Jan. 9, 2009 | EE 241 | CAPT Cameron

Problem Set 1

1.2 List five types of functional blocks found in electronics systems.

Solution (p. 2) amplifiers, filters, signal sources, wave-shaping circuits, digital logic functions, digital memories, power supplies, converters

1.3 Discuss some of the distinctions between information-processing electronics and power electronics.

Solution

In information-processing electronics, the focus is on the meaning of a particular signal. This could be a radio signal, and audio signal, or digital data, for example.

In power electronics the focus is on delivering power in a controlled, safe manner. Such signals have no particular meaning, except in the area of control, where the lines between information and power begin to blur.

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1.6 An analog signal is to be converted to digital form as illustrated in Figure 1.3, except that 16-bit code words (instead of 3-bit code words) are used to represent each amplitude zone, the signal is sampled at 44.1 kHz. (these are the values for each channel of audio on a compact disc.) How many bits per second result? How many amplitude zones can be represented by 16 bit code words? Suppose that the highest amplitude represented is +5V and the lowest is -5V. Determine the width Δ (illustrated in Figure 1.3) of each quantization zone.

Solution

the bit-sampling rate is

$$r = \left(\frac{\text{samples}}{\text{s} \cdot \text{channel}}\right)\left(\frac{\text{bits}}{\text{sample}}\right)\left(\#\text{ of channels}\right)$$

$$= \left(44{,}100 \ \frac{\text{samples}}{\text{s} \cdot \text{channel}}\right)\left(\frac{16\text{-bits}}{\text{sample}}\right)\left(2 \text{ channels}\right)$$

$$\boxed{r = 1{,}411{,}200 \ \frac{\text{bits}}{\text{s}}}$$

$\boxed{\text{The number of amplitude zones is } 2^{16} = 65{,}536.}$

$$\Delta = \frac{V_{max} - V_{min}}{2^{16}}$$

$$= \frac{5V - (-5V)}{2^{16}}$$

$$\boxed{\Delta = 153 \ \mu V}$$

1.8 List the steps in the design of an electronic system.

Solution

1. Develop detailed system specifications.
2. Invent solution approaches.
3. Create one or more potential block diagrams for each approach.
4. Perform detailed design, build prototypes, and test circuits for each block diagram selected.
5. Combine tested subsystems into a complete system, test it, and track down errors.
6. Produce final products.

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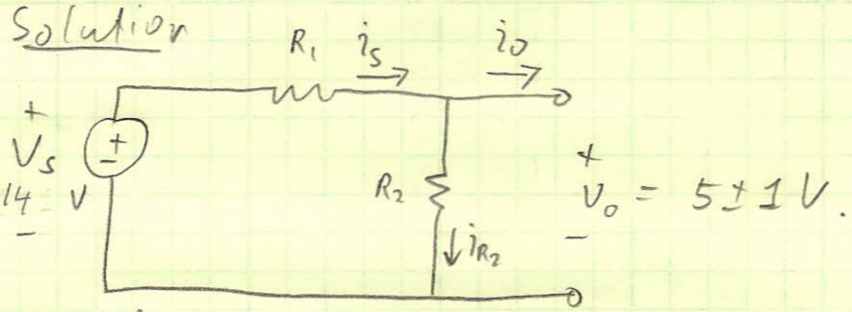
D1.9 Voltage-divider design. Suppose that we need to supply 5 ± 1 V to a computer that draws a variable current ranging from 0 to 300 mA. A constant 14 V source is available. Design a circuit composed of resistors to supply the required voltage to the computer. Assume that resistors having any nominal value are available, but that the resistors have tolerances of $\pm 5\%$. Use a resistive voltage divider.

Solution



By Ohm's law, $v_o = i_{R_2} R_2$

and $i_s = \dfrac{v_s - v_o}{R_1}$. But $i_s = i_o + i_{R_2}$ by KCL.

$= i_o + \dfrac{v_o}{R_2}$

So $\dfrac{v_s - v_o}{R_1} = i_o + \dfrac{v_o}{R_2}$

Now v_o is maximal when $i_o = 0A$, R_2 is maximal, and R_1 is minimal.

So $\dfrac{14V - 6V}{0.95\,R_1} = \dfrac{6V}{1.05\,R_2}$

$\dfrac{R_2}{R_1} = \dfrac{(0.95)\,6V}{1.05\,(14V - 6V)} = 0.6786$ and $\dfrac{R_1}{R_2} = 1.474$

Similarly, v_o is minimal when $i_o = 300mA$, R_2 is minimal, and R_1 is maximal.

So $\dfrac{14V - 4V}{1.05\,R_1} = 300mA + \dfrac{4V}{0.95\,R_2}$

$\dfrac{10V}{1.05} - \dfrac{4V}{0.95}\dfrac{R_1}{R_2} = (300\ mA)R_1$

$R_1 = \dfrac{1}{300mA}\left(\dfrac{10V}{1.05} - \left(\dfrac{4V}{0.95}\right)(1.474)\right) = 11.06\Omega$

$R_2 = 0.6786\,R_1 = 7.507\,\Omega$

$\boxed{R_1 = 11.06\,\Omega}$ $\boxed{R_2 = 7.507\,\Omega}$

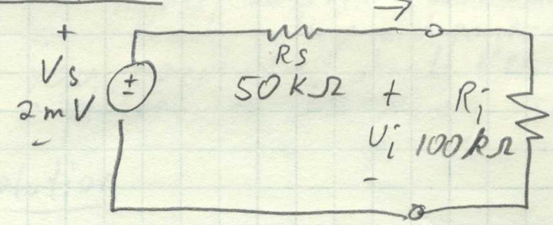
1.14 What are the loading effects in an amplifier circuit?

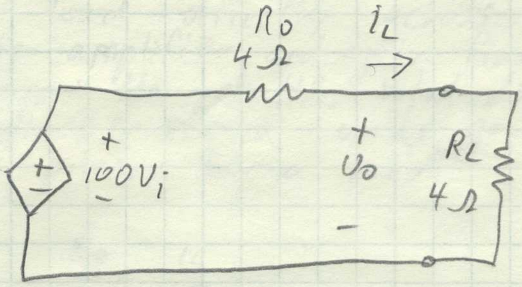
Solution

Because the output resistance of an amplifier is greater than $0\ \Omega$, drawing current from the amplifier causes a voltage drop across the output resistance. this reduces the voltage available to the load. this is known as the loading effect. the load resistance imposes a current load on the amplifier and so gets a diminished voltage.

1.15 A signal source with an open-circuit voltage of $V_s = 2\,mV$ rms and an internal resistance of $50\,k\Omega$ is connected to the input terminals of an amplifier having an open-circuit voltage gain of 100, an input resistance of $100\,k\Omega$, and an output resistance of $4\,\Omega$. A $4\,\Omega$ load is connected to the output terminals. Find the voltage gains $A_{vs} = V_o/V_s$ and $A_v = V_o/V_i$. Also find the power gain and current gain.

Solution





By the voltage-divider rule

$$V_o = \frac{R_L}{R_o + R_L} 100 V_i = \frac{R_L}{R_o + R_L} 100 \frac{R_i}{R_s + R_i} V_s$$

$$A_{vs} = \frac{V_o}{V_s} = \frac{4\,\Omega}{4\,\Omega + 4\,\Omega} 100 \frac{100\,k\Omega}{50\,k\Omega + 100\,k\Omega} = \cancel{0.333}\ 33.3$$

$$A_v = \frac{v_o}{v_i} = \frac{R_L}{R_o + R_L} 100 = 50$$

$$P_i = i_i v_i = \left(\frac{v_i}{R_i}\right) v_i = \frac{v_i^2}{R_i}$$

$$P_o = i_L v_o = \left(\frac{100 V_i}{R_o + R_L}\right)\left(\frac{R_L}{R_o + R_L} 100 v_i\right)$$

$$G = \frac{P_o}{P_i} = \left(\frac{100^2 v_i^2 (4\,\Omega)}{(4\,\Omega + 4\,\Omega)^2}\right)\left(\frac{100\,k\Omega}{v_i^2}\right) = 62.50 \times 10^6$$

$$i_o \quad \frac{100 v_i}{R_o + R_L} = \frac{V_o}{R_L} = \frac{100}{R_o + R_L} \frac{R_i}{R_s + R_i} V_s$$

$$i_i = \frac{v_i}{R_i}$$

$$A_i = \frac{i_o}{i_i} = \frac{100 R_i}{R_o + R_L} \quad \frac{100(100\,k\Omega)}{8\,\Omega} = 1.25 \times 10^6$$

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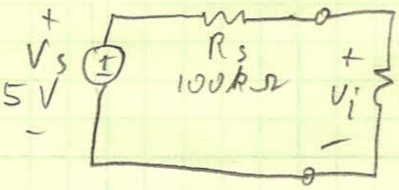
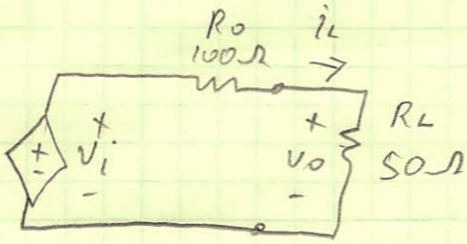
1.16 A certain amplifier has an open-circuit voltage gain of unity, an input resistance of 1 MΩ, and an output resistance of 100 Ω. The signal source has an internal voltage of 5 V and an internal resistance of 100 kΩ. The load resistance is 50 Ω. If the signal source is connected to the amplifier input terminals and the load is connected to the output terminals, find the voltage across the load and the power delivered to the load. Next, consider connecting the load directly across the signal source without the amplifier, and again find the load voltage and power. Compare the results. What do you conclude about the usefulness of a unity-gain amplifier in delivering signal power to a load?

Solution

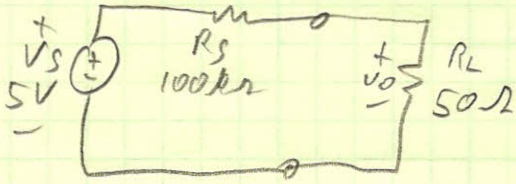




$$V_o = \frac{R_L}{R_o+R_L} V_i = \frac{R_L}{R_o+R_L}\,\frac{R_i}{R_s+R_i} V_s$$

$$= \frac{50\,\Omega}{100\,\Omega+50\,\Omega}\;\frac{1\,M\Omega}{100k\Omega+1\,M\Omega}\,5V = 1.52\,V$$

$$P_o = \frac{V_o^2}{R_L} = \frac{(1.52V)^2}{50\,\Omega} = 45.9\,mW \qquad \boxed{P_o = 45.9\,mW}$$



$$V_o = \frac{R_L}{R_s+R_L} V_s = \frac{50\,\Omega}{100k\Omega+50\,\Omega}\,5V = 2.50\,mV$$

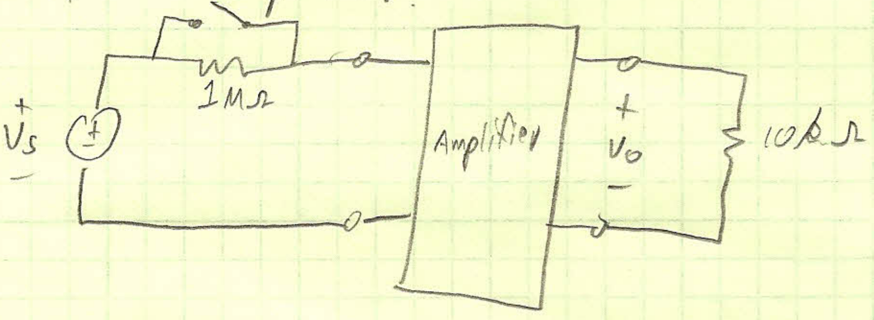
$$P_o = \frac{V_o^2}{R_L} = \frac{(2.50mV)^2}{50\,\Omega} = 125\,nW. \qquad \boxed{P_o = 125\,nW}$$

Without the unity-gain amplifier the power is just $\frac{125\,nW}{45.9\,mW} = 2.7\times10^{-6}$ that available with the amplifier.

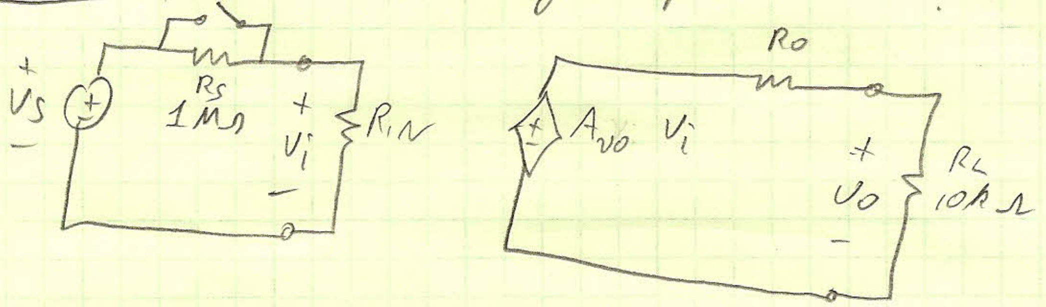
The unity-gain amplifier provides large power gain without any voltage gain.

This amplifier is often called a current buffer. It is especially useful when the source has a large output resistance, as it does in this case.

1.19 The output voltage v_o of the circuit of Figure P1.19 is 100 mV with the switch closed. With the switch open, the output voltage is 50 mV. Find the input resistance of the amplifier.



Solution Use the voltage-amplifier model.



$$V_O = \frac{R_L}{R_O+R_L} A_{vo} V_i = \frac{R_L}{R_O+R_L} A_{vo} \frac{R_{IN}}{R_S+R_{IN}} V_s$$

With the switch closed,

$$100\text{ mV} = \frac{R_L}{R_O+R_L} A_{vo} \frac{R_{IN}}{R_{IN}} V_S = \frac{R_L}{R_O+R_L} A_{vo} V_s$$

With the switch open,

$$50\text{ mV} = \frac{R_L}{R_O+R_L} A_{vo} \frac{R_{IN}}{R_S+R_{IN}} V_s$$

Let $y = \frac{R_L}{R_O+R_L} A_{vo} V_s$

$$100\text{ mV} = y$$

$$50\text{ mV} = y \frac{R_{IN}}{R_S+R_{IN}} = y \frac{1}{1+\frac{R_S}{R_{IN}}}$$

$$1+\frac{R_S}{R_{IN}} = \frac{y}{50\text{ mV}} = 2$$

$$\frac{R_S}{R_{IN}} = 1$$

$$R_{IN} = R_S = 1\text{ M}\Omega$$

$$\boxed{R_{IN} = 1\text{ M}\Omega}$$

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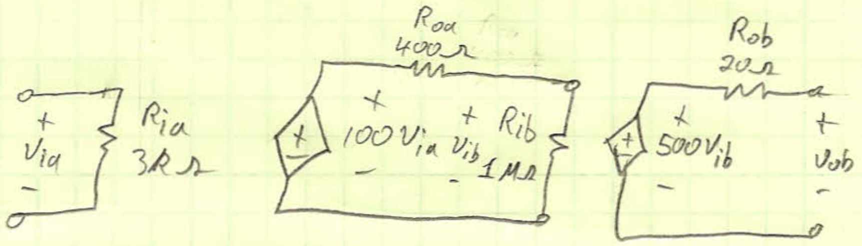
1.21 Two amplifiers have the characteristics shown in Table P1.21. If the amplifiers are cascaded in the order A-B, find the input impedance, output impedance, and open-circuit voltage gain of the cascade. Repeat if the order is B-A.

Amplifier	Open-Circuit Voltage Gain	Input Resistance	Output Resistance
A	100	3kΩ	400Ω
B	500	1MΩ	20Ω

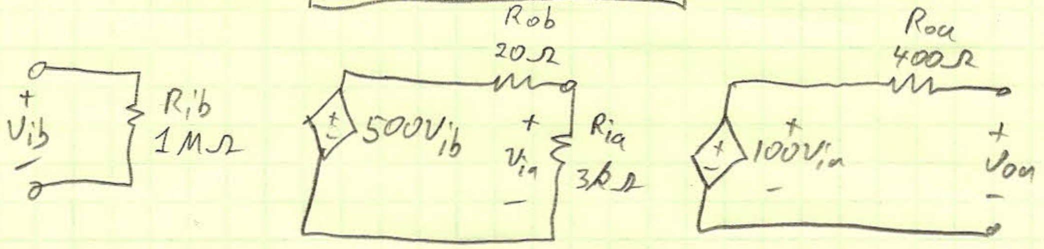
Solution



$$A_{vab} = \frac{V_{ob}}{V_{ia}} = \frac{500\,V_{ib}}{V_{ia}} = 500\,\frac{R_{ib}}{R_{oa}+R_{ib}}\,\frac{100\,V_{ia}}{V_{ia}}$$

$$= 500\,\frac{1M\Omega}{400\Omega + 1M\Omega}\,100$$

$$\boxed{A_{vab} = 50.0\times 10^3}$$



$$A_{vba} = \frac{V_{oa}}{V_{ib}} = \frac{100\,V_{ia}}{V_{ib}} = 100\,\frac{R_{ia}}{R_{ob}+R_{ia}}\,\frac{500\,V_{ib}}{V_{ib}}$$

$$= (100)\,\frac{3k\Omega}{20\Omega + 3k\Omega}\,500$$

$$\boxed{A_{vba} = 49.7\times 10^3}$$

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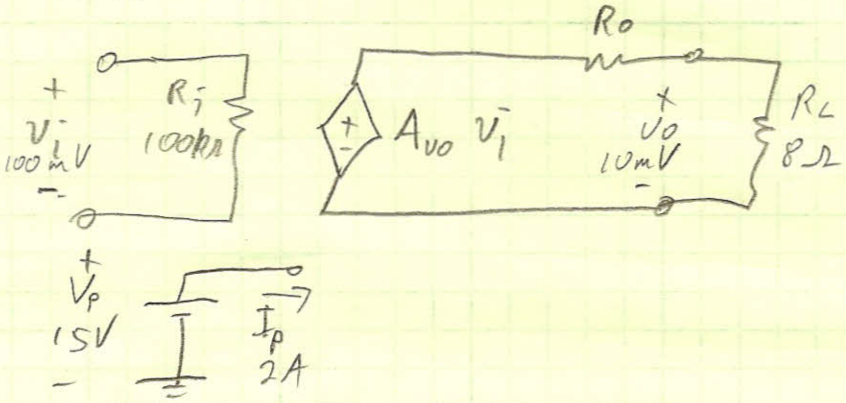
1.27 A certain amplifier has an input voltage of 100 mV rms and an input resistance of 100 kΩ. It produces an output of 10 mV rms across an 8 Ω load resistance. The power supply has a voltage of 15 V and delivers an average current of 2 A. Find the power dissipated in the amplifier and the efficiency of the amplifier.

Solution



$$P_s = V_P I_P = (15\,V)(2\,A) = 30\,W$$

$$P_o = \frac{V_o^2}{R_L} = \frac{(10\,mV)^2}{8\,\Omega} = 12.5\,\mu W.$$

$$P_{dissipated} = P_s - P_o = 30\,W - 12.5\,\mu W = 17.5\,W.$$

$$\eta = \frac{P_o}{P_s} = \frac{12.5\,\mu W}{30\,W} = 41.7\,\%.$$

1.30 How is power gain converted to decibels? How is voltage gain converted?

Solution

For power, $G_{dB} = (10 \log_{10} G)\ dB$.

For voltage gain, $A_{vdB} = (20 \log_{10} A_v)\ dB$.

1.31 An amplifier has an input voltage of 10 mV rms and an output voltage of 5 V rms across a 10 Ω load. The input current is 1 μA rms. Assume that the input and output impedances are purely resistive. Find the input resistance. Find the voltage gain, current gain, and power gain as ratios and in decibels.

Solution

$$R_{IN} = \frac{V_i}{i_i} = \frac{10\,mV}{1\,\mu A} = 10\,k\Omega$$

$$A_v = \frac{V_O}{V_i} = \frac{5V}{10\,mV} = 500 = (20 \log_{10} 500)\,dB = 54\,dB$$

$$i_O = \frac{V_O}{R_L} = \frac{5V}{10\,\Omega} = 500\,mA$$

$$A_i = \frac{i_O}{i_i} = \frac{500\,mA}{1\,\mu A} = 500{,}000 = (20 \log_{10} 5\times10^5)\,dB = 114\,dB$$

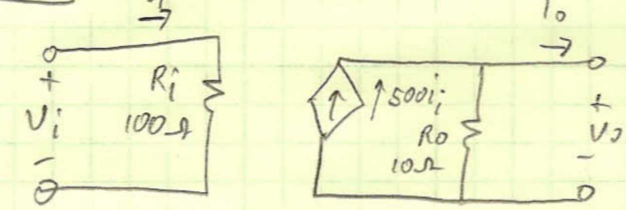
$$G = \frac{P_O}{P_i} = \frac{V_O i_O}{V_i i_i} = A_v A_i = (500)(500{,}000) = 250\times10^6$$

$$G_{dB} = (10 \log_{10} 250\times10^6)\ dB = 84\ dB$$

$$\boxed{\begin{aligned} A_v &= 500 = 54\,dB \\ A_i &= 500{,}000 = 114\,dB \\ G &= 250\times10^6 = 84\,dB \end{aligned}}$$

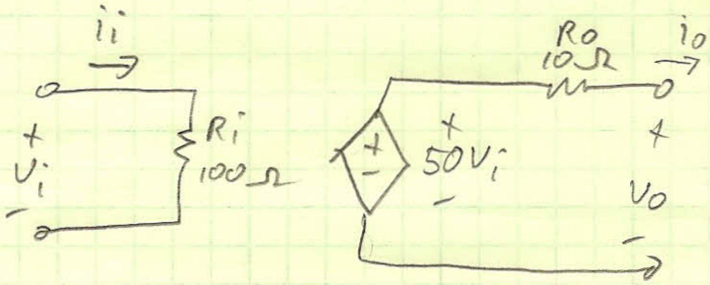
1.38 An amplifier has an input resistance of 100 Ω, an output resistance of 10 Ω, and a short-circuit current gain of 500. Draw the voltage-amplifier model for the amplifier including numerical values for all parameters. Repeat for the transresistance and transconductance models.

Solution



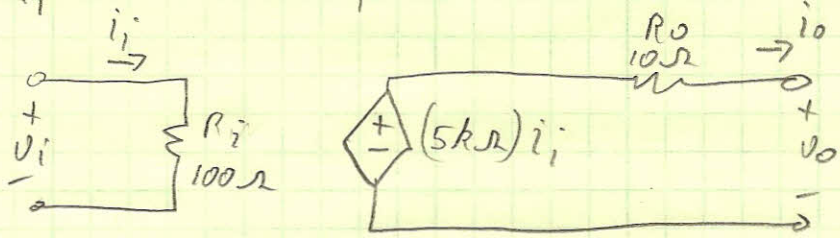
Current-amplifier model

$$v_{oc} = 500\, i_i R_o = 500 \frac{v_i}{R_i} R_o = \frac{(500)(10\,\Omega)}{100\,\Omega} v_i = 50\, v_i$$



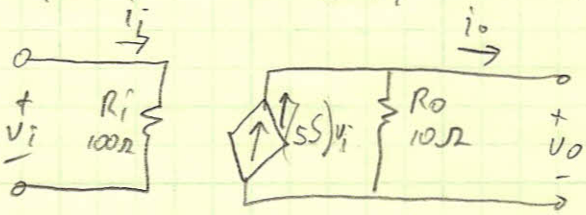
Voltage-amplifier model

$$\frac{v_{oc}}{i_i} = R_{moc} = \frac{50\, v_i}{i_i} = 50\, R_i = (50)(100\,\Omega) = 5\,k\Omega$$



Transresistance Model

$$\frac{i_{osc}}{v_i} = G_{msc} = \frac{500\, i_i}{v_i} = \frac{500}{R_i} = \frac{500}{100\,\Omega} = 5\,S.$$



transconductance Model

D1.48 Block-diagram-level amplifier design. We need to design an amplifier for use in recording the short-circuit current of experimental electrochemical cells versus time. (For this purpose, a short circuit is any resistance less than 10 Ω.) The amplifier output is to be applied to a strip-chart recorder that deflects 1 cm ± 1% for each volt applied. The input resistance of the recorder is unknown and likely to be variable, but it is greater than 10 kΩ. A deflection of 1 cm per mA of cell current is desired with an accuracy of about ±3%. What type of ideal amplifier is best suited for this application? Using your best judgment, find specifications for the amplifier's input impedance, output impedance, and gain parameter.

1. Consider whether zero or infinite input resistance would be best for sensing the short-circuit current of the cells.
2. Consider whether zero or infinite output resistance would be best for making the output voltage independent of the input resistance of the chart recorder.
3. Based on these selections of input and output resistances, use Table 1.1 on page 39 to select the amplifier type.

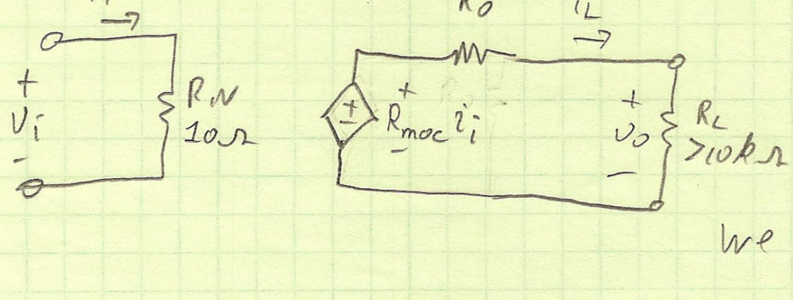
Solution

1. Sensing current works best if input resistance is zero because in this case, all of the source current is available to the amplifier.

2. Zero output resistance permits all of the voltage generated by the amplifier to be available to the strip-chart recorder for conversion to a deflection.

3. A transresistance model matches these requirements.

Choose $R_{in} < 10\,\Omega$,



$$D = \frac{1\,\text{cm} \pm 1\%}{V}\, v_o$$

We want $D = \dfrac{1\,\text{cm} \pm 3\%}{\text{mA}}\, i_i$

These deflections are equal. Neglecting the uncertainties,

$$D = \frac{1\text{ cm}}{V} v_0 = \frac{1\text{ cm}}{mA} i_i.$$

$$R_{moe} = \frac{v_0}{i_i} = \frac{1\text{ cm}}{mA} \cdot \frac{1\text{ V}}{\text{cm}} = 1\text{ k}\Omega.$$

We know that R_L can vary from $10\text{k}\Omega$ to ∞.

Let the relative error in $\begin{cases} R_{moe} & \text{be } p_1. \\ R_o & \text{be } p_2. \end{cases}$

$$D = (1 \pm 0.01)\frac{\text{cm}}{V} v_o$$
$$= (1 \pm 0.01)\frac{\text{cm}}{V} \frac{R_L}{R_o(1 \pm p_2) + R_L} R_{moe}(1 \pm p_1) i_1$$

For any given relative errors p_1 and p_2, D is maximal when $R_L \to \infty$ and minimal when $R_L = 10\text{k}\Omega$.

$$D_{max} = (1 \pm 0.01)\frac{\text{cm}}{V} R_{moe}(1 \pm p_1) i_1.$$

$$D_{min} = (1 \pm 0.01)\frac{\text{cm}}{V} \frac{10\text{k}\Omega}{R_o(1 \pm p_2) + 10\text{k}\Omega} R_{moe}(1 \pm p_1) i_1.$$

The relative error in D is certainly less than

$$\frac{D_{max} - D_{min}}{D_{min}} = \frac{D_{max}}{D_{min}} - 1 = \frac{R_o(1 \pm p_2) + 10\text{k}\Omega}{10\text{k}\Omega} - 1$$
$$= \frac{R_o(1 \pm p_2)}{10\text{k}\Omega}$$

R_o is not the only source of error. Suppose we decide to keep this error below 1%, choose

$$R_o = \frac{(10\text{k}\Omega)(1\%)}{1 \pm p_2} = \frac{100\,\Omega}{1 \pm p_2}$$

If we use 5%-accurate resistors we should choose

$$R_o = \frac{100\,\Omega}{1.05} = 95.2\,\Omega$$

The nearest 5% resistor below this is $R_o = 91\,\Omega$.