This figure belongs to 1.47

1.45 continued here
The signal loses about 90% of its strength when connected to the amplifier input (because \( R_i = R_s / 10 \)). Also, the output signal of the amplifier loses approximately 90% of its strength when the load is connected (because \( R_L = R_s / 10 \)). Not a good design! Nevertheless, if the source were connected directly to the load,

\[
\frac{v_o}{v_s} = \frac{R_L}{R_L + R_s} = \frac{100 \Omega}{100 \Omega + 100 \Omega} = 0.001 \text{ V/V}
\]

\( R_s = 100 \text{ k} \Omega \)

which is clearly a much worse situation. Indeed inserting the amplifier increases the gain by a factor 8.3/0.001 = 8300.

1.46

\[
v_o = 1 \text{ V} \times \frac{1 \text{ M} \Omega}{1 \text{ M} \Omega + 100 \text{ k} \Omega} \times \frac{1}{100 \text{ k} \Omega + 10 \text{ k} \Omega}
\]

\[= \frac{1}{100 \Omega + 110 \Omega} = 0.83 \text{ V} \]

Voltage gain = \( \frac{v_o}{v_s} = 0.83 \text{ V/V} \) or -1.6 dB

Current gain = \( \frac{v_o/100 \Omega}{v_s/1.1 \text{ M} \Omega} = 0.83 \times 1.1 \times 10^4 \)

= 9091 A/A or 79.2 dB

This figure belongs to 1.48a

\[\text{Power gain} = \frac{v_o^2/100 \Omega}{v_i^2/1.1 \text{ M} \Omega} = 7578 \text{ W/W} \]

or \(10 \log 7578 = 38.8 \text{ dB} \) (This takes into acct. the power dissipated in the internal resistance of the source.)

1.47 In example 1.3 when the first and the second stages are interchanged, the circuit looks like the figure above

\[
\frac{v_o}{v_s} = \frac{100 \text{ k} \Omega}{100 \text{ k} \Omega + 100 \text{ k} \Omega} = 0.5 \text{ V/V}
\]

\[A_{v1} = \frac{v_o}{v_i} = 100 \times \frac{1 \text{ M} \Omega}{1 \text{ M} \Omega + 1 \text{ k} \Omega} = 99.9 \text{ V/V} \]

\[A_{v2} = \frac{v_o}{v_i} = 10 \times \frac{10 \text{ k} \Omega}{10 \text{ k} \Omega + 1 \text{ k} \Omega} = 9.09 \text{ V/V} \]

\[A_{v3} = \frac{v_s}{v_s} = 1 \times \frac{100 \text{ k} \Omega}{100 \text{ k} \Omega + 10 \Omega} = 0.909 \text{ V/V} \]

Total gain = \( A = A_{v1} \times A_{v2} \times A_{v3} \)

= 99.9 \times 9.09 \times 0.909 = 825.5 \text{ V/V} \)

The voltage gain from source to load is

\[
\frac{v_s}{v_o} = A_{v1} \times A_{v2} \times A_{v3} = 825.5 \times 0.5 = 412.7 \text{ V/V} \]

The overall voltage has reduced appreciably. It is due to the reason because the input impedance of the first stage, \( R_i \), is comparable to the source resistance \( R_s \). In example 1.3 the input impedance of the first stage is much larger than the source resistance.

1.48 a. Case S-A-B-L

\[
\frac{V_o}{V_s} = \frac{V_o}{V_{ib}} \times \frac{V_{ib}}{V_{ib}} \times \frac{V_{ib}}{V_s} \]

\[= \left( \frac{1 \times \frac{100 \text{ k} \Omega}{100 \text{ k} \Omega + 10 \text{ k} \Omega}}{100 \text{ k} \Omega + 10 \text{ k} \Omega} \times \frac{100 \text{ k} \Omega}{100 \text{ k} \Omega + 10 \text{ k} \Omega} \right) \times \frac{10}{100 \text{ k} \Omega + 10 \text{ k} \Omega} \]

\[= 4.13 \text{ V/V} \text{ and gain in dB } 20 \log 4.1 = 12.32 \text{ dB} \text{ (See figure below)} \]
1.50 Deliver 0.5 W to a 100 Ω load
Source is 30 mV RMS with 0.5 MΩ source resistance. Choose from 3 amplifiers types

\[ R_L = 1 \text{MΩ} \quad R_L = 10 \text{kΩ} \quad R_L = 100 \text{kΩ} \]
\[ A_v = 10 \text{v/v} \quad A_v = 100 \text{v/v} \quad A_v = 1 \text{v/v} \]
\[ R_{in} = 10 \text{kΩ} \quad R_{in} = 1 \text{kΩ} \quad R_{in} = 20 \text{Ω} \]

Choose order to eliminate loading on input and output
A - 1st-to minimize loading on 0.5 MΩ source
B - 2nd-to boost gain
C - 3rd - to minimize loading at 100 Ω output.

(See figure below)

\[ \frac{v_o}{v_s} = \frac{2}{30 \text{mV}} = 235.7 < \left( \frac{1}{0.5 \mu + 1 \mu} \right) \]

\[ \frac{235.7}{253.6} = (253.6)(30 \text{mV}) = 7.61 \text{v RMS} \]
\[ P = \frac{v_o^2}{R_L} = \frac{(7.61)^2}{100} = 0.58 \text{ W} \]

1.51 (a) Required voltage gain \[ \frac{v_o}{v_s} \]

\[ = \frac{3 \text{ V}}{0.01 \text{ V}} = 300 \text{ V/V} \]

(b) The smallest \( R \) allowed is obtained from

\[ 0.1 \mu A = \frac{10 \text{ mV}}{R_S + R_L} \Rightarrow R_S + R_L = 100 \text{ kΩ} \]

Thus \( R_L = 90 \text{ kΩ} \).

For \( R_L = 90 \text{ kΩ} \), \( i_i = 0.1 \mu A \) peak, and

Overall current gain \[ \frac{v_o}{i_i} \]

This figure belongs to 1.50
This figure belongs to 1.55b

\[ R_s = 2 \, k\Omega \]

\[ G_m = 40 \, mA/V \]

\[ R_0 = 20 \, k\Omega \]

\[ R_s = 1 \, k\Omega \]

\[ v_i = \frac{v_o}{R_s + R_f} \]

\[ v_i = \frac{v_o}{2} = \frac{v_i}{2} \]

\[ v_o = G_m v_i (R_s \parallel R_0) \]

\[ v_o = 40 \times 2 \times 1 = \frac{v_i}{2} \]

\[ v_o = 40 \times \frac{v_o}{21} \]

Overall voltage gain \( \frac{v_o}{v_i} = 19.05 \, V/V \)

1.55 Need \( V_o = 10 v_1 + 20 v_2 \)

\( R_{x1} \) and \( R_{x2} \) are used to get the appropriate gains on \( v_1 \) and \( v_2 \)

\[ R_{x2} = 30 \, \Omega \]

Use superposition (See figure above)

\[ v_o = G_m v_x \left( \frac{10 \, k}{5 \, k + 10 \, k} \right) \left( 5 \, k \right) \]

\[ = G_m \left( \frac{10 \, k}{5 \, k + 10 \, k} \right) \left( 5 \, k \right) \left( 10 \, k \right) \left( \frac{10 \, k + 10 \, k + R_{x1}}{10 \, k + 10 \, k + R_{x1}} \right) \]

\[ v_o = i \times R \]

\[ \frac{v_o}{v_1} = 10 = \left( \frac{20 \, mA}{V} \right) \left( \frac{10 \, k}{5 \, k + 10 \, k} \right) \left( 5 \, k \right) \left( \frac{10 \, k}{20 \, k + R_{x1}} \right) \]

\[ 0.15 = \frac{10 \, k}{20 \, k + R_{x1}} \]

\[ \therefore R_{x1} = 46.67 \, k\Omega \]

Use same procedure for \( v_2 \) but you will find 1 stage is not enough again, thus:

\[ \frac{v_o}{v_2} = 20 = \left( \frac{20 \, mA}{V} \right) \left( \frac{10 \, k}{5 \, k + 10 \, k} \right) \left( 5 \, k \right) \left( \frac{20 \, mA}{V} \right) \]

\[ \left( \frac{10 \, k}{10 \, k + 10 \, k} \right) \left( 10 \, k \right) \left( \frac{10 \, k}{10 \, k + 10 \, k + R_{x2}} \right) \]

\[ 20 = 6.67 \times 10^3 \left( \frac{10 \, k}{20 \, k + R_{x2}} \right) \]

\[ \therefore R_{x2} = 3.3 \, M\Omega \]

series

or can use of \( v_2 \)

This figure belongs to 1.55c
Finally, for $R_i$ varying in the range 1 to 10 kΩ, the change in $i_i$ can be kept to 10% if $R_o$ is selected sufficiently large; $R_o \leq R_{\text{Lmax}}$

Thus $R_o = 100$ kΩ

For $v_o = 10$ mV,

$$v_{o\text{min}} = 10^{-2} \frac{R_o}{R_i + R_{\text{max}}} G_m \frac{R_o}{R_o + R_{\text{Lmax}}}$$

$$10^{-3} = 10^{-2} \frac{100}{100 + 10} G_m \frac{100}{100 + 10}$$

$$G_m = 1.21 \times 10^{-1} \text{ A/V}$$

$$= 121 \text{ mA/V}$$

1.58 Transresistance amplifier

To limit $\Delta V_o$ to 10% corresponding to $R_i$ varying in the range 1 to 10 kΩ, we select $R_i$ sufficiently low;

$$R_i \leq \frac{R_{\text{min}}}{10}$$

Thus $R_i = 100$ kΩ

To limit $\Delta v_o$ to 10% while $R_i$ varies over the range 1 to 10 kΩ, we select $R_o$ sufficiently low;

$$R_o \leq \frac{R_{\text{Lmin}}}{10}$$

Thus $R_o = 100$ kΩ

Now, for $i_o = 10 \mu A$

For $R_i$ varying in the range 1 to 10 kΩ, and $\Delta i_i$ limited to 10% we have to select $R_i$ sufficiently large;

$$R_i \geq 10R_{\text{max}}$$

$$R_i = 100 \text{ kΩ}$$
1.61

Apply Kirchhoff’s current law in the mesh on the left:

\[-V_b + r_a i_b + R_e (B_i_b + i_b) = 0\]
\[v_b = i_b r_a + (B + 1)R_e\]

Now, \(v_c = -\beta \times i_b \times R_L\)
\[v_x = \frac{-\beta R_L}{r_a + (B + 1)R_e}\]
\[v_x = i_b (B + 1)R_e\]
\[v_x = \frac{(B + 1)R_e}{r_a + (B + 1)R_e}\]

\[\frac{v_x}{v_b} = \frac{r_a}{\beta + 1} + R_e\]

1.62

Open-circuit output voltage: 10 V
Short-circuit output current: 10 mA

1 kΩ

\[v_o = 10 \times \frac{4}{1 + 4} = 8 \text{ V}\]

1.63 Using the voltage divider rule:

\[a. \quad i_o = g_m v_1 - g_m v_2\]
\[v_o = i_o R_l = g_m R_l (v_1 - v_2) = v_0\]
\[b. \quad v_1 = v_2\]
\[v_1 = 1.01 \quad v_2 = 0.99\]

1.64

\[A_v = \frac{v_o}{v_i} = \frac{8}{1 \times 10^{-3} \times (100 \parallel 10) \times 10^3}\]
\[= 888 \frac{V}{V/V} \text{ or } 58.9 \text{ dB}\]

\[A_i = \frac{i_o}{i_i} = \frac{v_o/R_L}{10^{-3} \times \frac{100}{100 + 10} \times 10^{-3} \times \frac{100}{110}}\]
\[= 2200 \frac{A}{A/A} \text{ or } 66.8 \text{ dB}\]
\[ I_1 = g_{11} V_1 + g_{12} I_a \]
\[ V_2 = g_{21} V_1 + g_{22} I_a \]

Thus
\[ \frac{V_2}{I_2} \bigg|_{I_a=0} = g_{22} = R_0 \frac{I_1}{V_1} \bigg|_{I_a=0} = g_{11} = \frac{1}{R_1} \]
\[ \frac{V_2}{I_2} \bigg|_{I_a=0} = g_{21} = \frac{A V}{I_2} \bigg|_{I_a=0} = g_{12} = \infty \]

Due to unilateral nature of Figure 1.65

1.65

\[ \begin{array}{c}
\text{RC} \\
\text{Vo} \\
V_i \\
R \\
C \\
\text{V}_o
\end{array} \quad \begin{array}{c}
\text{RC} \\
\text{Vo} \\
V_i \\
R \\
C \\
\text{V}_o
\end{array} \]

For (a) \[ V_o = V_i \left( \frac{1/SC}{1/SC + R} \right) \]
\[ \frac{V_0}{V_i} = \frac{1}{1 + SCR} \]
where \( k = \frac{1}{RC} \) from Table 2.1 it is low pass.

For (b) \[ V_o = V_i \left( \frac{R}{R + \frac{1}{SC}} \right) \]
\[ \frac{V_0}{V_i} = \frac{SRC}{1 + SCR} \]
\[ \frac{V_0}{V_i} = \frac{S}{S + \frac{1}{RC}} \]
where \( k = \frac{1}{RC} \)
\[ \omega_0 = \frac{1}{RC} \] from Table 2.1 it is high pass.

1.66

\[ \begin{array}{c}
R_s \\
V_s \\
R \\
C_f \\
V_i \\
\end{array} \]

\[ \frac{V_s}{V_i} = \frac{\frac{R_i}{R_s C_f}}{R_s + \frac{1}{sC_f}} = \frac{\frac{R_i}{1 + sC_f R_s}}{R_s + \frac{1}{sC_f}} \]

\[ \frac{R_i}{R_s + sC_f R_s + R_i} \]

\[ \frac{V_i}{V_s} = \frac{\frac{R_i}{R_s + sC_f R_s + R_i}}{(R_s + R_f) + sC_f R_s} = \frac{\frac{R_i}{(R_s + R_f)}}{1 + s \left( \frac{C_f R_s}{R_s + R_f} \right)} \]

Where \( K = \frac{R_i}{(R_s + R_f)} \)
\[ \omega = \frac{R_s + R_f}{C_f R_s} \]
from Table 2.1 low pass for given values \( \omega_0 = 12.5 \text{ MHz} \)

1.67 Using the voltage divider rule.

\[ \begin{array}{c}
R_1 \\
R_2 \\
V_o \\
V_i \\
\end{array} \]

\[ T(s) = V_o/V_i = \frac{\frac{R_2}{R_2 + R_1 + \frac{1}{sC}}}{\frac{s}{s + \frac{1}{C(R_1 + R_2)}}} \]

Which is from Table 2.2 is of the high-pass type with
\[ K = \frac{R_2}{R_1 + R_2} \quad \omega_0 = \frac{1}{C(R_1 + R_2)} \]

As further verification that this is a high-pass network and \( T(s) \) is a high-pass transfer function, we assume as \( s \to 0 \), \( T(s) \to 0 \); and as \( s \to \infty \), \( T(s) = R_2/(R_1 + R_2) \). Also, from the circuit observe as \( s \to \infty \), \( (1/SC) \to 0 \) and \( V_o/V_i = R_2/(R_1 + R_2) \). Now, for
\[ R_1 = 10 \text{ k}\Omega, R_2 = 40 \text{ k}\Omega, \text{ and } C = 0.1 \mu \text{F}. \]
\[ f_0 = \frac{\omega_0}{2\pi} = \frac{1}{2\pi \times 0.1 \times 10^{-6} \times (10 + 40) \times 10^3} = 31.8 \text{ Hz} \]
\[ |T(j\omega_0)| = \frac{\omega_0}{\omega_0} = \frac{40}{10 + 40} = 0.57 \text{ V/V} \]

1.68 Using the voltage divider rule.

\[ \begin{array}{c}
V_s \\
R_L \\
V_L \\
\end{array} \]

\[ V_s \]
\[
\text{CMRR} = 20 \log \left| \frac{A_d}{A_{CM}} \right| = 20 \log \frac{G_m}{\Delta G_m}
\]

20 \log_{10} A_d = 80 \text{ dB} \Rightarrow A_d = 10^4

\[
A_{CM} = \frac{\Delta G_m}{G_m} \Rightarrow A_{cm} = \frac{10^4 \times 0.1}{100} = 10
\]

CMRR = 20 \log \frac{G_m}{\Delta G_m} = 20 \log \frac{1}{0.1 / 100} = 60

### 2.8

<table>
<thead>
<tr>
<th>Circuit</th>
<th>(\frac{v_o}{v_i} (\text{V/V}))</th>
<th>(R_m (\text{k}\Omega))</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>(-100)</td>
<td>10</td>
</tr>
<tr>
<td>b</td>
<td>-10</td>
<td>10</td>
</tr>
<tr>
<td>c</td>
<td>-10</td>
<td>10</td>
</tr>
<tr>
<td>d</td>
<td>-10</td>
<td>10</td>
</tr>
</tbody>
</table>

Virtual ground: no current in 10 k\(\Omega\)

### 2.9

Closed loop gain is \(\frac{v_o}{v_i} = A\)

\[
A = \frac{v_o}{v_i} = -\frac{R_2}{R_1} = -\frac{10\ \text{k}\Omega}{10\ \text{k}\Omega} = -1 \text{ V/V}
\]

For \(v_i = +1.000 \text{ V}\)

\(v_o = A v_i = +1 \times 1.000 = -1.000 \text{ V}\)

The two resistors are 1\% resistors

\[
\begin{align*}
\left( \frac{v_o}{v_i} \right)_{\text{min}} &= -\frac{10(1-0.01)}{10(1+0.01)} = -0.98 \text{ V/V} \\
\left( \frac{v_o}{v_i} \right)_{\text{max}} &= -\frac{10(1+0.01)}{10(1-0.01)} = -1.02 \text{ V/V}
\end{align*}
\]

Range is -0.98 to -1.02 V/V

### 2.10

There are four possibilities:

\[
\frac{v_o}{v_i} = -2 \text{ V/V} \quad R_{in} = 10 \text{ k}\Omega
\]

\[
\frac{v_o}{v_i} = -0.5 \text{ V/V} \quad R_{in} = 10 \text{ k}\Omega
\]

\[
\frac{v_o}{v_i} = -0.5 \text{ V/V} \quad R_{in} = 20 \text{ k}\Omega
\]

\[
\frac{v_o}{v_i} = -2 \text{ V/V} \quad R_{in} = 5 \text{ k}\Omega
\]

### 2.11

a. \(G = -1 \text{ V/V}\) b. \(G = -10 \text{ V/V}\)

c. \(G = -0.1 \text{ V/V}\) d. \(G = -100 \text{ V/V}\)

e. \(G = -10 \text{ V/V}\)
Chapter 2-3

2.12

a. \( G = -1 \) V/V = \(-\frac{R_2}{R_1}\) \( \Rightarrow R_1 = R_2 = 10 \) k\( \Omega \)

b. \( G = -2 \) V/V

\[ \frac{-R_2}{R_1} \Rightarrow R_1 = 10 \) k\( \Omega , \) \( R_2 = 20 \) k\( \Omega \)

c. \( G = -0.5 \) V/V

\[ \frac{-R_2}{R_1} \Rightarrow R_1 = 20 \) k\( \Omega , \) \( R_2 = 10 \) k\( \Omega \)

d. \( G = -100 \) V/V

\[ \frac{-R_2}{R_1} \Rightarrow R_1 = 10 \) k\( \Omega , \) \( R_2 = 1 \) M\( \Omega \)

2.13

For largest possible input resistance choose \( R_2 = 1 \) M\( \Omega \)
\( R_1 = \frac{1}{19.95} \approx 50.1 \) k\( \Omega \)
\( R_e = R_1 = 50.1 \) k\( \Omega \)

2.15

\[ \frac{v_o}{v_i} = \frac{-R_2}{R_1} = \frac{-100}{10} = -10 \]
\( v_{in} = 10 \) V, \( v_{inb} = 0, \) \( v_{eq} = -5 \) V

2.16

\[ \frac{v_o}{v_i} = \frac{10 \) k\( \Omega }{1 \) k\( \Omega } = -10 \) V/V

\( v_o = -10 \) \( v_i \)
\( = -10 \times (0.5) \)
\( = -5 \) V/V

In the figure

\[ i_o = \frac{v_o}{2 \) k\( \Omega } = \frac{-5}{2 \) k\( \Omega } = -2.5 \) mA

2.14

Gain is 26 dB

\[ \frac{v_o}{v_i} = -4 \) V/V = \(-\frac{R_2}{R_1}\)

\( \Rightarrow R_2 = 4 \) \( R_1 \)

Total resistance used is 100 k\( \Omega \)
\( \therefore R_1 + R_2 = 100 \) k\( \Omega \)
\( R_1 + 4 \) \( R_1 = 100 \) k\( \Omega \)
\( R_1 = 20 \) k\( \Omega \)
and \( R_1 = 4 \) \( R_1 = 80 \) k\( \Omega \)

2.17

Gain is 26 dB

\[ G = 10^{26/20} = 19.95 \]

\[ \frac{v_o}{v_i} = -19.95 \) V/V = \(-\frac{R_2}{R_1}\)

\[ \Rightarrow R_2 = 19.95 \) \( R_1 \approx 1 \) M\( \Omega \)

So 2X is the tolerance on the closed loop gain G
\( G = -100 \) V/V and X = 1

Gain variation \(-102 < G < -98\)