In this exercise, you will be accessing audio and video from Moodle. Please ensure you have suitable hardware.

Frequency Response: The Last (op amp) Frontier

In our introduction to the op amp, we said there were some goals designers had in mind when developing a useful operational amplifier:

- differential inputs
- infinite input impedance
- zero output impedance
- infinite gain
- bandwidth from zero to infinity

So far, we've seen that even the cheapest of op amps does a pretty good job of the first four:

- differential inputs allow for inverting, non-inverting, difference, and summing configurations
- input impedances are greater than the resistance of air
- output impedances are less than the resistance of wire
- gains in the hundreds of thousands to millions allow us to reduce the gain with negative feedback, and provide us with a model that says the voltage between the two inputs will be essentially zero whenever the amplifier's output is linear

However, we haven't tackled the bandwidth question. Here, unfortunately, things aren't so rosy. The frequency characteristics of inexpensive op amps are really not that great, so we need to know what their limitations are and we need to come up with design techniques to ensure that the circuit response is at least predictable if not desirable.

Frequency Response Background

Over the past two semesters, you've learned a lot of things related to frequency response, and yet we find that many students have a very tenuous grasp on what that was all about.

- You've learned about complex numbers and applied these to the impedances of inductors and capacitors, learning that the impedance of a capacitor decreases as frequency increases, whereas the impedance of an inductor increases as frequency increases. That means that inductors appear as short circuits to low frequency signals and capacitors appear as shorts to high frequency signals.
- You've learned how to do all sorts of complicated math with resistors, capacitors, and inductors in circuits -- Vectors and Phasors, Laplace Transforms, and Fourier Analysis, all of which are frequency-based (that's the ω or s in all those calculations) and help to explain the effects of electronic components on signals of different frequencies.
- You've combined capacitors with resistors, inductors with resistors, and capacitors with inductors in various voltage divider arrangements that showed how the change in frequency resulted in different output amplitudes (and phases) depending on the frequency of the input signal.
- These various arrangements of capacitors, resistors, and inductors all formed filters -- low pass filters, high pass filters, band pass filters, and even band reject filters. For these filters, you've both mathematically predicted and empirically determined the cut-off frequencies.

But still I find many students can't tell me what a cut-off frequency means or how to use an oscilloscope to find one.

So lets get back to the basics of AC signals and what different frequencies are all about, and then discuss the effects of different filters on signals containing a mixture of frequency components, and also on a single sinewave as its frequency changes.

Listen to the audio recording "Audio Demo on Frequencies", available in Moodle.

What was the highest frequency you could hear? 15 kHz

Listen to the audio recording "Alice Cooper Demo", also available in Moodle. Please don't share this outside the "class" setting for copyright purposes!

Here's a summary:

- A Low Pass Filter (LPF) allows the lower and midrange frequencies (bass guitar, bass drum, human voice) through but removes the higher frequencies (cymbals, hissing vocal sounds like 's')
- A High Pass Filter (HPF) allows the higher and midrange frequencies through but removes the lower frequencies
- A Band Pass Filter (BPF) allows the midrange frequencies (voice, guitar) but removes the lower and higher frequencies
- A Band Reject Filter (BRF) allows both the low and high frequencies through but removes the midrange frequencies

Now, watch the video "Various Filters with Frequency Sweep". https://nait.hosted.panopto.com/Panopto/Pages/Viewer.aspx?id=fb646365-370a-44dd-bfb2-ab8a01786a6e (https://nait.hosted.panopto.com/Panopto/Pages/Viewer.aspx?id=fb646365-370a-44dd-bfb2-ab8a01786a6e)

Match the following:

2	Band Pass Filter
4	Band Reject Filter
1	Low Pass Filter
3	High Pass Filter

1. Does not allow high frequencies to pass through.
2. Removes low and high frequencies.
3. Allows high frequencies to pass through.
4. Passes only low and high frequencies