IEP Design Project – Sound to Light

The final part of the IEP coursework is a short design project combining a lot of the ideas you have already covered in exercises A to F. It is worth a total of 8 coursework marks and will be assessed based on a short report and video uploaded onto Moodle. Please note that what follows is a guide to how you might approach the project deliverable. Unlike Exercises A to F there are no clear step by step instructions and the approach you take to both the design and the testing is up to you. You can follow the guide below or you may take your own approach to the problem. The only restriction to your design is that it must only use the components found in the ADALP2000 kitset.

1. Introduction

Many different audio devices employ a volume unit (VU) meter to visually indicate the volume level of an audio signal. This is basically a visual indication of the voltage level of the signal in real time and can b indicated by a moving arm meter or LED bar as shown in Figure 1.

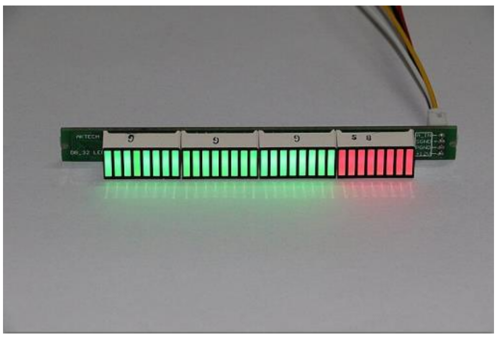

Figure 1 VU Meters, left – moving coil, right - LED

The aim of the IEP project is to design, build and test a simple VU meter using the ADALP2000 kitset of parts, running off a 5V USB phone charger. The basic structure of the VU meter is shown in Figure 2.

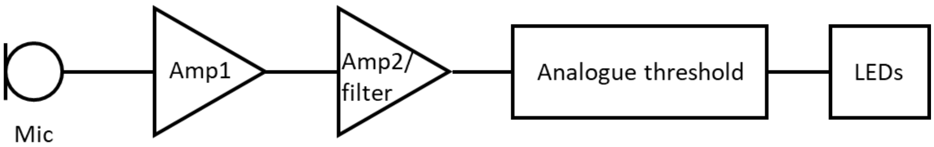

Figure 2 Basic structure of the VU Meter

The electret microphone picks up and audio signal and produces a small voltage which is proportional to the sound it receives. This has to be amplified to a level that can be detected and displayed by the display unit. The signal will also need to be filtered to remove unwanted noise from the dual rail power supply. The display unit will then light up a sequence of LEDs which are proportional to the volume of the audio signal detected like the one in Fig. 1.

The idea is to build on the circuits you have already tried and tested in Exercises A to F. All of the parts you will need are in the ADAPL2000 kitset including an electret microphone. The aim of the project is not only to design and build a working VU meter, but also to document the process and where possible test out different parts of the circuit. The final deliverable is a video of your (hopefully) working VU Meter and a short report (max 5 pages) to be uploaded onto Moodle. Please note the report should take the form of a lab write-up similar to the one you did for Exposition rather than the PowerPoint notebook style of the IEP Exercises

The biggest challenge in this design project is to make sure that the whole project will fit onto the breadboard and that there are no unwanted errors due to crossed-wore shorts or bad connections. As you build each stage try and think of the best possible way to lay it out on the breadboard and conserve space. Useful tips like using a staple to connect parts together as seen in the introductory videos can be a way of reducing some of the wire loops needed to connect various parts of the circuit. A useful tool for planning breadboard layout is PEBBLE from PicAxe which is free to download (and also on the IEP Moodle). Another alternative is Fritzing. The layout of the MOSFET amplifier from Exercise E is shown in Figure 3

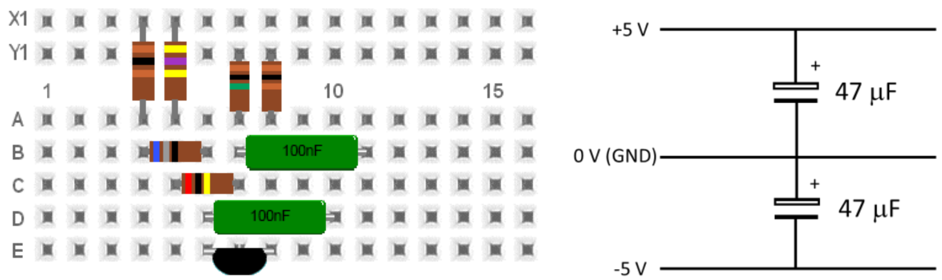

Figure 3. PEBBLE layout of the MOSFET amplifier, Power supply filter caps

You should already have the dual rail power supply mounted on the left hand side after completing Exercise F and this should be set up for +/- 5 V supply rails. Another problem you may face is excess noise due to the power supply which can be reduced by placing two capacitors across the rails as shown in Fig, 3. They should be large values so use electrolytics and can go anywhere on the breadboard but be very careful of the polarity when you connect them up. The remaining parts of the design are based around circuits that you tested in Exercises A to F, although if you think you can meet the specifications using alternative components that are in the kitset, then that is fine as long as you explain what you have done in your report. You should aim to test and characterise each part of the system in Figure 2 on its own before combining them to make the whole VU meter. There are MP3 test files on the Moodle site which contain test tones at 100, 250, 440, and 1000 Hz. These can be played through a phone or computer speaker to provide suitable audio to test the microphone and resulting circuits.

2. The microphone.

The kitset contains a HCM9765-P11-453 electret condenser microphone as shown in Figure 4a. The electret microphone contains inside it an open-drain FET preamplifier, and requires a drain resistor connected between its output and the +5V supply as shown in Figure 4b. The drain resistor is set at 4.7 kΩ. The drain of the internal FET is connected to the (+) wire in Fig. 4. This can be identified as the wire labelled 'Term1' in the datasheet and Fig 4c.

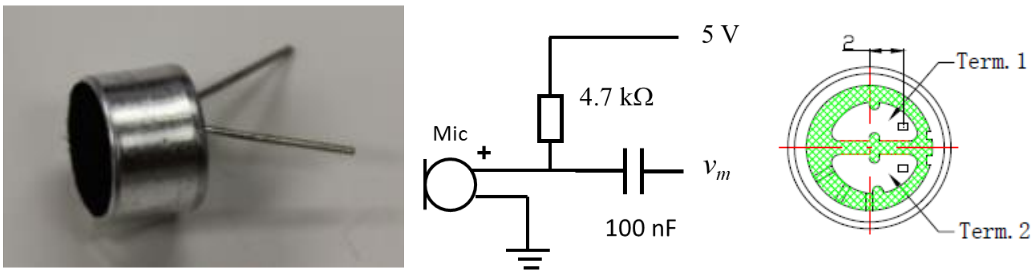

Figure 4 HCM9765-P11-453 microphone, bias circuit and view from below

The microphone is then decoupled from the DC biasing of the internal FET with a 100nF capacitor. The output voltage from the microphone (v_m) is proportional to the audio signal. This voltage is very small, but can be seen on the PicoScope (probe set to x1). Test the microphone using the test tones on Moodle and record the waveforms. You will probably find that the signal is very noisy as it is so small. Some of the noise comes from the power supply circuitry, you should be able to get an estimate of the output voltage of the microphone (the 1 kHz tone is the best) and also an estimate of the frequency of the noise signal. It is difficult to get a consistent signal level to the microphone so you may want to think about how to deliver the audio signal in a repeatable manner.

3. Amplifier #1.

The aim of the project is to get a visual indication of the volume of sound being picked up by the microphone. In order to do this you will need to amplify the voltage from the microphone to somewhere around 500 mV. Hence an amplifier of a gain of at somewhere around 100 (40 dB) will be needed. Given the presence of noise in the signal as well it would be useful if there was a low pass filter somewhere to filter out the high frequency noise. While a gain of 100 is possible to design, it is a more robust solution to use two amplifiers each with a gain of 10 (20 dB) in series (cascade) to amplify and filter the signal.

The first amplifier (labelled Amp 1 in Fig. 2) should have a gain of 10. You have two options here based on what you have designed in Exercise F. The more challenging option is to utilize your MOSFET amplifier from Exercise F as its gain was nearly 10 when bypassed correctly. It can be relocated close to the BoB used for the dual rail supply with the layout shown in Figure 3. Does it matter that it is an inverting amplifier? The other option is to build Amp 1 using an OP27 (or equivalent) OpAmp. You will need to test your Amp 1 to verify its performance. Then you can connect the microphone to it (via a 100 nF coupling cap) and test the two together using the test tones. Another option you may want to consider with the OpAmp based circuit is to make the gain adjustable using a potentiometer.

4. Amplifier #2.

In order to get to around 100, a second stage amplifier is also required and can be designed using the OP27 (or equivalent) OpAmp to give a gain of 10. More importantly this amplifier can also be designed to have a low pass characteristic which will allow you to filter out the noise coming from the power supply. You will need to decide on a suitable 3dB cut off frequency based on the upper limit of the audio signal and the measured frequency of the noise. You can use LTSpice to verify your design and to estimate the suppression of the high frequency component of the noise. Don't forget that you need to design this filter keeping in mind the limited range of resistors and capacitors available in the kitset.

Once you are happy with the design, then you can build it, test it and connect it to the output of Amp 1 (with suitable coupling). Do you get the performance you expect? Does the low pass filter reduce the noise at the output?

5. The LED display (flashing lights).

By this stage you should have an audio signal with a voltage of at around 500 mV. You want a maximum signal, when the audio is loudest of no more than 1 V, however it will depend a bit on your audio source and its alignment with the microphone. The final stage of the project is to design and build a LED bar-graph display which indicates the level of the signal. The higher the voltage, the more LEDs that will illuminate as seen in Fig. 1.

There are several design options here, depending on your own ideas and how much you can fit onto the breadboard. If you have laid out the microphone and 2 amplifiers carefully you should have half of the breadboard left. The simplest display would use 4 LEDs to indicate the volume level however up to 6 are available in the kitset. In Exercise F you designed and tested an OpAmp based comparator which switches its output when a test voltage goes above or below a reference voltage. You will use the same principle here, but with 4 comparators and a sequence of voltage references that govern the threshold above which the LEDs will illuminate. The basic structure of the circuit is shown in Fig 5 (only one of 4 OpAmp comparators shown).

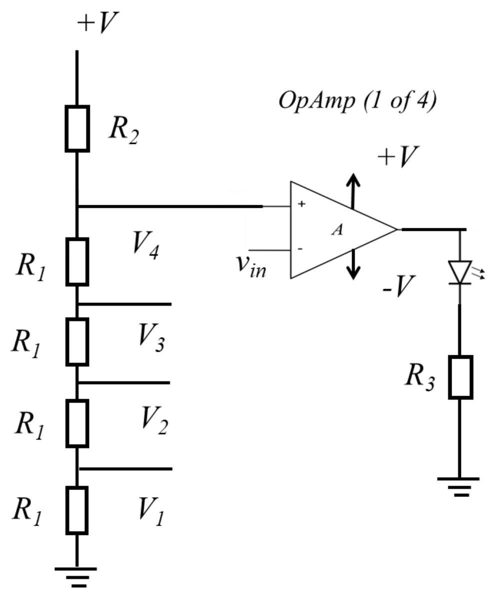

Figure 5. LED display circuit (one OpAmp and LED shown)

The circuit in Fig. 5 is based on a potential divider and 4 OpAmp comparators. The highest voltage to be detected is V_4 which will be defined by the ratio of R_2 and $4R_1$. All resistance should be in the low kΩ range to avoid significant current through the potential divider. The value of R_3 (4 required) should be set at 1 kΩ to protect the LED. There are several choices of OpAmp within the kitset, however given that 4 are required a quad-chip (i.e. 4 OpAmps in one chip) is a good choice. To design the circuit you will need a rough idea of the maximum voltage level that your audio signal might have (ignoring noise and glitches). This is difficult as it will depend on your choice of audio source and its location as well as the amount of gain you have in your amplifiers. A useful tip would be to make R_2 out of a fixed resistor and a potentiometer so that you can adjust the threshold voltage level.

Once you have designed and built the circuit in Figure 5, it can be tested and calibrated by measuring V1 to V4 with the PicoScope. A second potential divider using a potentiometer (50 or 10kΩ across 0 and 5 V with the wiper connected as V_{in}) can also be used to test the comparators to make sure that the LEDs light up in the right sequence. Another test scenario could be to apply a signal from the PicoScope AWG in place of the microphone to see how the level registers on the LEDs as you vary the amplitude. This will also allow you to test the frequency response of your amplifiers and display. Once you have confirmed your LED lights are working, you are ready to test the circuit with the audio input from your amplifier stages.

6. Testing and tuning the VU Meter

Once you have the amplifiers and LED display connected and a suitable audio source playing you should see the LED's illuminate with the sound. Sharp attack noise such as finger clicking, clapping or whistling is a good place to start. You can now adjust your comparator threshold and/or gain to get a suitable signal on the LEDs. You may find that the signal from the microphone has the occasional glitch or high level pulse which will also trigger the LEDs and may even appear as a flicker. There are several videos on Moodle which show the various stages of testing the LED display and audio response. There are many variables in play, so it may not be perfect! Record the output of your LED display as a short 10 second video clip. This can be uploaded onto Moodle as part of your final report submission.

While testing you may find that the LEDs flicker in a way that does not match the audio. This is partly due to noise, but also due to the fact that the meter is responding to a wide range of frequencies across the audio spectrum. A simple solution is to put a low pass filter at the input of the display section to limit the frequencies into the comparator. You may need to experiment with what frequency cut off best suits your display dynamics. Remember if you are using electrolytic capacitors to connect them with the right polarity. Finally you may also find that if you rectify the audio signal with a diode it may improve the response of the meter.

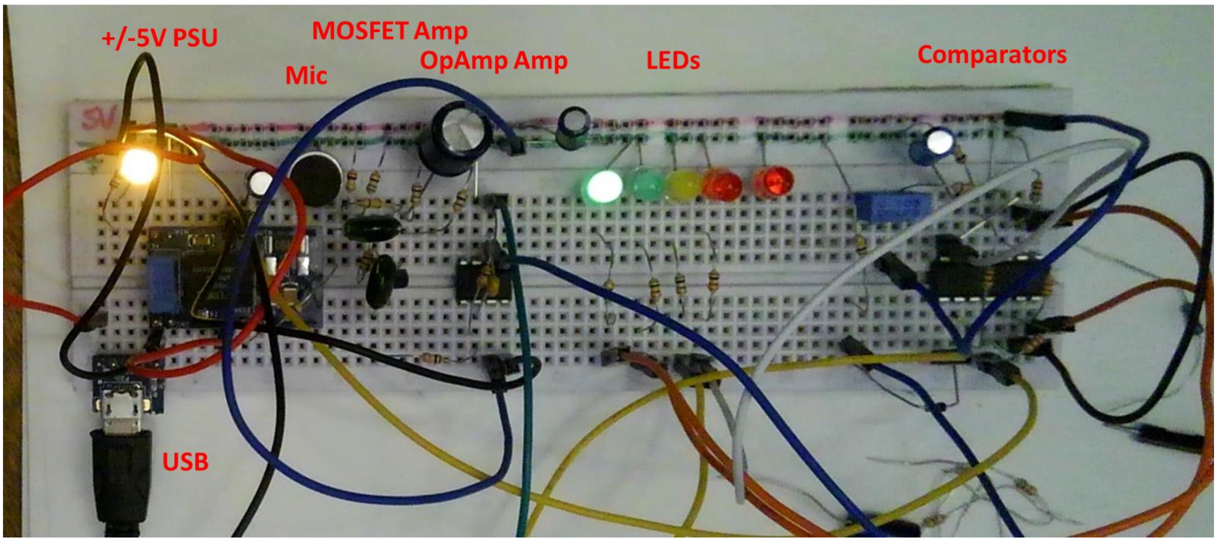

Figure 6. It will work! See videos on Moodle

Once you have completed a working VU meter, record a short video of it working (using appropriately themed music). Write up a brief report (5 pages max) which summarises your design approach and testing of the various stages. Please note the report should take the form of a lab write-up similar to the one you did for Exposition rather than the PowerPoint notebook style of the IEP Exercises. Include a conclusion section that summarises the performance of your meter and any problems that you have faced in the design.

Finally, if you want to go the optional extra distance (for no extra marks) you can try and enhance the performance of your meter. There are many options such as including more LEDs or using the fact that the OpAmp output swings from +5 to -5V etc… Or you could investigate some sort of spectral filtering to give basic bass, midrange and treble responses. Or you could convert it into a simple thermometer to light meter.