WIRELESS SPEAKER

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Acknowledgements

I am greatly indebted to Dr. Ahmadi for his constant encouragement and patient guidance when I had expressed my interest in taking the Analog Electronics course. This course has been a first in involving lab work and actual PCB manufacture. I wouldn't have learnt as much without the help from the Teaching Assistant Roy Zou. Roy always welcomed questions and never once expressed of being inconvenienced in our constant cry for help. Lastly I would like to acknowledge the great support from Huawa and Gebe the lab assistants who helped us with the equipment and software.

Abstract

The project involves the design and implementation of a Wireless Speaker. The output from a CD player is to be transmitted across a wireless link using Infra Red LED and Phototransistor based receiver. The speaker is designed for a maximum power output of 2Watts and operates on AC power 110V 60Hz. The Speaker is also designed to filter frequencies beyond the mid band of 50Hz – 20Khz. The circuit components were simulated in OrCad, tested in breadboard before final realization in PCB form.

Background

ECE 121 is an Analog Electronics course. The course is built on the basic transistor knowledge, and introduces us to the building blocks of Integrated Circuit technology. We learnt the construction and operation of differential amplifiers, current mirrors, level shifters, configuration that improves frequency response and current booster circuits. In essence our learning curve was geared towards the making of the omnipresent Operational Amplifier.

We have 3 projects and many labs aimed to test our ability to build analog circuits in breadboard. CAD tools were extensively used for the simulation of circuits and Layout Plus was used for making the printed circuit boards.

The lab work and projects enabled us to understand the elements that ultimately make the wireless speaker. We had worked with Voltage Regulators, OpAmps as compararator’s and amplifiers and had implemented a light sensitive switch as Project I. We understood the use of Opto-Coupler’s use in isolating High voltage circuits from the Low voltage control circuitry and the functioning of Triacs as a bidirectional high voltage switches.

We next explored differential amplifiers, level shifter's to remove the DC bias and various current mirror's. The Amplifier's frequency response was determined using the *Spectrum analyzer* and the simulation results of discrete cascade and OpAmps were verified. Frequency response took us to the next area of interest - Active Filters. We learnt to implement Sallen-Key based higher order Filters, Butterworth and Chebyshev filters were designed and implemented. I had also implemented a 4th Order Butterworth Filter with a Bandwidth of 20Khz and break frequencies at 50hz and 20Khz.

The output stage of the OpAmp is crucial for driving the external load. Special OpAmp's like LM386 have been designed with the capability to directly drive a speaker. The current booster circuit based on Class AB Push-Pull transistors was implemented and tested.

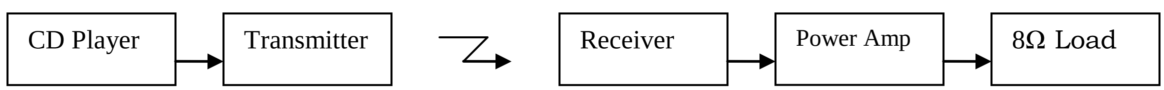
The design and testing of the elements of the Wireless Speaker is discussed hereon in this report.

Design Requirements

1. The wireless speaker must have a transmitter, receiver and should work over a minimum range of 1m
2. The transmitter must have input impedance greater than 2KΩ and Sensitivity* greater than 170mVrms
3. Frequency response f3db at 50Hz and 20KHz
4. Output Power of 2Wrms to the 8Ω speaker

*Sensitivity is defined as the minimum signal level that the system can detect with acceptable signal to noise ratio.

Overview of the System



Design Specifications

1. The transmitter receiver is to be implemented using Infra Red LED and Phototransistor.
2. The transmitter should able to detect input signals of 10mV to 200mV.
3. An active filter with f3db at 50Hz and 20 KHz is to be implemented for filtering extraneous noise and unwanted signals.
4. The preamplifier, power amplifier and regulated power supply are to be designed for the required power to the 8Ω speaker.

Design

Design of Transmitter Receiver

The IR transmitter receiver was chosen for the ease of implementation.

It works on the principle of Amplitude modulation. The carrier (in the infra red spectrum) amplitude is modulated by the base band signal from the CD player.

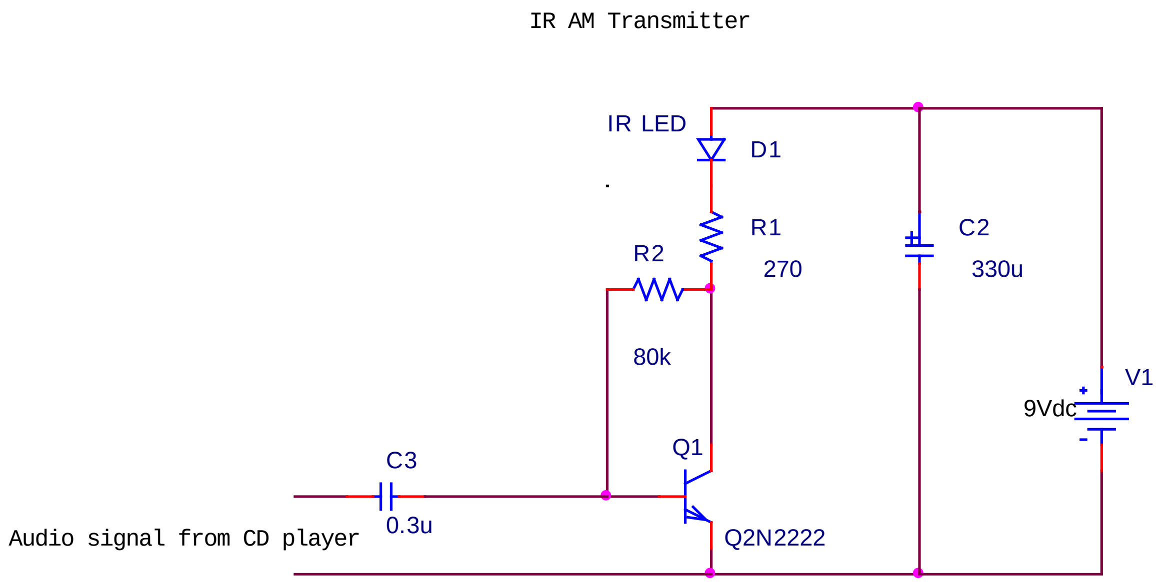
The modulated signal is of the form $y(t) = m(t)Cos(wct + \Phi)$ where $m(t)$ is the base band CD output and wc is the infrared carrier.

A common modulation technique is the switching modulation wherein a a periodic square wave $w(t)= ½ + 2/\Pi$ ($coswct – 1/3 cos3wct + 1/5 cos5wct + ….$) is used to switch the base band signal. This is how the cosine multiplication of base band and carrier signal is implemented, and AM is achieved by removing the higher and unwanted harmonics using a BPF.

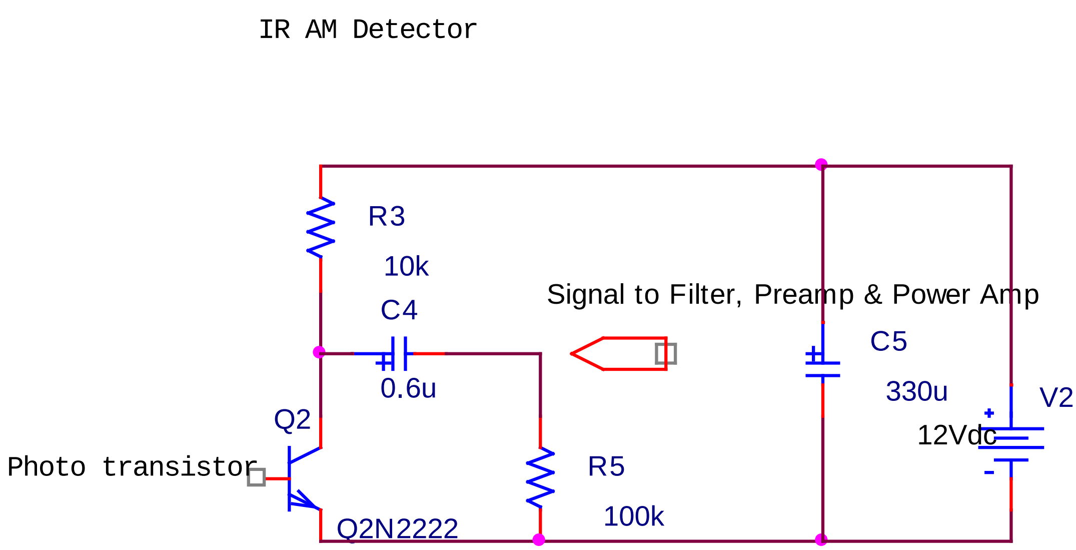
Demodulation is carried out in a similar manner by using a diode that produces the equivalent square wave to get the original spectrum by using a LPF

The IR AM modulation demodulation agrees with the intuitive definition that the amplitude of the carrier is modulated by the base band.

The current flowing through the IR LED controls its transmission. Since the switching transistor's collector is connected to the LED, the transistor acts like a CE amplifier. The IR transmission is modulated by the signal input from the CD player.



The receiver or IR Detector is a simple phototransistor that acts like the envelope detector in demodulating the sensed AM signal.
The DC bias of the phototransistor is filtered using a 0.6u capacitor and 100k drain resistor.

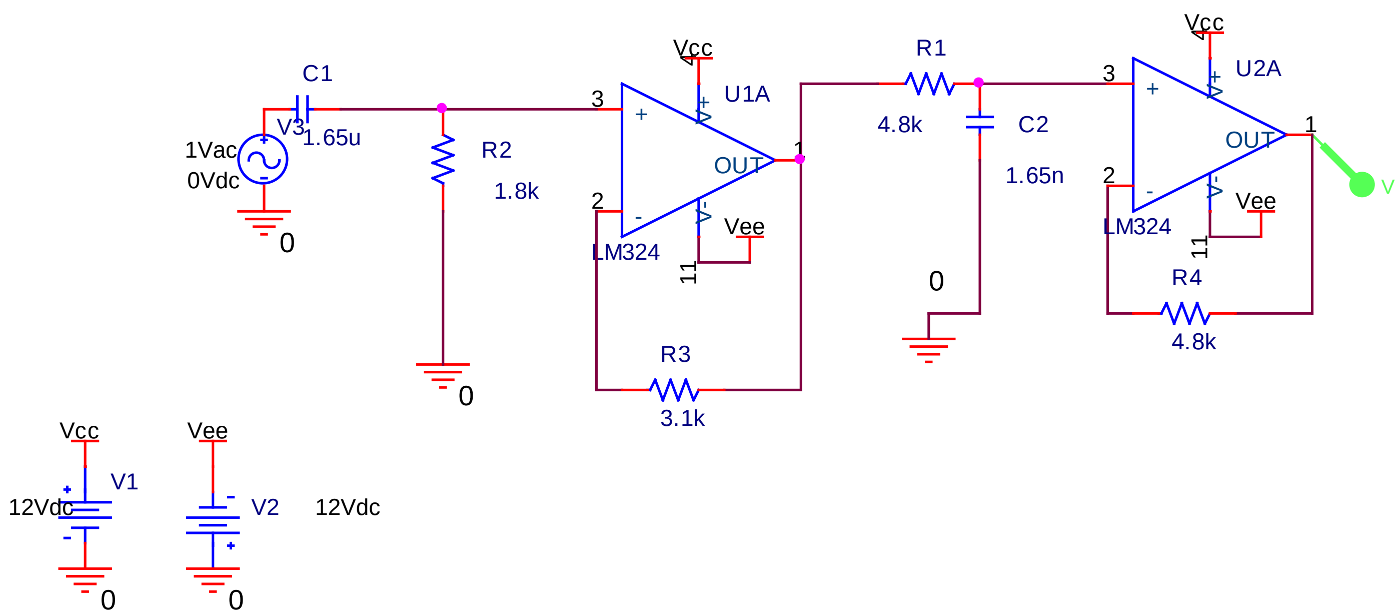


Design of Filter

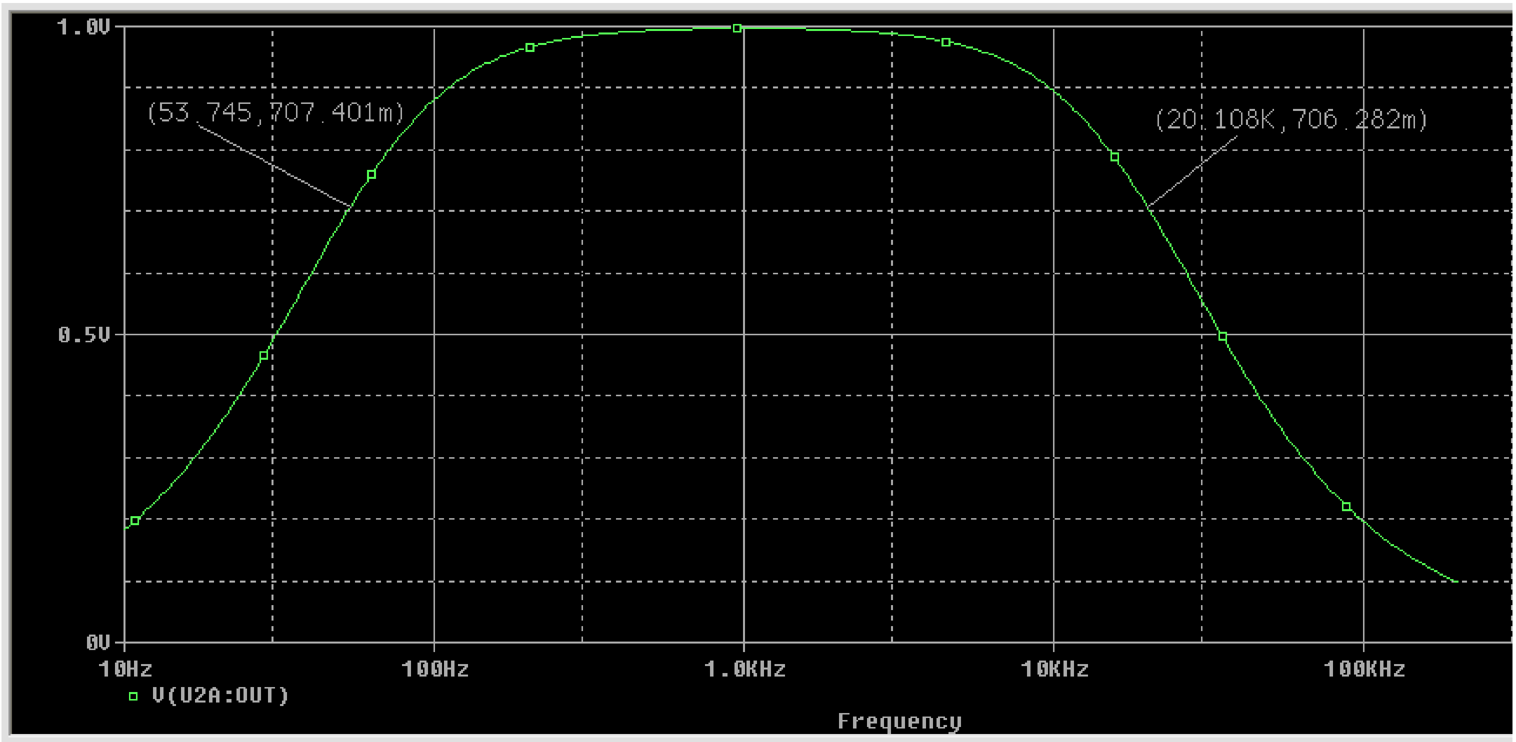
Active filters use amplifiers in addition to passive RC elements to obtain the desired frequency response. The advantage of the active filters over passive ones is the ability to incorporate the required gain on insertion, to compensate the insertion loss of the passive elements.

Single Pole Band Pass Filter

A band pass filter may be made by cascading a high pass filter with f3db at 50hz with a low pass filter with f3db at 20Khz. The 1st order band pass filter and its frequency response is shown below:



Note the Break frequencies in the frequency response.

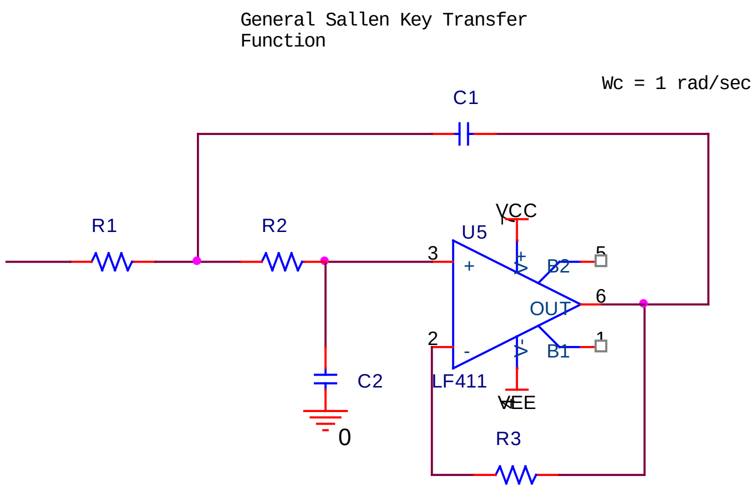


Higher order Active filters based on Sallen-Key Configuration can also be designed. Here the Design of a 4th Order Butterworth Band Pass filter is presented.

Sallen Key Higher Order Filter

The transfer function of a Sallen Key Filter of 2nd Order filter is :

$$\frac{Vout}{Vin} = \frac{A\ /(R1R2C1C2)}{s2 + s(1/R1C1 + 1r2C1 + 1/r2c2(1-A)) + 1/R1R2C1C2} \qquad \text{Eq 1.0}$$



The generic 2nd order system transfer function

$$G = \frac{A\omega^2}{s^2 + \alpha\omega s + \omega^2}$$

Where A is the gain and α is the damping factor of the 2nd order system. When the filter is designed for unity gain, the parameters in Eq 1.0 reduce as follows:

A = 1, ω = 1 Rad/Sec, the filter is designed for normalized frequency so that it can be scaled to any break frequency.

R1=R2=1 therefore C1C2 = 1 since $\omega 2 = 1/R1R2C1C2$

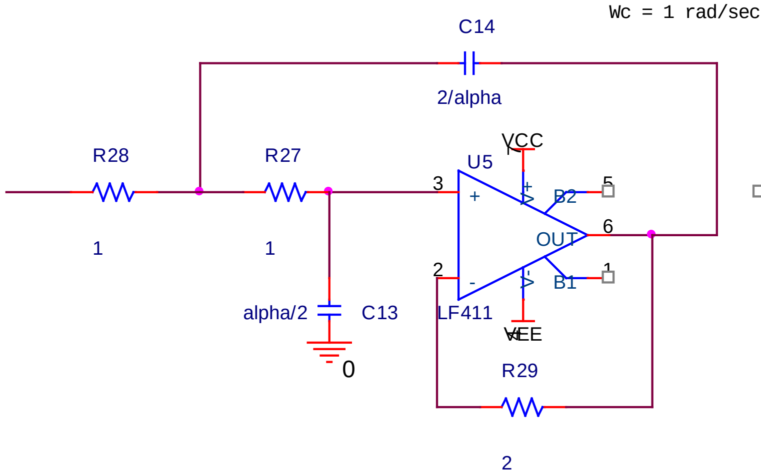
Substituting in Eq 1.0

$\alpha = 2/C1$ i.e C1 = $2/\alpha$ and C2 = $\alpha/2$ for low pass filters and

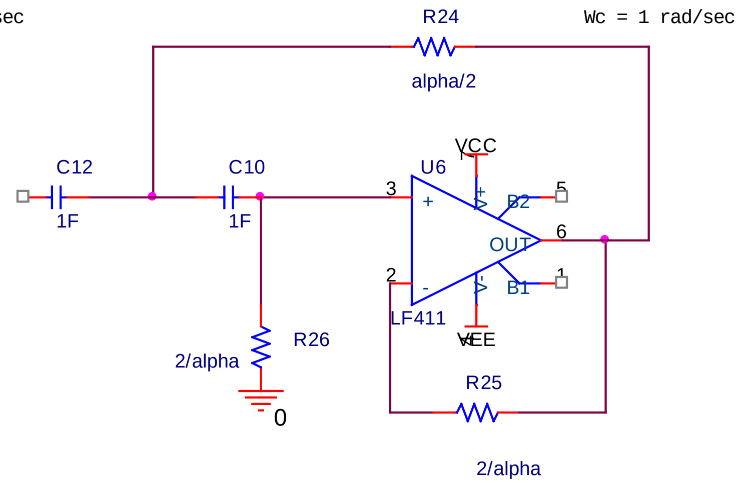
R1= $\alpha/2$ and R2 = $2/\alpha$ for high pass filters.

Adjusting the RC values and substituting the damping and frequency coefficients from the tables one design's higher order filters.

LOW PASS UNITY GAIN SALLEN KEY



HIGH PASS UNITY GAIN SALLEN KEY



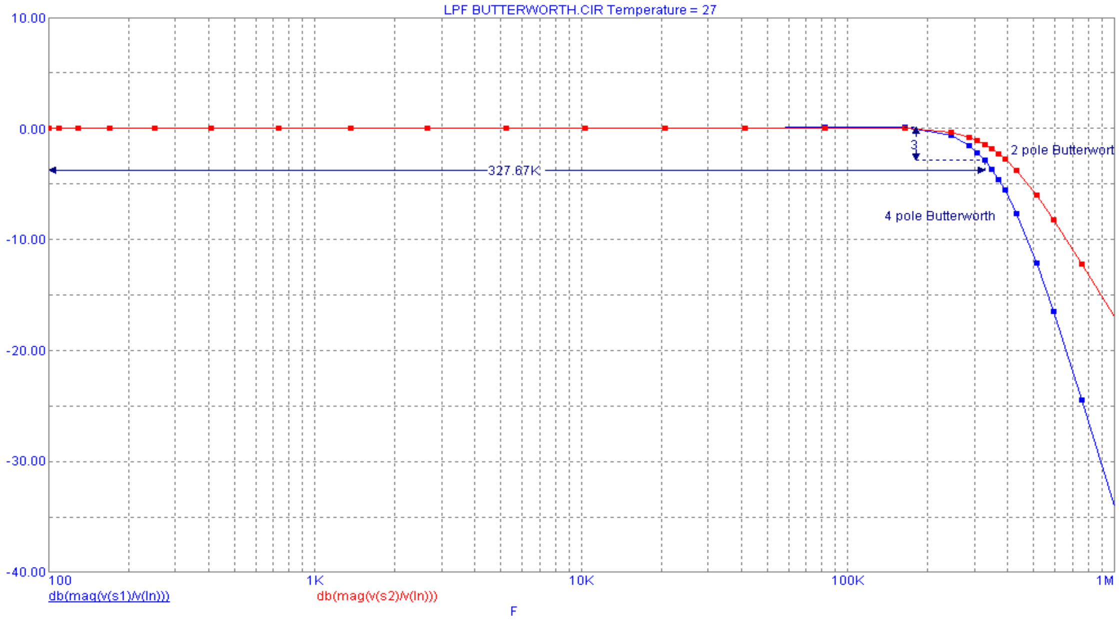
Fourth Order Filter Parameters - Butterworth:

Second Order Section		Second Order Section	
Damping	Fc Factor	Damping	Fc Factor
1.848	1.0	0.765	1.0

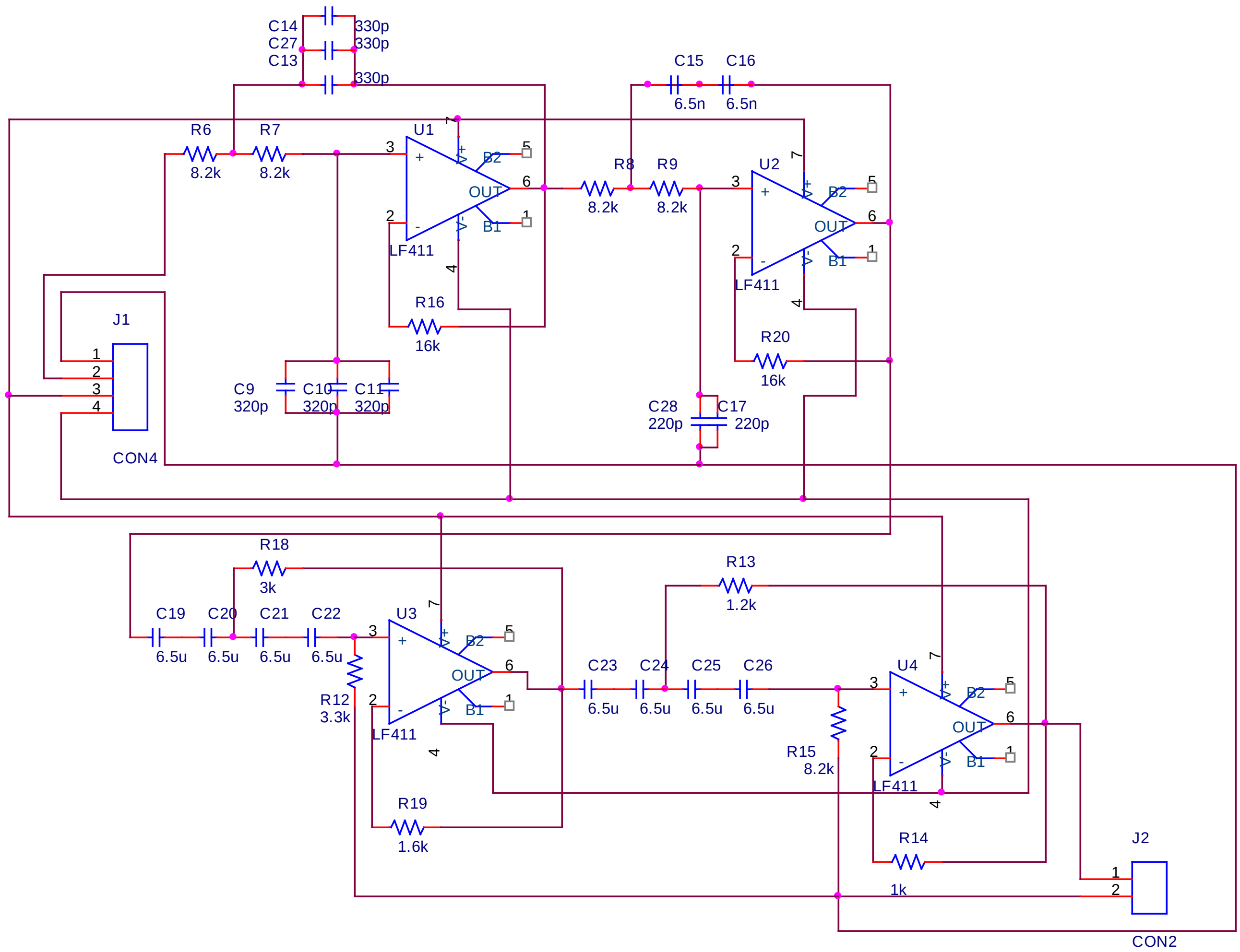
Fc Factor used to obtain the design frequency by dividing the f3db/Fc Factor.

Thus the Band Pass 4th order Butterworth filter was realized and tested using spectrum analyzer.

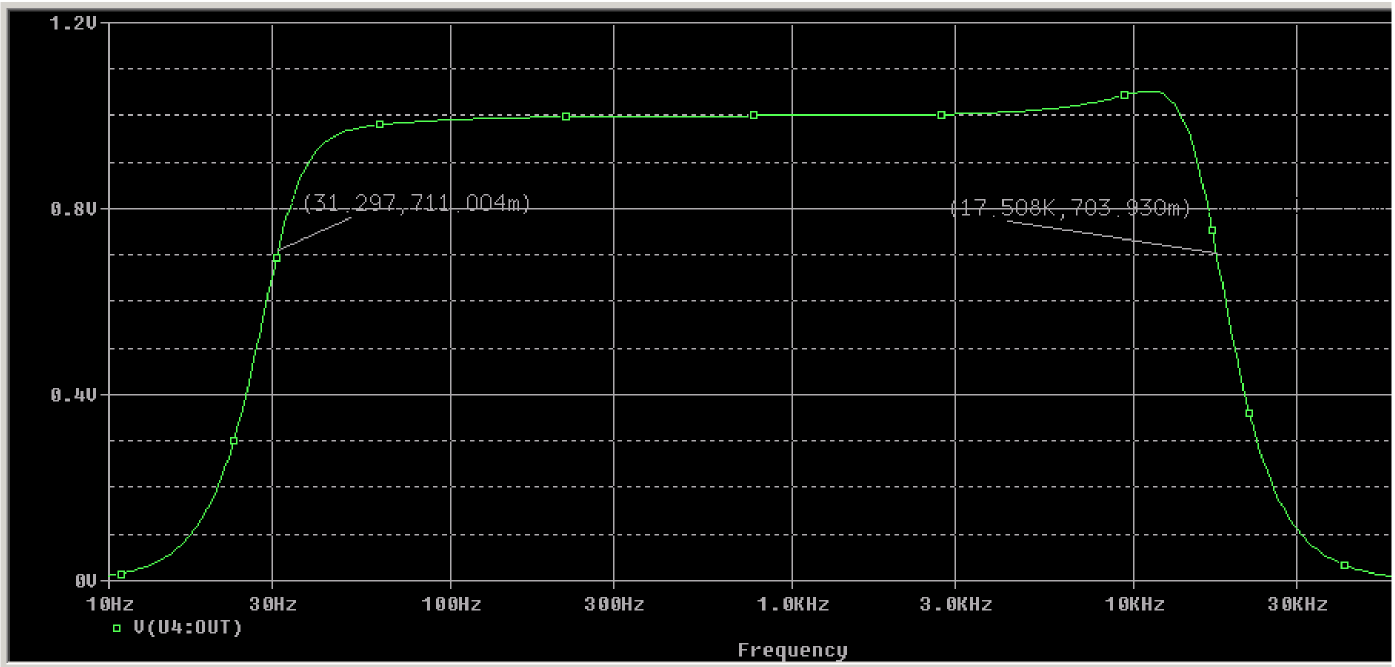
The simple 1st order band pass filter will be used for the wireless speaker, as it does not entail the steep response of higher order filters.



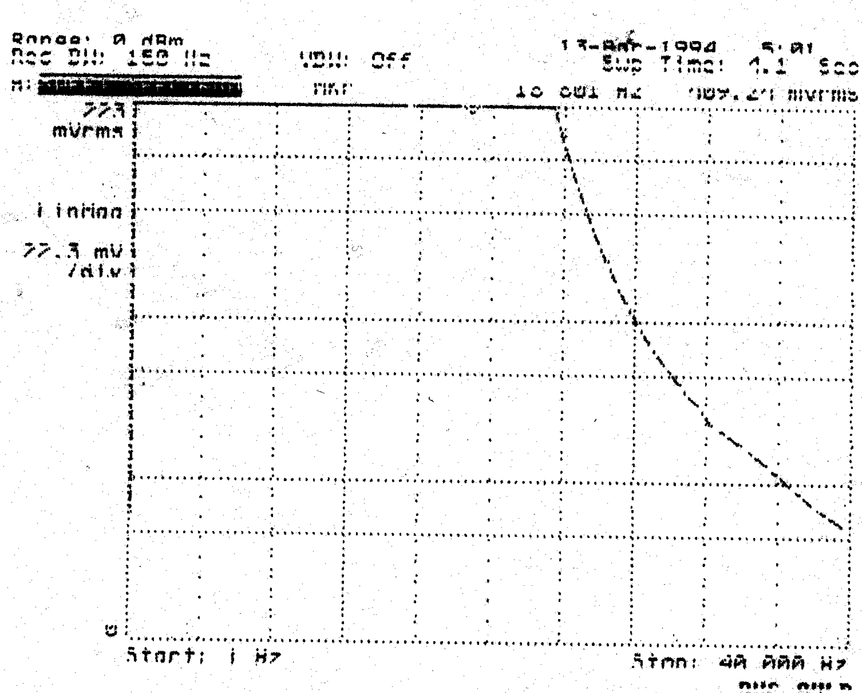
Butterworth 4 Pole Band Pass Filter



Frequency Response Simulation



Spectrum Analyzer Scan

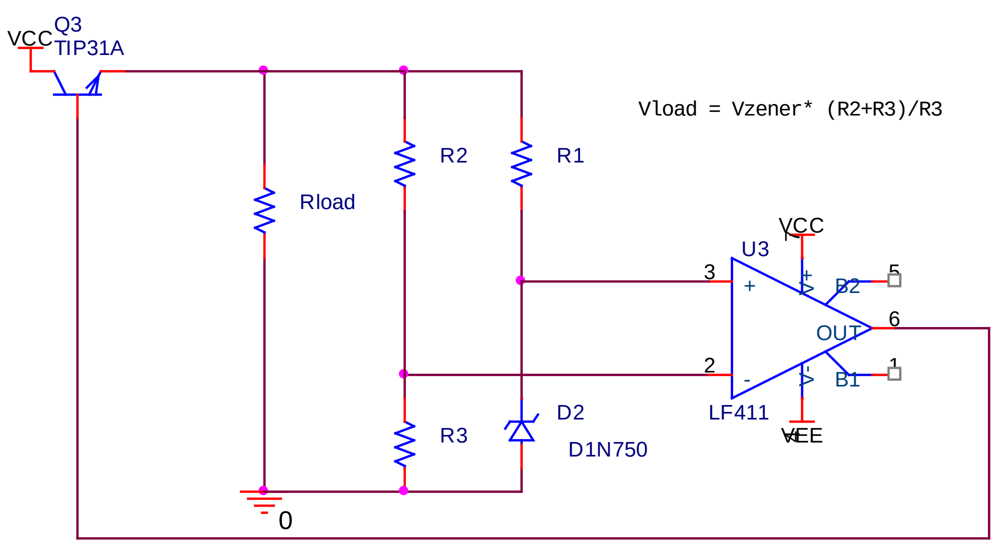


Design of Power Supply

A constant power supply is crucial for proper functioning of any circuit. Variations in Load or Line may result in variations in the supply voltage. Most power supply regulators have in them a feedback mechanism to track an input reference source.

A simple OpAmp regulator, which describes the functioning of the standard 78XX and 79XX regulator's, is shown below. The Vload is tracked based on the reference Zener breakdown voltage and the feedback voltage divider. The ideal OpAmp tries to do everything in its means to equalize its 2 inputs. Vload is fed as a feedback to the inverting end of the opamp through a voltage divider. Thus Vload is regulated to a constant value of Vzener*(R2 +R3)/R3.

Opamp based Linear Regulator

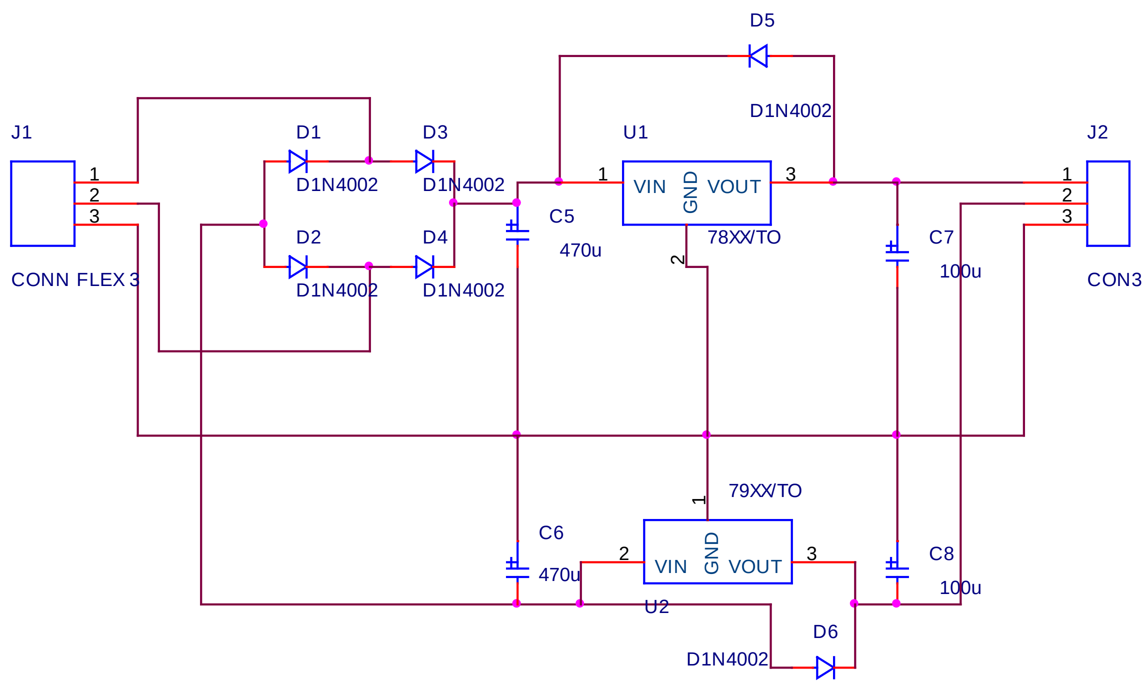


Dual supply using 7812 & 7912 regulators

The 7812 uses the +ve rectified output as reference to produce the ripple free +12VDC supply, while the 7912 uses the –ve rectified output to produce the ripple free -12VDC supply.

The 470u capacitors are a part of the rectifier circuit in reducing the ripple while the 100u capacitors improve the transient response of the regulator.

The Diodes across the input and output of the regulators protect the regulator from over voltage conditions experienced with inductive loads.



Design of Voltage and Current Amplifiers

The voltage amplifier and current amplifiers are required to boost the signal power to the required 2Watts to the 8Ω load.

The voltage amplifier can be realized by a CE amplifier with a CC buffer, or by a cascade configuration, or by a differential pair. These were attempted and understood. In addition Active loads, transistor biasing and level shifting to remove the DC bias were also understood.

Since Operation amplifiers have been designed with all the above elements, I choose to use OpAmp's for the voltage amplification. Selection of an OpAmp from the available (LM741, CA3140E, TL082) OpAmp's is a crucial task for the satisfactory operation of the audio circuit.

Characteristics of the audio amplifier

The voltage amplifier is intermediary to the filter and the current booster and hence should exhibit very high input impedence and low output impedence to prevent loading when cascaded with other elements of the audio system.

The amplifier should exhibit high slew rate i.e should be fast enough to prevent distortion of signals and exhibit minimum offset and total harmonic distortion.

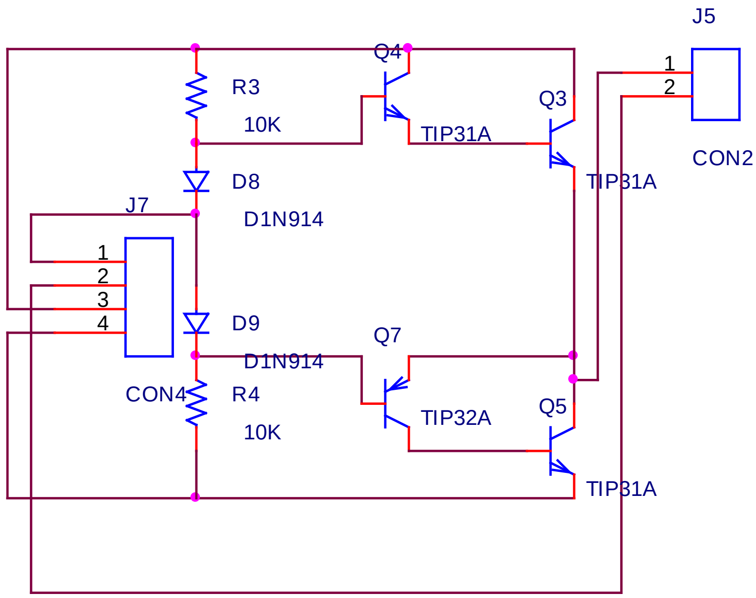
LM741 the general purpose OpAmp does not satisfy either of the abovementioned criteria.

CA3140E is faster when compared to LM741 and has a funity of 10MHz, but has a finite input impedence and hence would get loaded when cascaded with other stages.

TL082 BIFET OpAmp is the ideal candidate for the audio application. The FET input stage affords very high input impedence (>$10^{12}\Omega$), it has a high slew rate of 13V/us and the BJT stage allows for a maximum power dissipation of 680mw.

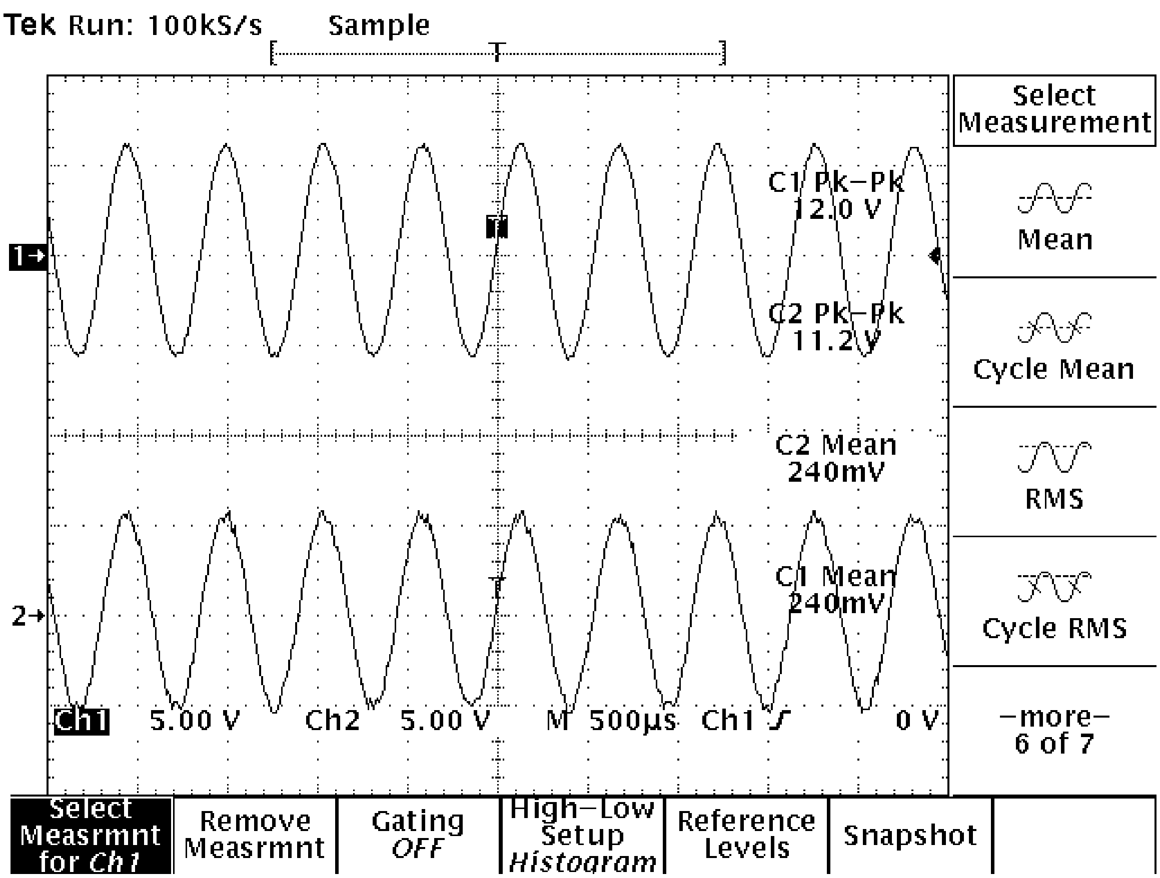
Therefore the Dual BIFET TL082 was used for the active filter and the inverting voltage amplifier designed with a maximum gain of 100. (Gain = Rf/Ri =10KΩ/100Ω).

The Current booster stage is a Class AB Push-Pull amplifier using TIP31A and TIP32A Power transistors. The TIP power transistor is designed to handle a maximum collector current of 3Amp and 40Watts.

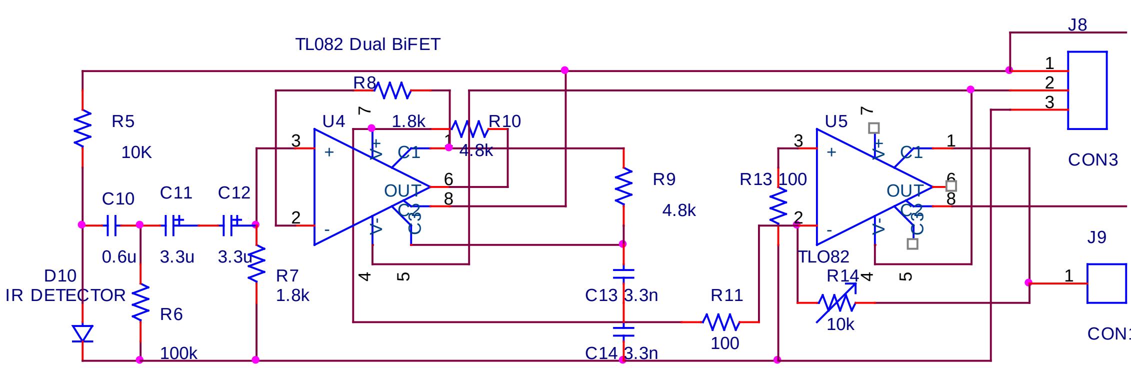


The 2Watt across the 8Ω corresponds to a collector current (Ic rms) of √2/8 = 0.5Amp. And in terms of Voltage, Vo = √ 2*8 = 4Vrms amplitude or 11.31 peak to peak.

A darlington configuration enables us to effectively design the output stage with very high gain of the order of 1600 (hfe of a TIP being 40 when used in darlington configuration effective hfe = 40*40). The high gain ensures negligible base current when compared to the bias current required by the diodes. The constant current through the diodes bias the NPN and PNP transistors of the Push Pull to be ON for the +ve and –ve half's of the signal. The biasing diodes eliminate crossover distortion. See below, the oscilloscope plot for the Class AB output stage for 2Watt output through 8Ω load.

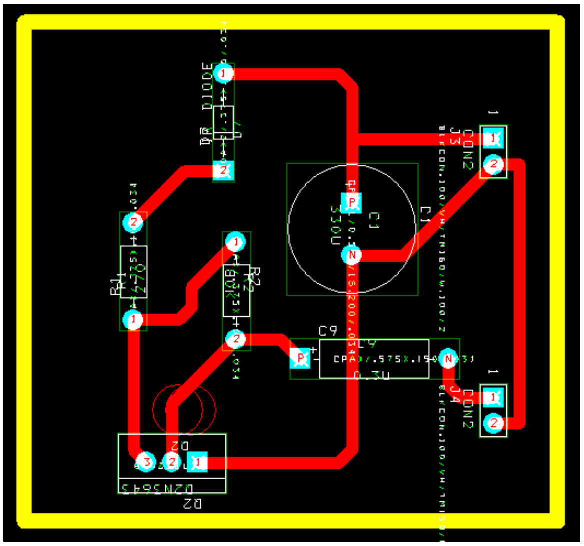


The Receiver circuit consists of the Simple Band Pass Filter and Voltage amplifier shown below

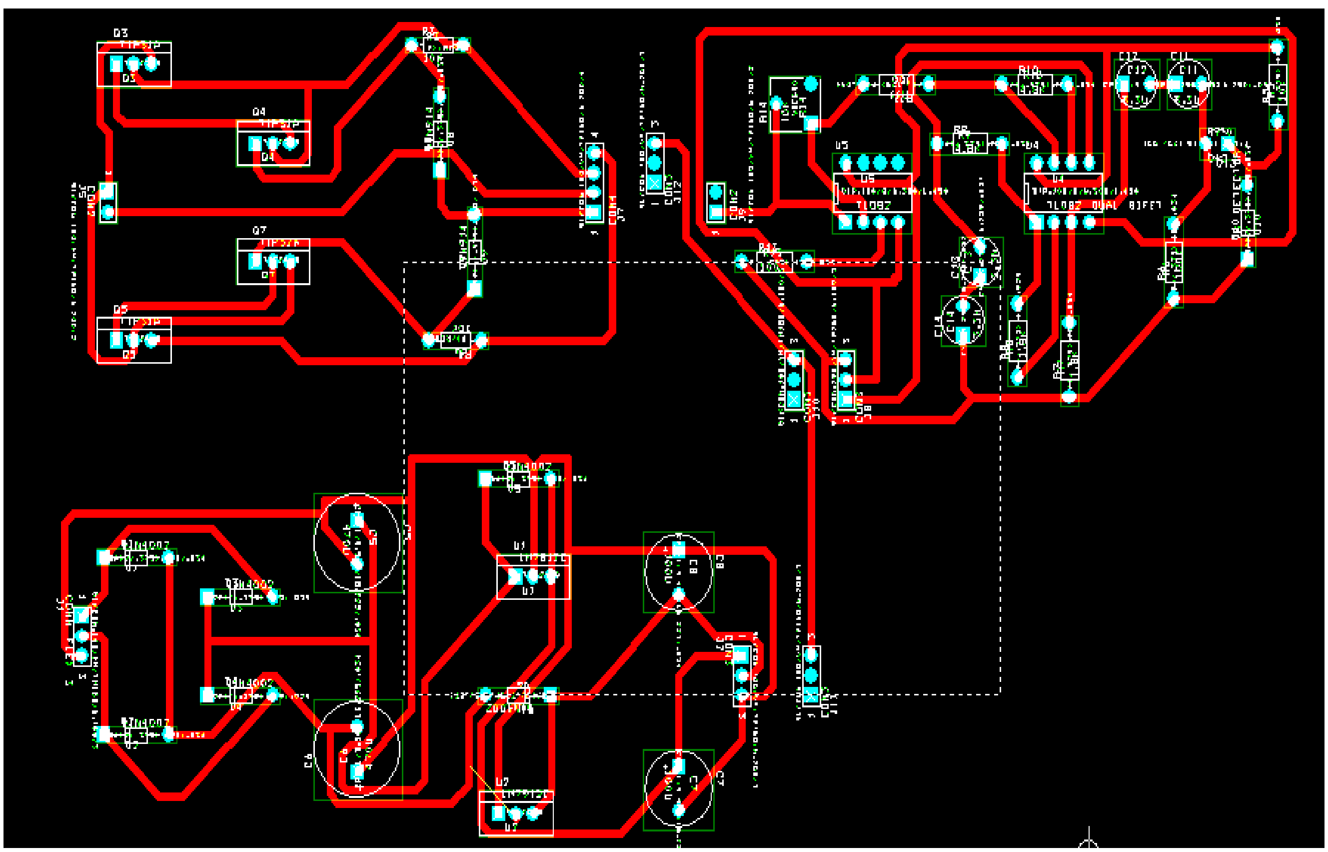


Layout for PCB manufacture

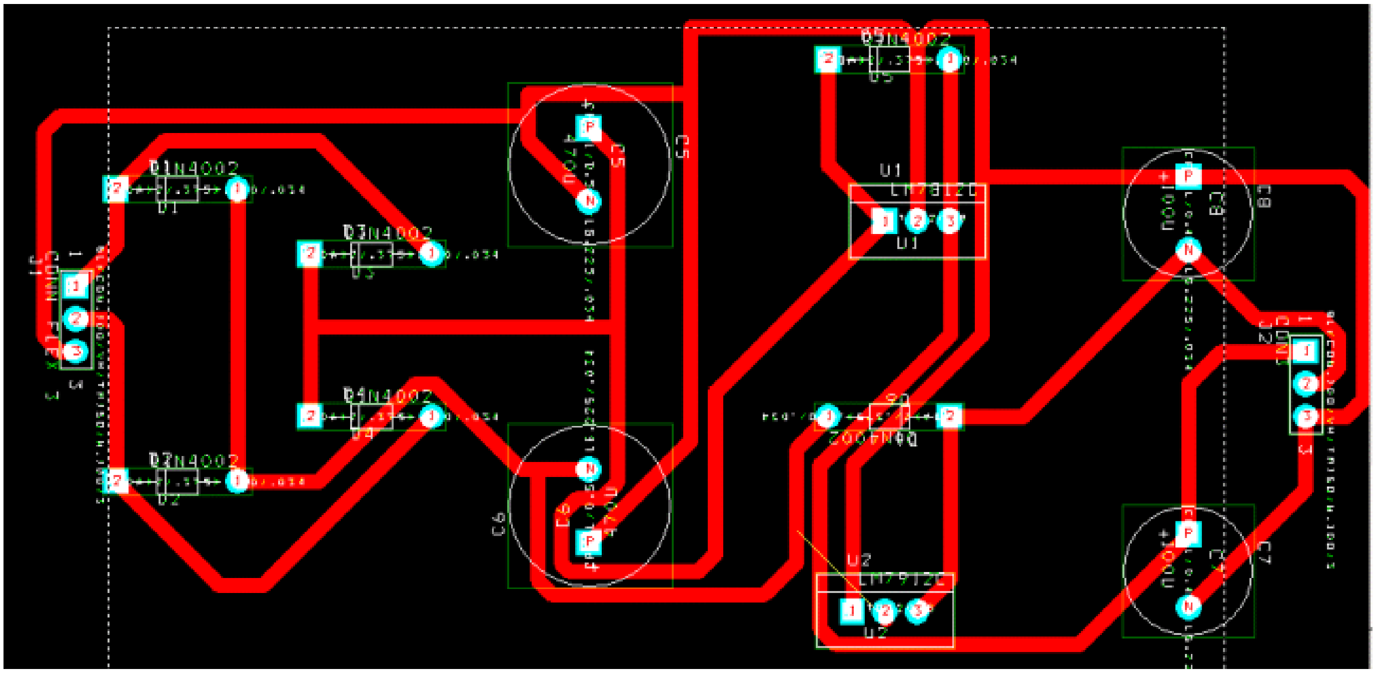
Layout of IR Transmitter



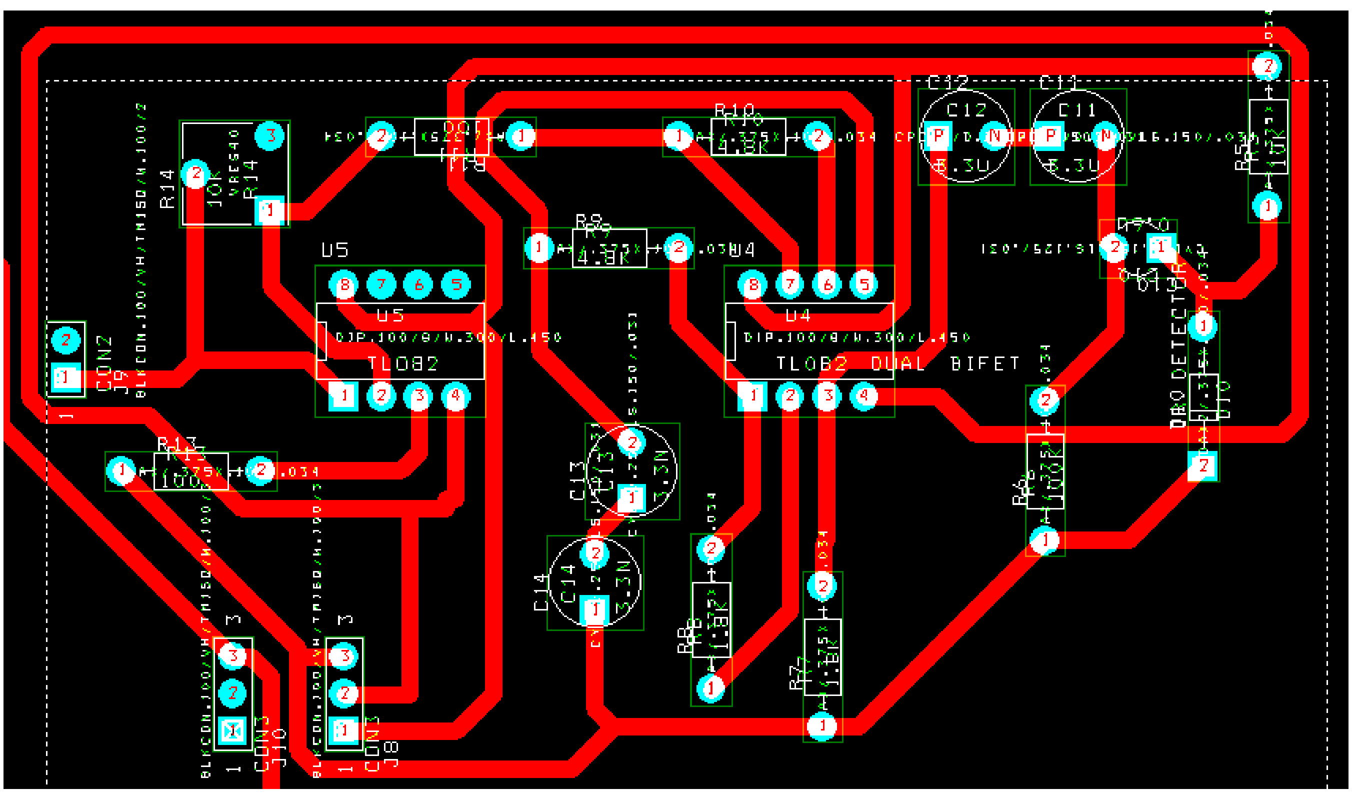
Layout of IR Receiver



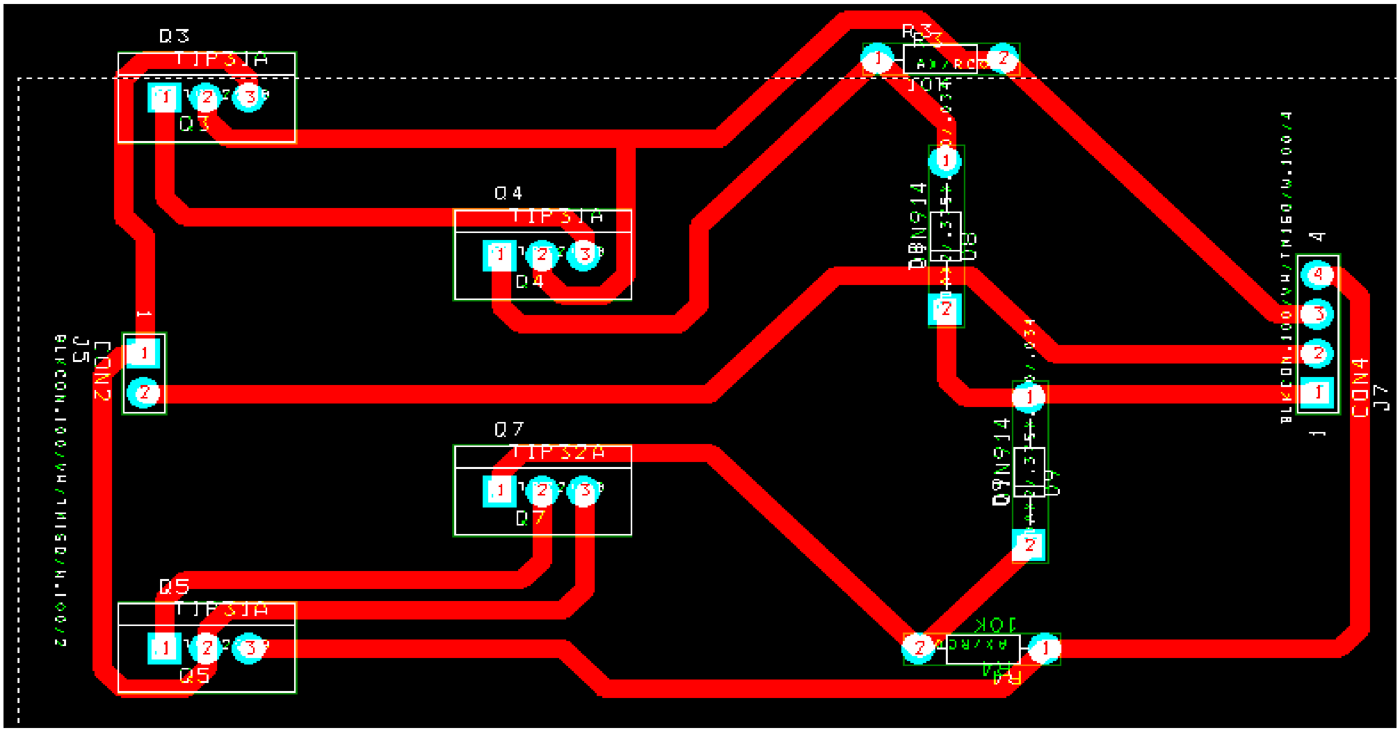
Layout of Power Supply



Layout of Receiver, BPF and Voltage Amplifier



Layout of Class AB Output Stage



Conclusion and Observations

The individual modules were assembled on PCB and tested before interconnecting them as a whole. The PCB was designed with the interconnects to allow for individual testing.

The interconnects that link the various modules were overlooked and had to be manually connected this can be redone on PCB. The IR transmitter acts like a point source and transmits in all directions thus decreasing the range. Using a transmitter with a focusing lens would improve directionality and range.

The IR transmitter receiver works over a distance of 1m and delivers the 2Watt power to the 8Ω speaker satisfying the requirement.

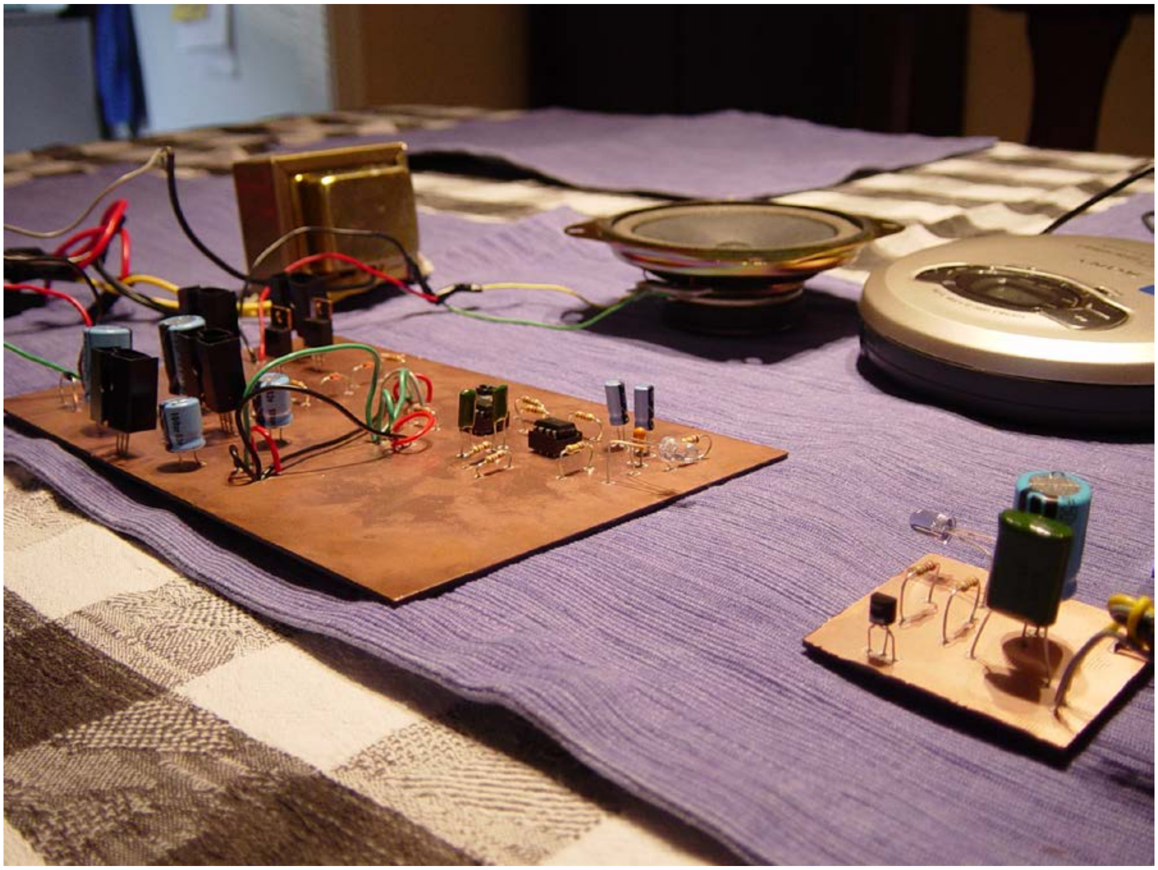


Figure 1 My Wireless Speaker

References

1. Op Amps and Linear Integrated Circuits – James M Fiore
2. Microelectronic Circuits – Sedra / Smith
3. Art of Electronics Student Manual – Thomas C Hayes, Paul Horowitz