LECTURE 270 – SERIES-SERIES FEEDBACK
(READING: GHLM – 569-579)

Objective

The objective of this presentation is:

1.) Illustrate the analysis of series-series feedback circuits

Outline

- Series-series feedback with nonideal source and load
- Examples
- Summary

Series-Series Feedback including Source and Load Resistances

Configuration:

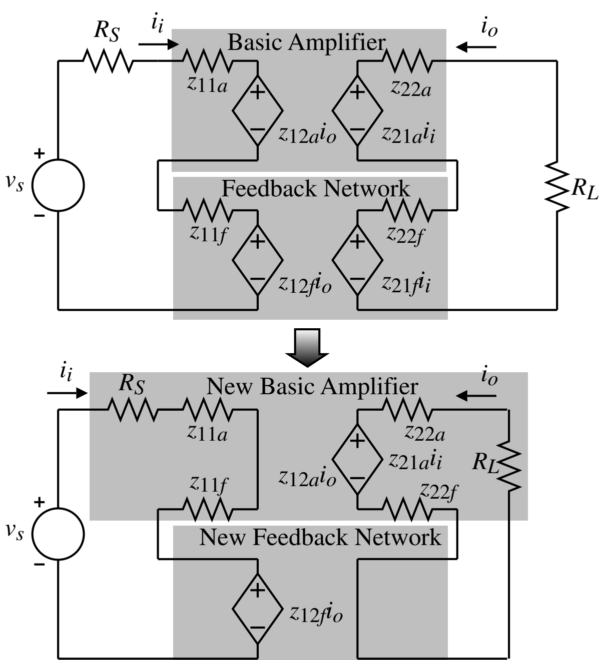

Fig. 270-01

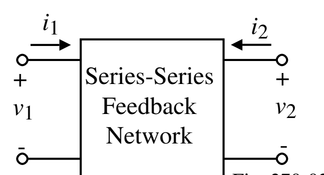

Fig. 270-02

$$v_1 = z_{11}i_1 + z_{12}i_2$$

$$v_2 = z_{21}i_1 + z_{22}i_2$$

where for the new basic amplifier,

$$z_{11} = \frac{v_1}{i_1}\bigg|_{i_2=0} = R_S + z_{11a} + z_{11f}$$

$$z_{12} = \frac{v_1}{i_2}\bigg|_{i_1=0} = 0$$

$$z_{21} = \frac{v_2}{i_1}\bigg|_{i_2=0} = z_{21a}$$

$$z_{22} = \frac{v_2}{i_2}\bigg|_{i_1=0} = R_L + z_{22a} + z_{22f}$$

$$\frac{i_o}{v_s} = \frac{i_2}{v_1} = A = \frac{a}{1+af} = \frac{(-z_{21a}/z_{11}z_{22})}{1+(-z_{21a}/z_{11}z_{22})\, z_{12f}} \Rightarrow a = \frac{-z_{21a}}{z_{11}z_{22}} \quad \text{and} \quad f = z_{12f}$$

Example 1 – Two-Transistor Feedback Amplifier

For the amplifier shown, find v_2/v_1, v_1/i_1, and v_2/i_2. Assume that $r_{\pi 1} = r_{\pi 2} = 1000\Omega$ and $\beta_{F1} = \beta_{F2} = 150$ for the BJTs.

Solution

1.) Topology identification. We see that the circuit is series-series, negative feedback. Also, note that R_S is "outside" the feedback circuit.

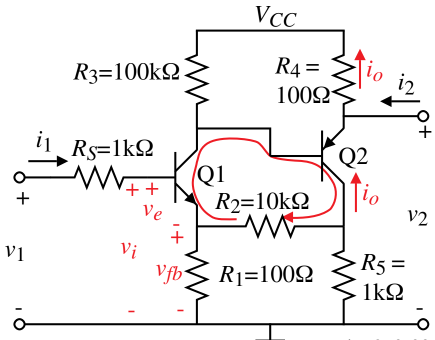

Fig. 270-03

2.) Closed loop small-signal model is shown below.

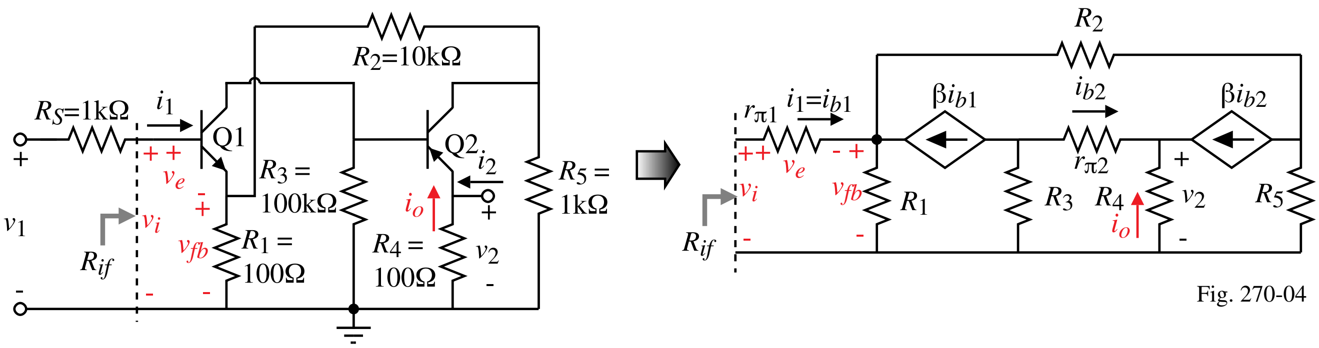

Fig. 270-04

3.) Break open the loop by finding the loading effects of the feedback network on the amplifier. This involves finding z_{11f} and z_{22f}.

Example 1 – Continued

3.) Continued

$$z_{11f} = \frac{v_{1f}}{i_{1f}}\bigg|_{i_{2f}=i_o=0}$$

(Resistance seen looking back into the feedback network from the input with $i_o = 0$.)

$$\therefore\ z_{11f} = R_2 + R_5$$

$$z_{22f} = \frac{v_{2f}}{i_{2f}}\bigg|_{i_{1f}=i_i=0}$$

(Resistance seen looking back into the feedback network from the input with $i_i = 0$.)

$$\therefore\ z_{22f} = R_1 + R_5$$

4.) Open-circuit small-signal model:

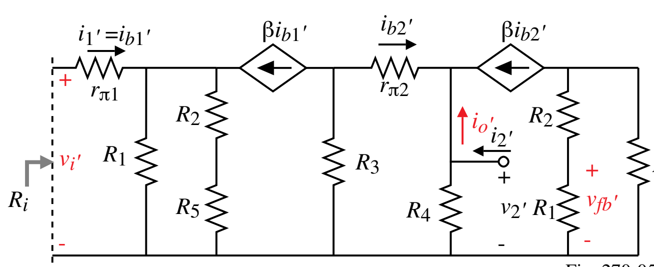

Fig. 270-05

$$f = \frac{v_{fb}'}{i_o'} = \left(\frac{v_{fb}'}{i_{b2}'}\right)\left(\frac{i_{b2}'}{i_o'}\right) = \left(\frac{-\beta R_5}{R_1+R_2+R_5}\,\mathrm{x}R_1\right)\left(\frac{1}{1+\beta}\right)$$

$$\approx \frac{-R_1R_5}{R_1+R_2+R_5} = -9.009\Omega$$

$$a = \frac{i_o'}{v_i'} = \left(\frac{i_o'}{i_{b2}'}\right)\left(\frac{i_{b2}'}{i_{b1}'}\right)\left(\frac{i_{b1}'}{v_i'}\right) =$$

$$(1+\beta)\left(\frac{-\beta R_3}{R_3+r_{\pi 2}+(1+\beta)R_4}\right)\left(\frac{1}{r_{\pi 1}+(1+\beta)[R_1 \| (R_2+R_5)]}\right)$$

$$= (151)\left(\frac{-150\cdot 100\text{k}\Omega}{116.1\text{k}\Omega}\right)\left(\frac{1}{15.96\text{k}\Omega}\right) = -1.222\text{S} \quad \Rightarrow \quad T = (-1.222)(-9.009) = 11.01$$

Example 1 – Continued

5.) Input resistance, v_1/i_1.

$R_i = r_{\pi1}+(1+\beta)[R_1||(R_2+R_5)] = 15.96\text{k}\Omega \rightarrow R_{if} = R_i(1+T) = 15.96\text{k}\Omega\cdot 12.01=191.73\text{k}\Omega$

However, we must add R_S to this to get the requested v_1/i_1 = 192.73kΩ

6.) Voltage gain, v_2/v_1. First find i_o/v_i.

$$\frac{i_o}{v_i} = \frac{a}{1+af} = \frac{-1.222}{1+11.01} = -0.1017\text{S}$$

$$\frac{v_2}{v_1} = \left(\frac{i_oR_4}{v_i}\right)\left(\frac{v_i}{v_1}\right) = \left(\frac{i_o}{v_i}\right)\left(\frac{v_i}{v_1}\right)R_4 = \left(\frac{i_o}{v_i}\right)\left(\frac{R_{if}}{R_{in}}\right)R_4 = (-0.1017)\left(\frac{191.73}{192.73}\right)(100) = -10.122\text{V/V}$$

7.) Ouput resistance, v_2/i_2. First, we must realize that the resistances involved with series input or output is *in series with the loop*. Consider the equivalent model of the output.

$$R_o = R_4 + \frac{r_{\pi2}+R_3}{1+\beta} = 100 + \frac{101\text{k}\Omega}{151} = 769\Omega$$

$$R_{of} = R_o(1+af) = 769(12.01) = 9234\Omega$$

But, this is not v_2/i_2.

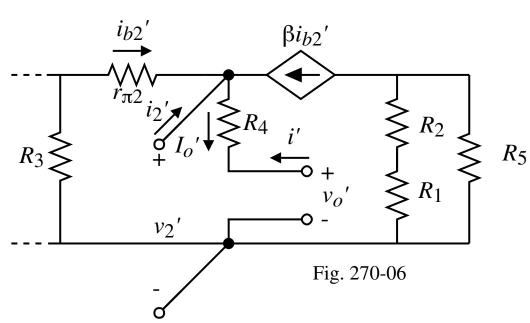

Fig. 270-06

Example 1 – Continued

8.) Use the model shown to calculate v_2/i_2.

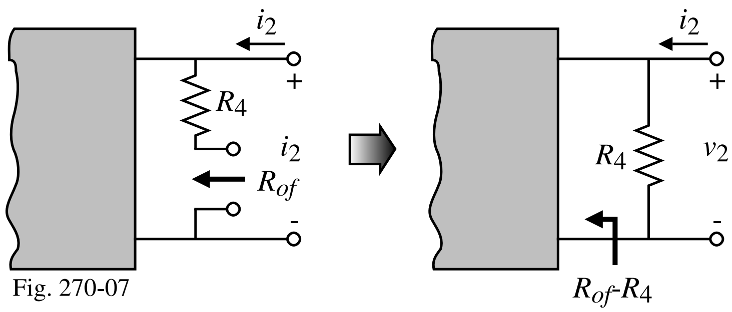

Fig. 270-07

From this model, we see that

$$\frac{v_2}{i_2} = R_4||(R_{of} - R_4) = 100\Omega||9134\Omega = \underline{98.9\Omega}$$

Example 2 – Series-Series Feedback Triple

For the amplifier shown, find v_2/v_1, v_1/i_1, and v_2/i_2. Assume that all MOSFET transconductances are 1mS.

Solution

1.) The feedback is negative, series-series feedback.

2.) Closed loop small-signal model is shown below.

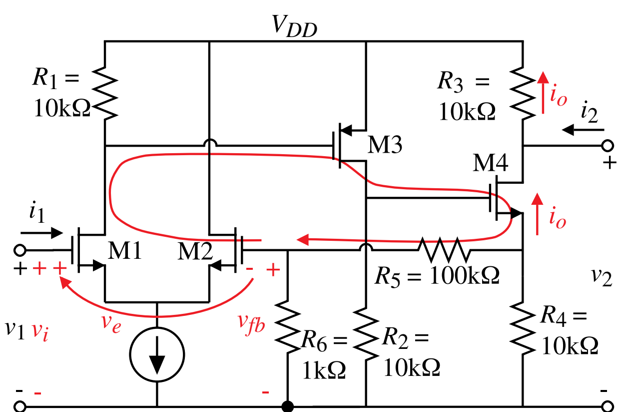

Fig. 270-08

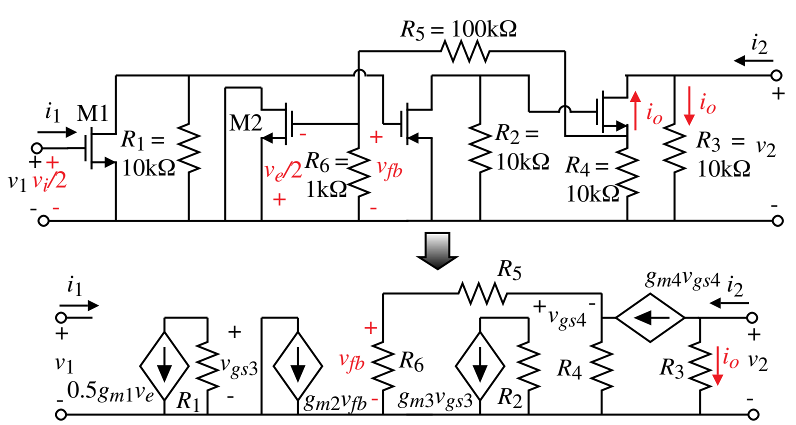

Fig. 270-09

Example 2 – Continued

3.) Break open the loop by finding the loading effects of the feedback network on the amplifier. This involves finding z_{11f} and z_{22f}.

$$z_{11f} = \frac{v_{1f}}{i_{1f}}\bigg|_{i_{2f}=i_o=0} = R_4 + R_5$$

$$z_{22f} = \frac{v_{2f}}{i_{2f}}\bigg|_{i_{1f}=i_i=0} = R_5 + R_6$$

4.) The open-loop model is:

$$f = \frac{v_{fb}'}{i_o'} = \frac{-R_4R_6}{R_4+R_5+R_6} = \frac{-10\cdot 1}{10+100+1}\text{k}\Omega = -909\Omega$$

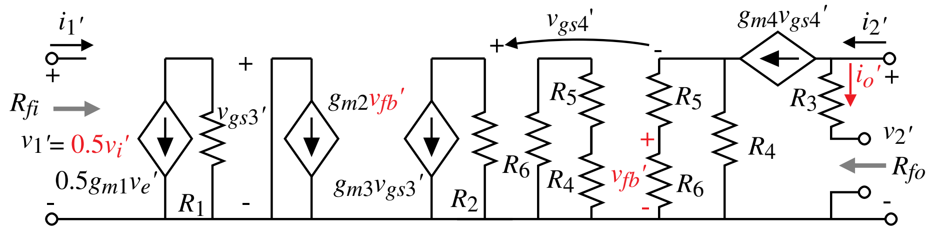

Fig. 270-10

$$a = \frac{i_o'}{v_i'} = \left(\frac{i_o'}{v_{gs4}'}\right)\left(\frac{v_{gs4}'}{v_{gs3}'}\right)\left(\frac{v_{gs3}'}{v_i'}\right) = (-g_{m4})\left(\frac{-g_{m3}R_2}{1+g_{m4}[R_4||(R_5+R_6)]}\right)\frac{-g_{m1}R_1}{2}$$

$$= (-1\text{mS})(-0.99)(-5) = -4.95\text{mS} \quad \Rightarrow \quad T = af = 4.5$$

5.) Input resistance, v_1/i_1.

$$R_i = \infty \;\rightarrow\; R_{if} = R_i(1+T) = 5.5\infty = \underline{\underline{\infty}}$$

Example 2 – Continued

6.) Voltage gain, v_2/v_1. First find i_o/v_i.

$$\frac{i_o}{v_i} = \frac{a}{1+af} = \frac{-4.95\text{mS}}{1+4.5} = -0.9\text{mS} \qquad (1/f = -1.1\text{mS})$$

$$\frac{v_2}{v_1} = \left(\frac{i_oR_3}{v_i}\right) = (-0.9\text{mS})(10\text{k}\Omega) = \underline{\underline{-9.0\text{V/V}}}$$

7.) Ouput resistance, v_2/i_2. However, since we have assumed that $r_{ds4} \approx \infty$, then

$$\frac{v_2}{i_2} = R_3||(R_{of} - R_3) = R_3||\infty = R_3 = \underline{\underline{10\text{k}\Omega}}$$

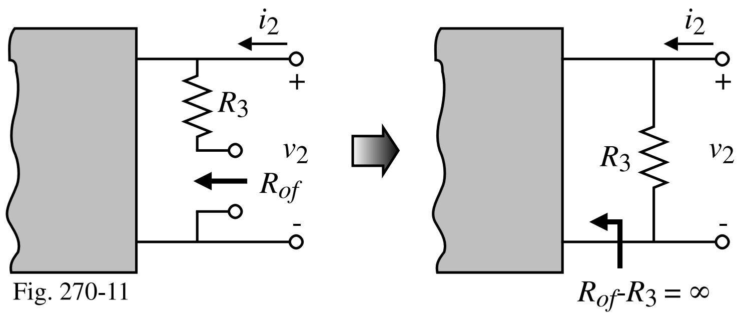

Fig. 270-11

(R_3 is not really inside the feedback loop and therefore is not influenced by the feedback.)

SUMMARY

- Series-series feedback increases both the input and output impedances
- If the mixing circuit is associated with the collector/drain (Example 1), then the output resistance designated as v_2/i_2 is found by finding R_{of} (which is the resistance *in series* with the output feedback loop) and using the following relationship,

$$\frac{v_2}{i_2} = R_L||(R_{of} - R_L)$$

- If the mixing circuit is associated with the emitter/source (Example 2), then the output resistance designated as v_2/i_2 is simply equal to R_L.
- Several useful points to emphasize:

  1.) If T >>1, then $A \approx 1/f$.

  2.) The product of a and f must always be positive for negative feedback

