Audio Visualizer: Sizing the LED Loudness Ladder

Lucas Krippendorff

Ten LEDs per channel that light in sequence with loudness. No driver IC, just transistors, resistors, and half an LM358 per channel. This is the math behind the resistor values.

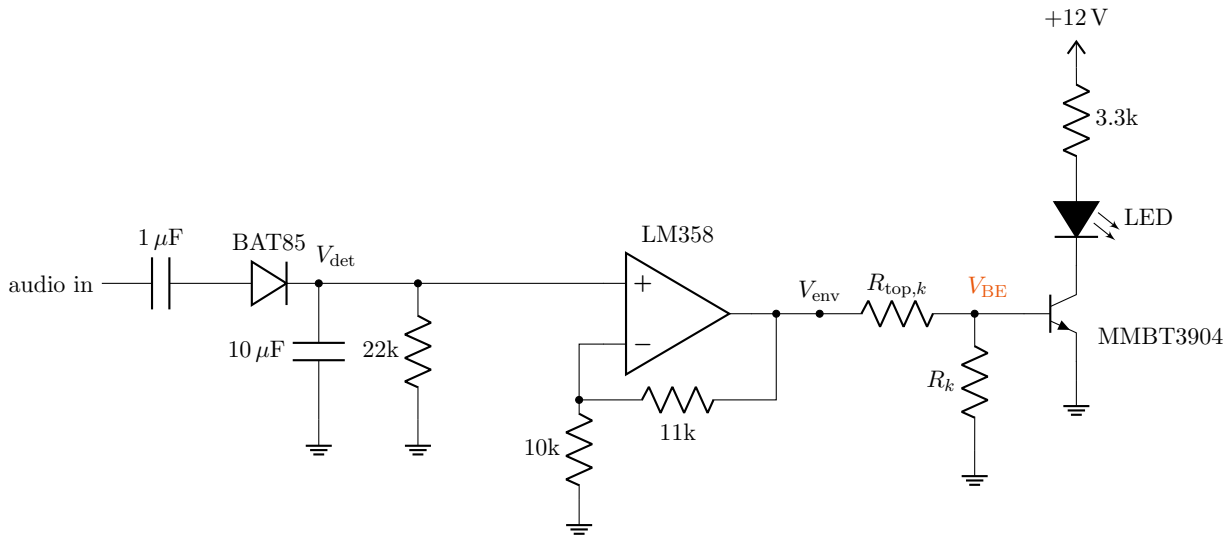

Figure 1: Front end and one of ten ladder stages (one channel of two). The divider pair $R_{\text{top},k}/R_k$ changes from stage to stage. LED k turns on when its base hits V_{BE}; the threshold V_k is not a node, just the V_{env} value that gets the base there.

Getting a loudness voltage

Audio is AC; the ladder needs a DC voltage that tracks volume. A 1 μF cap couples the signal in, a Schottky rectifies it, a 10 μF cap holds the peak, and a 22 kΩ bleed lets it fall ($\tau = 22\,\text{k}\Omega \times 10\,\mu\text{F} \approx 0.22\,\text{s}$). That's V_{det}.

I call $V_{\text{det}} = 5\,\text{V}$ clipping. That's an educated guess: the speakers can theoretically swing 6 V, but the Schottky eats ~0.3 V right after the coupling cap and the other parts in series take their share. This display is purely cosmetic, so being off by a little here costs nothing. 5 V it was.

Log spacing, because hearing is logarithmic

Equal steps in perceived loudness are equal voltage *ratios*, not equal volts. So the thresholds are spaced in dB, the same call the LM3915 bar driver this circuit replaces makes. 30 dB of range, 13

steps, 2.5 dB each:

$$L_k = -30 + 2.5\,(k-1)\ \text{dB}, \qquad V_k = V_{\text{fs}} \cdot 10^{L_k/20}. \tag{1}$$

Filling the 12 V rail

The detector tops out at 5 V but the board runs on 12. An LM358 on a 12 V rail can only swing to about 10.5 V, so I picked the gain to land full scale exactly there: $A = 10.5/5 = 2.1$, built as $1 + 11\text{k}/10\text{k}$. Full scale and clipping are the same voltage on purpose, which makes the top LED the clip light. The op amp also buffers the detector: the ladder pulls its current from the op amp instead of draining the peak-hold cap.

One transistor, three resistors per LED

Each stage is an NPN with a grounded emitter and an LED with its 3.3 kΩ current limiter on the collector. Two more resistors form the base divider that decides when the stage turns on:

$$V_k = V_{\text{BE}}\left(1 + \frac{R_{\text{top}}}{R_k}\right) \quad\Longrightarrow\quad \frac{R_{\text{top}}}{R_k} = \frac{V_k}{V_{\text{BE}}} - 1. \tag{2}$$

A divider can only divide, so nothing below $V_{\text{BE}} \approx 0.65$ V is reachable. Any division under that line simply can't be built. The 13 came from trial and error: with 13 divisions, exactly three (0.33, 0.44, 0.59 V) fall under V_{BE}, and the 10 LEDs I wanted survive. Usable range: −22.5 to 0 dB.

I adjust both the top and bottom resistor per stage: two free values hit each ratio with less error, and it gives me the most flexibility to pick parts JLCPCB stocks in its *basic* catalog (extended parts each add a loading fee). The error column is how far the built threshold lands from the ideal V_k. Worst case is 1.4%, and adjacent thresholds are 33% apart, so turn-on order is never in danger:

LED	L_k	ideal V_k	R_{top}	R_k	threshold	error
1	−22.5 dB	0.787 V	10 kΩ	47 kΩ	0.788 V	+0.1%
2	−20.0 dB	1.050 V	20 kΩ	33 kΩ	1.044 V	−0.6%
3	−17.5 dB	1.400 V	27 kΩ	24 kΩ	1.381 V	−1.4%
4	−15.0 dB	1.867 V	22 kΩ	12 kΩ	1.842 V	−1.4%
5	−12.5 dB	2.490 V	6.8 kΩ	2.4 kΩ	2.492 V	+0.1%
6	−10.0 dB	3.320 V	10 kΩ	2.4 kΩ	3.358 V	+1.1%
7	−7.5 dB	4.428 V	27 kΩ	4.7 kΩ	4.384 V	−1.0%
8	−5.0 dB	5.905 V	22 kΩ	2.7 kΩ	5.946 V	+0.7%
9	−2.5 dB	7.874 V	30 kΩ	2.7 kΩ	7.872 V	−0.0%
10	0.0 dB	10.500 V	15 kΩ	1 kΩ	10.400 V	−1.0%

Collector resistors: $R_C = (12 - 2.0 - 0.2)\,\text{V}/3\,\text{mA} \approx 3.3\,\text{k}\Omega$ per LED. The board carries two identical channels, left and right.

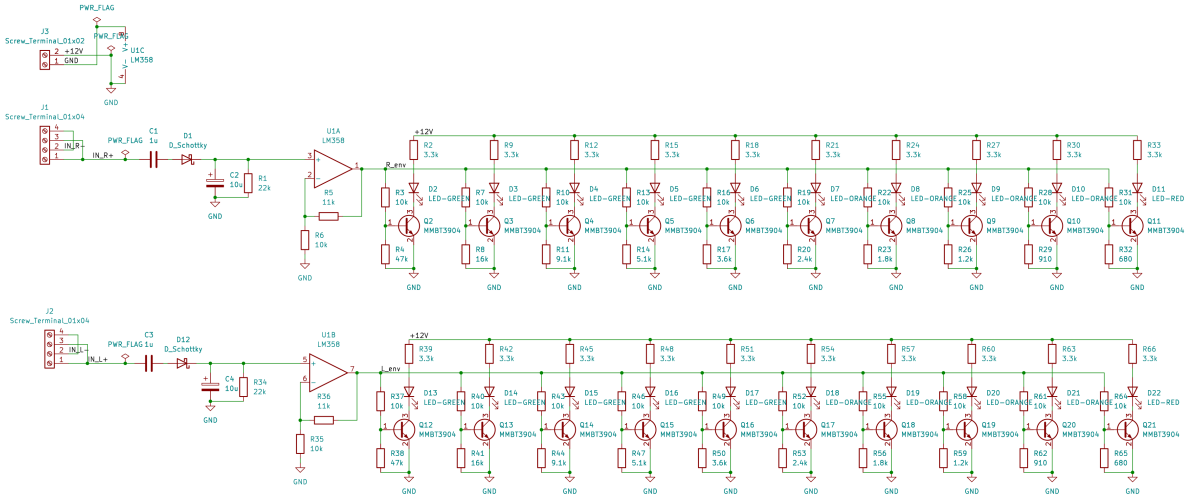

Figure 2: Full schematic: both channels, each half of the LM358 driving its own ten-stage ladder.

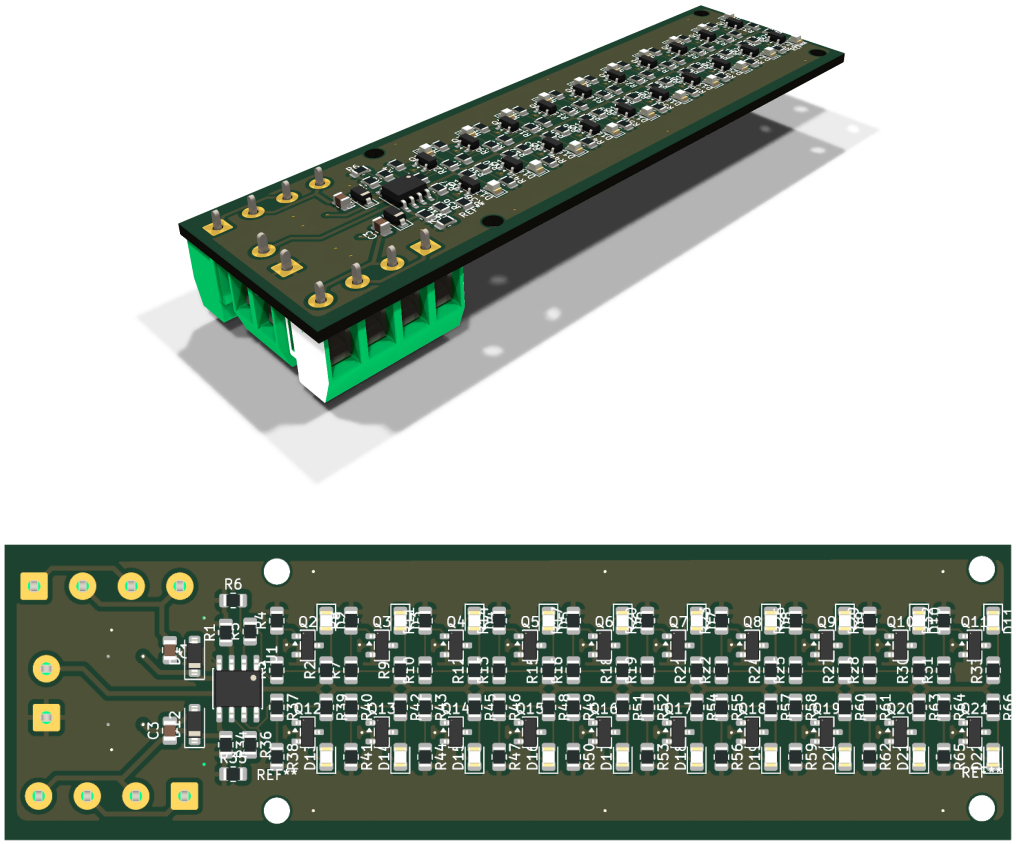

Figure 3: V1 board: two 10-LED channels, MMBT3904 ladder, LM358 front end.