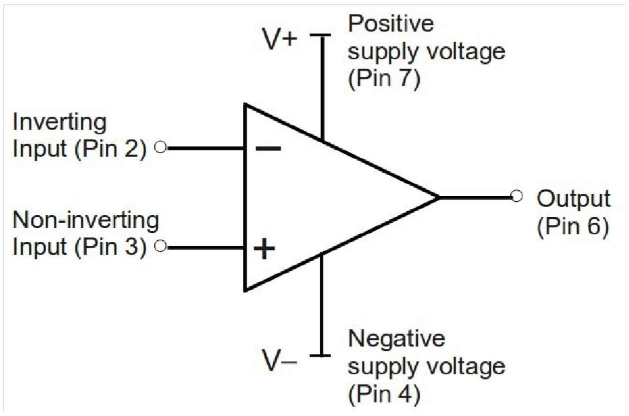
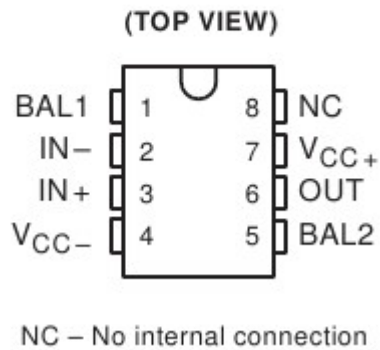
Lab 10: Oscillators (version 1.3)

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

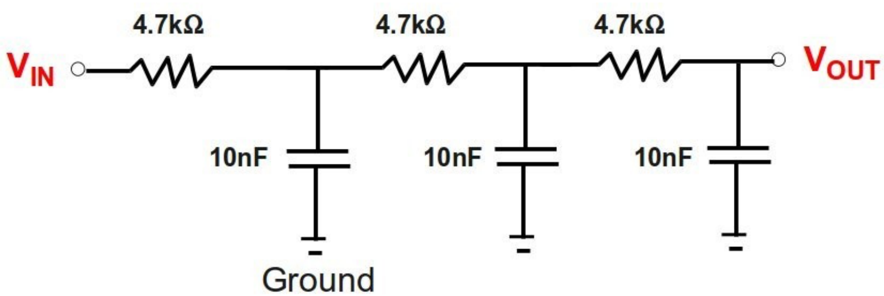
Electronic oscillators can often be more difficult to make work compared to circuits requiring only amplification. This lab uses the LF411 operational amplifier having junction field-effect transistors to achieve a very high input resistance.





Phase-shift oscillator

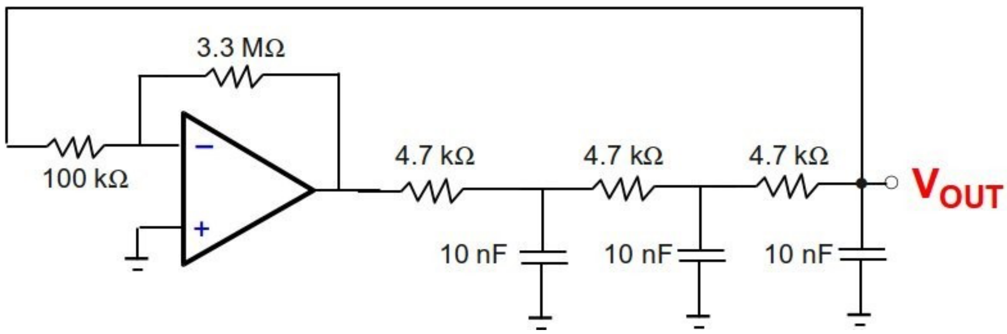
The phase-shift oscillator uses a cascade of three RC filters to achieve a −180º phase-shift between input and output. This feedback circuit is crucial for starting and sustaining oscillations. Measure all 6 component values and then build the following circuit. Investigate the frequency response of the oscillator. Use a sinusoidal waveform for V_{IN} and monitor V_{IN} and V_{OUT} in the Scope.



Investigate the frequency response of this oscillator in terms of amplitude V_{IN} /V_{OUT} and phase for different frequencies. That provides two important numbers that characterize the feedback circuit: i) the frequency at which a −180º phase shift occurs and ii) the amplitude decrease between output and input at this critical frequency. Find this frequency. For the circuit above, this frequency should be around 7-10 kHz with a corresponding amplitude loss of about −30 dB. Take enough data to g**enerate the Bode diagram for this circuit.**

The LF411 op-amp will provide an additional −180º of phase-shift to initiate oscillations at the frequency set by the RC network (op-amp + RC network = 360º 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 dB. Values of 3.3 MΩ and 100 kΩ, respectively, can accomplish this. For the op-amp use +/-15V voltage sources (alternative you can use +/-12Vdc).

Modify your circuit to include the LF411 op-amp:



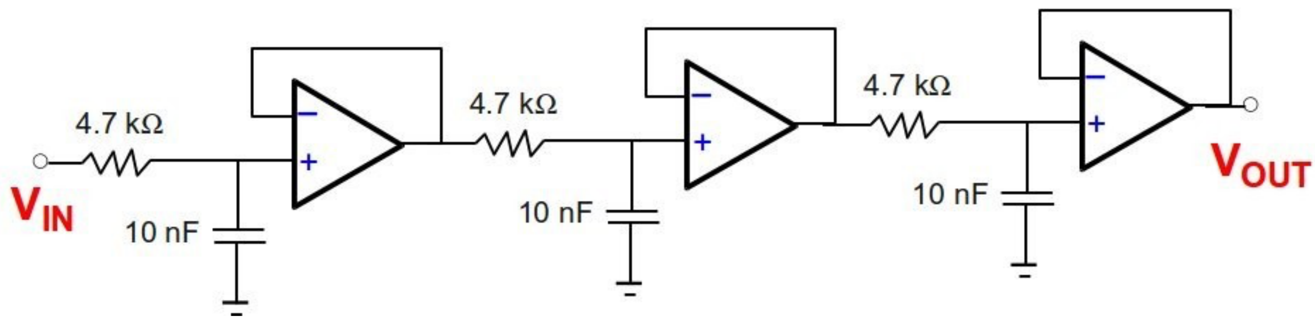
Confirm the presence of sinusoidal oscillations at the design frequency. Investigate the output spectrum of the oscillator. Use the FFT from the scope function. You will see a spectral peak with a width that indicates the (temporal) coherence and stability of the oscillations. Estimate the center and width of the peak.

FFT analysis (off line with data collection and analysis)

Save a long trace of the output of the oscillator (showing the sinusoidal oscillators) with a deep memory scope. Then perform spectral analysis in a computer program (matlab, python, etc.). Characterize the spectrum from your spectral analysis in terms of resonance frequency, and spectral purity (width of the resonance). This analysis will be more accurate than the observations using a scope. Note that to obtain high resolution in the spectrum, the saved trace output from the oscillator needs to contain many points.

Buffered phase-shift oscillator

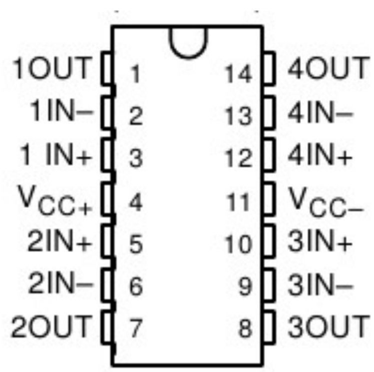
The cascaded sequence of RC filters above presents considerable difficulty for analysis and design. This is because each stage loads the preceding stage resulting in a complicated frequency response function. To eliminate this problem, the RC stages can be isolated using buffers, implemented with unity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



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

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

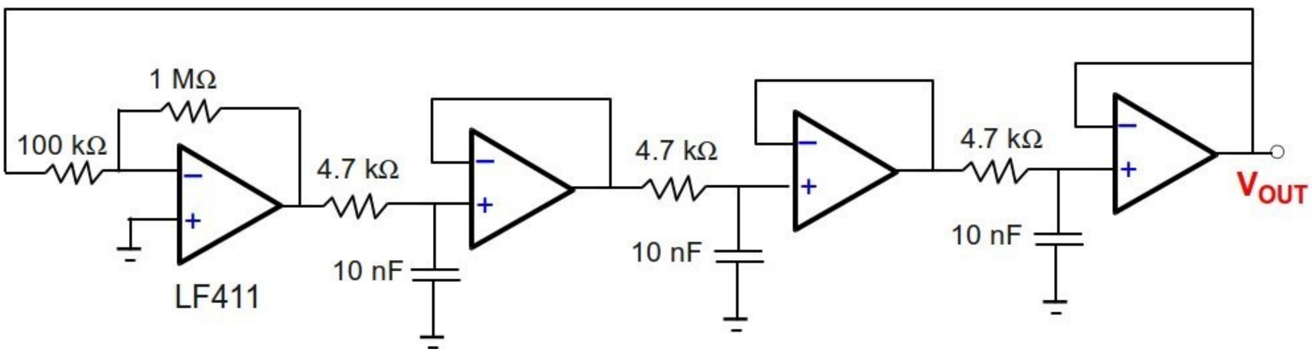
The LF441 op-amp can adequately perform the buffer function, although placing three additional op-amps make it complicated. As an alternative, one can use the LM348 IC, which contains four op-amps on a single chip. The pin layout is as follows:



If using this IC to implement the buffered feedback circuit, you will wire three of the four available op-amps. Connect pin 4 to +15V (or +12V) and pin 11 to −15V(or -12V). Build the feedback network shown above using three op-amp buffer stages.

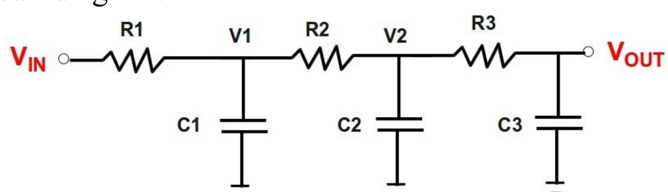
Power on the circuit and repeat the procedure from the first part of the lab by getting the frequency response. You will see a lower expected oscillation frequency (i.e. frequency where the phase = -180^{o}) compared to the passive circuit; this should be close to 6 kHz. In addition, the buffered circuit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

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.



FFT analysis (off line with data collection and analysis)
Save a long trace of the output of the oscillator (showing the sinusoidal oscillators) with a deep memory scope. Then perform spectral analysis in a computer program (matlab, python, etc.). Characterize the spectrum from your spectral analysis in terms of resonance frequency, and spectral purity (width of the resonance).

Analysis
Provide model curves for your experimental Bode data (amplitude and phase) for the feedback circuit. These involve impedances described by complex numbers and the algebra will get very messy. It is better to use a program like MatLab 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 circuit in the non-buffered case 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 VOUT and V2 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: which then

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

leads directly to the circuit transfer function:

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

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

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

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

It is important to understand that you are modeling the transfer function of the feedback network ONLY. Do not analyze the complete oscillator circuit.

The second part of the analysis is about analyzing the oscillators. This includes the spectra analysis from oscillators from FFT, as described above.