LECTURE 260 – SHUNT-SHUNT FEEDBACK
(READING: GHLM – 563-569)

Objective

The objective of this presentation is:

1.) Show how to identify the type of feedback topology

2.) Illustrate the analysis of shunt-shunt feedback circuits

Outline

- Feedback identification procedure
- Shunt-shunt feedback with nonideal source and load
- Examples
- Summary

IDENTIFICATION OF THE FOUR, SINGLE-LOOP FEEDBACK TOPOLOGIES

Two-Terminal Representation of a Single-Loop, Negative Feedback System

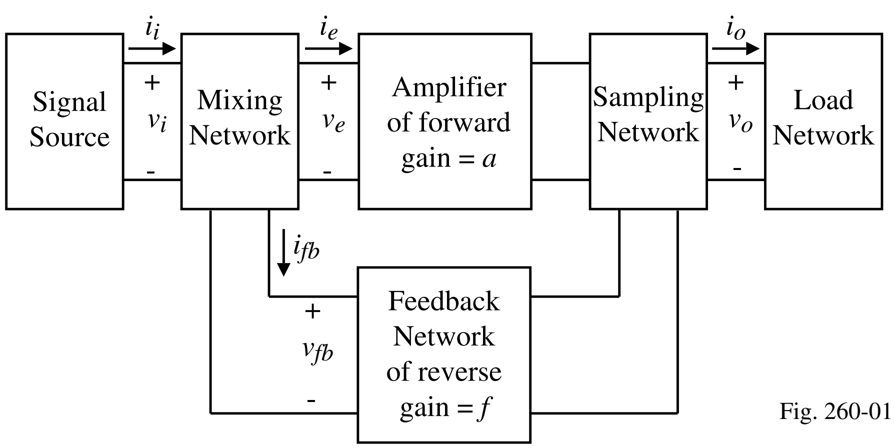


Fig. 260-01

Feedback Topology Identification Procedure

1.) Identify the feedback loop by tracing around the feedforward and feedback path. Also check to see if the feedback is positive or negative.

2.) Identify whether or not the mixing network is series or shunt. If the signal source has one terminal on ac ground then:

a.) If the input active device has one of its input terminals on ac ground, then the mixing network must be shunt.

b.) If the signal and feedback sources are applied to different input terminals of the input active device, then the mixing network is series (this includes differential amplifiers where two devices form the input active device).

c.) If the signal source does not have one of its input terminals on ac ground or to check the above steps, try to assign the variables x_i, x_{fb}, and x_e on the schematic in such a manner as to implement the equation,

$$x_e = x_i \pm x_{fb}$$

If this equation can be written using voltages (currents) then the mixing circuit is series (shunt).

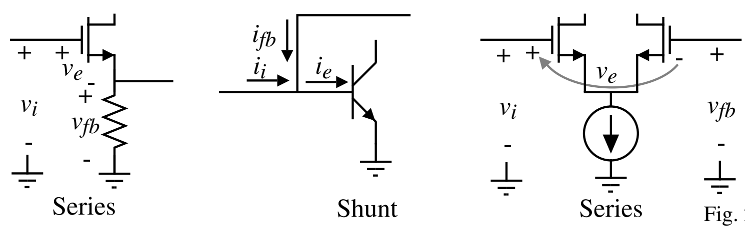


Fig. 260-02

Feedback Topology Identification Procedure - Continued

3.) Next identify the sampling circuit as series or shunt. If the load is grounded then,

a.) If the out active device has one of its two possible output terminals grounded, then the feedback is shunt.

b.) If the output active device has neither of its output terminals on ground and if the output signal is taken from one of its output terminals and the fed back signal from the other output terminal, then the feedback is series.

c.) If the load is not grounded or to check the above test, identify the load resistor, R_L, and apply the following test:

i.) If x_{fb} becomes zero when $R_L = 0$, then the sampling network is shunt.

ii.) If x_{fb} becomes zero when $R_L = \infty$, then the sampling network is series.

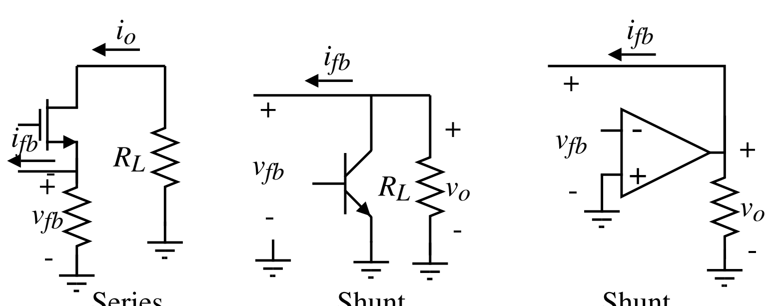


Fig. 260-03

Transistor Examples of Negative Feedback Topology Identification

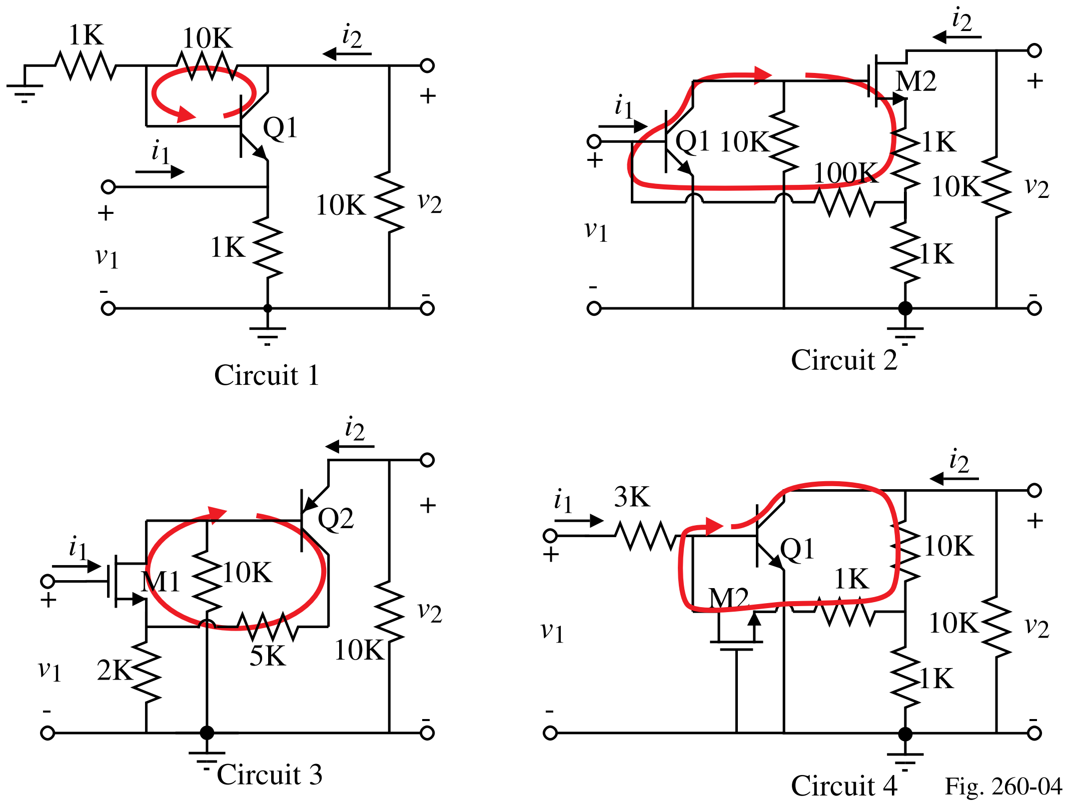


Fig. 260-04

Shunt-Shunt Feedback including Source and Load Resistance

Configuration:

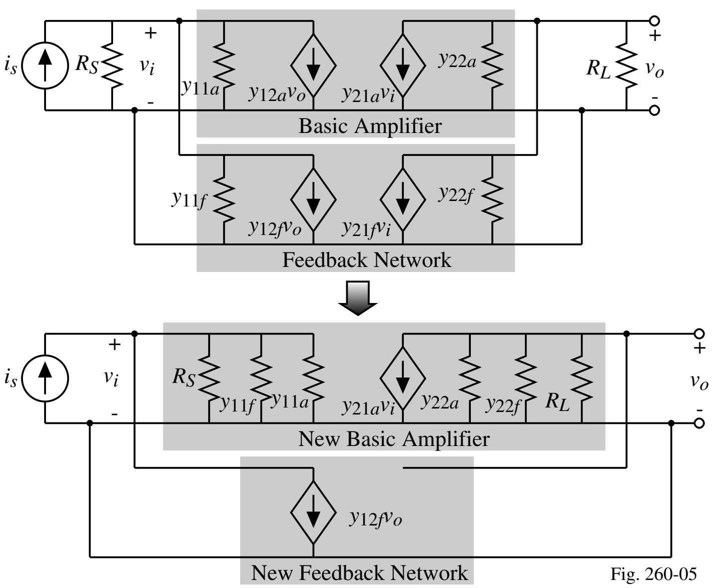


Fig. 260-05

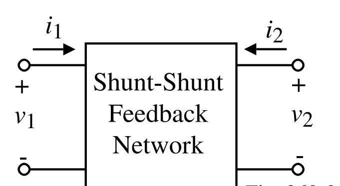


Fig. 260-06

$$i_1 = y_{11}v_1 + y_{12}v_2$$

$$i_2 = y_{21}v_1 + y_{22}v_2$$

where for the new basic amplifier,

$$y_{11} = \frac{i_1}{v_1}\bigg|_{v_2=0} = G_S + y_{11a} + y_{11f}$$

$$y_{12} = \frac{i_1}{v_2}\bigg|_{v_1=0} = 0$$

$$y_{21} = \frac{i_2}{v_1}\bigg|_{v_2=0} = y_{21a}$$

$$y_{22} = \frac{i_2}{v_2}\bigg|_{v_1=0} = G_L + y_{22a} + y_{22f}$$

$$\frac{v_o}{i_s} = \frac{v_2}{i_1} = A = \frac{a}{1+af} = \frac{(-y_{21a}/y_{11}y_{22})}{1+(-y_{21a}/y_{11}y_{22})\, y_{12f}} \Rightarrow a = \frac{-y_{21a}}{y_{11}y_{22}} \quad \text{and} \quad f = y_{12f}$$

Example 1 – Inverting Op Amp

Find the closed-loop transfer function, A, the closed-loop input resistance, Z_{if}, and the closed-loop output resistance, Z_{of} of the shunt-shunt configuration shown. The op amp has a differential input resistance of z_i, voltage gain of a_v, and output resistance of z_o.

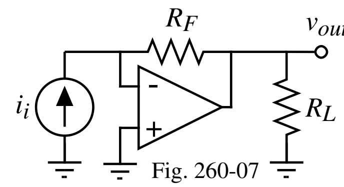
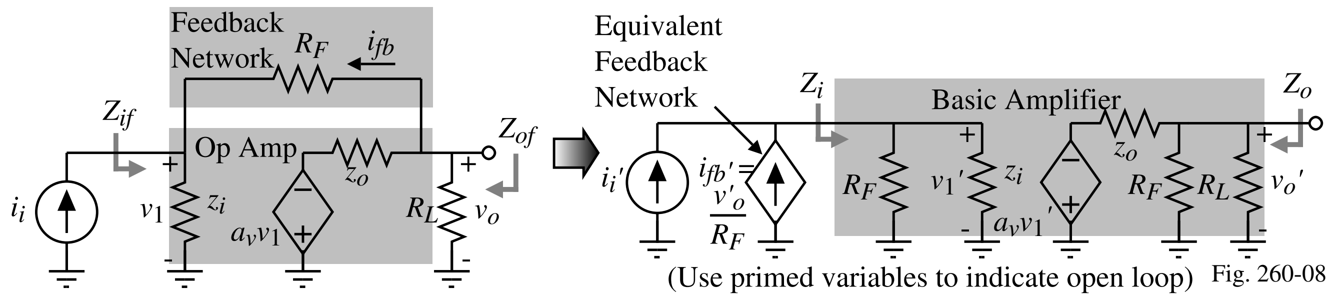


Fig. 260-07

Solution

Equivalent circuit:



(Use primed variables to indicate open loop) Fig. 260-08

It is easy to show that $f = y_{12f} = \left.\frac{i_1'}{v_2'}\right|_{v_1'=0} = \frac{-1}{R_F}$

The forward gain, a, is

$$a = \frac{v_o'}{i_i'} = \left(\frac{v_o'}{v_1'}\right)\left(\frac{v_1'}{i_i'}\right) = \left(\frac{-a_v(R_F||R_L)}{z_o+(R_F||R_L)}\right)\left(\frac{z_iR_F}{z_i+R_F}\right) = \left(\frac{-a_vR_FR_L}{z_oR_F+z_oR_L+R_FR_L}\right)\left(\frac{z_iR_F}{z_i+R_F}\right) \qquad \text{where } i_{fb}' = 0$$

Example 1 – Continued

The loop gain is

$$T = af = \left(\frac{a_vR_FR_L}{z_oR_F+z_oR_L+R_FR_L}\right)\left(\frac{z_i}{z_i+R_F}\right)$$

The closed-loop gain is

$$\frac{v_o}{i_i} = \frac{a}{1+af} = \frac{\left(\frac{-a_vR_FR_L}{z_oR_F+z_oR_L+R_FR_L}\right)\left(\frac{z_iR_F}{z_i+R_F}\right)}{1+\left(\frac{a_vR_FR_L}{z_oR_F+z_oR_L+R_FR_L}\right)\left(\frac{z_i}{z_i+R_F}\right)} = \frac{(-a_vR_F^2R_Lz_i)}{(z_oR_F+z_oR_L+R_FR_L)(z_i+R_F) + a_vR_FR_Lz_i}$$

The closed-loop input impedance is

$$Z_{if} = \frac{Z_i}{1+T} = \frac{\frac{z_iR_F}{z_i+R_F}}{1+\left(\frac{a_vR_FR_L}{z_oR_F+z_oR_L+R_FR_L}\right)\left(\frac{z_i}{z_i+R_F}\right)} \approx \frac{z_oR_F+z_oR_L+R_FR_L}{a_vR_L}$$

The closed-loop output impedance is

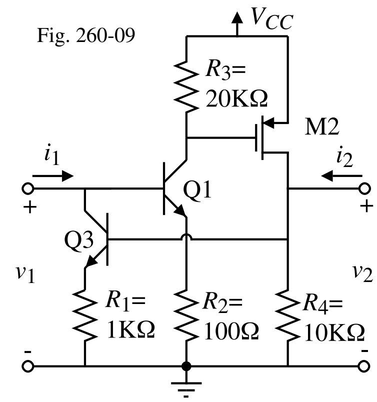
$$Z_{of} = \frac{Z_o}{1+T} = \frac{z_o||R_F||R_L}{1+\left(\frac{a_vR_FR_L}{z_oR_F+z_oR_L+R_FR_L}\right)\left(\frac{z_i}{z_i+R_F}\right)}$$

If $a_v = 200{,}000$, $z_i = 2\text{M}\Omega$, and $z_o = 75\Omega$, $R_F = 1\text{M}\Omega$, and $R_L = 10\text{k}\Omega$, then $T = 133{,}333$, $Z_i = 2||1 = 0.667\text{M}\Omega \rightarrow Z_{if} = 5\Omega$, $Z_o \approx 75\Omega \rightarrow Z_{of} = 0.563\text{m}\Omega$ and $A = -999{,}992\Omega$

Example 2 – Transistor Feedback Amplifier

For the amplifier shown, find v_2/v_1, v_1/i_1, and v_2/i_2. Assume that g_m = 5mS and $r_{ds} = \infty$ for the MOSFET and $r_{\pi1} = r_{\pi3}$ =1000Ω and $\beta_{F1} = \beta_{F3}$ = 100 for the BJTs.

Fig. 260-09



Solution

1.) Find the feedback topology and polarity of feedback.

The loop consists of base-collector of Q1, gate-drain of M2, and base-collector of Q3. A positive change at the base of Q1 gives a "-" and the gate of M2, which gives a "+" at the base of Q3, which gives a "-" at the base of Q3. ∴ feedback is negative.

2.) The mixing circuit is shunt because only the base terminal of Q1 is connected to the input and feedback. Note that $i_{C3} = i_{fb}$ and $i_{B1} = i_e \Rightarrow i_e = i_i - i_{fb}$.

3.) The feedback circuit is shunt because the output transistor (M2) has one of its possible output terminals on ac ground. Also, if $R_L = R_4$ goes to zero, i_{fb} = 0.

4.) Draw the closed-loop circuit and small-signal model.

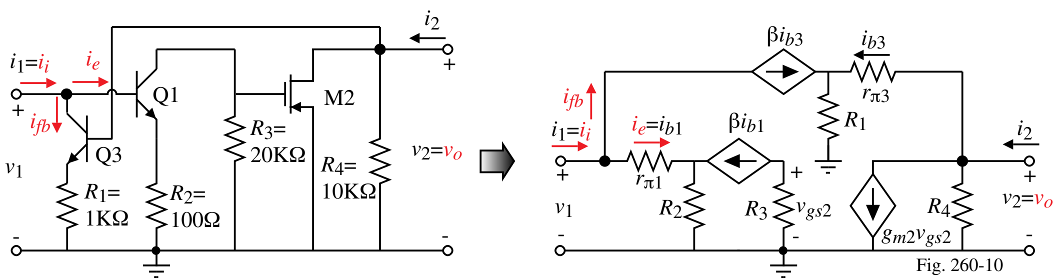


Fig. 260-10

Example 2 – Continued

5.) AC open-loop model is drawn by,

a.) Looking back into the feedback network (Q3,R1) to the left with v_1 = 0.

b.) Looking back into the feedback network (Q3,R1) to the right with v_2 = 0.

The result is,

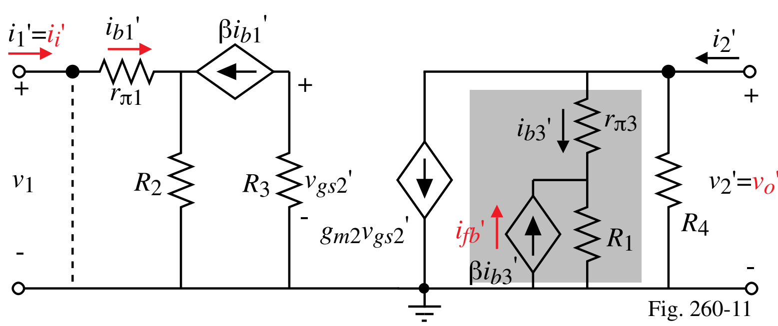


Fig. 260-11

6.) Next, find a and f.

$$a = \frac{v_o'}{i_1'} = \left(\frac{v_o'}{v_{gs2}'}\right)\left(\frac{v_{gs2}'}{i_1'}\right) = -g_{m2}\{R_4||[r_{\pi3}+(1+\beta_3)R_1]\}(-\beta_3 R_3) = (-45.54)(-2\text{x}10^6) = 91.07\text{M}\Omega$$

$$f = \frac{i_{fb}'}{v_o'},\quad i_{B1}' = \frac{v_o'}{r_{\pi3}+(1+\beta_3)R_1} \;\rightarrow\; i_{fb}' = \beta_3 i_{B3}' \;\rightarrow\; f = \frac{\beta_3}{r_{\pi3}+(1+\beta_3)R_1} = 0.98\text{mS} \;(\approx 1/R_1)$$

Example 2 – Continued

7.) Calculate R_i and R_o.

$$R_i = \frac{v_1'}{i_1'} = r_{\pi 1}+(1+\beta_1)R_2 = 11\text{k}\Omega$$

and

$$R_o = \frac{v_2'}{i_2'} = R_4||[r_{\pi 3}+(1+\beta_3)R_1] = 10\text{k}\Omega||102\text{k}\Omega = 9.107\text{k}\Omega$$

8.) Find v_2/v_1, v_1/i_1, and v_2/i_2.

$$\frac{v_o}{i_1} = \frac{a}{1+T} = \frac{91.07\text{M}\Omega}{1+89.287\text{x}10^3} = 1019.2\Omega \quad (\text{Note: } \frac{1}{f} = 1020\Omega)$$

$$R_{if} = \frac{v_1}{i_1} = \frac{R_i}{1+T} = \frac{11\text{k}\Omega}{1+89.287\text{x}10^3} = \underline{\underline{0.1243\Omega}}$$

$$R_{of} = \frac{v_2}{i_2} = \frac{R_o}{1+T} = \frac{9.107\text{k}\Omega}{1+89.287\text{x}10^3} = \underline{\underline{0.102\Omega}}$$

Now,

$$\frac{v_2}{v_1} = \left(\frac{v_2}{i_1}\right)\left(\frac{i_1}{v_1}\right) = \frac{v_2/i_1}{R_{if}} = \frac{1019.2\Omega}{0.1243\Omega} = \underline{\underline{8204.5\text{V/V}}}$$

SUMMARY

- We have shown how to identify the type of feedback topology
- Illustrate the analysis of shunt-shunt feedback circuits
- Procedure

  1.) Identify the type of feedback topology

  2.) Draw the schematic for the closed-loop amplifier

  3.) Break the feedback loop by replacing the feedback network with the resistance seen looking into each end of the feedback network with the other end shorted.

  4.) Draw a schematic of the open-loop amplifier with all variables primed.

  5.) Solve for a, f, R_i, and R_o.

  6.) Calculate A and R_{if} and R_{of} by the following formulas:

$$A = \frac{a}{1+T}, \qquad R_{if} = \frac{R_i}{1+T}, \text{ and } \qquad R_{of} = \frac{R_o}{1+T}$$

  7.) If necessary, use the results of 6.) to find the desired closed-loop transfer function.