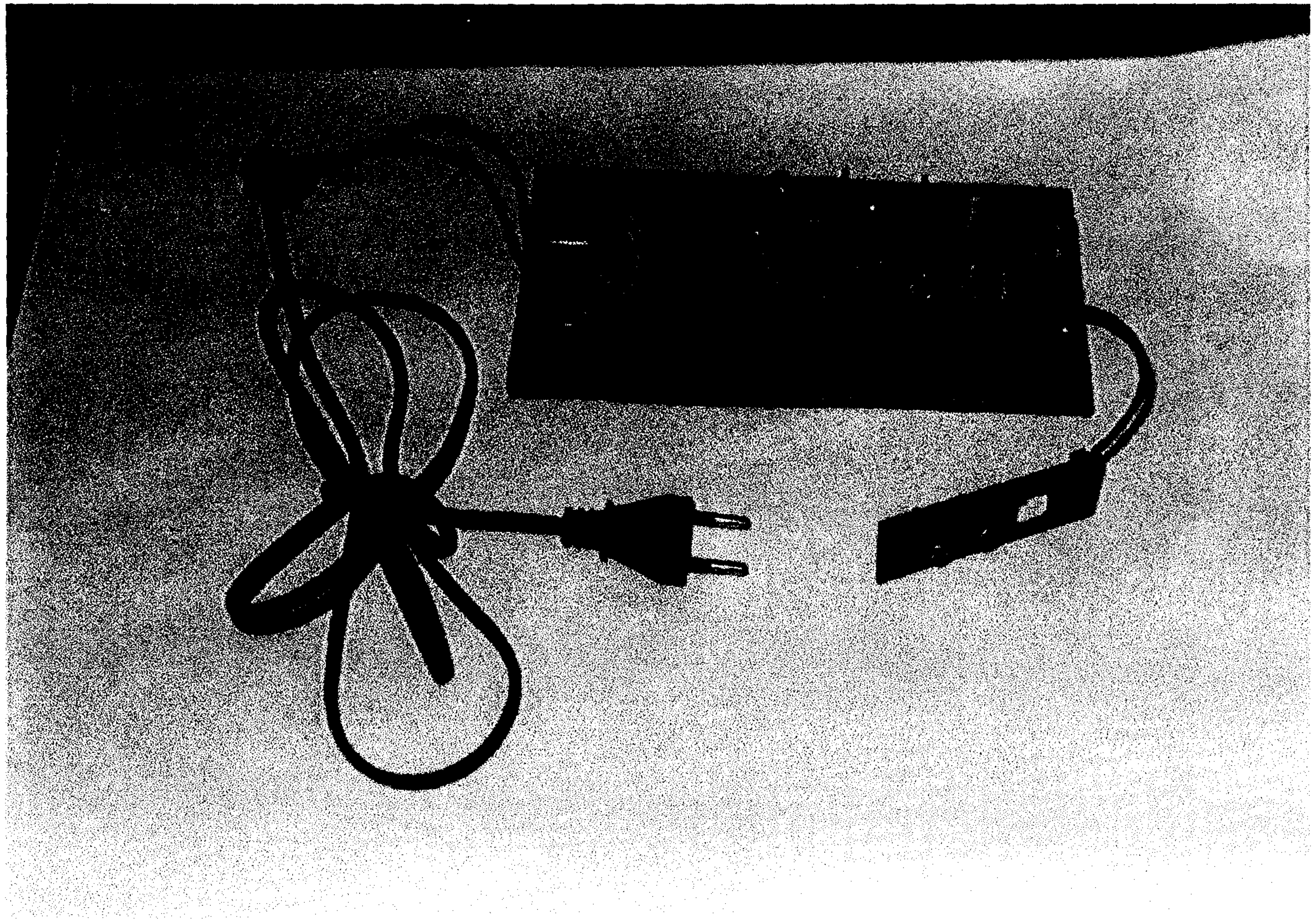

FIGURE 3.1 PHOTOGRAPH OF THE CONSTRUCTION

3.2 TESTS AND RESULTS

Tests on the power supply were carried out using a digital multimeter. Each DC output voltage level tested yielded quite satisfactory results. The two DC levels obtained conformed to acceptable tolerance levels. Accordingly they were: +12.34 / +12 V

-12.40 / -12 V

A fidelity test for the audio output from the graphic equalizer, with an audio input from a compact disc player, yielded acceptable results. The reproduced sound being faithful to the original sound was accompanied with reduced noise. In addition, the sliding contacts or tuners for each of the frequency bands (60 Hz – 4 kHz; 4 – 8 kHz; 8 – 12 kHz; 12 – 16 kHz) were adjusted accordingly. The higher frequency ranges, i.e. from 8 to 16 kHz, were observed to be audibly preemphasized and deemphasized when the contacts were slided upwards and downwards respectively. Hence, the problem of high frequency background noise has been adequately taken care of. Furthermore, it was observed that on the manual adjustment of the sliding contacts upwards and downwards respectively, for the lower frequencies i.e. from 60 Hz to 8 kHz; the bass-like audio output was accordingly boosted and attenuated in a satisfactory manner.

CHAPTER 4

CONCLUSION AND RECOMMENDATIONS

CONCLUSION

The efficacy of active filter realizations in audio signal processing systems has been remarkably proven in this project. The aspect of audio signal equalization treated which is based on basic principles of the filter network and filter related systems dealing with frequency response modification, is a clear example of such applications.

The set out objectives stated earlier on were achieved to a great extent. However, in the process of noise reduction, some attenuation, which is a fractional loss of audio signal amplitude when a signal passes through a system, was observed. Where an increased sound level is desired, the graphic equalizer can be used in conjunction with an audio power amplifier of minimal distortion.

RECOMMENDATIONS

Further improvement on this active filter based system can be made in the area of *miniaturization*. Presently, thick and thin film technologies for the manufacture of resistors and capacitors, where these components are deposited on ceramic substrate with the op-amp IC chip bonded to the substrate are available.

Unlike the discrete component based circuits, these miniature active filter circuits are small, light and reliable, and the technology is quite economical where large numbers of these medium quality filters in the order of up to 100,000 per year can be produced.

In addition, more tunable frequency bands can be incorporated in the specified frequency range of the system to provide a more detailed modification of the amplitude – frequency response to a desired level for listening.

Finally, a liquid crystal display (LCD) or a light emitting diode (LED) based indicator can be used to give a graphical depiction of the amplitude - frequency response variation when adjustment is being carried out for any band within the spectrum.

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