

Summary

Board 1 is a business card sized, two layer PCB that takes power from a 5 V wall adapter and uses an LMC555 CMOS timer in astable mode to blink four LEDs, each with a different series resistor ($10\text{ k}\Omega$, $1\text{ k}\Omega$, 300Ω , and 50Ω). The board worked on the first power up with no rework. The 555 output measured 502 Hz at a 66 % duty cycle, which matches the 481 Hz and 66.7 % predicted from the component values to within the capacitor tolerance. Loading the output with all four LEDs dropped the high level from 4.95 V to 4.05 V, which gives a Thevenin output resistance of about 32Ω for the 555. The output edges are fast (the LMC555 datasheet specifies a typical rise time of 15 ns) and the switching noise on the 5 V rail was about 0.2 V peak to peak.

1 Project Overview and Plan of Record

1.1 Plan of Record (POR)

The board contains:

1. A barrel jack (P1) for an external 5 V AC to DC adapter, with a $22\text{ }\mu\text{F}$ bulk capacitor (C1).
2. A power indicator LED (LED1 with $R1 = 1\text{ k}\Omega$) labeled “5V on”.
3. An LMC555 timer (U1) in astable mode, designed for about 500 Hz and a 60 % to 70 % duty cycle.
4. Four LEDs of the same color driven by the 555 output through $10\text{ k}\Omega$, $1\text{ k}\Omega$, 300Ω and 50Ω resistors, to show how LED brightness depends on current.
5. Two isolation switches (2 pin headers with shorting jumpers): SW1 disconnects the 555 from the 5 V rail and SW2 disconnects the LED loads from the 555 output.
6. Three 4 hole test points for a 10x probe with a short ground spring: the 5 V rail, the 555 output, and the voltage across the $1\text{ k}\Omega$ LED resistor (for LED current).
7. All 1206 passives and LEDs for hand assembly, a solid ground plane on the bottom layer, and my name, board ID and date in silkscreen.

1.2 The 555 timer

The timer used on this board is the **LMC555CMX** (SOIC 8), the CMOS version of the 555 provided for the class. Compared to the bipolar NE555, the CMOS part draws much less quiescent current and has a lower supply current spike on each transition. The four LEDs need roughly 30 mA total when the output is high (estimated in Section 2.4), which the LMC555 can source at 5 V. Its output high voltage drops under this load, and that drop is one of the things this board was designed to measure.

1.3 Timing design

With $R2 = R3 = 1\text{ k}\Omega$ and $C3 = 1\text{ }\mu\text{F}$:

$$t_H = 0.693 (R_2 + R_3) C_3 = 0.693(2\text{ k}\Omega)(1\text{ }\mu\text{F}) = 1.39\text{ ms}$$

$$t_L = 0.693 R_3 C_3 = 0.693(1\text{ k}\Omega)(1\text{ }\mu\text{F}) = 0.69\text{ ms}$$

$$f = \frac{1}{t_H + t_L} = 481\text{ Hz}, \quad D = \frac{t_H}{t_H + t_L} = 66.7\%$$

1.4 What it means for this board to work

Before bring up, I defined working as the following measurable specifications, all verified with a scope rather than a DMM:

- S1. The 5 V rail is present at the 5V test point and LED1 lights when the adapter is plugged in.

- S2. With SW1 installed, the 555 output is a 0 to 5 V square wave at about 500 Hz and about 67 % duty cycle.
- S3. With SW2 installed, all four LEDs blink with visibly different brightness, brightest on the 50 Ω resistor.
- S4. The LED current through the 1 k Ω resistor can be measured at its test point and is on the order of 1 mA.
- S5. The switching noise on the 5 V rail, synchronous with the 555 edges, can be measured and is small compared to the rail.

1.5 Schematic and layout

The design started as the hand sketch in Figure 1a: one LED and resistor branch (repeated for each resistor value) on the 555 output, a first pass current estimate of $(5\text{ V} - 2\text{ V})/R$ for each resistor, and the $1\text{ k}\Omega$, $1\text{ k}\Omega$, $1\text{ }\mu\text{F}$ timing network targeting about 500 Hz and a 66 % duty cycle.

Figure 1b shows the Altium schematic, split into power conditioning, the timer circuit, and the LED loads. The decoupling capacitor C2 sits on the 555 side of SW1, so opening the switch never separates U1 from its decoupling capacitor. Each LED is placed with the resistor on the low side, so the voltage across R4 is ground referenced and can be read directly with a 10x probe at the “1k R” test point.

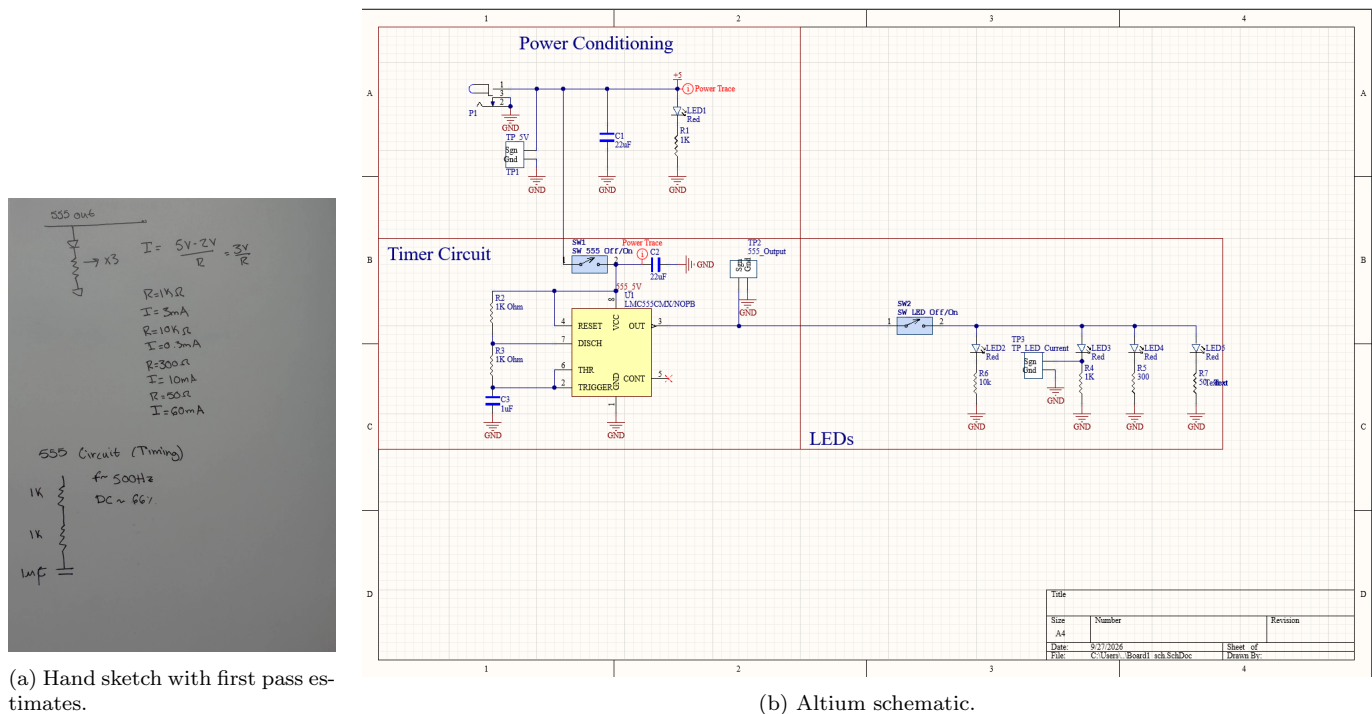


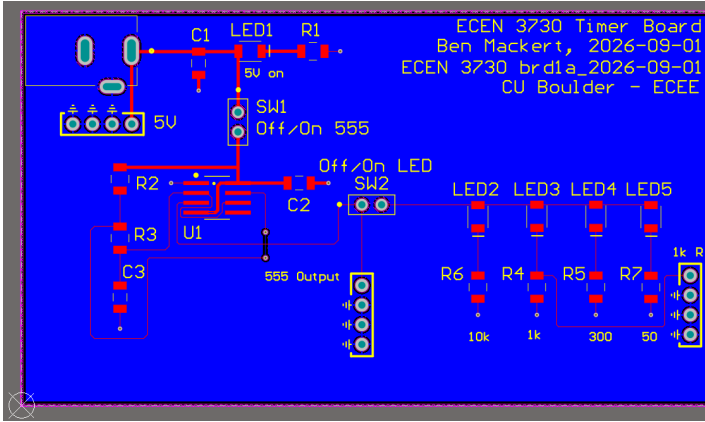
Figure 1: From hand sketch to schematic capture.

Figure 2a shows the final layout and Figure 2b the assembled board. Signals and power are routed on the top layer (red) and the bottom layer (blue) is a continuous ground pour. The power traces from the jack to SW1 and U1 are wider than the signal traces. All test points and switches are labeled in silkscreen so the board can be tested without looking up reference designators.

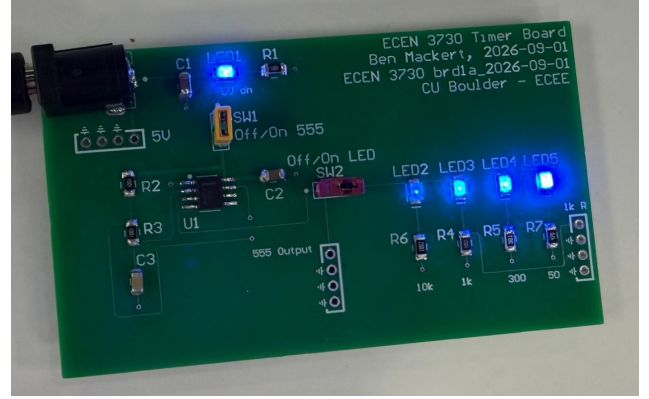
2 Bring Up and Measurements

2.1 Measurement setup

All measurements used a Keysight DSO-X 3024G with a 10x passive probe. The probe tip went into pin 1 of each 4 hole test point and the short ground spring went into the adjacent ground hole, which keeps the probe loop inductance low. The board was brought up one section at a time using the isolation switches: first the rail only (SW1 and SW2 open), then the 555 with no load (SW1 in, SW2 out), and finally the full board (both in).

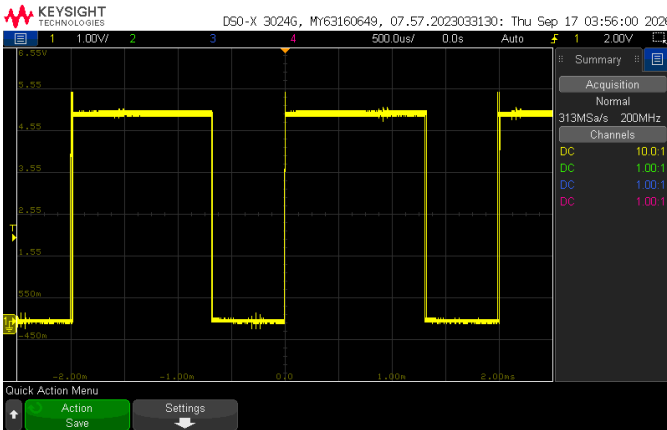


(a) Final two layer layout (top copper red, bottom ground pour blue).

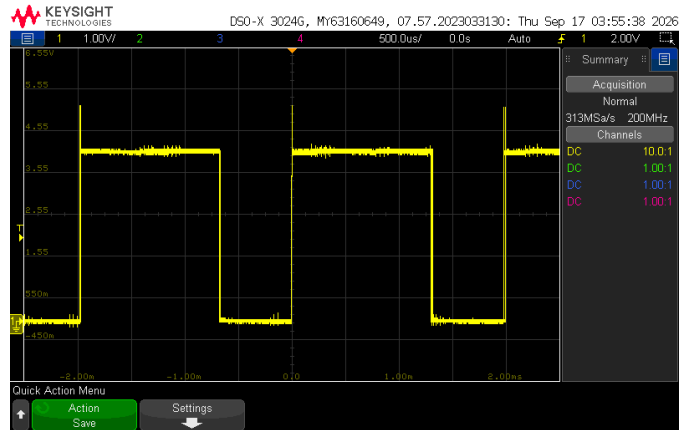


(b) Assembled board powered in the lab with SW1 and SW2 installed.

Figure 2: Layout and assembled board. LED1 (power) and all four load LEDs are lit. LED2 on 10kΩ is dim but visible and LED5 on the 50Ω resistor is the brightest.



(a) SW2 open (no LED load).



(b) SW2 installed (all four LEDs).

Figure 3: 555 output at the “555 Output” test point, 1 V/div, 500 μs/div. The only change between the two is SW2.

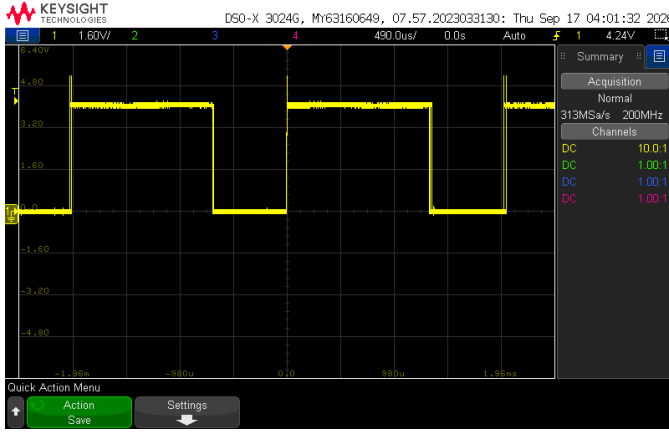
2.2 555 output with and without the LED load (S2, S3)

Figure 3a shows the open circuit output. The period is 1.99 ms (502 Hz) and the output is high for 1.32 ms, a 66 % duty cycle. The duty cycle matches the 66.7 % prediction almost exactly because it only depends on the resistor ratio. The frequency is 4 % above the 481 Hz prediction, which corresponds to an effective C3 of about 0.96 μ F, well within the tolerance of a ceramic capacitor. The output swings from about 0 V to 4.95 V, a little under the 5.5 V rail.

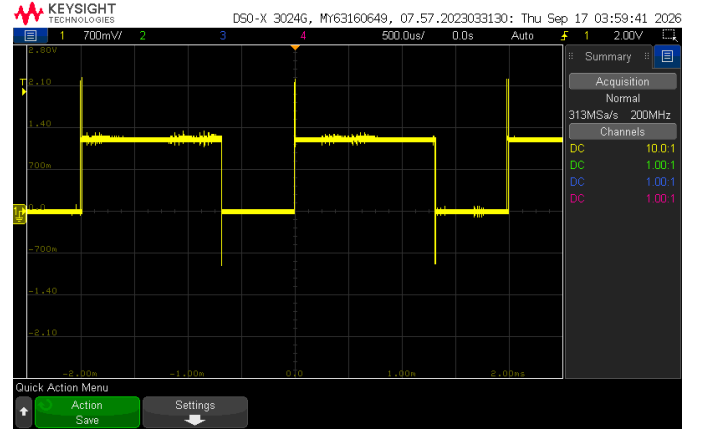
The LMC555 datasheet specifies a typical output rise time of 15 ns. On the 500 μ s/div captures shown here the edges appear vertical, consistent with an edge that is a tiny fraction of the 1.99 ms period, so the output is a clean square wave on the time scale of the LED blinking.

With the LEDs connected (Figure 3b) the frequency and duty cycle do not change (504 Hz, 66 %), which is expected since the timing is set by R2, R3 and C3 on the discharge and threshold pins, not by the output stage. The high level drops to 4.05 V. A second loaded capture taken later at 1.6 V/div (Figure 4a) agrees to within 0.05 V, so the drop is repeatable. There is also an overshoot of about 1 V on every rising edge (peaking near 5.2 V to 5.5 V), discussed in Section 3.

2.3 Current through one LED (S4)



(a) Loaded 555 output, repeat capture, 1.6 V/div.



(b) Voltage across R4 (1 kΩ), 700 mV/div.

Figure 4: Repeat of the loaded output and the LED3 current measurement at the “1k R” test point, both at about 500 μ s/div.

Because R4 is on the ground side of LED3, the voltage at the “1k R” test point is the voltage across the resistor. It measures 1.23 V when the output is high (Figure 4b), so

$$I_{LED3} = \frac{1.23 \text{ V}}{1 \text{ k}\Omega} = 1.23 \text{ mA (peak)}, \quad V_{f,LED3} = 4.05 \text{ V} - 1.23 \text{ V} = 2.82 \text{ V}.$$

This forward drop is used below to estimate the current in the other LEDs. Averaged over the 66 % duty cycle the LED3 current is about 0.81 mA. The short spikes at each edge are the fast edge transition coupling into the measurement, discussed in Section 3.

2.4 Estimated current in each LED

Using the loaded output voltage of 4.05 V and the measured forward drop of 2.82 V as a first order model for all four LEDs: The kit supplied a 47 Ω part (marked “470”) for the 50 Ω position. The LED5 value is a range because the

LED	Resistor	I_{peak} (estimate)	I_{avg} at 66%	Brightness
LED2	R6 = 10 k Ω	0.12 mA	0.08 mA	dim, visible
LED3	R4 = 1 k Ω	1.23 mA (measured)	0.81 mA	clearly on
LED4	R5 = 300 Ω	4.1 mA	2.7 mA	bright
LED5	R7 = 47 Ω	20 mA to 26 mA	13 mA to 17 mA	very bright
Total from 555		25 mA to 31 mA		

Table 1: Estimated LED currents with the 555 output high.

forward drop rises at higher current. Using 2.82 V gives 26 mA, while a more realistic 3.1 V at that current gives about 20 mA. LED5 dominates the load: it draws more than 80 % of the total 555 output current.

The hand sketch (Figure 1a) estimated 0.3 mA, 3 mA, 10 mA and 60 mA using a 5 V output and a 2 V forward drop. The measured values are lower for two reasons: the LEDs on the board drop about 2.8 V rather than 2 V, and the 555 output sits at 4.05 V under load instead of 5 V. The effect is largest on the 50 Ω branch, where the 555 output resistance (next section) is comparable to the series resistor.

2.5 Thevenin output resistance of the 555

Treating the 555 output as a Thevenin source, the open circuit voltage is $V_{oc} = 4.95$ V and the loaded voltage is $V_L = 4.05$ V at a load current of 25 mA to 31 mA:

$$R_{th} = \frac{V_{oc} - V_L}{I_L} = \frac{0.90 \text{ V}}{25 \text{ mA to } 31 \text{ mA}} \approx 29 \Omega \text{ to } 36 \Omega, \quad \text{about } 32 \Omega.$$

This is the on resistance of the LMC555 PMOS output transistor. It is why the LED5 current is lower than a simple “5 V minus V_f over 50 Ω ” estimate would give: the 32 Ω output resistance is in series with the 47 Ω resistor and nearly doubles the resistance in that branch.

2.6 Power rail and switching noise (S1, S5)

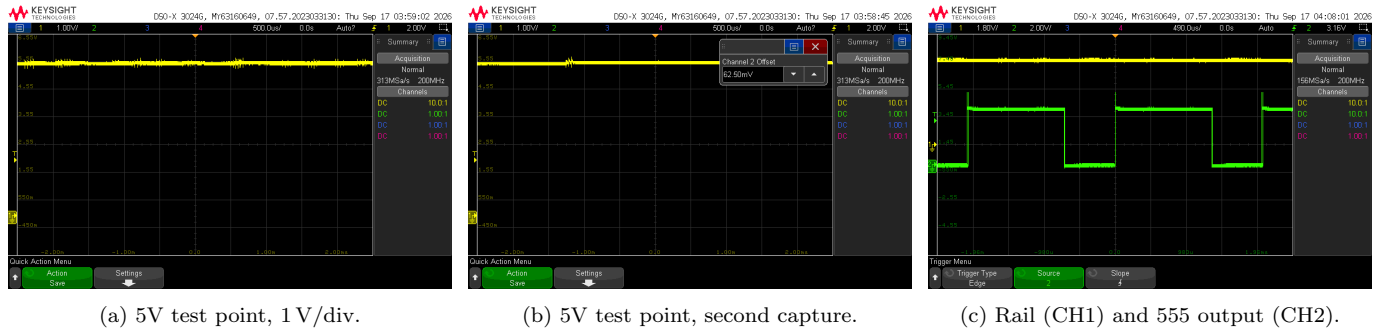


Figure 5: The 5 V rail. In (c) the rail is yellow at 1.8 V/div and the 555 output is green at 2 V/div, triggered on the 555 output.

The rail sits at about 5.5 V (Figure 5). The adapter is unregulated and lightly loaded, so it runs about 10 % above its 5 V label. LED1 therefore draws about $(5.5 \text{ V} - 2.8 \text{ V})/1 \text{ k}\Omega \approx 2.7 \text{ mA}$.

In Figure 5c the scope is triggered on the 555 output (CH2) so that any rail disturbance synchronous with the switching would line up with the edges. The measured switching noise on the rail is about 0.2 V peak to peak, which is under 4 % of the 5.5 V rail. The noise appears as short bursts at the 555 transitions, when the output stage and the LED load current switch on and off. C1 (bulk) and C2 (local decoupling at U1) supply this transient current and keep the rail steady between edges, so the noise is well below anything that would affect the 555 or the LEDs.

2.7 Specification scorecard

Spec	Expected	Measured
S1: rail, power LED	5 V, LED1 on	5.5 V, LED1 on
S2: frequency	481 Hz	502 Hz
S2: duty cycle	66.7 %	66 %
S2: output high, no load	near rail	4.95 V
S3: output high, loaded	below no load value	4.05 V
S3: LEDs blink, graded brightness	yes	yes
S4: LED3 current	about 1 mA	1.23 mA peak
S5: rail switching noise	small	0.2 V pk-pk
Output rise time	15 ns typ. (datasheet)	edges vertical at 500 $\mu\text{s}/\text{div}$

Table 2: Specification versus measurement.

The board met every specification on the first power up with no rework.

3 Analysis

3.1 What worked and what I will keep doing

- **First pass success with no rework.** Every functional spec was met on the first power up. Following the class checklist, the peer design review, and the JLC DFM check before submitting meant there were no hard errors.
- **Isolation switches made bring up safe and simple.** Bringing up the rail, then the unloaded 555, then the loaded 555 meant that if anything had been shorted, I would have known which section it was in. The same switches made the Thevenin measurement possible with no rework: SW2 in or out is the only difference between the two captures in Figure 3.
- **Low side current sense resistor.** Putting R4 between the LED and ground made the LED current a single ended, ground referenced measurement with a normal 10x probe. I will keep using this pattern anywhere I want to measure current without a differential probe.
- **Decoupling on the correct side of the switch.** C2 is on the IC side of SW1, so the 555 always has its local charge reservoir.
- **Labeled test points with a ground hole next to the tip.** Every test point accepts the probe tip and short ground spring, and each is labeled by function (5V, 555 Output, 1k R) instead of TP1, TP2, TP3.

3.2 Fast edges

The captures show short spikes at each transition: about 1 V of overshoot on the 555 output and brief spikes on the LED current signal. When the output switches, the current into the LEDs changes by about 30 mA in a short time, and the inductance of the current loop (the trace from U1 to SW2 and the LEDs, the return through the ground plane, and the probe ground spring) produces a brief voltage spike. Keeping the return path on a solid ground plane directly under the traces and using the short probe ground spring keeps these spikes brief, and they settle well before the next transition. Understanding this behavior on a simple board is the foundation for the switching noise work in Board 2.

3.3 Future improvement

The board has open space next to the LEDs. On the next revision I will add a QR code linking to my LinkedIn profile, which turns the board into a working business card for interviews and career fairs.

3.4 Recommended minimum LED current for an indicator

LED2 at about 0.12 mA peak (0.08 mA average) is still visible in normal lab lighting (Figure 2b), and LED3 at about 1.2 mA peak is clearly on. Past a few milliamps, the extra brightness costs power and puts more load on the driver. LED5 alone pulls about 80 % of the 555's output current and causes most of the 0.9 V output droop. For future indicator LEDs I will design for about 1 mA (at most 2 mA), which with a 3.3 V or 5 V drive and a blue or white LED means a resistor around 1 k Ω to 2.2 k Ω .

3.5 Takeaways for future boards

1. Isolation switches and labeled, probe friendly test points make bring up fast and let each section be characterized on its own.
2. A low side sense resistor makes LED or load current an easy, ground referenced measurement with a standard 10x probe.
3. Account for the driver's output resistance when sizing LED resistors on a logic output. The 32 Ω output resistance of the LMC555 is comparable to the 47 Ω resistor on LED5.
4. Trigger on the switching signal when measuring rail noise so the noise can be tied directly to its source.