Part 14: Application of feedback theory to amplifiers

Summary so far:

1. Negative feedback converts a high gain but poorly stabilised amp. Into one which is nearly ideal
   – having practically constant gain independent of source and load impedances

2. An ideal amplifier has R_{in}, R_{out} values which are either
   – ∞ (open circuit)
   – 0 (short circuit)

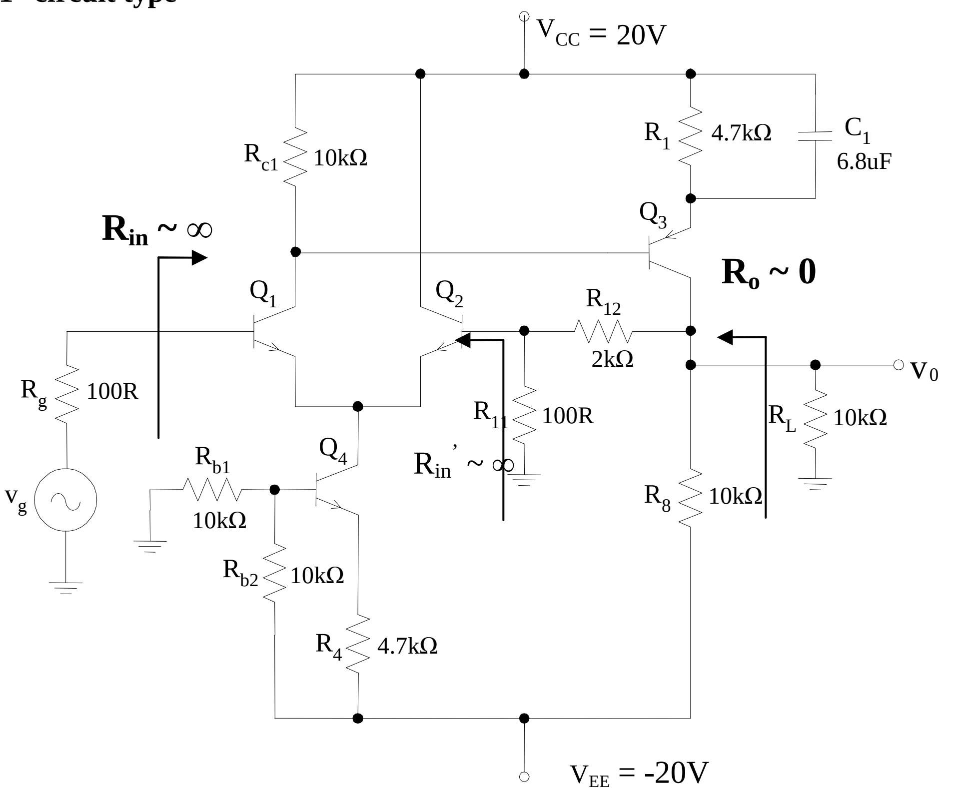
   THE FEEDBACK TOPOLOGY DETERMINES WHICH!

3. If the loop gain, $A_{ol}\,\beta$ is sufficiently large, then the closed loop gain, A is equal to 1/β:

   $\boxed{A_f \sim \frac{1}{\beta}}$ TO A GOOD APPROXIMATION

We will now apply these ideas to some real amplifier circuits and establish a simple method for finding the gain.

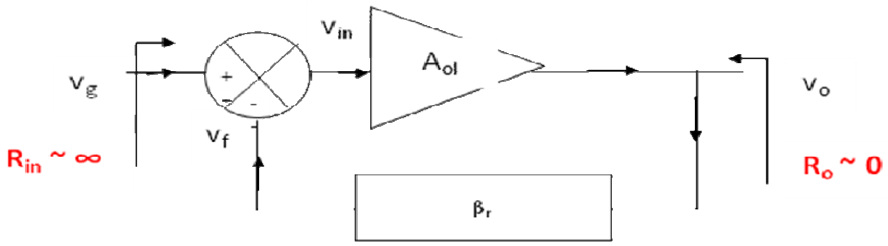
1st circuit type



Output sampling: ?
Input summing: ?

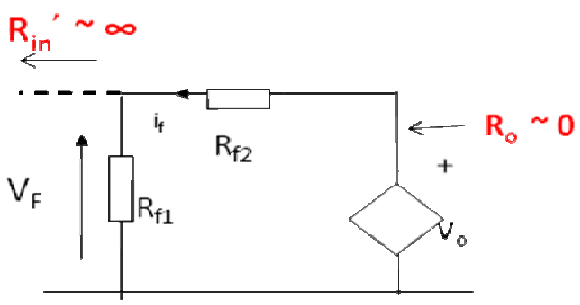
So amplifier type is: ?

Compare with figure below (arrows indicate paths of signals)



By symmetry, expect R_{in}' to be ∞.

Then can draw feedback circuit as shown



Then

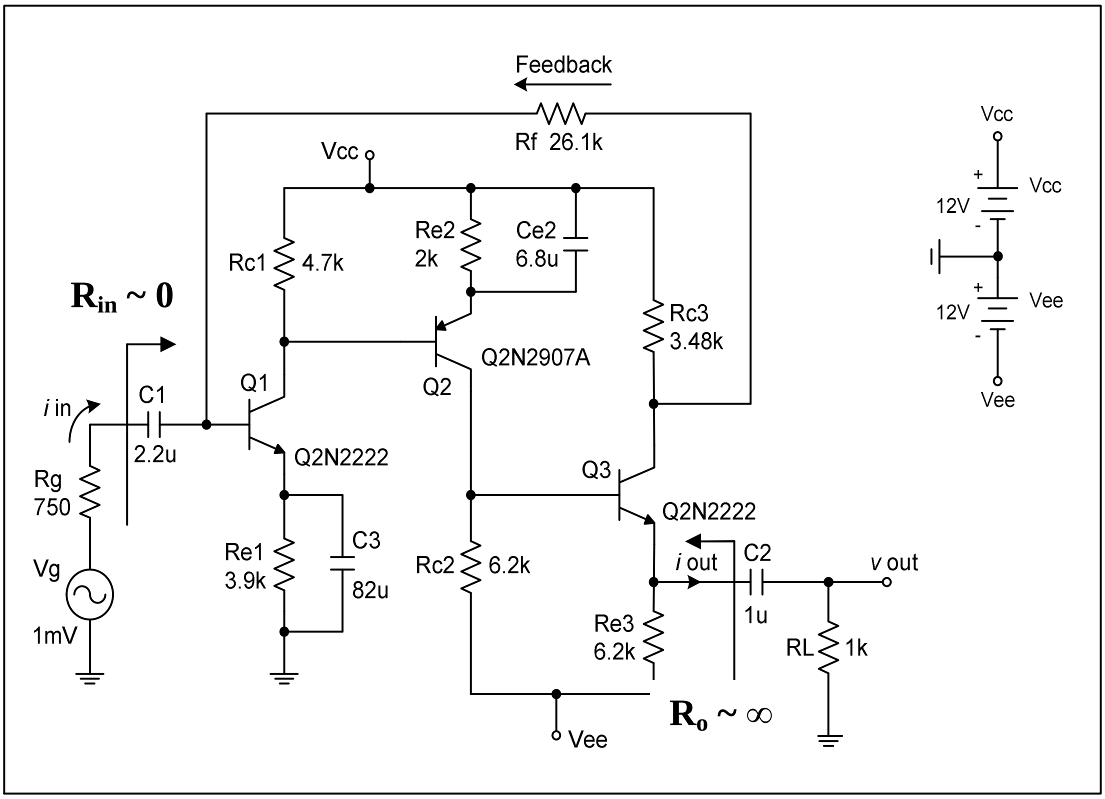
$$v_f = \frac{R_{f1}}{R_{f1} + R_{f2}} v_o$$

$$\beta_v = \frac{v_f}{v_o} = \frac{100}{100 + 2k} = \frac{1}{21}$$

$$\boxed{A_{fv} = \frac{v_o}{v_g} = \frac{1}{\beta_v} = 21}$$

Agrees very well with the PSPICE simulation result obtained in Part 10.

2nd circuit type

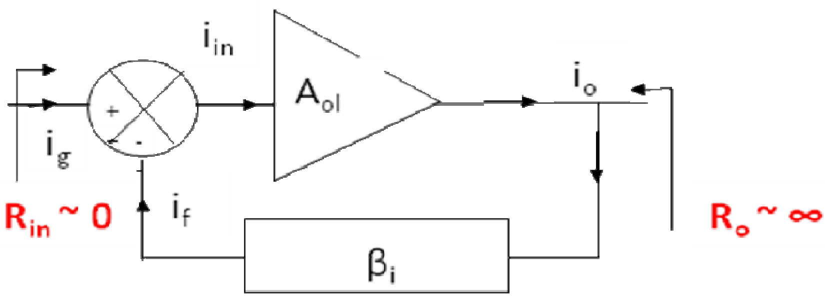


Output sampling: ?
Input summing: ?

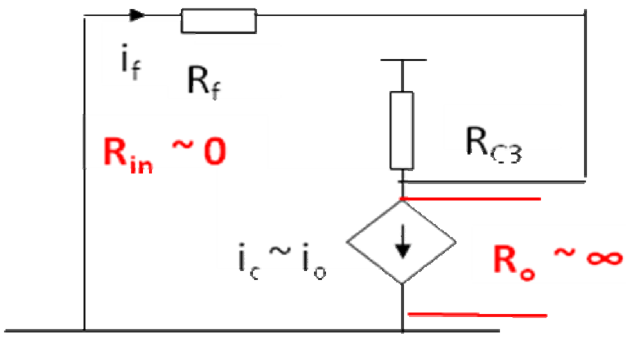
So amplifier type is: ?

So compare with:

(arrows indicate paths of signals)



Then can draw feedback circuit as shown opposite ($i_c \sim i_o$)



Then

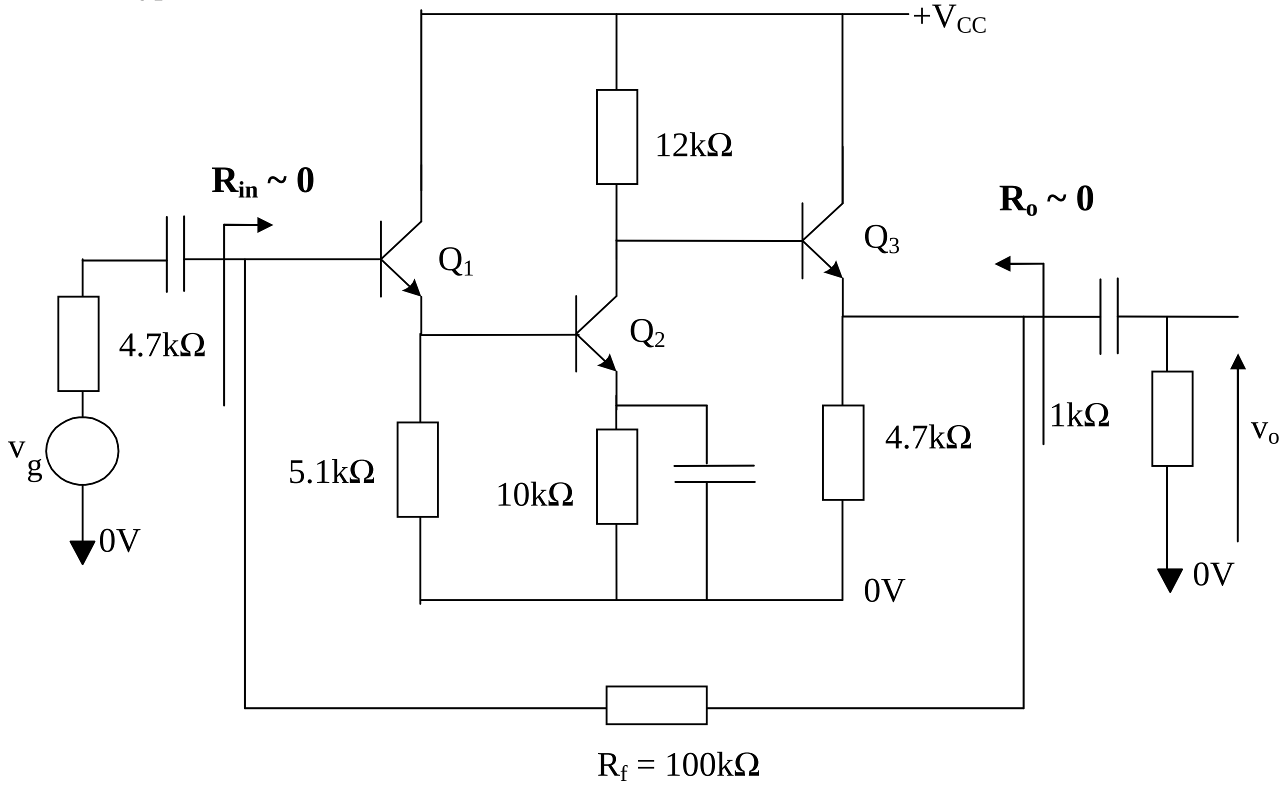
$$i_f = \frac{R_{C3}}{R_{C3} + R_f} i_o$$

$$\beta_i = \frac{i_f}{i_o} = \frac{3.48k}{3.48k + 26.1k} = \frac{1}{8.5}$$

$$\boxed{A_{fv} = \frac{i_o}{i_g} = \frac{1}{\beta_i} = 8.5}$$

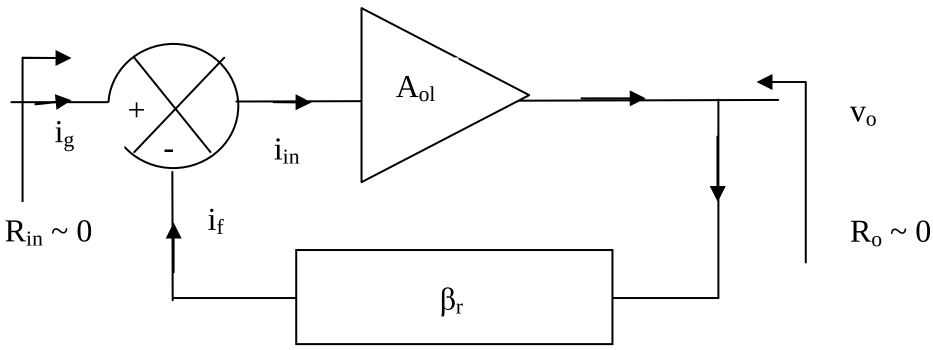
Compares well with SPICE (see part 11)

3rd circuit type



Voltage sensing at output, current summing at input – feedback stabilises a TRANS RESISTANCE AMPLIFIER

Compare the circuit with a negative feedback system:

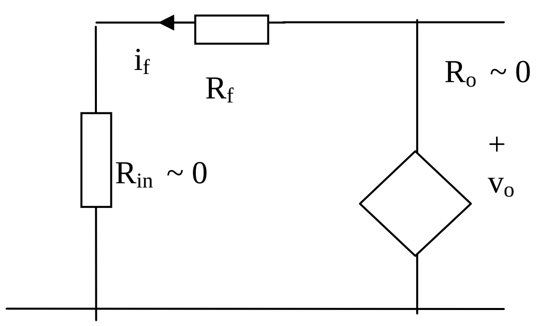


(arrows indicate signal path)

We need to find $\beta_r = \dfrac{i_f}{v_o}$; Can do this by considering the generic trans-R amplifier equivalent circuit as shown opposite:

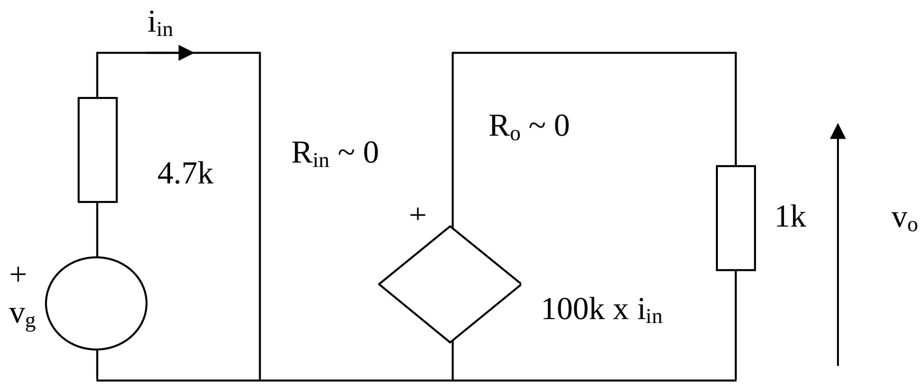
So $i_f = \dfrac{v_o}{R_f}$ and we get $\beta_r = \dfrac{i_f}{v_o} = \dfrac{1}{R_f} = \dfrac{1}{100k\Omega}$,

hence $A_{fr} \sim \dfrac{1}{\beta_r} = \dfrac{v_o}{i_g} = 100k\Omega$ **= trans-R gain**



What if we want to find the voltage gain of the transresistance amplifier?

Replace amplifier circuit schematic with ideal equivalent circuit of trans-R amplifier **system**:



Ideal transresistance amp has zero input resistance and zero output resistance as shown above.

$v_o = 100k i_{in}$ $\quad i_{in} = \dfrac{v_g}{4.7k}$ $\quad$ so $\quad A_V = \dfrac{v_o}{v_g} = \dfrac{100k}{4.7k} = 21.3$

PSPICE gives a voltage gain of 18.6… Agreement not as good as before.. Why

Possible reasons:

1. Forward path is EF, CE, EF; so A_{ol} may not be very big

   $A_{ol}\,\beta_r$ may not be big enough to make $A_{fr} \approx \dfrac{1}{\beta_r}$ a good approximation

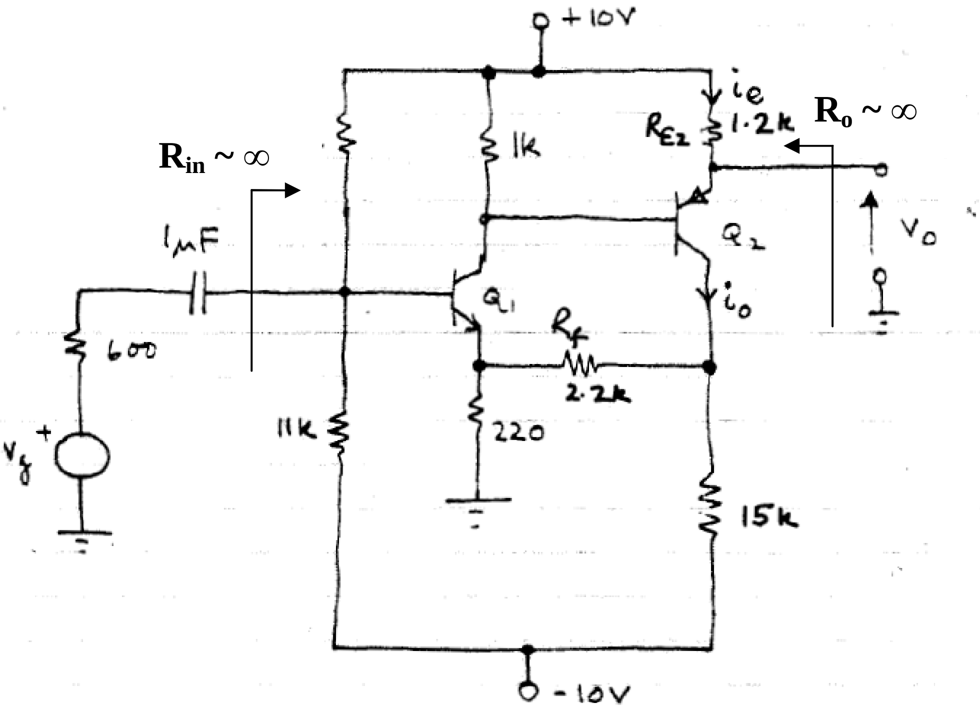
2. Negative feedback is trying to force $R_{in} \rightarrow 0$….

   … but input stage is EF which has a very high input resistance without feedback!

   bad! If we had started with a design having an input stage with a low input resistance then effect of NF would have been better…

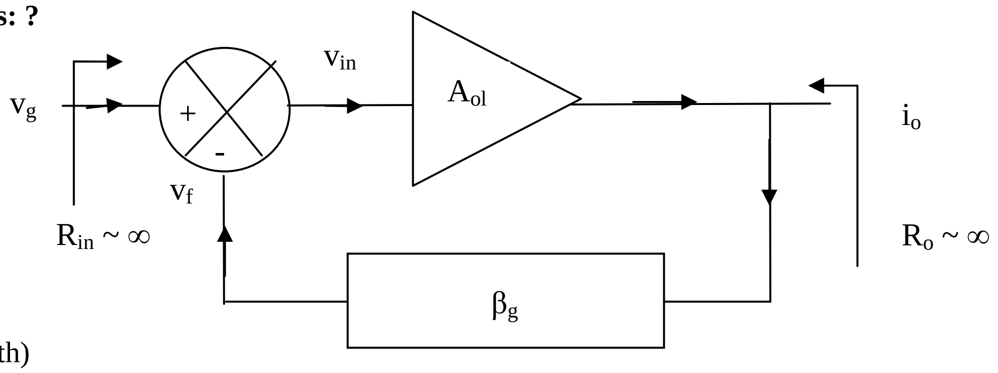
NB PSPICE gives R_{in} ~ 500R $\rightarrow \dfrac{v_o}{v_g} \sim 19.2$ using equivalent circuit - nearer to PSPICE value 0f 18.6!

4th circuit type



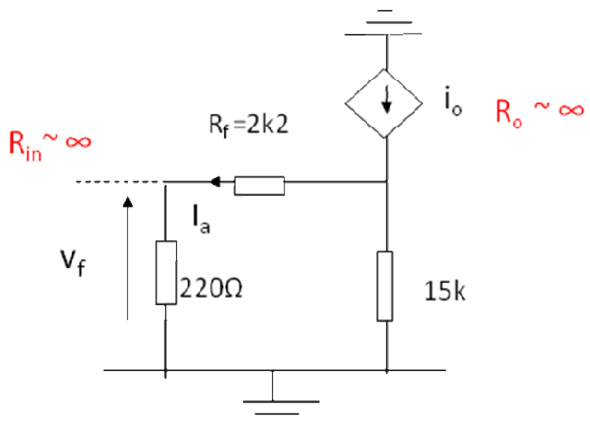
Output sampling: ?
Input summing: ?

So amplifier type is: ?



(arrows show signal path)

We need to find $\beta_g = \frac{v_f}{i_o}$; Can do this by considering the generic trans-G amplifier equivalent circuit:
(R_{in}' ~∞ as for amp.1)



$$i_a = \frac{15k}{15k + 2.2k + 220} i_o = 0.861 i_o$$

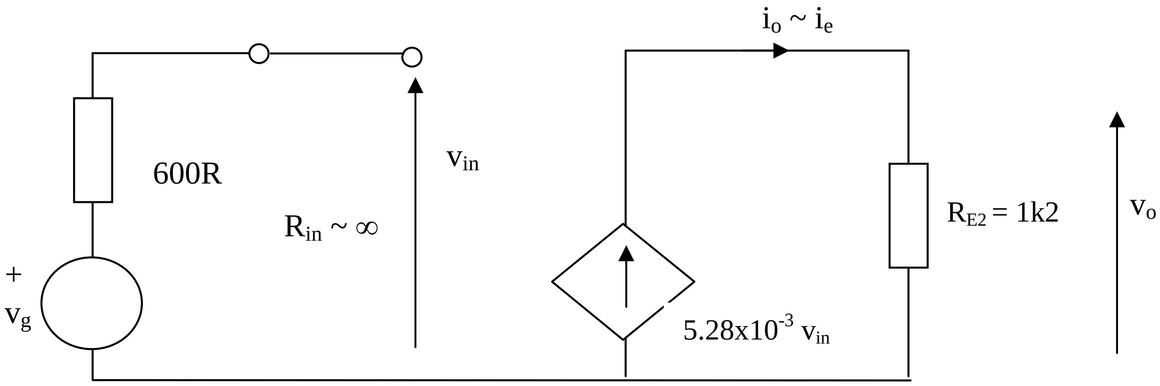
$$v_f = 220\Omega \times 0.861 i_o$$

$$\beta_g = \frac{v_f}{i_o} = 189.4\Omega$$

$$\boxed{A_{fg} = \frac{1}{\beta_g} = \frac{1}{189.4\Omega} = 5.28 mA/V}$$

What if we want to find the voltage gain of the transconductance amplifier?

Replace amplifier circuit schematic with ideal equivalent circuit of trans-G amplifier **system**:



Ideal trans-G amp has infinite input resistance and infinite output resistance as shown above.

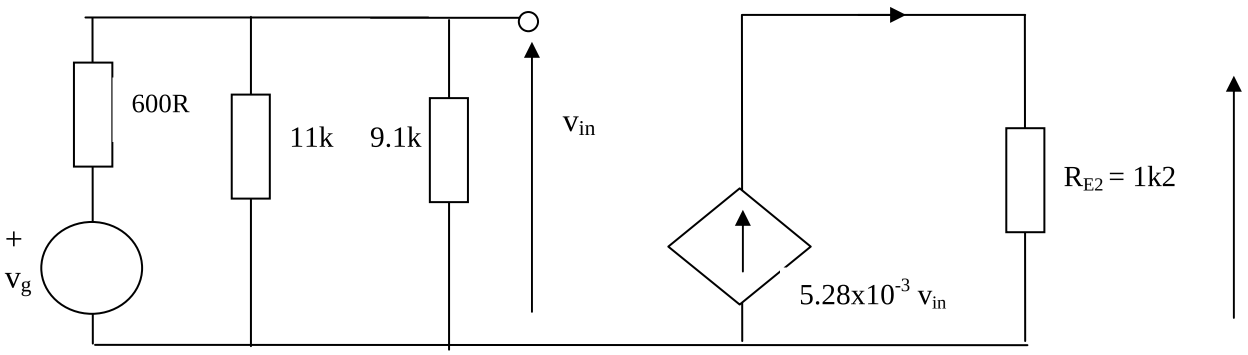
$v_o = 1.2k \times 5.20.10^{-3} v_{in}$ $\quad v_{in} = v_g$ $\quad$ so $\quad A_V = \frac{v_o}{v_g} = 6.34$

PSPICE gives a voltage gain of 2.15 – factor of 3 out! **Why??**

Reasons

1. **R_{in} is actually at base of Q_1** – where voltage summing occurs – so v_g is attenuated by base biasing resistors which are 'outside the feedback loop.'

∴ improved equivalent circuit is:



So that $v_{in} = \frac{11k // 9.1k}{11k // 9.1k + 600} v_g = 0.89 v_g$

And $\frac{v_o}{v_g} = 0.89 \times 6.34 = 5.64$ **-still too big!**

2**. LOOP GAIN is too small.** I calculated loop gain to be only 0.634 – certainly small!! – should be much bigger than 1 for our approximate formula $A_f \sim \frac{1}{\beta}$ to be accurate.

Can we use this value of loop gain to get a better estimate of gain?

$A_f = \frac{1}{\beta}\frac{A_{ol}\beta}{1+A_{ol}\beta}$ which we can also write as $A_f = A_\infty \frac{T}{1+T}$

T = loop gain ($A_{ol}\beta$) and A_∞ is the gain assuming T is large (ie infinite)

For our example, $A_{fg} = 5.28x10^{-3} \times \frac{0.634}{1+0.634}$ = $2.05x10^{-3}$ Siemens

This gives us $\frac{v_o}{v_g} = 0.89 \times 1.2k \times 2.05.10^{-3} = 2.19$

Compared with 2.15 from PSPICE

NB PSPICE has to invert a 6x6 matrix with complex coefficients to solve this problem.
Our 'back of the envelope' method is much simpler!

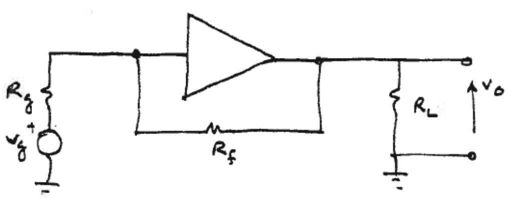
Conclusions

To calculate the approximate gain of an amplifier with feedback:

1. Determine the **topology** of the feedback network
2. Identify WHICH **ideal** amplifier is approximated: what are the ideal values for R_{in}, R_{out}
3. What form does $\beta = \frac{x_f}{x_o}$ take?
4. Calculate β (use R_{in} and R_{out} ideal values to help!)
5. Calculate A_f from $A_f \sim \frac{1}{\beta}$
6. Calculate the gain you require if it is not the gain stabilised by feedback by using the Ideal op-amp model (this assumes LOOP GAIN, T >> 1)

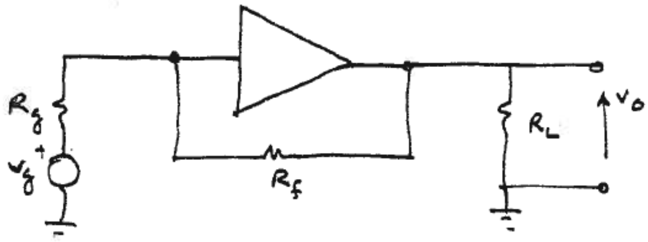
Worked Example

Calculate the voltage gain, v_o/v_g assuming that the loop gain is infinite.
Obtain a better estimate of the gain given that the loop gain is 15.
R_g = 1k, R_f = 10k, R_L =500R



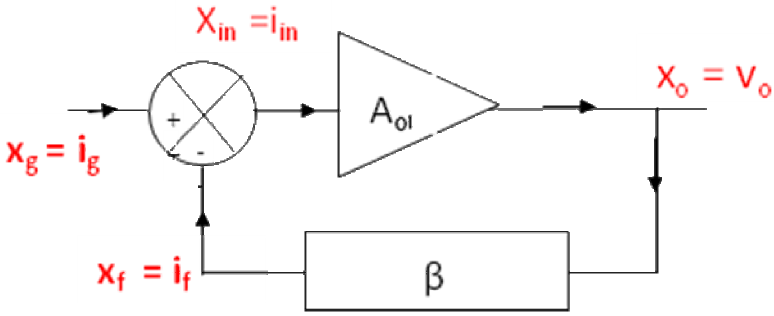
Solution

1. Feedback topology
   at output?
   at input?

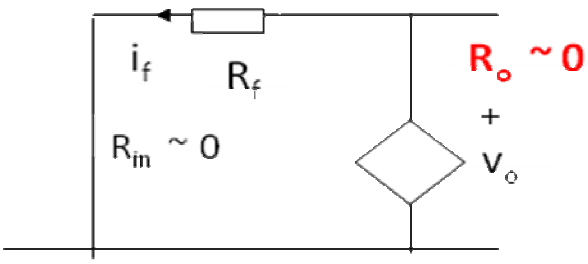


2. 'Ideal' (stabilised) amplifier?
   R_{in} = , R_o =

3. What from does β take?



4. Calculate β



5. A_f =

6. V_o / V_g

Obtain a better estimate of the gain given that the loop gain is 15.

Exercises

1. Apply the technique to the emitter-follower (common collector); that is, identify the feedback topology and the type of 'ideal' amplifier associated with the feedback. Then work out the voltage gain and compare with the result found in PART 2.

2. Undertake the same analysis as in (1) for the common emitter with emitter degradation.