

**EE 410 Final Linear Electronic Design
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5-Band Graphic Equalizer

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INTRODUCTION

The design project being discussed in this report is the 5-Band Graphic Equalizer. The sequence of operation for the equalizer is as follows: have an audio device supply an input signal to go through filtering circuits, have the output of each band of the filter be cut or boosted, and then each band is also displayed graphically by LEDs. The output of all the filters is also recombined and is to drive a pair of speakers or headphones.

The purpose of the audio equalizer is to make adjustments to the frequency response of an audio device and supply either a boost or cut of certain frequency ranges. The spectral display will give a visual representation of each spectral band, with the lighted LEDs representing the magnitude of that band. This project will utilize our acquired knowledge in electrical engineering with specific focus on analog design and linear combination of circuits.

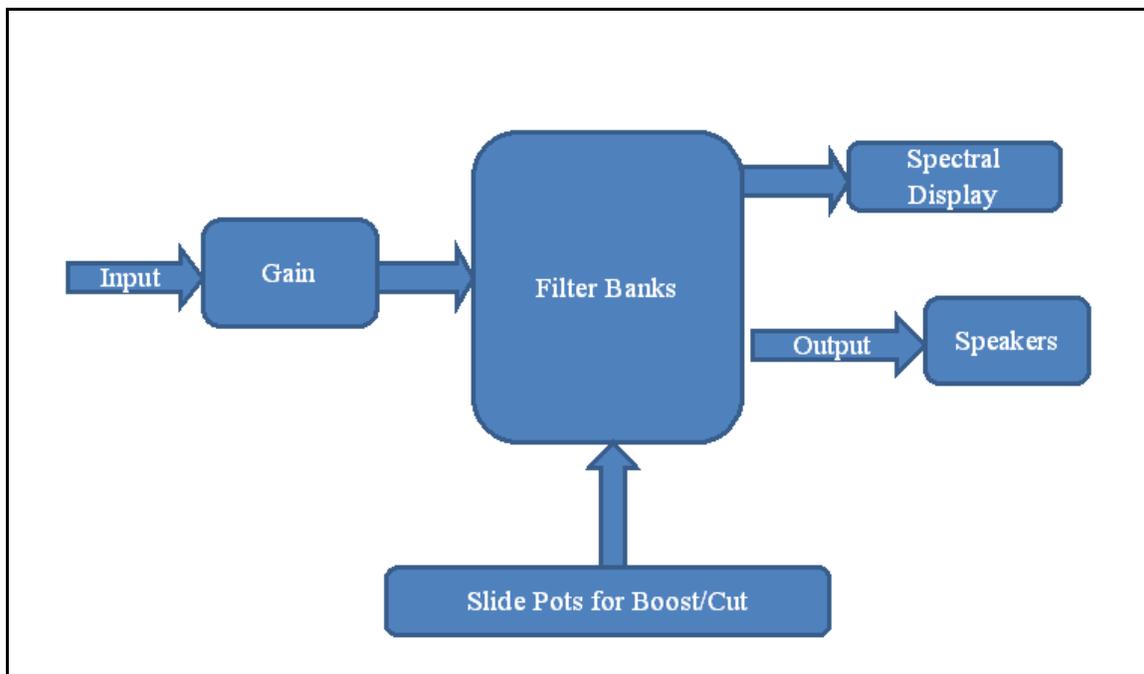
The project specifications are show in the table below. Along with the goal of getting a working device, there are also these requirements that must be considered through all stages of design.

Specifications, 5-Band Graphic Equalizer Project					
Parameter	Min	Typ	Max	Units	Comment
<i>Input Characteristics:</i>					
Input Impedance		10 k		Ω	
Input level		-10	0	dBV	0 dBV = 1 V _{RMS}
Connector	1/8" stereo mini-jack				Mono – use tip and gnd
<i>Output Characteristics:</i>					
Maximum Output Level	0			dBV	without clipping
Rated Load Impedance		32		Ω	For driving headphones
Output Impedance			3.2	Ω	
Connector	1/8" stereo mini-jack				
<i>Overall Characteristics (End-to-end measurement):</i>					
Frequency Range	20		20 k	Hz	
Frequency Response			± 1.5	dB	All EQ settings midrange
Number of Equalizer Bands	5				
EQ Adjustment Range	± 12			dB	Per band
Overall Gain		0		dB	With no boost or cut
Gain Adjustment Range	± 10			dB	
THD			0.1	%	At -10 dBV into rated load
Noise Density at output			-133	dBV/ $\sqrt{\text{Hz}}$	At $f = 1$ kHz, unity gain
Bar graph resolution	6			steps	
<i>Power Requirements:</i>					
Input Voltage			9	VDC	Unipolar
Power Consumption			1	W	Design goal
<i>Cost:</i>					
Materials cost			\$100		Design Goal

These specs were always accounted for when designing each circuit and choosing the parts for the device. With the specifications of the final product determined, the designing and testing stages could begin.

Our group's main objective for the project was to create a working device, first and foremost. Once we knew our design worked we would then aim to tweak certain components of the design to help meet or exceed the specifications. Our main goals were as follows: a monophonic design, operate in the range of frequencies between 20 – 20kHz (audio range), ability to boost or cut certain frequency ranges, a working and responsive spectral display for each band, have an overall gain control, and have the ability to drive a pair of headphones. We also wanted to have low cost as a priority, since that is a common goal of most electronics. Once we ensured we had the basics of the project were complete we would then focus on the specs like THD, power consumption, and dB range for cut and boost. A working design was the most important task we sought out to complete, and improving on the design would come once we were ensured of a functioning device.

The first stage of the design was to come up with an overall block diagram of what the project entails. The block diagram for our 5-Band Graphic Equalizer is shown below.



As shown above, the input signal from the audio device goes immediately into the overall gain control. This signal is also buffered to ensure a clean signal and is also a good engineering practice. As discussed later in the report, having the overall gain control at the input stage also aided in meeting project specifications.

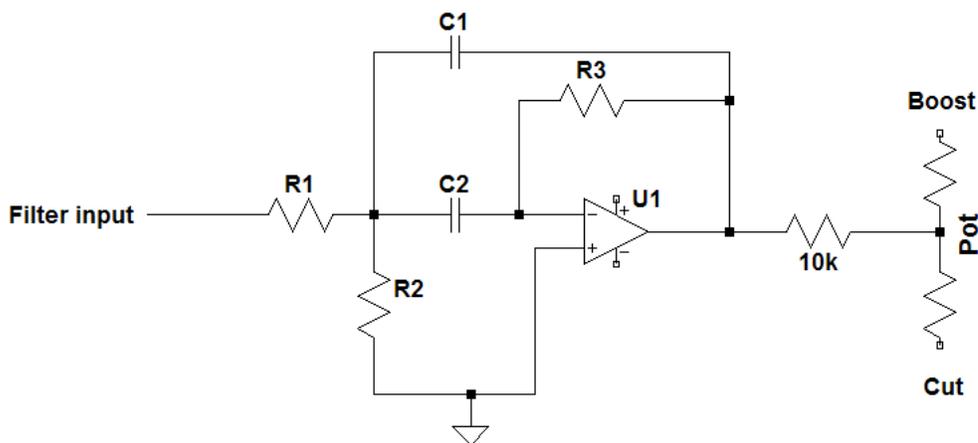
The output of the overall gain stage then goes into the filter bank, which is the main part of the equalizer. Also note that the sliding potentiometers are incorporated into the filter bank to provide the cut and boost of each filter band. The design of these filters will be discussed in detail in the report. All five filters used were bandpass two-pole filters and the center frequencies will also be discussed, and were determined based on the audio range from 20-20kHz.

The output of the each filter also gets sent into an LED display that will give a visual representation of that spectral band. The output of all the filters will then be recombined and will drive a set of speakers. This will give an audio representation of the filtered signal and the speakers will allow us to hear the cut or boosting of each band of frequency.

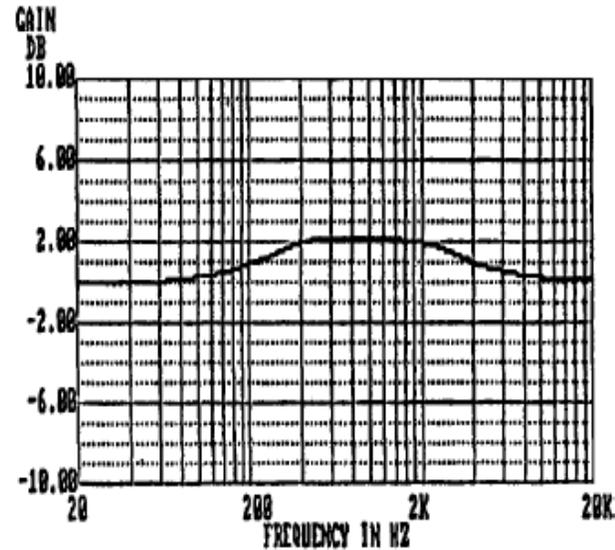
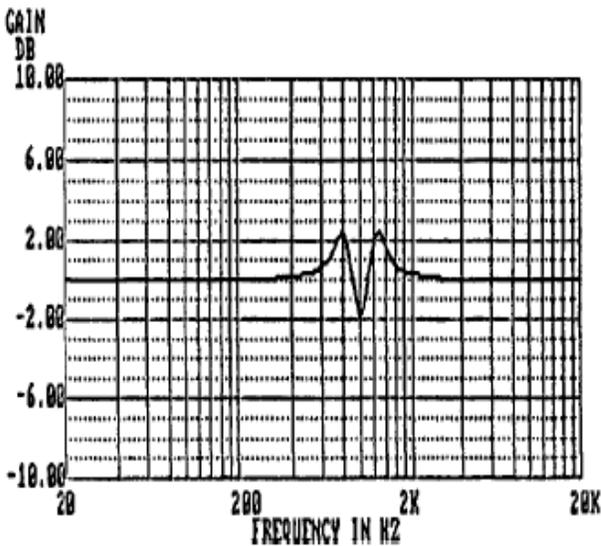
The remainder of the report will go into detail of each stage of design. Each stage discussed will include the parts used and will discuss the overall operation of each circuit involved. The problems that arose in the design process as well as the tradeoffs that were made in order to get a working design will also be discussed. The report concludes with performance measurements of our equalizer and compares them to the specifications we set out to meet.

FILTERS

Because we are building a five band graphic equalizer, we are going to need five separate filters, each with a different center frequency. We chose our frequencies based on industry standard values and came up with center frequencies of 63Hz, 250Hz, 1kHz, 4kHz, and 16kHz. The next step was deciding which type of filter to use. After some brief research, we decided to design multiple feedback (MFB) bandpass filters. The circuit for this filter topology is shown in the figure below.



This design allows us to design a bandpass filter with only operational amplifier. Another positive with this design is that it allows us to design a graphic equalizer with a constant Q. Most conventional graphic equalizers have a Q that is dependent on the setting of the potentiometer, but this design will maintain the same Q at all settings. This means that specific frequencies can be dealt with regardless of the level and will make room equalization far better behaved. This point can be demonstrated with the following figure that shows a constant Q graphic equalizer (left) and a conventional graphic equalizer (right), both with three adjacent potentiometers set to +3dB, -3dB, and +3dB.



control of specific frequencies. Determining the Q required is the first step of the design process. Because we are only using five bands, a low Q is going to be required. A Q of approximately 1 would give us a decent response. Using such a low Q however negates some of the benefits from using a constant Q design because it will make the filter response wider, and will decrease the amount of tight control that would be obtained with a larger number of filters and a higher Q.

One downside to the MFB filter is that the design equations can become tedious when calculating for a certain set of design parameters. The following formulas are used to calculate the component values and design parameters of each filter.

$$R1 = Q / (G * 2 * \pi * f * C)$$

$$R2 = Q / ((2 * Q^2 - G) * 2 * \pi * f * C)$$

$$R3 = Q / (\pi * f * C)$$

$$G = 1 / ((R1 / R3) * 2)$$

$$f = (1 / (2 * \pi * C)) * \sqrt{((R1 + R2) / (R1 * R2 * R3))}$$

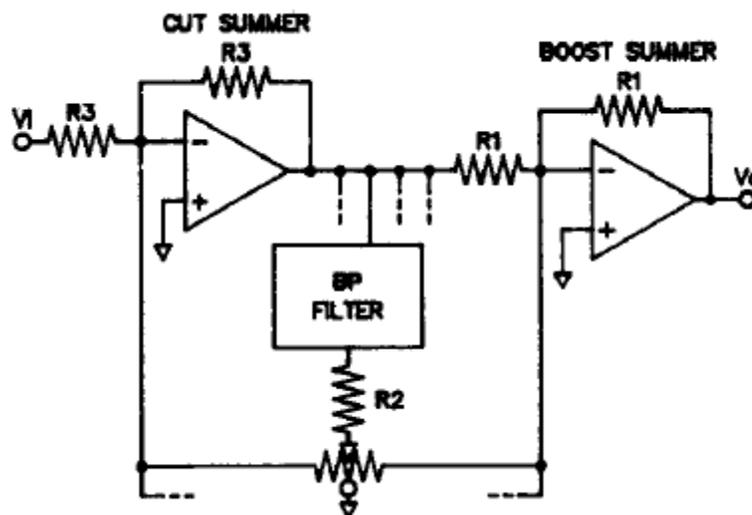
To go through the equations, we knew the Q should be 1, we wanted unity gain ($G=1$), and we selected a value for the capacitors that would give reasonable values for the resistors. Below are the values that we calculated for our design.

	R1=R2	R3	C1=C2
63Hz	25k Ω	50k Ω	100nF
250Hz	6.3k Ω	12.7k Ω	100nF
1kHz	7.2k Ω	14.5k Ω	22nF
4kHz	40k Ω	80k Ω	1nF
16kHz	10k Ω	20k Ω	1nF

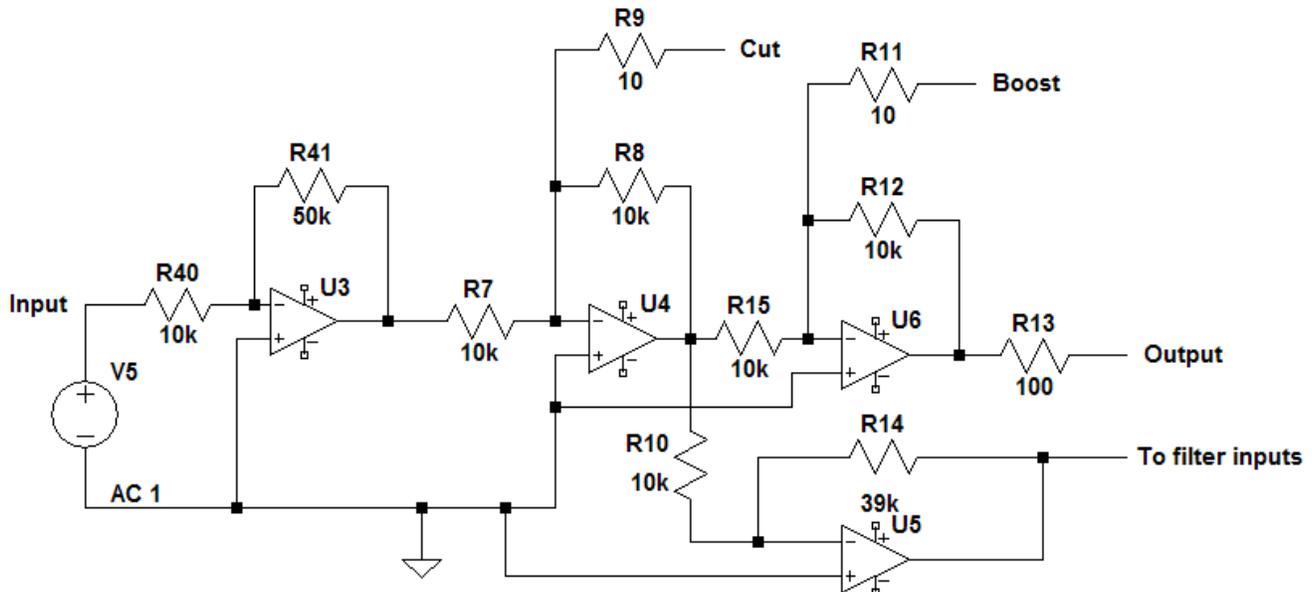
Decreasing the capacitor values increases the resistor values for any specific frequency and care must be taken, especially when using multiple filters, that the resistor values are not too low to cause loading on the input op amp.

IMPLEMENTATION

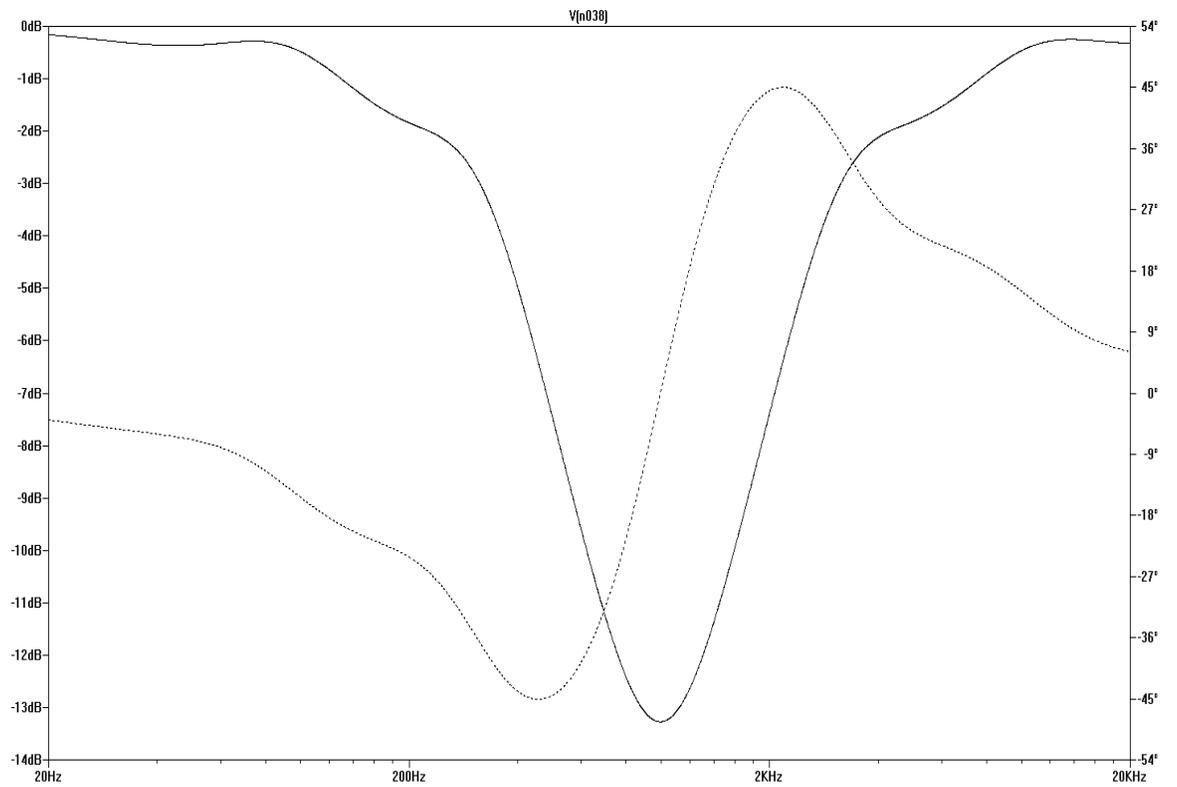
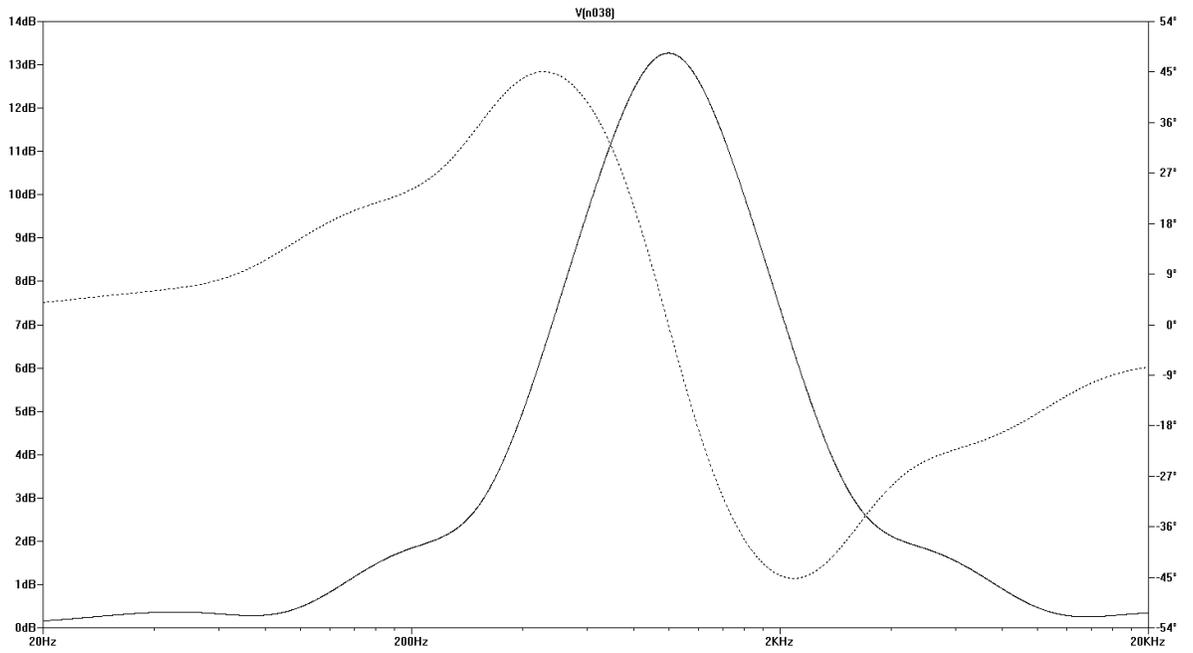
Now that we have our filters sorted out, we need a way to recombine each filter output to form a resultant total output characterized by boosting and cutting certain frequencies. The output will be recombined by electronically summing all of the filter outputs together. In order to accomplish this, any number of filter sections can be paralleled in between two inverting summing amplifiers. A slider potentiometer can then be used to feed the output of each filter section to either the first summing amplifier for cutting or the second summing amplifier for boosting. Leaving the potentiometer in the middle will result in an output that is neither cut or boost. The following figure shows the basic circuit topology that is described above.



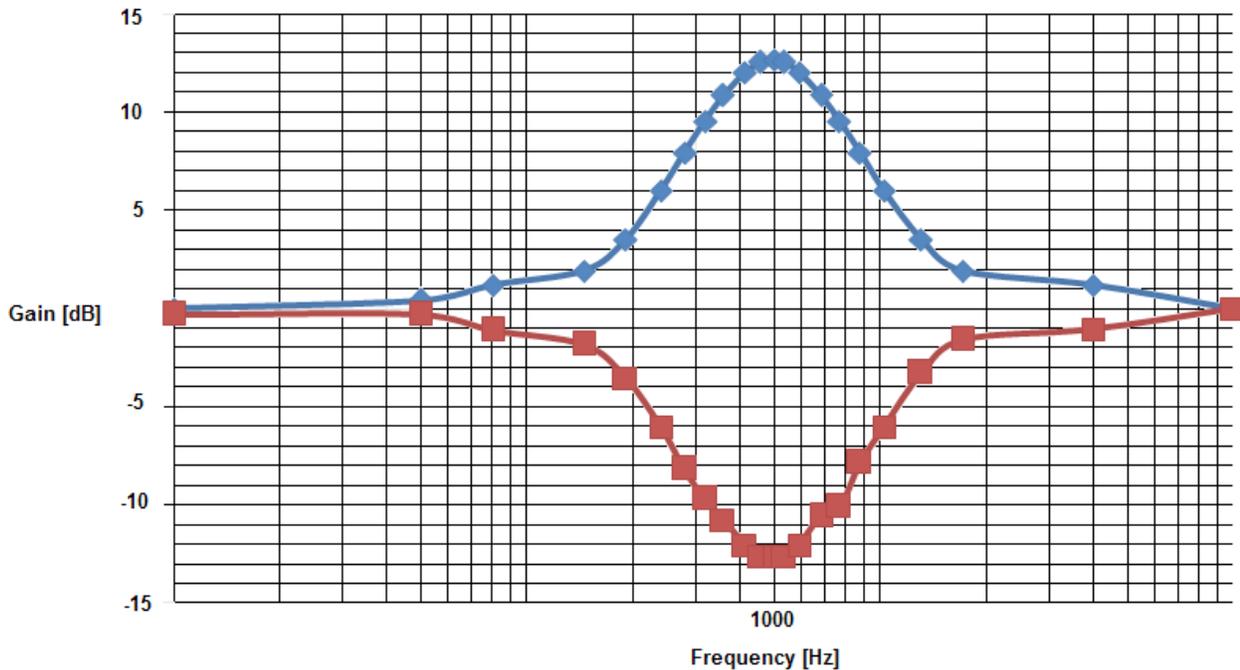
Because we used the MFB bandpass filter, which is an inverting filter, the input into each of the filters needs to be inverted by adding an inverter in series with the inputs leading to all of the filters. Our final design can be seen below.



There are a few important things to note with our final circuit design. The topology used allows the cut and the boost to be symmetrical. The addition of the inverting amplifier at the beginning is added to meet the gain specification of 10dB and sets the input impedance at 10k Ω . The 50k Ω feedback resistor shown in the circuit is actually a potentiometer and can be used as a volume control. The cut summing amplifier and the boost summing amplifier allow the input signal to pass through with unity gain, although with a 180 degree phase shift. It is also worth noting that the inverting amplifier that feeds the filter inputs sets the overall cut and boost magnitudes. The feedback resistance of 39k Ω allows a cut or boost of 12dB. The following two graphs are computer simulations done in Linear Technology's LTSpice, showing all bands set to the 0dB point except for the 1kHz filter set to full boost and cut, respectively.



The next graph shows the curves from our actual design from points showing the equalizer under full boost and cut that were measured with an oscilloscope under the same conditions that are described above.



It can be seen that the results are very good and are close to what was simulated in LTSpice. The Q can be easily calculated by dividing the center frequency and the difference between -3dB frequency points on either side. The center frequency is 1kHz and the -3dB points are approximately 1.5kHz and 500Hz, which gives a resultant Q of approximately 1, which is what we designed each of the filters to be.

CHARGE PUMP

The design proposed for the five band equalizer required a bipolar power supply from +9V to -9V. In order to achieve this parameter, it was necessary to obtain a negative rail from a single unipolar positive supply via DC to DC conversion. This was done utilizing the TC962 high current charge pump.

Selection for this device hinged primarily on the maximum current able to be provided by the device as well as the viable voltage range. The TC962 possessed the highest maximum output current of all devices considered and was able to be powered from 3V to 18V.

The circuit used to implement the charge pump was taken directly from the datasheet and is illustrated in Figure 1. A photograph of the actual circuit is shown in Figure 2. Not shown in the schematic is a ground connection to pin 6 of the charge pump. This connection selected an oscillation frequency of 24 kHz rather than the default 12 kHz. This was done in order to eliminate buzzing through the speakers from noise on the power rails.

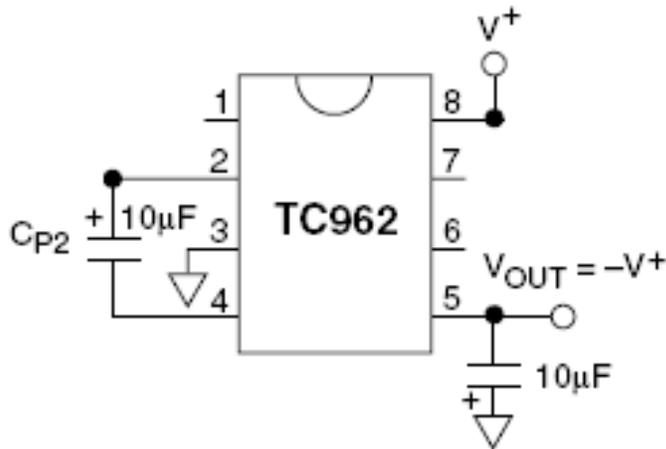


Figure 1. Charge pump schematic connected to produce -9V rail.

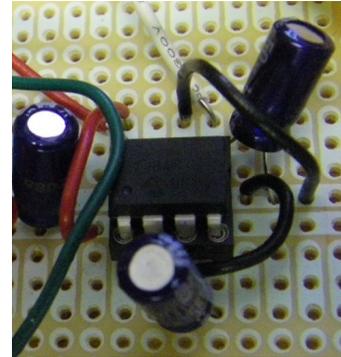


Figure 2. Actual charge pump circuit

LED DRIVERS

Part of the design goals for the five band equalizer was a graphic display. For each band a graph resolution of 6 bars was required. In order to achieve this, packaged LED drivers were utilized. The product selected was the LM3916. This chip operated well within our voltage range, was capable of powering up to ten LEDs, and possessed an adjustable voltage and current reference in order to control the brightness and sensitivity of the LEDs. Additionally, the chip was capable of operating in bar mode or dot mode. Dot mode was selected in order to conserve power.

The LED drivers were connected initially to reflect the example circuit provided in the datasheet. Figure 3 depicts this circuit. A few minor changes were made include a signal input buffer shown in Figure 4. This input buffer eliminated attenuation at high frequencies and blinking at low frequencies. Additionally, an input diode allowed only the positive side of the signal to pass into the driver. Resistor R2 was also shorted in order to achieve the peak sensitivity for the LED levels. LEDs number 1 and 2 were also eliminated due to lack of space. These circuits were repeated five times, once for each band in the equalizer.

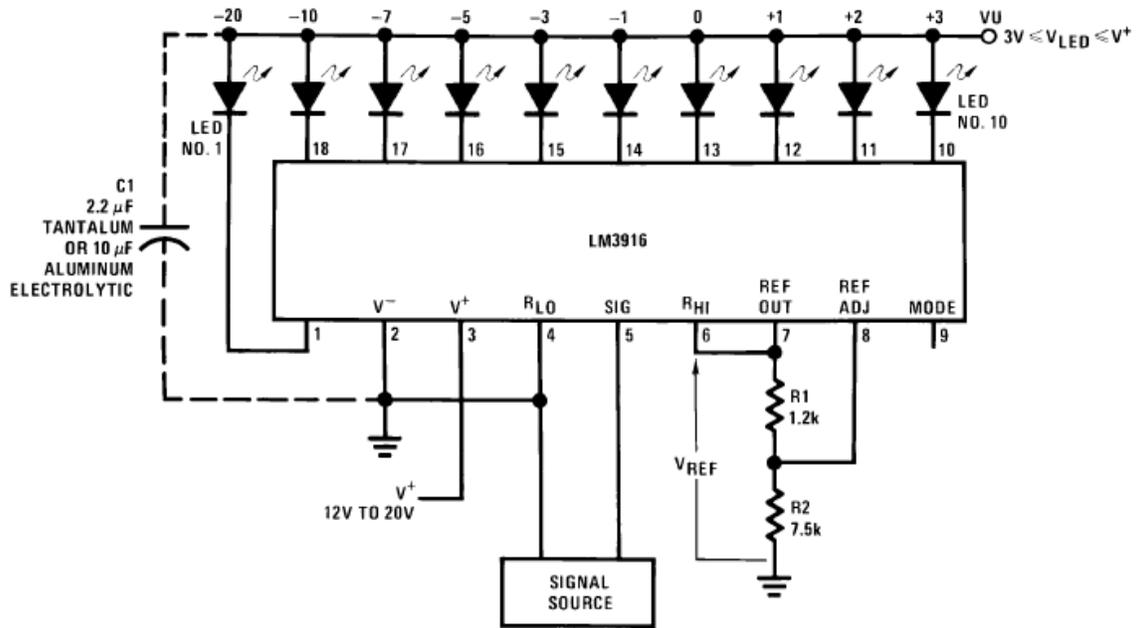


Figure 3. LED Driver circuit.

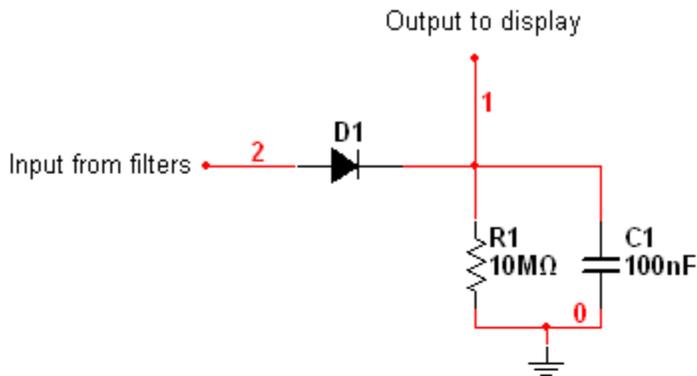


Figure 4. LED driver input buffer circuit

COMPARISON

Our design met most of the original specifications of the project. The table below compares these values.

Parameter	Goal	Actual	Units
Input Impedance	10k	10k	Ω
Output Impedance	3.2 max	Low	Ω
Frequency Response	± 1.5 max	± 0.5	dB
EQ Range	± 12 min	± 12.3	dB
Gain Range	± 10 min	± 12	dB
THD	0.1 max	0.02	%
Noise	-133 max	-141	dBV/ $\sqrt{\text{Hz}}$
Bar Graph Resolution	6	8	
Power Consumption	1 max	1.05	W
Cost	100 max	76.34	US Dollars

The spec for the input impedance was the easiest to meet, being achieved with a resistor on the input. The output impedance was estimated based upon the datasheets from the op-amps that were used in the project. The frequency response of the project could actually be adjusted, due to the placement of the gain stage in the circuit. The range of the EQ adjustment was measured by inputting a 1 kHz signal at 1V to the circuit and measuring the maximum and minimum values that could be achieved while adjusting the slide potentiometer. After converting the voltage to dB, we found that we had an adjustment range of ± 12.3 dB.

The measurement for THD was taken using a spectrum analyzer; however, we believe that our actual value for THD is much lower than 0.02% due to the quality of the equipment in the lab. The measurement for noise was estimated using the op-amp data sheets; however, this could have been measured more accurately using the spectrum analyzer.

The power consumption was the only design goal that was not met. This was measured with the voltage and current readings off of the 9 V power supply in the lab.

The cost, while still under \$100 was fairly high. The following table shows a breakdown of the costs.

Part	Price per 100	Quantity	Total
OPA2132	\$3.36	6	\$20.16
LM3916	\$1.45	5	\$7.25
LEDs	\approx \$0.20	40	\$8.00
TC962	\$2.20	1	\$2.20
Slide Pots	-----	5	\$12.00
18 pin socket	\$0.49	5	\$2.45
8 pin socket	\$0.27	7	\$1.89
Perfboard	\$2.23	\approx 1	\$2.23
		TOTAL	\$56.18

CONCLUSION

During our design process, we strove to meet all of the design parameters specified in the original project requirements. Overall, the only design goal that was not met was the power consumption of the circuit. This could be reduced to be under 1W by the use of smaller resistors and capacitors, and possibly redesigning the circuit to work with fewer op amps.

Unfortunately, the overall design of this project was finished in about 2-3 weeks, even though we had more time than that to finish it. Some of the specifications of the project may have been able to be improved beyond the goals in a troubleshooting process if we had budgeted our time better.

DIVISION OF LABOR

Joe Tearpock – Introduction

Owen and Dylan Gaffney – Filters and Implementation

Justin Spagnuolo – Charge Pump and LED Drivers

Kevin Brown – Comparison and Conclusion