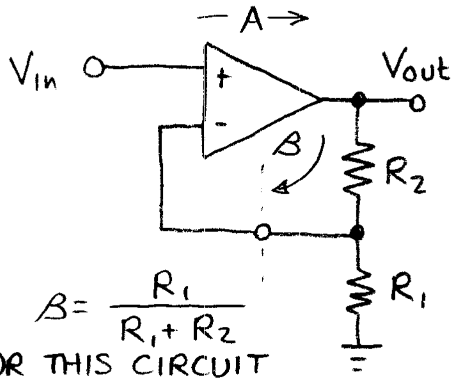
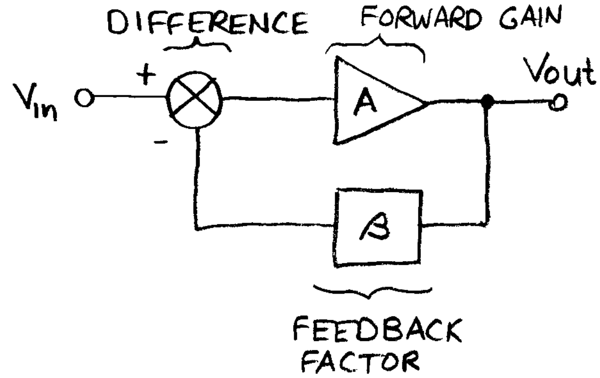
OP-AMP AS A CLASSICAL FEEDBACK SYSTEM

OP-AMP CIRCUIT:



$$\beta = \frac{R_1}{R_1 + R_2}$$
FOR THIS CIRCUIT

CLASSICAL FEEDBACK:



β: "FEEDBACK FACTOR" FRACTION OF V_{out} FED BACK TO V_-

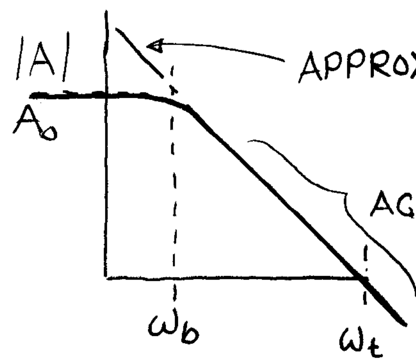
FIND CLOSED LOOP GAIN $G = \frac{V_{out}}{V_{in}}$

$$V_{out} = A\left(V_{in} - \beta V_{out}\right) \Rightarrow \boxed{\frac{V_{out}}{V_{in}} = \frac{A}{1 + A\beta} = G}$$

✓AS EXPECTED $G \to \frac{1}{\beta}$ AS $A \to \infty$

WHAT IS CLOSED LOOP GAIN G WHEN A IS FINITE?
REAL OP-AMP HAS SINGLE POLE TRANSFER FUNCTION

$$A = A(s) = \frac{A_0}{1 + \frac{s}{\omega_b}}$$



APPROXIMATE WITH $A(s) \approx \frac{\omega_t}{s}$

AGREES WELL FOR $\omega > \omega_b$, AROUND ω_t

SUBSTITUTE IN G EXPRESSION

$$G = \frac{A}{1 + A\beta} = \frac{\frac{\omega_t}{s}}{1 + \beta\frac{\omega_t}{s}}$$

} MULTIPLY NUM, DEN BY $\frac{s}{\beta\omega_t}$

MASSAGE INTO GENERAL FIRST ORDER FORM

$$G = \frac{[\text{DC GAIN}]}{1 + \frac{s}{[\omega_{3dB}]}}$$

$$G = \frac{\frac{\omega_t}{s} \frac{s}{\beta \omega_t}}{\left(1 + \beta \frac{\omega_t}{s}\right) \frac{s}{\beta \omega_t}} \Rightarrow \boxed{\frac{\overbrace{\frac{1}{\beta}}^{\text{DC GAIN}}}{1 + \frac{s}{\underbrace{\beta \omega_t}_{\text{CLOSED LOOP BANDWIDTH } \omega_{3dB}}}}}$$

GAIN-BANDWIDTH TRADEOFF!:

WHEN WE CHOOSE A FEEDBACK FACTOR β (FRACTION <1)

TO GET A CLOSED LOOP DC GAIN OF $\frac{1}{\beta}$

CLOSED LOOP BANDWIDTH ω_{3dB} IS $\beta \omega_t$

UNITY GAIN FREQUENCY ω_t REDUCED BY β FACTOR

INVERSE RELATIONSHIP: PRODUCT IS CONSTANT

$$\begin{bmatrix} \text{CLOSED LOOP} \\ \text{GAIN} \end{bmatrix} \times \begin{bmatrix} \text{CLOSED LOOP} \\ \text{BANDWITH} \end{bmatrix} = \begin{bmatrix} \text{GAIN-BANDWIDTH} \\ \text{PRODUCT} \end{bmatrix}$$

$$\frac{1}{\beta} \qquad \underbrace{\beta \omega_t}_{\omega_{3dB}} \qquad \underbrace{\omega_t}_{\text{UNITY GAIN FREQUENCY}}$$

FOR LM741, $f_t = 1$ MHz

FOR LF356, $f_t = 4$ MHz

GRAPHICALLY