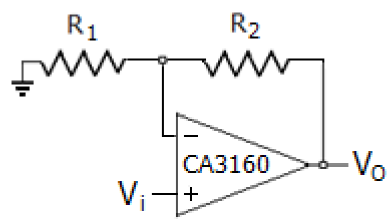
Electronics

Basic circuits with opamps

Problem 1.- An SFRA test instrument (sweep frequency response analyzer) generates a signal from 0 to 0.1V with an output impedance of 1kΩ and frequencies from DC to 200kHz. This signal has to be taken by another instrument whose input range is 0-1V and 10kΩ. Design a circuit that will amplify the signal to that level.

Solution: If we need a gain of 10 with a LM741 the cut-off frequency would be 100kHz, but the circuit needs to work up to 200kHz. It is possible to use the CA3160 opamp whose unit cut-off frequency is 4MHz, so it would have a cut-off at 400kHz for a gain of 10.



We could select R_1=1kΩ and R_2=9kΩ.

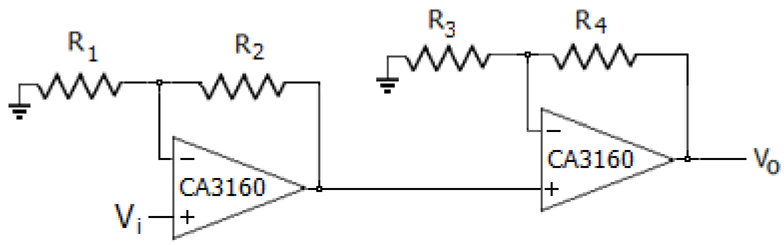
It is also possible to use two LM741 and make a cascade circuit splitting the gain between them, for example with factors of 2.5 and 4.

Problem 1a.- An instrument for testing transformers by sweeping frequency generates a signal 0-0.1V, with an output impedance of 10kΩ and frequencies between DC to 500kHz. This output needs to be connected to another instrument that has a range 0-1V and input impedance of 100kΩ. Design a circuit that amplifies the signal to that level.

Solution: It is possible to connect the instruments directly. The input impedance of the second instrument is much larger than the output impedance of the first one and its range of 0-1V can accommodate the 0-0.1V of the signal. However, if the signal is not amplified you would be using only 1/10 of the input range, which is equivalent to throwing away 3 bits of its DAC. It is better to amplify the signal by a factor of 10 to use the whole range. If we do that with an opamp LM741, the cut-off frequency would be 100kHz and we need at least 500kHz.

Using a CA3160 whose unity frequency is 4MHZ would give us a gain of 10 with a cut-off frequency of 400kHz, which is closer to what we want. One solution would be to use two CA3160s, distributing the gain between a factor of 4 (cut-off at 1MHz) and a factor of 2.5 (cut-off at 1.6MHz), so the cascade arrangement would work up to 500kHz without attenuation.

This would be the circuit:

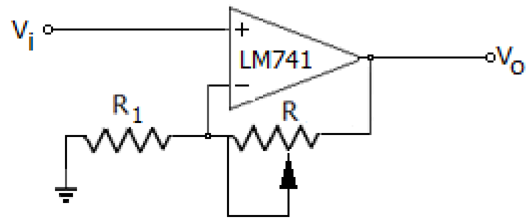


With resistors:

$R_1 = 10k\Omega$, $R_2 = 30k\Omega$, $R_3 = 10k\Omega$ and $R_4 = 15k\Omega$

Problem 2.- For an application in utility telephones, it is necessary to design an audio amplifier for the band [20Hz - 4.0kHz] with variable voltage gain (to be controlled by a potentiometer) from 0dB to 26dB. The polarity should be maintained, the input impedance has to be 16kohm and output impedance 4kohm. Maximum output voltage 10V.

Solution: There are several ways to design the circuit. One way could be using an opamp instead of discrete BJTs or FETs. Because we want the polarity to be the same, we could use a non-inverting configuration as follows:

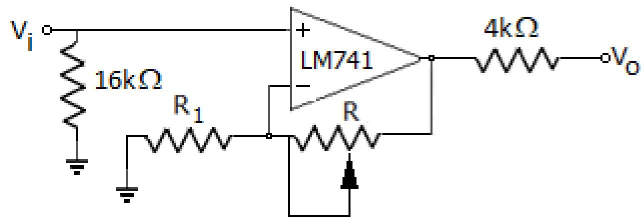


The voltage gain is given by $A = 1 + \frac{R}{R_1}$

With the potentiometer at zero, the gain would be 1 or 0dB. With the potentiometer at maximum, we want 26dB, which is a factor of 20. We can select R = 100kohm and R_1 = 5kohm, effectively getting a variable gain of 1to 21.

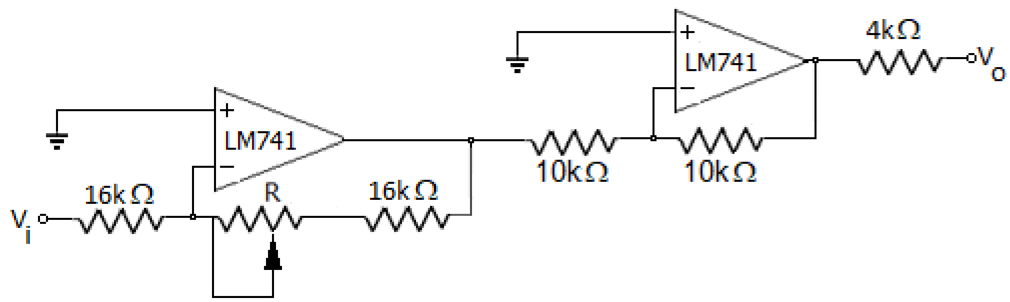
The non-inverting amplifier has a very large input impedance (order of MΩ), so we would need to add a 16kohm to ground to comply with the specifications. Notice that this resistor should not be in series with the opamp since it would not change anything there.

To comply with the specification of the output impedance we can add 4kohm in series with the opamp output:



Notice that this time the resistance is in series. Connecting a 4kohm to ground would only add load to the opamp without changing its small output impedance.

Another possible solution is to use two inverting amplifiers. This way we can obtain the desired gain and maintain the positive polarity. The 16kohm resistance in the first stage will already comply with the required input impedance and we still connect 4kohm in series with the output:

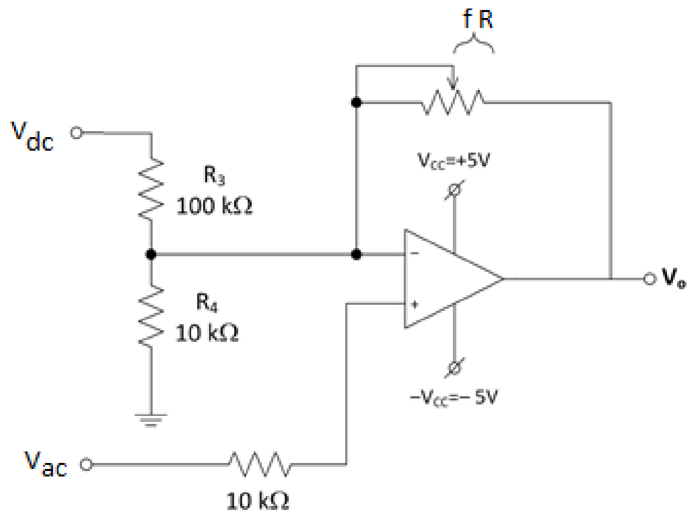


Notice that the feedback resistor has to be at least 16kohm to keep the gain limit at 0dB. That is accomplished by adding 16kohm in series with the potentiometer. If you have a 300kohm potentiometer, the upper limit will be

$$A = \frac{300k\Omega + 16k\Omega}{16k\Omega} = 19.8$$

This gives us the 26dB we wanted.

Problem 3.- Part of an instrument includes the circuit shown below. Find an equation that gives us the output voltage V_o as a function of the potentiometer resistance fR and the input voltages V_{ac} and V_{dc}.



Solution: This problem can be solved by superposition. The contribution from V_{dc} when V_{ac} is grounded is the same as an inverting amplifier:

$$V = -V_{dc}\frac{fR}{100k\Omega}$$

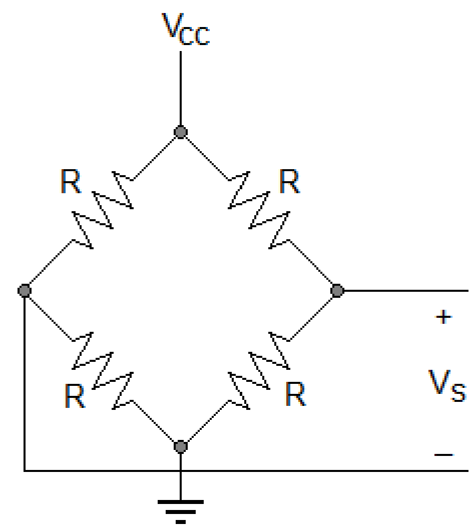
Instead, if V_{dc} were grounded, V_{ac} would be amplified by a non-inverted amplifier, giving an output of:

$$V = V_{ac}\left(1+\frac{fR}{100k\Omega//10k\Omega}\right)$$

Adding the two contributions, we get:

$$V_o = V_{ac}\left(1+\frac{fR}{100k\Omega//10k\Omega}\right) - V_{dc}\frac{fR}{100k\Omega}$$

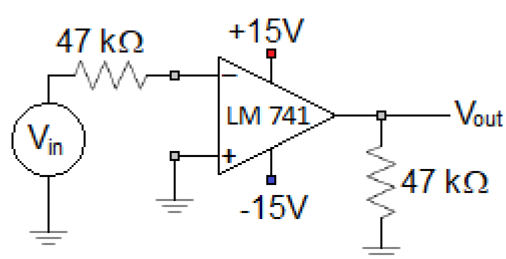
Problem 4.- A pressure cell to weigh minerals in a chute can be modeled by the network of resistors shown in the figure below.



They are 350-ohm resistors fed by V_{CC} at 12V. Due to strain in the cell, the values of the resistances change slightly and produce Vs=24mV at maximum scale. We need to amplify this signal to 2.4V maintaining a precision of 0.1%

Estimate the value of CMRR necessary and propose a design with opamps to achieve that rejection ratio.

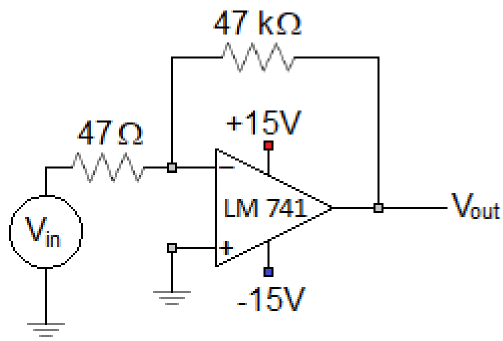
Problem 5.- Assume that negative saturation occurs at -13.5V in the following circuit (is that reasonable?). How much inverting input voltage does it take to drive the opamp into negative saturation? V_{in} is a DC voltage source.



Solution: The opamp is a 741 that has an open loop gain of 100dB, which is $10^{100/20}$=100,000. Therefore, to get an output of -13.5V the inverting input needs to be higher than the non-inverting input by:

$$\frac{13.5V}{100{,}000} = 135\mu V$$

Problem 6.- What is the close loop voltage gain of the following circuit? What is the bandwidth?



Solution: The circuit shown in the diagram is an inverting amplifier with gain of:

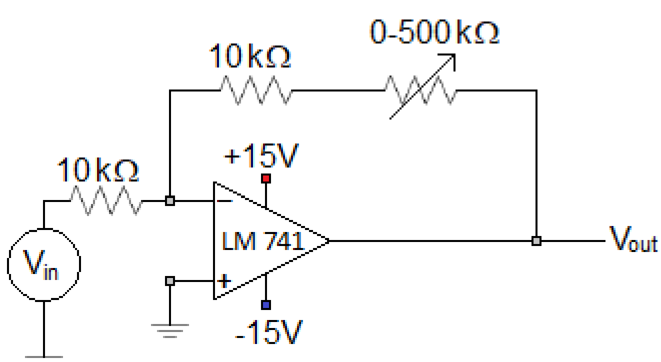
$$A = -\frac{47k\Omega}{47\Omega} = -1000$$

Since the opamp is a 741C, the frequency unity is 1MHz, so the upper cutoff frequency will be:

$$f_2 = \frac{1Mhz}{1000} = 1kHz$$

The low cutoff frequency is zero because the opamp will amplify DC.
Even though this circuit is in principle OK, you should know that it is stretching the opamp outside its comfort zone.

Problem 7.- Find the maximum and minimum gain and bandwidth of the following circuit:



Solution: If the potentiometer is at the zero end, the gain will be:

$$A = -\frac{10k\Omega}{10\Omega} = -1$$

With a bandwidth from $f_1 = 0Hz$ to $f_2 = \frac{1MHz}{1} = 1MHz$

If the potentiometer is at the maximum value, we get the maximum gain as well:

$$A = -\frac{510k\Omega}{10\Omega} = -51$$

With a bandwidth from $f_1 = 0Hz$ to $f_2 = \frac{1MHz}{51} = 19.6kHz$

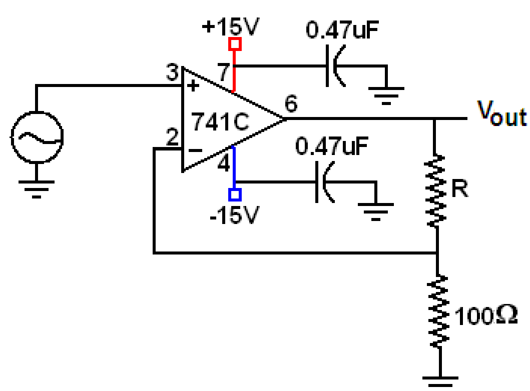
Problem 8.- An amplifier based on an opamp has a cutoff frequency of 100 kHz. If we increase the gain by a factor of 10 (20dB), what will be the new cutoff frequency?

Solution: If the gain is increased by a factor of 10, the cutoff frequency will drop by a factor of 10 to **10kHz**.

Problem 9.- Design a voltage amplifier with gain 200 using a LM741C and estimate its upper cutoff frequency f_2.

Solution: The following circuit has a gain of $\frac{R+100}{100}$, so to get 200 we need:

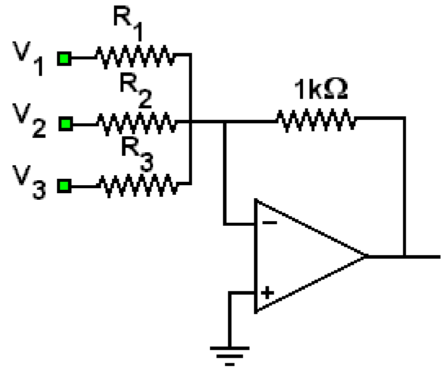
$$200 = \frac{R+100}{100} \rightarrow R = 19{,}900\Omega$$



The upper-cutoff frequency is:

$$f_2 = \frac{f_{unity}}{200} = 5kHz$$

Problem 10.- Calculate the values of R_1, R_2 and R_3 if you want a gain of -1.5, -2 and -5 for the signals V_1, V_2 and V_3 respectively.



Solution: Notice that the output of this amplifier is:

$$V_{out} = -\frac{1k\Omega}{R_1}V_1 - \frac{1k\Omega}{R_2}V_2 - \frac{1k\Omega}{R_3}V_3$$

So, to get gains of -1.5, -2 and -5 we need:

$$-\frac{1k\Omega}{R_1} = -1.5 \rightarrow R_1 = \frac{1k\Omega}{1.5} = 667\Omega$$

$$-\frac{1k\Omega}{R_2} = -2 \rightarrow R_2 = \frac{1k\Omega}{2} = 500\Omega$$

$$-\frac{1k\Omega}{R_3} = -5 \rightarrow R_3 = \frac{1k\Omega}{5} = 200\Omega$$