# IEP Final Design Project: Sound to Light

24th February 2021 • Lorcan Nicholls • Girton College

## Summary

An analogue VU (Volume Unit) meter is built and tested for its response at various frequencies and sound levels. It is based on a series of comparator circuits connected to LEDs. It was found that music played at a standard loudness for human hearing results in 2 of the 4 LEDs being consistently lit up while louder sounds such as whistling into the microphone light up the remaining lights. The spectral response of the system has a slightly more sensitive response to higher frequency sound, although this may be influenced by the nonlinear sensitivity of human hearing at these frequencies.

## Design Process

The VU meter consists of four main stages: the microphone, the amplifier and filter, the comparator, and the LEDs. Calculations were applied at each stage and verified with testing throughout the building process.

### Microphone stage

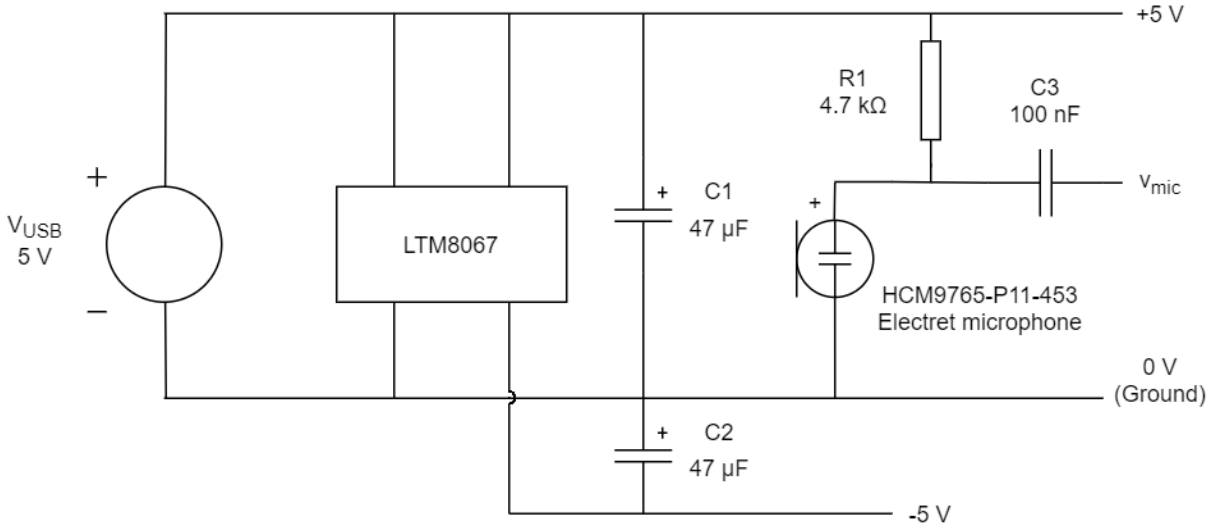


*Figure 1*: Circuit diagram for the bipolar power supply, which takes the USB as the input and outputs to the ± 5 V rails, filters C1 and C2, and the microphone biasing circuit R1 and C3.

## Amplifier and Filter stage

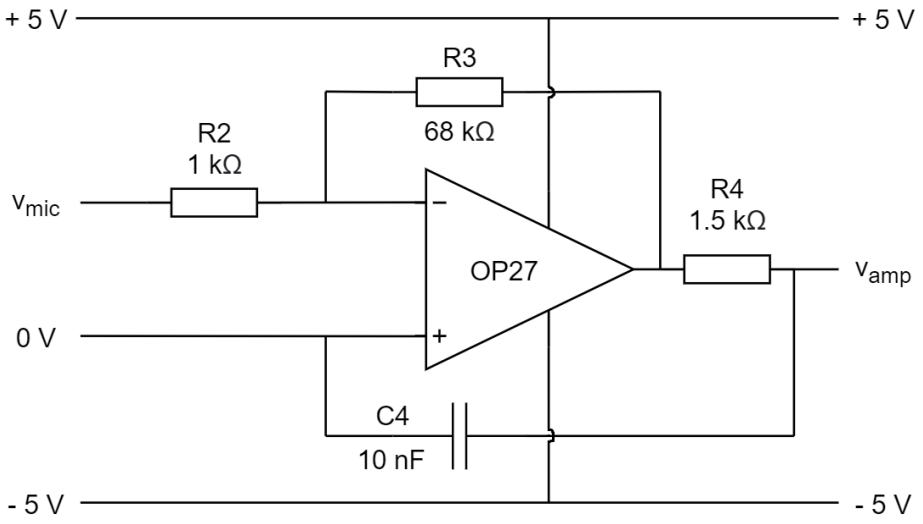


*Figure 2:* Circuit diagram for amplifier OP27 and low-pass filter.

The op-amp is used as an inverting amplifier. The gain is set by *R*2 and *R*3 and is 68. At the output of the amplifier is a low-pass filter, set by *R*4 and *C*4, with a -3 dB cutoff frequency of 11 kHz, which is sufficiently far into the upper-end of human hearing so as to not affect the response to music.

## Comparator and LED stage

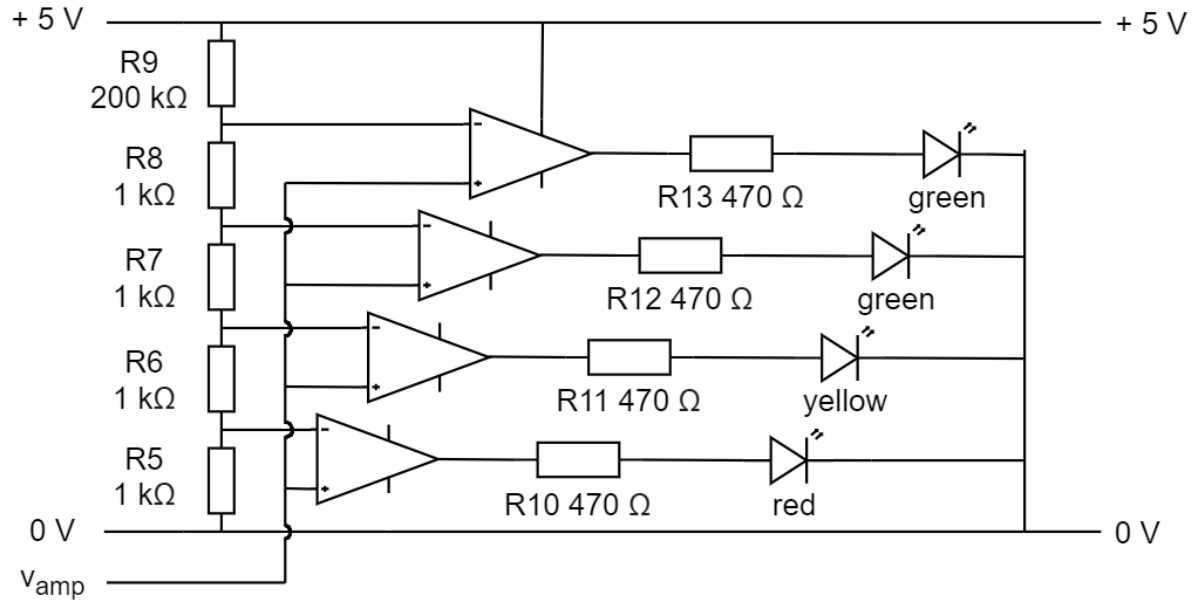


*Figure 3*: Circuit diagram for comparator and LED output stage. Op-amp power supplies omitted for clarity. Each potential divider activates the comparator at an increasing voltage $v_{amp}$.

## Final Design

*(Components are described as defined in Figures 1-3 in the Design Process.)*

The end result functioned as intended, with louder volume sounds triggering more LEDs to light up. The volume response was not quite as linear as expected, with the first two and last two LEDs sometimes appearing to 'group together', becoming lit at the same time. While this may have been due to an unidentified short circuit between these comparator inputs, it is more likely that it is a result of the simplicity and low-resolution of the circuit.

The output of the microphone before its amplification stage was completely unidentifiable: its millivolt-magnitude output was entirely masked by the noise from the power supply. This noise had a frequency of 300 kHz and therefore was easily filtered by *R*4 and *C*4, although some noise unavoidably returned due to the amplifier power supply being connected to the same noisy signal.

Four comparators, whose inputs were set by potential dividers, form the basis of the VU. The potentials at each input were, due to resistors *R*5-9 respectively: 25, 50, 75 and 100 mV. These were lower magnitudes than recommended, but using a second amplifier stage to boost initial gain was infeasible due to space constraints on the breadboard. The picoscope was used regularly to check these voltages.

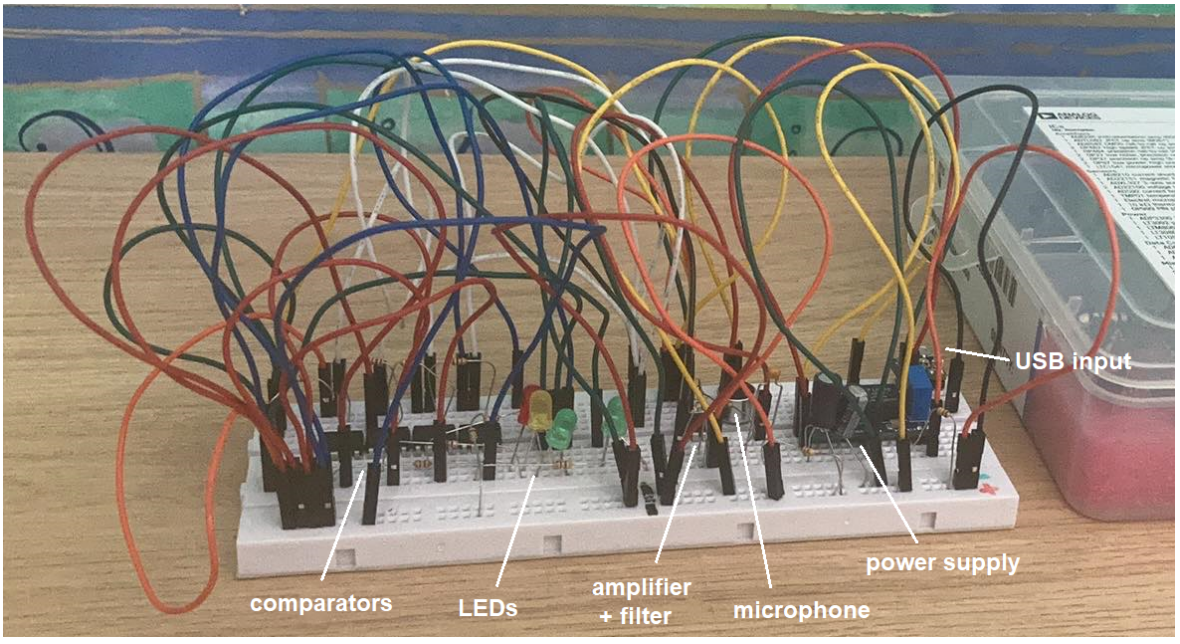


*Figure 4*: VU as built on the breadboard (unpowered).

## Analysis

### Amplitude response

The 1 kHz test tone was played with the microphone at a fixed distance from the speaker. The voltage $v_{amp}$ was recorded and plotted against volume level.

| Volume level (%) | # LEDs lit up | r.m.s. voltage (comparator input) |
|---|---|---|
| 0 | 0 | 16 mV |
| 25 | 0 | 16 mV |
| 50 | 2 | 58 mV |
| 75 | 4 | 102 mV |
| 100 | 4 | 128 mV |

*Table 1*: volume and circuit response.

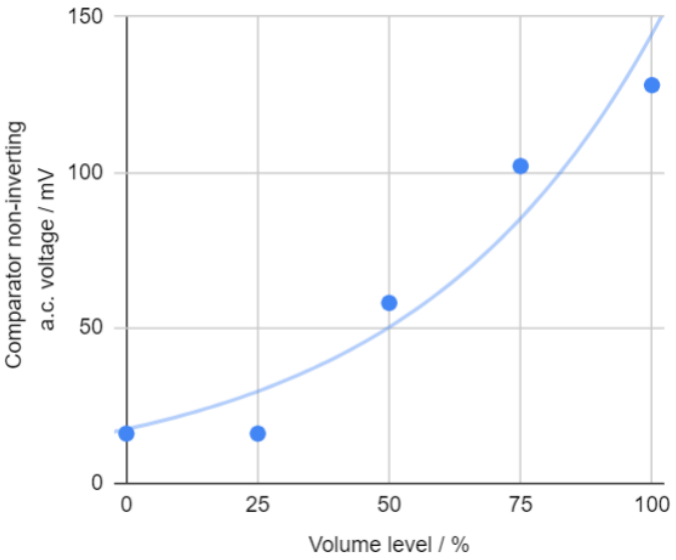


*Figure 5:* plot of r.m.s. voltage vs. volume.

### Frequency response

Songs from various genres and constituent frequencies were played at the same system volume, with the microphone located at the same distance from the speaker. The response is shown in Table 2.

| **Song** | **Genre** | **Frequencies** | **LEDs consistently lit up** |
|---|---|---|---|
| Lauv - Reforget | Pop | Mid-range | 2 / 4 |
| Lauv - Paranoid | Electro | Very high | 4 / 4 |
| Jungkook (BTS) - My Time | K-Pop | High | 3 / 4 |
| Ren - Money Game Part 2 | Rap | Low | 2 / 4 |

*Table 2*: a qualitative test for the system's spectral response to various genres of music.

## Conclusions

I believe this project was a success: the VU meter met the design specifications, and within the constraints of the kitset given, is sufficiently near optimal performance.

Some of the specific points deduced from this project are:

- The microphone is not particularly sensitive: it is only effective at close range. It also responds to 'false-positives' such as blowing, and even sometimes more responsive than to sound.

- Despite being used with a.c. signals, the LEDs respond excellently to persistent signals, with no visible 'fluttering' or random activation.

- At audible frequencies, the op-amps are easily able to amplify with large gains without parasitic capacitances (e.g. Miller effect) becoming an issue.

Some of the key results taken from this project are:

- LEDs placed directly between the +5 V and ground lines without a protective resistor have a 100% probability of being destroyed (sample size: 2).

- Space-limited design is extremely important and design approaches need to be carefully planned before proceeding to the next stage of building.

- Regular testing of a circuit is crucial to ensure the system can operate with random time-varying inputs such as the USB supply.

- 'Sensor circuits' such as this one can easily be modified to respond to changes in light intensity, temperature, magnetic fields, acceleration, using the appropriate sensing components.

- Knowledge of electronics and circuit theory is necessary but not sufficient: real-world issues can occur which need to be handled with care.