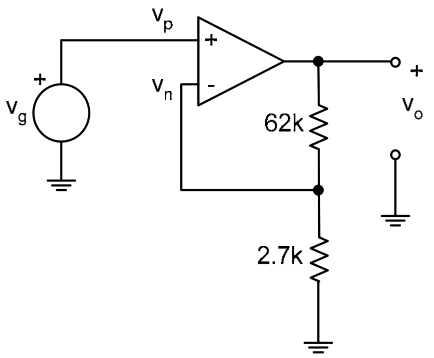
Part 18: Loop Gain

How to calculate its value <u>directly</u>

Consider:



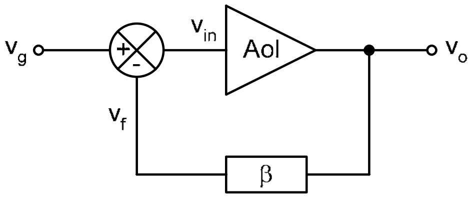
1. **V.S.P. Method** gives $v_n = v_p \equiv v_g$;

But $v_n = \dfrac{2.7k}{2.7k+62k} v_o = \dfrac{1}{24.0} v_o$

$$\therefore v_g = \frac{1}{24.0} v_o \quad or \quad \frac{v_o}{v_g} = 24.0$$

2. **Feedback Method** $A_f \cong \dfrac{1}{\beta}$

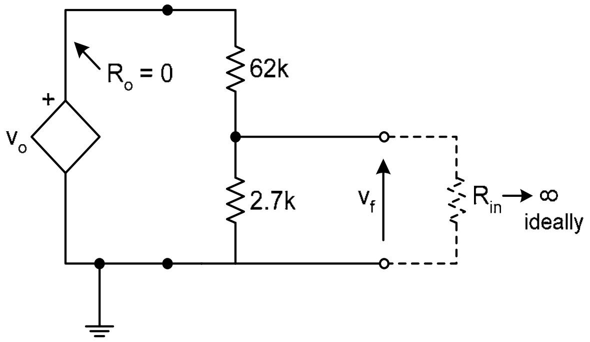
For this circuit; we have voltage **sensing** at output
voltage **summing** at input



$$A_{ol} = \frac{v_o}{v_{in}}$$

$$\beta = \frac{v_f}{v_o}$$

β can be found from



Thevenin equivalent of output

$$\therefore \beta = \frac{2.7k}{2.7k+62k} = \frac{1}{24.0}$$

Op-amp Neg. fdbk made $R_o \to 0$ ideally

$$\& \, A_f = \frac{v_o}{v_g} = \frac{1}{\beta} = 24.0 \text{ as before}$$

1st method assumes ideal op-amp with $A_{ol} = \infty$ (so $A_{ol}\,\beta >> 1$)

2nd Method $T = A_{ol}\,\beta >> 1$

What if T is not all that large? Feedback theory tells us that a **better estimate** of gain is

$$A_f = A_\infty \frac{T}{1+T}$$

Better estimate

Gain calculated using VSP or $\frac{1}{\beta}$

How do we find T?

If we know A_{ol} & β separately then easy BUT not always easy to find A_{ol} - especially for transistor circuits (rather than op-amps)

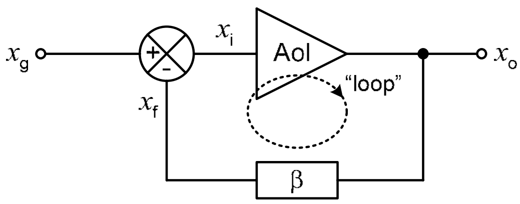
Better to find T directly

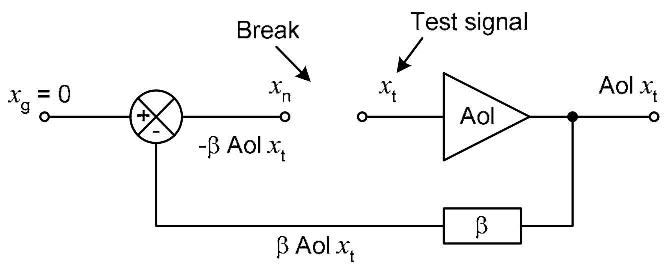
Method based on following

1) Suppress x_g (set at zero)

2) Break loop at some convenient point

3) Inject a test signal x_t





4) Trace round loop to find return signal x_r

$$x_r = -\beta A_{ol}\ x_t$$

Then we see that $\frac{x_r}{x_t} = -\beta A_{ol} = -T$

Or $T = -\left(\frac{x_r}{x_t}\right)_{\text{suppressed source}}$

Note

1) If $\frac{x_r}{x_t}$ is not negative, then feeddback is positive!

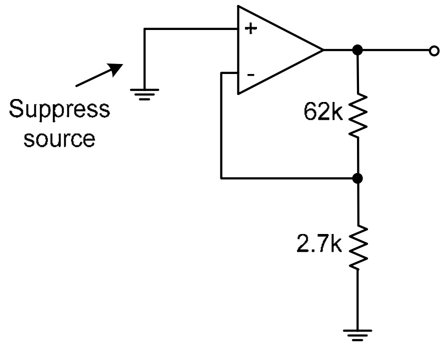
2) Doesn't matter where in the loop, the break is made (see 'Problems 1'; solutions on VITAL)

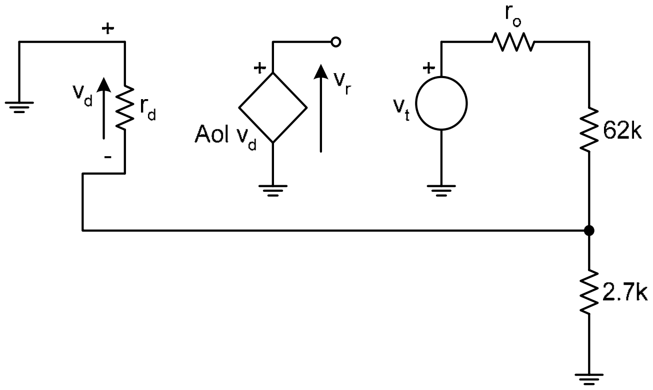
Application to non-inverting amplifier

1. Replace op-amp by equivalent circuit

2. Make break in circuit:
[best place to break loop is directly after a generator]

3. Inject test voltage v_t

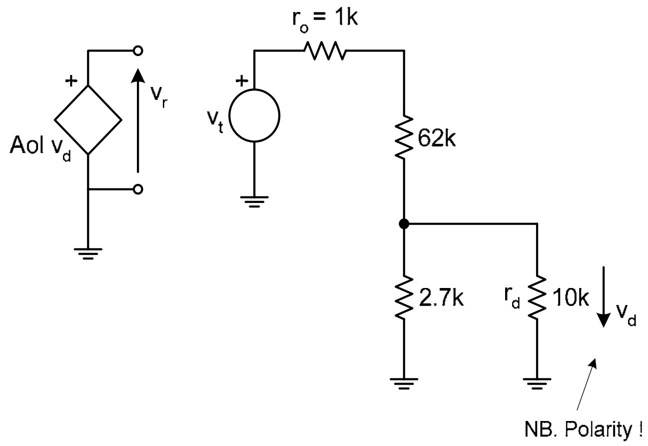




Now suppose $r_o = 1k\Omega; r_d = 10k\Omega; A_{ol} = 10^2$ **(not a very good op-amp!)**

Easier to see analysis by re-drawing above circuit,

then



$$v_d = -\frac{(2.7k \| 10k)}{2.7k \| 10k + 62k + 1k} \times v_t$$

$$= -\frac{2.126k}{65.126k} \times v_t = -\frac{1}{30.63} v_t$$

$$\therefore v_r = A_{ol}\, v_d = -\left(10^2 \times \frac{1}{30.63}\right) v_t \quad ie \frac{v_r}{v_t} = -3.264$$

That is, $T = 3.264$

(note earlier method would have given:

$$10^2 \times \frac{1}{24.0} = \text{ 4.167 – over-estimate!}$$

$\therefore$ A better estimate of gain of this circuit is $A_f = A_\infty \times \dfrac{T}{1+T} \qquad = 24.0 \times \dfrac{3.264}{1+3.364}$

$$\therefore {}^{v_o}\!/_{v_g} = 18.37$$

Conclusion:

our calculation of feedback fraction, β is only valid if T >> 1

We can now make a better estimate of R_{in}

$$R_{in} \cong r_d\left(1+T\right) \quad = \quad 10k \times 4.264 \quad = 42.64k$$

and $R_o \cong \dfrac{r_o}{1+T} = \dfrac{1k}{4.264} = 234.5\Omega$

Now repeat the example with $A_{ol} = 2\times10^5$ (typical value for 741 op-amp)

Performing the previous analysis again gives:

$$\left(\frac{v_r}{v_t}\right)_{\text{suppressed source}} = -8.33\times10^3$$

So feedback is negative and T = $8.33\text{x}10^3$

So a better estimate of the gain is:

$$\frac{v_o}{v_g} = 24.0\times\frac{8.33\times10^3}{1+8.33\times10^3} = 24.0$$

! ie approximation $A_f \equiv A_\infty \sim \dfrac{1}{\beta}$ is a good one!

Can also calculate $R_{in} = r_d\left(1+T\right) = 2\text{M}\Omega\times\left(1+8.33\times10^3\right)$

ie $\quad ie\, R_{in} = 16.6\times\ 10^9\ \Omega$ **- which is big! (as required for a V-amp)**

also, output resistance is

$R_o = \dfrac{r_o}{1+T} = \dfrac{75\Omega}{1+8.33\times10^3} = 9.00\times10^{-3}\ \Omega$ **- which is small! (as required for a good V-amp)**

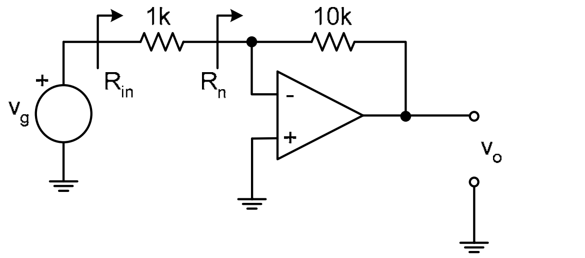
Note that feedback gives very high and very low values for R_{in} / R_o– depending on the topology!

Another Example

Inverting amplifier (recall it's a trans-resistance amp.)

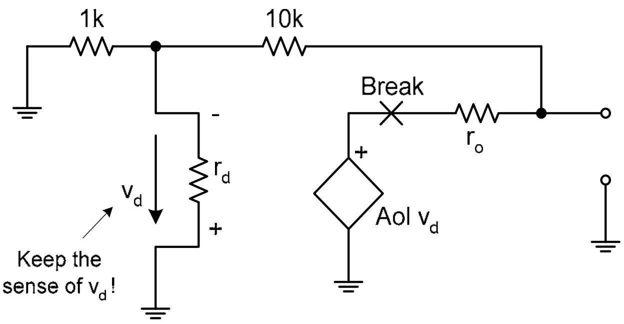
$$V.S.P. \rightarrow \frac{v_o}{v_g} = -\frac{10k}{1k} = 10$$

With 180^o phase shift

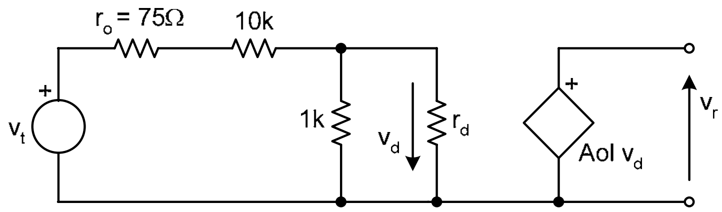


Loop gain?

Suppress source and use equiv. circuit



Break loop and apply v_t to produce circuit shown below



$$1k \| r_d \cong 1k \qquad A_{ol} = 2\times10^5$$

$$v_d = -\frac{1k}{1k\ 10k+75} v_t = -\frac{1}{11.075} v_t$$

$$\therefore \frac{v_r}{v_t} = 2\times10^5 \times -\frac{1}{11.075}$$

$$= -1.806\times10^4$$

So feedback is negative and loop gain is $T = 1.806\times10^4$

$$\left(\frac{v_o}{v_g}\right)_{better\,estimate} = -10\times\frac{1.806\times10^4}{1+1.806\times10^4} = -10$$

(as expected because T is so large)

$R_o = \frac{r_o}{1+T} 4.15\times10^{-3}\Omega$ - small! - as expected

$R_n = \frac{10k}{1+A_{ol}} = 0.05\Omega$ - small! - as expected (because the feedback makes it an 'ideal' transresistance amplifier)

So $R_{in} = 1k$ + R_n ~ 1k – ie R_{in} is set by the external resistor!