Bistable Multivibrators - circuit with 2 stable output states.

- Use positive feedback.

- Consider case where \( V^+ \) starts at 0 V.
  - Noise pushes \( V^+ \) momentarily positive to \( \Delta V^+ \).
  - \( V^+ \) is driven to \( \Delta V^+ A_0 \) by opamp.
  - Opamp open-loop gain.
  - \( \Delta V^+ A_0 R_1 \) fed back to \( V^+ \), adding to \( R_1 + R_2 \).
  - Initial disturbance of \( V^+ \).
  - This gets amplified and fed back, a turn, repeats until \( V^+ \) slams into the positive rail.

\[ V_{out} = V + V_{pp}, \quad V^+ = V_{pp} \frac{R_1}{R_1 + R_2} \]

If initial disturbance had been negative, opposite process would occur, we would have:

\[ V_{out} = -V_{pp}, \quad V^+ = -V_{pp} \frac{R_1}{R_1 + R_2} \]

\[ V_{out} = 0 V \] is called a metastable state, since any disturbance will push it into one of the stable states (\( V_{out} = V \pm V_{pp} \)).

Transfer Characteristics

- Assume we are in the state where \( V_{out} = -V_{pp}, \quad V^+ = -V_{pp} \frac{R_1}{R_1 + R_2} \)

- Apply input voltage:

\[ V_{out} = \frac{R_1}{V_{in}} V_{in} \]

1. When \( V_{in} \) is positive, since \( V^+ = -V_{pp} \frac{R_1}{R_1 + R_2} \), \( V_{out} \) will remain at \( -V_{pp} \).
2. As \( V_{in} \) is reduced, nothing changes until \( V_{in} = -V_{pp} \frac{R_1}{R_1 + R_2} \), at which point the positive feedback clamps the output to the positive rail, \( +V_{pp} \).

\[ V_{out} = +V_{pp}, \quad V^+ = +V_{pp} \frac{R_1}{R_1 + R_2} \]

- Now, \( V_{out} = +V_{pp}, \quad V^+ = +V_{pp} \frac{R_1}{R_1 + R_2} \)

3. Start increasing \( V_{in} \), nothing happens, and it is negative, since \( V^+ = +V_{pp} \frac{R_1}{R_1 + R_2} \).
4. When \( V_{in} = +V_{pp} \frac{R_1}{R_1 + R_2} \), positive feedback clamps the output to the negative rail, \( -V_{pp} \).
- Note the hysteresis, asymmetry in VTC depending on whether we are moving from high-to-low or vice versa.

- This is useful for a number of applications, one of which is the oscillator built for the lab.

- This is an inverting circuit, we can also build a non-inverting bistable multi-vibrator, as was used in the lab:

  - Assume \( V_{in} = V_{DD} \), then \( V_{out} = V_{DD} \).

  - As we reduce \( V_{in} \), we have:

    \[
    V_{+} = V_{in} + \frac{R_{L}}{R_{1} + R_{2}} (V_{out} - V_{in}) \Rightarrow V_{in} = \frac{R_{L} \cdot V_{DD}}{R_{2}}
    \]

  - Circuit will change state to \( V_{out} = -V_{DD} \) when \( V_{+} = 0 \):

    \[
    0 = V_{in} + \frac{R_{L}}{R_{1} + R_{2}} (V_{DD} - V_{in}) \Rightarrow V_{in} = -\frac{R_{L}}{R_{2}} \cdot V_{DD}
    \]

  - Now, we have \( V_{out} = -V_{DD} \), as we reduce \( V_{in} \), we have:

    \[
    V_{+} = V_{in} + \frac{R_{L}}{R_{1} + R_{2}} (-V_{DD} - V_{in})
    \]

  - Follow same procedure to find circuit will change state at \( V_{in} = \frac{R_{L}}{R_{2}} \cdot V_{DD} \)

Voltage Transfer Characteristics:

- Same as before, but flipped and with different thresholds.

Astable Multi-vibrator - as the name suggests, this is a multi-vibrator with no stable state so it oscillates back and forth between its two possible states.

- Is built using an inverting bistable multi-vibrator.

- Circuit in dashed lines is the bistable M-V.

- Addition of \( R + C \) makes it astable.
Operation: Consider state where \( V_{out} = V_{DD} \), \( V_+ = \frac{R_1}{R_1+R_2} V_{DD} \). Let \( V_- = -V_{DD} \).

1. \( V_- \) starts to increase as \( C \) charges through \( R \):
   \[
   V_- = V_{DD} - 2V_{DD}(1 - e^{-t/RC})
   \]

2. Once \( V_- \) reaches \( V_{th} = \frac{V_{DD}}{R_1+R_2} \), output switches to \( V_+ = -V_{DD} \), \( V_- = \frac{R_1}{R_1+R_2} V_{DD} \).

3. \( V_- \) then starts to decrease as \( C \) discharges through \( R \):
   \[
   V_- = V_{DD} - \frac{V_{DD}}{R_1+R_2} \left[ -\frac{V_{DD}}{R_1+R_2} + V_{DD} \right] (1 - e^{-t/RC})
   \]

4. Once \( V_- \) reaches \( V_{th} = -\frac{V_{DD}}{R_1+R_2} \), output switches back to \( V_+ = V_{DD} \).

**D Waveforms**: 

- **Book** calls \( \frac{R_1}{R_1+R_2} = \alpha \) since it is the feedback factor.

- Based on the exponential settling, we can solve for the period of oscillation to find:
  \[
  T = 2 \pi R C \ln \left( 1 + \frac{R_1}{R_1+R_2} \right)
  \]

- In the lab, we used an alternate adjustable M.V. topology that generates a triangular output waveform.

- Replaces the R-C circuit with an op-amp based integrator.
- Uses a non-inverting bistable multivibrator.

This is the circuit used in the lab. It differs from one in the text in that addition of diode \( D \) and \( R_1 \) allows the frequency to be controlled by \( V_{Cont} \).