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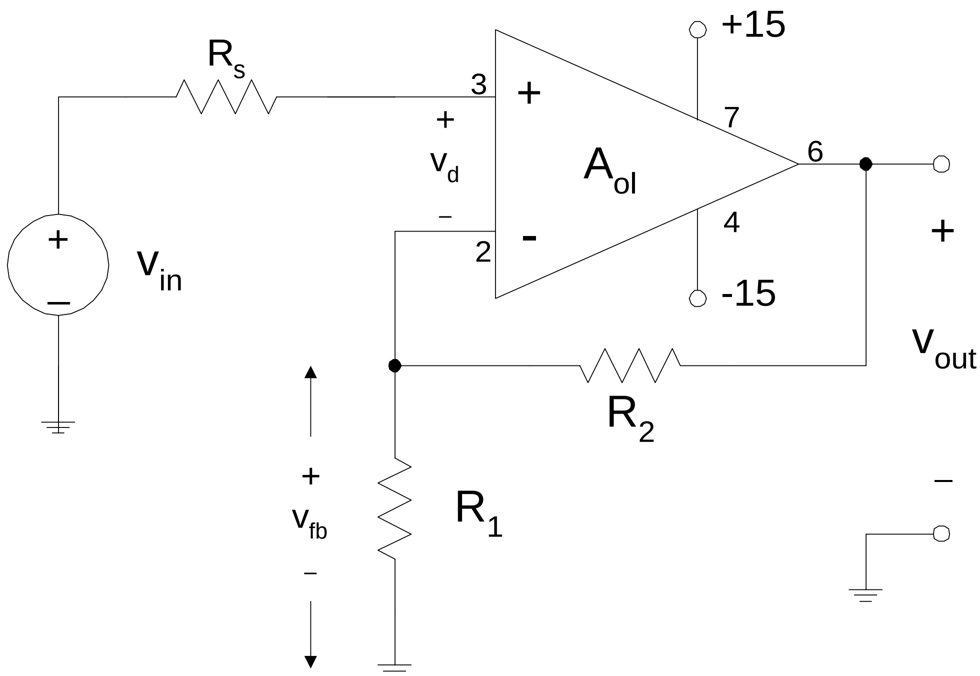
FEEDBACK



SERIES-SHUNT FEEDBACK [NON-INVERTING AMPLIFIER]

Derivation of voltage gain as a function of the open-loop gain and the feedback factor. Assume $R_s = 0$.

$$v_{out} = A_{ol} \times v_d$$

$$v_{fb} = \beta \times v_{out}$$

$$v_{in} = v_d + v_{fb}$$

$$v_{in} = \frac{v_{out}}{A_{ol}} + \beta \times v_{out}$$

$$\frac{v_{in}}{v_{out}} = \frac{1}{A_{ol}} + \beta$$

$$A_{ol} \times \frac{v_{in}}{v_{out}} = 1 + \beta A_{ol}$$

$$\frac{v_{in}}{v_{out}} = \frac{1 + \beta A_{ol}}{A_{ol}}$$

$$\frac{v_{out}}{v_{in}} = \frac{A_{ol}}{1 + \beta A_{ol}};$$

$$if \quad \beta A_{ol} >> 1, \qquad then: \qquad \frac{v_{out}}{v_{in}} = \frac{1}{\beta}$$

$$\left(1 + \beta A_{ol}\right) is\ known\ as\ the\ feedback\ factor$$

$$\beta = \frac{R_1}{R_1 + R_2}; \qquad \frac{1}{\beta} = \frac{R_1 + R_2}{R_1} = 1 + \frac{R_2}{R_1}$$

If, at some frequency, the magnitude of A_{ol} falls to 10,000, and you expect a closed loop gain of 1000 from the amplifier (β=.001, 1/β=1000=10^3=60dB), the actual closed loop gain will be:

$$\frac{v_{out}}{v_{in}} = \frac{A_{ol}}{1 + \beta A_{ol}} = \frac{10^4}{1 + 10^{-3} \times 10^4} = \frac{10^4}{11} = 909 = 59.2dB$$

In general, the series connection raises amplifier characteristics by the amount of the feedback factor; the shunt connection reduces amplifier characteristics by the amount of the feedback factor. Therefore, at this certain frequency where ($1+\beta A_{ol}$)=11, **for this amplifier configuration,** the input impedance will be 11 times higher than the input impedance of the opamp without feedback, and the output impedance will be 11 times lower than the output impedance of the opamp without feedback. The bandwidth of the amplifier is increased by a factor of 11, and of course, the open loop gain is decreased by a factor of 11. Considering the open-loop gain bandwidth plot of a 741, it is easy to see that building an amplifier with a gain of 1000 at low frequencies using a 741 is a foolish endeavor, since increasing the bandwidth 11 times only moves the upper 3dB point from 10 Hz to about 110 Hz.!!!

Using the normal, typical low frequency A_{ol} for the 741 = 100,000, the feedback factor would become 101 for this 60 dB amplifier, so now we would be able to increase our high frequency rolloff point out to about 1000 Hz!!!

For this shunt-series connection, feedback always stabilizes voltage gain, raises input impedance and lowers output impedance, all by $[1+\beta A_{ol}]$. Thus, this configuration is an ideal voltage amplifier or voltage source.

THE GOLDEN RULES OF OP-AMPS

(From Horowitz & Hill, page 177)

1. Assuming the op-amp voltage is so high that a fraction of a millivolt between the input terminals will swing the output over its full range, we can ignore that small voltage and state golden rule one:

The output attempts to do whatever is necessary to make the voltage difference between the inputs zero.

Note: This does not mean that the op-amp actually changes the voltage at its input. What it does is "look" at its input terminals and swing its output terminal around so that the external feedback network brings the input differential to zero whenever possible.

2. Assuming that op-amps draw very little input current (nanoamps to picoamps), we round this down and state:

The inputs draw no current.

Note: They must have some DC current or the op-amp won't work, so a corollary to this rule is that you must ALWAYS provide a DC current path to both inputs.

BENEFITS OF FEEDBACK

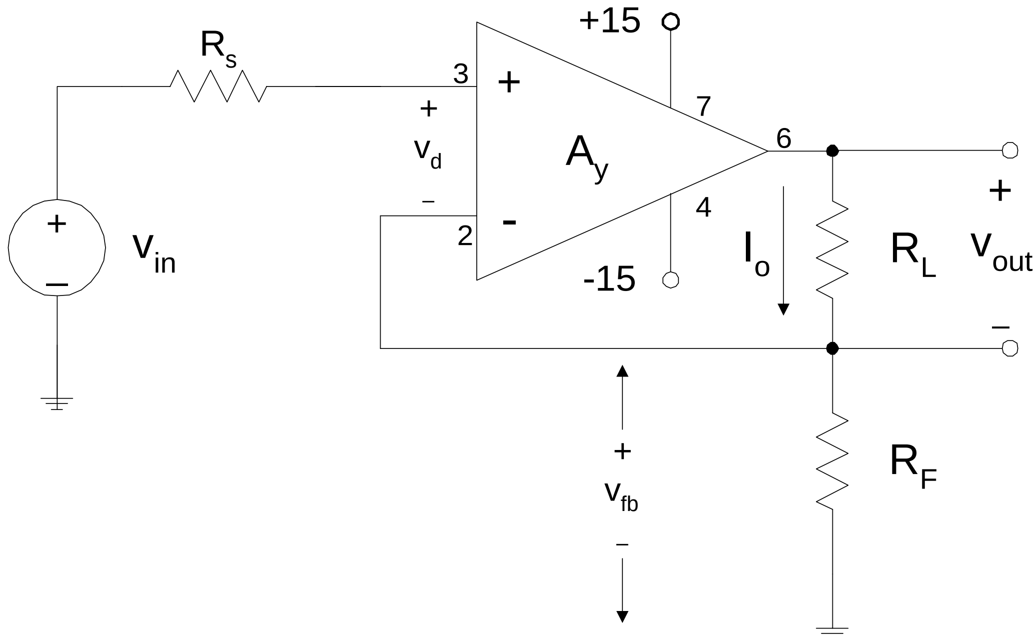
STABILIZE GAIN AGAINST DEVICE VARIATIONS, TEMPERATURE, AGING	REDUCE DISTORTION BY THE FEEDBACK FACTOR $[1+\beta A_{ol}]$
MANIPULATE INPUT AND OUTPUT IMPEDANCES BY FEEDBACK FACTOR $[1+\beta A_{ol}]$	INCREASE BANDWIDTH BY THE FEEDBACK FACTOR $[1+\beta A_{ol}]$

TYPICAL FEEDBACK FACTOR FOR 741 $[A_{ol} = 100{,}000]$

A=60 dB =1000; β=0.001; $[1+\beta A_{ol}]$ = 101	A=40 dB =100; β=0.01; $[1+\beta A_{ol}]$ = 1001
A=20 dB = 10; β=0.1; $[1+\beta A_{ol}]$ = 10,001	A=10 dB = 3.16; β=0.32; $[1+\beta A_{ol}]$ = 31,622
A=0 dB = 1; β=1; $[1+\beta A_{ol}]$ = 100,001	

DISADVANTAGES OF FEEDBACK

LOSS OF GAIN; NEED MORE STAGES	GREATER TENDENCY TO OSCILLATE



SERIES-SERIES FEEDBACK [NON-INVERTING AMPLIFIER, FLOATING LOAD, HIGH OUTPUT IMPEDANCE]

$$v_{in} = v_d + v_{fb}$$

$$v_d = \frac{i_o}{A_y}$$

$$v_{fb} = i_o R_F;$$

$$\therefore v_{in} = \frac{i_o}{A_y} + i_o R_F = i_o\left(\frac{1}{A_y} + R_F\right)$$

$$\frac{v_{in}}{i_o} = \left(\frac{1}{A_y} + R_F\right)$$

$$\frac{A_y v_{in}}{i_o} = 1 + A_y R_F;\ \textit{inverting}:$$

$$\frac{i_o}{v_{in}} = \frac{A_y}{1 + A_y R_F} \approx \frac{1}{R_F}$$