GTU
Electronics Engineering

ELEC 331
Electronic Circuits 2

Fall Semester

Instructor: Assist. Prof. Önder Şuvak

HW 9
Questions and Answers

Updated November 17, 2017 - 13:04

Assigned:

Due:

Answers Out:

Late Due:

Contents

Phase Margin as a Measure of Stability in Feedback Systems **Sedra 8.73**

8.73 An amplifier has a dc gain of 10^5 and poles at 10^5 Hz, 3.16×10^5 Hz, and 10^6 Hz. Find the value of β, and the corresponding closed-loop gain, for which a phase margin of 45° is obtained.

Notes: None.

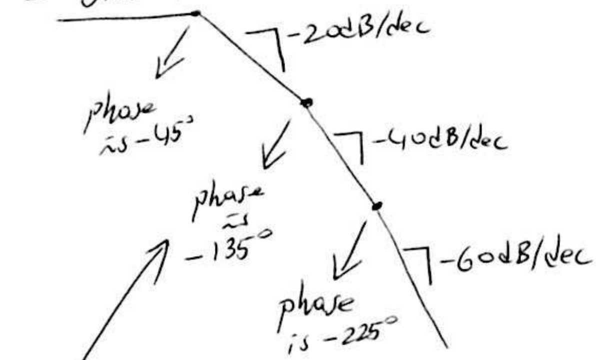
Additional Tasks: None.

Necessary Knowledge and Skills: Open-loop and closed loop gains in feedback, feedback factor, stability, phase margin as a stability measure, transfer functions, magnitude and phase Bode plots, phases at the poles of a transfer function when the poles are far apart.

Sedra 8.73

Magnitude Bode plot for $A(jf)$

$20\log_{10}|10^5| = 100\,\text{dB}$



The asymptotic Bode plot and the phase values are accurate if the poles of $A(jf)$ are far apart.

→ β is given to be indep of frequency, positive and real.

→ Note that

$$20\log_{10}|A(jf)\beta| = 20\log_{10}|A(jf)| - 20\log_{10}\left|\frac{1}{\beta}\right|$$

$$\angle A(jf)\beta = \angle A(jf) \quad \text{since } \beta \text{ is real and positive.}$$

→ Phase margin to be 45°

then $|A(jf_u)\beta| = 1$ and $\angle A(jf_u)\beta = -(180^\circ - 45^\circ)$
$= -135^\circ$

Since β is real and positive, the unity gain frequency f_u (for $A(jf)\beta$) needs to be at the second pole of $A(jf)$. See here.

→ Note that

$$A(jf) = \frac{10^5}{\left(1+\frac{jf}{10^5}\right)\left(1+\frac{jf}{3.16\times10^5}\right)\left(1+\frac{jf}{10^6}\right)}$$

1

Sedra 8.73 contin.

Now solve for β in

$$\left| A(jf_u)\beta \right| = \left| \frac{10^5 \beta}{\left(1 + \frac{jf_u}{10^5}\right)\left(1 + \frac{jf_u}{3.16\times10^5}\right)\left(1 + \frac{jf_u}{10^6}\right)} \right| = 1$$

where $f_u = 3.16\times10^5$ Hz (the second pole)

then

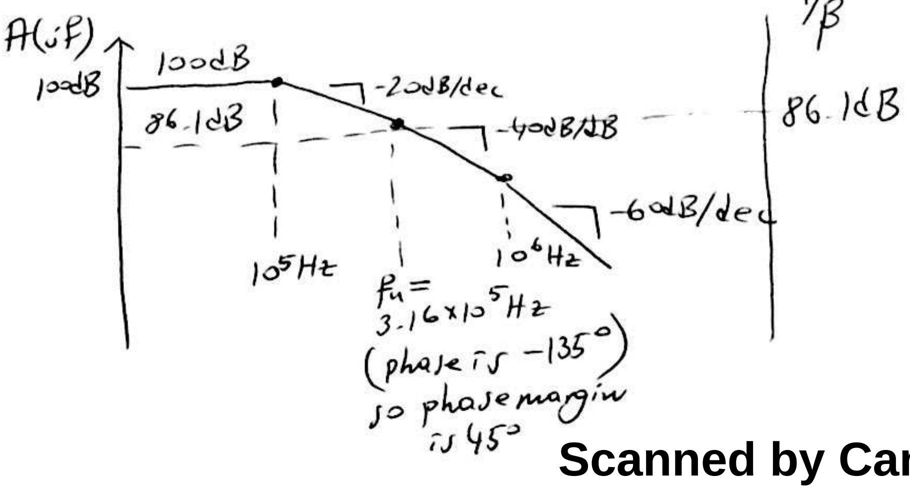
$$1 = \frac{10^5 \beta}{\sqrt{1+\left(\frac{3.16\times10^5}{10^5}\right)^2}\sqrt{1+\left(\frac{3.16\times10^5}{3.16\times10^5}\right)^2}\sqrt{1+\left(\frac{3.16\times10^5}{10^6}\right)^2}}$$

$$= \frac{10^5 \beta}{\sqrt{1+(3.16)^2}\ \sqrt{2}\ \sqrt{1+(0.316)^2}}$$

$$\beta = 4.9\times10^{-5}$$

then $\frac{1}{\beta} = 2.03\times10^4$

and $20\log_{10}\left|\frac{1}{\beta}\right| = 86.1\,\text{dB}$



2

Sedra
8.73
contin.

Midband gain with feedback

$$A_f = \frac{10^5}{1+10^5(4.9\times10^{-5})} \simeq 16.9\times10^3$$

$$= \frac{A}{1+A\beta}$$

③

Analysis of Feedback in OpAmp Circuits **Sedra 8.26**

***8.26** For each of the op-amp circuits shown in Fig. P8.26, identify the feedback topology and indicate the output variable being sampled and the feedback signal. In each case, assuming the op amp to be ideal, find an expression for β, and hence find A_f.

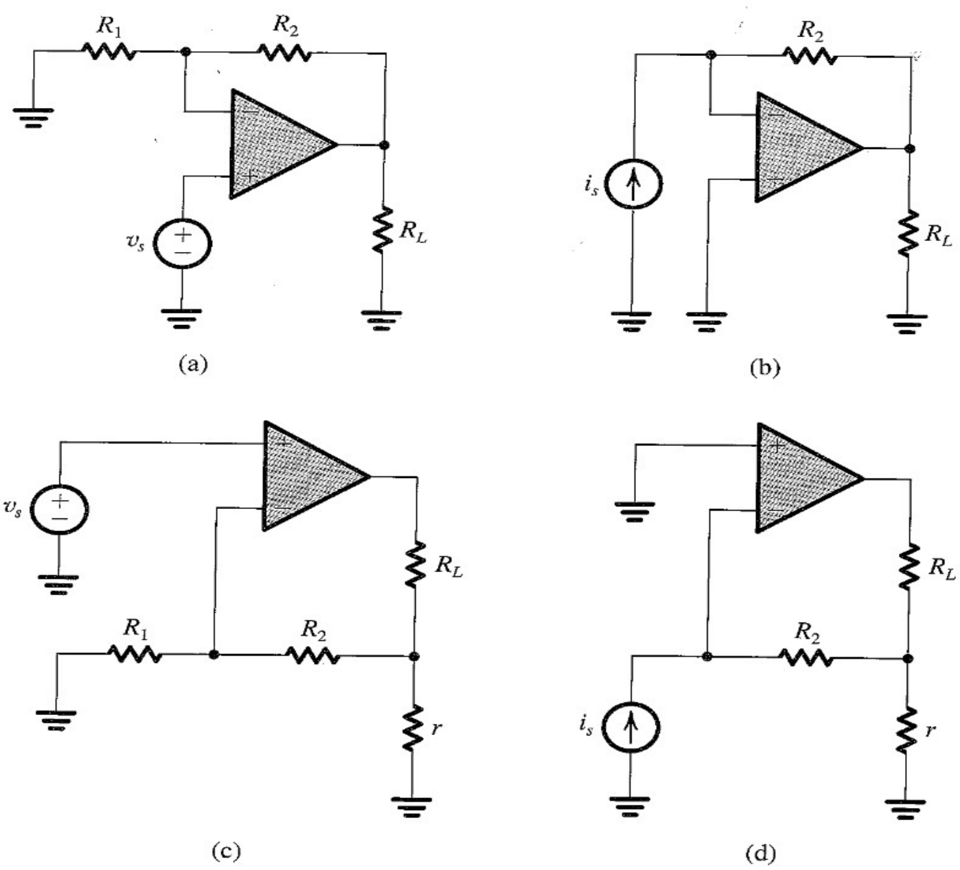


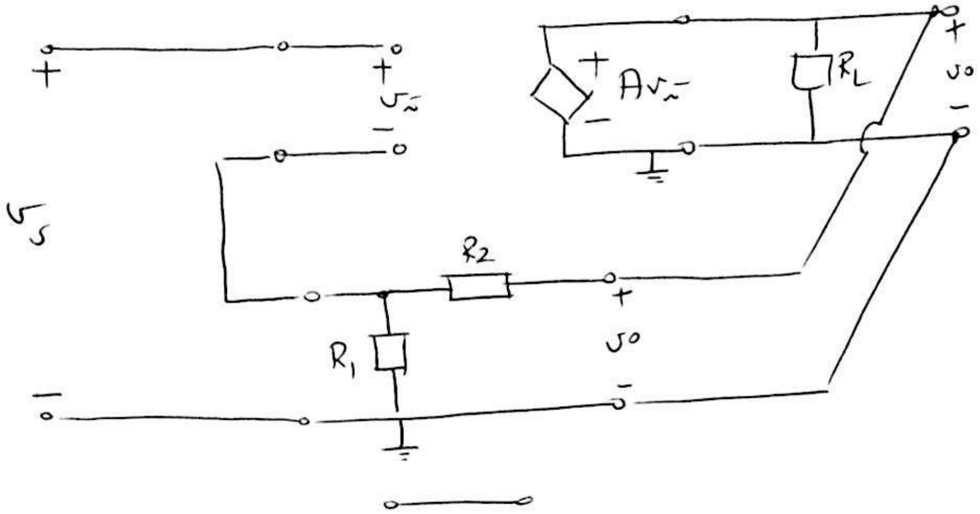
FIGURE P8.26

Notes: None.
Additional Tasks: None.
Necessary Knowledge and Skills: The four types of feedback, identification and modeling of feedback networks, feedback-loaded amplifier analysis, gain and input/output imp. computation.

This is a voltage amplifier with voltage series feedback.

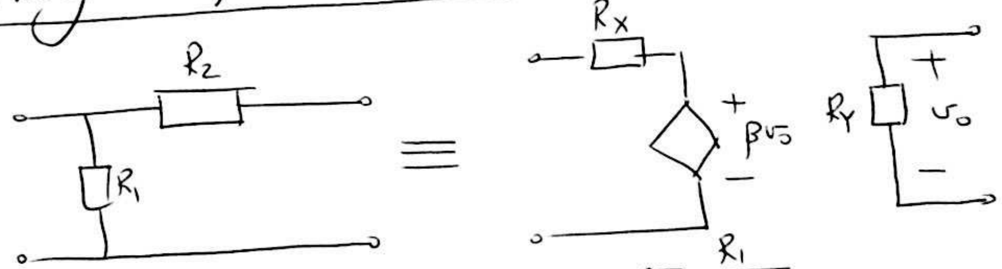
Sedra 8.26 a)

(*)



Analyze the feedback network:

(**)

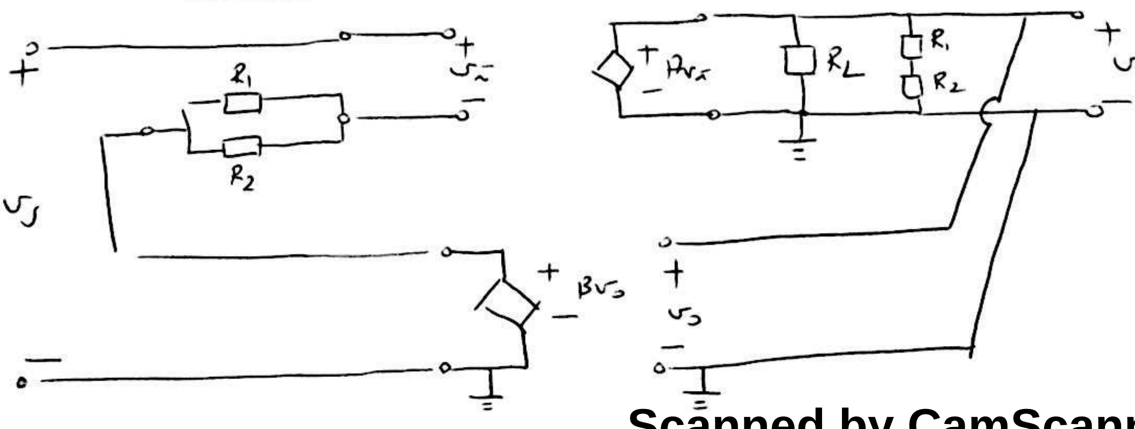


$$\beta = \frac{R_1}{R_1+R_2}$$

$$R_X = R_1 // R_2$$

$$R_Y = R_1 + R_2$$

(***) Schematic of VA, FB and the feedback network (idealized)



(1)

Sedra 8.26a) contin.

$\Rightarrow$ Kill β ($\beta = 0$)

$\Rightarrow$ Analyze VA, FL

$r_{in,VA,FL} = +\infty$ (would be $r_{in} + R_1 // R_2$ if the op amp were nonideal)

$r_{out,VA,FL} = 0$ (would be $r_{out} // R_L // (R_1 + R_2)$ if the opamp were nonideal)

$$A_{VA,FL} = A \left(\text{would be } \frac{r_{in}}{r_{in} + R_1 // R_2} A \frac{R_L // (R_1 + R_2)}{R_L // R_1 + R_2) + r_{out}} \text{ if the opamp were nonideal} \right)$$

Now analyze the whole feedback amplifier

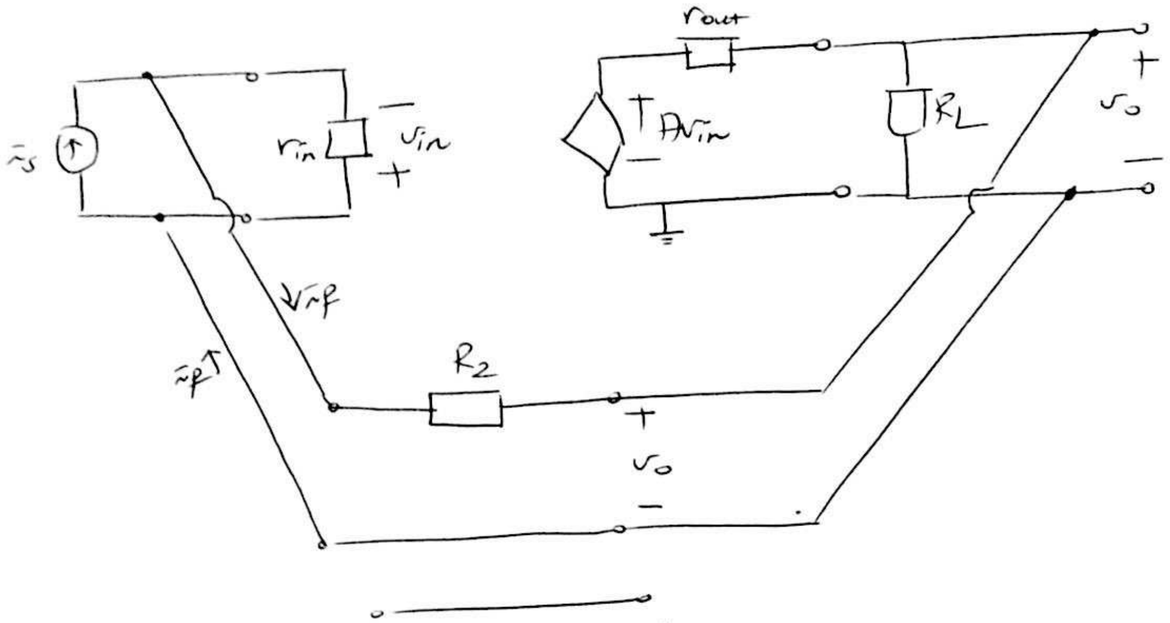
$r_{in,f} = r_{in,VA,FL} (1 + \beta A_{VA,FL}) = +\infty$ (or plug in the value above and β)

$$r_{out,f} = \frac{r_{out,VA,FL}}{1 + \beta A_{VA,FL}} = 0$$

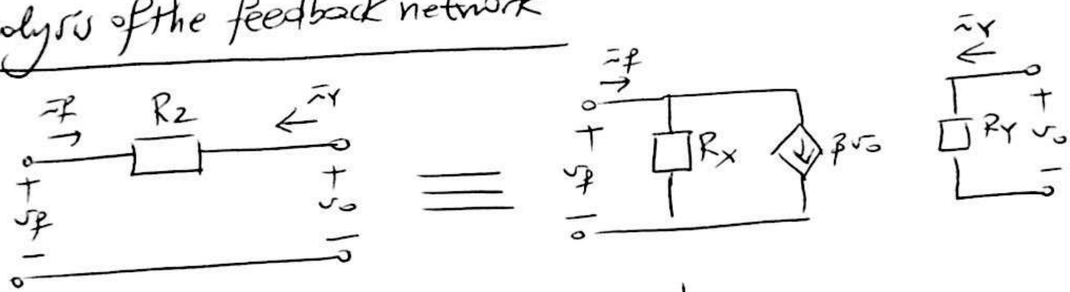
$$A_f = \frac{A_{VA,FL}}{1 + \beta A_{VA,FL}} = \frac{A}{1 + \frac{R_1}{R_1 + R_2} A} \simeq \frac{R_1 + R_2}{R_1} = 1 + \frac{R_2}{R_1}$$

(if $A \gg 1$)

This is a transresistance amplifier with voltage-shunt feedback. Sedra 8.26b)



Analysis of the feedback network



$$\beta = \frac{i_f}{v_o}\bigg|_{v_f=0} = \frac{-i_Y}{v_o} = -\frac{1}{R_2}$$

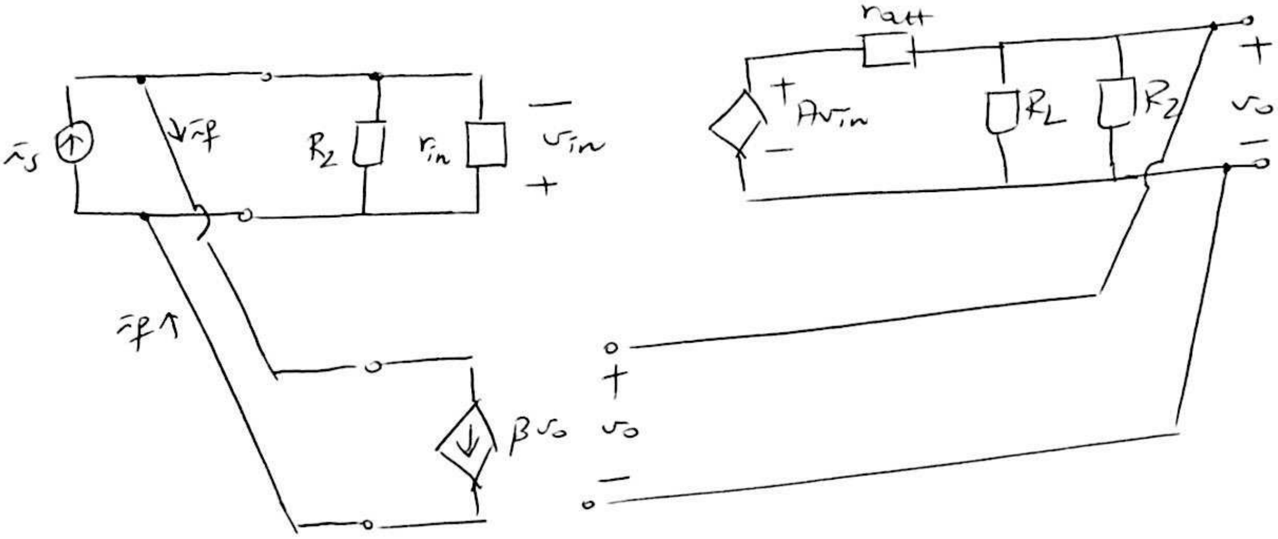
$$R_Y = \frac{v_o}{i_Y}\bigg|_{v_f=0} = R_2$$

$$R_X = \frac{v_f}{i_f}\bigg|_{v_o=0} = R_2$$

1

TRA, fe and the idealized feedback network

Sedra 8 26b)



Kill β ($\beta = 0$) and analyze TRA, fe

$$r_{in, TRA, fe} = R_2 // r_{in}$$

$$r_{out, TRA, fe} = r_{out} // R_L // R_2$$

$$A_{TRA, fe} = \left[- R_2 // r_{in} \right] A \left[\frac{R_L // R_2}{R_L // R_2 + r_{out}} \right]$$

Note that with $r_{in} = +\infty$ and $r_{out} = 0$ the above would be

$$r_{in, TRA, fe} = R_2$$

$$r_{out, TRA, fe} = 0$$

$$A_{TRA, fe} = -R_2 \cdot A$$

2

Sedra 8.26 b) contin

Now analyze the whole feedback ampli.

$$r_{in,f} = \frac{r_{in,TRA,fl}}{1+\beta A_{TRA,fl}}$$

$$= \frac{R_2 // r_{in}}{1+\left(-\frac{1}{R_2}\right)\left(-R_2 // r_{in}\right) A \left(\frac{R_L // R_2}{R_L // R_2 + r_{out}}\right)}$$

with $r_{in} = +\infty$, $r_{out} = 0$

$$\cong \frac{R_2}{1+\left(-\frac{1}{R_2}\right)\left(-R_2\right) A}$$

$$= \frac{R_2}{1+A}$$

with $A \gg 1$

$$\cong 0$$

$$r_{out,f} = \frac{r_{out,TRA,fl}}{1+\beta A_{TRA,fl}}$$

with $r_{in} = +\infty$, $r_{out} = 0$

$$\cong \frac{0}{1+\left(-\frac{1}{R_2}\right)\left(-R_2 \cdot A\right)}$$

$$A_f = \frac{A_{TRA,fl}}{1+\beta A_{TRA,fl}} = \frac{\left[-R_2 // r_{in}\right] A \left[\frac{R_L // R_2}{R_L // R_2 + r_{out}}\right]}{1+\left(-\frac{1}{R_2}\right)\left[-R_2 // r_{in}\right] A \left[\frac{R_L // R_2}{R_L // R_2 + r_{out}}\right]}$$

3

Sedra 8.26 cont-

$$A_f \cong \frac{-R_2 A}{1 + \left(-\frac{1}{R_2}\right)(-R_2) A}$$

with $r_{in} = +\infty$
$r_{out} = 0$

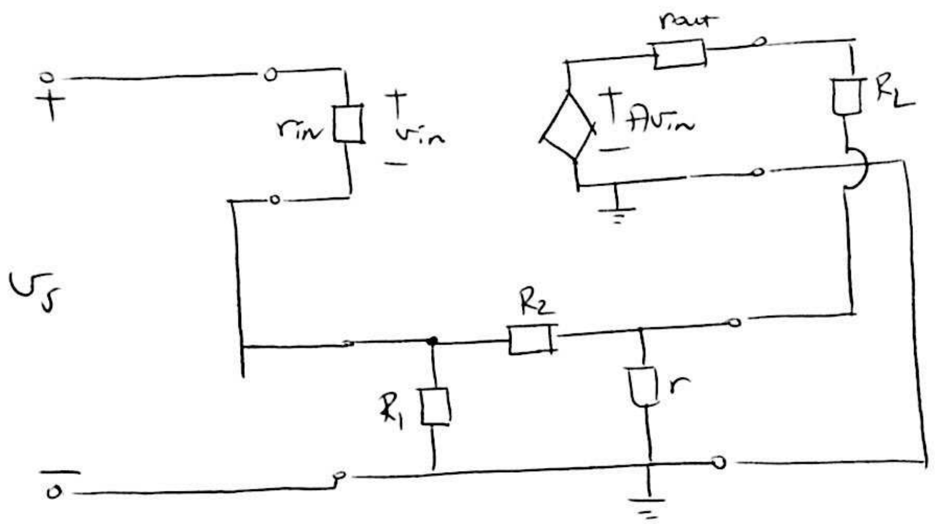
$$= \frac{-R_2 A}{1 + A}$$

with $A \gg 1$ $\cong -R_2$

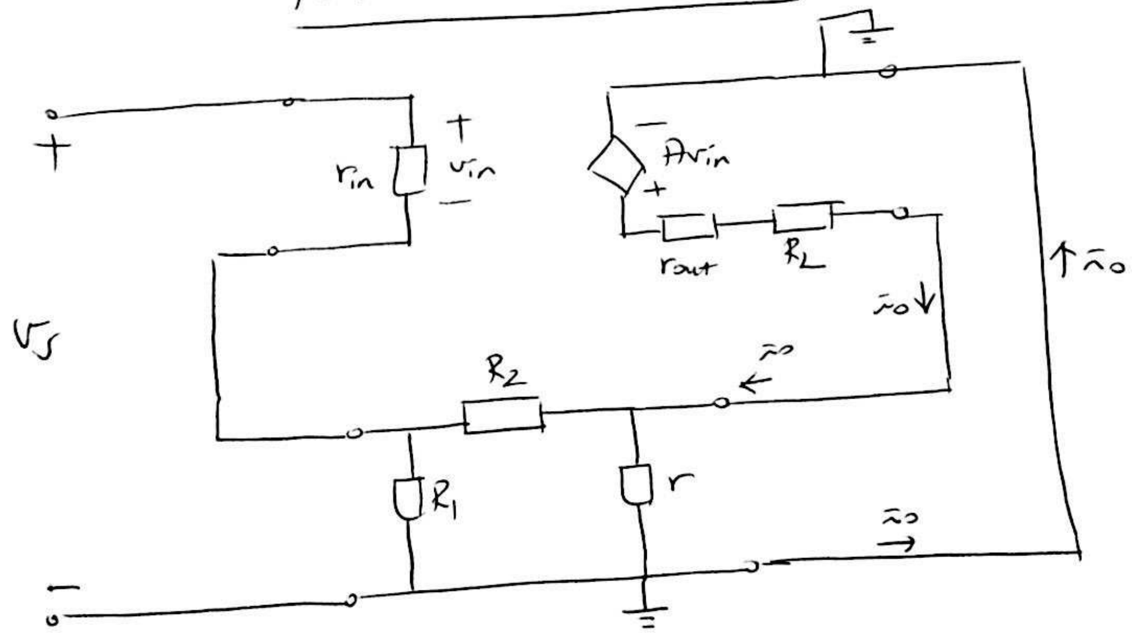
(4)

Transconductance amplifier with current-series feedback

Sedra 8.26c



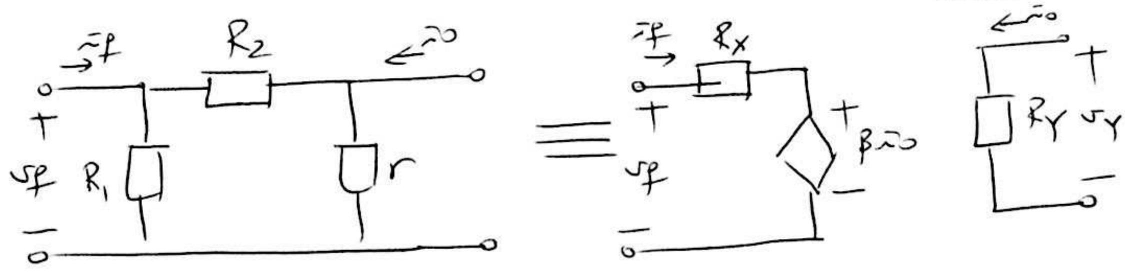
Redraw the above schematics:



1

Analyze the feedback network

Sedra 8.26c cont.

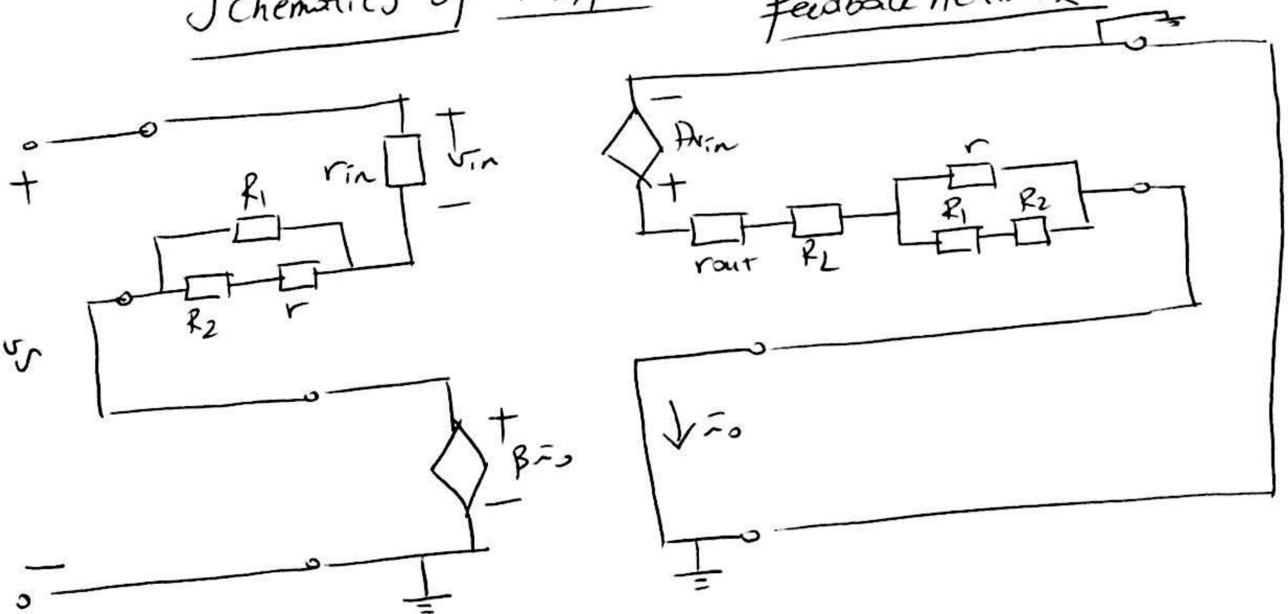


$$\beta = \left.\frac{v_f}{i_o}\right|_{i_f=0} = \frac{r}{r+R_1+R_2}\cdot R_1$$

$$R_X = \left.\frac{v_f}{i_f}\right|_{i_o=0} = R_1 \,//\, (R_2+r)$$

$$R_Y = \left.\frac{v_Y}{i_o}\right|_{i_f=0} = r \,//\, (R_1+R_2)$$

Schematics of T(A), fl and the idealized feedback network



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2

Sedra 8.26c) contin.

$\Rightarrow$ Kill β ($\beta = 0$)

$\Rightarrow$ Analyze TCA, fl

$$r_{in,TCA,fl} = r_{in} + R_1 // (R_2 + r)$$

$$r_{out,TCA,fl} = r_{out} + R_L + r // (R_1 + R_2)$$

$$A_{TCA,fl} = \frac{r_{in}}{r_{in} + R_1 // (R_2 + r)} A \frac{1}{r_{out} + R_L + r // (R_1 + R_2)}$$

Note that with $r_{in} = +\infty$, $r_{out} = 0$

$$r_{in,TCA,fl} \cong +\infty$$

$$r_{out,TCA,fl} \cong R_L + r // (R_1 + R_2)$$

$$A_{TCA,fl} \cong A \frac{1}{R_L + r // (R_1 + R_2)}$$

(3)

Now analyze the whole feedback amplifier

Sedra 8.26c contin.

$$r_{in,f} = \left(1+\beta A_{TCA,FL}\right) r_{in,TCA,FL}$$

$$r_{out,f} = \left(1+\beta A_{TCA,FL}\right) r_{out,TCA,FL}$$

$$A_f = \frac{A_{TCA,FL}}{1+\beta A_{TCA,FL}}$$

Note that with $r_{in} = +\infty$, $r_{out} = 0$

$\rightarrow$ $r_{in,f} = +\infty$

$$\rightarrow \quad r_{out,f} = \left(1 + \frac{rR_1}{r+R_1+R_2} A \frac{1}{R_L + r /\!/ (R_1+R_2)}\right) \cdot \left[R_L + r /\!/ (R_1+R_2)\right]$$

with $A \gg 1$ $\cong \dfrac{rR_1 A}{r+R_1+R_2}$

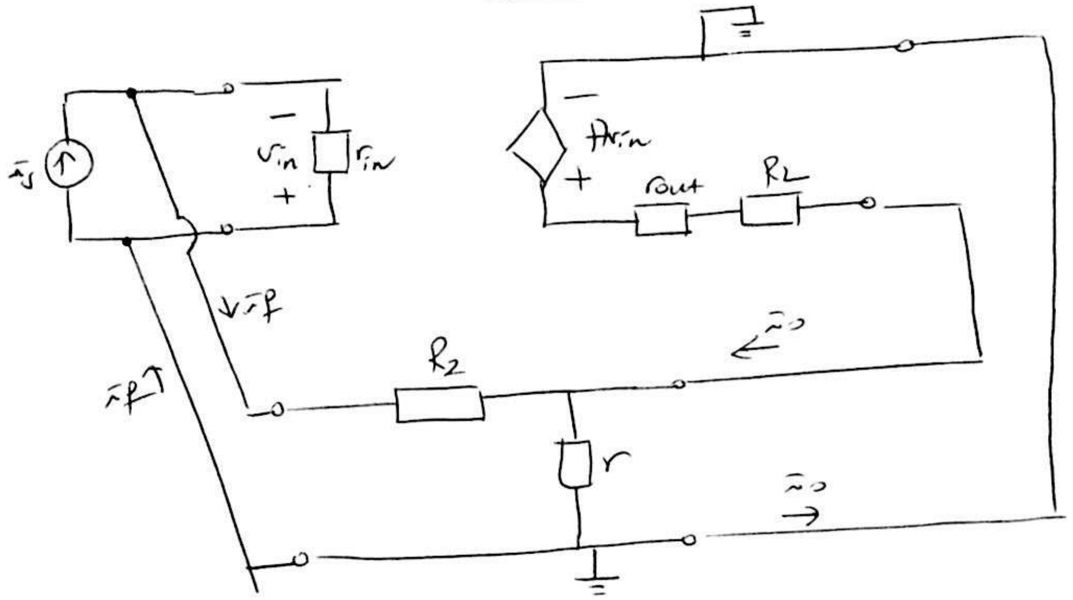
$$\rightarrow \quad A_f \cong \frac{A \dfrac{1}{R_L + r /\!/ (R_1+R_2)}}{1 + \dfrac{rR_1}{r+R_1+R_2} A \dfrac{1}{R_L + r /\!/ (R_1+R_2)}}$$

with $A \gg 1$ $\cong \dfrac{r+R_1+R_2}{rR_1} = \dfrac{1}{r /\!/ R_1} + \dfrac{R_2}{rR_1}$

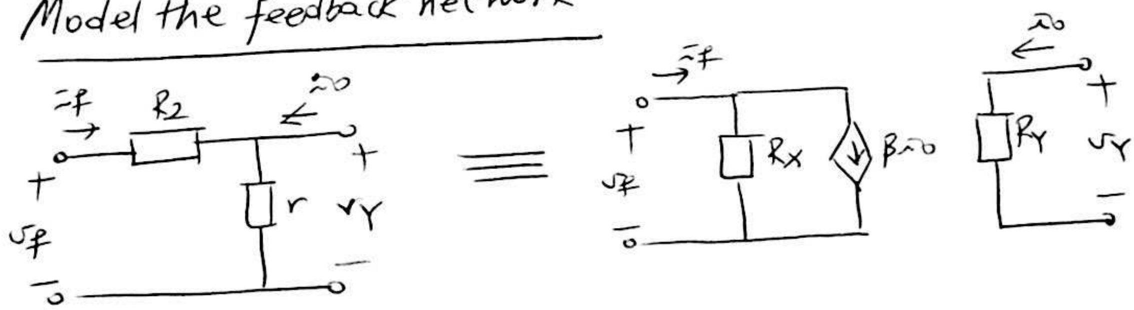
4

This is a current amplifier with current-shunt feedback

Sedra 8.26d



Model the feedback network



$$R_X = \left.\frac{v_f}{i_f}\right|_{i_o=0} = R_2 + r$$

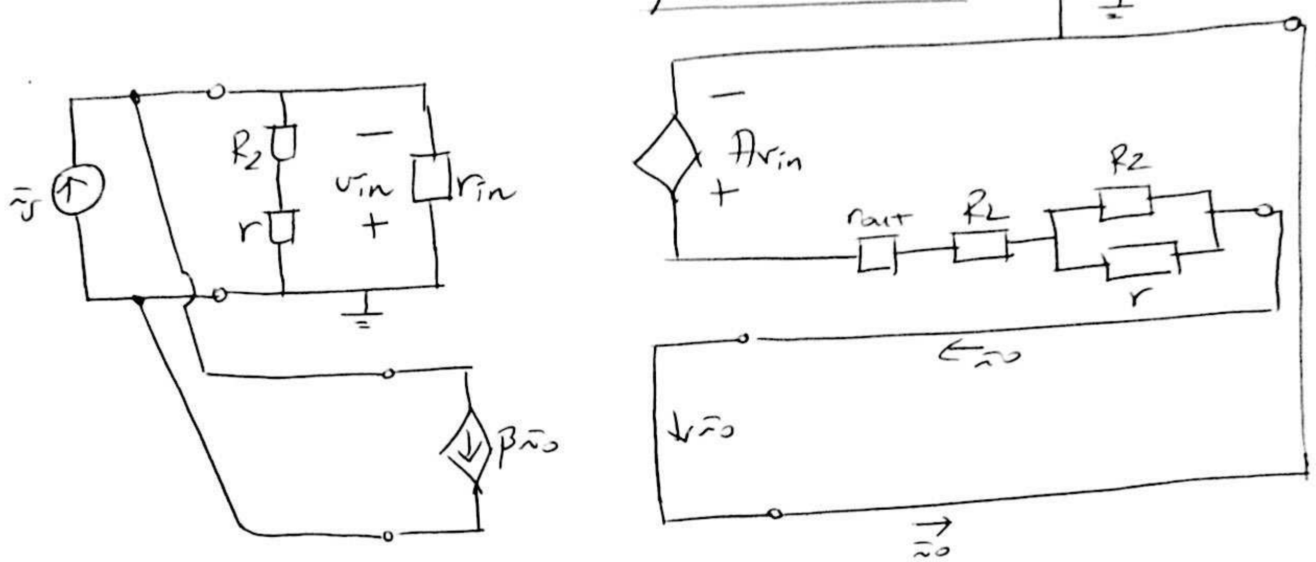
$$R_Y = \left.\frac{v_Y}{i_o}\right|_{v_f=0} = R_2 \parallel r$$

$$\beta = \left.\frac{i_f}{i_o}\right|_{v_f=0} = -\frac{r}{r+R_2}$$

1

Schematics of CA, fl and the idealized feedback network

Sedra 8.26d cont.



$\Rightarrow$ Kill β ($\beta = 0$)

$\Rightarrow$ Analyze CA, fl

$$r_{in,CA,fl} = r_{in} \,//\, (R_2 + r)$$

$$r_{out,CA,fl} = r_{out} + R_L + R_2 // r$$

$$A_{CA,fl} = -\frac{R_2 + r}{R_2 + r + r_{in}} \cdot r_{in} A \frac{1}{r_{out} + R_L + R_2 // r}$$

2

Sedra 8.26d)

With $r_{in} = +\infty$
$r_{out} = 0$

$$r_{in, CA, fe} \cong R_2 + r$$

$$r_{out, CA, fe} \cong R_L + R_2 // r$$

$$A_{CA, fe} \cong -A \frac{(R_2+r)}{R_L + (R_2 // r)}$$

Analyze the whole current amplifier:

$$A_f = \frac{A_{CA,fe}}{1 + \beta A_{CA,fe}}$$

with $r_{in} = +\infty$, $r_{out} = 0$

$$\cong \frac{-A \frac{(R_2+r)}{R_L + (R_2 // r)}}{1 + \left(\frac{-r}{\cancel{r+R_2}}\right)(-A)\left(\frac{\cancel{R_2+r}}{R_L + R_2 // r}\right)}$$

with $A \gg 1$

$$\cong \frac{-A \frac{(R_2+r)}{R_L + R_2 // r}}{rA \frac{1}{R_L + R_2 // r}} = -\frac{R_2+r}{r} = -\left[1 + \frac{R_2}{r}\right]$$

$$r_{in,f} = \frac{r_{in,CA,fe}}{1 + \beta A_{CA,fe}} \cong \frac{R_2 + r}{1 + \left(\frac{-r}{\cancel{r+R_2}}\right)(-A)\left(\frac{\cancel{R_2+r}}{R_L + R_2 // r}\right)}$$

with $r_{in} = +\infty$, $r_{out} = 0$

with $A \gg 1$

$$\cong \frac{1}{rA}\left[(R_2+r)\left[R_L + \frac{R_2 r}{R_2 + r}\right]\right]$$

$$= \frac{(R_2+r) R_L + R_2 r}{rA}$$

③

Sedra 8.26d)

Contin.

$$r_{out,f} = \left(1+\beta A_{CA,fl}\right) r_{out,CA,fl}$$

with $r_{in}=+\infty$, $r_{out}=0$

$$\cong \left[1+\left(\frac{-r}{\cancel{r+R_2}}\right)(-A)\left[\frac{\cancel{R_2+r}}{R_L+R_2/\!/r}\right]\right]\left(R_L+R_2/\!/r\right)$$

with $A \gg 1$

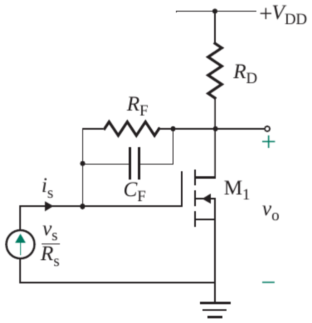
$$\cong Ar\,\frac{\cancel{R_L+R_2/\!/r}}{\cancel{R_L+R_2/\!/r}} = Ar$$

4

Voltage-Shunt Feedback on a Trans-Resistance Amplifier **Rashid 10.42**

10.42 The MOS amplifier shown in Fig. P10.42 is biased to have the following small-signal MOS parameters: $g_{m1} = 1.2\ \text{mA/V}$ and $r_{o1} = 25\ \text{k}\Omega$. If $R_F = 100\ \text{k}\Omega$, then $R_D = 2\ \text{k}\Omega$ and $C_F = 10\ \text{nF}$. Determine **(a)** the voltage gain without feedback $A = v_o/i_s$, **(b)** the voltage gain with feedback A_f, and **(c)** the high cutoff frequency f_H.

FIGURE P10.42



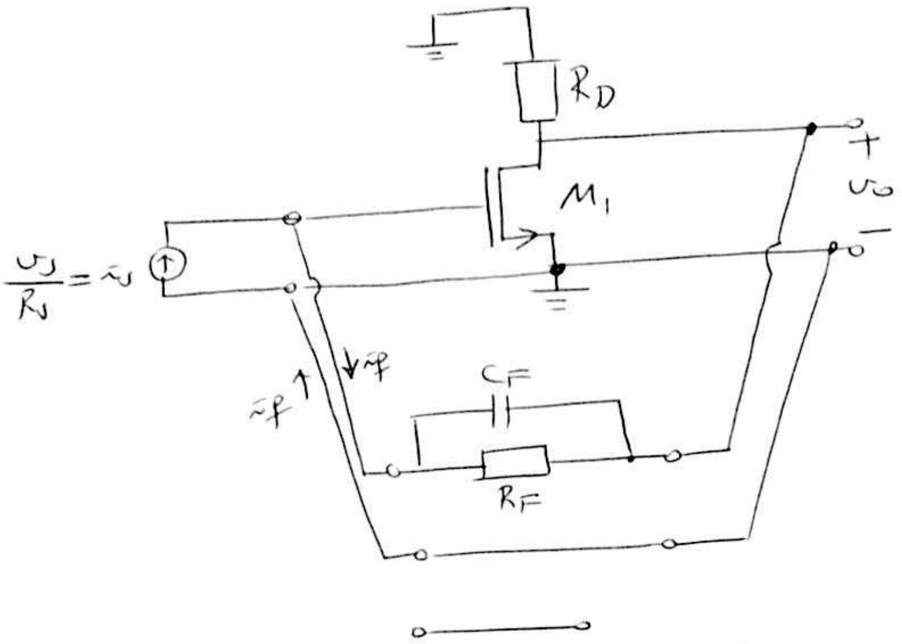
Notes: None.

Additional Tasks: None.

Necessary Knowledge and Skills: Trans-resistance amplifiers, voltage-shunt feedback, identification and modeling of feedback networks, feedback-loaded amplifier analysis, gain and input/output impedance calculations, OCTC for approximating high-frequency cut-off, transfer functions and high-frequency cut-off and zero/pole approximations.

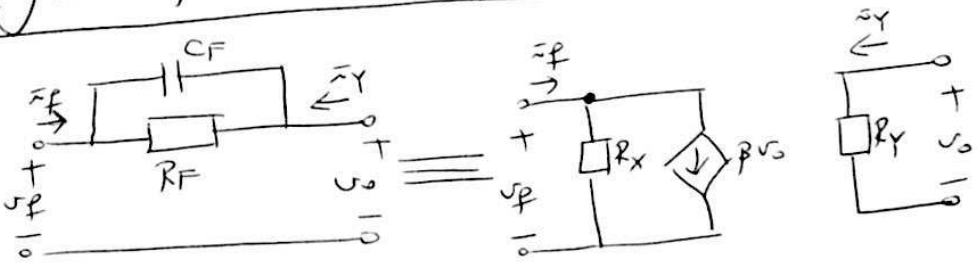
Voltage-Shunt Feedback

Rashid 10.42

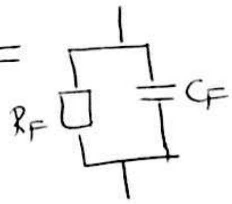


(*) Transresistance amplifier with voltage-shunt feedback

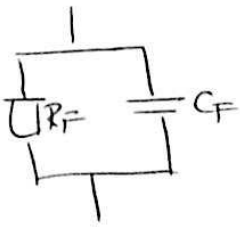
Analyze the feedback network:



$$Z_X = \frac{v_f}{i_f}\Big|_{v_o=0} =$$



$$Z_Y = \frac{v_o}{i_Y}\Big|_{v_f=0} =$$



$$\beta(s) = \frac{i_f}{v_o}\Big|_{v_f=0} = -\frac{i_Y}{v_o}\Big|_{v_f=0} = \frac{-1}{R_F // \frac{1}{sC_F}}$$

1

Rashid
10.42
contin.

$$\beta(s) = \frac{-1}{\dfrac{R_F \frac{1}{sC_F}}{R_F + \frac{1}{sC_F}}}$$

$$= -\frac{R_F + \frac{1}{sC_F}}{R_F \frac{1}{sC_F}}$$

$$= -\frac{1 + sC_F R_F}{R_F}$$

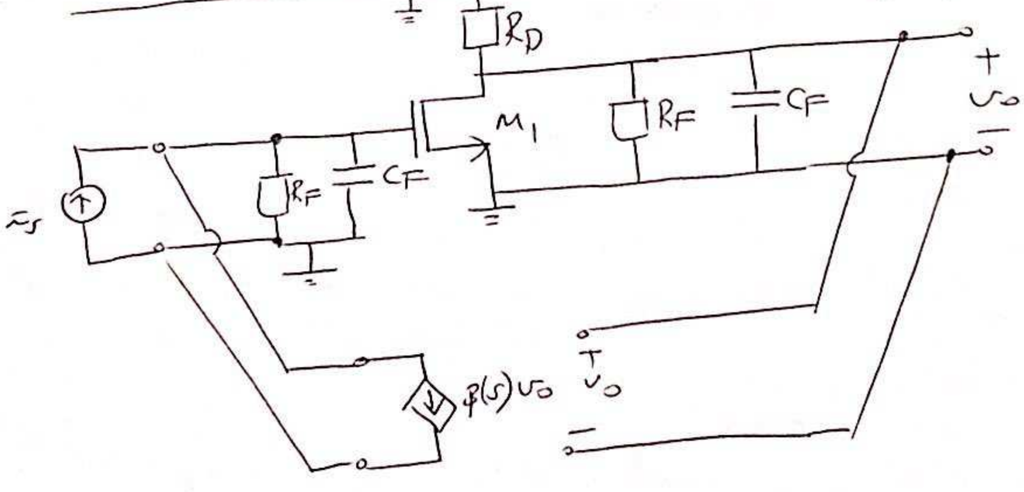
$$\beta(s) = \left(-\frac{1}{R_F}\right)\left[1 + \frac{s}{\left(\frac{1}{C_F R_F}\right)}\right]$$

call this β (midband value)

call this w_z

Identify TRA, FL (feedback-loaded trans-resistance amplifier) and the feedback network.

(**)



 2

Rashid 10.42 contin.

Kill $\beta \Rightarrow \beta_{(s)} = 0$

Now analyze TRA, fe:

$$A_{TRA,fe} = \frac{v_o}{i_s} = R_F\,(-g_{m1})\left[R_D \,//\, R_F \,//\, r_{o1}\right]$$

$$r_{in,TRA,fe} = R_F$$

$$r_{out,TRA,fe} = R_D \,//\, R_F \,//\, r_{o1}$$

$$W_{H,TRA,fe} = \,?$$

$$\tau_1 = R_F C_F$$

$$\tau_2 = C_F\,(R_D \,//\, R_F \,//\, \cancel{C_F}\; r_{o1})$$

$$W_{H,TRA,fe} = \frac{1}{\tau_1 + \tau_2}$$

Note that the frequency response of the gain is:

$$A_{TRA,fe}(jw) = \frac{A_{TRA,fe}}{1 + \dfrac{jw}{W_{H,TRA,fe}}}$$

3

Analysis of the whole feedback amplifier is: Rashid 10.42 contin.

$\Rightarrow$ in midband:

$$r_{in,f} = \frac{r_{in,TRA,fl}}{1 + \beta A_{TRA,fl}}$$

$$r_{out,f} = \frac{r_{out,TRA,fl}}{1 + \beta A_{TRA,fl}}$$

Where the ~~feed~~ improvement factor is:

$$1 + \beta A_{TRA,fl}$$

$$= 1 + \left(-\frac{1}{R_F}\right)\left(R_F\,(-g_{m1})\,(R_D /\!/ R_F /\!/ r_{o1})\right)$$

$$= 1 + g_{m1}\left[R_D /\!/ R_F /\!/ r_{o1}\right]$$

Then

$$r_{in,f} = \frac{R_F}{1 + g_{m1}\left[R_D /\!/ R_F /\!/ r_{o1}\right]}$$

$$r_{out,f} = \frac{R_D /\!/ R_F /\!/ r_{o1}}{1 + g_{m1}\left[R_D /\!/ R_F /\!/ r_{o1}\right]}$$

4

Rashid 10.42 contin.

Analysis of the frequency dependent gain

$$A_f(j\omega) = \frac{A_{TRA,FE}(j\omega)}{1+\beta(j\omega)A_{TRA,FE}(j\omega)}$$

$$= \frac{\dfrac{A_{TRA,FE}}{1+\dfrac{j\omega}{\omega_{H,TRA,FE}}}}{1+\dfrac{A_{TRA,FE}}{1+\dfrac{j\omega}{\omega_{H,TRA,FE}}}\cdot\beta\left[1+\dfrac{j\omega}{\omega_Z}\right]}$$

$$= \frac{A_{TRA,FE}}{1+\dfrac{j\omega}{\omega_{H,TRA,FE}}+A_{TRA,FE}\beta+\dfrac{j\omega}{\dfrac{\omega_Z}{A_{TRA,FE}\beta}}}$$

$$= \frac{A_{TRA,FE}}{1+A_{TRA,FE}\beta}\;\frac{1}{1+\dfrac{j\omega}{(1+A_{TRA,FE}\beta)\left[\omega_{H,TRA,FE}\,//\,\dfrac{\omega_Z}{A_{TRA,FE}\beta}\right]}}$$

midband value of the gain (as expected)

$$\omega_{H,f} = (1+A_{TRA,FE}\beta)\left[\omega_{H,TRA,FE}\,//\,\frac{\omega_Z}{A_{TRA,FE}\beta}\right]$$

high-freq cut-off of the feedback ampli.

(5)

Rashid 10.42 contin.

Compute the voltage gain: (midband)

$$\frac{v_o}{v_s} = \frac{v_o}{R_s \frac{v_s}{R_s}} = \frac{1}{R_s}\frac{v_o}{i_s}$$

$$= \frac{1}{R_s} A_f = \frac{1}{R_s}\frac{A_{TRA,fe}}{1+A_{TRA,fe}\beta}$$

Numerical values:

improvement factor

$$1+\beta A_{TRA,fe} = 1 + g_{m1}(R_D // R_F // r_{o1})$$

$$= 1 + (1.2mS)(2k // 100k // 25k)$$

$$\approx 1 + (1.2mS)(2k)$$

$$= 1 + 2.4 = 3.4$$

$$W_z = \frac{1}{C_F R_F} = \frac{1}{(10nF)(100k)} = \frac{1}{(10\times10^{-9})(100\times10^{3})} = \frac{1}{10^{-3}} = 10^3 \text{ rad/s}$$

$$\frac{W_z}{A_{TRA,fe}\beta} = \frac{10^3 \text{ rad/s}}{2.4} \approx 417 \text{ rad/s}$$

$$r_{in,f} = \frac{R_F}{\text{improvement factor}} = \frac{100k}{3.4} = 2.94\times10^4 \text{ k}$$

$$r_{out,f} \cong \frac{R_D}{\text{improvement factor}} = \frac{2k}{3.4} = 588\,\Omega$$

$$W_{H,TRA,fe} \cong \frac{1}{(10nF)(100k+2k)} = \frac{1}{10\times10^{-9}\times102\times10^{3}} = 980 \text{ rad/s}$$

6

Rashid 10.42 contin

Numerical values (contin)

$$w_{H,f} \cong (3.4)\underbrace{\left[980\text{ rad/s} \,//\, 417\text{ rad/s}\right]}_{\approx 293\text{ rad/s}}$$

$$= 994\text{ rad/s}$$

$$\beta = -\frac{1}{100k} = -\frac{10^6}{10^5}10^{-6} = -10\mu S$$

$$A_{TRA,fl} \cong -(100k)(1.2mS)(2k)$$

$$= -\underbrace{(200)(1.2)}_{240}\cancel{\#}\underbrace{(10^6)(10^{-3})}_{10^3}$$

$$= -240k\Omega$$

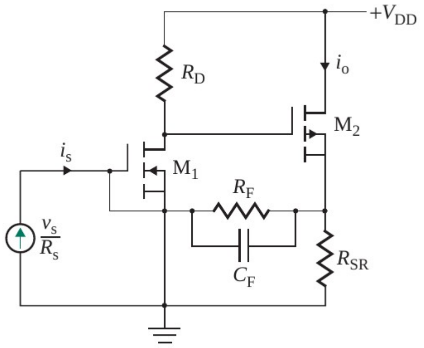
$$\frac{A_{TRA,fl}}{1+\beta A_{TRA,fl}} = \frac{-240k\Omega}{1+2.4} = \frac{-240k\Omega}{3.4}$$

$$= -70.6\,k\Omega$$

Current-Shunt Feedback on a Current Amplifier — Rashid 10.50

10.50 The MOS amplifier shown in Fig. P10.50 is biased to have the following small-signal MOS parameters: $g_{m1} = 1.2\ \text{mA/V}$, $r_{o1} = 25\ \text{k}\Omega$, $g_{m2} = 1.6\ \text{mA/V}$, and $r_{o2} = 25\ \text{k}\Omega$. If $R_D = 1.5\ \text{k}\Omega$, then $R_{SR1} = 500\ \text{k}\Omega$, $R_{SR2} = 2\ \text{k}\Omega$, and $R_F = 8\ \text{k}\Omega$. Determine **(a)** the voltage gain without feedback $A = i_o/v_s$, **(b)** the voltage gain with feedback A_f, and **(c)** the feedback capacitor C_F to limit the high frequency $f_H = 50$ kHz.

FIGURE P10.50



Notes: None.

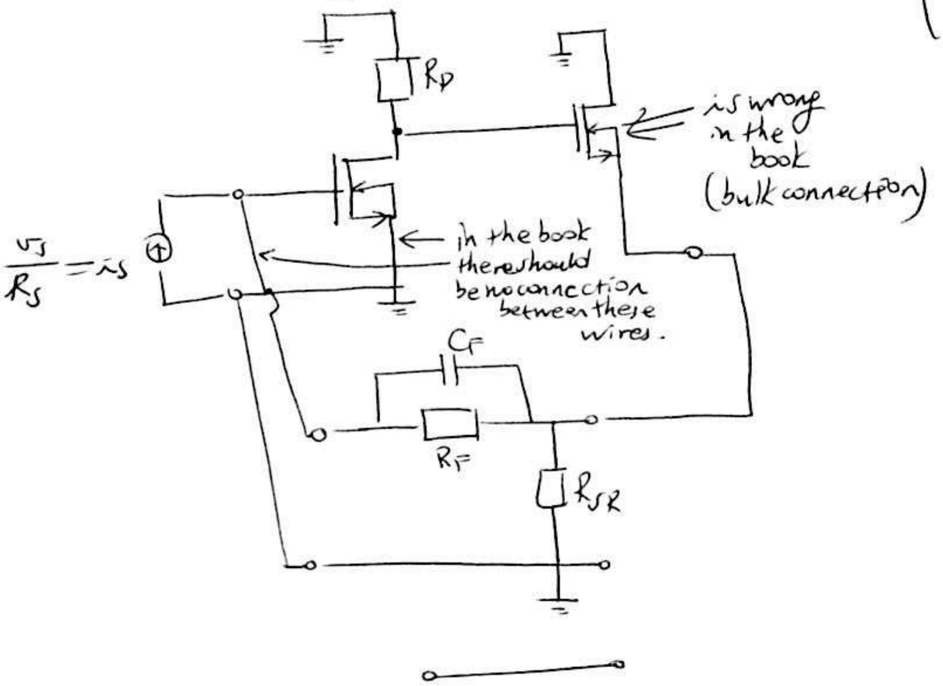
Additional Tasks: Point out and correct the two mistakes in the schematic before beginning to solve the question.

Necessary Knowledge and Skills: Current amplifiers, current-shunt feedback, identification and modeling of feedback networks, feedback-loaded amplifier analysis, gain and input/output impedance calculations, OCTC for approximating high-frequency cut-off, transfer functions and high-frequency cut-off and zero/pole approximations, design question.

Current amplifier with current shunt feedback

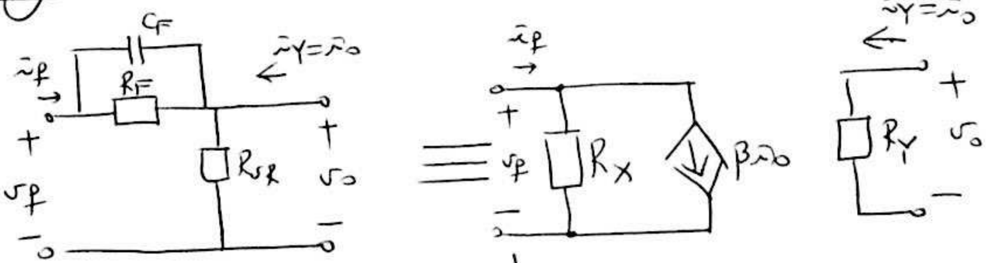
Rashid
10.5

Identify the feedback network

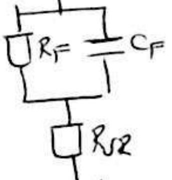


(*) Current ampli with current shunt feedback

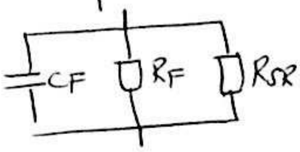
Analyze the feedback network



$Z_X = \frac{v_f}{i_f}\Big|_{i_Y=0} =$



$Z_Y = \frac{v_o}{i_Y}\Big|_{v_f=0} =$



$$\beta(s) = \frac{i_f}{i_Y}\Big|_{v_f=0} = -\frac{R_{SR}}{R_{SR} + R_F // \frac{1}{sC_F}}$$

Rashid
10.50
contin

$$\beta(s) = -\frac{R_{SR}}{R_{SR} + \dfrac{R_F \frac{1}{sC_F}}{R_F + \frac{1}{sC_F}}}$$

$$= -\frac{R_{SR}}{R_{SR} + \dfrac{R_F}{1+sC_F R_F}} = -\frac{R_{SR}\left(1+sC_F R_F\right)}{R_{SR}+R_F+sC_F R_F R_{SR}}$$

$$= -\frac{R_{SR}}{R_{SR}+R_F} \frac{1+sC_F R_F}{1+\dfrac{s}{\dfrac{1}{C_F\left(R_F // R_{SR}\right)}}}$$

$$= \left(-\frac{R_{SR}}{R_{SR}+R_F}\right) \frac{1+\dfrac{s}{1/C_F R_F}}{1+\dfrac{s}{\dfrac{1}{C_F\left(R_F // R_{SR}\right)}}}$$

call this w_z

call this w_p

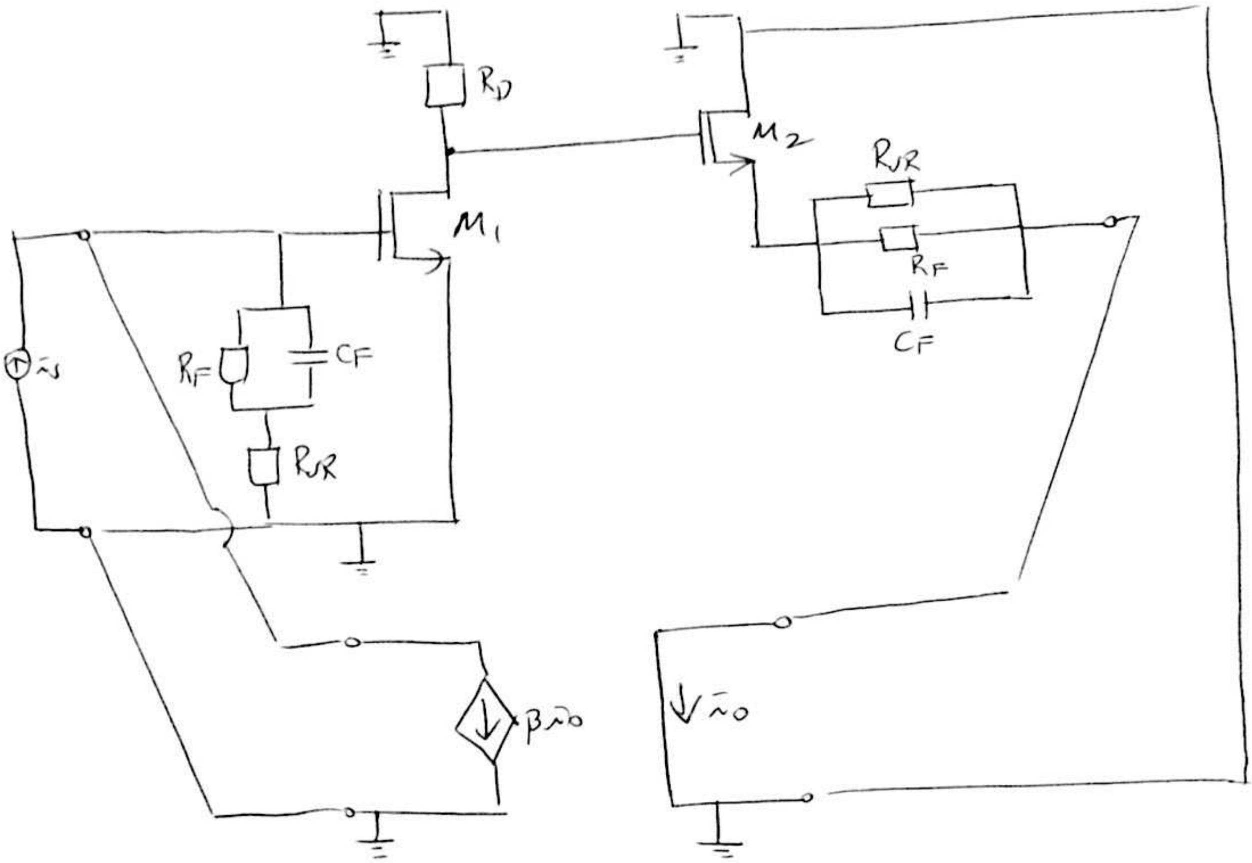
call this β (midband value)

$$= \beta \frac{1+\dfrac{s}{w_z}}{1+\dfrac{s}{w_p}}$$

2

CA, FL (feedback-loaded current amplifier) and the feedback network

Rashid 10.50 contin.



Analyze CA, FL (in midband)

$$r_{in,CA,FL} = R_F + R_{SR}$$

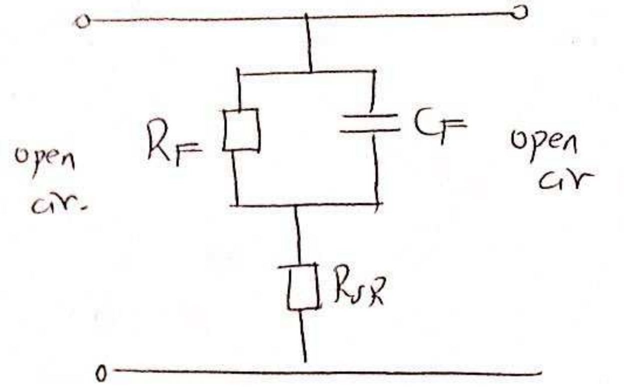
$$r_{out,CA,FL} \cong r_{o2}\left(1 + g_{m2}\left(R_{SR} // R_F\right)\right)$$

$$A_{CA,FL} \cong (-g_{m1})(R_D)\left[\frac{g_{m2}}{1 + g_{m2}(R_{SR}//R_F)}\right](R_F + R_{SR})$$

3

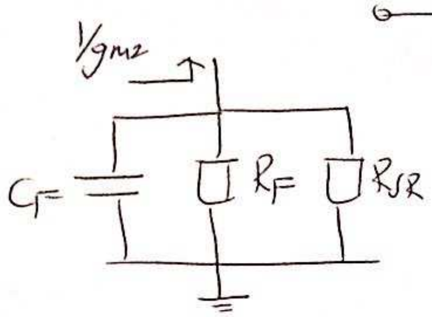
Compute $w_{H,CA,ef}$ by OCTC

Rashid
10.50
contin-



no current through R_{SR}

$$\tau_1 = R_1 C_1$$
$$C_1 = C_F$$
$$R_1 = R_F$$



$$\tau_2 = R_2 C_2$$
$$C_2 = C_F$$
$$R_2 = R_F // R_{SR} // \underbrace{\frac{1}{g_{m2}}}$$

in reality $\frac{r_{o2}}{1+g_{m2}r_{o2}}$, but $g_{m2}r_{o2} \gg 1$

$$w_{H,CA,\cancel{ef}\,fe} \simeq \frac{1}{\tau_1 + \tau_2}$$

Note that the freq response of the gain is

$$A_{CA,fe}(jw) = \frac{A_{CA,fe}}{1 + \frac{jw}{w_{H,CA,fe}}}$$

4

analysis the whole feedback amplifier

Rashid 10.50 contin.

$$r_{in,f} = \frac{r_{in,CA,fe}}{1+\beta A_{CA,fe}}$$

$$r_{out,f} = r_{out,CA,fe}\left(1+\beta A_{CA,fe}\right)$$

Now analyze the gain with feedback:

$$A_f(jw) = \frac{A_{CA,fe}(jw)}{1+\beta(jw)A_{CA,fe}(jw)}$$

$$= \frac{\dfrac{A_{CA,fe}}{1+\dfrac{jw}{w_{H,CA,fe}}}}{1+\dfrac{A_{CA,fe}}{1+\dfrac{jw}{w_{H,CA,fe}}}\,\beta\,\dfrac{1+\dfrac{jw}{w_z}}{1+\dfrac{jw}{w_p}}}$$

$$\cong \frac{A_{CA,fe}\left(1+\dfrac{jw}{w_p}\right)}{1+\dfrac{jw}{w_{H,CA,fe}}+\dfrac{jw}{w_p}+A_{CA,fe}\beta+\dfrac{\dfrac{jw}{w_z}}{A_{CA,fe}\beta}}$$

$$= \frac{A_{CA,fe}}{1+A_{CA,fe}\beta}\;\frac{1+\dfrac{jw}{w_p}}{1+\dfrac{jw}{(1+A_{CA,fe}\beta)\left[w_{H,CA,fe}//w_p//\dfrac{w_z}{A_{CA,fe}\beta}\right]}}$$

Midband value as expected.

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