FREQUENTLY ASKED QUESTIONS

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Content Questions

How do transistors figure into op-amps?

Op-amps are made out of multi-transistor circuits. If we were to go through about another three or four lectures on multi-transistor circuits, we would cover how the various multi-transistor components of an op-amp (current mirrors, differential amplifiers) work. If this were a two-semester course, we'd be covering this, but unfortunately we are going to skip this material so that we can spend some time on digital electronics.

This Wikipedia article has a schematic of the 741 op-amp, which has a bunch of bipolar transistors in it.

Why does the feedback make a difference if it goes to the negative vs. the positive op-amp input? Or does it not make a difference?

In an *ideal* op-amp, the rules treat the + and - terminals symmetrically, so in principle, it does not matter which terminal is which in this idealization. However, real life op-amps are not ideal, and the inner guts do not treat the inputs symmetrically. Op-amps are designed to work best if the (negative) feedback goes into the negative terminal. (I'm not sure if there's a simple explanation for this, without going into details of op-amp schematics and operation.)

Why do we have $I_+ = I_- = 0$? Does it have anything to do with $I_G = 0$ in a FET?

Well, yes, sort of (note that the transistors inside op-amps can be bipolars rather than FETs— that's the case for the vanilla 741 op-amp). The op-amp inputs do indeed lead into transistor bases, and current drawn is very small (they have high input impedance).

What is meant by "virtual ground"?

This refers to one of the op-amp inputs when the other input is grounded (when the op-amp is in a feedback configuration). By the ideal op-amp rules, the op-amp does whatever it has to do at the output to make the input voltages equal. So if one op-amp input is at ground, the other must be too, even if it's not physically grounded. (Of course this only works if the op-amp is in operation.)

What is the general utility of Rule #2 of op-amps? I'm struggling to see how it's more useful that just a ground.

For some of the cases we looked at today, one of the op-amp inputs was tied to ground, which made the other a "virtual ground". But Rule #2 still works even if one of the inputs isn't ground, and the rule can help analyze the circuit behavior. An example is the non-inverting amplifier, for which the op-amp's inverting input voltage is given by the feedback voltage divider. If we use Rule #2, we can calculate the gain.

What is the difference between $G(\omega)$ and $H(\omega)$ transfer functions?

These are both used to indicate transfer functions of a network. The convention is that H is used to mean a generic transfer function (could describe any network) whereas G is used to refer to the closed-loop gain of an amplifying network with feedback.

How does the voltage-current converter work?

In this op-amp circuit, one of the op-amp inputs is tied to ground and the other is then a virtual ground. Since the op-amp input terminals draw no current, all the current goes through the feedback resistor from the output to the negative terminal. The output is then $V_{\text{out}} = -RI$, the drop across the resistor. So the output voltage is proportional to the input current. The device then acts like a voltage source, providing a voltage independent of load.

For the differentiator op-amp, what is the difference between active and passive high-pass? Is this just when you input a voltage or no voltage?

A *passive* high-pass filter is just the simple CR circuit, with no active components. It will have a gain of 1 for high frequencies (high ω gets through the capacitor) but will attenuate low frequencies. This circuit also acts as a differentiator for (low) frequencies at which the signal is getting attenuated. If the circuit is passive — no energy added to it — you always lose signal amplitude in the low-frequency regime.

An *active* high-pass filter includes an op-amp (or some other amplifying circuit involving transistors). This provides a gain to the input signal. But the active high-pass filter will still attenuate low frequencies (and differentiate) with respect to the nominal gain at high frequencies (and the gain can go below unity).

In both active and passive filter cases you are putting in a signal voltage. But in the active case you are adding energy to the circuit via a power supply (controlled by the op-amp, which has transistors inside), so that the output can have larger amplitude than input.

BTW the same discussion holds for passive low-pass vs active low-pass filters.

Can you explain the intrinsic low pass filter for an op-amp?

Op-amps intrinsically behave like low-pass filters, due to their stray capacitance (so they look a bit like the RC circuit). There will pretty much always be some roll-off at high-enough frequency. For op-amp integrators and differentiators, this intrinsic frequency response gets combined with the frequency response due to the impedance of the capacitors at the input or in the feedback loop. So for example, if you put in a capacitor at the input to make an active high-pass filter (differentiator), in combination with the intrinsic high-frequency roll-off, you'll end up with an active band-pass filter.

How high does it take for amps to attenuate? Does it really matter?

The corner frequency depends on the specific op-amp, and information about frequency response can be found in the manufacturer documentation. For the 741 op-amp, open-loop roll-off starts around 10 Hz, but closed-loop roll-off may start at kHz or so (see Eggleston Fig. 6.17).

Yes, it can matter a lot if you are feeding high frequency signals into the op-amp. Attenuation of high frequencies can distort a signal that has sharp features (the Fourier components that make them up get killed).

How do you find corner frequencies of differentiators or integrators?

You do this the same as for any transfer functions: figure out the limiting values for ω large or small (which usually involves an expression in either numerator or denominator of the transfer function), and then find the value of ω at which the values match. To take into account the intrinsic frequency-response properties of the op-amp, you would consult the manufacturer materials.