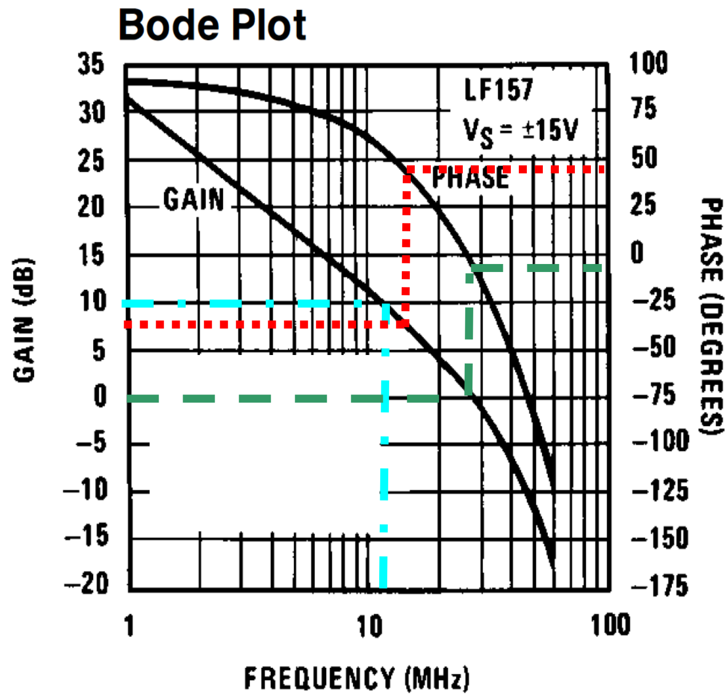
Physics 623 — Problem Set 4 — solutions

1. The open-loop gain curve for an LF157/357 op-amp is shown at the right. This is a detailed view of the high frequency end of the curve, and explicitly shows the phase as well as the magnitude of the gain. The reference for the phase at low frequencies for this plot is +180° instead of the usual 0°, so you'll need to subtract 180° from the values given here.



a) What is the gain-bandwidth product for this op-amp?

$$10^{10dB/20} \cdot 12 \text{ MHz} = 38 \text{ MHz}$$

b) If you use it as a unity-gain buffer ($\beta = -1$), what is the phase margin? Is this a useable amplifier circuit?

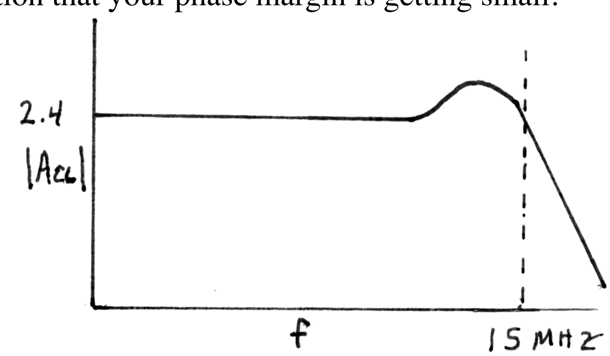
$\beta A = 1$ @ 18 MHz, $\phi = \text{"}-5°\text{"} \Rightarrow -185°$, This is a –5° phase margin, therefore it *will* oscillate.

c) What is the minimum closed-loop gain ($-\beta^{-1}$) that will provide a reasonably safe 45° phase margin?

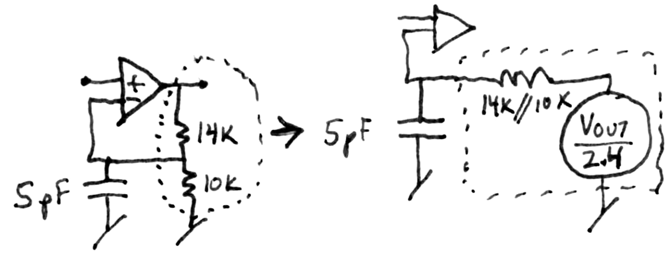
45° phase margin is –135° → +45° on this plot. This is ~15 MHz, where the open loop gain is 7.5 dB or 2.4. Making $|\beta A| = 1$ here requires $\beta = -1/2.4$, or a closed loop gain of 2.4.

d) What is the 3 dB bandwidth of the amplifier at this gain? The gain-bandwidth product?

Nominally, the answer is 15 MHz x 2.4 = 36 MHz, but the neat result that the $-\frac{1}{\beta} = |A|$ intersection is the –3 dB point of a simple single-pole low-pass response is only strictly true for 90° phase margin. If you calculate the closed loop gain $A_{\text{C.L.}} = \left|\frac{A}{1 - \beta A}\right|$ explicitly for this 45° case you will find it has a peak just below the intersection frequency and just drops back to 2.4 at 15 MHz, as shown in the plot below. If you see significant closed loop gain "peaking" in your circuit, it is an indication that your phase margin is getting small.



e) Suppose your circuit in part c) is a conventional non-inverting amplifier with a voltage divider on the output connecting a fraction β of the output back to the negative input. We usually assume this β is entirely real, but suppose there is a significant stray capacitance between the wiring to the negative input and ground. Explain the qualitative effect on your phase margin. If the bottom resistor in the divider is 10 K ohms (the gain then determines the top one) and the stray capacitance is 5 pF, at what frequency do you get an additional 45° phase shift?



$f_C = 1/2\pi R_{th}C$ = 5.5 MHz is where there will be 45° phase shift.

Since this is less than the 15 MHz where your phase margin was already down to 45°, the total phase shift will reach 180° and the circuit will oscillate at some frequency between 5.5 MHz (where you still have over 40° phase margin, with a little over 90° from the op amp and 45° from the feedback circuit) and 15 MHz (where the total phase shift will be almost 225°, since at 15 MHz you are well above f_C for your feedback circuit, and it will add almost 90° of phase shift to the 135° of the op amp).