

## 6.301 Solid-State Circuits

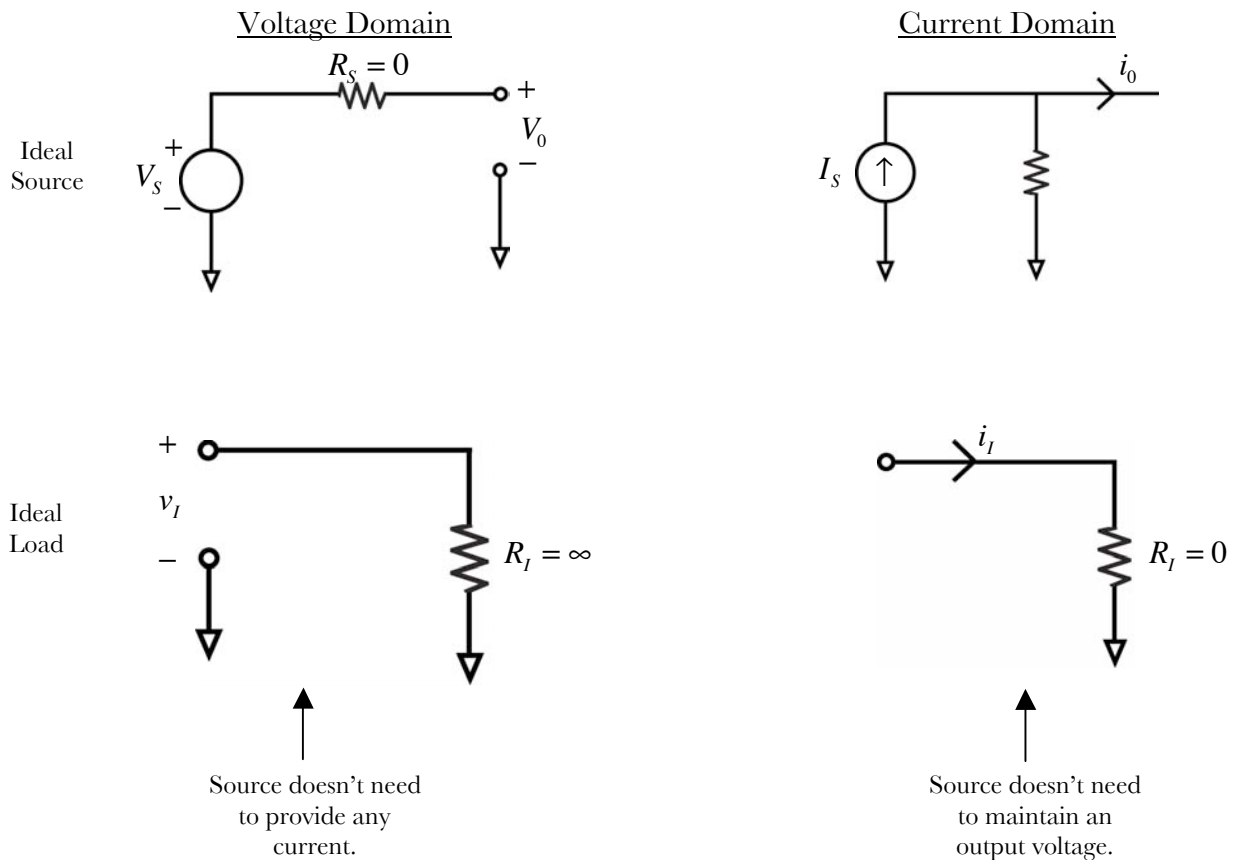
Recitation 20: I/V and V/I Conversion

Prof. Joel L. Dawson

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Now we get to a topic that we have somewhat glossed over during our discussion of translinear circuits. The circuits we have shown you have all taken currents as inputs and provided currents as outputs. But we know that in practice, the variables of interest to us are often voltages. What do we do? We must address the issue of voltage-to-current and current-to-voltage conversion.

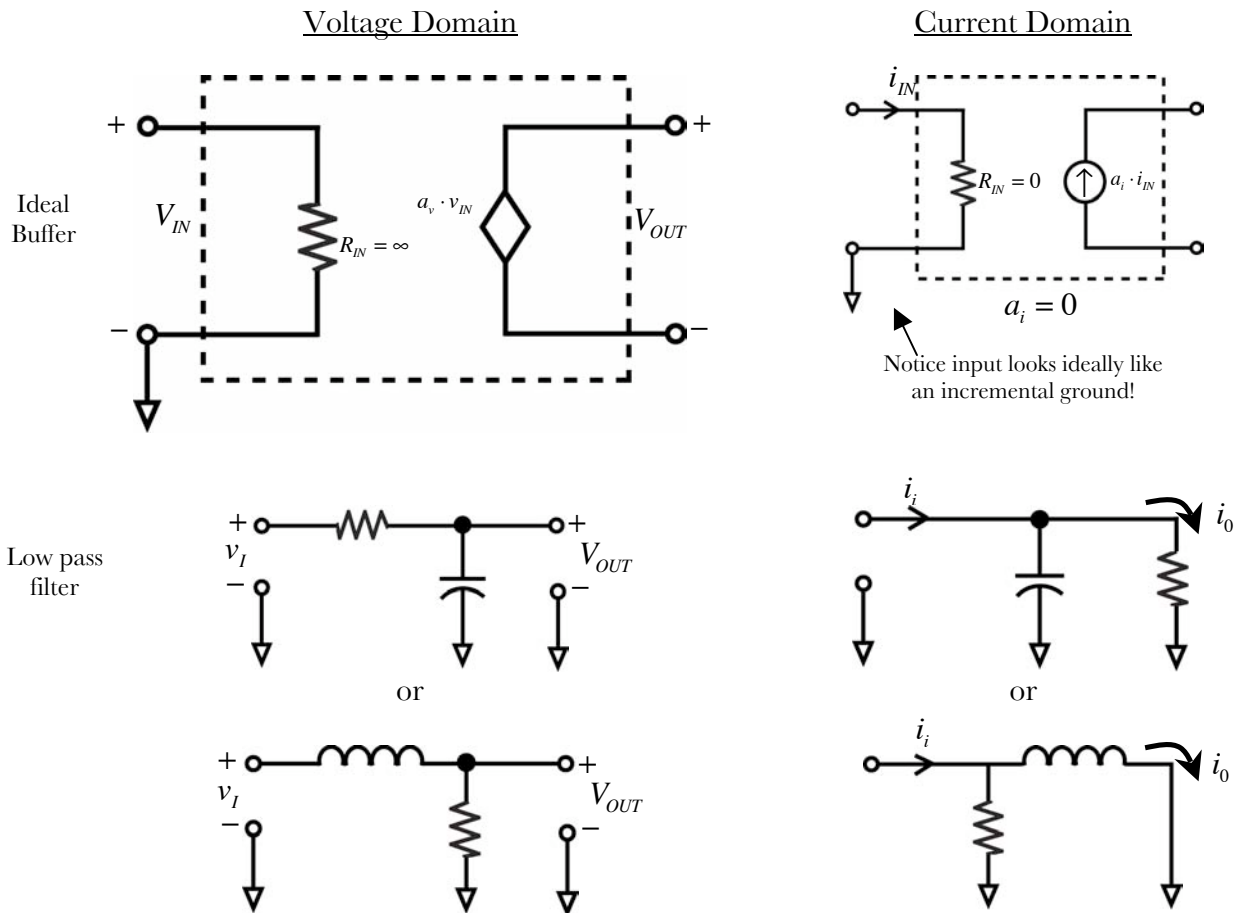
Let's begin by reviewing our views of the world when we're concerned about voltages vs. currents.



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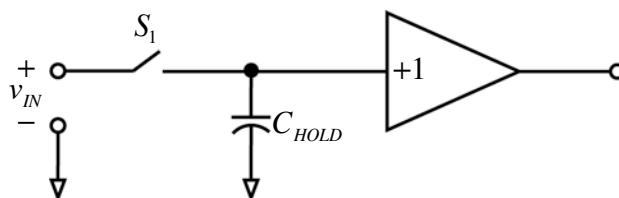
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Notice that the voltage LPF assumes an infinite impedance load, while the current LPF assumes a zero impedance load.

**CLASS EXERCISE:** A “sample-and-hold” is a circuit that, fittingly enough, samples the variable of interest at a predetermined time, and then holds it. For voltages, we might have



When  $S_1$  is closed, the voltage across  $C_{HOLD}$  is just  $v_{IN}$ . When  $S_1$  is open, an ideal capacitor and buffer will hold the sampled value indefinitely. Design a current mode sample-and-hold.

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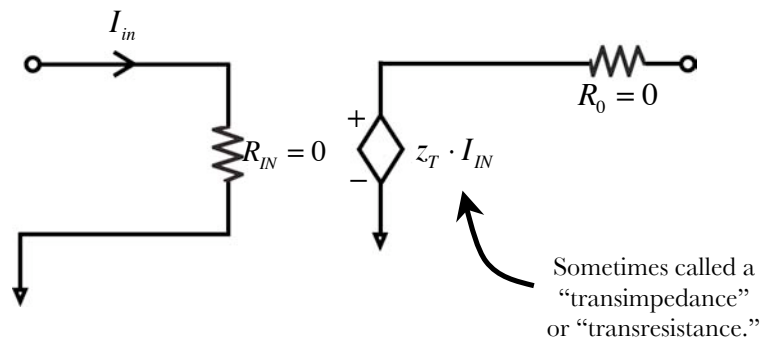
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(Workspace)

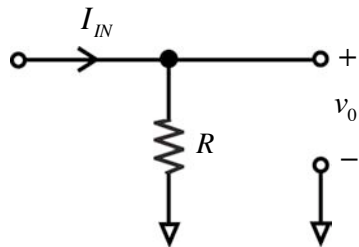
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### Current-to-Voltage Converters

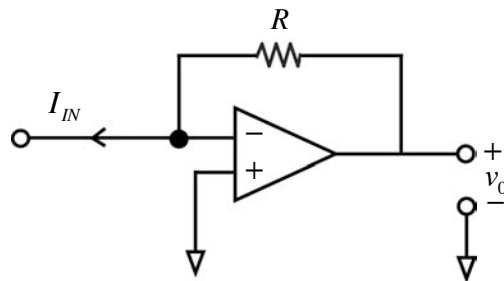
What do we ask of a good current-to-voltage converter? It should have low input impedance and low output impedance, right?



I/V Converter #1:



I/V Converter #2:

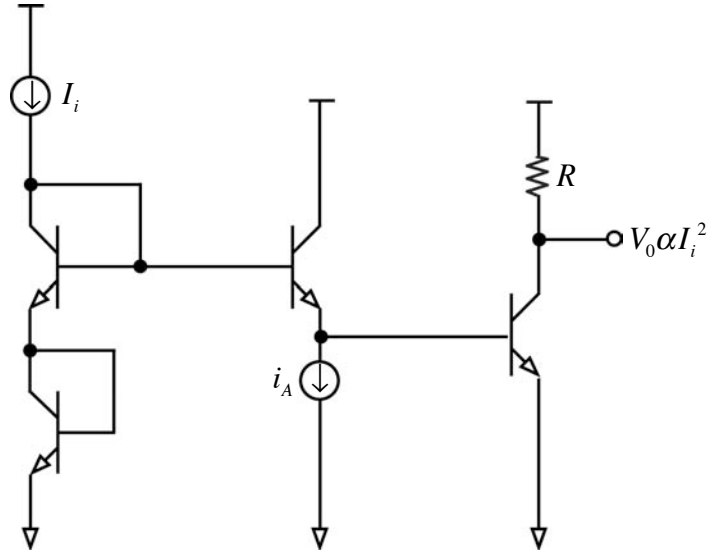


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Example: Squarer Circuit

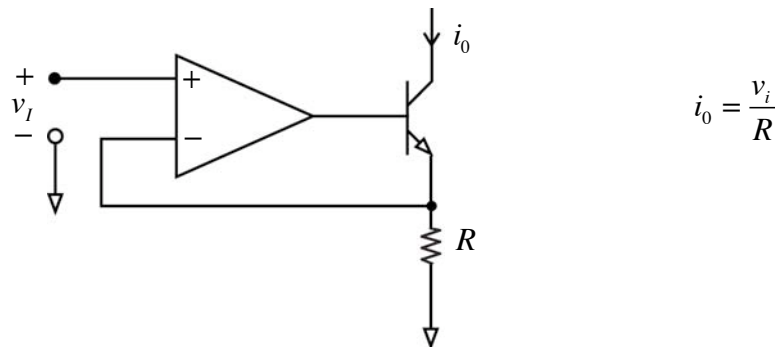


How does this I/V converter affect the speed of the square-root circuit?

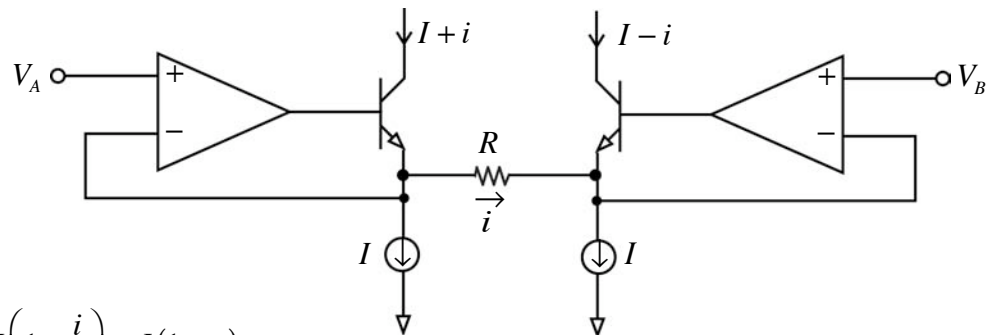
### Voltage-to-Current Converters

Here we want high input impedance and high output impedance. We can use op-amps to help us out here:

Single-Ended:



Differential:



$$i = \frac{V_A - V_B}{R}; \quad I + i = I \left( 1 + \frac{i}{I} \right) = I(1 + x)$$

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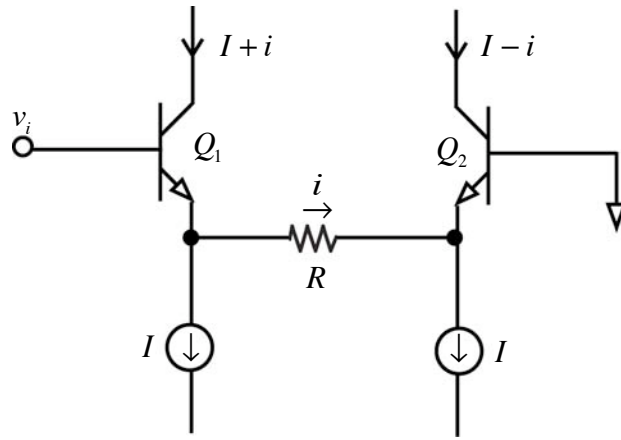
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These V/I converters are very good in some ways: very linear, nice, high output and input impedances. Their dynamics are much more cluttered than we might like, though: remember that translinear circuits can operate up to significant fractions of  $f_T$ . Op-amps don't do that.

What to do? We go back to our detailed knowledge of BJTs, and see what is possible. Notice that this is only necessary if the op-amp solutions are too slow, or if they consume too much die area.



Why not  $R=0$ ? Because it would be too nonlinear. The input voltage range would only span a few  $V_T$ 's. With the resistor in place, we can write KVL:

$$v_i - V_{BE1} - V_R + V_{BE2} = 0$$

$$V_R = v_i - (V_{BE1} - V_{BE2})$$

$$iR = v_i - (V_{BE1} - V_{BE2})$$

$$i = \frac{v_i}{R} - \frac{V_{BE1} - V_{BE2}}{R}$$

$$= \frac{v_i}{R} - \frac{1}{R} \left( V_T \ln \frac{I_1}{I_S} - V_T \ln \frac{I_2}{I_S} \right)$$

$$i = \frac{v_i}{R} - \frac{V_T}{R} \ln \left( \frac{I + i}{I - i} \right)$$

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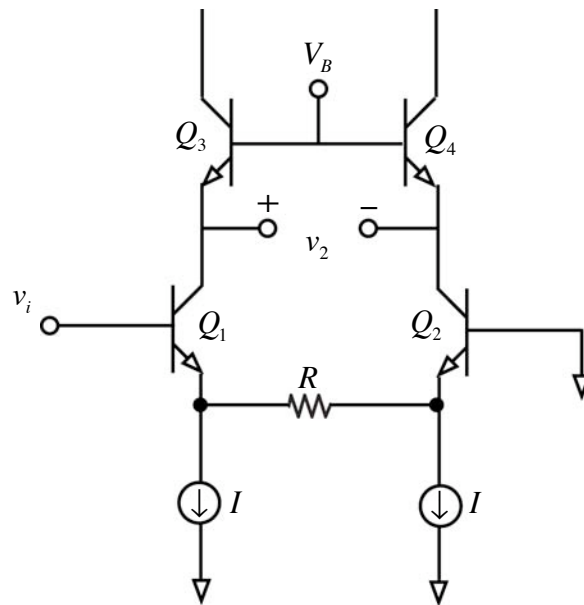
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$$i = \underbrace{\frac{v_i}{R}}_{\text{Linear, desirable term}} - \underbrace{\frac{V_T}{R} \ln\left(\frac{I+i}{I-i}\right)}_{\text{Nonlinear, undesirable term}}$$

In the course reader, Dr. Lundberg goes on to describe a correction for this nonlinear problem. Conceptually, the relevant question: How can we measure this corruption somehow? If we can measure it, perhaps we can subtract it out.

It turns out that we can measure it:



$$v_2 = (V_B - V_{BE3}) - (V_B - V_{BE4}) = V_{BE4} - V_{BE3}$$

But since  $I_{C3} = I_{C1}$  and  $I_{C4} = I_{C2}$ , we have

$$v_2 = V_{BE2} - V_{BE1} = -V_T \ln\left(\frac{I+i}{I-i}\right)$$

Having measure the nonlinear corruption, the text goes on to show how to use this measurement to improve things.

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