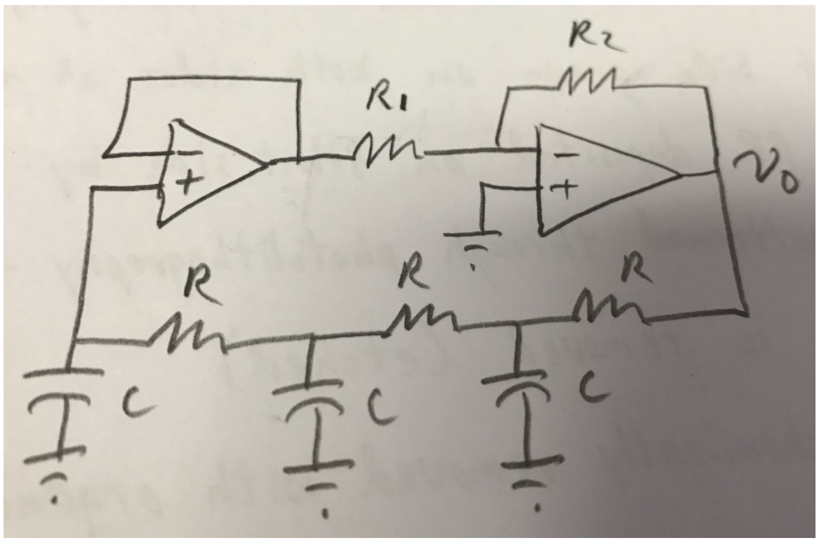
Tuesday 9/2/25

b. RC : CR transformation phase shift oscillator

Here, the R's and C's have been interchanged compared to the earlier phase shift oscillator circuit.

The voltage follower buffer (a second op amp) is needed to prevent loading of the CR ladder circuit.

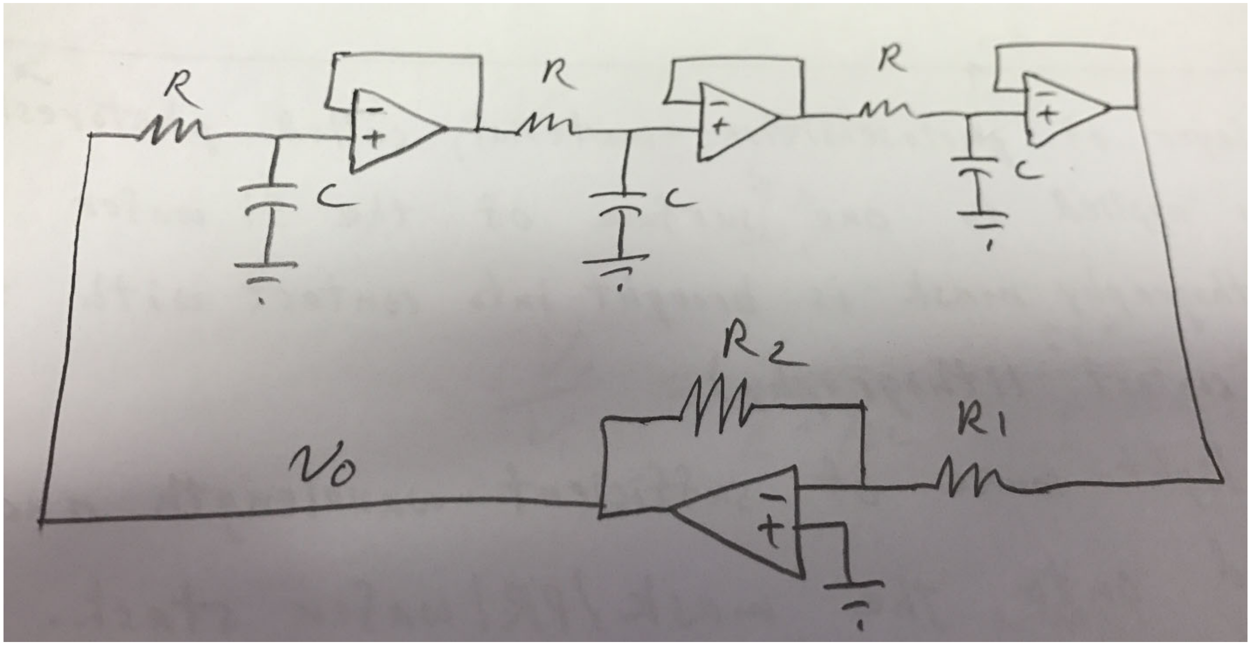


$$A(j\omega)\beta(j\omega) = \frac{-\frac{R_2}{R_1}}{(sCR)^3 + 5(sCR)^2 + 6sCR + 1}$$

Consider: $A(j\omega)\beta(j\omega)|_{\omega=\frac{\sqrt{6}}{RC}} = \frac{-\frac{R_2}{R_1}}{-j6\sqrt{6}-30+j6\sqrt{6}+1} = \frac{-\frac{R_2}{R_1}}{-29}$

Therefore for oscillation: $\omega = \frac{\sqrt{6}}{RC}$ and $\frac{R_2}{R_1} = 29$

c. <u>Buffered RC phase delay oscillator</u>



Easy to build with a quad op amp package.

Each buffered RC stage must provide -60° phase delay at the oscillation frequency:

$$G_{RC} = \frac{1}{1 + j\omega RC}$$

$\emptyset = -\tan^{-1}(\omega RC) = -60^{o}$ per stage

Therefore: $\omega = \frac{\sqrt{3}}{RC}$

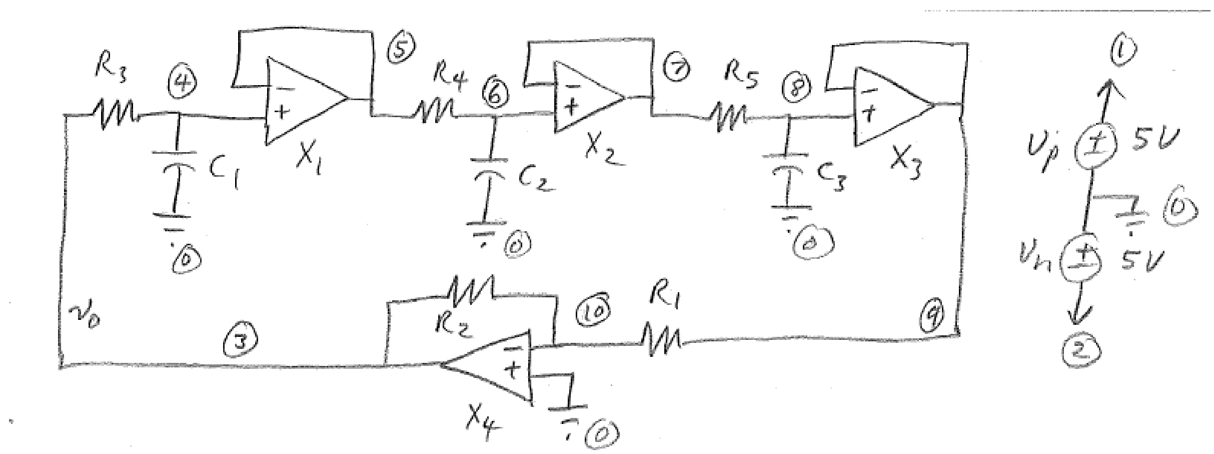
Per RC stage: $|G_{RC}| = \frac{1}{\sqrt{1+(\omega RC)^2}} = \frac{1}{2}$

Therefore, for all 3 RC stages: $|G| = \frac{1}{8}$

Therefore A(jω) to satisfy the BSC for oscillation has a gain of 8.

A gain of 8 is much less restrictive on op amp BW that a gain of 29!

The circuit does require 4 op amps though.



op amp: ADI AD8610

select $f = 1KHz$, $R_3 = R_4 = R_5 = 1k\Omega$

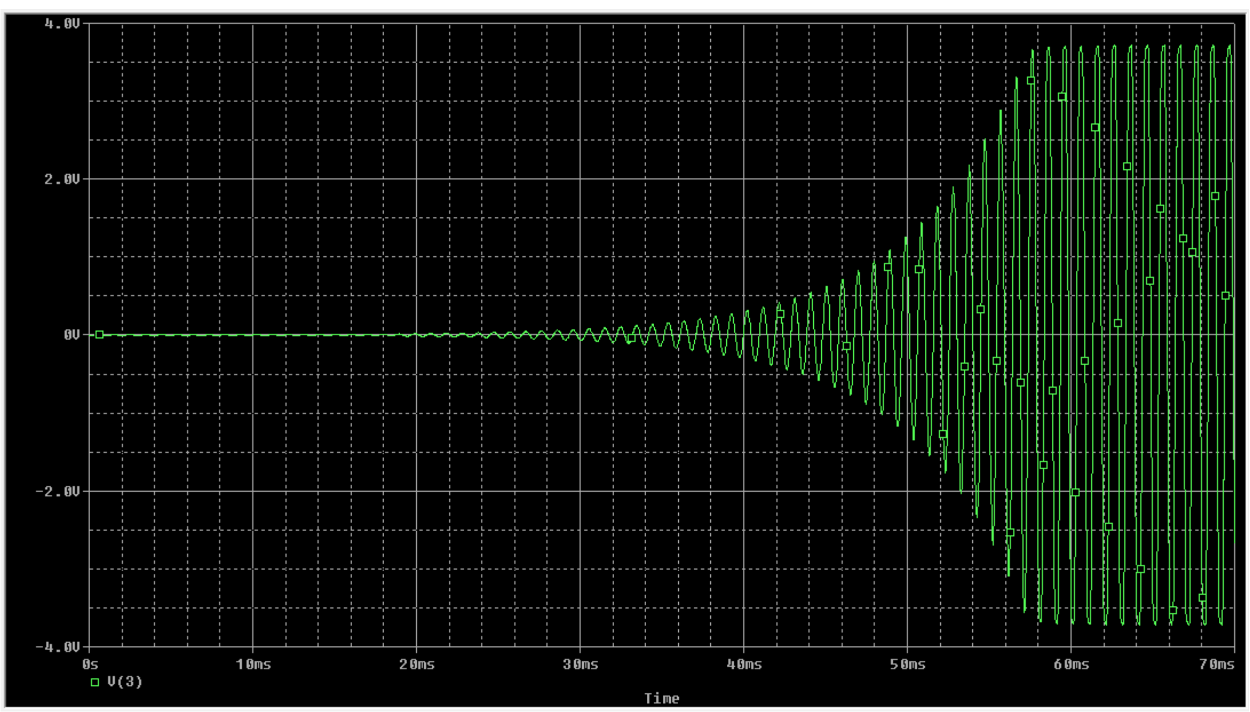
$$C = \frac{\sqrt{3}}{2\pi R f} \approx 0.276\mu F = C_1 = C_2 = C_3$$

let $R_1 = 1k\Omega$, $R_2 = 8k\Omega$

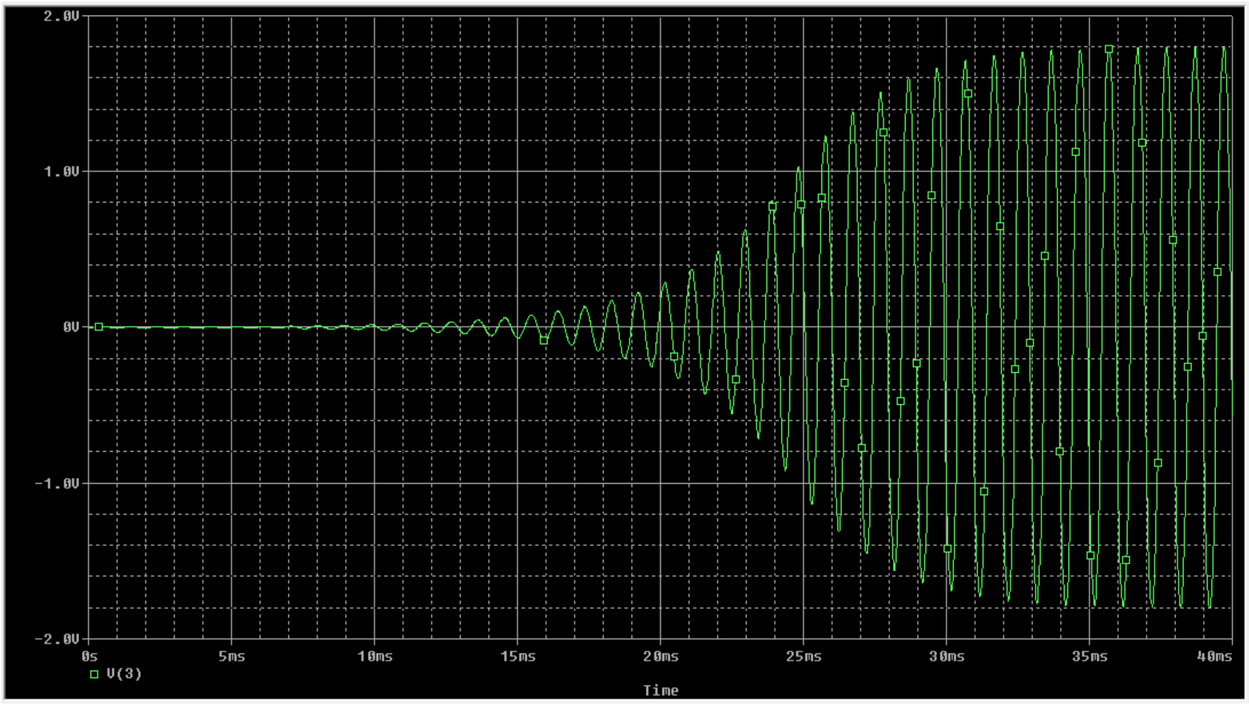
PSpice simulation result: no oscillation

$\therefore$ set $R_2 = 9k\Omega$ → now it oscillates

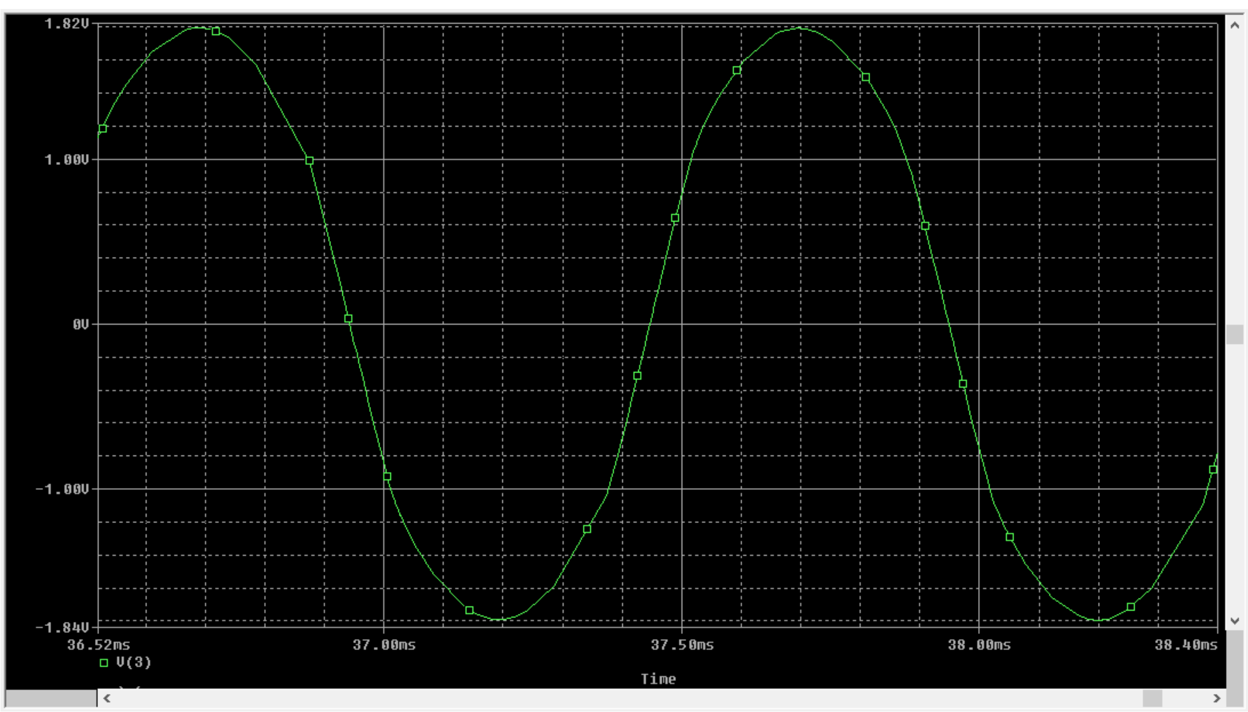
$f_0 \approx 1000\,Hz$



AGC: R_2 replaced with a 10 kΩ pot, two 0.5V Schottky diodes connected between the wiper and one end, in opposite directions. The pot is set with 5 kΩ on each side of the wiper:



Close up:



d. Buffered RC phase delay oscillator with four RC stages

This circuit requires 5 op amps.

Each buffered RC stage must provide -45° phase delay at the oscillation frequency:

$$G_{RC} = \frac{1}{1 + j\omega RC}$$

$$\emptyset = -\tan^{-1}(\omega RC) = -45^o$$

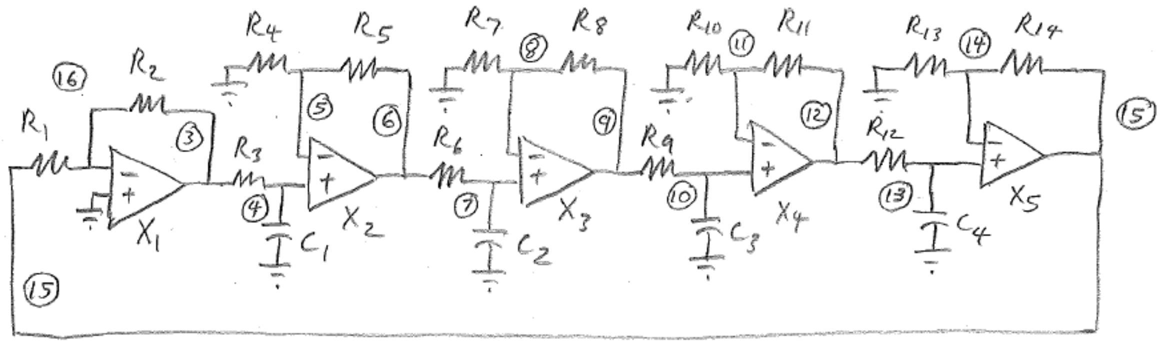
Therefore: $\omega = \frac{1}{RC}$

Per RC stage: $|G_{RC}| = \frac{1}{\sqrt{1+(\omega RC)^2}} = \frac{1}{\sqrt{2}}$

Therefore, for all 4 RC stages: $|G| = \frac{1}{4}$

Therefore A(jω) to satisfy the BSC for oscillation has a gain of 4.

Advantage to this circuit: two sinusoids 90° apart are available from the circuit, which are needed for quadrature signal processing applications.



$1 + \frac{R_5}{R_4} = \sqrt{2} = 1.414$: $R_4 = 10K\Omega$ and $R_5 = 4140\Omega$

$R_4 = R_7 = R_{10} = R_{13}$ and $R_5 = R_8 = R_{11} = R_{14}$

desire $f = 1KHz$: $f = \frac{1}{2\pi RC} \rightarrow C = \frac{1}{2\pi Rf} = \frac{1}{2\pi(1000)(1000)} = 159.16nF$

$R_3 = R_6 = R_9 = R_{12} = 1K\Omega$

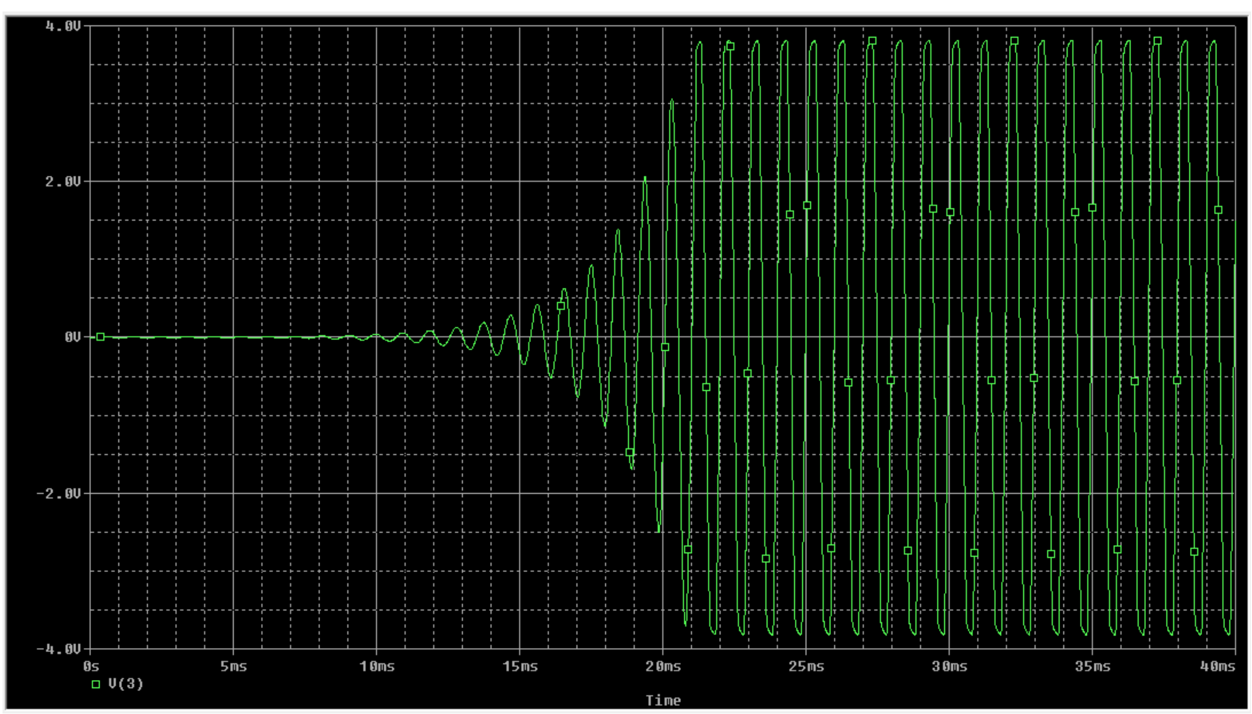
$C_1 = C_2 = C_3 = C_4 = 159.16\,nF$

Let $R_1 = R_2 = 10K\Omega \rightarrow A(j\omega) = -1$

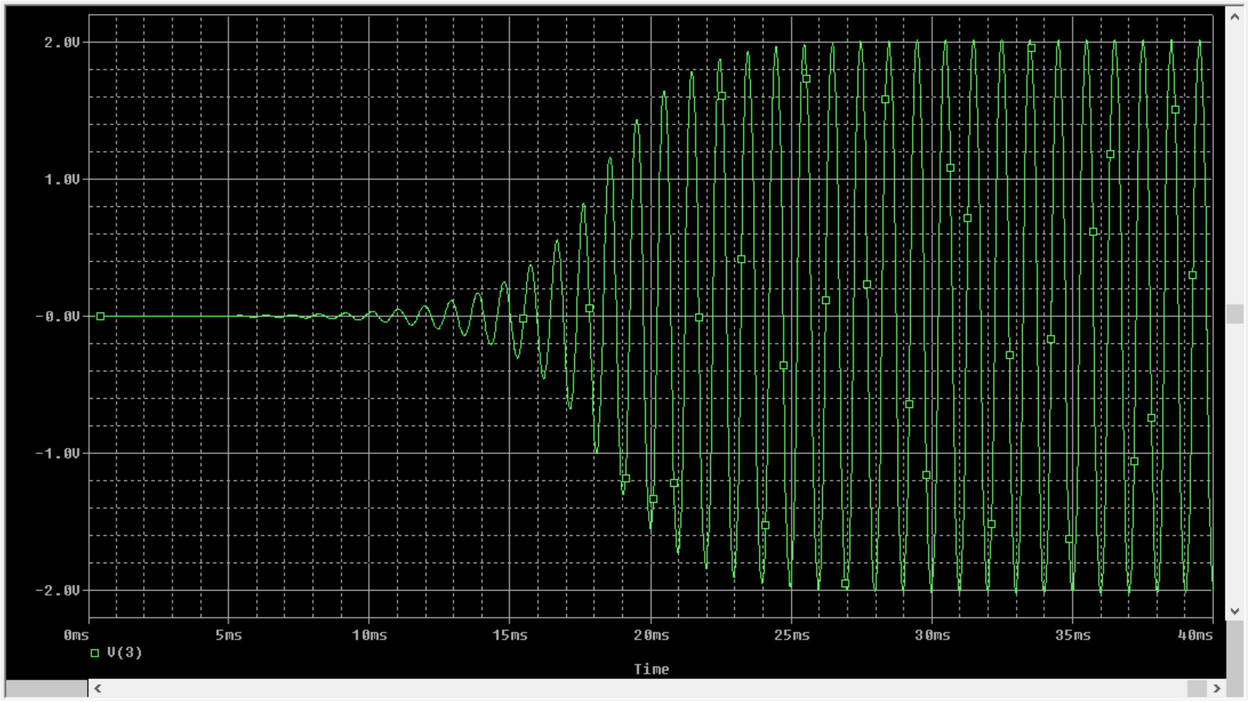
Result : no significant oscillation

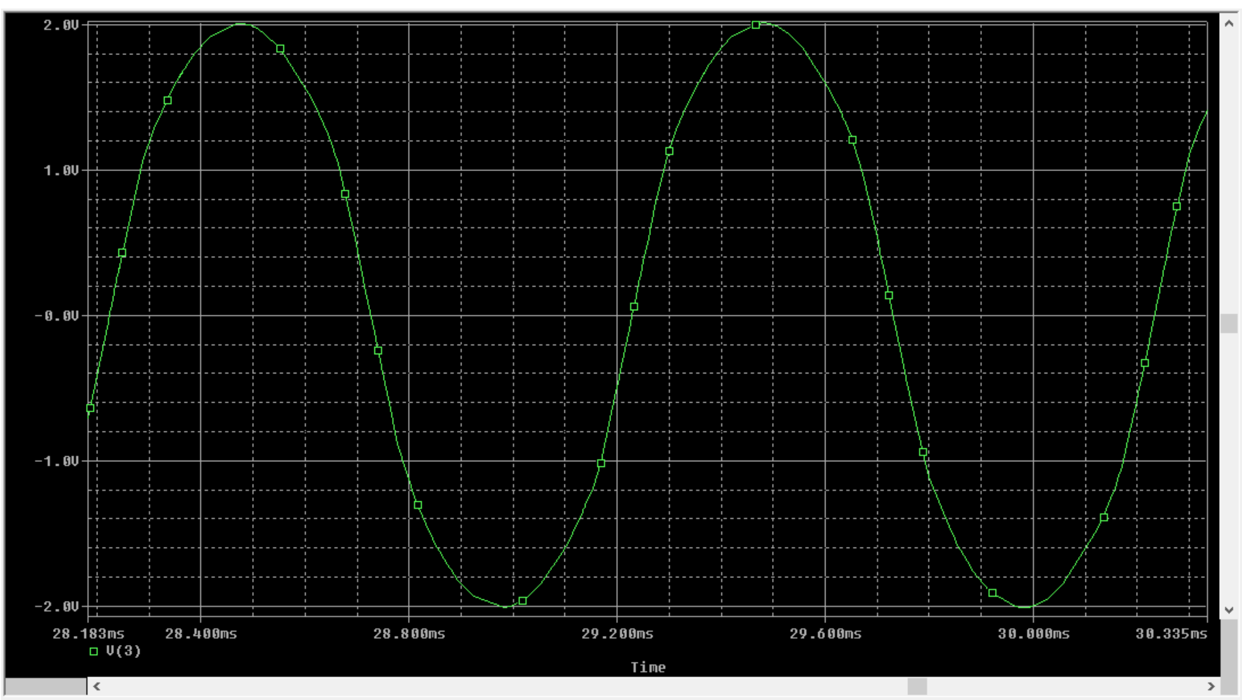
set $R_2 = 13K\Omega \rightarrow$ good oscillation

measured oscillation frequency $\approx 1KHz$

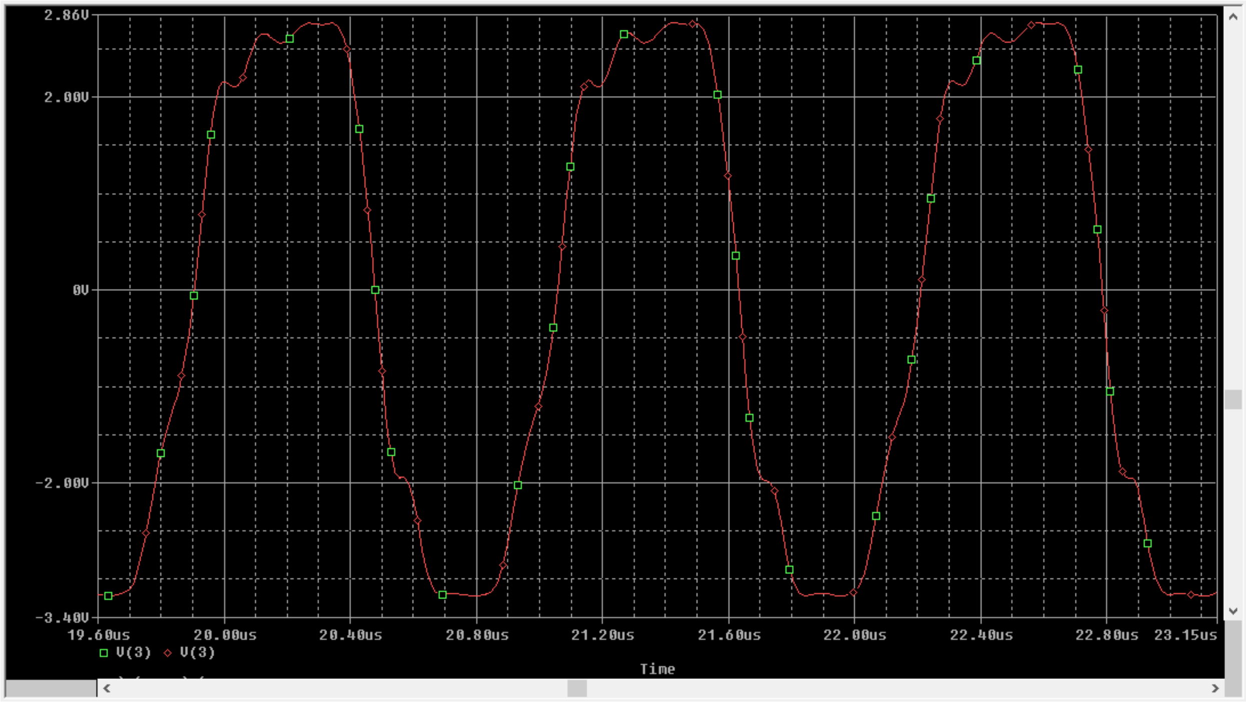


Replacing R_2 with 13 kΩ pot and two Schottky diodes between the wiper and node 3, with 6.4 kΩ between the diodes results in a sinewave with an amplitude of approximately 2V:





How high in frequency can this oscillator go? All C's were replaced with 159.16pF, which should result in a 999,969 Hz (almost 1 MHz) sinewave.



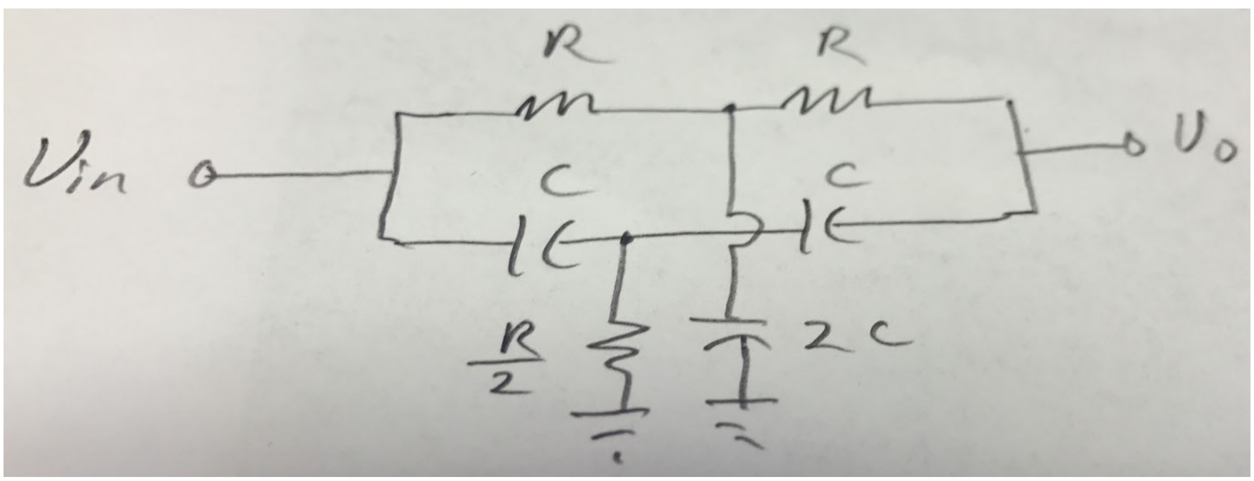
The distorted sinewave has a fundamental frequency of approximately 950 KHz.

The oscillator used the 25 MHz GBW product AD8610 op amp for all op amps.

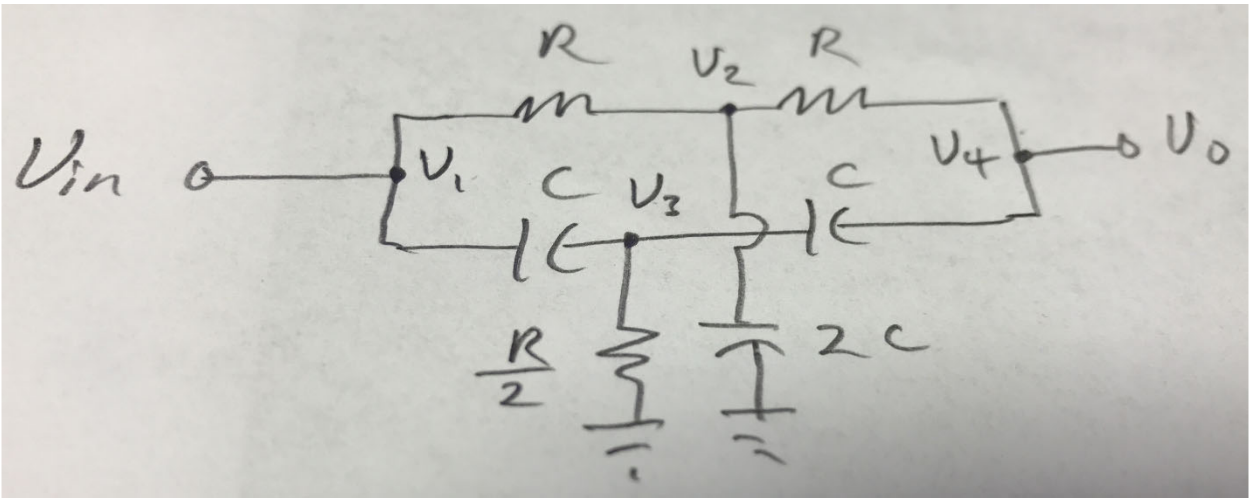
The distortion might also be due to the AGC diodes.

3) Twin T Oscillator

Consider the twin T network below:



To analyze, assign nodes and perform nodal analysis:



$V_1 = V_{in}$ (1)

$$\frac{V_2 - V_1}{R} + \frac{V_2 - V_4}{R} + V_2 2sC = 0$$

Therefore: $V_2 - V_1 + V_2 - V_4 + V_2 2sCR = 0$

And: $V_2(2 + 2sCR) = V_1 + V_4$

Leading to: $V_2 = \frac{V_1+V_4}{2+2sCR}$ (2)

$$(V_3 - V_1)sC + (V_3 - V_4)sC + \frac{2V_3}{R} = 0$$

Therefore: $(V_3 - V_1)sCR + (V_3 - V_4)sCR + 2V_3 = 0$

And: $V_3(2 + 2sCR) = (V_1 + V_4)sCR$

Leading to: $V_3 = \frac{(V_1+V_4)sCR}{2+2sCR}$ (3)

$$\frac{V_4 - V_2}{R} + (V_4 - V_3)sC = 0$$

Therefore: $V_4 - V_2 + (V_4 - V_3)sCR = 0$

And: $V_4(1 + sCR) = V_2 + V_3 sCR$ (4)

(2) into (3) into (4):

$$V_4(1+sCR) = \frac{V_1+V_4}{2+2sCR} + \frac{(V_1+V_4)sCR}{2+2sCR}sCR$$

$$V_4(1+sCR)(2+2sCR) = V_1 + V_4 + (V_1+V_4)(sCR)^2$$

$$V_4(2+2sCR+2sCR+2(sCR)^2-1-(sCR)^2) = V_1(1+(sCR)^2)$$

$$V_4(1+4sCR+(sCR)^2) = V_1(1+(sCR)^2)$$

$V_4 = V_o$

And

$V_1 = V_{in}$

Therefore:

$$\frac{V_o}{V_{in}} = \frac{1+(sRC)^2}{1+4sCR+(sRC)^2}$$

Leading to:

$$\frac{V_o}{V_{in}}(j\omega) = \frac{1-(\omega RC)^2}{1-(\omega RC)^2+4j\omega CR}$$

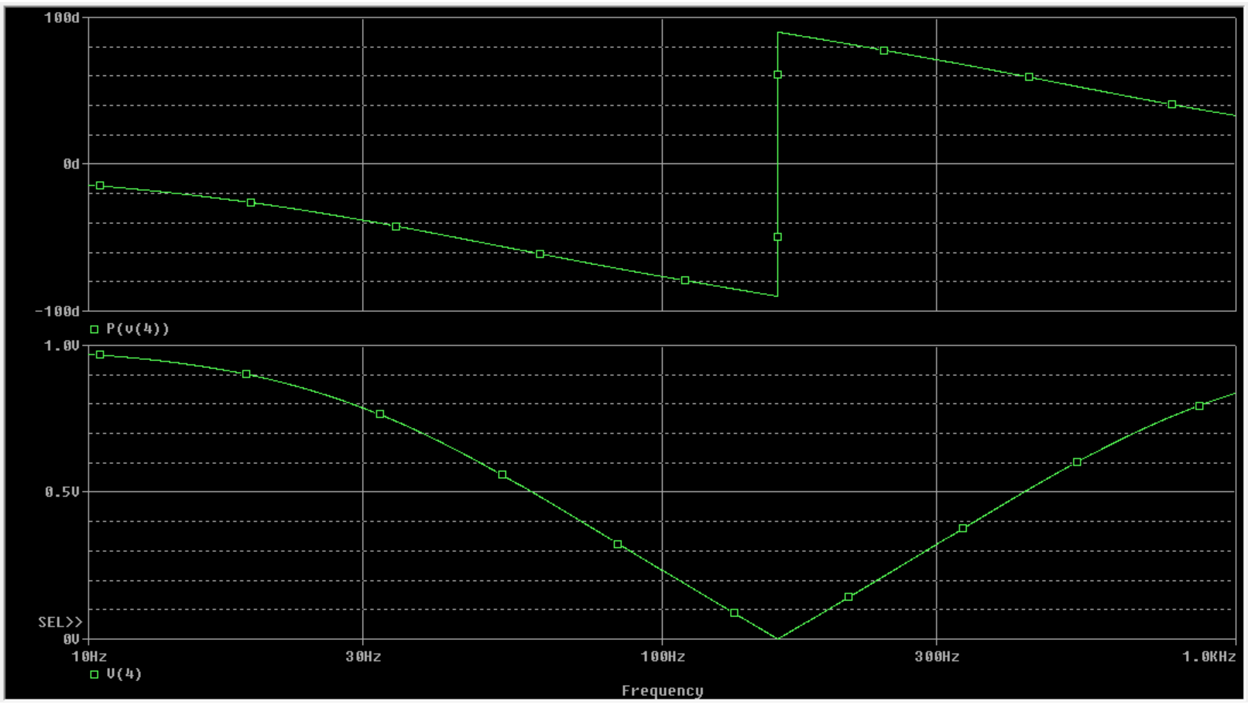
Evaluate at $\omega_o = \frac{1}{RC}$:

$$|\frac{V_o}{V_{in}}(j\omega)|_{\omega=\omega_o} = \frac{1-1}{\sqrt{(1-1)^2+4^2}} = 0$$

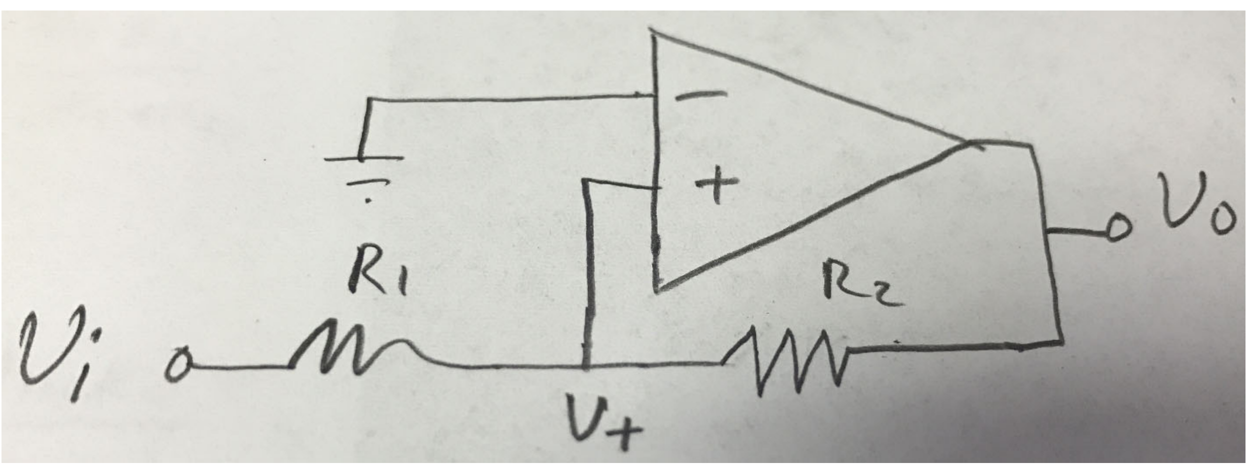
At ω_o, 100% of the transmission from V_i to V_o is blocked!

Consider this PSpice simulation of the twin T network is a notch filter:

PSpice simulation with R = 1 kΩ and C = 1 µf:



Consider the op amp circuit shown below:



The op amp circuit is in a positive feedback configuration.

Using superposition:

$$V_+ = V_i \frac{R_2}{R_1 + R_2} + V_o \frac{R_1}{R_1 + R_2}$$

And:

$$V_o = AV_+$$

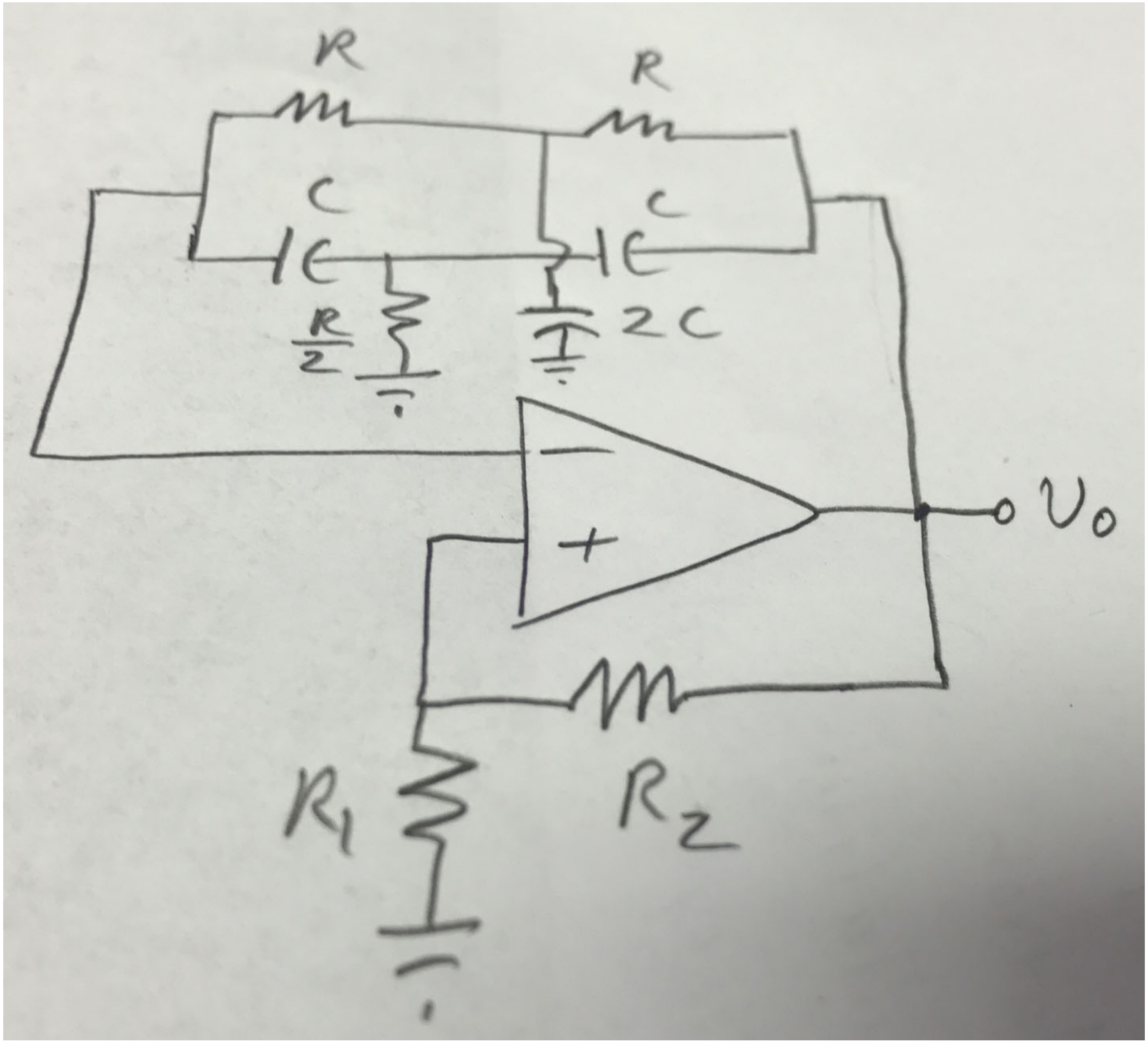
Where A is the op amp open loop gain.

For $V_+ > 0$: V_o goes to the + power supply rail.

For $V_+ < 0$: V_o goes to the - power supply rail.

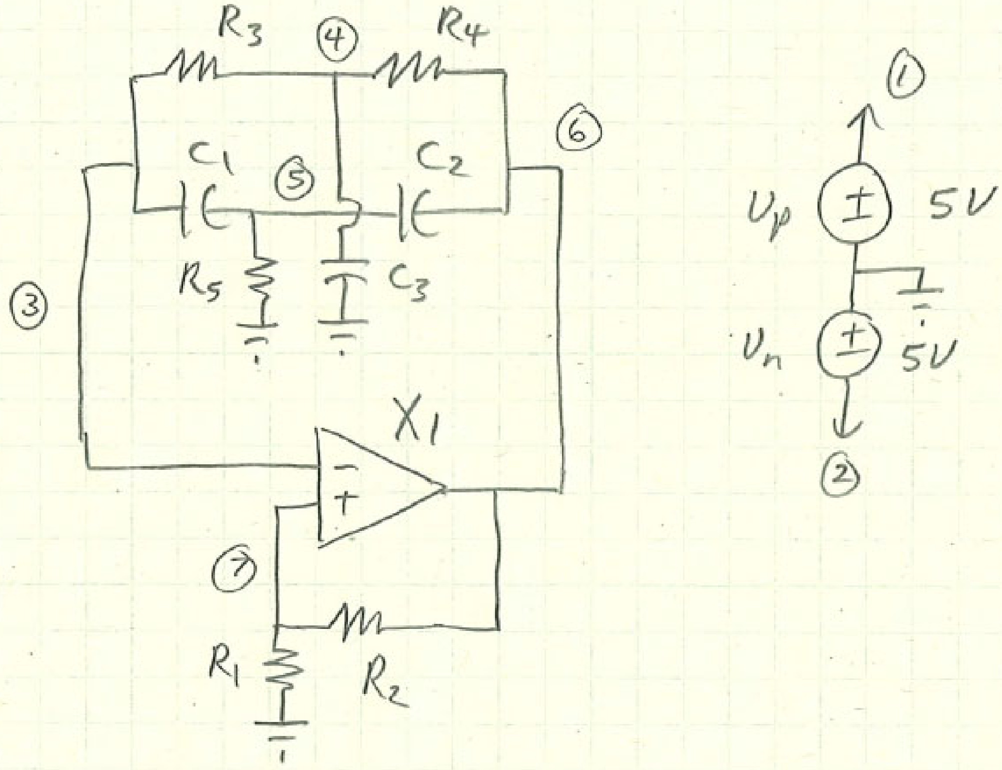
Observe that this circuit has hysteresis.

Putting the two subcircuits together:



The op amp circuit is unstable due to positive feedback. However, the twin T network provides negative feedback except at ω_o, which stabilizes the circuit at other frequencies. At ω_o, the op amp circuit is unstable due to positive feedback, and oscillates at that frequency.

PSpice Simulaton of Twin T Oscillator



$f = 1kHz$, $R_3 = R_4 = 1k\Omega$

$$C = \frac{1}{2\pi R f} = \frac{1}{2\pi (1000)(1000)} = 0.159\mu F = C_1 = C_2$$

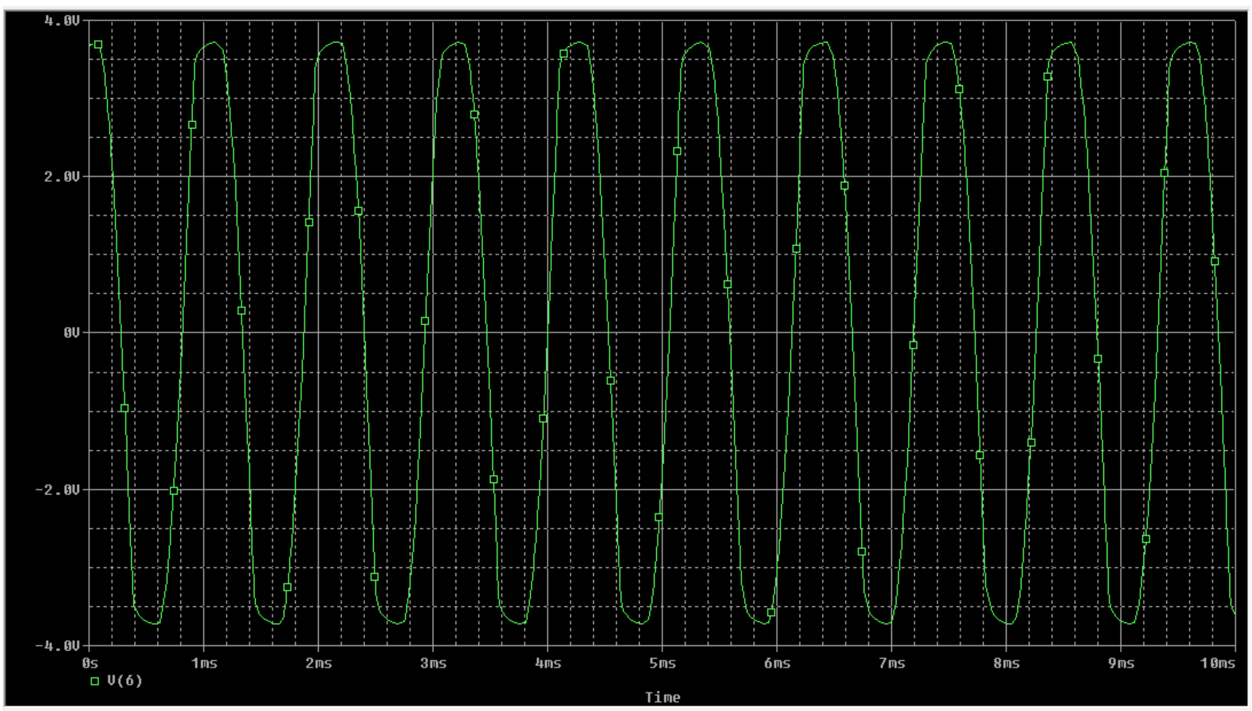
$R_5 = 500\Omega$

$C_3 = 0.3138\mu F$

let $R_1 = 1k\Omega$, $R_2 = 10k\Omega$

X_1 = AD8610 op amp

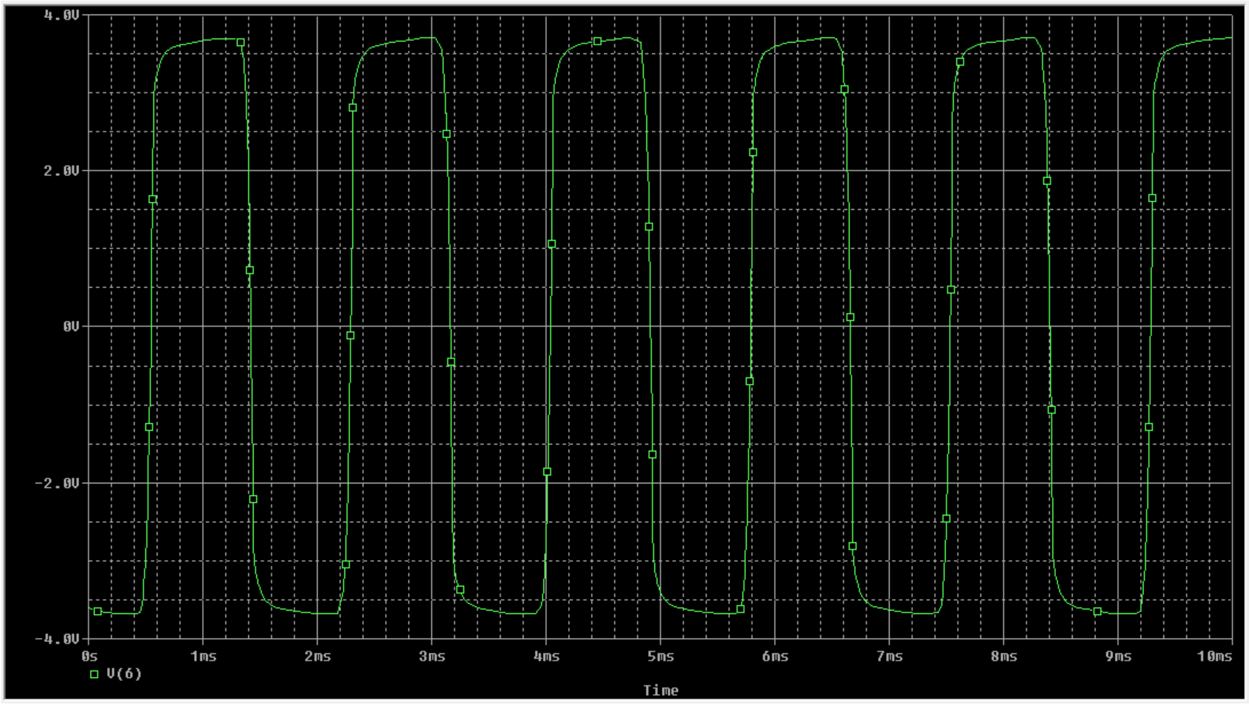
```
* Twin T network osc 2/6/17

Vp 1 0 DC 5
Vn 0 2 DC 5

R1 7 0 1k
R2 7 6 10k
R3 3 4 1k
R4 4 6 1k
R5 5 0 500
C1 3 5 0.159u
C2 5 6 0.159u
C3 4 0 .3183u ic=0
X1 7 3 1 2 6 AD8610

.tran 100u 10m

.probe
.end
```



Frequency Approximately 1 KHz

Diode AGC circuit does not work here.

If $R_2 : R_1$ ratio is too small, the output is more distorted: $R_1 = 1\ k\Omega$ and $R_2 = 1\ k\Omega$:



$R_1 = 10\ k\Omega$ and $R_2 = 1\ k\Omega$: