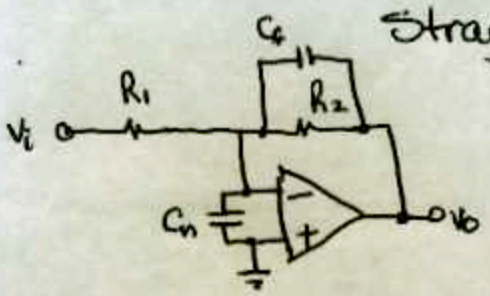
Stray Capacitance - Stability



$$a \simeq -j\, f_t/f$$

$$\beta = \frac{Z_1}{Z_1+Z_2} \; ; \; Z_1 = \frac{R_1/sC_n}{R_1 + 1/sC_n} = \frac{R_1}{1+sC_nR_1}$$

$$Z_2 = \frac{R_2/sC_f}{R_2 + 1/sC_f} = \frac{R_2}{sC_fR_2+1}$$

$$\beta = \frac{Z_1}{Z_1+Z_2} = \frac{R_1/1+sC_nR_1}{\frac{R_1}{1+sC_nR_1} + \frac{R_2}{sC_fR_2+1}} = \frac{R_1}{R_1 + \frac{R_2(1+sC_nR_1)}{1+sC_fR_2}}$$

$$= \frac{R_1(1+sC_fR_2)}{R_1(1+sC_fR_2) + R_2(1+sC_nR_1)}$$

$$= \frac{R_1(1+sC_fR_2)}{R_1+R_2 + s(C_f+C_n)R_1R_2}$$

$$= \frac{R_1}{R_1+R_2} \; \frac{1+sC_fR_2}{1+s(C_n+C_f)(R_1||R_2)}$$

$$\omega_1 = \frac{1}{C_fR_2} \; ; \; \omega_2 = \frac{1}{(C_n+C_f)(R_1||R_2)}$$

at $s \to 0$ $\quad \beta = R_1/R_1+R_2$

at $s \to \infty$ $\quad \beta(\infty) = \frac{\cancel{R_1}}{\cancel{R_1+R_2}} \; \frac{C_f\cancel{R_2}}{(C_n+C_f)\frac{\cancel{R_1R_2}}{\cancel{R_1+R_2}}}$

$$\beta(\infty) = \frac{1}{1+C_n/C_f}$$

$$\frac{1}{\beta(\infty)} = 1 + C_n/C_f$$

Analytica approach

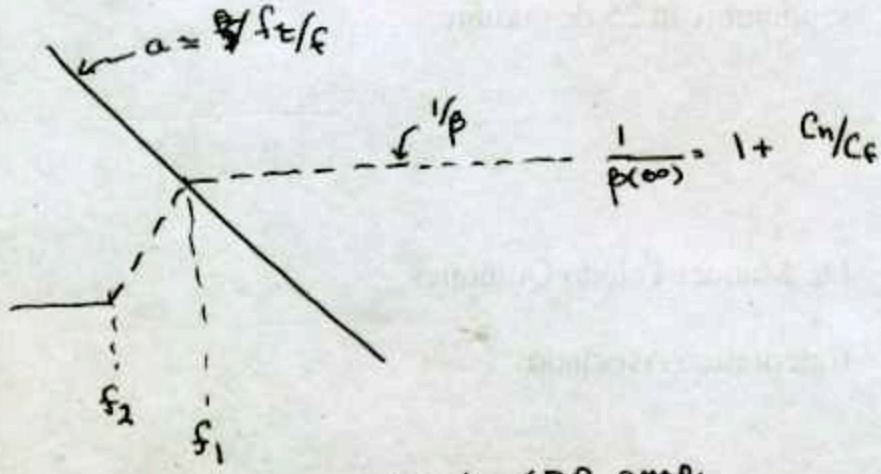
$$|T| = \frac{f_t}{f_x} \frac{\sqrt{(\omega_x/\omega_1)^2 + 1}}{\sqrt{(\omega_x/\omega_2)^2 + 1}} = 1 \qquad (\text{at } \omega = \omega_x)$$

$$\left(\frac{\omega_x}{\omega_1}\right)^2 + 1 = \left(\frac{\omega_x}{\omega_2}\right)^2 \left(\left(\omega_x/\omega_2\right)^2 + 1\right)$$

$$\phi = -90 - \tan^{-1}\left(\frac{f_x}{f_2}\right) + \tan^{-1}\left(f_x/f_1\right)$$

In theory these equations could be used to select C_f, but the process is cumbersome and difficult.

Graphical approach



Since the opamp is a constant GBP amp.

$$f_1\left(1 + C_n/C_f\right) = f_t$$

$$f_1 = \frac{1}{2\pi R_2 C_f} = \frac{C_f f_t}{C_n + C_f}$$

$$\frac{C_n + C_f}{2\pi R_2 f_t} = C_f^2$$

we have a quadratic in C_f

$$C_f^2 - \frac{1}{2\pi R_2 f_t} C_f - \frac{C_n}{2\pi R_2 f_t} = 0$$

$$C_f = \frac{-B \pm \sqrt{B^2 - 4AC}}{2A}$$

Since C is neg. only the + sign makes physical sence.

$$C_f = \frac{\frac{1}{2\pi R_2 f_t} + \sqrt{\frac{1}{4\pi^2 R_2^2 f_t^2} + \frac{4C_n}{2\pi R_2 f_t}}}{2}$$

$$= \frac{1 + 2\pi R_2 f_t \sqrt{\frac{1}{4\pi^2 R_2^2 f_t^2} + \frac{4C_n}{2\pi R_2 f_t}}}{4\pi R_2 f_t}$$

$$\boxed{C_f = \frac{1 + \sqrt{1 + 8\pi R_2 f_t C_n}}{4\pi R_2 f_t}}$$

This choice of C_f should give $\phi_m = 45^\circ$

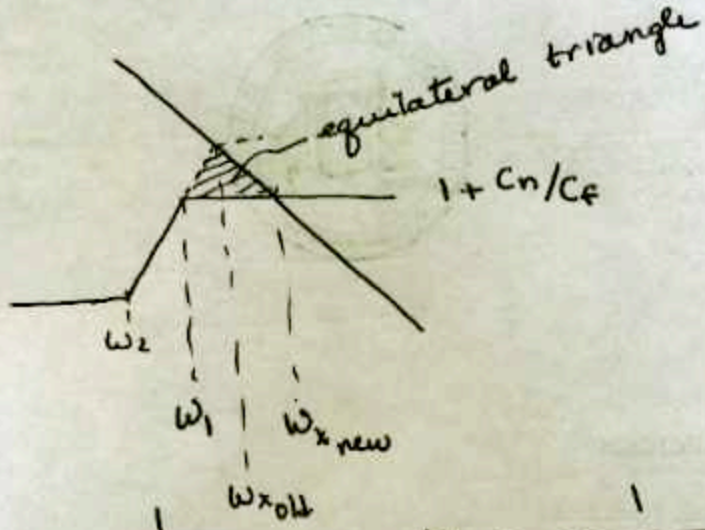
<u>Example:</u> $f_t = 1MHz$, $C_n = 16nF$, $R_1 = R_2 = 30K\Omega$

$$C_f = \frac{1 + \sqrt{1 + 8\pi(30k)(10^6)(16)(10^{-9})}}{4\pi(30k)(10^6)}$$

$$C_f = 293.77pF$$

See simulation "stray-cir"

How do you select C_f to get $65° = \phi_m$



$$\omega_1 = \frac{1}{C_f R_2} \qquad \omega_2 = \frac{1}{(C_n + C_f)(R_1 \| R_2)}$$

we want $\phi_m = 65°$. The pole (in $1/\beta$) must provide this many degrees at $\omega_{x\,new}$

$$\tan^{-1}(\omega_x/\omega_1) = 65°$$

$$\omega_{x\,new} = \omega_1 \tan 65°$$

Since we have the equilateral triangle and a logarithmic scale in freq.

$$\frac{\log \omega_1 + \log \omega_{x\,new}}{2} = \log \omega_{x\,old}$$

↳ the one we get for $\phi_m = 45°$

$$\omega_{x\,old} = \frac{1}{R_2 C_{f\,old}} = \sqrt{\omega_1 \omega_{x\,new}}$$

$$= \omega_1 \sqrt{\tan 65°}$$

$$= \frac{1}{(30k)(294\,pF)} = 2\pi(18)\,krps$$

$$\omega_1 = \frac{2\pi(18k)\,rps}{\sqrt{\tan 65°}} = 2\pi(12.3\,kHz)$$

$$\omega_x = 2\pi(12.3\,\text{kHz})(\tan 65^\circ) = (26.4\,\text{kHz})2\pi$$

$$C_f = \frac{1}{R_2\omega_1} = \frac{1}{(30k)(12.3)(10^3)(2\pi)}$$

$$\boxed{C_f = 431\,\text{pF}}$$

See second simulation "stray-phim-65.cir"