ECE2100 Lecture Notes 1/29/03

Stuff

Exam 1 Friday, 2/7/03
  Chapters 1 & 2 in text, Lectures through 1/31
  homeworks 1 - 8
We will move to EMCB 101 on Monday 2/3

HW #8, due F, 2/7 Ex2.21 - Ex2.26, problems 2.78, 2.84, 2.95 DO HW #8 BEFORE EXAM 1!

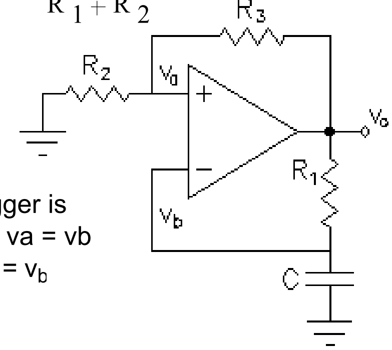
A. Stolp
1/27/03

HW #7, due W, 2/5
Problems 2.37, 2.39 (use standard resistor values, possibly in series or parallel), 2.49, 2.64, 2.69, 2.73bc, Design a Schmitt trigger. Power supplies: 12V & 0V. Op amp outputs 11V (high) or 1V (low). Output goes high if input goes under 3V. Output goes low if input goes above 4V. R_1 = 10kΩ. ans: Circuit below with R_2 = 27kΩ, R_f = 68kΩ.
Ex2.17 - Ex2.20

More Nonlinear Circuits

Multivibrator oscillator based on a schmitt trigger.
How here's a new situation, this circuit has both positive and negative feedback. So how do you tell if it's a linear or a nonlinear circuit? Notice that the positive feedback has no delay. When the output changes, the noninverting input voltage also changes immediately. The negative feedback is delayed by the RC circuit, so the positive feedback wins and the circuit is nonlinear.

$$v_a = \frac{R_2}{R_1+R_2}\cdot v_o$$



R_2, R_3, and the op amp make an inverting schmitt trigger. The input to the schmitt trigger is the voltage across the capacitor. If the output is high, then the capacitor charges until va = vb and the output switches low. If the output is low, then the capacitor discharges until $v_a = v_b$ and the output switches high again.

For **ALL** first order transients:

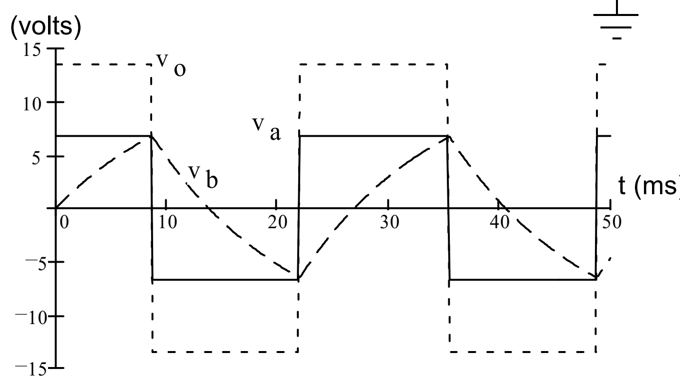
$$v_X(t) = v_X(\infty) + \left(v_X(0) - v_X(\infty)\right)\cdot e^{-\frac{t}{\tau}}$$

OR

$$i_X(t) = i_X(\infty) + \left(i_X(0) - i_X(\infty)\right)\cdot e^{-\frac{t}{\tau}}$$

Or fluid level, or temperature whatever variable.

$$v_b = v_C(t) = v_o + \left(v_C(0) - v_o\right)\cdot e^{-\frac{t}{R_1 C}}$$



To find half the period:

$$\frac{R_2}{R_2+R_3}\cdot v_o = v_o + \left(-\frac{R_2}{R_2+R_3}\cdot v_o - v_o\right)\cdot e^{-\frac{T}{2R_1C}}$$

$$\frac{R_2}{R_2+R_3} = 1 - \left(\frac{R_2}{R_2+R_3}+1\right)\cdot e^{-\frac{T}{2\cdot R_1\cdot C}}$$ Solve for T

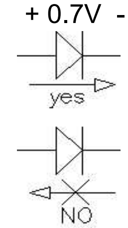
$$(R_2+R_3)\cdot\left(\frac{R_2}{R_2+R_3} - 1\right) = -\left(\frac{R_2}{R_2+R_3}+1\right)\cdot e^{-\frac{T}{2R_1C}}\cdot(R_2+R_3)$$

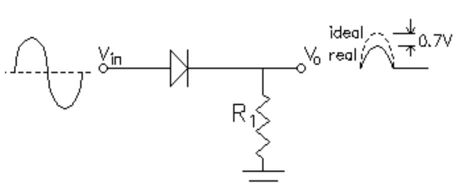
$$R_2 - (R_2+R_3) = -\left[R_2 + (R_2+R_3)\right]\cdot e^{-\frac{T}{2\cdot R_1\cdot C}}$$

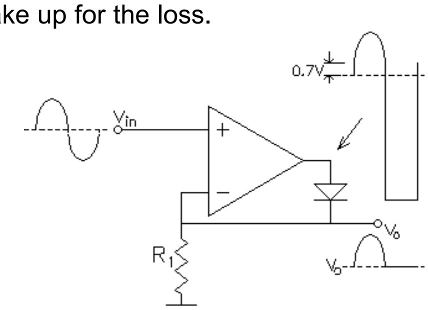
$$\frac{R_2-(R_2+R_3)}{-(R_2+2\cdot R_3)} = \frac{-R_3}{-(R_2+2\cdot R_3)} = e^{-\frac{T}{2\cdot R_1\cdot C}}$$

$$\frac{T}{2\cdot R_1\cdot C} = -\ln\left(\frac{R_3}{R_2+2\cdot R_3}\right)$$

Precision Diode
You will study diodes in the next part of this class. A diode is a device that only lets current flow through it in one direction. Unfortunately, even if the voltage is in the right direction, it still takes about 0.7V to make current flow. That much voltage drop can be a problem in small signal circuits. A precision diode uses an op amp to make up for the loss.

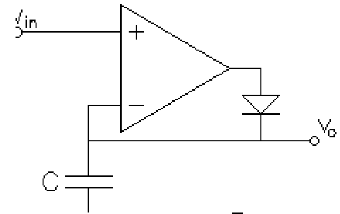






Peak Detector

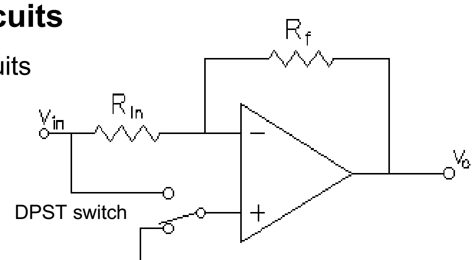
Replace the resistor with a capacitor and you have a peak detector or peak holder. Of course, in practice, you'll need to provide some way to discharge the capacitor.



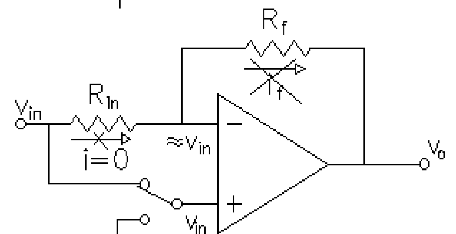
More Interesting Linear Circuits

Switchable invert/noninvert circuits

Inverting amp if switch hooks noninverting input to ground. Voltage follower if switch hooks v_{in} to noninverting input.



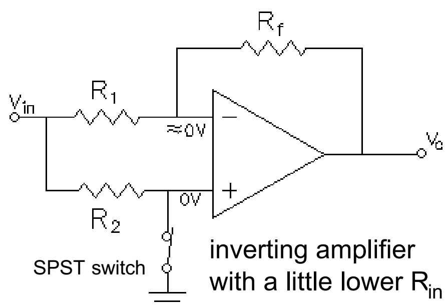
inverting amplifier



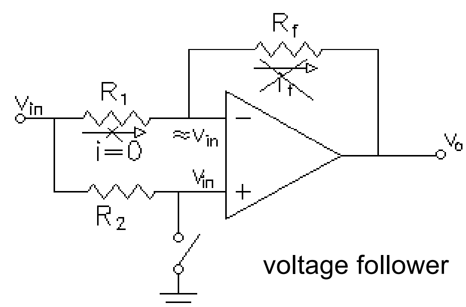
voltage follower

Problems: requires two position (double pole) switch & v_o will rail as switch moves between poles.

Inverting amp if switch hooks noninverting input to ground. Voltage follower if switch is open and v_{in} is effectively hooked to noninverting input.

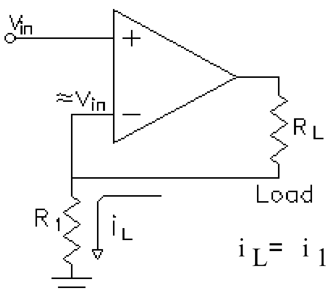


inverting amplifier with a little lower R_{in}.



voltage follower

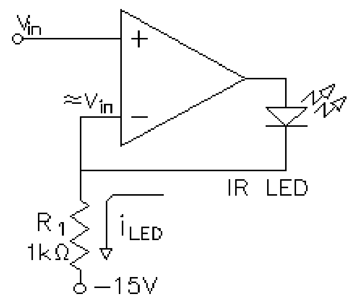
Voltage-to-Current converter



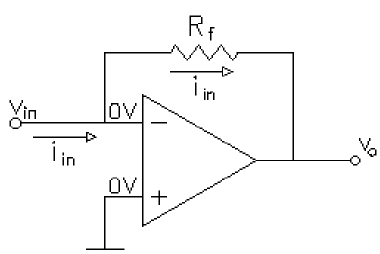
$$i_L = i_1 = \frac{v_{in}}{R_1}$$

We use a variation of this in the lab to drive the infrared LED with an audio signal. the output of the LED is proportional to the current through it, but that current should always be positive.

$$i_{LED} = i_1 = \frac{v_{in} - (-15 \cdot V)}{R_1}$$



Current-to-Voltage converter



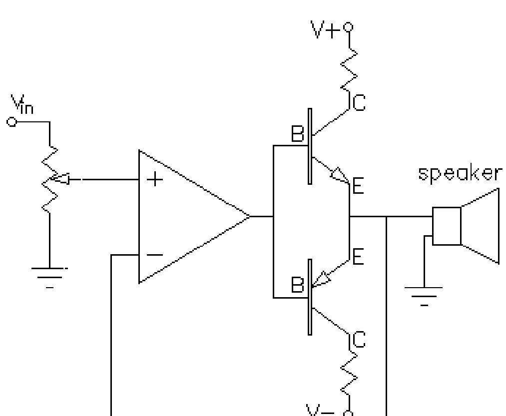
$$v_o = -R_f \cdot i_{in}$$

Big deal, it's just an inverting amp with no R_{in}.

Power amplifier

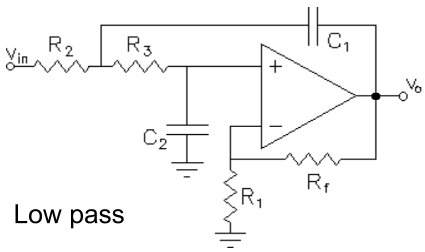
Utilizes two transistors to increase the current to the load. This circuit may require additional capacitors to keep it stable.

The input is connected through a potentiometer which is acting as a volume control. This is a very common way to connect a volume control. It's just a

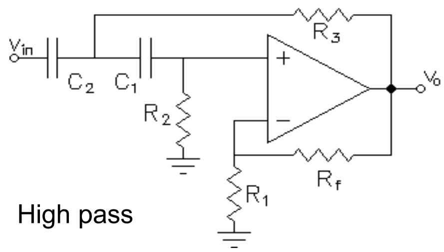


The load doesn't have to be a speaker, it could be a motor, or lights, or the input to another circuit or whatever.

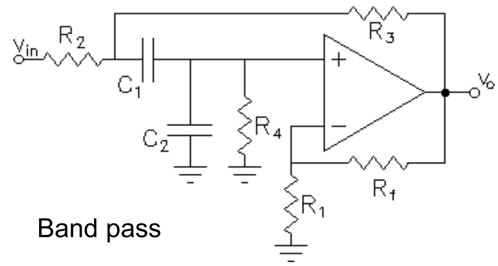
2-Pole Active Filters



Low pass



High pass



Band pass

May be cascaded for more poles. Consult other texts for design specifics.

Non-ideal (Real) Op amps

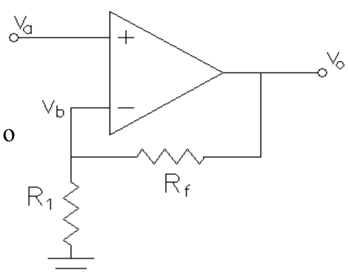
Gain < ∞

One of the ideal op-amp assumptions is that the gain is so great it can be considered∞, that leads to the familiar $v_a = v_b$ assumption that we tend to over-use. But this is not always a good assumption, in particular, the rather crummy frequency response of the op amp often leads to finite gain factors.

If the op amp has a finite gain of A then v_a does not = v_b

Noninverting Amplifier

v_{in}



$$v_b = \frac{R_1}{R_1 + R_f} \cdot v_o$$

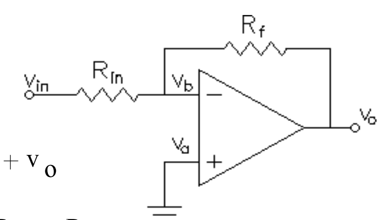
$$v_o = A \cdot (v_a - v_b) \quad = A \cdot \left(v_{in} - \frac{R_1}{R_1 + R_f} \cdot v_o \right)$$

$$\frac{v_o}{A} = v_{in} - \frac{R_1}{R_1 + R_f} \cdot v_o \qquad \frac{v_o}{A} + \frac{R_1}{R_1 + R_f} \cdot v_o = v_{in}$$

$$\frac{v_o}{v_{in}} = \frac{1}{\frac{1}{A} + \frac{R_1}{R_1 + R_f}} = \frac{R_1 + R_f}{\frac{1}{A} \cdot (R_1 + R_f) + R_1}$$

Divide top & bottom by R_1 to get eq 2.1 (p.67) in textbook.

Inverting Amplifier



$$v_b = \frac{R_f}{R_{in} + R_f} \cdot (v_{in} - v_o) + v_o$$

$$= \frac{R_f (v_{in} - v_o)}{R_{in} + R_f} + v_o \cdot \frac{R_{in} + R_f}{R_{in} + R_f}$$

$$= \frac{R_f v_{in} - R_f v_o}{R_{in} + R_f} + \frac{v_o \cdot R_{in} + v_o \cdot R_f}{R_{in} + R_f}$$

$$= \frac{R_f v_{in} + v_o \cdot R_{in}}{R_{in} + R_f}$$

$$v_o = A \cdot (v_a - v_b) \quad = A \cdot \left(0 \cdot V - \frac{R_f v_{in} + v_o \cdot R_{in}}{R_{in} + R_f} \right)$$

$$\frac{v_o}{A} = -\frac{R_f v_{in} + v_o \cdot R_{in}}{R_{in} + R_f}$$

$$\frac{v_o}{A} \cdot (R_{in} + R_f) = -(R_f v_{in} + v_o \cdot R_{in})$$

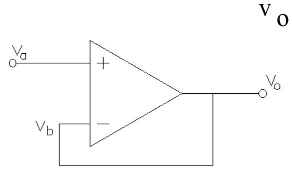
$$\frac{v_o}{A} \cdot (R_{in} + R_f) + v_o \cdot R_{in} = -R_f v_{in}$$

$$\frac{v_o}{v_{in}} = \frac{-R_f}{\frac{1}{A} \cdot (R_{in} + R_f) + R_{in}}$$

Divide top & bottom by R_1 to get eq. 2.11 (p.83) in textbook.

Notice that both cases revert to the familiar gain expressions if A =∞:

Op Amp Frequency Response



$$v_o = A \cdot (v_a - v_b)$$

right? Well yes, but you are ignoring any time delay in the op amp. This time delay gives rise to a phase shift at the output. At a sufficiently high frequency, the negative feedback may be phase-shifted by 180°, which means you can have *positive* feedback. Bad thing, that. To prevent this from being a problem, op amp manufacturers intentionally roll off the gain so that the gain will be less than 1 at the frequency where the output is phase-shifted by 180°. This is called ***internal compensation***.

Internally Compensated Op Amp

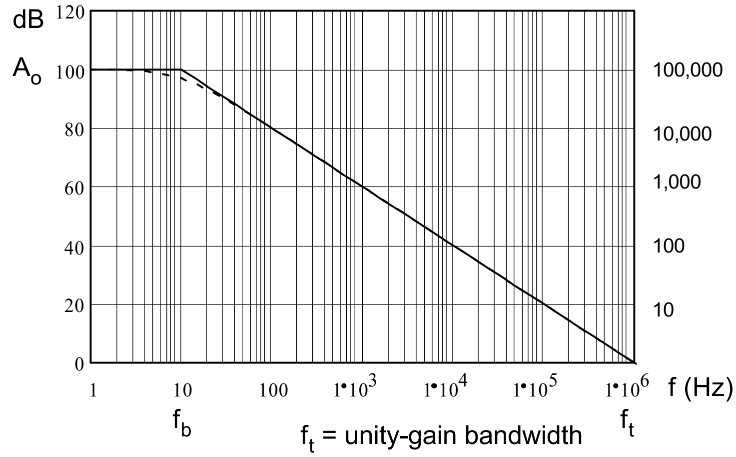
This is the open-loop gain (A) of a LM741 (worst case). Usually f_b and f_t are a little higher than those shown here, especially in better quality op-amps. you probably measured f_t somewhere between 1 & 2 MHz in the lab, even for a 741. They normally exceed their specifications a little.

$$A = \frac{A_o}{1 + j\cdot\frac{f}{f_b}} \cong \frac{A_o\cdot f_b}{j\cdot f} = \frac{f_t}{j\cdot f}$$

above f_b

Other symbols for f_t: f_T, f_U, f_{Unity}, GB, Bandwidth

A (open-loop) gain



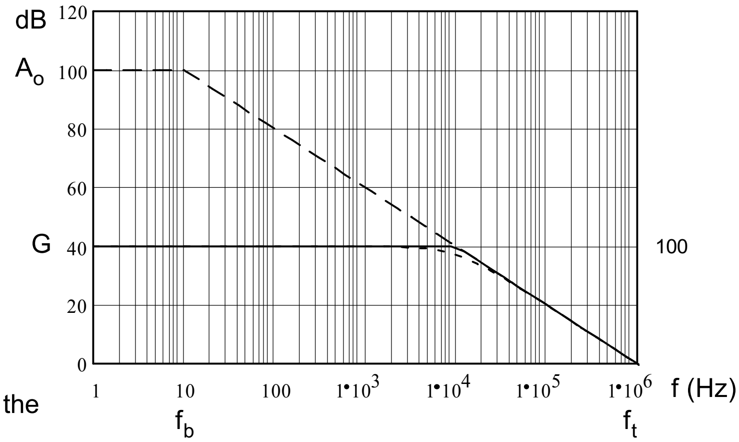
f_t = unity-gain bandwidth = gain-bandwidth product

Closed-loop (with negative feedback) Frequency Response

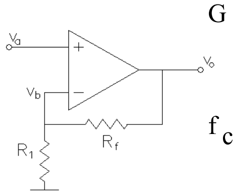
If your op-amp circuit is designed to have a gain of 100 (40dB) then a very good estimate of its frequency response is shown at right. To find the bandwith of your amplifier, you take the gain-bandwith product (f_t) and divide by the gain of your amp.

$$f_c \cong \frac{A_o\cdot f_b}{G} = \frac{f_t}{G}$$

G = ideal gain of amplifier

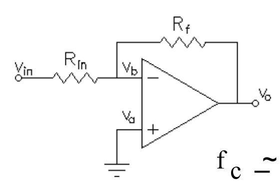


If you plug $A = \frac{f_t}{j\cdot f}$ into the finite-gain equations on the last page, you'll find that this estimate is exact for a noninverting amplifier, but not quite right for an inverting amplifier.



$$G = 1 + \frac{R_f}{R_1}$$

$$f_c \cong \frac{A_o\cdot f_b}{G} = \frac{f_t}{G} = \frac{f_t}{1 + \frac{R_f}{R_1}}$$



$$G = \frac{R_f}{R_{in}}$$

$$f_c \cong \frac{A_o\cdot f_b}{G+1} = \frac{f_t}{G+1} = \frac{f_t}{1 + \frac{R_f}{R_{in}}}$$

If G > 20 or so, you can usually neglect the + 1 in the denominator

Example

Say you'd like to amplify a microphone signal by 500.

$f_t := 1\cdot MHz$

If you use a single op-amp stage, the frequency response would be: $f_c := \frac{f_t}{500}$ $\quad f_c = 2\cdot kHz$

for the inverting amp: $f_c := \frac{f_t}{500+1}$ $\quad f_c = 1.996\cdot kHz$

Pretty dismal

Try two stages, gain of each stage = $G := \sqrt{500}$ $\quad G = 22.361$

If you use a single op-amp stage, the frequency response would be: $f_c := \frac{f_t}{G}$ $\quad f_c = 44.7\cdot kHz$

for the inverting amp: $f_c := \frac{f_t}{G+1}$ $\quad f_c = 42.8\cdot kHz$

Plenty good for audio

For the two stages together, this is actually -6dB, not -3dB, see homework problem 2.73

Actual: $f_{3dB} = 44.7\cdot kHz\cdot\sqrt{\sqrt{2}-1} = 28.8\cdot kHz$ Still OK