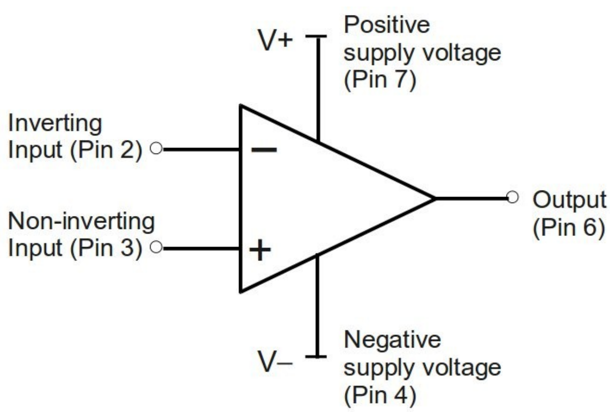
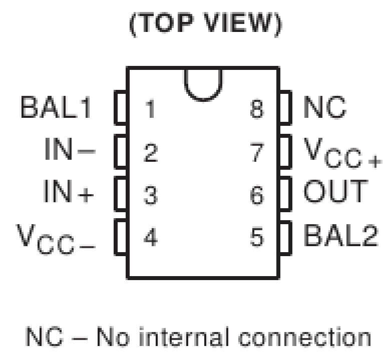
Lab 10: Oscillators (version 1.1)

WARNING: Use electrical test equipment with care! Always double-check connections before applying power. Look for short circuits, which can quickly destroy expensive equipment.

Electronic oscillators can often be more difficult to make work compared to circuits requiring only amplification. This lab uses the LF411 operational amplifier having junction field-effect transistors to achieve a very high input resistance. This greatly reduces loading of the feedback circuit and make it a much better choice than the LM741 in this application. If an obvious notch is not visible on the plastic DIP package, look for a circular indent adjacent to pin 1.

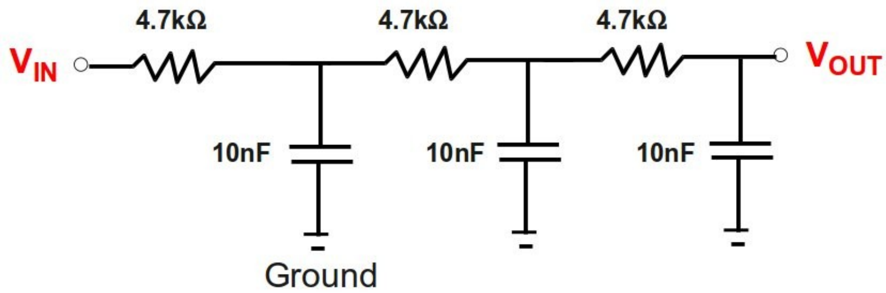




Note: All the experiments in this lab are performed with the Elvis board and software on the computer. No external scope, function generator, or power supply are used.

Phase-shift oscillator

The phase-shift oscillator uses a cascade of three RC filters to achieve a –180° phase-shift between input and output. This feedback circuit is crucial for starting and sustaining oscillations. Measure all 6 component values with the Elvis DMM and then build the following circuit. Evaluate its frequency response with the Bode Analyzer in the Elvis software suite. The Elvis Function Generator (FGEN) is connected to V_{IN} and also to Scope Ch 0 via the BNC 1 port and a coax cable. V_{OUT} is connected using the BNC 2 port to Scope Ch 1. Refer to the Lab 4 for detailed instructions on how to setup a Bode measurement.

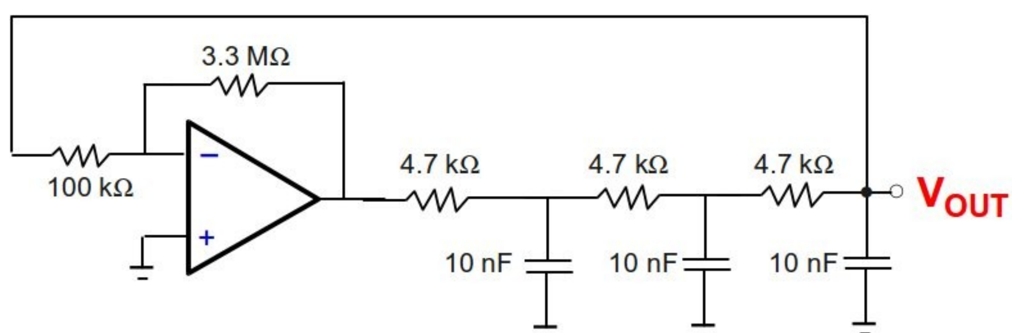


The Bode analyzer provides two important numbers that characterize the feedback circuit: i) the frequency at which a –180° phase-shift occurs and ii) the amplitude decrease between output and input at this critical frequency. To find this frequency accurately, you will need to change the frequency step-size above the default value of 5 steps/decade. In addition, you may have to increase the peak amplitude to a value of 3 or more to reduce noisy data. If you have done this correctly, you should identify a frequency around 8.5 kHz with a corresponding amplitude loss of about –30 dB. Use the LOG function to save the Bode data for your write-up.

Troubleshooting: If the Bode Analyzer does not produce meaningful data, troubleshoot the circuit using the Elvis function generator (FGEN) and the Elvis scope. A 20 kHz sine wave with 1 Vpp on the input should produce a ~ 200 mVpp 180° phase-shifted output signal.

The LF411 op-amp will provide an additional –180° of phase-shift to initiate oscillations at the frequency set by the RC network (op-amp + RC network = 360° total). In addition, it must compensate for the ~ 30 dB of loss the network introduces. This is achieved by selecting a feedback/input resistor ratio to get a gain in excess of –29. Values of 3.3 MΩ and 100 kΩ, respectively, can accomplish this.

Disconnect the feedback circuit from FGEN and scope; connect it to the LF411 op-amp as shown in the following diagram:

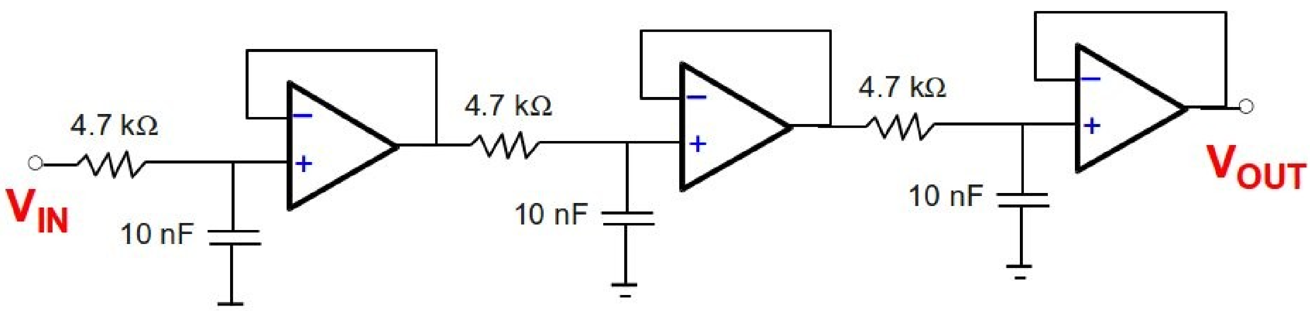


Place the op-amp on the Elvis board (power should be off) so that it straddles a row divider, which allows independent connection of all 8 pins. Connect pin 7 to the +15V and pin 4 to –15V voltage sources on the lower left. Be sure to connect the non-inverting op-amp input and one side of each capacitor to the power supply ground on the Elvis board (adjacent to the ±15V dc supply pins).

Turn on the power and confirm the presence of approximately sinusoidal oscillations at the design frequency by using the Ch 0 input of the Elvis scope. Stop the scope and enable the Elvis Dynamic Signal Analyzer (DSA). This will display the output spectrum of the oscillator. You will see a spectral peak with a width that indicates the coherence and stability of the oscillations. There may be other weaker peaks and harmonics. Stop the DSA and record the data to disk using the LOG function. Include this spectrum in your write-up. Note: The LOG file also records a temporal trace of the signal that should be omitted from the report.

Buffered phase-shift oscillator

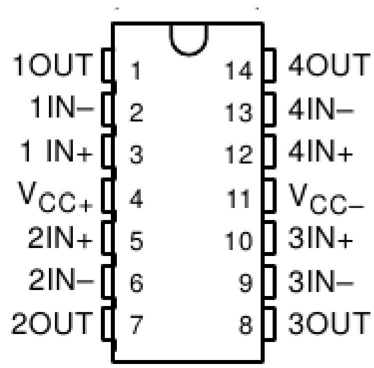
The cascaded sequence of RC filters above presents considerable difficulty for analysis and design. This is because each stage loads the preceding stage resulting in a complicated frequency response function. To eliminate this problem, the RC stages can be isolated using buffers, implemented with unity-gain op-amps as shown in the following circuit:



The response (i.e. transfer function) is simply the product of the three individual RC low-pass filters. For three identical sections this is:

$$G = \frac{V_{\mathrm{OUT}}}{V_{\mathrm{IN}}} = \left[\frac{1}{1 + j\omega RC}\right]^3$$

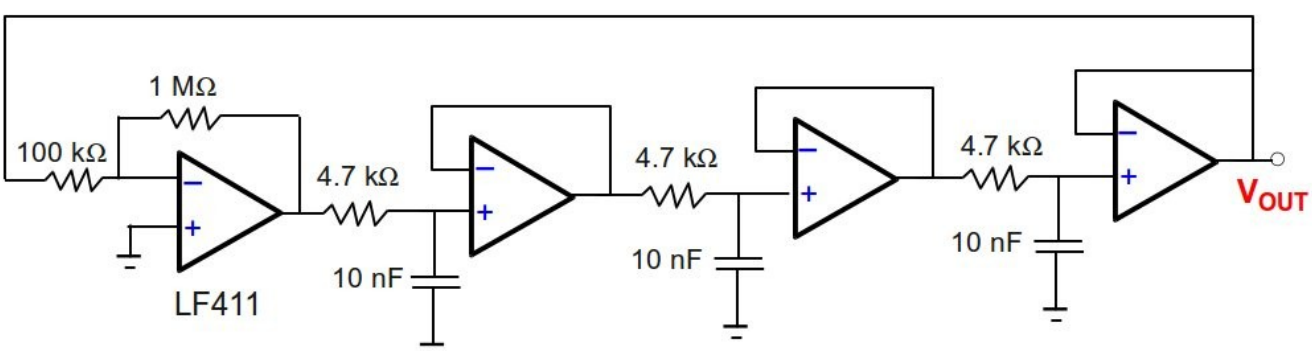
The LM741 op-amp can adequately perform the buffer function, although placing three additional op-amps on the breadboard can make wiring complicated and increases the chance for mistakes. As an alternative, one can use the LM348 IC, which contains four LM741 op-amps on a single chip. The pin layout is as follows:



If you choose to use this IC to implement the buffered feedback circuit, you will wire three of the four available op-amps. Connect pin 4 to +15V and pin 11 to –15V. Build only the feedback network shown above using three op-amp buffer stages. Use extreme care here as there are many connections to be made and wiring mistakes can be difficult to track down.

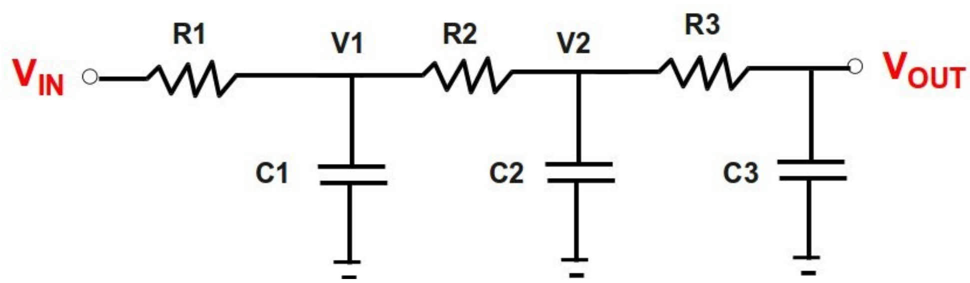
Power on the circuit and repeat the procedure from the first part of the lab by getting the frequency response using the Bode Analyzer. You will see a lower expected oscillation frequency (i.e. frequency where the phase = –180°) compared to the passive circuit; this should be close to 6 kHz. In addition, the buffered circuit has 10 times less loss; you will observe an amplitude reduction at the expected oscillation frequency by approximately –20 dB. This means about 20 dB of gain is required from the high-impedance op-amp to overcome the loss in the feedback network. Record the Bode data using the LOG function.

Now build the buffered phase-shift oscillator by following the schematic diagram below. Be sure to reduce the gain of the amplifying stage accordingly; a 1 MΩ resistor replaces the 3.3 MΩ feedback resistor used in the non-buffered circuit above. Observe the presence of oscillations at the point marked V_{OUT}. Obtain a power spectrum using the Elvis DSA and save it using the LOG button.



Writeup

Provide model curves for your experimental Bode data (amplitude and phase) for both feedback circuits. These involve impedances described by complex numbers and the algebra will get very messy. It is better to use a program like MatLab or LabView to generate the amplitude and phase curves without trying to simplify the equations. The buffered feedback circuit is described by the equation shown above and is very easy to program. Analysis of the non-buffered feedback circuit requires additional steps that are described by referring to this circuit diagram.



The analysis can be performed by realizing that this is a sequence of voltage dividers. The relation between V_{OUT} and V_2 is:

$$\frac{V_{\mathrm{OUT}}}{V_2} = \frac{Z_{C3}}{R3 + Z_{C3}}$$

where Z_{C3} is the capacitor impedance 1/jωC3. The relation between V1 and V2 is slightly more complicated. The impedance Z2 at node V2 is:

$$\frac{1}{Z_2} = \frac{1}{Z_{C2}} + \frac{1}{R3 + Z_{C3}}$$

which then defines the ratio between V2 and V1:

$$\frac{V_2}{V_1} = \frac{Z_2}{R2 + Z_2}$$

The impedance Z1 at the node marked V1 is:

$$\frac{1}{Z_1} = \frac{1}{Z_{C1}} + \frac{1}{R2 + Z_2}$$

This determines the relation between V_{IN} and V_1:

$$\frac{V_1}{V_{\mathrm{IN}}} = \frac{Z_1}{R1 + Z_1}$$

which then leads directly to the circuit transfer function:

$$G = \frac{V_{\mathrm{OUT}}}{V_{\mathrm{IN}}} = \left(\frac{V_{\mathrm{OUT}}}{V_2}\right)\left(\frac{V_2}{V_1}\right)\left(\frac{V_1}{V_{\mathrm{IN}}}\right)$$

The amplitude (dB) and phase (radians) are:

$$\text{Amplitude (dB)} = 20\log_{10}|G|$$

$$\text{Phase (rad)} = \text{atan}\left[\frac{\text{Im}(G)}{\text{Re}(G)}\right]$$

You will need to convert radians to degrees to match the Bode analyzer data. Make four plots (2 for each circuit) showing amplitude (dB) and phase (degrees) as a function of frequency (on a log-10 scale) to compare with your data. It is important to understand that you are modeling the transfer function of the feedback network ONLY. Do not analyze the complete oscillator circuit. Do, however, include the DSA spectra from both oscillators. Send as a single .pdf file to the instructor before the next class meeting.