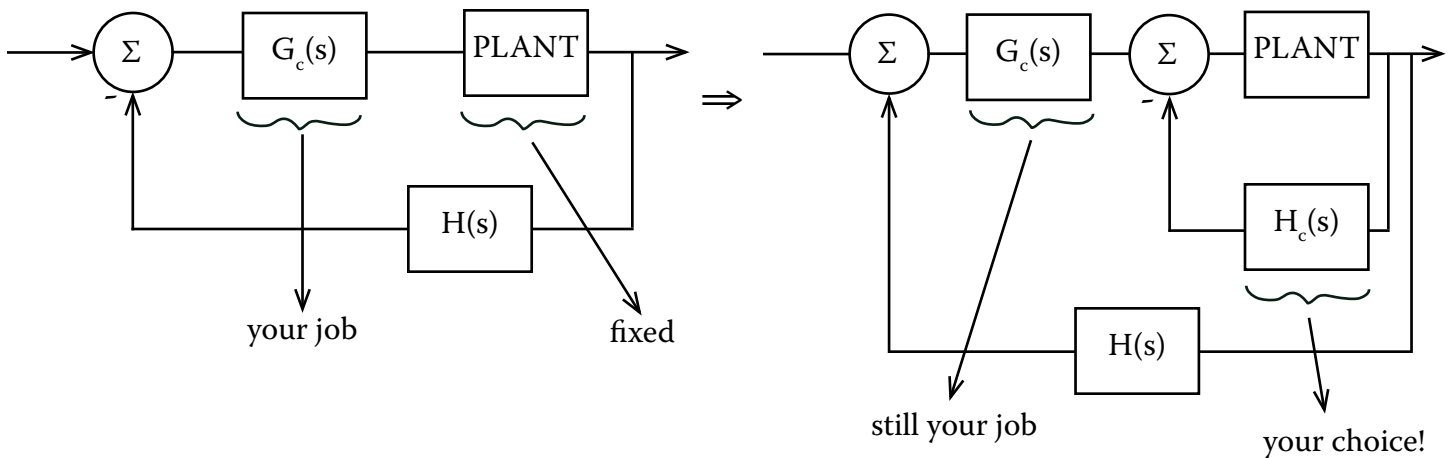# 6.302 Feedback Systems
Recitation 18: Minor Loop Feedback
Prof. Joel L. Dawson

What is going on here? Why are we even thinking about yet another compensation technique? After all, one suspects that being able to arbitrarily place poles and zeros, as we do for series compensation, should be enough to accomplish <u>anything</u>.

True, in principle. In practice, though, sometimes it is easier to close a minor loop than it is to implement a series compensation network. And minor loop compensation has one extremely compelling advantage that should make us give it a second look: it offers the possibility of changing the plant!



Over frequencies of interest, you can make the plant look like $\dfrac{1}{H_c(s)}$ .

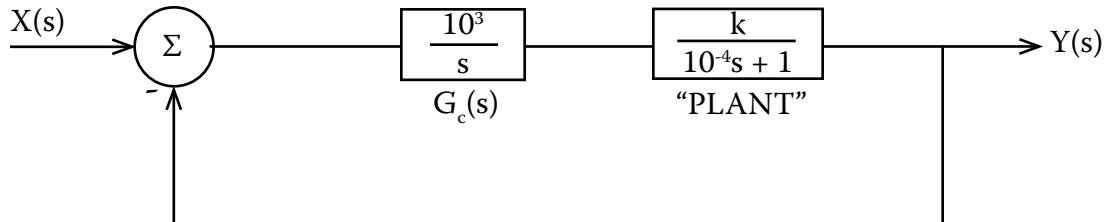A nice degree of freedom. Let's see if we can take advantage.

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CLASS EXERCISE: "Why minor loop compensation might help."

Consider the following feedback system.

X(s) →　Σ →　$\frac{10^3}{s}$ →　$\frac{k}{10^{-4}s + 1}$ →　Y(s)

　　　$G_c(s)$　　"PLANT"

The problem is that k can range anywhere from $10^1$ to $10^2$! Calculate the phase margin and loop crossover frequency at the two extremes.

So we see here that variation in the plant makes things hard. To account for the variation, we wind up needing to choose $G_c(s)$ such that we get a sufficiently low crossover frequency.

But what do we have that naturally supresses variation? Feedback, of course! Consider the following minor loop, and the corresponding change in $G_c(s)$:

X(s) + → Σ → $\frac{10^4}{s}$ → + Σ → $\frac{k}{10^{-4}s + 1}$ → Y(s)
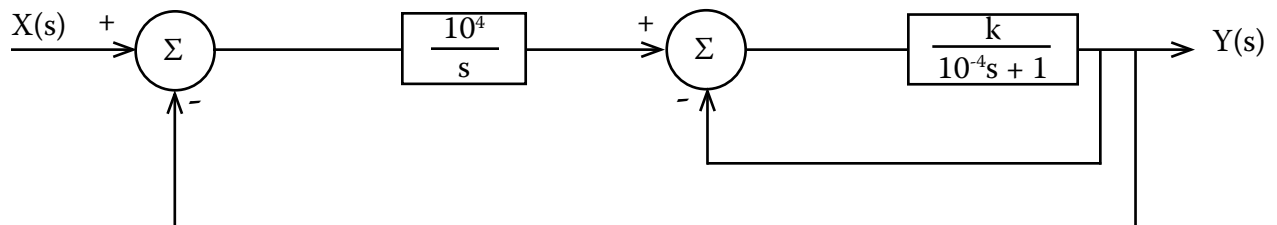
If we approximate $1 + k$ as just k, our system now looks like
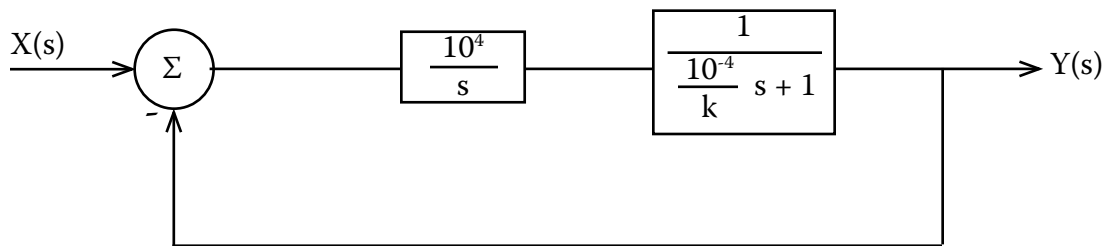
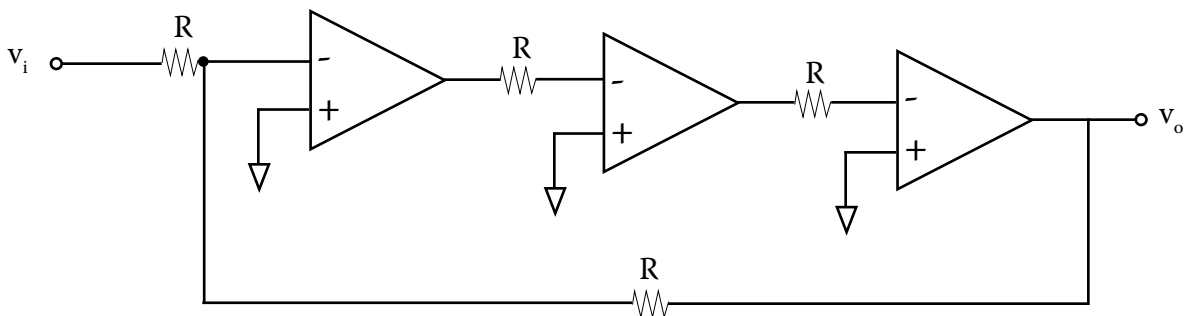X(s) → Σ → $\frac{10^4}{s}$ → $\frac{1}{\frac{10^{-4}}{k} s + 1}$ → Y(s)

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Now let's compute phase margins and $\omega_c$'s
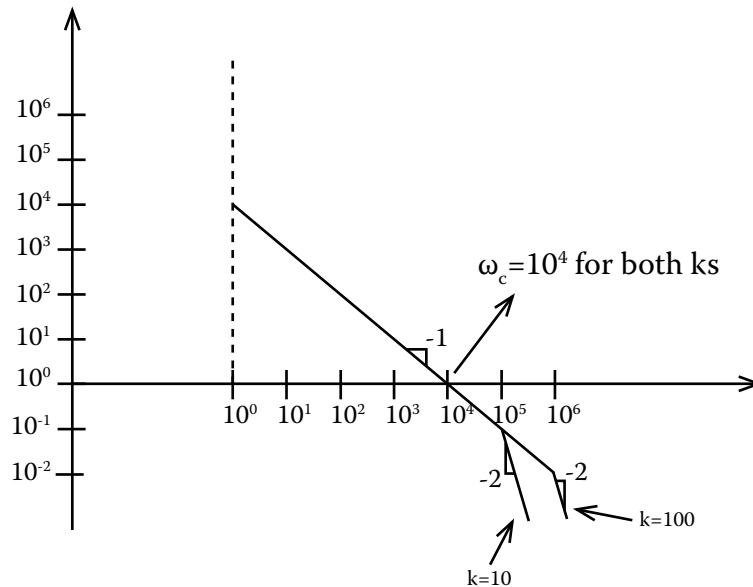


$\omega_c = 10^4$, $\phi_m = 90°$ for both cases! Minor loop feedback gave us what feedback always gives us: it calmed down variations in the forward path.

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Often in circuits, minor loop feedback is the easiest thing to do. Consider the problem of trying to stabalize the following system:



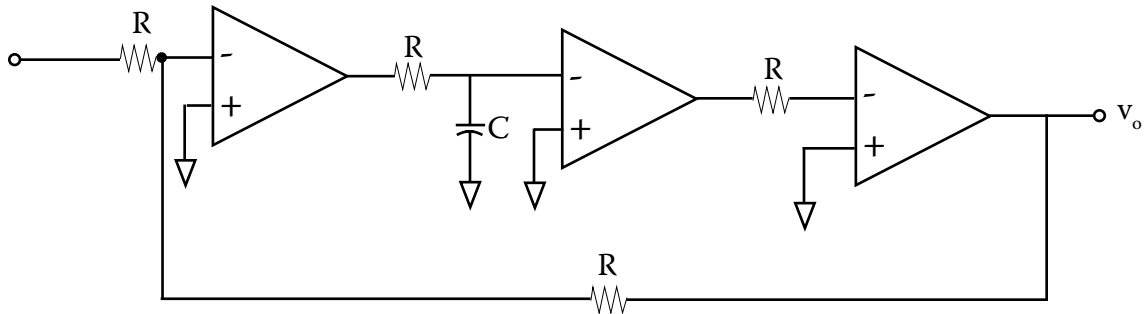Let's say that the open-loop transfer function of each op-amp is

$$a(s) = \frac{A_0}{\tau s + 1} \qquad \rightarrow \qquad L(s) = -\frac{1}{2}\left[-\frac{A_0}{\tau s + 1}\right]^3$$

You could try to compensate this thing using series compensation...say dominant pole:



$$L(s) = -\frac{1}{2} \cdot \frac{1}{RCs + 1}\left[-\frac{A_0}{\tau s + 1}\right]^3$$

Some numbers would help clarify the issue here. Let $A_0 = 10^6$, and let $\tau = 10°$. If we ask that we crossover at least a decade before the trio of poles @ 1 rps, then we require:

$$\omega_C = 10^{-1} \text{ rps} \quad \rightarrow \quad \frac{1}{2} \cdot \frac{A_0^3}{RC\omega_C} = 1$$

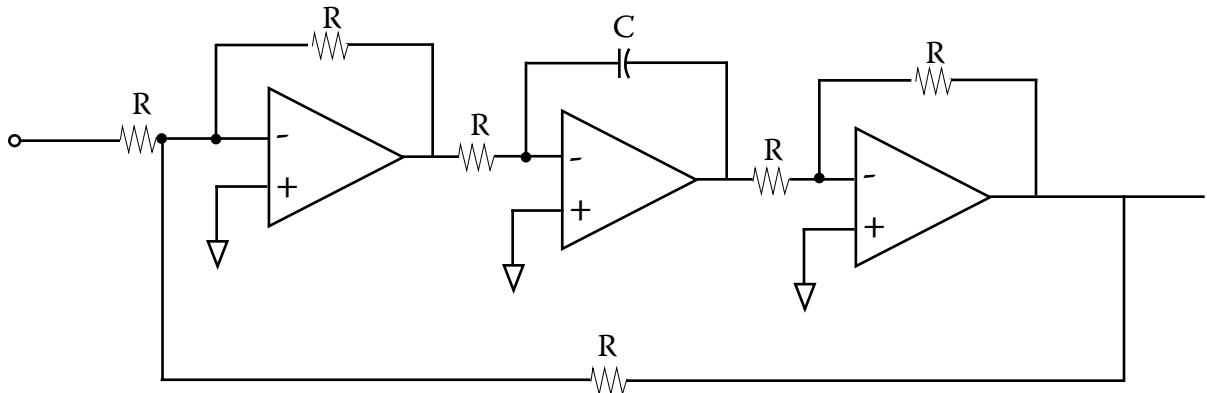$$RC = \frac{1}{2} \cdot \frac{A_0^3}{10^{-1}} = \frac{1}{2} \cdot 10^{19} = 5 \times 10^{18} \text{ sec}$$

That is an <u>enormous</u> time constant! If we chose $R = 10 \text{ M}\Omega$, we would still need $C = 5 \times 10^{11}$F. Even a capacitor of 1F is too big to imagine.

Fortunately, minor loop compensation comes to the rescue...

# 6.302 Feedback Systems
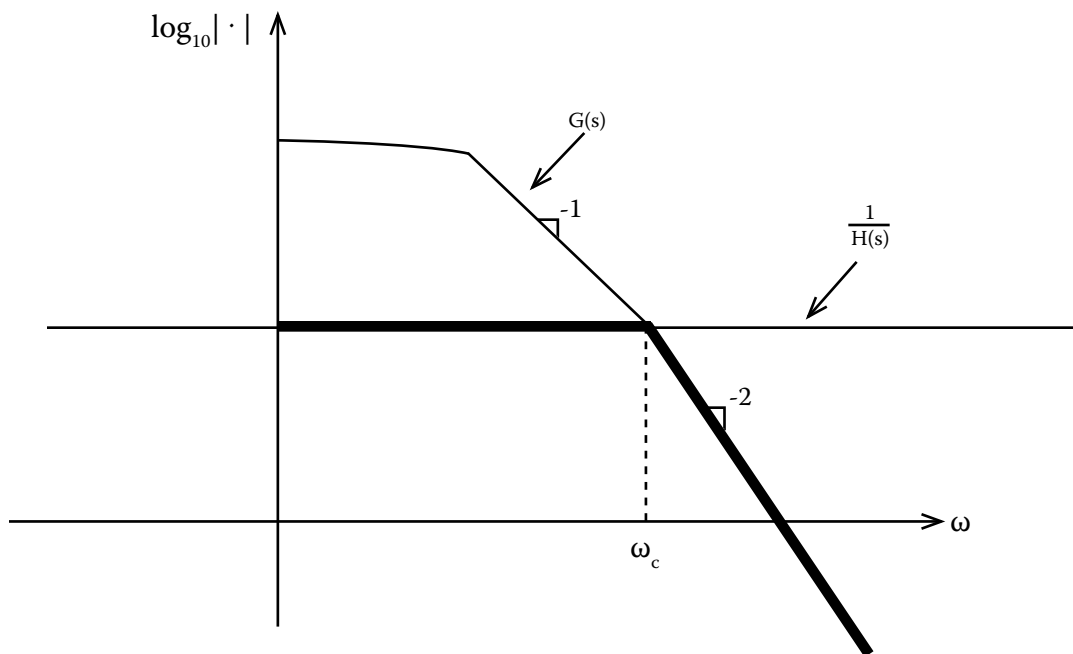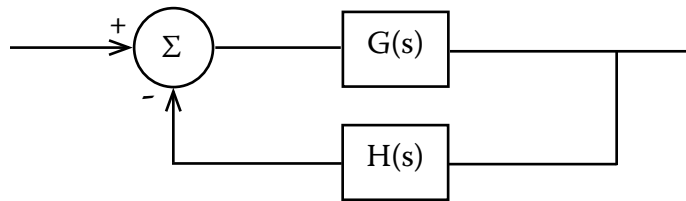Recitation 18: Minor Loop Feedback
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$$L(s) = -(-1)(-\tfrac{1}{RCs})(-1) = \tfrac{1}{RCs}$$

Nice.

One more thing to know about minor loop feedback. Remember that in the last recitation, we talked about a graphical interpretation of Black's Formula:





The trick for graphing the closed-loop response for the system was to overlay $G(s)$ and $\frac{1}{H(s)}$, and then
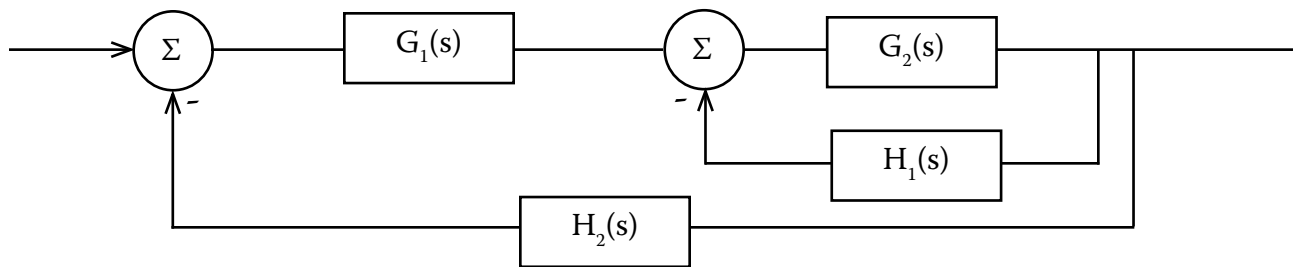
Trace out the lower of the two curves at all frequencies.

We can apply a similar trick to determine the <u>forward path</u> of the <u>major loop</u> of a minor loop compensated system.



To obtain the forward path of the major loop, we just overlay plots of $G_1(s)G_2(s)$ and $G_1(s) \cdot \frac{1}{H_1(s)}$. The forward path is the lower of the two curves at all frequencies·