

ECE 340 - Lab 5 - Switching circuits

Dan White – dan.white@valpo.edu – 2026

that trigger themselves

Objective: Use the BJT-based astable multivibrator circuit to relate transistor switch mode operation to the resulting time-domain waveforms.

1. Pulse generator → astable multivibrator

1.1. Review the pulse generator

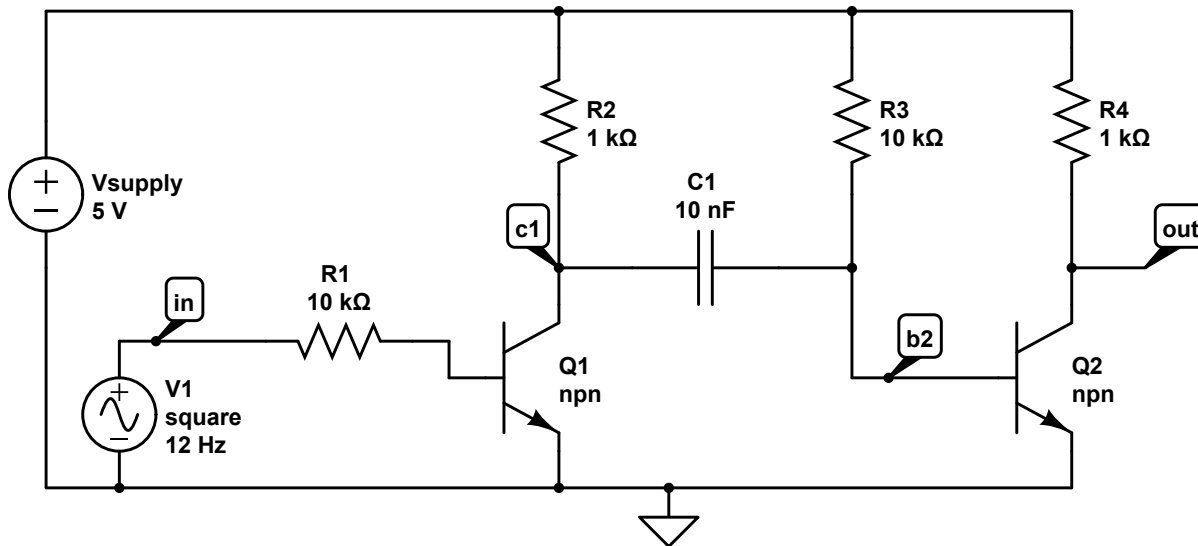


Figure 1. AoE Pulse generator - I

Review **Art of Electronics**, section 2.2.2.C Pulse generator - I on page 77.

Drive the input with a 0—5V square wave of a slow frequency.^[1] Connect probes to nodes **in**, **c1**, **b2**, and **out**. It is not necessary to have all 4 at once, but it is important to see the progression of the signal's cause→effect action ripple through the circuit.

Configure the **trigger** of the oscilloscope as:

- **[Mode | Coupling]** button → Mode → Normal

In the default **Auto** mode, the trigger system waits for a **trigger event** (like a rising edge on channel 1 through 1.5 V. BUT if the event is *not found* within X seconds, then the wait *times out* and *triggers anyway*. When auto-triggered in this way, the capture is then not synchronized with the waveform.

Since the input from the WaveGen is slow, and thus longer than this timeout, it seems difficult to see each pulse sequence. Using **Normal** mode triggering removes this automatic timeout and **only** triggers on a real event.

1.2. Analyze the circuit

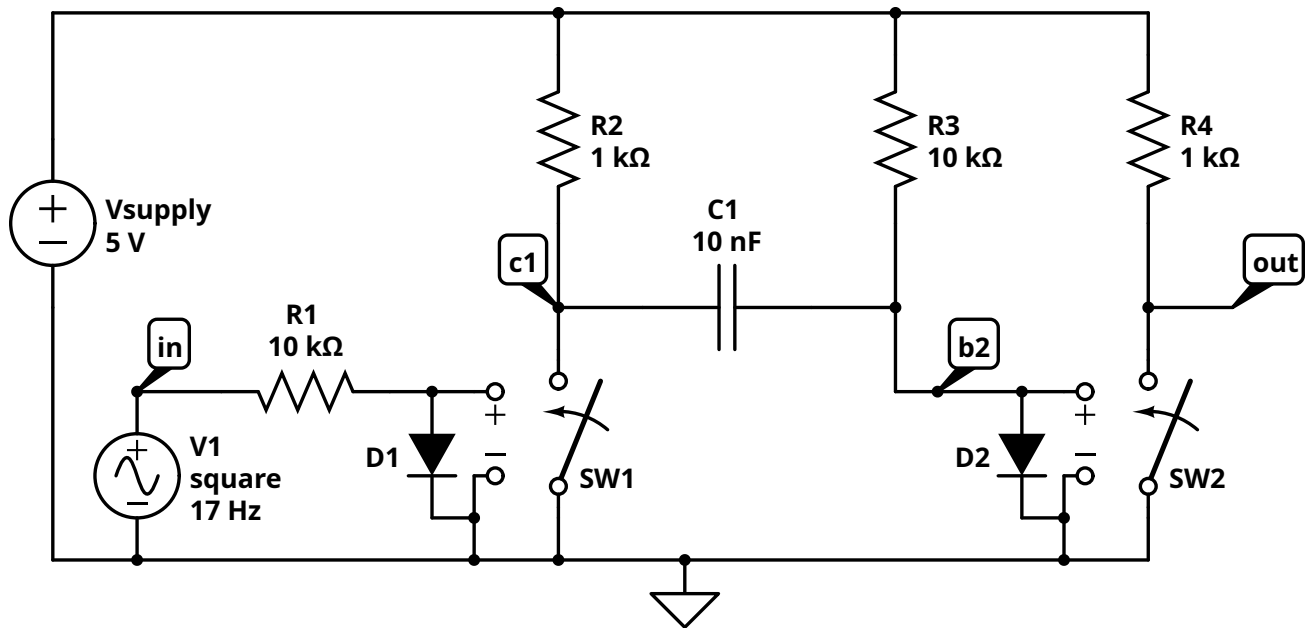


Figure 2. AoE Pulse generator - I

$V_1 = 0\text{ V}$

- Find the DC solution and the state of all *pn* junctions and BJT operating modes. (all node voltages and branch currents)

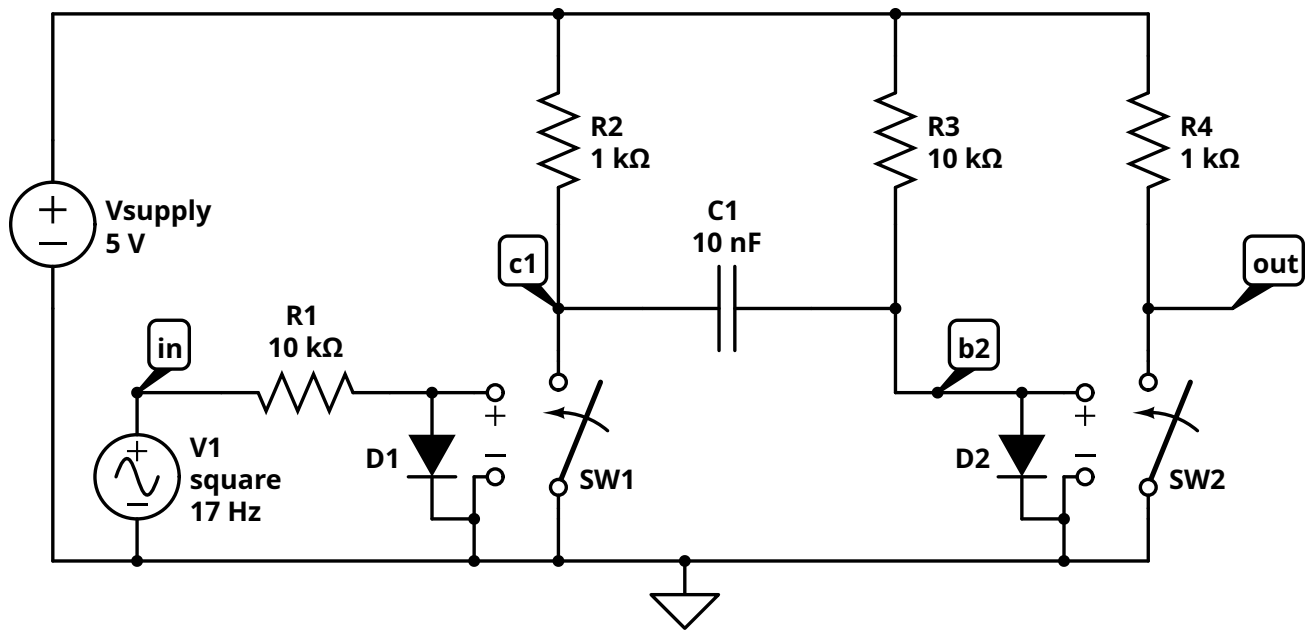


Figure 3. AoE Pulse generator - I

$V_1 = 5\text{ V}$

- From the 0 V initial condition,
- Find the solution immediately after the input jumps to 5 V. (all node voltages and branch currents)
- The voltage across the capacitor MUST BE exactly the same as the prior solution!

Then solve the circuit as a function of time. Node voltage `c1` and current through `R2`, `C1`, `R3`, and `D2`.

1.3. Make the circuit trigger itself

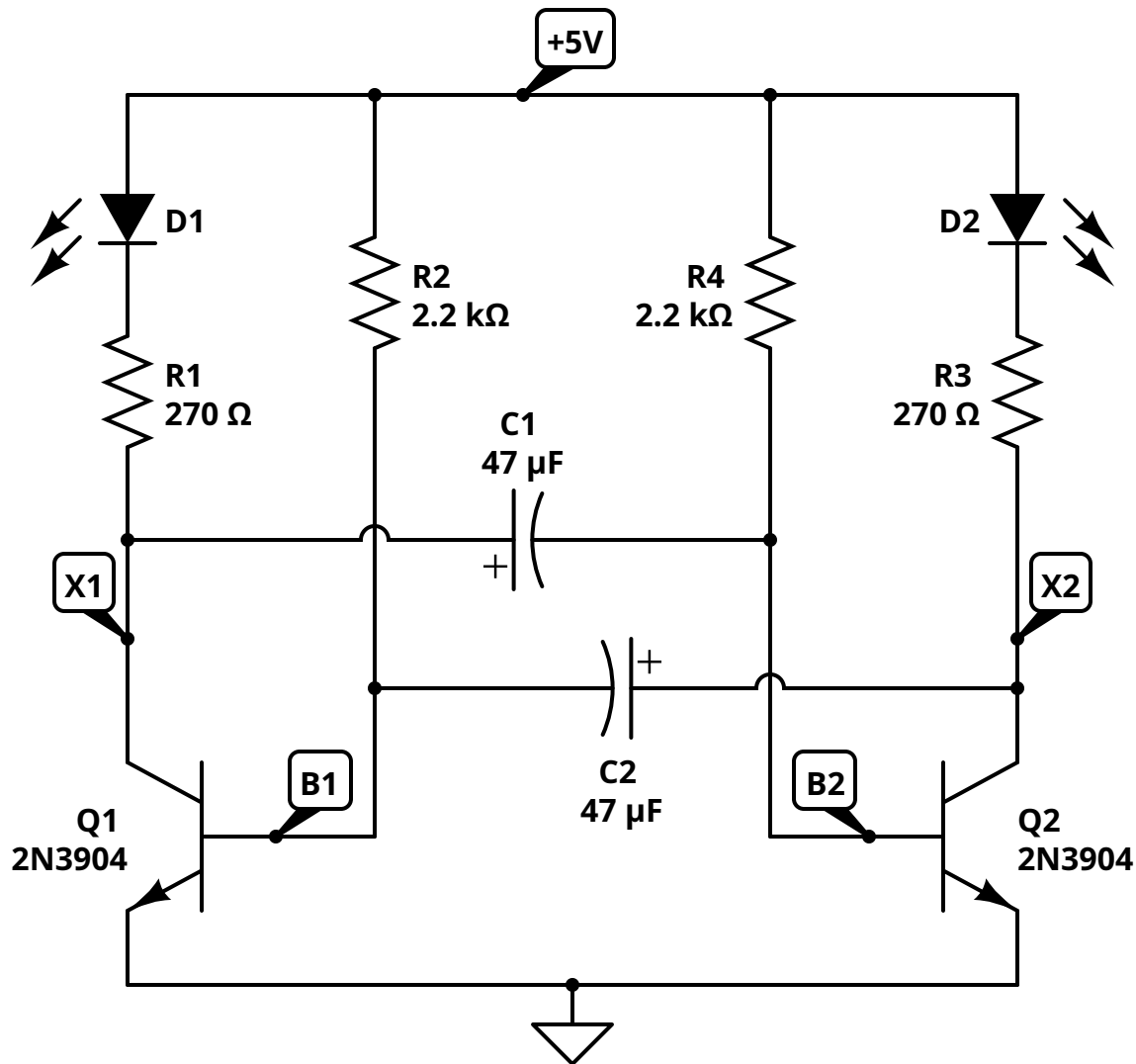


Figure 4. Astable multivibrator

Compare Figure 1 to Figure 4 and notice the two major changes:

- Connect in to V_{supply} instead of a signal generator.
- Connect a capacitor between out and the base of Q1.

1.4. Tasks

Construct Figure 4, then

- ☐ Measure the Q1 ON (saturation mode) time, the Q2 ON time, and oscillation frequency.
- ☐ Measure the transition time from cutoff to saturation mode for each transistor. Probe the collector voltage, it is rather quick so zoom in the horizontal scale to see the shape of the transition waveform.^[2]
- ☐ Probe the circuit nodes to help understand how the waveforms are a proper result of how the circuit and components work.
- ☐ Construct a description of the process by which this circuit oscillates.
- ☐ Modify the circuit to achieve an Q1 ON time which is about 25% of the total oscillation period.

Demonstrate that your paper, hand-calculated, prediction matches the observed behavior (this was hw11).

Use the waveforms and the schematic to find which components create the timing. Use circuit analysis to determine the circuit's voltages, currents, and time constants. This hand analysis should be plotted and match the waveforms measured with an oscilloscope.

You can view this type of oscillator's operation as a circular state machine:

- Begin your analysis/description at the edge of one transition
- Redraw the circuit since one transistor is in cutoff mode
- Figure out the initial condition of the capacitor voltages
- Observe the resulting RC exponential curve and the capacitor charging current path
- Find the condition which turns ON the transistor what was previously OFF.

Use lots of scratch paper to draw circuits, draw waveforms on paper to match the measured ones, and constantly reference between the paper schematic, the constructed circuit, and the waveforms displayed on the oscilloscope. Leverage your knowledge of how current through and voltage across capacitors behaves and combine with how transistors operate in cutoff and saturation modes.



This circuit has **three** solutions: two unstable solutions which switch between each other to flash the LEDs and a stable operation point where current flows in both branches. Depending on the relative matching of the transistors, you may find that your circuit has entered the stable state and does not flash. Attaching the power supply leads (as opposed to raising the power supply output voltage with the knob) will usually provide enough of a “shock” to the circuit to induce the astable operating mode.

2. Electronic devices review

2.1. bipolar transistor

The base current must be large enough to ensure the collector voltage is forced below the base voltage (for an *npn*, everything is opposite for *pnp*). This is accomplished by finding the maximum collector current and then designing a base current such that $i_B > i_C / \beta_{\text{sat}}$

What is β_{sat} ? The largest value this number should be is equal to the smallest listed value in the transistor's datasheet *at the expected collector current*.^[3]

2.2. capacitor

The voltage across each capacitor will always have an "R-C" single time-constant, exponential shape.

Your Analog Discovery 2 can directly measure the capacitor voltage as a differential quantity.

See this using the benchtop oscilloscopes by using two channels and the "Math" function to display waveforms "X1 - B2" or "X2 - B1".

When one end of a capacitor is driven to a certain voltage (a transistor turns ON and collector voltage drops to near zero), the voltage at the other node of the capacitor must change by the same amount. This is because the voltage across a capacitor can not instantaneously change.

Recall that "capacitor's law" is

$$i_C(t) = C \frac{dV}{dt} \quad (1)$$

or

$$v_C(t) = \frac{1}{C} \int_0^t i_C(x) dx + v_C(0^-) \quad (2)$$

2.3. single time-constant circuit solution

See [first-order](#)

A circuit with a reactive element (i.e. a capacitor) has a circuit analysis solution that involves a differential equation. Since there is only one reactance, there is only one time constant. The solution to this **first-order** differential equation is an exponential with general form: $A \exp(-t/\tau) + B$



The **R** in the $\tau=R \cdot C$ is an **effective** resistance and may NOT be the value of a single physical resistor! Think "Thevenin-equivalent resistance seen by the capacitor" instead.

3. Report

Individually submit a document which describes:

- The circuit you constructed
- Measurements you performed
- A clear description of how the circuit oscillates.
- The math and calculations used to modify the circuit values to obtain the 25% Q1 duty cycle. Your numbers need to match the new measurements you took to verify the new operation condition.

Write this document for a reader who is familiar with transistors but has never seen this particular circuit. Use a slightly more verbose style than used in **Art of Electronics**. Pay particular attention to how the figures and waveforms used in the book are not merely oscilloscope screenshots. Instead, they are drawn or “photoshopped” to highlight the important aspects of the circuit diagram or waveform that fits with the text description. Equations are used as sentences to support the discussion.

	(5) Exceeds	(4) Meets	(3) Partial	(1) Insufficient	(0) Missing
Description of measurements					
Principle of operation description					
Duty cycle modification process					
Proper audience					
Figures and math integrated with discussion					

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1. 10's of Hz
 2. Key to making oscilloscope-based measurements is to actually **see** the shape of the waveform on the screen before you believe any numbers. The MEAS features only use the **pixels on the screen** as input to those functions --- you need as many pixels as possible to have a quality measurement result.
 3. If h_{FE} is minimum 30 at 5 mA and minimum of 70 at 100 mA and you are switching 80 mA, then **70** is a better number to use.