EE 254

Electronic Instrumentation

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Lecture Note #10

Content (Brief)

2. Op-Amp Applications

- Linear Applications
  - Inverting amplifiers
  - Noninverting amplifiers
  - Differential amplifiers
  - Summing amplifiers
  - Integrators
  - Differentiators
  - Low/ High pass filters
  - Instrumentational amplifiers
- Nonlinear Applications
  - Precision rectifiers
  - Peak detectors
  - Schmitt-trigger comparator
  - Logarithmic amplifiers

① **Precision Rectifiers**

② **Peak Detectors**

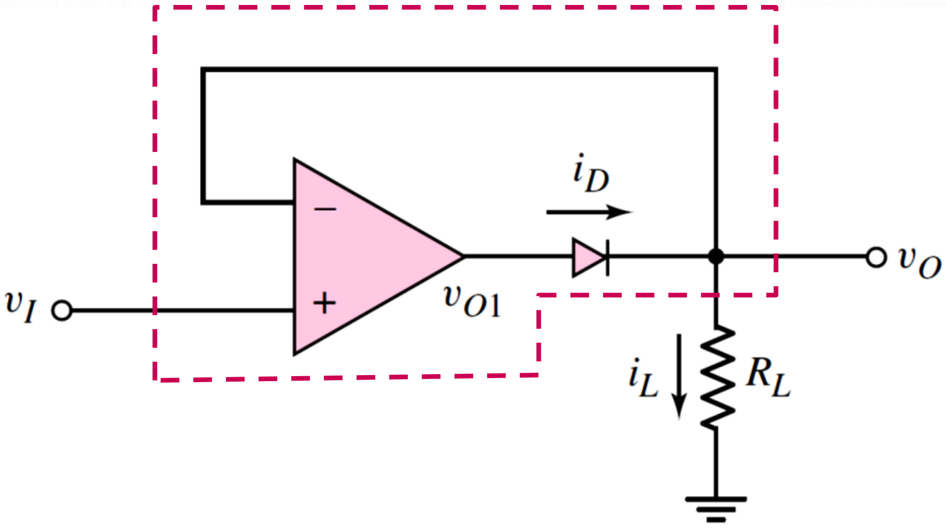
③ **Logarithmic Amplifiers**

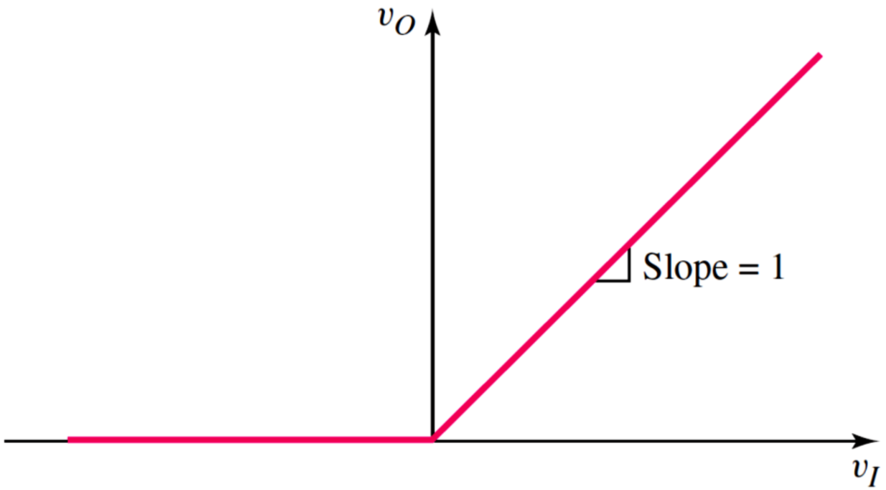
① Precision Half-Wave Rectifier

- For $v_I \geq 0$

$$v_o = v_I$$

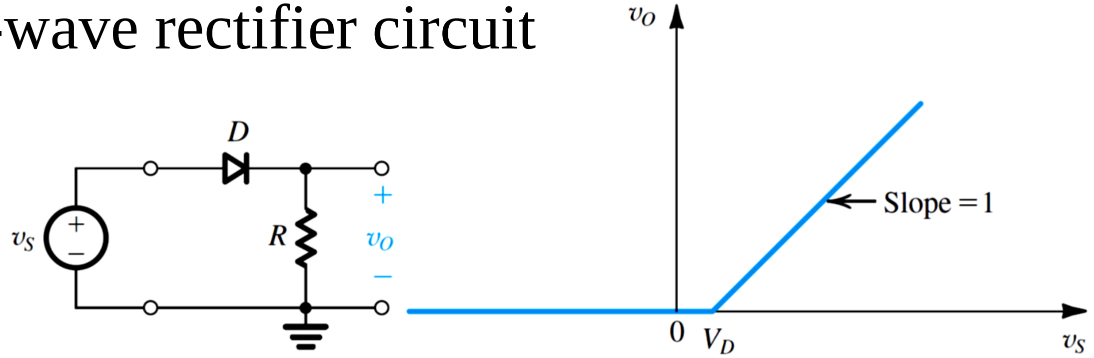
Super-diode



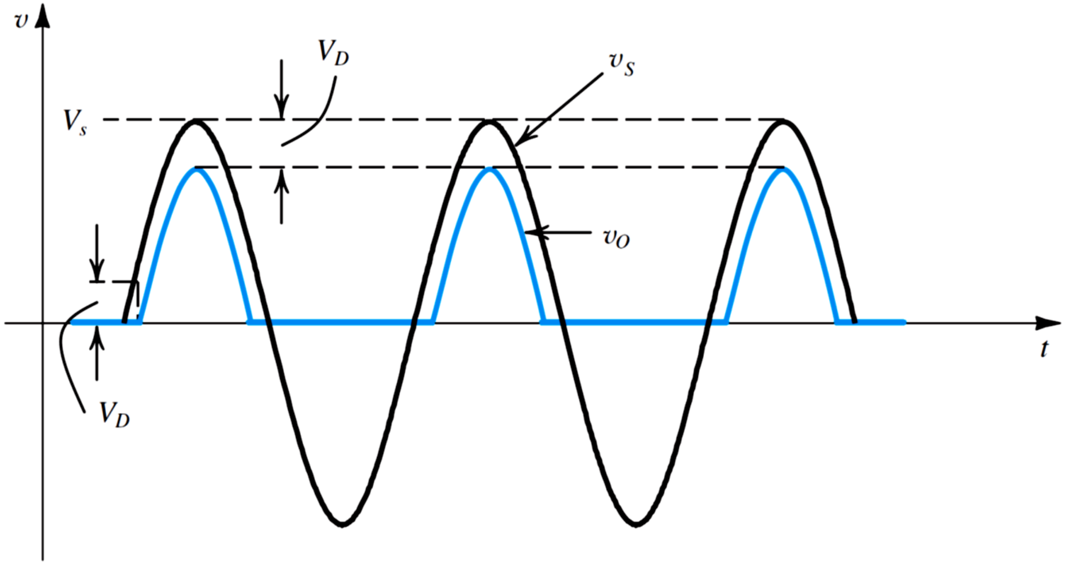


① Precision Half-Wave Rectifier

Simple half-wave rectifier circuit



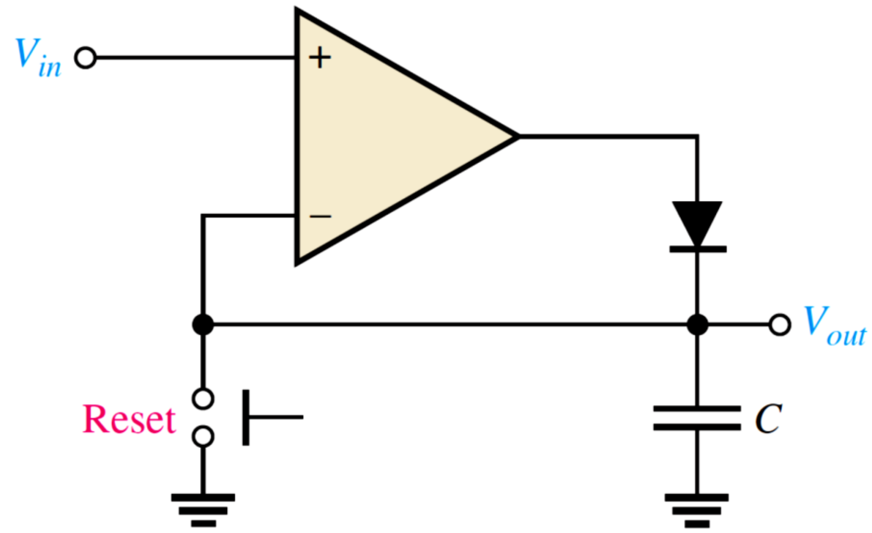
(a) (b)



(c)

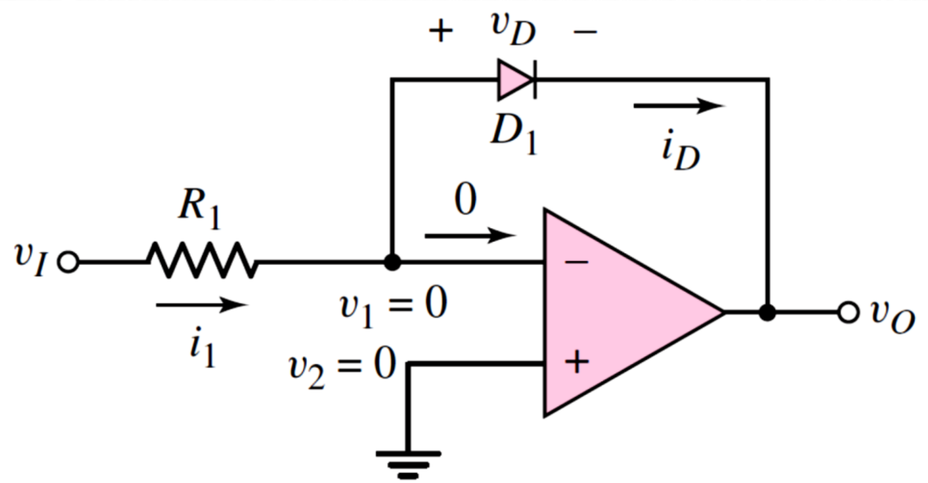
② Peak Detector

- An interesting application of the op-amp is in a peak detector circuit.
- This circuit is used to detect the peak of the input voltage and store that peak voltage on a capacitor.
- For example, to detect and store the maximum value of a voltage surge



③ Logarithmic Amplifier

- The diode is to be forward biased, so the input signal voltage is limited to positive values.



- The diode current

$$i_D = I_S(e^{v_D/V_T} - 1)$$

- If the diode is sufficiently forward biased, the (-1) term is negligible

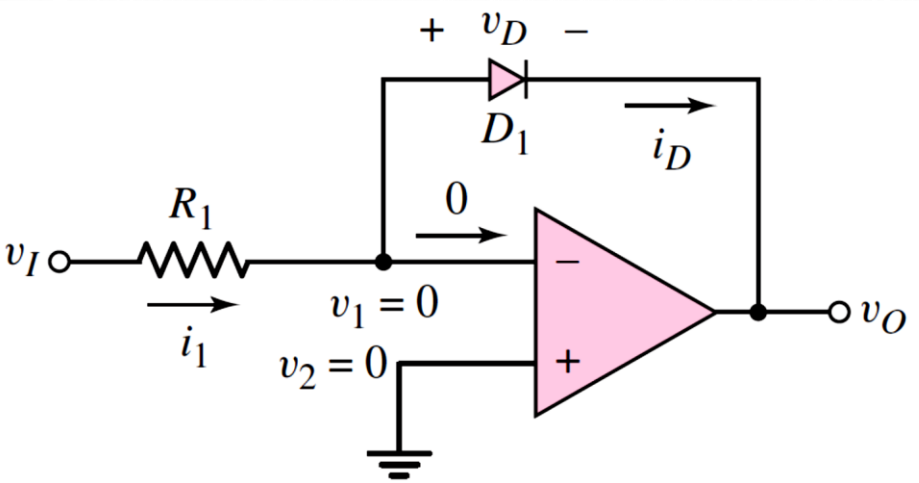
$$i_D \cong I_S e^{v_D/V_T}$$

- The input current $i_1 = \dfrac{v_I}{R_1}$

③ Logarithmic Amplifier

- The output voltage, since v_1 is at virtual ground

$$v_O = -v_D$$



- Noting that $i_1 = i_D$,

$$i_1 = \frac{v_I}{R_1} = i_D = I_S e^{-v_O/V_T}$$

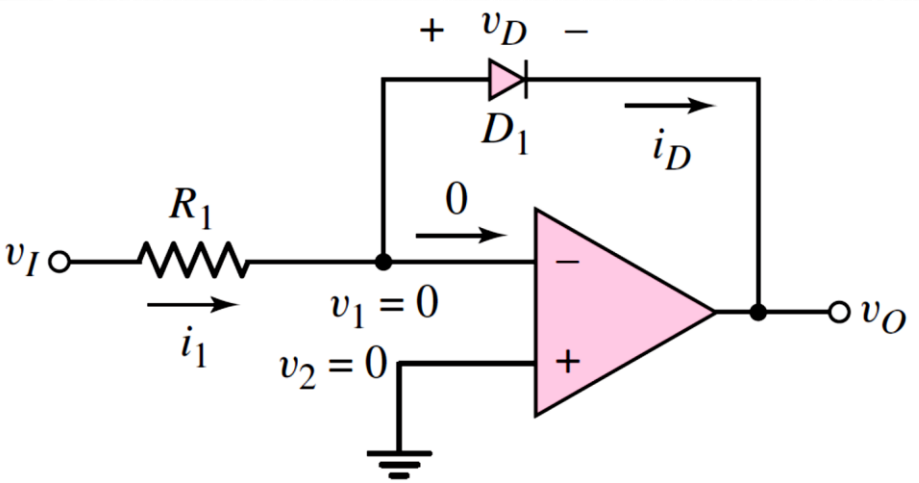
- Take the natural log of both sides

$$\ln\left(\frac{v_I}{I_S R_1}\right) = -\frac{v_O}{V_T}$$

$$v_O = -V_T \ln\left(\frac{v_I}{I_S R_1}\right)$$

③ Logarithmic Amplifier

$$v_O = -V_T \ln\left(\frac{v_I}{I_S R_1}\right)$$

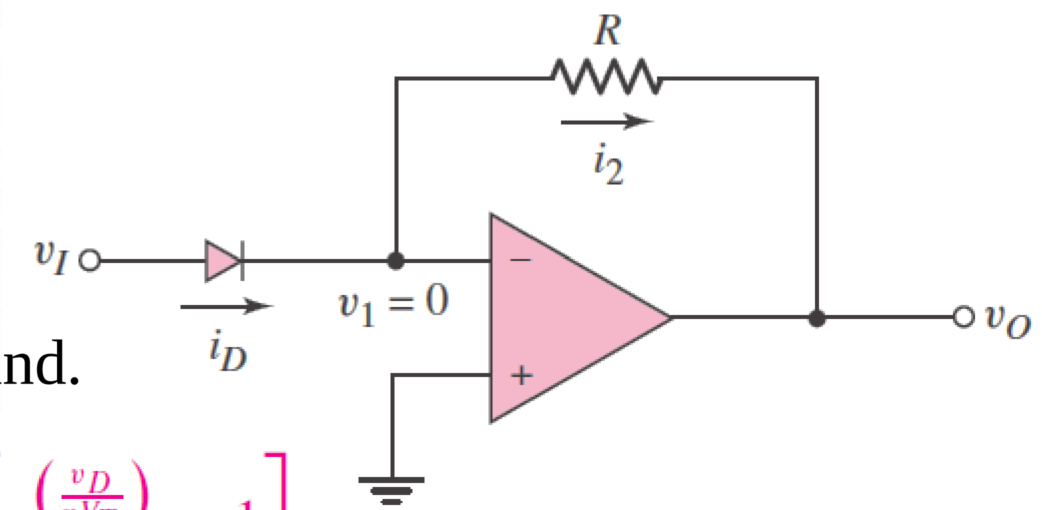


- The output voltage is proportional to the log of the input voltage.

- Analyze the disadvantages of this circuit configuration and explain the solutions to overcome them.

④ Antilog or Exponential Amplifier

- Example using a diode as the current through the diode is in exponential form.



$v_I > 0$ and v_1 is virtually ground.

$$i_D \cong I_S e^{v_I/V_T} \qquad i_D = I_S\left[e^{\left(\frac{v_D}{nV_T}\right)} - 1\right]$$

and $\quad v_O = -i_2 R = -i_D R \quad$ or $\quad v_O = -I_S R \cdot e^{v_I/V_T}$

- **The output voltage is an exponential function of the input voltage.**

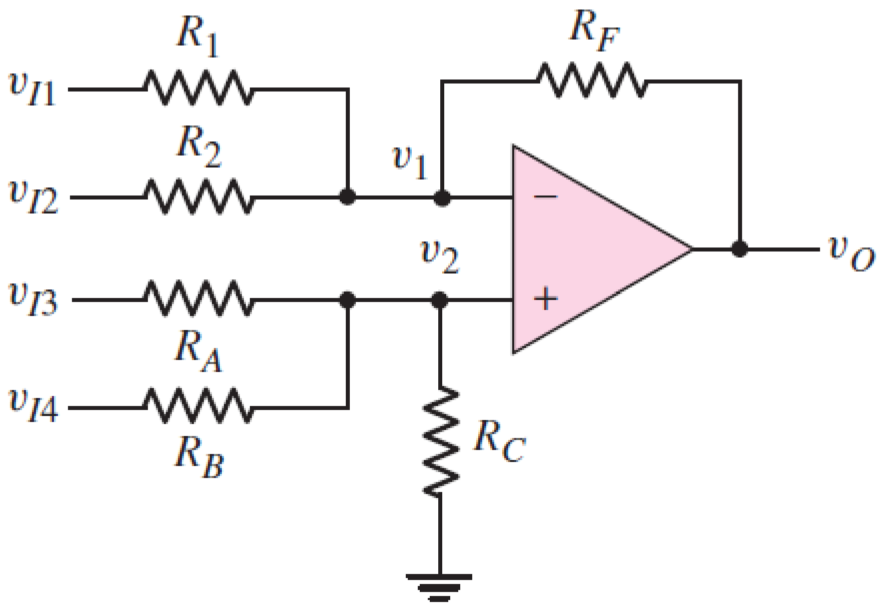
v_T is the Thermal voltage approximately $0.026\,V$ at room temperature. The parameter I_S is the **reverse-bias saturation current.** For silicon pn junctions, typical values are in the range of 10^{-18} to $10^{-12}\,A$.

Design Examples

Summing Op-Amp Circuit Design

- How to design a circuit such that the output is:

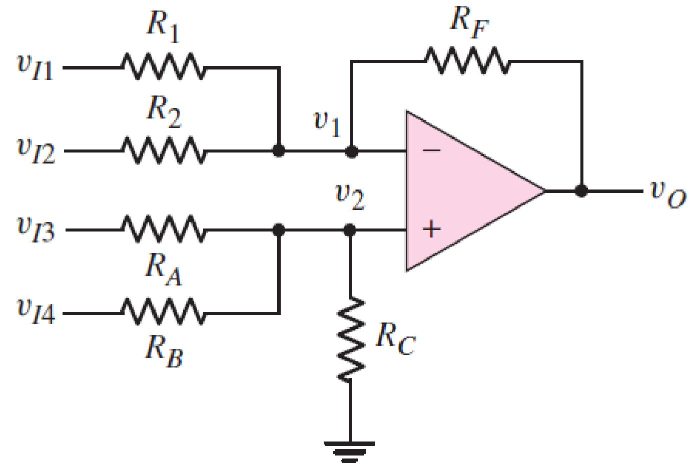
$$v_O = -a_1 v_{I1} - a_2 v_{I2} + a_3 v_{I3} + a_4 v_{I4}$$



Determine the output voltage in terms of input voltages and resistors in the circuit.

Summing Op-Amp Circuit Design

- The output terms due to the inputs given to the inverting terminal v_{I1} and v_{I2}.



$$v_O(v_{I1}) = -\frac{R_F}{R_1}v_{I1} \qquad v_O(v_{I2}) = -\frac{R_F}{R_2}v_{I2}$$

- The output terms due to the inputs given to the non-inverting terminal v_{I3} and v_{I4}.

$$v_2(v_{I3}) = \frac{R_B \| R_C}{R_A + R_B \| R_c}v_{I3} = v_1(v_{I3})$$

$$v_O(v_{I3}) = \left(1 + \frac{R_F}{R_1 \| R_2}\right)v_1(v_{I3}) = \left(1 + \frac{R_F}{R_1 \| R_2}\right)\left(\frac{R_B \| R_C}{R_A + R_B \| R_C}\right)v_{I3}$$

$$v_O(v_{I3}) = \left(1 + \frac{R_F}{R_N}\right)\left(\frac{R_P}{R_A}\right)v_{I3}$$

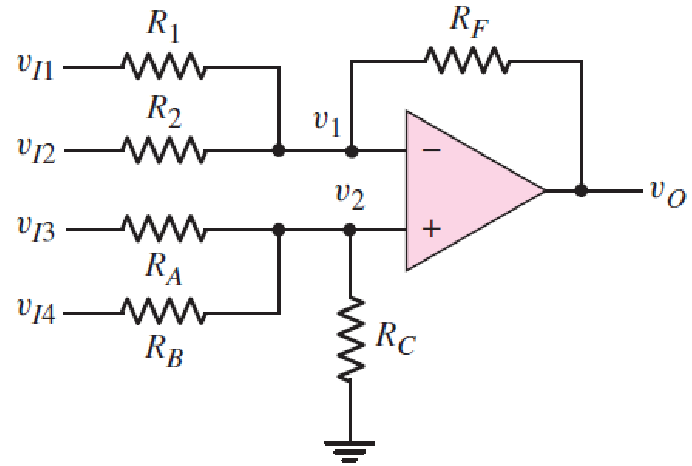
where,

$$R_N = R_1 \| R_2$$

$$R_P = R_A \| R_B \| R_C$$

Summing Op-Amp Circuit Design

- The output voltage due to v_{I4} is similarly determined.



$$v_O(v_{I4}) = \left(1 + \frac{R_F}{R_N}\right)\left(\frac{R_P}{R_B}\right)v_{I4}$$

- Applying superposition theorem, the total output voltage can be computed as a sum of the individual terms.

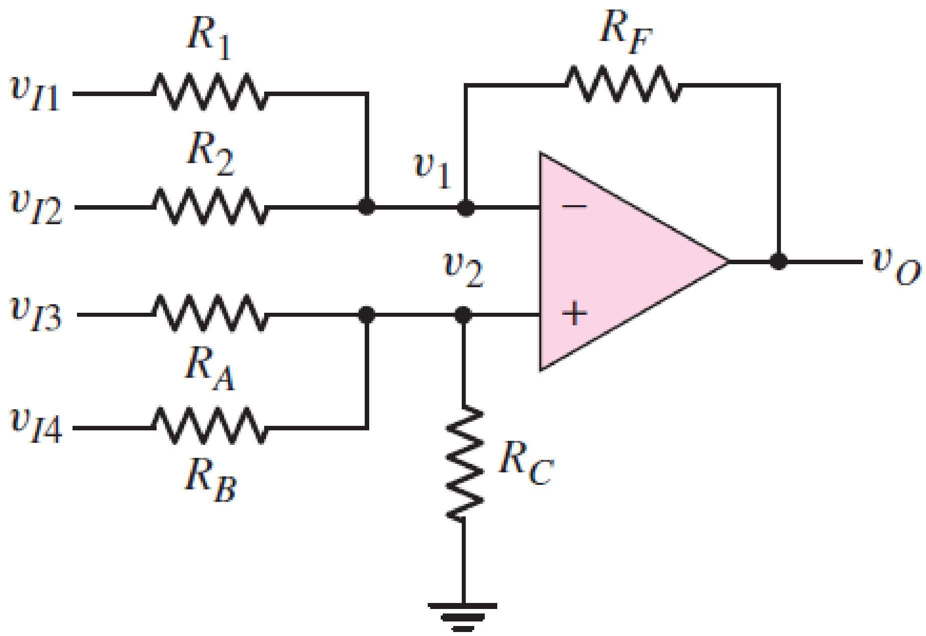
$$v_O = -\frac{R_F}{R_1}v_{I1} - \frac{R_F}{R_2}v_{I2} + \left(1 + \frac{R_F}{R_N}\right)\left[\frac{R_P}{R_A}v_{I3} + \frac{R_P}{R_B}v_{I4}\right]$$

Design Example 01: Summing Amplifier

Design a summing op-amp to produce the output

$$v_O = -10v_{I1} - 4v_{I2} + 5v_{I3} + 2v_{I4}$$

The smallest resistor value allowable is $20k\Omega$. Consider the circuit in Figure below.



Design Example 01: Summing Amplifier

Solution:

First we determine the values of resistors R_1, R_2, and R_F. (associated with the inverting terms)

$$v_O = -10v_{I1} - 4v_{I2} + 5v_{I3} + 2v_{I4}$$

$$v_O = -\frac{R_F}{R_1}v_{I1} - \frac{R_F}{R_2}v_{I2} + \left(1 + \frac{R_F}{R_N}\right)\left[\frac{R_P}{R_A}v_{I3} + \frac{R_P}{R_B}v_{I4}\right]$$

Then, $\frac{R_F}{R_1} = 10$ and $\frac{R_F}{R_2} = 4$

The resistors R_1 will be the smallest value and set it as $20k\Omega$.

Then, $R_F = 200\,\mathrm{k\Omega}$ and $R_2 = 50\,\mathrm{k\Omega}$

Design Example 01: Summing Amplifier

Solution:

The multiplying factor in the noninverting terms;

$$\left(1+\frac{R_F}{R_1 \| R_2}\right)=\left(1+\frac{200}{20 \| 50}\right)=15$$

We then need;

$$(15)\left(\frac{R_P}{R_A}\right)=5 \quad \text{and} \quad (15)\left(\frac{R_P}{R_B}\right)=2$$

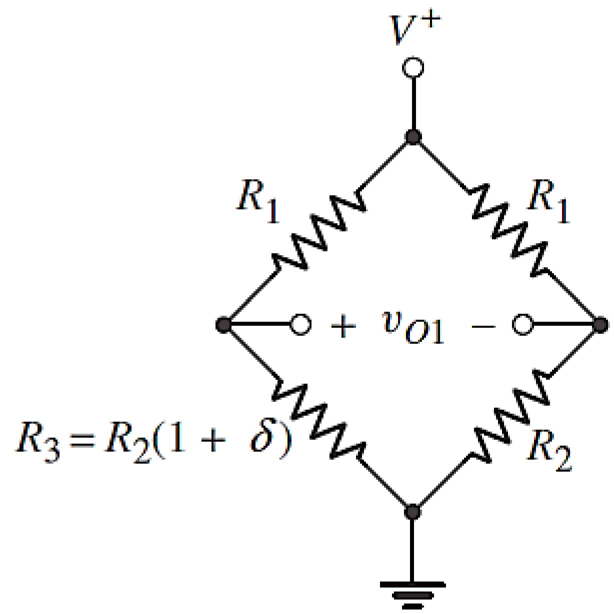
Then; $$\frac{R_B}{R_A}=\frac{5}{2}$$

If we choose $R_A = 80k\Omega$, then $R_B = 200k\Omega$, $R_P = 26.67k\Omega$, and R_C becomes $R_C = 50k\Omega$.

Difference Amplifier and Bridge Circuit Design

- Resistance R_3 represents the transducer, and parameter δ is the deviation of R_3 from R_2 due to the input response of the transducer.

- The output voltage v_{O1} is a measure of δ. If v_{O1} is an open-circuit voltage;



Bridge Circuit

$$v_{O1} = \left[\frac{R_2(1+\delta)}{R_2(1+\delta)+R_1} - \frac{R_2}{R_1+R_2} \right] V^+$$

Which can be reduced to;

$$v_{O1} = \delta \left(\frac{R_1 \| R_2}{R_1 + R_2} \right) V^+$$

Ex. 02: Difference Amplifier and Bridge Circuit Design

Design an amplifier system that will produce an output voltage of $\pm 5V$ when the resistance R_3 deviates by ±1% from the value of R_2. This would occur, for example, in a system where R_3 is a thermistor whose resistance is given by;

$$R_3 = 200\left[1 + \frac{(0.040)(T - 300)}{300}\right]\text{k}\Omega$$

where T is the absolute temperature. For R_3 to vary by $\pm 1\%$ means the temperature is in the range $225 \leq T \leq 375K$. Consider biasing the bridge circuit at $V^+ = 7.5V$ using a $5.6\,V$ Zener diode. Assume $\pm\,10V$ is available for biasing the op-amp and reference voltage source, and that $R_1 = R_2 = 200k\Omega$.

Ex. 02: Difference Amplifier and Bridge Circuit Design

Solution:

With $R_1 = R_2$, $v_{O1} = \delta \left(\frac{R_1 \| R_2}{R_1 + R_2} \right) V^+$ ⇒ $v_{O1} = \left(\frac{\delta}{4} \right) V^+$

For $V^+ = 7.5\,V$ and $\delta = 0.01$ (1%), the maximum output voltage,

$$v_{O1} = 0.01875\,V$$

If the output is to be +5 V, the gain of the amplifier must be $\frac{5}{0.01875} = 266.7$

Ex. 02: Difference Amplifier and Bridge Circuit Design

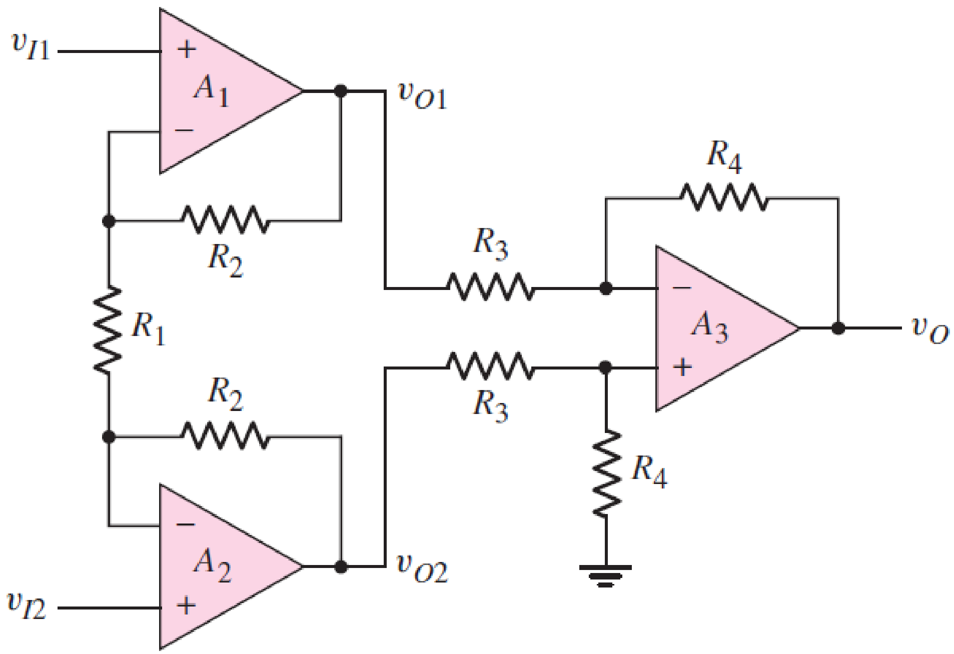
- Let's consider the instrumentation amplifier below; the output voltage:

$$v_O = \frac{R_4}{R_3}\left(1+\frac{2R_2}{R_1}\right)(v_{I2}-v_{I1})$$

$$\frac{v_O}{v_{O1}} = \frac{R_4'}{R_3'}\left(1+\frac{2R_2'}{R_1'}\right) = 266.7$$

We would like the ratios R_4'/R_3' and R_2'/R_1' to be the same order of magnitude.

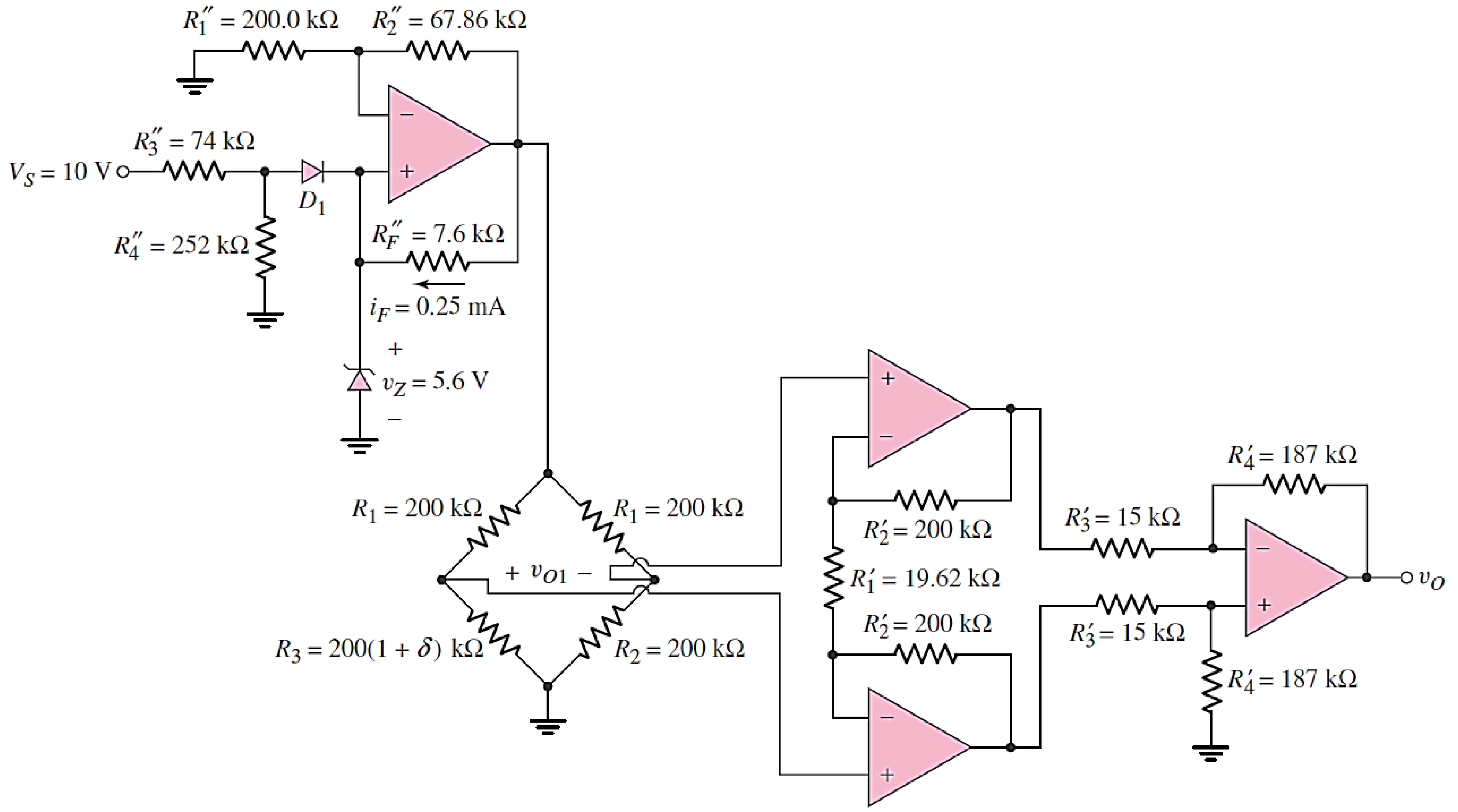
If set $R_3' = 15\ k\Omega$ and $R_4' = 187\ k\Omega$, then $R_4'/R_3' = 12.467$ and $R_2'/R_1' = 10.195$.



If set $R_2' = 200\ k\Omega$ then $R_1' = 19.62\ k\Omega$

Ex. 02: Difference Amplifier and Bridge Circuit Design

- The complete design of the instrumentation amplifier:

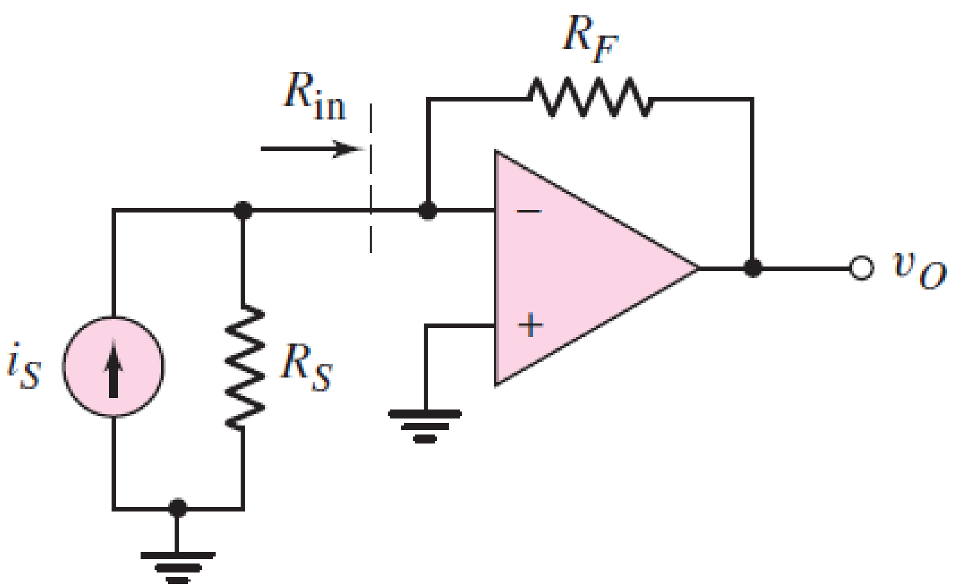


Ex. 03 : Current–to–Voltage Converter

A current-to-voltage converter is shown in Figure below. The current source has a finite output resistance R_S, and the op-amp has a finite open-loop differential gain A_{od}.

a) Show that the input resistance is given by: $$R_{\text{in}} = \frac{R_F}{1 + A_{od}}$$

b) If $R_F = 10k\Omega$ and $A_{od} = 1000$, determine the range of R_S such that the output voltage deviates from its ideal value by less than 1 percent.



Ex. 04 : Current–to–Voltage Converter

Figure below shows a phototransistor that converts light intensity into an output current. The transistor must be biased as shown. The transistor output versus input characteristics are shown. Design a current-to-voltage converter to produce an output voltage between 0 and 8 V for an input light intensity between 0 and 20 mW/cm^2. Power supplies of +10V and −10V are available.