Lecture 20 -- Post

Sunday, July 23, 2023 10:15 PM

Lecture 6D (7/26/23):

Announcements:

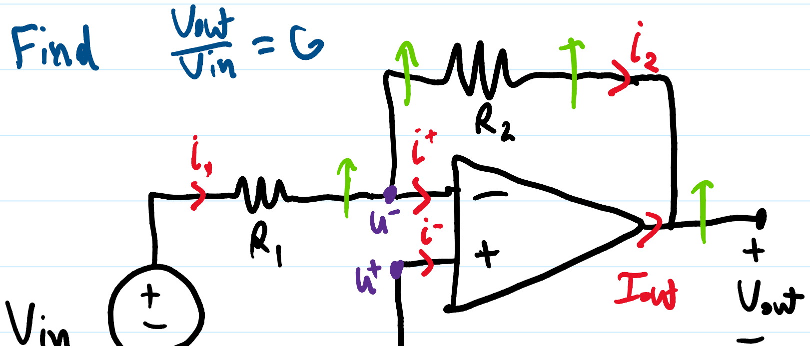
- Last day of Module #2 :)
  - Module #3 next week ← Learn how GPS works
- Midterm Review tomorrow from noon-2pm in Cory 144MA
  - Midterm Redo due Sunday night
- Lab - Touch 3 tonight ← Long lab!

Today's Topics:

- Inverting op-amp circuit (Note 18.6)
- Circuit Design (Note 20)
- Using an op-amp circuit (Note 18/19)
- Capacitor Touch circuit (Note 20)

Inverting op-amp circuit:

Find $\frac{V_{out}}{V_{in}} = G$



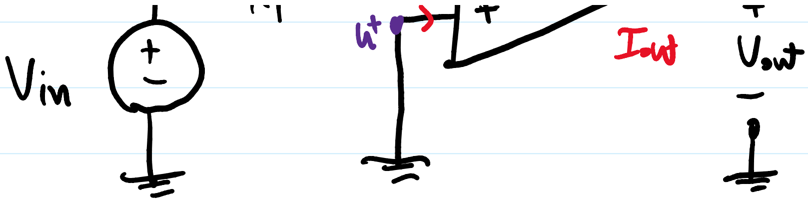
Negative feedback test:

Increase V_{out}

↓

Increase u^-

↓



$$V_{out} = A \cdot (u^+ - u^-)$$

increase u^-
$\downarrow$
Decrease $u^+ - u^-$
$\downarrow$
Decrease V_{out}

Passes test (NF) ✓

KCL @ u^-:

$$i_1 - \cancel{i^-}^{\,0} - i_2 = 0$$

GR #1: $i^- = 0$

$$\frac{V_{in} - u^-}{R_1} - 0 - \frac{u^- - V_{out}}{R_2} = 0$$

GR #2: $u^- = u^+$ since NF
$\uparrow$
$u^+ = 0$

$$\frac{V_{in}}{R_1} + \frac{V_{out}}{R_2} = 0$$

$$\boxed{V_{out} = -\frac{R_2}{R_1} V_{in}}$$

Gain of inverting op-amp: $\frac{V_{out}}{V_{in}} = \underbrace{-\frac{R_2}{R_1}}_{} = G$

can negate (invert) the input voltage $\rightarrow$ $G \leq 0$

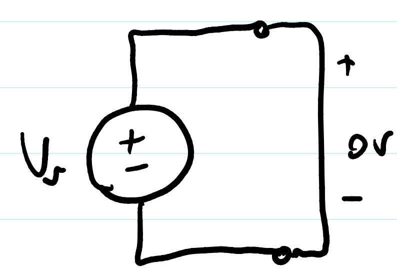
Aside: When applying NVA to op-amp circuits, do NOT write a KCL equation at the output. This is because we do not know I_{out} (it depends on the rest of the circuit).

Circuit Design:

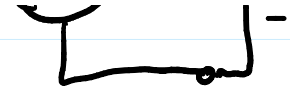
Ambiguous like proofs in Module #1 (Note 20)

Step 1: Specify Design Goals

Step 2: Describe a Strategy



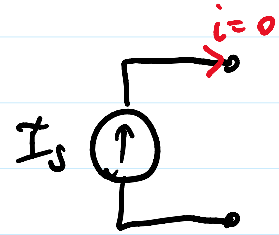
Step 2: Describe a Strategy



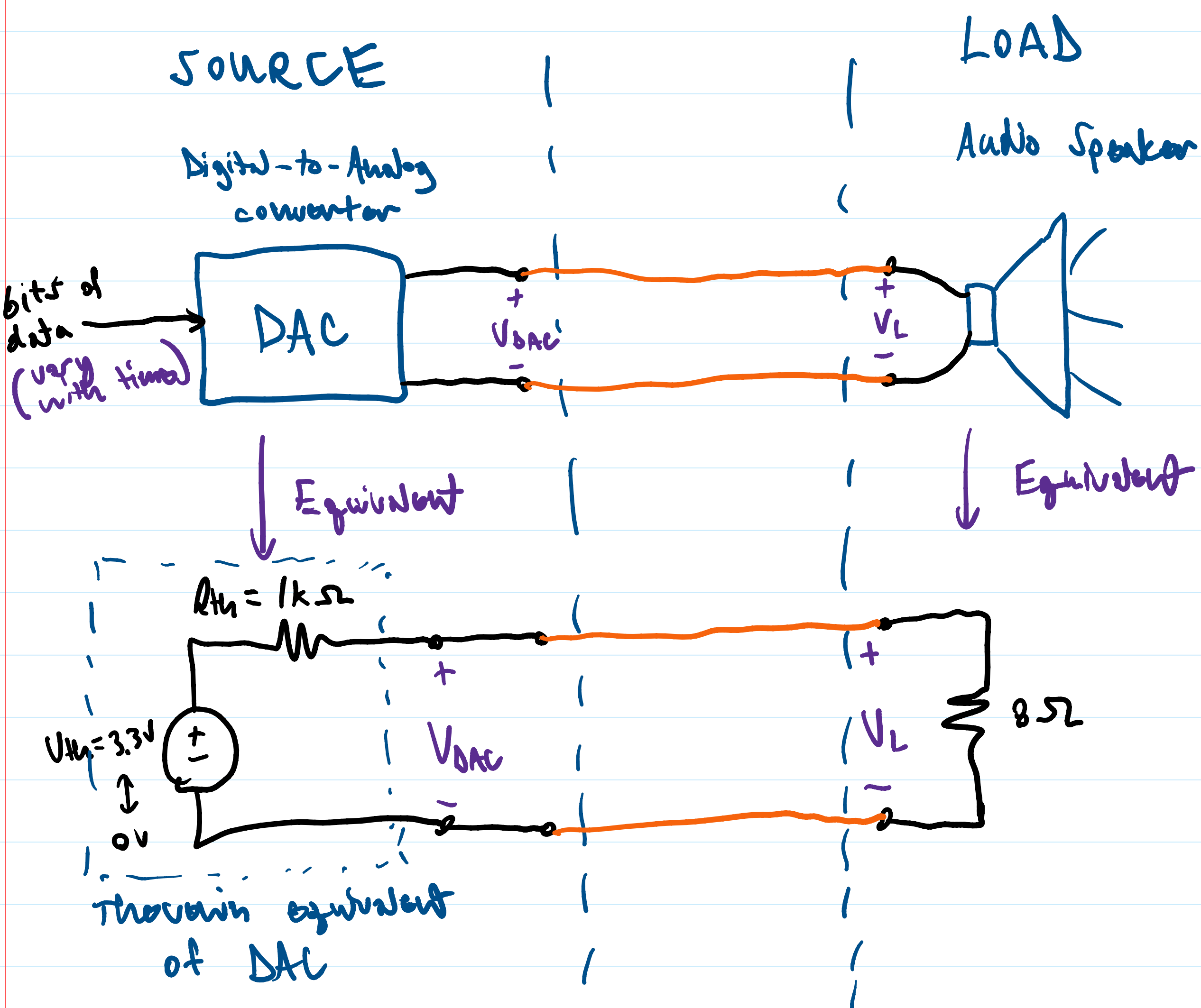
Step 3: Implement Strategy

$V = IR = \infty \cdot 0$

Step 4: Verify whether solution is consistent



Using an op-amp circuit:

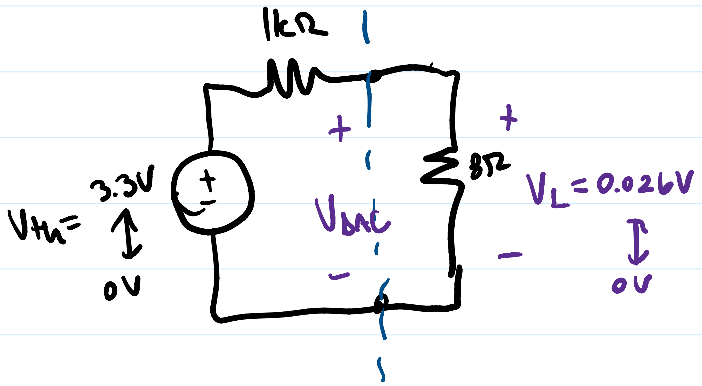


Design Step 1: Let's try to turn our bits of audio data

Design Step 1: Let's try to turn our bits of audio data into audible music.

First, let's connect the DAC directly to the speaker.

$\rightarrow V_L = V_{DAC}$

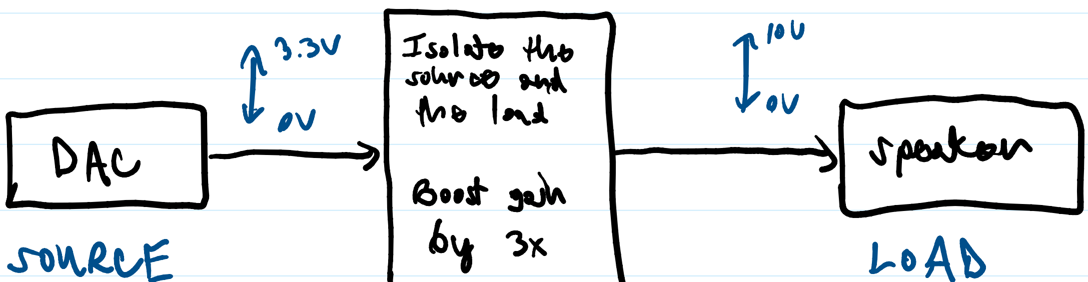


$$V_L = \frac{8\Omega}{1k\Omega + 8\Omega} \cdot V_{th}$$

$$= 0.0079 \cdot (3.3V) = 0.026V$$

We need this voltage to be 10V to drive the speaker

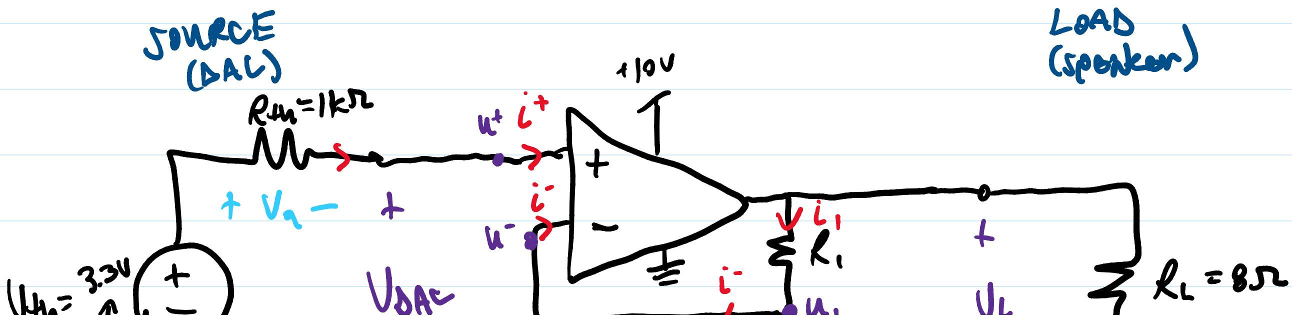
Design Step 2:

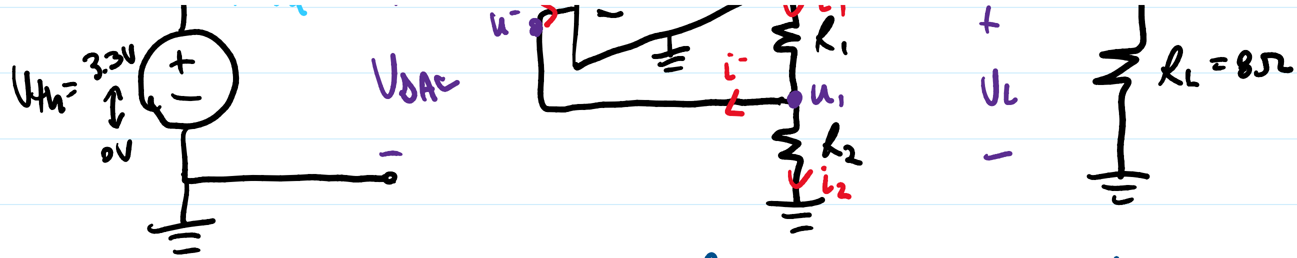


Let's use a non-inverting op-amp!

Design Step 3: Implement

We need to map: $V_{DAC} = 0V$ to $3.3V \rightarrow V_L = 0V$ to $10V$

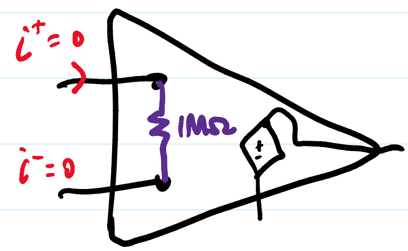




$$V_{out} = \left(1 + \frac{R_1}{R_2}\right) \cdot V_{in}$$
$$= 3 \cdot V_{in}$$

Pick $R_1 = 2k\Omega$
$R_2 = 1k\Omega$

Design Step 4: check consistency



GR #1: $i^+ = 0 \rightarrow V_n = 0 \rightarrow u^+ = V_{DAC} = V_{th}$
$= 3.3V$

Negative Feedback: GR #2: $u^- \approx u^+ = V_{th} \rightarrow u_1 = u^- = V_{th}$

KCL @ u_1: $i_1 - i^- - i_2 = 0 \leftarrow$ GR #1: $i^- = 0$

$$\frac{V_L - u_1}{R_1} - 0 - \frac{u_1 - 0}{R_2} = 0 \rightarrow V_L = R_1 \cdot \left(\frac{1}{R_1} + \frac{1}{R_2}\right) \cdot u_1$$

$$V_L = \left(1 + \frac{R_1}{R_2}\right) \cdot 3.3V$$

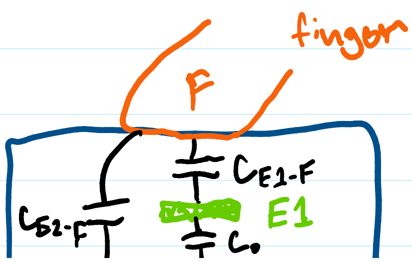
$$10V = G \cdot 3.3V$$

$$= \underbrace{\left(1 + \frac{2k\Omega}{1k\Omega}\right)}_{3} \cdot 3.3V \approx 10V \checkmark$$

Designing a circuit for capacitive touch:

Recall from capacitive touch:

Equivalent capacitance between nodes E1 and E2



Before touch: $C_e = C_0$

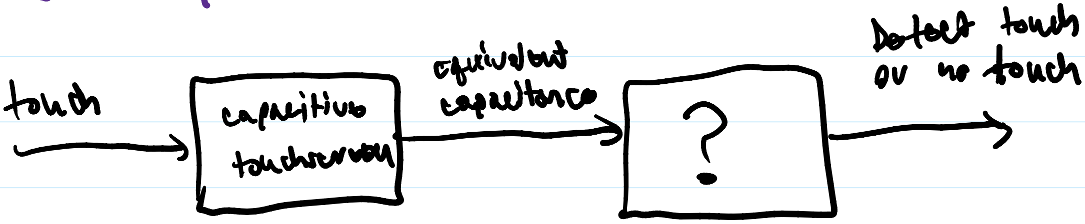
After touch: $C_e = C_0 + (C_{E1-F} \parallel C_{E2-F})$

After touch: $C_e = C_0 + (C_{E1-F} \| C_{E2-F})$
$= C_0 + C_\Delta$

The equivalent capacitance increases when there is a touch

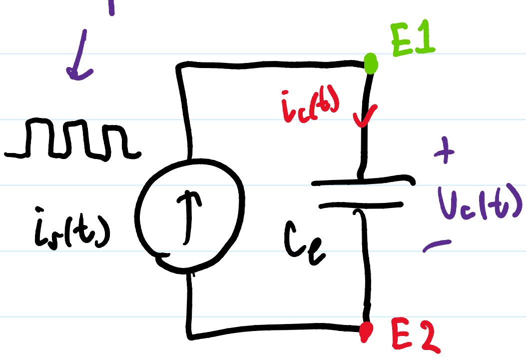
Design Step #1 { How do we measure a change in capacitance?

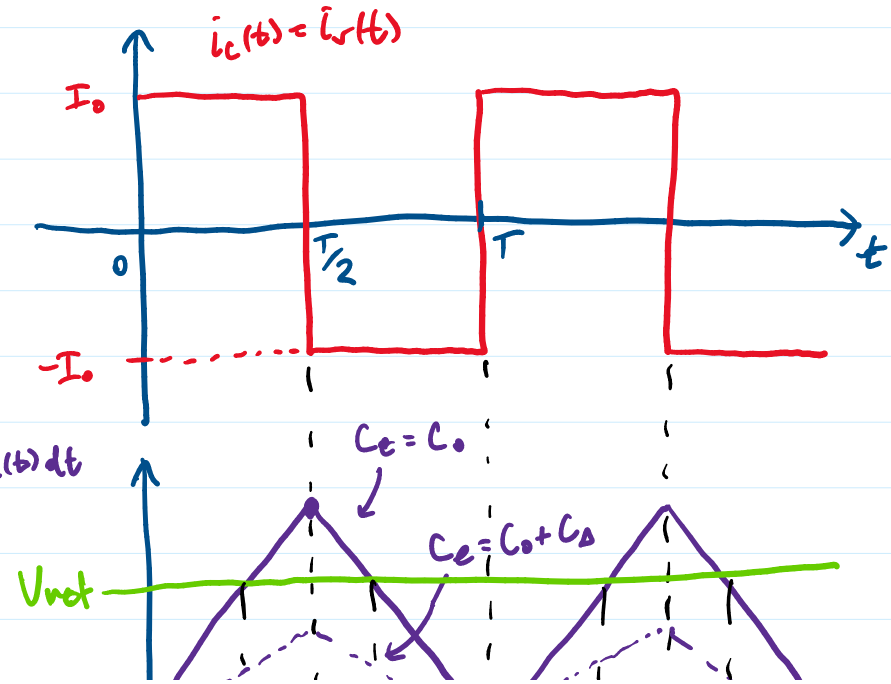
Design Step #2:



Design Step #3:
Connect the equivalent capacitance to a current source

vary w/ time





$i_c(t) = C_e \frac{\partial V_c(t)}{\partial t} \rightarrow V_c(t) = \int i_c(t)\,dt$

① $i_c(t) = I_0 > 0$
so capacitor is charging

(1) $i_c(t) = I_o > 0$

so capacitor is charging

$$V_c(t) = +\frac{1}{C_e} I_o \cdot (t - t_o) + V_c(t_o)$$

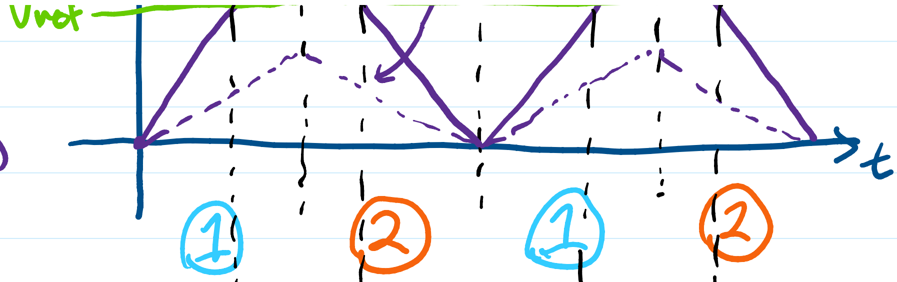
↑ Increasing linearly with time

(2) $i_c(t) = -I_o < 0$

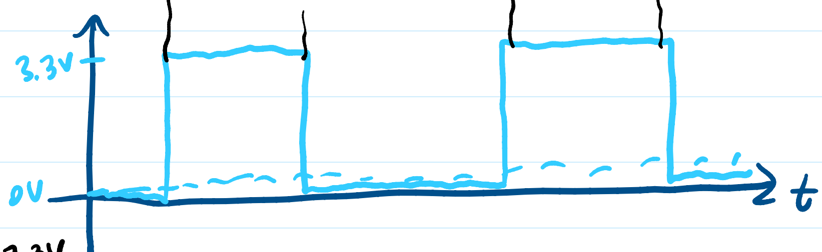
so capacitor is discharging

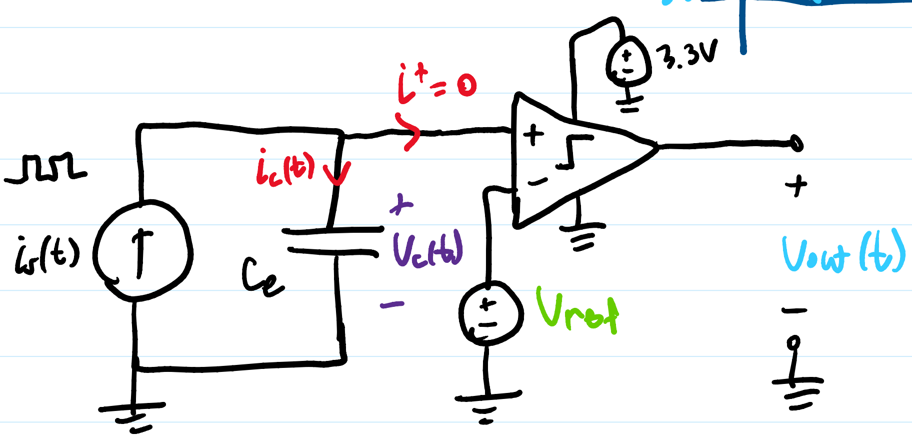
$$V_c(t) = -\frac{1}{C_e} I_o \cdot (t - t_o) + V_c(t_o)$$

↑ Decreasing linearly with time



If touch, then C_e increases and slope of $V_c(t)$ decreases

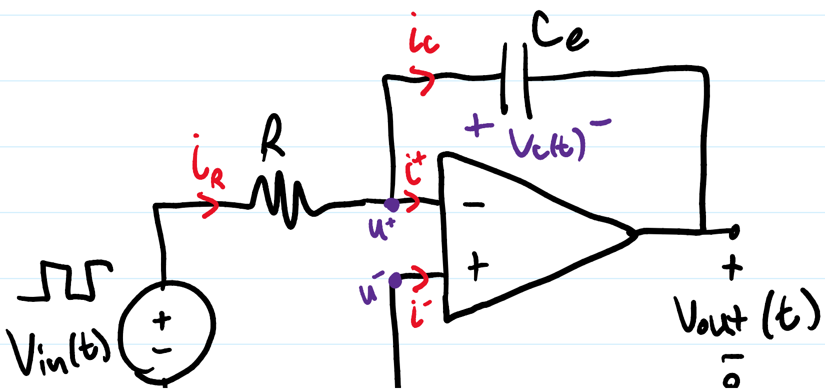




If touch, then the comparator output is zero. If no touch, then $V_{out}(t)$ is alternating.

It turns out current sources are hard to implement. How can we force a constant current through a capacitor?

Integrator circuit: $V_{out}(t) = \int V_{in}(t)\, dt$

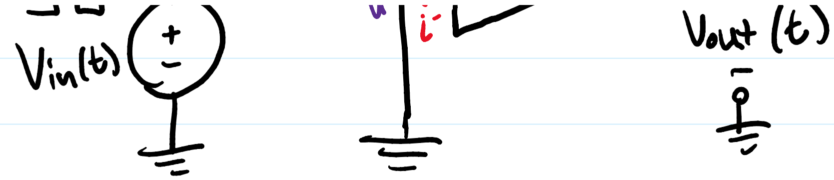


negative feedback? ✓

GR #2: $u^+ = u^- \rightarrow = 0$

KCL @ u^+: GR #1

$$i_R - \cancel{i^+}^{\,0} - i_c = 0$$



$$i_R - \cancel{i^-}^{\to 0} - i_C = 0$$

$$\frac{V_{in} - \cancel{u^+}^{\to 0}}{R} - 0 - C_e \frac{\partial V_c}{\partial t} = 0$$

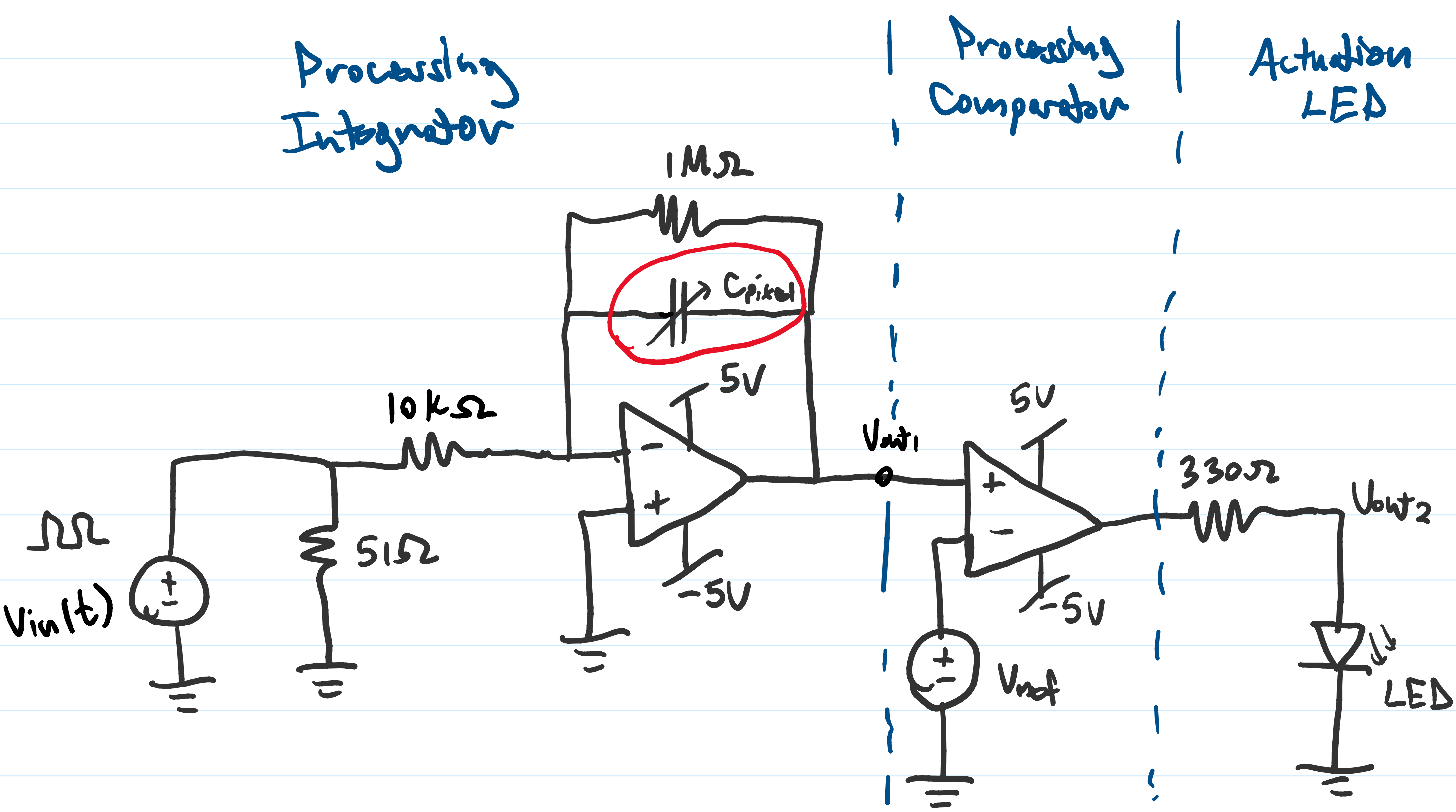
$$V_c = \cancel{u^+}^{\to 0} - V_{out}$$
$$= -V_{out}$$

$$\frac{V_{in}}{R} + C_e \frac{\partial V_{out}}{\partial t} = 0$$

$$\boxed{V_{out}(t) = -\frac{1}{RC_e}\int V_{in}(t)\,dt}$$

Connect output of integrator to earlier comparator circuit
- Skipped a few steps but more explanation in Note 20 and Touch 3 lab

Touch 3 (Lab) Final Circuit



When touch, Cpixel increases and LED stops flashing

THE END (of Module #2)

Thank you! :)