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Abstract **- At George Fox University, all engineering students are required to take the sophomore level circuits course. In an effort to more effectively engage the students in the course, a new final project was designed to leverage the interest in music and audio that is shared by undergraduate students. This paper details the design and implementation of a battery powered, three-band graphic equalizer and amplifier for a portable MP3 player or IPOD® and the associated labs and project that accompany it. There are three circuit design elements of the final project, the first teaching students how to use comparators to create a graphic display, the second detailing active filters, and the final lab describing peak rectifiers and the mixer that ties everything together. As a final project experience, each student is given a kit containing a PCB, a speaker, an on/off switch, a battery-holder, and every electronic component required to construct the final system. Students are also required to write a major lab report detailing the operation of the final project. After providing the experience one time, student engagement was noticeably higher, the results of the final project being significantly beyond the expectations of the course instructors.**

Index Terms - MP3-Player, Amplifier, 3-Band Graphic Equalizer, Active Filter.

INTRODUCTION

Undergraduate engineering students at George Fox University can select to major in one of two concentrations: electrical or mechanical engineering. For either concentration, the first two years of the curriculum are identical. Concentration specific courses are taught in the junior and senior years. Many students enter the engineering program without a clear idea which concentration they will select. It is not uncommon for some of these students to have a lack of understanding about electronics and electrical engineering. As part of the common curriculum, all engineering students are required to take ENGE250: Electrical Circuit Analysis. As students do not decide their concentration until after their sophomore year, it was hoped that an engaging final project in this important circuits course might help to demonstrate some of the thrills shared by electrical engineers and might help students better connect with the discipline.

The circuits course has an accompanying laboratory and the laboratory portion at George Fox University has always had some sort of final design project – however, in the past the project has tended to be part of a more esoteric system that seemed abstract to students. It was recognized that a more challenging and distinct experience where the students took a circuit design from theory to a completely finished product would be preferred. It would be increasingly beneficial if the students were able to keep the project upon completion, thus taking ownership of the entire process.

To capture the interest of the students, the chosen project was a battery powered three-band graphic equalizer and amplifier that could be used with their MP3 players or IPOD's. The engineering department recently purchased a milling machine for creating prototype printed circuit boards (PCB's), and the design of this system could be tested with the new equipment. It was also in the interest of the program to introduce circuits students to PCB's – schematics, parts, soldering, and other elements involved in the proper assembly of a PCB. Thus the final project is not only built on a breadboard, but also soldered to the PCB, giving students experience in soldering as well. This paper details how the final lab project fits into the existing course structure. The three new lab procedures that lead up to the final project are presented, along with the design and implementation of the project.

COURSE STRUCTURE

The first week of the circuits lab begins with Ohm's law. In the following weeks, Kirchoff's voltage and current laws are tested along with nodal analysis, followed by active components such as op-amps and comparators. By the eighth week of the semester, frequency dependent components have been covered through the testing of the transient response of *RC* and *RL* circuits, and the students become proficient with circuit simulation tools. The final six weeks of the laboratory are reserved for the final project. The final project is broken up into two major sections:

1. Lab experiments using a breadboard.
2. PCB assembly and testing.

There are three lab experiments that cover each of the main sections of the circuitry in the final project. In each week of these labs, students work in pairs and build up their breadboard circuit from the previous week. To enhance the design experience, each of these labs is written such that the student must design some of the circuit using their understanding of circuits and mathematical theory rather than simply following a set procedure.

The first of these labs covers the use of comparators, specifically the LM339, and the design of a primitive voltmeter. The second lab introduces the concept of active filters and the theory of their operation; high-pass, low-pass, and band-pass filters are designed and tested. In the third and final lab, the filtered signals are peak rectified to drive the comparator circuit and also mixed using a weighted summer to drive the power amplifier stage. It should be noted that the sophomore circuits course does not cover transistor operation, and it is therefore not required of the students to understand its operation. A lab report is required for each of these labs, as is a SPICE schematic and simulation. A more detailed description of each of the three labs is given below.

As nearly all pieces of the circuit have been introduced and tested in the three weeks prior, week four of the final project is a lecture on the operation of the entire circuit that is to be soldered on the PCB. Each student is then given their kit for the project, and has two weeks to solder it together. The fifth week of the final project is in-lab time both to solder and to help students troubleshoot any problems with their board. It is expected that students will finish soldering the board on their own time, though a person with experience in soldering would find it a reasonable task in the two hour lab period. All of the students have already received basic training in soldering as freshmen in the introductory engineering course.

As additional incentive, the students have two extra-credit opportunities. The first is two describe the theory and operation of the transistor power amplifier, and the second is to build an enclosure for the circuit board and audio speaker. The last day of the lab in the sixth week of the project is scheduled for presentations of the final working circuit and enclosure. The student with the most aesthetically pleasing enclosure and a properly working circuit is given the opportunity to present their work at the George Fox University Engineering Banquet.

LABORATORY 1

The purpose of laboratory 1 is to use a comparator to give a logical (or digital) representation of an analog signal. This involves building the front end of a simple Analog to Digital Converter - one that is simply lacking the priority encoder needed as a final stage.

Figure 1 shows the comparator circuit that will be built in the lab. The students connect each of the four comparators of the LM339 as shown in Figure 10, tying the non-inverting terminal of each comparator together. VCC is set to 5V and the students are to build a voltage divider such that they have four reference voltages, 1, 2, 3, and 4V. The circuit is stimulated by adjusting the DC voltage at the non-inverting inputs by building a voltage divider with a potentiometer and one other resistor.

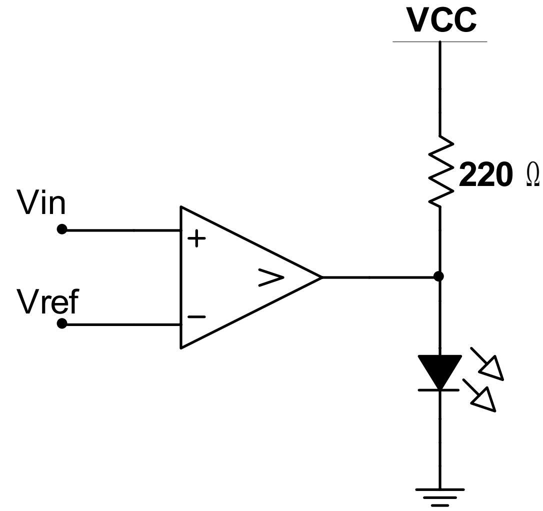

FIGURE 1
COMPARATOR CIRCUIT

The circuit is also stimulated using AC signals that are DC offset to 2.5V with amplitude of 5V peak-to-peak. This allows students to witness the dynamic display. Students are to then record their findings, measuring when the LED's come on and turn off and compare that with the respective reference voltages. Finally, using a circuit simulator, such as SPICE, students are also to build and test the circuit virtually and include the SPICE schematic in their report.

For the lab report, students are asked to explain the voltage divider that they created for the reference voltages. Specifically, "why use 100 kΩ as opposed to something smaller?" Students are encouraged to think about power dissipation. Students are also asked to discuss how using a priority encoder instead of LED's at the output would create an Analog to Digital Converter (ADC). They are then encouraged to think about the size of such a circuit and speculate as to whether or not this is effective.

LABORATORY 2

In laboratory 2, the students are introduced to the principles of active filters. It is explained to the students that an active filter is a filter that is powered by an amplifier that effectively separates the filter from the load. To illustrate this principle the students are asked to consider a simple *RC* filter as shown in Figure 2 and its cutoff frequency as in (1). The student should recognize that the load resistor will vary the cutoff frequency.

$$f_{3dB} = \frac{1}{2\pi RC} \qquad (1)$$

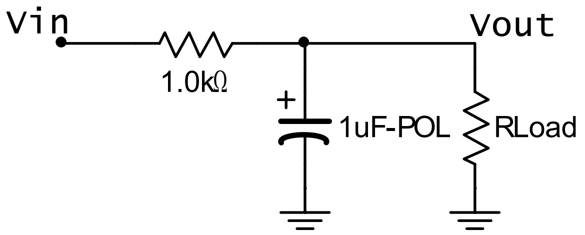

FIGURE 2
LOW-PASS FILTER

The students are then shown another low-pass filter with an op-amp that is used to buffer the *RC* filter from the load and also provide gain (see Figure 2). Students build the low-pass filter shown and are asked to design and test high-pass and band-pass active filters for given cutoff frequencies. It should be noted that in these designs, the filters are on the front end of the op-amp and not part of the feedback loop. The reasons for this are two-fold: The first is to build on the students current understanding of *RC* filters, buffer them and correctly calculate the cutoff frequency given the added gain resistor. The second reason is that the students later change the feedback resistor to a potentiometer; thus putting a filter in the feedback network would not allow for the proper change in gain (from 0 to 5 V/V).

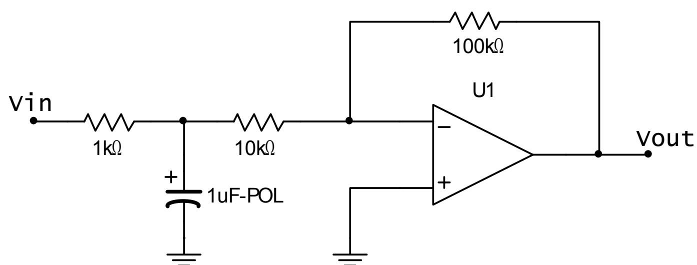

FIGURE 3
ACTIVE LOW-PASS FILTER

LABORATORY 3

The third and final of the project labs is in two parts. First, the students are to build a peak rectifier as shown in Figure 4 and verify its operation. As the theory of diodes is not covered at the sophomore level, the operation of the diode in the circuit is explained to the students.

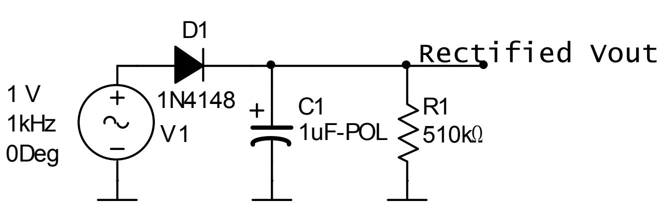

FIGURE 4
PEAK RECTIFIER

Next, the students drive the rectifiers with the output of the band-pass filter that was built in the previous lab. The rectified output then drives the comparator circuit from the first lab. The students are to drive the input to the filter for a range of frequencies and record their observations of the peak rectified output. They are also to vary the amplitude of the signal quickly to mimic an audio source, and should observe that the LED's on the comparator fluidly - but not exactly - follow the amplitude of the signal.

The final portion of the lab requires that the students use their understanding of op-amps to design and build a weighted summer with three inputs, each signal being added together with a 1:1 ratio and unity gain. It is explained to the students that the weighted summer is to combine the low, high, and mid-range frequencies back together, and it is this final stage that will drive the audio power amplifier. After going through the three lab experiences, the students are shown the entire schematic for the final project.

BOARD ASSEMBLY

The graphic equalizer/amplifier circuit consists of (a) a low-, high-, and band-pass filter, each with adjustable gain, (b) a volume control, (c) a weighted summer to mix the filtered signals back together, (d) a one-stage audio amplifier, (e) four peak rectifiers - one for volume, bass, mid-range, and treble - driving (f) four quad input comparators set up as in Lab 1 of the project. The audio input stage is a weighted summer buffer that has an input resistance of 22Ω to model the impedance of headphones often used with MP3 players.

Each student is given a prefabricated PCB and the necessary electronics and mechanical hardware to solder together the final project. The PCB layout is shown in Figure 5 and the final PCB is shown in Figure 6. Figures 9 through 13 show the schematics used to generate the final PCB.

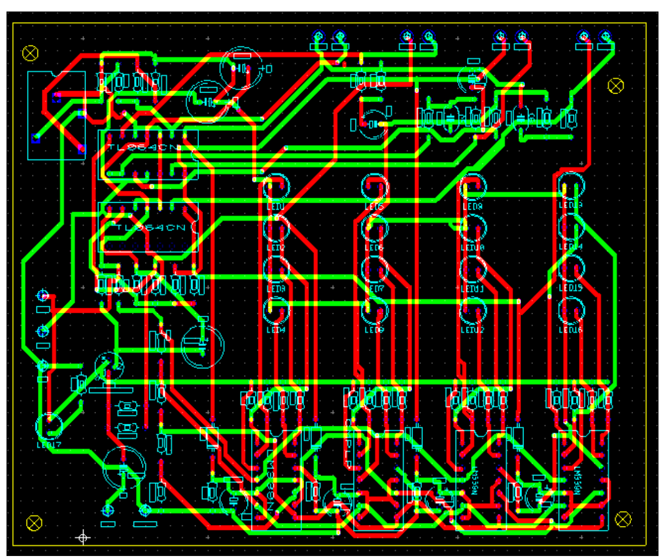

FIGURE 5
PCB DESIGN

STUDENT RESPONSES

At the end of the semester, students were asked to fill out comment sheets regarding both the course and the final project. With regard to the final project, multiple students said that "the final project was excellent." Other students commented that the final project "was a good balance of time and work," "built on the presented material perfectly," "was fun," and that "building something that is useful and works is really cool."

Also, to the instructor's surprise, every student built an enclosure for their project, many of them putting a lot of effort into their final enclosure design. Figure 7 and Figure are the two highlights of the enclosures that were designed.

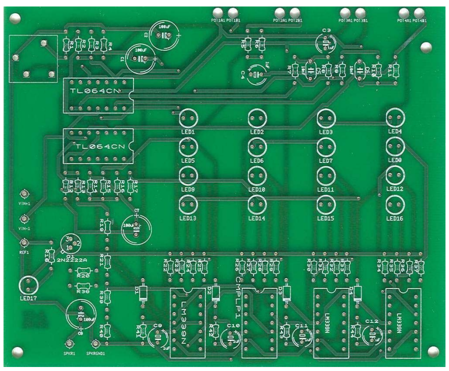

FIGURE 6
PCB BOARD

FIGURE 7
ENCLOSURE DESIGN 1

FIGURE 8
ENCLOSURE DESIGN 2

FUTURE ENHANCEMENTS

In retrospect, the current circuit design has two flaws. The first is that the inputs of the system, though designed to be matched to the impedance of a headphone, are not AC coupled. With such a low input resistance, a capacitor would have to be far too large for low frequencies not to be attenuated. Thus, the input impedance should be increased and the inputs should be AC coupled. Second, the filters do not all have the same amount of gain, which varies between 4 and 5 V/V. The components in the circuit could be adjusted so that each filter has the same maximum gain.

A design component could also be incorporated with the final PCB assembly. Instead of specifying the *R* and *C* values of the graphic equalizer filters to be soldered into the circuit, the students could use their own results from Lab 2 of the project. More lab-time would have to be scheduled in to accommodate additional testing and the potential need for replacing components.

To make the circuit less power consuming, a different transistor power amplifier could be implemented. The amplifier currently in the circuit is a class A; utilizing a class AB amplifier would improve the efficiency of the amplifier. Also, with the use of voltage regulators, the circuit could be powered by a DC wall transformer.

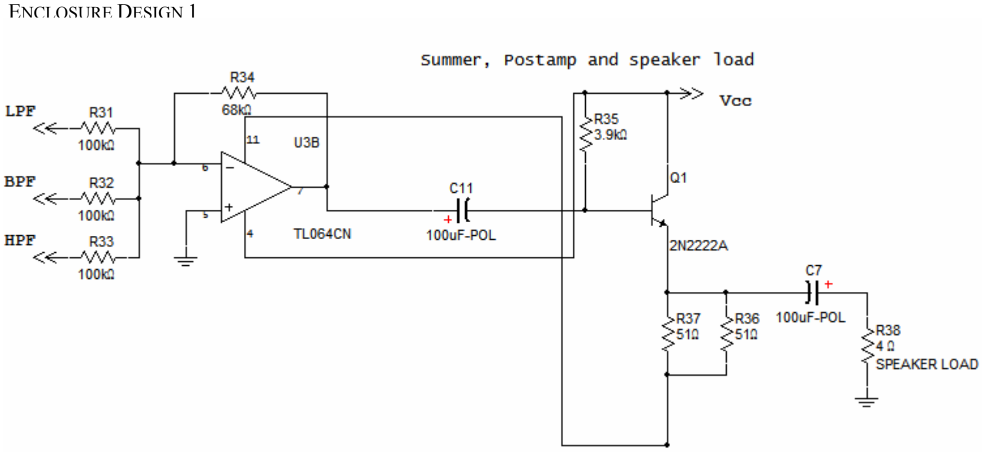

FIGURE 9
SUMMER, POSTAMP, AND SPEAKER LOAD

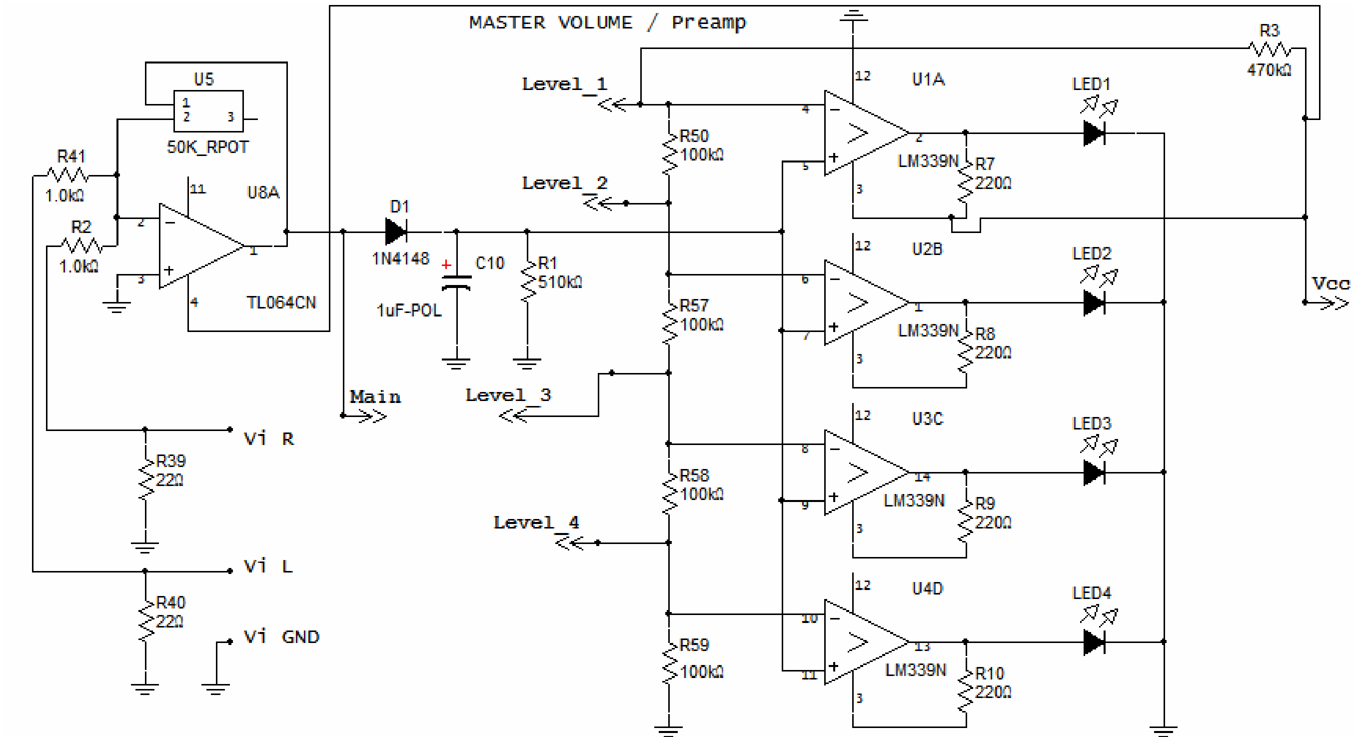

FIGURE 10
MASTER VOLUME AND PREAMP

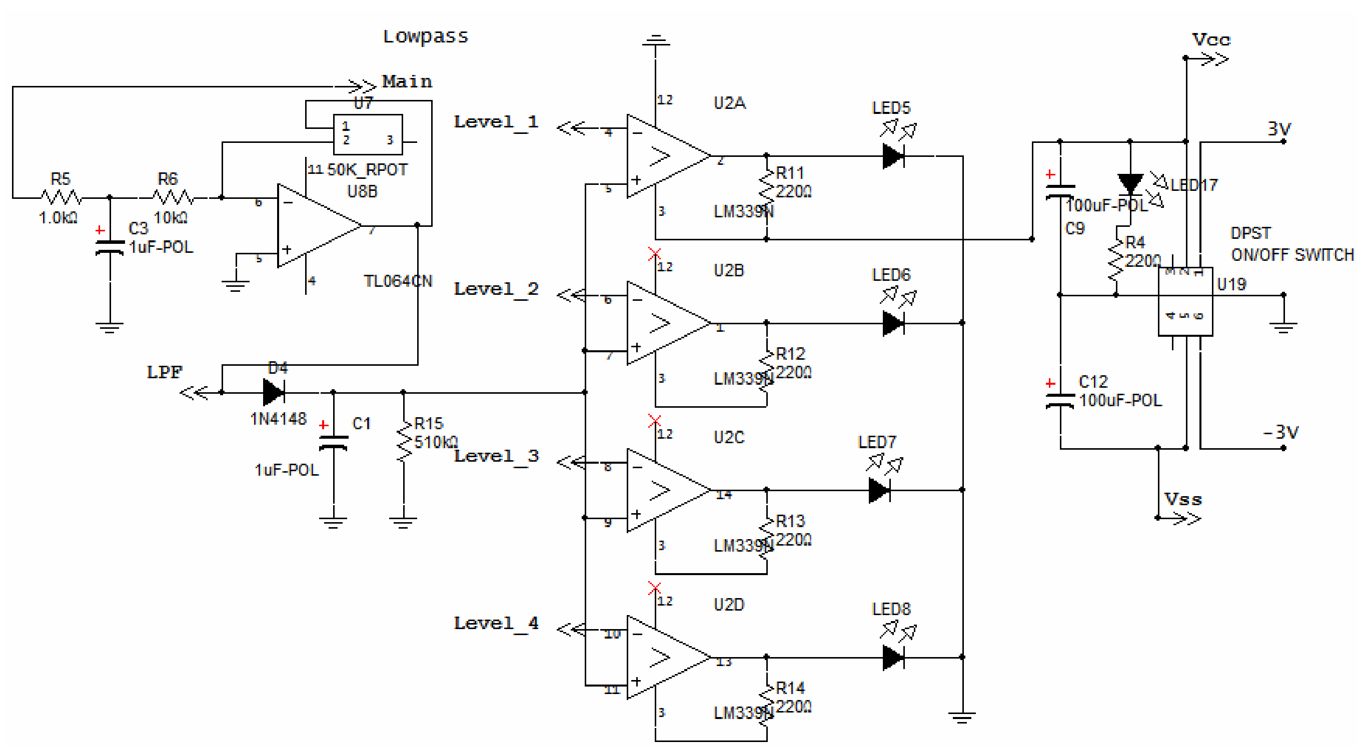

FIGURE 11
LOWPASS FILTER

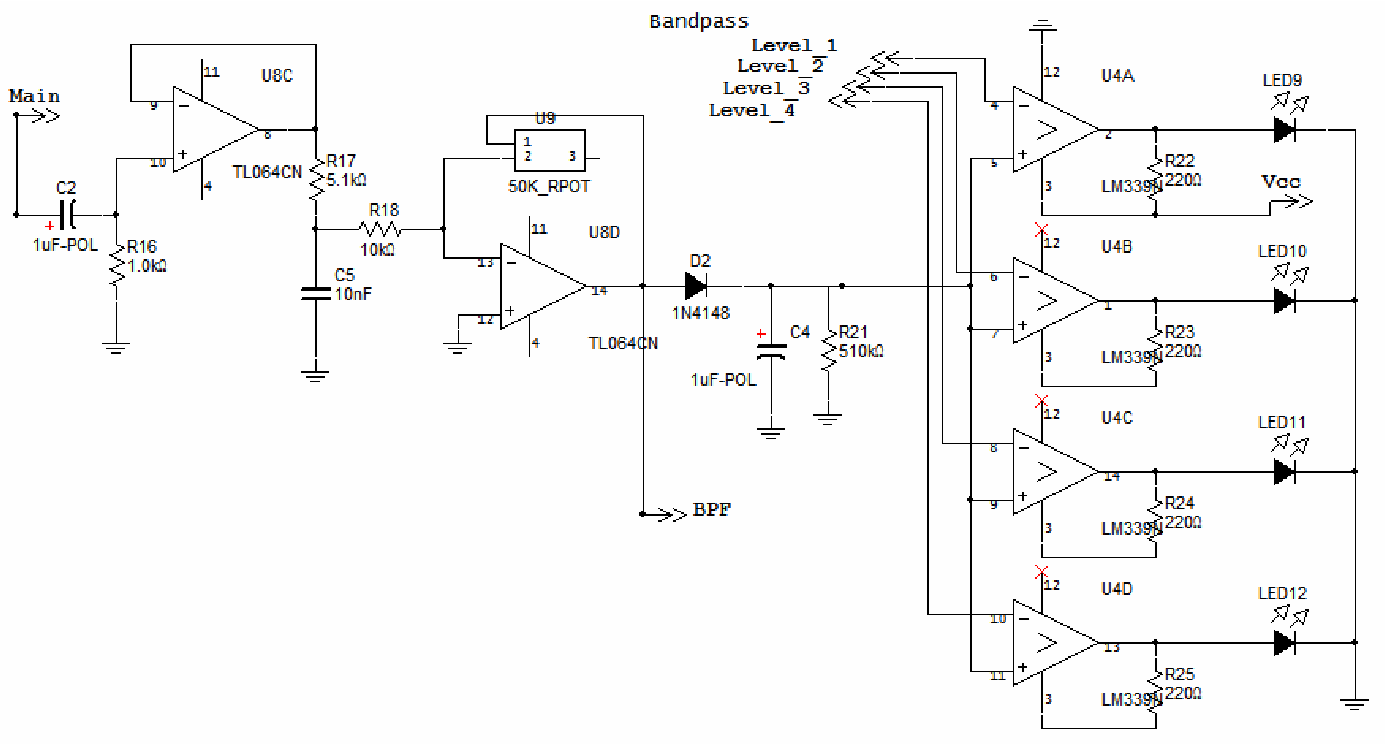

FIGURE 12
BANDPASS FILTER

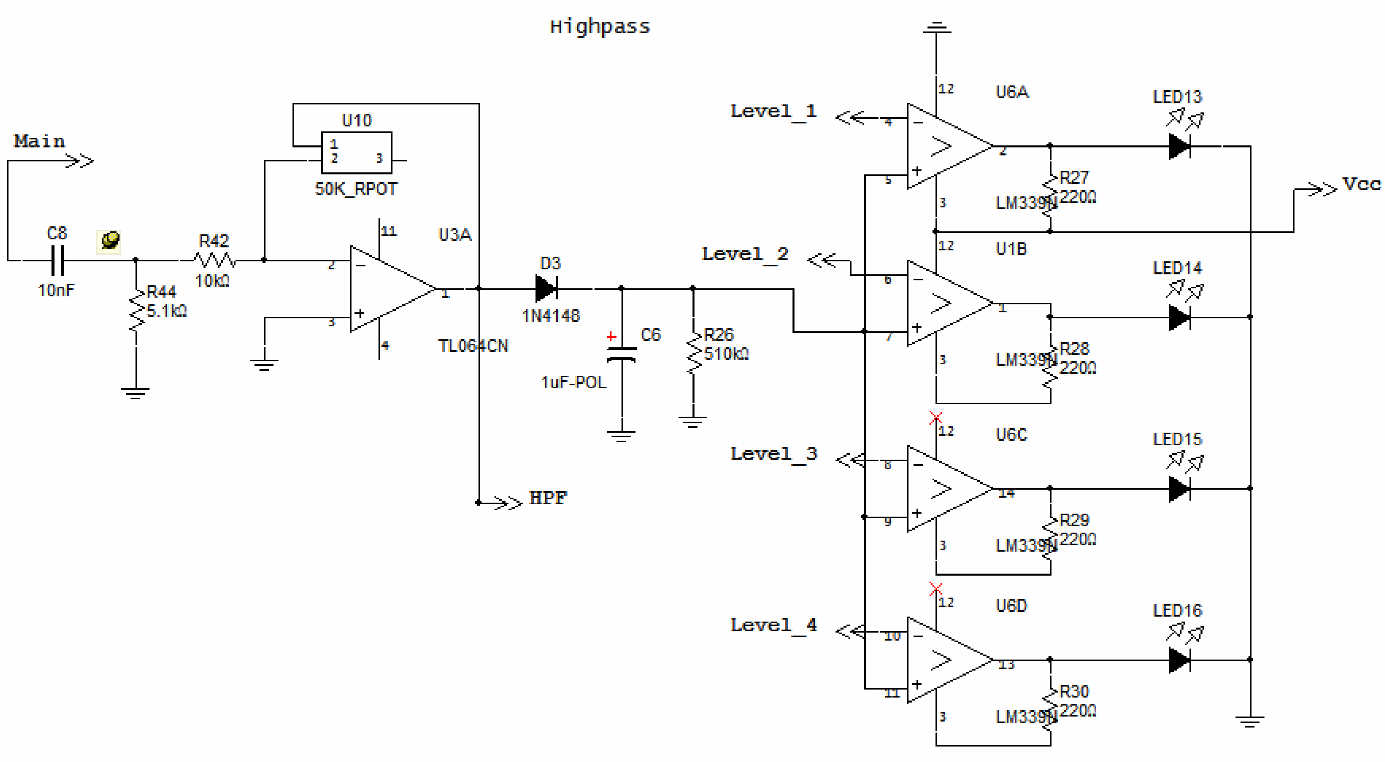

FIGURE 13
HIGHPASS FILTER