BEE 233 Circuits
Fall 2015
Lab 4: Opamp filters prelab notes

1 Circuits

You'll be analyzing these five opamp circuits in this lab. In all cases, the opamp is the same LM348 you worked with in Lab 3, VCC = +12 V and VEE = –12 V.

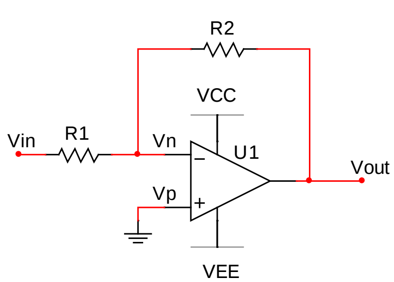


Figure 1. Inverting amplifier.

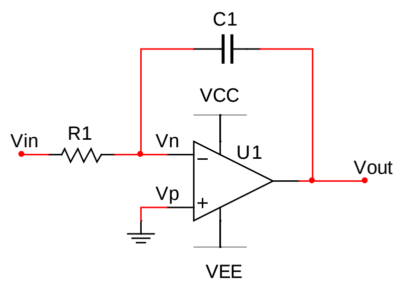


Figure 2. Simple integrator.

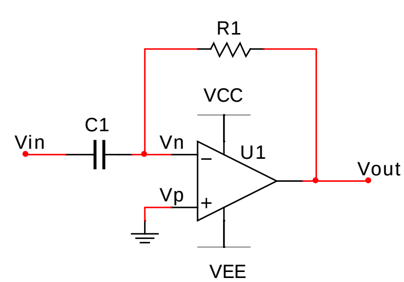


Figure 3. Simple differentiator.

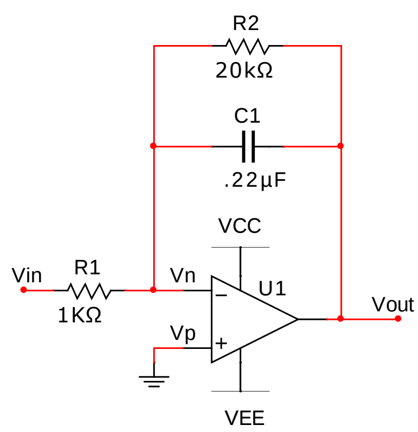


Figure 4. Integrator with shunt.

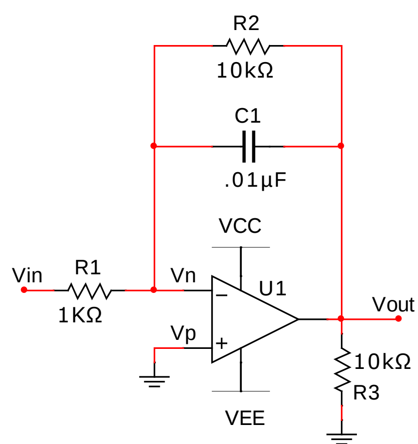


Figure 5. Low-pass filter.

4 Inverting amplifier

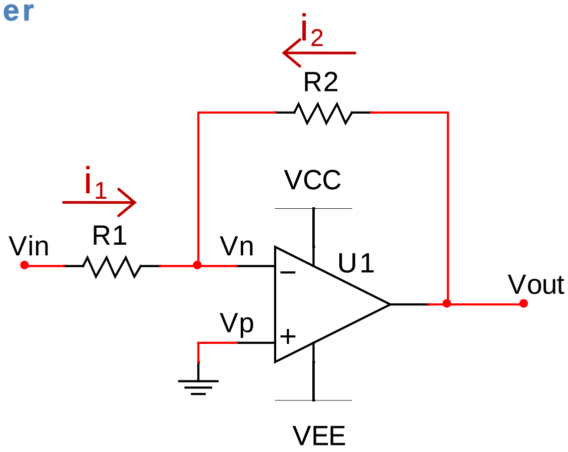


Figure 12. Inverting amplifier.

1. Analyze the inverting amplifier circuit in figure 12 (same as figure 1) to derive an equation for the gain, Av, as a function of R1 and R2.

   $$Vn = Vp = 0$$

   $$i1 = -i2$$

   $$Vin = i1\ R1 + Vn = i1\ R1$$

   $$Vout = i2\ R2 + Vn = i2\ R2 = \ -i1\ R2$$

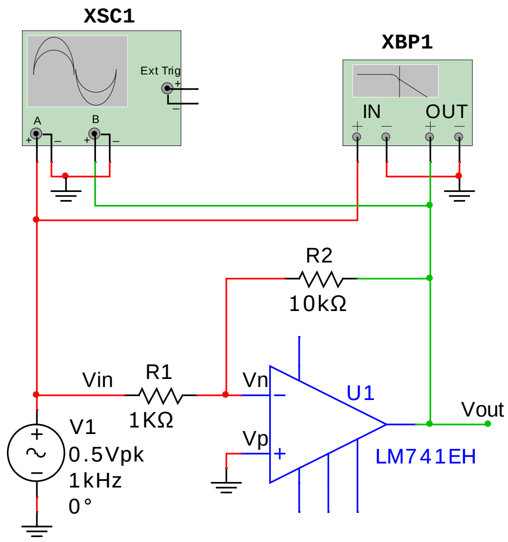
   $$Av = \frac{Vout}{Vin} = -\frac{i1\ R2}{i1\ R1} = -\frac{R2}{R1}$$

2. Choose values for R1 and R2 to produce a gain, Av = -10.

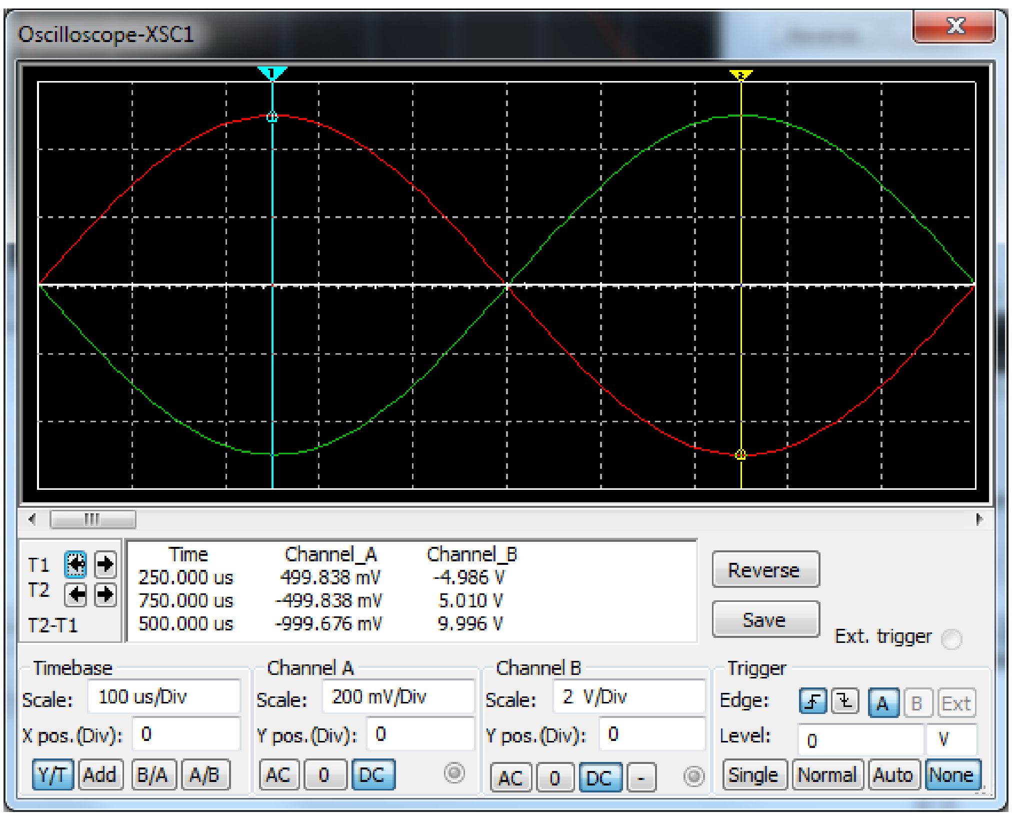
   For Av1 = –10 and R1 = 1 KΩ, R2 = 10 KΩ

3. Simulate your circuit. Capture images of the following.

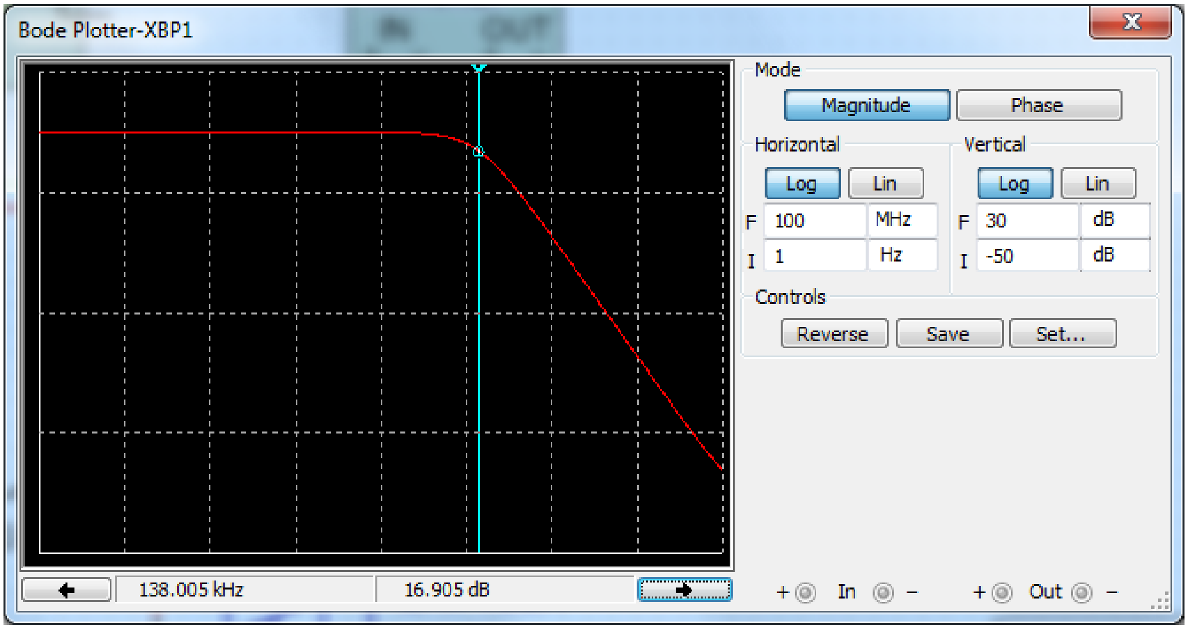
a. Your schematic.



b. An oscilloscope display of Vin and Vout for Vin = 1.0 Vpp, 1 KHz sine wave, 0 V DC offset.



c. A Bode plot of the frequency response with a cursor at the cutoff frequency.



Cutoff is at about 138 KHz.

5 Simple integrator

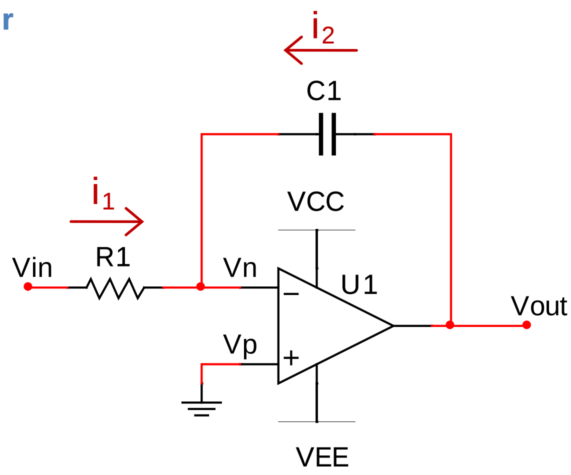


Figure 13. Simple integrator.

1. Analyze the integrator circuit in figure 13 (same as figure 2) to derive an equation for Vout(t) as a function of Vin(t). Show that the output is the integral of the input.

$$Vin = i_1 R_1$$

$$i_1 = \frac{Vin}{R_1} = -i_2$$

$$Vout = \int_0^t \frac{i_2}{C_1} dt$$

$$Vout = -\int_0^t \frac{Vin}{R_1 C_1} dt = -\frac{1}{R_1 C_1} \int_0^t Vin\, dt$$

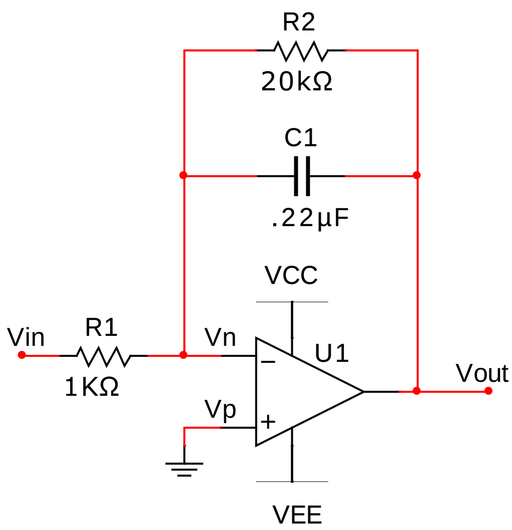


Figure 14. Integrator with shunt.

2. Analyze the circuit in figure 14 (same as figure 4) to calculate the low-frequency gain. Show that for $\gg \frac{1}{R_2 C_1}$, this circuit also functions as integrator.

   At low frequency Z_{C1} → ∞, making it behave like the inverting amp in 6.1.

   $$Av = -\frac{R2}{R1} = -\frac{20\ K\Omega}{1\ K\Omega} = -20$$

   At high frequency, the impedance of the capacitor is much less than that of R2, making it behave like an integrator.

   $$Z_{C1} = \frac{1}{sC_1} \ll R_2$$

3. Simulate this circuit and capture images of your schematic and of oscilloscope displays of Vin and Vout with Vin set to be a sine wave, a square wave and a triangle wave. In each case, set Vin = 1.0 Vpp at 1 KHz, 0 V DC offset.

4. Build this circuit and capture screenshots with Vin set to be a sine wave, a square wave and a triangle wave = 1.0 Vpp at 1 KHz, 0 V DC offset.

5. Reset Vin = 0.5 Vpp sine wave at 1 KHz, 0 V DC offset. While it's running, watch the oscilloscope as you remove R2 and then put it back. Describe what you observed. What is the purpose of R2?

6 Simple differentiator

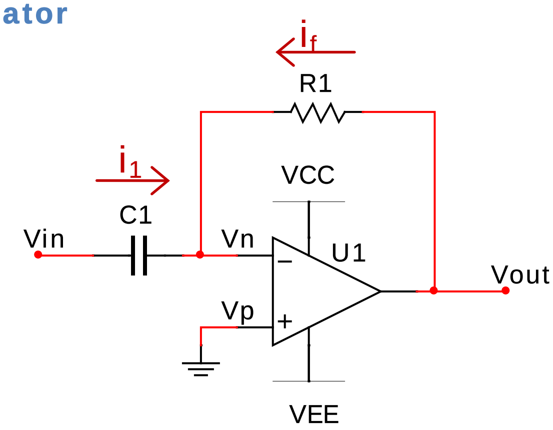


Figure 15. Simple differentiator.

1. Analyze the differentiator circuit in figure 15 (same as figure 3) to derive an equation for Vout(t) as a function of Vin(t). Show that the output is the derivative of the input.

$$Vout = i_f R_1$$

$$i_f = \frac{Vout}{R_1} = -i_1$$

$$Vin = \int_0^t \frac{i_2}{C_1} dt$$

$$Vin\, C_1 = \int_0^t i_2\, dt$$

$$i_2 = C_1 \frac{dVin}{dt}$$

$$i_2 = C_1 \frac{dVin}{dt} = -\frac{Vout}{R_1}$$

$$Vout = -R_1\, C_1 \frac{dVin}{dt}$$

2. Simulate or build the circuit with R1 = 1 KΩ and C1 = 0.22 μF and capture screenshots with Vin = 1.0 Vpp sine, triangle and square wave at 1 KHz. Describe what you observe. Does the circuit work as you expected? Can you explain the behavior?

7 Low pass filter

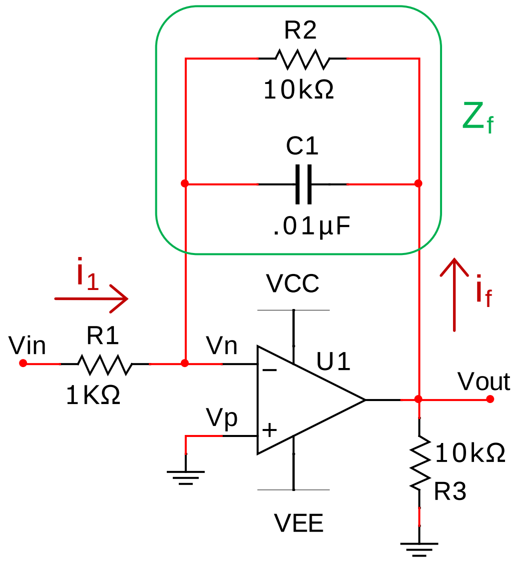


Figure 16. Low-pass filter.

1. Analyze the low-pass filter circuit in figure 16 (same as figure 5) to show that for $Vin(t) = Acos(\omega t)$:

$$Vout(t) = -\frac{R_2}{R_1}Acos(\omega t)\left(\frac{1 - j\omega R_2 C_1}{1 + \omega^2 {R_2}^2 {C_1}^2}\right)$$

$$Y_f = \frac{1}{R_2} + sC_1$$

$$Z_f = \frac{1}{Y_f} = \frac{1}{\frac{1}{R_2} + sC_1} = \frac{R_2}{sR_2C_1 + 1}$$

$$i_f = \frac{Vout}{Z_f} = Vout\left(\frac{sR_2C_1 + 1}{R_2}\right)$$

$$i_1 = \frac{Vin}{R_1}$$

$$i_f = -i_1$$

$$\frac{Vin}{R_1} = -Vout\left(\frac{sR_2C_1 + 1}{R_2}\right)$$

$$\frac{Vout}{Vin} = -\frac{R_2}{R_1}\left(\frac{1}{sR_2C_1 + 1}\right)$$

$$Vin = A\cos(\omega t)$$

$$s = j\omega$$

$$\frac{Vout}{Vin} = -\frac{R_2}{R_1}\left(\frac{1}{j\omega R_2C_1 + 1}\right)$$

$$\left(\frac{1}{j\omega R_2C_1 + 1}\right)\left(\frac{1 - j\omega R_2C_1}{1 - j\omega R_2C_1}\right) = \left(\frac{1 - j\omega R_2C_1}{1 + {R_2}^2{C_1}^2}\right)$$

$$\frac{Vout}{Vin} = -\frac{R_2}{R_1}\left(\frac{1 - j\omega R_2C_1}{1 + \omega^2{R_2}^2{C_1}^2}\right)$$

$$G = \frac{|Vout|}{|Vin|} = \frac{R_2}{R_1}\left|\frac{1 - j\omega R_2C_1}{1 + \omega^2{R_2}^2{C_1}^2}\right|$$

$$R_1 = 1K = 10^3$$

$$R_2 = R_3 = 10K = 10^4$$

$$C_1 = 0.01\,\mu F = 10^{-8}$$

$$G = \frac{R_2}{R_1}\left|\frac{1 - j\omega(10^4)(10^{-8})}{1 + \omega^2(10^4)^2(10^{-8})^2}\right| = \frac{R_2}{R_1}\left|\frac{1 - j\omega(10^{-4})}{1 + \omega^2(10^{-8})}\right|$$

$$G = \frac{R_2}{R_1}\left(\frac{1}{1 + \omega^2(10^{-8})}\right)|1 - j\omega(10^{-4})|$$

$$|1 - j\omega(10^{-4})| = \sqrt{1 + \omega^2(10^{-8})}$$

$$G = \frac{R_2}{R_1}\left(\frac{1}{1 + \omega^2(10^{-8})}\right)\sqrt{1 + \omega^2(10^{-8})}$$

$$G = \frac{R_2}{R_1}\left(\frac{1}{\sqrt{1 + \omega^2(10^{-8})}}\right)$$

$$G = \frac{R_2}{R_1}\left(\frac{1}{\sqrt{1+\omega^2(10^{-8})}}\right)\left(\frac{10^4}{10^4}\right) = \frac{R_2}{R_1}\left(\frac{10^4}{\sqrt{10^8+\omega^2}}\right)$$

2. Show that for the component values shown, the voltage gain, Av, of this circuit is:

$$Av = \frac{Vout}{Vin} = -\frac{10^5}{\sqrt{10^8+\omega^2}}$$

3. Create a Bode plot of the expected gain from 1 Hz to 100 KHz and calculate the expected cutoff frequency.
4. Simulate your circuit. Capture images of the following.
   a. Your schematic.
   b. An oscilloscope display of Vin and Vout for Vin = 1.0 Vpp, 1 KHz sine wave, 0 V DC offset.
   c. A Bode plot of the frequency response with a cursor at the 3 dB point.
5. Breadboard the circuit and capture screenshots with Vin = 1.0 Vpp sine wave, 0 V DC offset, at 100 Hz, 1 KHz and 10 KHz.
6. Find the frequency at which gain has dropped by 3 dB and capture a screenshot.
7. Create a table of measurements at increasing frequencies from 100 Hz to 100 KHz in a 1-2-5-10 sequence. Try to hold Vin fairly constant as you increase the frequency.

Frequency (Hz)	Vin	Vout	Gain (Av)	Gain (dB)
100				
200				
500				
1K				
2K				
:				
50K				
100K				

8. Create a Bode plot of Gain(dB) versus frequency from your measurements.
9. Compare your three Bode plots and cutoff frequencies based on your calculations, your simulation and your experimental results and explain any differences.