Intro to Measurement Systems - Practice 3
Op-amp Gain Bandwidth

LA-CoNGA physics

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1 Objective:

The objective of this activity is to explore a key parameter that affects the performance of op-amps at high frequencies. The parameter is the gain-bandwidth product (GBW) or unity gain bandwidth.

2 Background:

The forward gain, G is defined as the gain of the op-amp when a signal is fed differentially into the amplifier with no negative feedback applied. This gain is ideally infinite at all frequencies, but in a real op-amp is finite, and depends on the frequency. At low frequency the gain is maximum, decreases linearly with increasing frequency, and has a value of one at the frequency commonly referred to as the **unity gain** or **cut-off frequency** F_{cf}, in equation form:

$$G_{cf} = 1 \tag{1}$$

For the popular $uA741$ op-amp, the unity gain frequency is 900 KHz, the open-loop gain at this frequency is simply one. This is also the Closed-Loop Bandwidth or the maximum frequency when the feedback is configured with a closed loop gain of 1.

G_f is defined as the **gain-bandwidth product**, GBW, and for all input frequencies this product is constant and equal to f_c. The gain can be specified as a simple number (magnitude) or in dB.

The open-loop gain falls at 6 $dB/octave$ for a single-pole response. This means that if we double the frequency, the gain drops by a factor of two. Conversely, if the frequency is halved, the open-loop gain will double, as shown in figure 2.

This gives rise to what is known as the Gain-Bandwidth Product. If we multiply the open-loop gain by the frequency, the product is always a constant. The caveat for this is that we have to be in the part of the curve that is falling at 6 $dB/octave$.

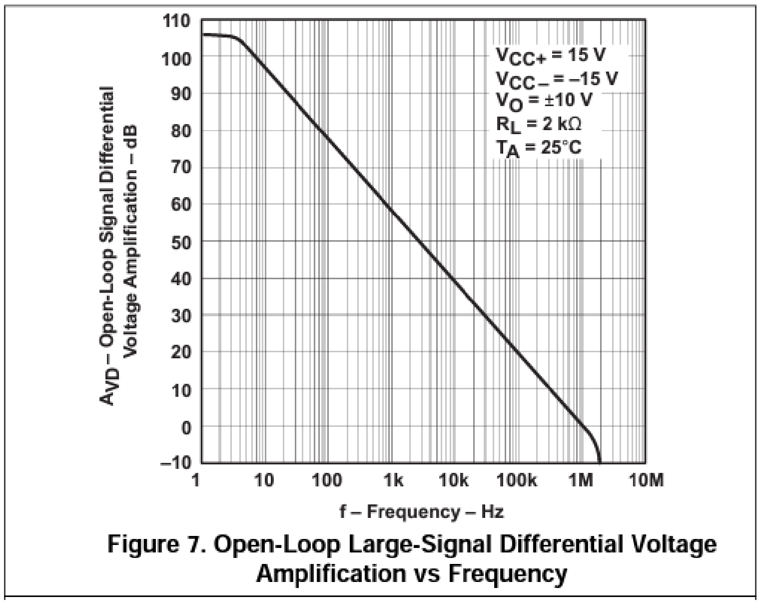

Figure 1: Open loop gain in dB versus frequency for $uA741$

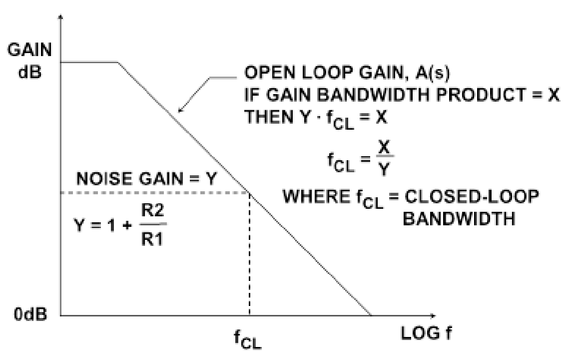

Figure 2: Gain-Bandwidth Product GBP

This gives us a convenient figure of merit with which to determine if a particular op-amp is useable in a particular application. Note that the gain-bandwidth product is meaningful only for voltage feedback (VFB) op-amps.

For example, if we have an design which requires a closed-loop gain of 10 and a bandwidth of 100 kHz, we need an op amp with a minimum gain-bandwidth product of 1 MHz. This is a slight oversimplification, however, because of the part to part variability of the gain-bandwidth product and the fact that at the location where the closed-loop gain intersects the open-loop gain, the response is actually down $3dB$. In addition, some extra margin should be allowed.

In the case described above, an op-amp with a gain-bandwidth product of $1MHz$ would be marginal. A safety factor of at least 5 would be better insurance that the expected performance is achieved, and an op amp with a gain-bandwidth product of $5MHz$ should therefore be selected

3 Prelab

3.1 Simulating

Simulate the circuit of figure 3 to measure the frequency response of a inverting amplifier configured with a closed loop gain of 1000. Because the circuit's gain is so high, the circuit needs to be driven with a very small input signal. Since the signal generator cannot accurately produce small signals with low noise, a 1/1000 voltage divider, R_3, $R_4//R_1$, is used to reduce a $2V_{pp}$ sine signal to $2mV_{pp}$ at the inverting amplifier input. R_4 and R_1 are effectively in parallel due to the "virtual ground" at the inverting inputp. The parallel combination of $R4$ and $R1$ will be 50Ω which with the $47K\Omega$ R_3 results in a divider ratio close to 1/1000.
Use $OP37$ op-amp model and $\pm 5V$ power supply

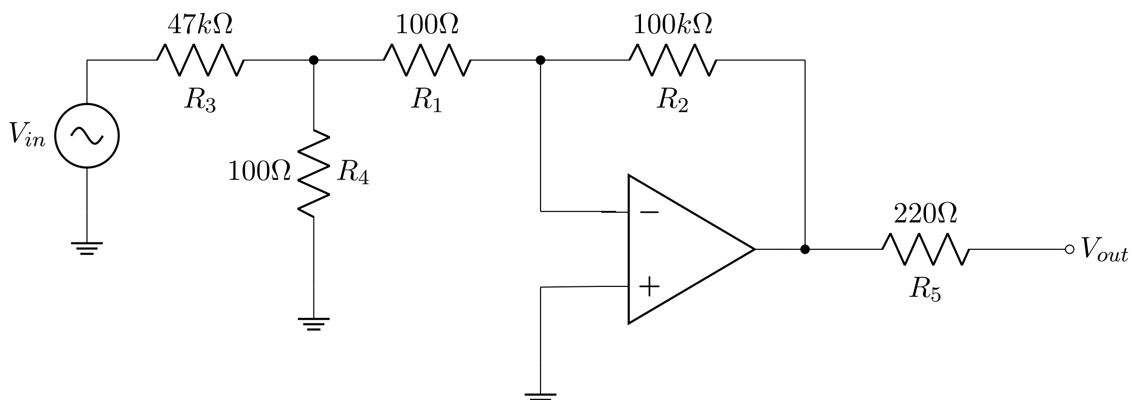

Figure 3: Inverting amplifier circuit with gain of 1000

1. Perform a transient simulation setting V_{in} as follows:
    - Amplitude: $2V$
    - Offset: $0V$
    - Frequency: varying from $100Hz$ to $1MHz$
2. Perform an AC analysis with the following parameters
    - Type of sweep: Octave
    - Number of points per decade: 100
    - Start frequency $100Hz$
    - Stop frequency $1MHz$
3. Find the $-3dB$ frequency or F_{cf} on the Bode plot. Calculate the GBW by multiplying this by the absolute value of the gain, R_2/R_1 or 1000 in this case.

4 Practice

4.1 Measuring

1. Set a sine wave of $2V_{pp}$ and $250Hz$. To be sure that the amplifier output is the correct amplitude and not clipped, use the Oscilloscope to measure the signal in the time domain. Because the attenuation of the voltage divider is approximately the same as the inverting gain the output should be inverted and have about the same amplitude as the input.
2. Perform a frequency sweep from $100Hz$ to $20KHz$ in octaves (doubling the frequency at each point) and record the amplitude of the signal and the phase related to input signal.
3. Calculate the GBW of the circuit.
4. The circuit acts as a Low-pass filter LPF, find the 3dB point and the rate of attenuation (dB per decade) of the slope.
5. Compare the results with simulations (repeat the simulation with the actual components if needed).

5 References

1. Gain Bandwidth Product
2. $uA741$ op-amp datasheet