Solution to Chapter 10 Problems

Problem 10

In steady state, the internal circuit voltages can't exceed the power supply limits.

a. $V_o)_{max} = +15V$ b. $V_o)_{min} = -9V$

Problem 11

• From the given gain plot & using a value for $V_i = V_B = 0.6V$, we can calculate the small signal gain as the slope of the curve.

$$\therefore A_V = \frac{4-12}{0.7-0.5} = -40$$

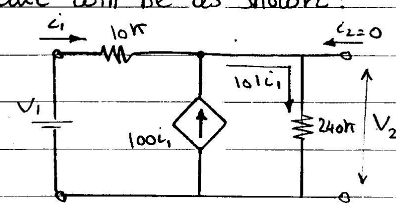
$$\Rightarrow |A_v| = 20 \log |A_v| = 32\ dB \quad , \quad \angle A_v = 180^\circ$$

• To have an undistorted output signal, the amplifier should be operating in the linear region.

$$\therefore V_H \leq 0.1\ V \text{ for the linear operation}$$

Problem 20

First we open circuit the o/p for $i_2 = 0$, so the circuit will be as shown:



$$\therefore g_{11} = i_1 / V_1 \quad , \quad g_{21} = V_2 / V_1$$

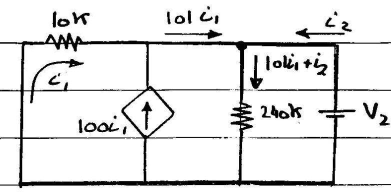
$$V_1 = 10K \cdot i_1 + 240K \cdot 101 i_1 = 24.25 \times 10^6\ i_1$$

$$\Rightarrow g_{11} = 4.12 \times 10^{-8}\ S$$

$$V_2 = 240K \cdot 101 i_1 \Rightarrow g_{21} = \frac{24.24 \times 10^6\ i_1}{24.25 \times 10^6\ i_1}$$

$$\therefore g_{21} \simeq 1$$

Now, we short circuit the i/p for $V_1 = 0$



∴ $g_{12} = i_1 / i_2$, $g_{22} = V_2 / i_2$

We've $V_2 = 240k\,(101 i_1 + i_2)$

$= -10k\,(i_1)$

∴ $240k\,(101 i_1 + i_2) = -10k \cdot i_1$

$2424\, i_1 + 24 i_2 = -10 i_1 \Rightarrow 2434\, i_1 = -24\, i_2$

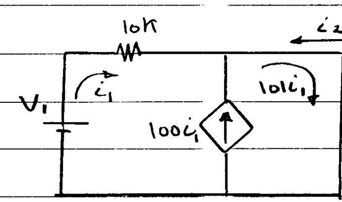
$\Rightarrow g_{12} = i_1/i_2 = -9.86 \times 10^{-3}$

& $V_2 = -10k \cdot i_1 = -10k \cdot \frac{-24}{2434}\, i_2 = 98.6\, i_2$

$\Rightarrow g_{22} = V_2/i_2 = 98.6\ \Omega$

Problem 21

First, we short circuit the o/p for $V_2 = 0$

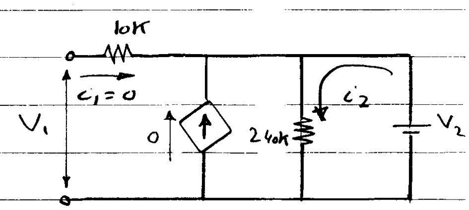


∴ $h_{11} = V_1 / i_1$, $h_{21} = i_2 / i_1$

From the circuit, we directly find $i_2 = -101\, i_1$

$\Rightarrow h_{21} = -101$

Also $V_1 = 10k \cdot i_1 \Rightarrow h_{11} = 10k$

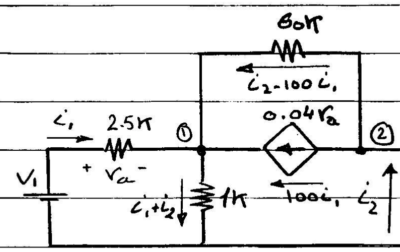


Now, we open circuit the i/p for $i_1 = 0$

∴ $h_{12} = V_1 / V_2$, $h_{22} = i_2 / V_2$

$V_1 = V_2 \Rightarrow h_{12} = 1$ & $V_2 = 240k\,(i_2) \Rightarrow h_{22} = 4.17\ \mu S$

Problem 27



First, we ~~open~~ short circuit the o/p for $V_2=0$

$\therefore y_{11} = i_1/V_1 \quad , \quad y_{21} = i_2/V_1$

$V_a = 2.5K \cdot i_1 \qquad \therefore 0.04 V_a = 100\, i_1$

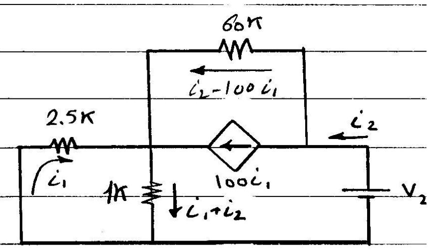
We've $V_{21} = 60K \cdot (i_2 - 100 i_1) = -1K \cdot (i_1+i_2)$

$\therefore 60 i_2 - 6000 i_1 = -i_1 - i_2 \quad \Rightarrow \quad \frac{i_1}{i_2} = \frac{61}{5999}$

$V_1 = 2.5K \cdot i_1 + 1K \cdot (i_1+i_2) = \left(2.5K + 1K + \left(\frac{61}{5999}\right)^{-1} \cdot 1K\right) i_1 = 101844.26\, i_1$

$\Rightarrow y_{11} = i_1/V_1 = 9.82\, \mu S$

& $y_{21} = i_2/V_1 = y_{11} \cdot (i_2/i_1) = 0.9656\ mS$



Now, we short circuit the i/p for $V_1=0$

$\therefore y_{12} = i_1/V_2 \quad , \quad y_{22} = i_2/V_2$

For the parallel resistors 2.5K & 1K :

$-2.5K \cdot i_1 = 1K \cdot (i_1+i_2) \quad \Rightarrow \quad i_2 = -3.5\, i_1$

Now using KVL for the outer loop : $V_2 = 60K \cdot (i_2 - 100 i_1) - 2.5K \cdot i_1$

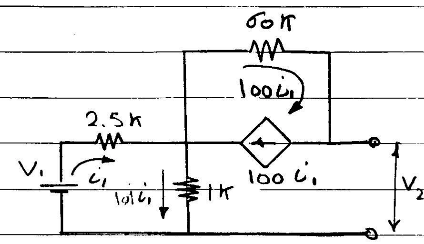
$\therefore V_2 = 60K\,(-3.5 i_1) - 60K\,(100 i_1) - 2.5K i_1 = -6212500\, i_1$

$\Rightarrow y_{12} = -0.161\, \mu S$

& $y_{22} = y_{12} \cdot (i_2/i_1) = 0.5634\, \mu S$

Problem 28

First, we open circuit the o/p for $i_2 = 0$



$\therefore Z_{11} = V_1 / i_1$, $Z_{21} = V_2 / i_1$

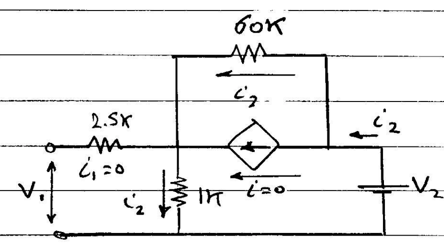
$V_1 = 2.5k \cdot i_1 + 1k \cdot i_1 = 3.5k \cdot i_1$

$\Rightarrow Z_{11} = 3.5k\Omega$

Using KVL: $V_2 = -100\, i_1 \cdot 60k + i_1 \cdot 1k = (-6000k + 1k)\, i_1 = -5999k\, i_1$

$\Rightarrow Z_{21} = -5.999\ M\Omega$

Now, we open circuit the i/p for $i_1 = 0$



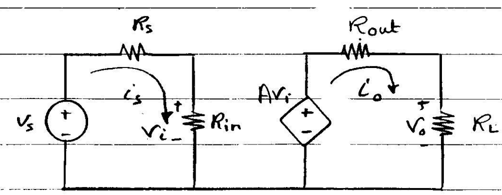
$V_2 = 60k \cdot i_2 + 1k \cdot i_2 = 61k \cdot i_2$

$\Rightarrow Z_{22} = V_2 / i_2 = 61\ k\Omega$

$V_1 = 1k \cdot i_2 \Rightarrow Z_{12} = 1k\Omega$

Problem 40

We can redraw the circuit as follows:



$A = 54\ dB \Rightarrow A = 10^{\frac{54}{20}} = 501.2$

a. $A_v = \frac{V_o}{V_s}$ but $V_o = R_L\, i_o = \frac{A V_i}{R_L + R_{out}} \cdot R_L$

& $V_i = R_{in}\, i_s = \frac{V_s}{R_s + R_{in}} \cdot R_{in}$

$$A_i = \frac{i_o}{i_s} \quad \text{but} \quad i_o = \frac{A V_i}{R_{out} + R_L} \quad \& \quad i_s = \frac{V_s}{R_s + R_{in}}$$

$$\therefore A_i = \frac{A R_{in} i_s}{R_{out} + R_L} \Big/ \frac{V_s}{R_s + R_{in}} \quad \text{but} \quad i_s = \frac{V_s}{R_s + R_{in}}$$

$$\therefore A_i = \frac{A R_{in}}{R_{out} + R_L} = 3.04 \times 10^7 = 149.65 \text{ dB} \simeq 150 \text{ dB}$$

$$A_P = \frac{V_o i_o}{V_s i_s} = A_v \cdot A_i = 1.47 \times 10^{10} = 101.7 \text{ dB} \simeq 102 \text{ dB}$$

<u>Remember</u> $A_P)_{dB} = 10 \log A_P$

b. $P_{R_L} = \dfrac{V_o^2}{2 R_L} = 1 \text{ W} \Rightarrow V_o = \sqrt{2 R_L} = 5.657 \text{ V}$

$$\therefore V_s = \frac{V_o}{A_v} = 11.65 \text{ mV}$$

c. The power dissipated in the amplifier is that dissipated in R_{in} & R_{out}

$$\therefore P = P_{R_{in}} + P_{R_{out}} = \frac{i_s^2 R_{in}}{2} + \frac{i_o^2 R_{out}}{2}$$

but $i_s = \dfrac{V_s}{R_s + R_{in}} = 1.164 \times 10^{-8} \text{ A}$ & $i_o = \dfrac{V_o}{R_L} = 0.3536 \text{ A}$

$$\therefore P = 67.7 \text{ pW} + 31.26 \text{ mW} = 31.26 \text{ mW}$$

<u>Problem 57</u>

$$A_v(S) = \frac{2\pi \times 10^7 S}{(S + 20\pi)(S + 2\pi \times 10^4)} = \frac{1000 S}{(S + 20\pi)\left(1 + \frac{S}{2\pi \times 10^4}\right)} = A_o \frac{S}{(S + \omega_L)} \cdot \frac{1}{\left(1 + \frac{S}{\omega_H}\right)}$$

$\therefore$ The midband gain $A_o = 1000 = 60$ dB

$$f_L = \frac{20\pi}{2\pi} = 10 \text{ Hz} \quad , \quad f_H = \frac{2\pi \times 10^4}{2\pi} = 10 \text{ kHz}$$

$$BW = f_H - f_L = 9.99 \text{ kHz}$$

Problem 58

$$A_v(s) = \frac{2\pi \times 10^6}{s + 20\pi} = \frac{10^5}{1 + \frac{s}{20\pi}} = \frac{A_0}{1 + \frac{s}{\omega_H}} \Rightarrow \text{Low pass amplifier}$$

$$A_{mid} = 10^5 = 100 \text{ dB}$$

$$f_H = \frac{20\pi}{2\pi} = 10 \text{ Hz}, \quad f_L = 0 \text{ Hz}, \quad BW = 10 \text{ Hz}$$

Problem 59

$$A_v(s) = \frac{10^4 s}{s + 100\pi} = \frac{A_0 s}{s + \omega_L} \Rightarrow \text{High-pass amplifier}$$

$$A_{mid} = 10^4 = 80 \text{ dB}$$

$$f_H = \infty, \quad f_L = \frac{100\pi}{2\pi} = 50 \text{ Hz}, \quad BW = \infty$$

Problem 12

For $V_B = 0.8V$ the voltage gain is calculated as follows

$$A_V = \frac{2-4}{0.9-0.7} = -10 \Rightarrow |A_V| = 20\,dB \;\&\; \angle A_V = 180°$$

For linear operation $V_M \leq 0.1\,V$

Problem 48

$$V_1 = \frac{V_s R_{in}}{R_s + R_{in}}, \quad V_2 = \frac{A V_1 R_{in}}{R_{in} + R_{out}}, \quad V_o = \frac{A V_2 R_L}{R_L + R_{out}}$$

$$A_V = \frac{V_o}{V_s} = \frac{V_o}{V_2} \cdot \frac{V_2}{V_1} \cdot \frac{V_1}{V_s} = \frac{A R_L}{R_L + R_{out}} \cdot \frac{A R_{in}}{R_{in} + R_{out}} \cdot \frac{R_{in}}{R_s + R_{in}} = 2.27 \times 10^5$$

$$\Rightarrow |A_V| = 107.12\,dB$$

$$A_i = \frac{I_o}{I_s} = \frac{V_o / R_L}{V_s / (R_s + R_{in})} = \frac{V_o}{V_s} \cdot \frac{R_s + R_{in}}{R_L} = A_V \cdot \frac{R_s + R_{in}}{R_L} = 1.36 \times 10^7$$

$$\Rightarrow |A_i| = 142.68\,dB$$

$$A_p = \frac{V_o I_o}{V_s I_s} = A_V \cdot A_i = 3.087 \times 10^{12}$$

$$\Rightarrow |A_p| = 124.9\,dB$$