Tuesday 2/19/19

Nonlinear Oscillators

Our definition: an oscillator with a periodic non-sinusoidal output, such as a square wave.

1) Sinusoidal oscillator circuit with really high amplifier gain, much higher than necessary to satisfy the BSC

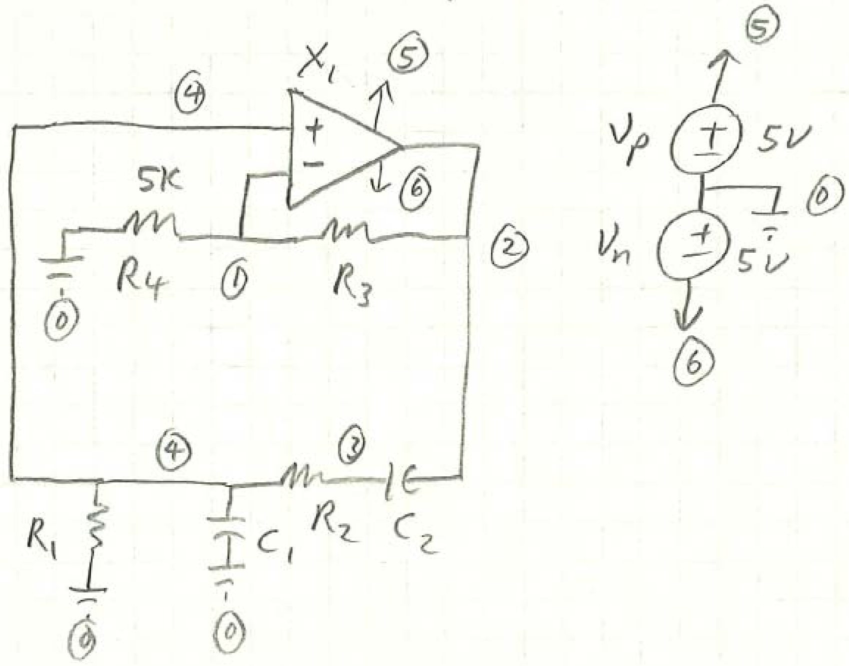
Let's revisit the Wein bridge oscillator (shown on next page)

R_3 of 15 kΩ achieved oscillation. Let's make R_3 by 25 kΩ and evaluate the difference. As R3 gets large, the tops of the output signal flatten out, more closely approximating a square wave. This forces more of the time varying signal to reside in the nonlinear range of the op amp, effectively clipping it.

However, the bottom part of the output square wave is close to -4V, not 0V, as would be expected of a digital signal. A clipping diode can be added off the op amp output signal and applied to a 100 kΩ load resistor. This removes most of the negative going part of the periodic signal.

Two CMOS inverters were added after the 100 kΩ load resistor, and fed to another 100 kΩ load resistor to square up the signal <see below>.

PSpice Simulated Wein Bridge Oscillator



$f = \frac{1}{2\pi RC} = \frac{1}{2\pi(159.155)(1\times10^{-6})} = 1000\ kHz$

$C_1 = C_2 = 1\mu F$

$R_1 = R_2 = 159.155\Omega$

$1 + \frac{R_3}{R_4} = 3 \rightarrow R_4 = 5K\Omega,\ R_3 = 10K\Omega$

X_1: AD8610 op amp → 25MHz GBW product

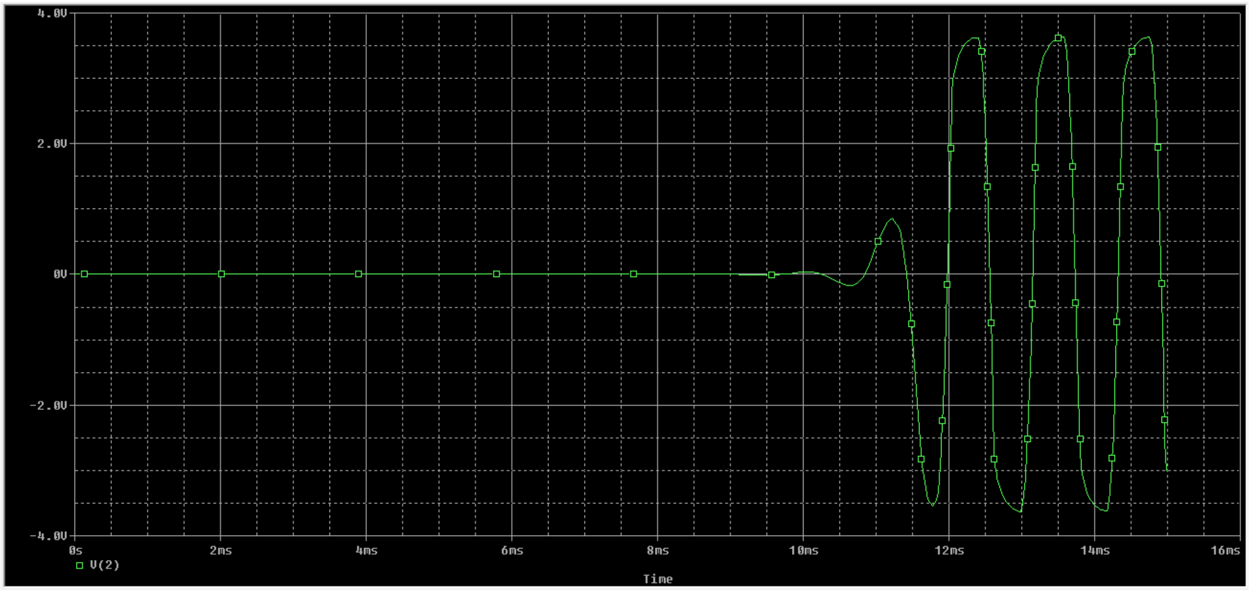
Result → no oscillation

∴ R_3 increased to $15K\Omega$ to achieve oscillation

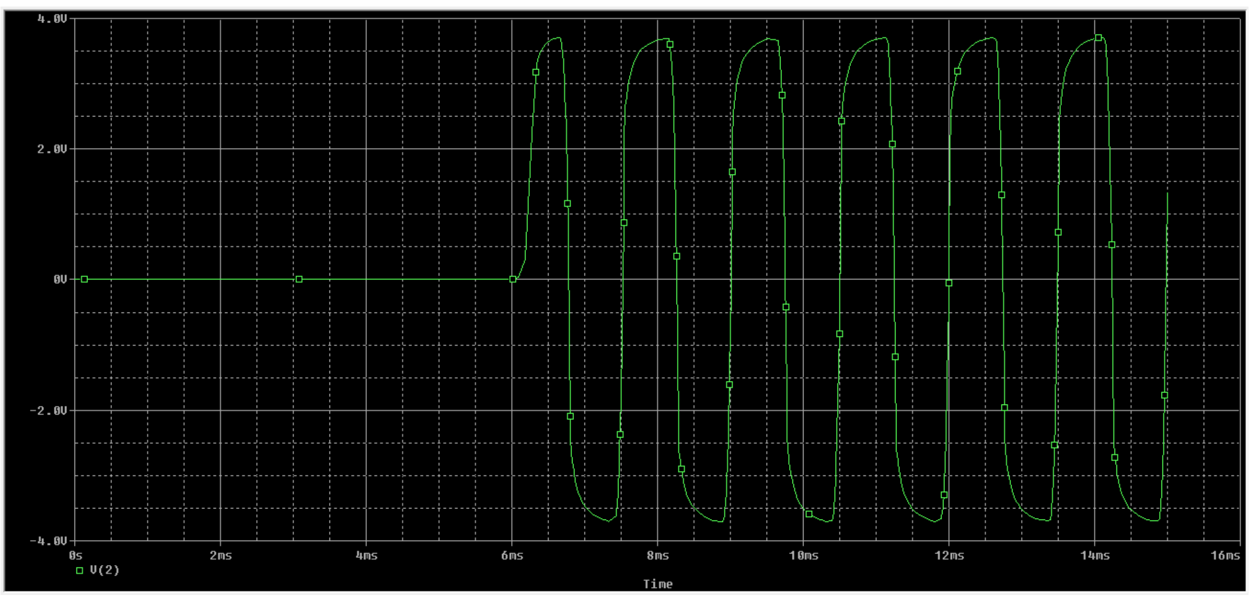
Output: Distorted sinusoid: f = 857.93 Hz

Possible causes for lower freq:

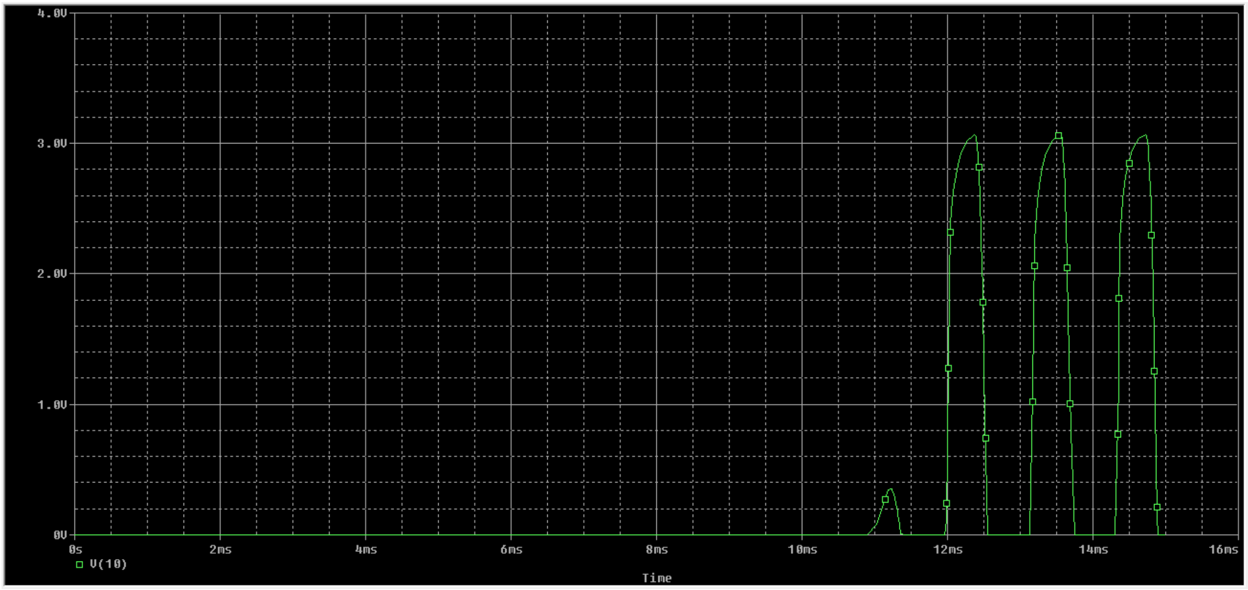
1. phase shift in op amp
2. nonlinear distortion near power supply rails



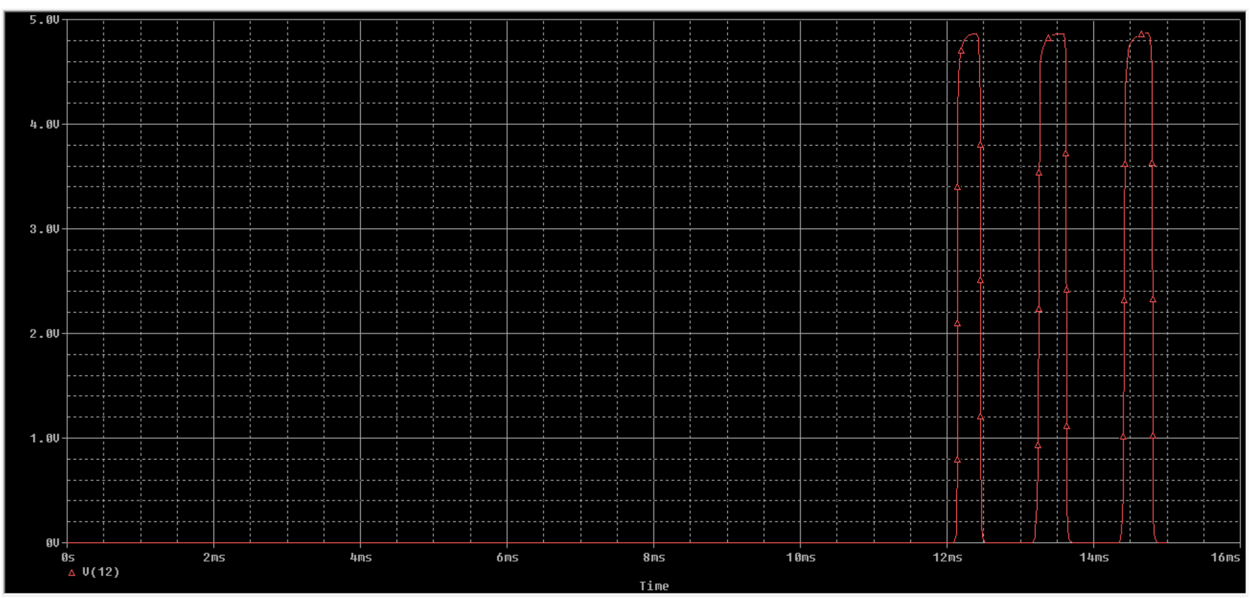
V(2) with R3 = 15 kΩ



V(2) with R3 = 25 kΩ



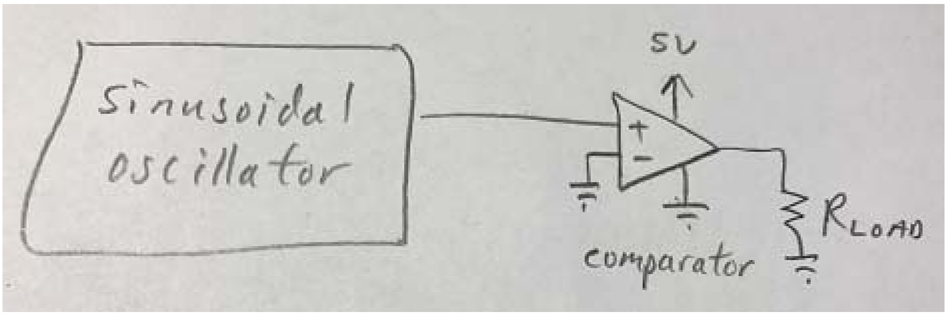
Voltage waveform after the diode. Observe that the peak voltage has dropped due to the voltage drop across the diode.



Voltage waveform after two CMOS inverters following the clipping diode circuit.

2) A rail-to-rail comparator added to the sinusoidal oscillator's output

This circuit can convert the sinusoidal output voltage to a square wave.



More on Nonlinear Oscillators

a. Terminology

The term Multivibrator is often used in texts describing nonlinear oscillators. A multivibrator is an electronic circuit that switches between 2 states and consists of two amplifying devices cross coupled with resistors and capacitors:

1. Astable Multivibrator: a multivibrator circuit where neither state is stable. It continually switches back and forth between the two states.

2. Monostable Multivibrator: a multivibrator circuit with one stable state and one unstable state. A trigger pulse causes the circuit to temporarily switch to the unstable state, where the circuit eventually switches back to the stable state and then stays there until another trigger pulse is applied. A One Shot is a multivibrator.

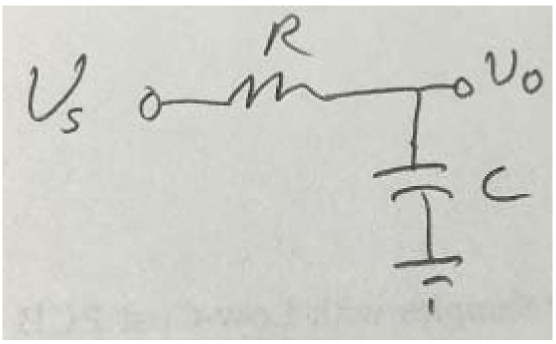
3. Bistable Multivibrator: a multivibrator with two stable states. A trigger pulse is required to change either state. A flipflop is a bistable multivibrator.

A Relaxation Oscillator is an astable multivibrator that uses an active circuit element to charge an inductor or a capacitor through a resistor until a threshold current or voltage is reached, where the circuit then changes states and discharges or recharges the inductor or capacitor. The time constant of the inductor or capacitor circuit determines the oscillation frequency.

A Ring Oscillator consists of an odd number of inverters (NOT gates) connected in a continuous chain. The odd number results in the impossibility of a stable condition, so the circuit oscillates, and the oscillation frequency is due to the propagation delay through each inverter. Adding more inverters to the chain reduces the oscillation frequency.

b. Time constant trigger for a state change

Consider the RC circuit below:



Initially, C has no stored charge (V_o = 0V). At t=0, a positive DC voltage, V_s, is applied to the resistor. V_o will increase until it reaches a trip voltage level, t_{tr} sec later.

$$V_o(s) = V_s(s)\frac{\frac{1}{sC}}{R+\frac{1}{sC}}$$

$$V_o(s) = V_s(s)\frac{\frac{1}{RC}}{s+\frac{1}{RC}}$$

$$V_s(s) = \frac{v_s}{s}$$

$$V_o(s) = \frac{v_s}{s}\frac{\frac{1}{RC}}{s + \frac{1}{RC}} = \frac{A}{s} + \frac{B}{s + \frac{1}{RC}}$$

Using partial fraction expansion:

$$A = \frac{v_s \frac{1}{RC}}{0 + \frac{1}{RC}} = v_s$$

$$B = \frac{v_s \frac{1}{RC}}{-\frac{1}{RC}} = -v_s$$

Therefore:

$$V_o(s) = \frac{v_s}{s} - \frac{v_s}{s + \frac{1}{RC}}$$

$$v_o(t) = v_s(1 - e^{-\frac{t}{RC}})$$

Rearranging terms:

$$\frac{v_o}{v_s} = 1 - e^{-\frac{t}{RC}}$$

$$e^{-\frac{t}{RC}} = 1 - \frac{v_o}{v_s}$$

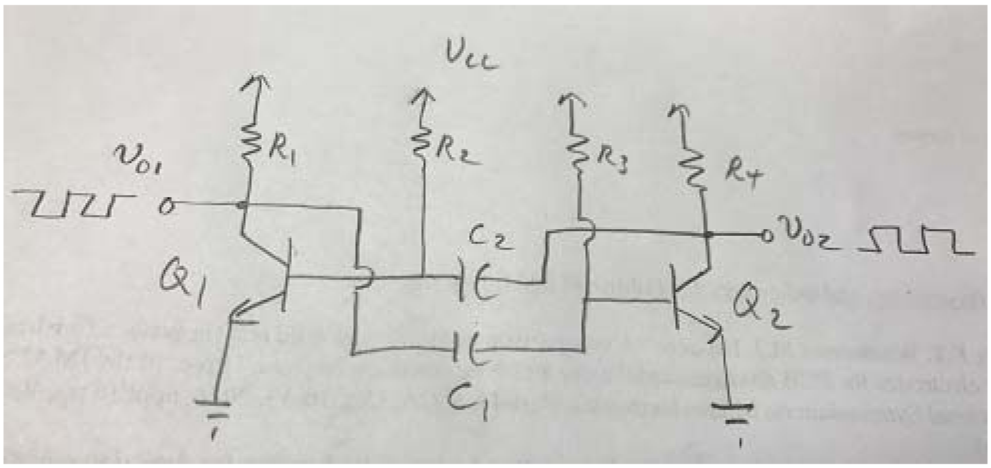
$$-\frac{t}{RC} = \ln\left(1 - \frac{v_o}{v_s}\right)$$

$$t = -RC\left[\ln\left(1 - \frac{v_o}{v_s}\right)\right]$$

τ is the time, t, it takes $v_o(t)$ to reach a trip voltage to cause the multivibrator circuit to change states. For an astable multivibrator with 2 time constant trip circuits, τ_1 and τ_2:

$$T \approx \tau_1 + \tau_2 \, .$$

c. 2 transistor classical astable multivibrator circuit



Q_1 and Q_2 are identical NPN transistors.

$C_1 = C_2$

$R_1 = R_4$, and are relatively small

$R_2 = R_3$

For $v_{BE} < 0.7V$, Q_1 and Q_2 are in cutoff ($I_c = 0A$)

Assume that Q_1 is on ($v_{BE} = 0.7V$) and Q_2 is in cutoff.

The left plate of C_1 is approximately at 0V (gnd) while the right plate is tied to V_{cc} through R_3, charging it up.

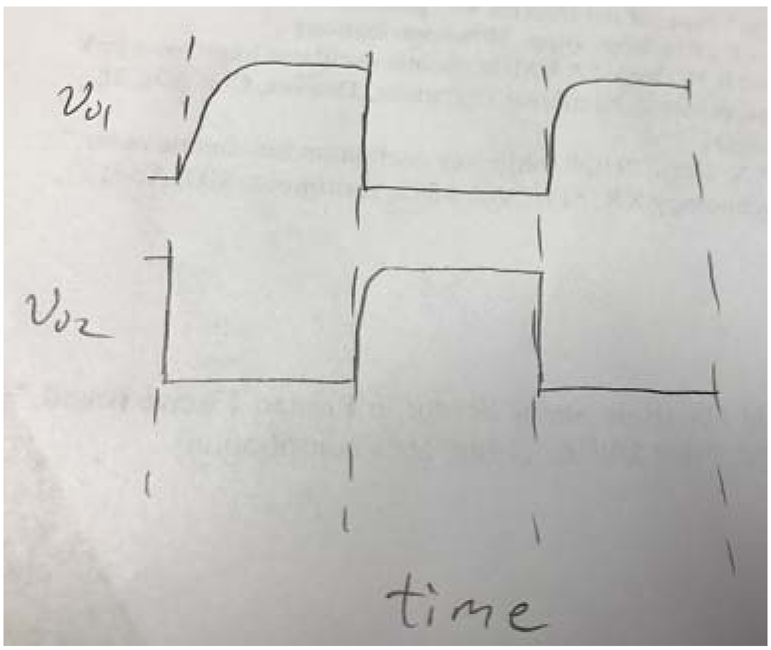
The left plate of C_2 is held at approx. 0.7 V (v_{BE} of Q_1) while the right plate is held at approximately V_{cc} through R_4 with Q_2's $I_c = 0V$)

Once the right plate of C_1 reaches 0.7V, Q_2 turns on (the right plate of C_2 drops to approx. 0V (gnd). Since the voltage across a capacitor cannot change instantaneously, the left plate voltage of C_2 drops from 0.7V to -4.3V, turning off Q_1.

C_2 then starts charging through R_2 until the Q_1's v_{BE} reaches 0.7V …

Therefore, τ_1 is set by C_1R_3 and τ_2 is set by C_2R_2.

$$f \approx \frac{1}{\tau_1 + \tau_2}$$



Approximate waveforms for $v_{o1}(t)$ and $v_{o2}(t)$.

The output voltages, $v_{o1}(t)$ and $v_{o2}(t)$, are inverted. The logic level 1 is V_{cc}. The exponential rise when either output voltage goes high is due to the capacitors charging through R_1 and R_4, respectively.

<u>Application</u>

Let V_{cc} be 12V and "gnd" be -12V. Connect $v_{o1}(t)$ to $v_{o2}(t)$ through the secondary of a 10:1 transformer. The voltage across the primary of the transformer switches between 120V and -120V and is approximately a square wave. The circuit is now a simple DC to AC inverter for power applications, useful for non-sinusoidal power applications.