Feature—You Can DIY!

Audio Spectrum Display

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This article describes an Audio Spectrum Display that can be configured for International Organization for Standardization (ISO) standard frequencies (i.e., those typically used for graphics equalizers). This system uses sets of 10 LEDs to show the relative amplitudes of frequency bands. The system can be implemented with essentially any number of frequency bands displayed. The standards currently used are 10, 15, and 31 bands. This article primarily refers to the unit I built, which is 10 bands.

Several tools are available that enable you to “view” an audio signal. One of the most common is a volume unit (VU) meter—with either an actual meter movement (pretty rare these days) or an LED display. In either case, the measurement shows the instantaneous total audio signal level. You are viewing the audio voltage over time. This is the same measurement performed with an oscilloscope, only with a significantly different presentation.

Another tool is the spectrum analyzer. This instrument enables you to view the frequency components and their relative levels. Although you can get audio Spectrum Analyzer applications for your PC, tablet or Smart Phone, sometimes it is preferable to have a device dedicated for this purpose.

Using a “real” spectrum analyzer can be very helpful if you need to do a detailed analysis of the frequency response of a system. However, during normal usage of an audio system, such as monitoring the output of a PA system console, it can show too much data to be useful.

Circuit Descriptions

My Audio Spectrum Display essentially contains three circuits in the display assembly: power supply, preamplifier, and filters. Each circuit is described in the article along with some of my design decision reasons. Figure 1 shows the design’s overall block diagram.

The power supply’s system requires two voltages: 12 and 22 V. The power supply circuit can be powered by a single 12-to-18-V, 100-ma unregulated DC wall wart (see Figure 2). If you use a regulated unit, it should be at least 13 V due to the protection diode in series with the input. The 12-V circuit uses a 12-V, low drop-out regulator, which only requires 12.5 V for operation. Its maximum allowable input is 20 V, so you should measure the unloaded output voltage of your wall wart to ensure you do not exceed this value. The 22 V is derived from a boost mode switching regulator and will work with 8 to 20 V. If you already have a 12-V regulated power supply, you can use it by simply shorting the input and output pins of U101 (the 12-V regulator). You can use up to a 16-V supply since the maximum VDD for the opamps is 16 V. However if you use more than 12-V, you may want to change the resistive divider for the bias voltage (R212 and R214) to keep it at 6 V.

In theory, the circuits should work fine with an unregulated power supply. However, I prefer to use simple regulators for most of my circuits. I also wanted to develop a fixed and known voltage for the Texas Instruments LM3915 references. For circuits that use a single LM3915, I typically use its internal reference feature. Since this system uses at least 10 LM3915 circuits I wanted the same reference for all of them. There is no simple way to use the reference from one LM3915 for the remaining ones and keep all the circuits identical. Figure 3 shows the 6-V reference using U201.1.

Both the preamplifier and the power supply are on a single board. The layout is such that the 12-V regulator’s ground and the 22-V switching regulator’s ground are kept separate. They are connected by a single jumper (H102). I did this to keep the LED current and the switching regulator noise out of the analog circuits as much as possible. Make sure you insert a jumper wire between the two points or the circuit will not properly work.

The power supply/preamplifier board has three six-pin headers on it, all connected in parallel. These enable you to connect up to three filter boards without splicing wires. Two pads in the power supply circuit enable you to insert your own power supply voltages for VDD and H2 for HiV.

Most of this system’s passive components are surface mount 0805. However, this circuit’s three large capacitors are thru-hole because the surface-mount packages for the equivalent parts are hard to manually solder.

If you build either the 15-band or 31-band unit, R101 and R102 may need to be decreased in value. I put two resistors in parallel to enable the 0805 parts to handle the higher current, which may be required. The formula in the regulator specifications for the resistor evaluates to approximately: R = 0.18/I. For instance, if each string in a 10-band display draws 5 ma for a total of 50 ma, then R101 and R102 in parallel should be about 3.6 Ω.

Preamplifier

The first stage is a differential amplifier with a gain of two (see Figure 3). The input can be balanced or unbalanced and the load is approximately 10 kΩ. The system was essentially designed to not load the applied signal—assuming it is low impedance. I selected the gain of two so that a 0-dBm signal will enable an almost full-scale indication with the second stage gain set to one.

The second stage has three selectable gain values: 0 dB (×1), 10 dB (×3.16) and 20 dB (×10). For circuit simplicity, the switch’s center off position is the highest gain. The second stage’s output feeds a fixed resistor and potentiometers. Then, the output of the filters can be calibrated to display one LED below full scale when the potentiometer (R213) is fully clockwise and a signal of 0 dBm (0.775 VRMS into 600 Ω) is applied. Stage three is a simple follower that can drive all the filters in parallel.

The value of resistor R210 and trimpot R215 are calculated based on the bandwidth (Q) of the filter circuits. For the 10-band unit, the required Q (and the gain) is 2.5. Ignoring trimpot R215 for the moment, this requires a 5.71-kΩ series resistor with the closest 1% value (lower than 5.71 kΩ) being 5.62 kΩ. The 15-band display requires a Q of 4 (R = 15 kΩ) while the 31-band display requires a Q of 8.7 (R = 45 kΩ). (See the description of the filter circuit for an explanation of the Q values.) These resistor values ensure that a 0-dBm signal applied to the preamplifier will yield an almost full-scale indication.

The purpose of R215 is to enable you to calibrate the system’s gain. If you skip that step, simply short out pins 2 and 3 and use the suggested fixed resistor. If you use R215, you may still want to use R210 in conjunction with it. Suggested values include:

For the 10-band unit: R210 = 2 kΩ, R215 = 5 kΩ

For the 15-band unit: R210 = 10 kΩ, R215 = 10 kΩ

For the 31-band unit: R210 = 30 kΩ, R215 = 25 kΩ

If you want a larger adjustment range, you can short R210 and simply have R215 large enough to cover the range you want.

If you need a different range of input levels, there are several easy ways you can change the circuit. The main criteria is that it takes 7 VPP into the rectifier circuit (U1.3) on the filter board for the display to show full scale. That is about 2.8 VPP into the filter of a 10-band unit. The easiest way to enable a higher input level is to reduce the input stage’s gain by reducing the values of R204 and R211. Another possibility is to change the resistors on SW210 – R201, R202, R207.

With a single supply, one section of the op-amp (U201.1) can be used to develop a buffered bias voltage centered on the power supply. This bias creates a virtual ground so the signals become centered on this voltage. This is why capacitive coupling is used on the preamplifier’s input and output. The 10-µf capacitors have a reactance of 513 Ω at 31 Hz. This equates to about a 0.5 dB drop in signa,l which I feel is acceptable. I would rather have used a transformer, but one that has good low-frequency response is quite expensive.

Filter

The design of the filter circuits is derived from an article, “A High-Q Band-Pass Filter Using Two Operational Amplifiers,” that I found on the web (See Resources). The circuit described in the article uses two op-amps to create a high-Q band-pass filter (see Figure 4). The Q is controlled by the ratio of two resistors (R6 and R7). In this particular circuit, the value of Q is also the gain which, in my opinion, is its main disadvantage. One of this filter design’s nicer features is that the three pairs of resistors and capacitors that determine the frequency have the same value. These two features are not found with many other filter configurations.

I determined the Q I needed by simulating the circuit using LTspice IV. This is a free circuit simulator available from Linear Technology. The simulation uses component values which yield a nominal frequency of 1 kHz to determine what Q was needed so the two “adjacent” frequencies were down about 12 dB. The 12-dB value is not a standard, it is simply what I chose to use. Photo 1 shows an LTspice screenshot of the 1-kHz filter. I have included the LTspice file (Filter LTspice.asc) with the other files for this project.

The adjacent frequencies are determined by the number of discrete frequencies in the display. The unit I built has 10 bands centered on these frequencies: 31.25, 62.5, 125, 250, 500, 1,000, 2,000, 4,000, 8,000, and 16,000. You can see that each frequency is double the preceding one. It is also possible to build 15-band and 31-band displays with these circuits. A spreadsheet that shows the frequencies and suggested component values for each of the three display variations is available online (see Project Files).

The LM3915 has 10 comparators with 3-dB spacing. There are two other devices similar to the LM3915 but with different spacing for the comparators—the LM3914 IC is linear while the LM3916 spacing is similar to the labeling of a VU meter. If you prefer the display be similar to that of a VU meter then use LM3916 ICs instead of the LM3915s. Each of the 10 outputs is capable of driving an LED with up to 30 ma.

This circuit has the LEDs for each band essentially in series. The LM3915 has two modes of operation relative to the LEDs—a bar mode and a dot mode. For most audio displays, the bar mode is preferred. This circuit uses the dot mode, but with the LEDs in series to simulate the bar mode. In some designs, each LED is connected to the same low-voltage power supply as the IC. In that case, each LED will draw its own current from its 3915 driver. Even with only 5 ma through each LED the total current, at full scale, would be 50 ma. Since this system has 10 sets of LEDs, operating them could require up to 500 ma from the power supply (for the 10-band unit) depending on the audio signal being monitored. This would also require the PCB to handle the high current without interfering with the analog circuitry. I chose to use the Series mode so that the same current (approximately 5ma) flows through each of the LEDs for each of the 3915 ICs. To do this, the LED supply must be able to handle the 10 LEDs in series. This can easily be 20 V and is why I have the 22-V boost regulator for the LED supply. The LM3915 upper voltage limit is 25 V, which means that most blue or white LEDs will not work in this configuration.

The LEDs I used are high brightness with a nominal output of 2,600 mcd at 20 ma and cost about $0.18 each. I originally operated the LEDs with 10 ma but found that the display was too bright. I changed R4 from my original value of 1.5 kΩ to 3.3 kΩ, which runs them at about 4 ma and is still is plenty bright! Since the light intensity is proportional to the current, I estimate they are outputting about 520 mcd. The spacing on the PCB is such that you can use T 1.75 LEDs, some of which are about half the cost of the ones I used. Photo 2 shows the unit monitoring some music. You can see that the LEDs are still so bright that their light is somewhat diffused by my enclosure’s front cover. I had to manually adjust my camera shutter speed to keep it from adding to the diffusion but it also makes the enclosure appear darker than it really is.

Mounting the LEDs to the circuit board was one of the more tedious parts of the assembly—especially since there are at least 100 of them! If you use the same LEDs I chose and want to mount them so do not protrude through the front panel, you will probably want 0.4” spacers.

I used the first filter circuit, with a few minor component changes as a display with no filtering (see Figure 5). Obviously, this circuit is more complex than is required for its function but being able to use the existing PCB was too much of an advantage to waste. You can compare Figure 4 and Figure 5 to see the differences. Other than eliminating the frequency dependent components, the only changes are in the resistor values and in shorting out C3. The bill of materials (BOM) file does not list these components.

Circuit Implementation and Construction

During this project’s design phase, I developed several physical iterations of the circuit. In general the basic schematic did not change. The first design had each filter on a separate 1.3” × 2.1” circuit board. Each board would be at a right angle to the display surface with a board-to-board connector between each one. This construction’s main advantage is that you can easily implement however many bands you want by simply changing the number of boards in your system. Two disadvantages are (1) physically attaching the boards to an enclosure and (2) the cost of the board-to-board connectors. Also, the total area of the boards is somewhat greater due in part to the connector.

I finally decided to implement several filter circuits on one board. I designed the boards with four, five, and six circuits each but finally decided on the board with four circuits. The main reason for this selection was the cost of the PCBs. Since I was going to get three boards from OSH Park (www.oshpark.com), I decided to use the board with four filters to implement my 10-band display. The board has a line in the silk screen that you can use as a guide to cut off the last filter circuit. I did this so the board can be shortened to fit in an enclosure.

S1 through S8 shown in Figure 1 are hand-assembled connectors that mate to six pin headers on the circuit boards. I have been using these connectors for quite a few years as the main method of I/O for my PCBs. The least expensive parts I have found are from Jameco and are listed in the BOM. If you want to save a few dollars, you can simply solder the connecting wires directly to the circuit boards. To use these connectors, cut them to size. The pin headers can be cut to size without losing any pins; however, when cutting the housings you will lose one pin per connector. When I first used these connectors, I had a small pair of pliers to crimp the wires to the socket pins. I have since obtained a crimp tool, which makes it much easier.

Figure 1 shows the 0.25” phone and XLR connectors. I have installed both to make the system easier to use. You can use whatever connectors suit your particular application. If you choose to use XLRs, note that the pin connections are in reverse order between them and S2. This is because S2 pin 3 is ground whereas pin 1 on an XLR is ground.

The system’s BOM includes all the parts, except for some mounting hardware, used to build this 10-band display. The frequency specific parts are indicated. The BOM includes the vendor part numbers.

The mounting holes in the boards are for 4-40 bolts. You will need about 15 nuts and bolts. You will also want some spacers for the bolts to keep the PCBs off the enclosure’s surface. The length of the bolts and standoffs will depend on how you decide to mount the PCBs to the enclosure. For this project, I purchased the LM3915 ICs from Tayda Electronics.

The enclosure I selected is transparent blue. I picked this one because I did not want to drill 110 holes in the front panel! The LEDs show quite nicely through the front of the enclosure. They are actually still a bit too bright. If I build another unit, I will probably use standard brightness LEDs! Also, the box is just wide enough to handle the 11 columns of LEDs so I mounted the power/preamplifier board’s controls on the side.

Photo 3 shows the assembled unit. Note that there are only the two 0.25” connectors in the picture. I had not yet mounted the XLRs. You will also see that the power indicator LED is hand-wired onto the PCB. The circuit board on my website (www.qsl.net/k3pto) and the audioXpress ([www.audioxpress.com](http://www.audioxpress.com)) website has been updated to include it. Also, the filter PCB on my unit has an LED spacing of 0.2”, which works fine for the LEDs I used. The PCB on the websites has been updated with larger spacing to accommodate larger LEDs.

All the work files are available from my website as well as from audioXpress. I use the program DipTrace, [www.diptrace.com](http://www.diptrace.com), for all my schematics and PCB designs. A free version of the software is available.

Further Thoughts

I have connected the unit to my home PC’s audio output. It is interesting to watch the display while listening to different types of music. However, I find that I now wish I had built a unit with more bands.

As I mentioned earlier in this article, the current in the high brightness LEDs is a bit too high. The LM3915 ICs have a minimum output current that is still higher than I like for these LEDs. I have since implemented a dimming circuit, which should work fine for standard brightness LEDs. This circuit is not the one on the OshPark website since I have not made any of the new PCBs. Except for the two minor modifications mentioned above, I wanted the PCBs to be the ones I built for this article.

I have also designed a new set of display and filter PCBs, based on the same schematics that enable a narrower assembly. This will enable a 31-band display to be implemented within a 13” width. It also has the dimming circuit I mentioned earlier. Anyone interested in either of these two modifications can contact me directly at k3pto@arrl.net.

Project Files

To download the bill of materials, code, DipTrace files, and frequency information,

visit http://audioxpress.com/ax-supplementary-material.

Resources

DipTrace, [www.diptrace.com](http://www.diptrace.com).

Jameco Electronics, www.jameco.com.

S. Rana, K. Dev Sharma, and K Pal, “A High-Q Band-Pass Filter Using Two Operational Amplifiers,” Journal of Physical Sciences, Vol. 11, 2007, www.vidyasagar.ac.in/journal/maths/Vol11/JPS11-16.pdf.

OSH Park, www.oshpark.com.

Sources

LTspice IV free circuit simulator

Linear Technology Corp. |[www.linear.com/designtools/software/#LTspice](http://www.linear.com/designtools/software/#LTspice)

LM3915 IC

Texas Instruments, Inc. | www.ti.com