1.44, 1.53, 1.68, 1.77, 2.42, 2.56

Engineering 72
Electronic Circuit Analysis
Assignment 2 Solutions

LAW 2005

① (1.44) Amplifier transfer function $v_o = 10 - 5(v_i - 2)^2$ for $2 \le v_I \le v_o + 2$ (otherwise saturation)

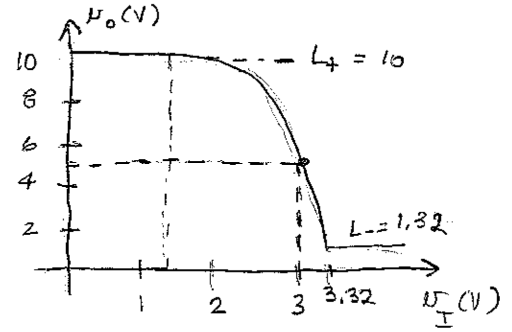
a Sketch transfer function

$v_I < 2V$, $v_O = 10\ V$

Upper limit: $v_I = v_o + 2$: $v_o = 10 - 5v_o^2$

or $v_o = 1.32\ V \Rightarrow v_I = 3.32\ V$

Use computer to obtain intermediate values



b. What V_I bias is required for dc $V_o = 5V$?

$5 = 10 - 5(V_i - 2)^2 \Rightarrow V_i - 2 = 1$ or $V_i = 3V$

c Small signal gain @ bias point $= \frac{\partial v_o}{\partial v_I}\Big|_{V_I = 3V} = -5(2)(v_I - 2)\Big|_{v_I = V_I = 3} = -10\ V/V$

d Superimpose a sinusoidal input on dc

$\Rightarrow v_I = V_I + V_i \cos\omega t = 3 + V_i \cos\omega t \Rightarrow v_o = 10 - 5(3 + V_i\cos\omega t - 2)^2$

$v_o = 10 - 5[1 + 2V_i \cos\omega t + V_i^2 \cos^2\omega t] = 5 - 10V_i\cos\omega t - 5V_i^2(\frac{1}{2})(1 + \cos 2\omega t)$

$\therefore v_o = (5 - 2.5V_i^2)$ (dc) $- 10V_i \cos\omega t$ (fundamental) $- 2.5V_i^2 \cos 2\omega t$ (2^{nd} harmonic).

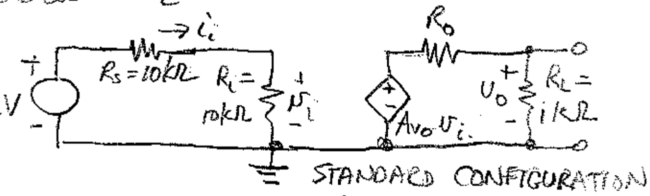
1% distortion $\frac{2.5V_i^2}{10V_i} = 0.01$

$\Rightarrow V_i = \frac{10(0.01)}{2.5} = 40mV$

② (1.53) Design voltage amplifier to be driven from signal source w/ 10 mV peak amplitude & source $R_s = 10k\Omega$ to supply 3 V peak output across $R_L = 1k\Omega$.

a. Voltage gain from source to load?

$\frac{v_o}{v_s} = \frac{3V}{0.01V} = 300\ V/V$



b Smallest R_i allowed for i_{peak} from source $= 0.1\mu A$: $0.1\mu A = \frac{10mV}{R_s + R_i}$ or $R_s + R_i = 10^5\Omega$

$\therefore R_i = 90\ k\Omega$.

Current Gain : $\frac{i_o}{i_i} = \frac{v_o/R_L}{i_i} = \frac{3mA}{0.1\mu A} = 3(10^4)\ A/A$.

Power Gain : $\frac{v_o^2/R_L}{v_s i_i} = \frac{3^2/1k}{(10m)(0.1\mu)} = 9(10^6)\ W/W$ (includes P_{diss} by source R_s)

c. If peak value of O.C. output voltage $A_v v_i$ is limited to 5 V, find $R_{o\,max}$.

$5\left(\frac{R_L}{R_o + R_L}\right) = 3 \Rightarrow R_o = \frac{2}{3}R_L = 667\ \Omega$ (larger $R_o \Rightarrow v_o < 3V$)

d. Given R_i & R_o in b & c, what is O.C. voltage gain $\frac{v_o}{v_i}\Big|_{R_L \to \infty}$?

$300\ V/V = \left(\frac{90}{90+10}\right)A_{vo}\left(\frac{1}{1+0.667}\right) \Rightarrow A_{vo} = 556\ V/V$

e. ↑ R_i to $1(10^n)$; ↓ R_o to $1(10^m)$, find achievable R_i, R_o, & A_{vo}.

$R_i = 100k\Omega$, $R_o = 100\Omega \Rightarrow 300\ V/V = \left(\frac{100}{100+10}\right)(A_{vo})\left(\frac{1000}{1000+100}\right) = 363\ V/V$

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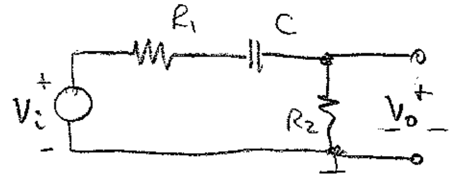
Assignment 2 Solutions Continued

(3.) (1.68) Find $T(s) = \frac{V_o(s)}{V_i(s)}$ & arrange in standard form

HPF or LPF? High freq response? Corner freq. ω_0?

Compute f_0 for $R_1 = 10\,k\Omega$, $R_2 = 40\,k\Omega$, $C = 0.1\,\mu F$.

Find $|T(j\omega_0)|$.



$$T(s) = \frac{R_2}{R_1 + R_2 + 1/sC} = \frac{R_2}{R_1 + R_2}\,\frac{s}{s + \frac{1}{C(R_1+R_2)}} = \text{HPF w/ } K = \frac{R_L}{R_L + R_s} \text{ \& } \omega_0 = \frac{1}{C(R_1+R_2)}$$

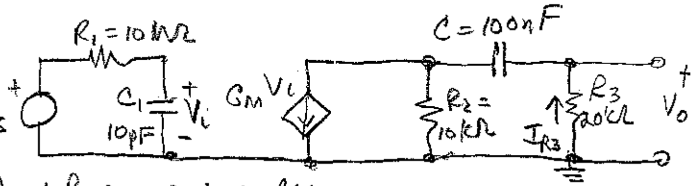
$$f_0 = \frac{\omega_0}{2\pi} = \frac{1}{2\pi C(R_1+R_2)} = \frac{1}{2\pi(10^{-7})(50)(10^3)} = 31.8\ Hz$$

Then $|T(j\omega_0)| = \frac{K}{\sqrt{2}} = \frac{40}{10+40}\left(\frac{1}{\sqrt{2}}\right) = 0.57\ V/V$

(4.) (1.77) Find $T_i(s) = \frac{V_i(s)}{V_s(s)}$ & corresponding ω_0

Find $T_o(s) = V_o(s)/V_i(s)$ & corresponding ω_0.

Put TFs in standard form & find overall $T(s)$ w/ Bode plot & BW



$$\underline{V_o} = -R_3 I_{R_3} = \frac{-R_2 R_3}{R_2 + R_3 + 1/sC}\,G_m \underline{V_i}\ ;\quad \underline{V_i} = \frac{1/sC_1}{R_1 + 1/sC_1}\,\underline{V_s}$$

so $T_i(s) = \frac{1}{1 + sR_1C_1}$; $T_o(s) = -\frac{sR_2R_3C}{1 + s(R_2+R_3)C}$; $T(s) = \frac{-sR_2R_3C}{[1 + sR_1C_1][1 + s(R_2+R_3)C]}$

Use Matlab to plot. BW is freq difference between 2 points where $|T(j\omega)| = \frac{1}{\sqrt{2}}|T(j\omega_0)|$

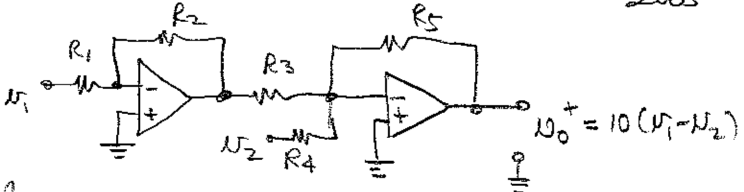
(5) (2.42) Want to obtain difference between

$v_1 = 3\sin(2\pi 60t) + 0.01\sin(2\pi 1000t)$

and $v_2 = 3\sin(2\pi 60t) - 0.01\sin(2\pi 1000t)$

Design circuit w/ 2 op amps & mostly 10kΩ resistors

Provide gain of 10 @ 1000 Hz.



$R_1 = R_2 = R_3 = R_4 = 10k\Omega$; $R_5 = 100k\Omega$

$$v_o = \frac{R_2}{R_1}\frac{R_5}{R_3}v_1 - \frac{R_5}{R_4}v_2 \qquad \text{want } \frac{R_2}{R_1}\frac{R_5}{R_3} = \frac{R_5}{R_4} = 10 \Rightarrow$$

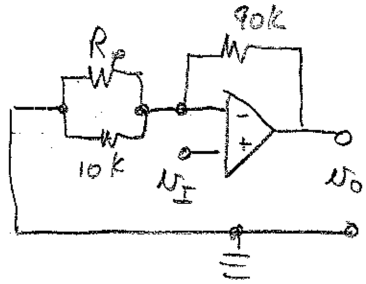
$$v_o = 10v_1 - 10v_2 = 10(0.02)\sin 2\pi(1000t) = 0.2\sin(2\pi 1000t)$$

(6) (2.56) $A = 50\,V/V$; $G = 1 + \frac{R_2}{R_1} = 10\,V/V$

$R_1 = 10k\Omega \Rightarrow R_2 = 90k\Omega$

$$G = \frac{v_o}{v_i} = \frac{1 + R_2/R_1}{1 + \frac{1}{A}(1 + R_2/R_1)} = \frac{1 + 90/10}{1 + \frac{1}{50}(1 + 90/10)} = \frac{10}{1.2} = 8.33\,V/V$$

Compensated Circuit :



Add resistor in parallel w/ R_1 to compensate for drop in gain

$$R_p : \quad 10 = \frac{1 + \left(\frac{90}{10} + \frac{90}{R_p}\right)}{1 + \frac{1}{50}\left(1 + \frac{90}{10} + \frac{90}{R_p}\right)} \Rightarrow R_p = 36k\Omega$$

If $A = 100$

$$G_{uncomp} = \frac{1 + 90/10}{1 + \frac{1}{100}(1 + 90/10)} = 9.09\,V/V$$

$$G_{comp} = \frac{1 + 90/10 + 90/36}{1 + \frac{1}{100}\left(1 + \frac{90}{10} + \frac{90}{36}\right)} = 11.1\,V/V$$