LTspice Basic Simulation Exercises

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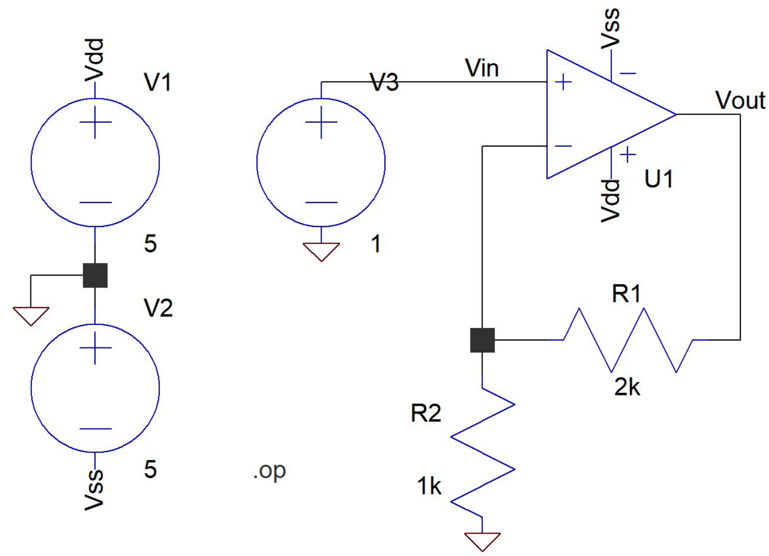
December 3, 2017

Wien Bridge Oscillator

- Create a new schematic and draw the following circuit.

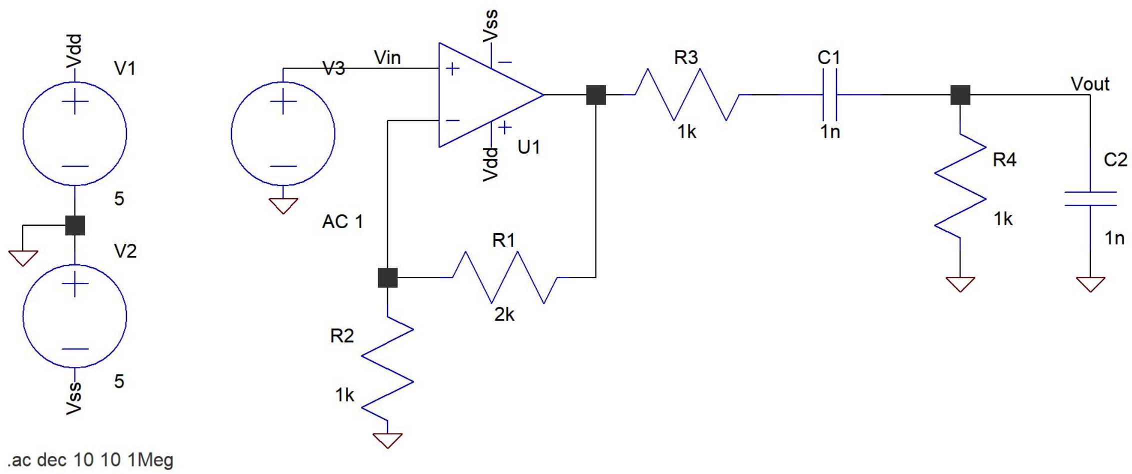


- This is the classic non-inverting gain configuration of the opamp. Run an operating point simulation to confirm this.

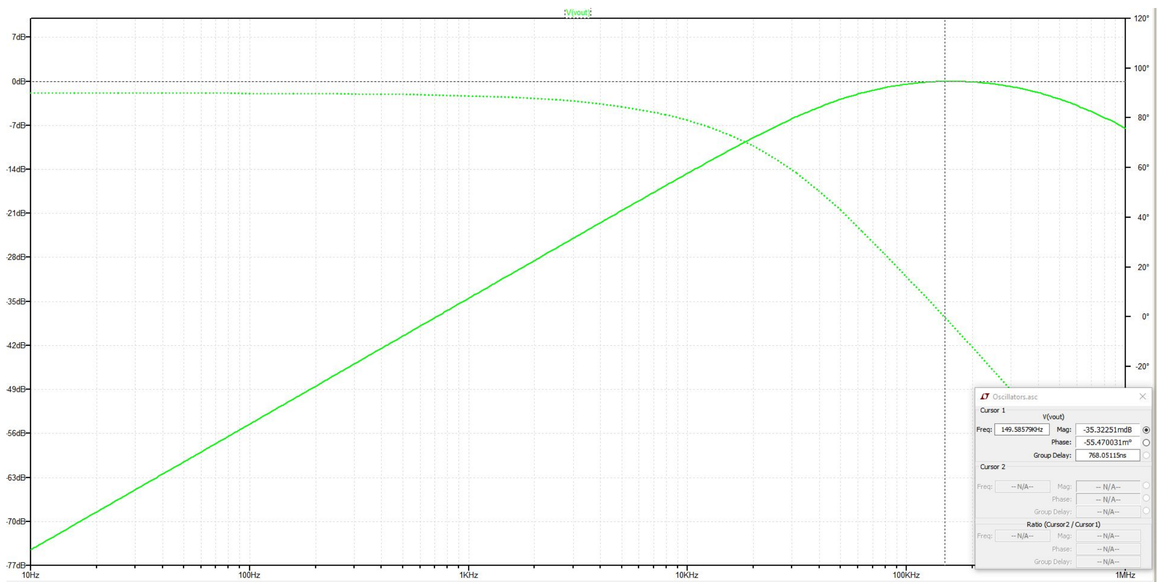
```
       --- Operating Point ---

V(vout):        2.99999         voltage
V(vdd):         5               voltage
V(vss):         -5              voltage
V(n001):        0.999997        voltage
V(vin):         1               voltage
I(R2):          -0.000999997    device_current
I(R1):          0.000999999     device_current
I(V3):          -2e-009         device_current
I(V2):          -0.000140277    device_current
I(V1):          -0.00114024     device_current
Ix(u1:1):       2e-009          subckt_current
Ix(u1:2):       1.99999e-009    subckt_current
Ix(u1:3):       0.00114024      subckt_current
Ix(u1:4):       -0.000140277    subckt_current
Ix(u1:5):       -0.000999999    subckt_current
```

Note that the opamp used does not have infinite gain. This causes the small error.

- Now modify the circuit to the one below. We have added a bandpass filter stage after the non-inverting gain stage.

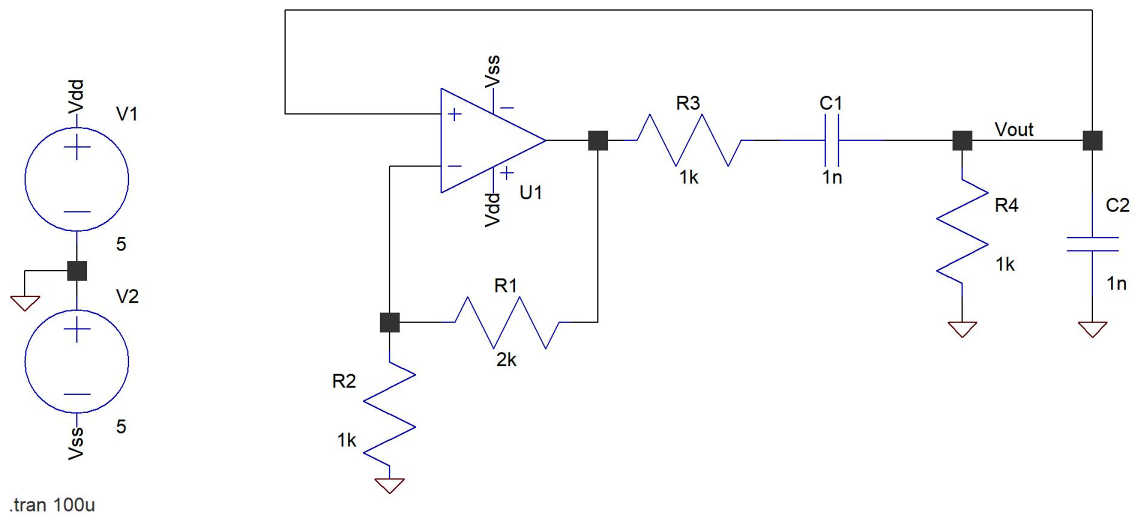


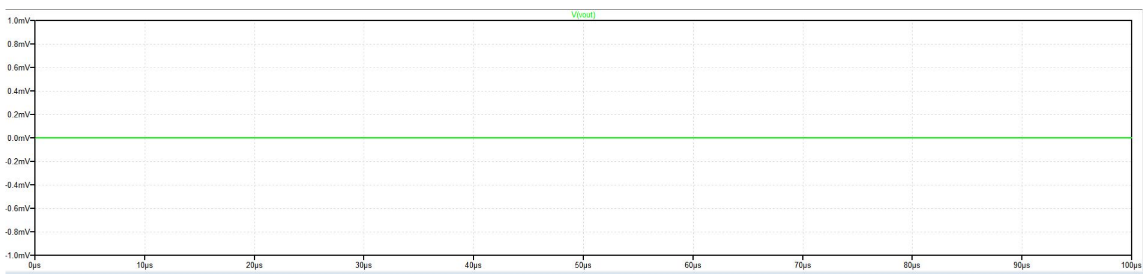
- Run an AC analysis to get the bode plot from the input of the opamp till the output of the bandpass filter.



Note that at the center frequency, the gain is $0dB$ and phase is $0°$(Almost, since the plot is not exact and the opamp is not completely ideal). This means that a sinusoid input at the center frequency does not get affected from the input to the output of this circuit, and since this is a bandpass filter, all other frequencies will get attenuated. Hence, if we connect the input and output of this circuit, only a sinusoid at the center frequency will be sustained, creating an oscillator.

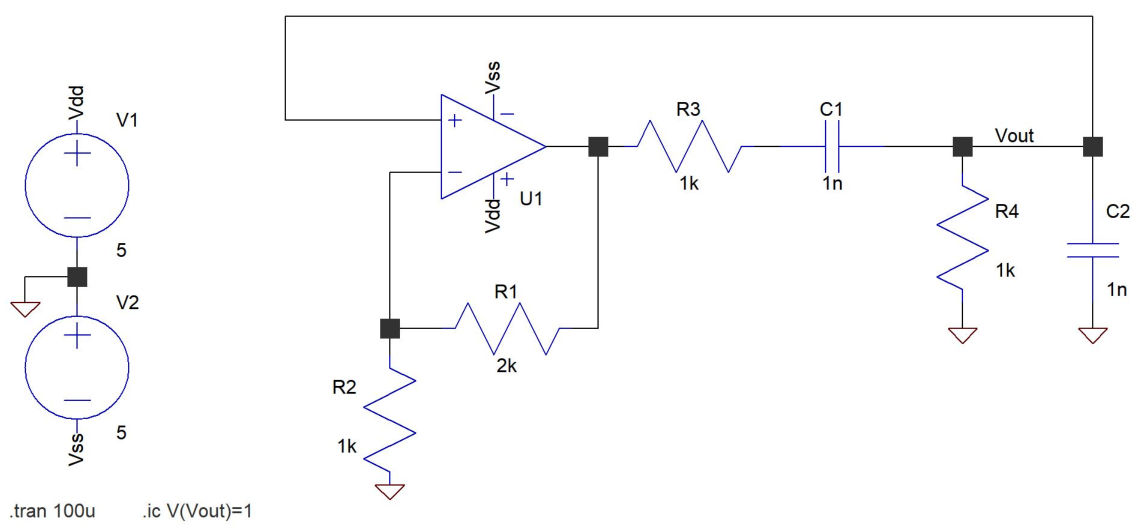
- Modify the circuit as shown below and run a transient simulation for $100\mu s$. Probe $Vout$



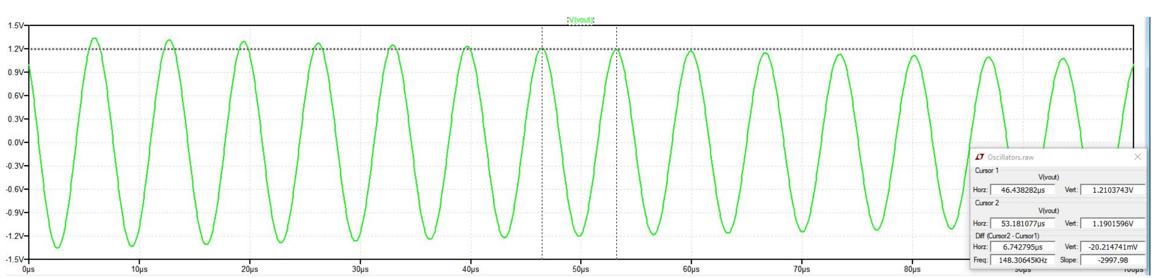


We do not get any waveform. This is due to the fact that there is ideally no input and hence zero output is also a metastable state. One way to see this is that the sinusoid at center frequency has zero amplitude.

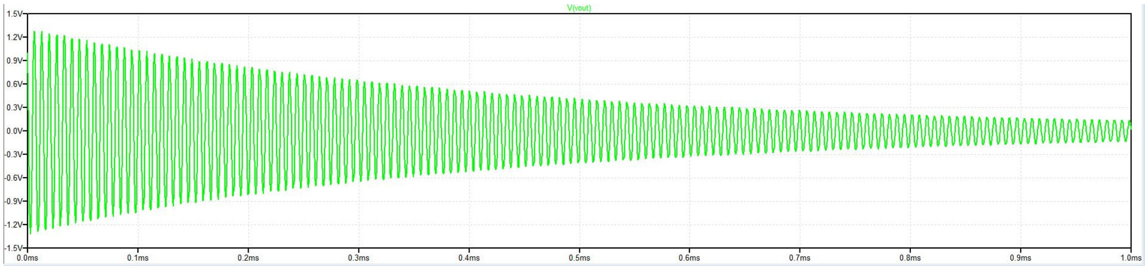
- We set up an initial condition to start the circuit. Use the *SPICE directive* icon to add the directive *.ic V(Vout)=1*.



- Now run the simulation. We see a sinusoid as expected. However, the amplitude of the sinusoid keeps decreasing



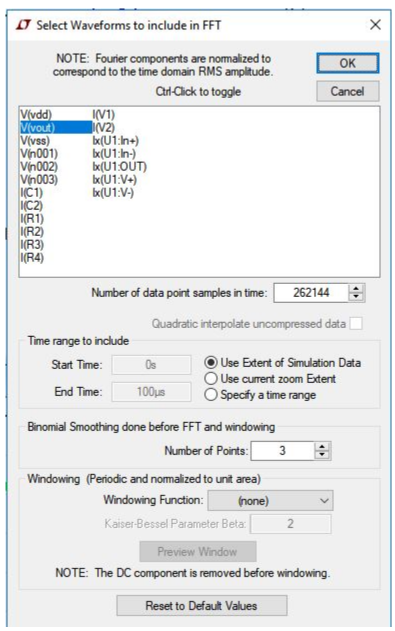
- Run the transient simulation for $1000\mu s$

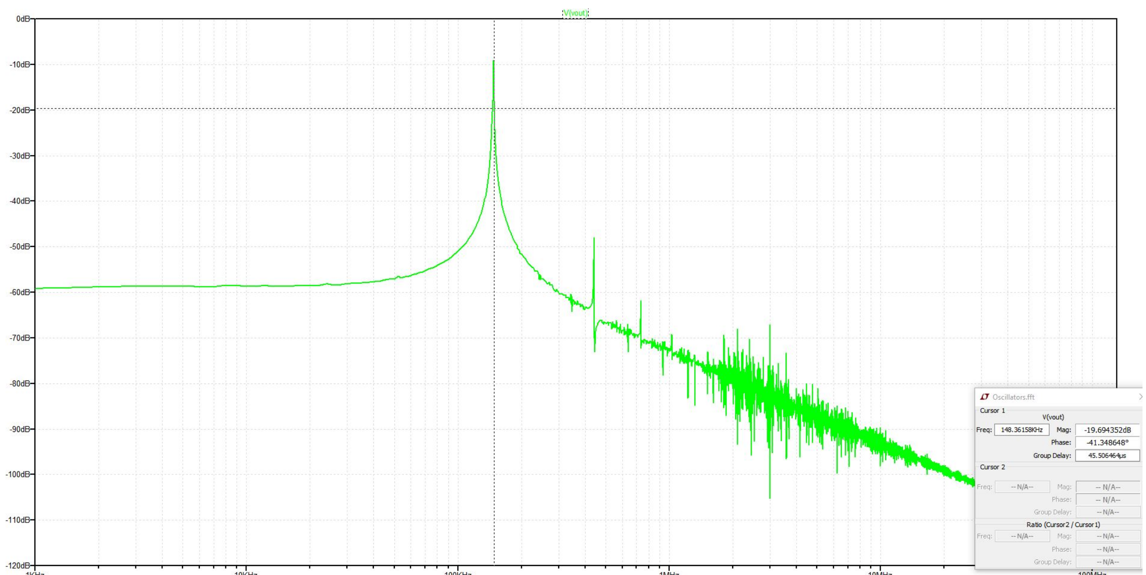


This confirms that the sinusoid decays with time, and the oscillations are not stable.

Note that theoretically, for a gain of 3, the oscillations must be stable, without getting amplified or attenuated, but since the opamp is not ideal, the gain is a little less than 3.

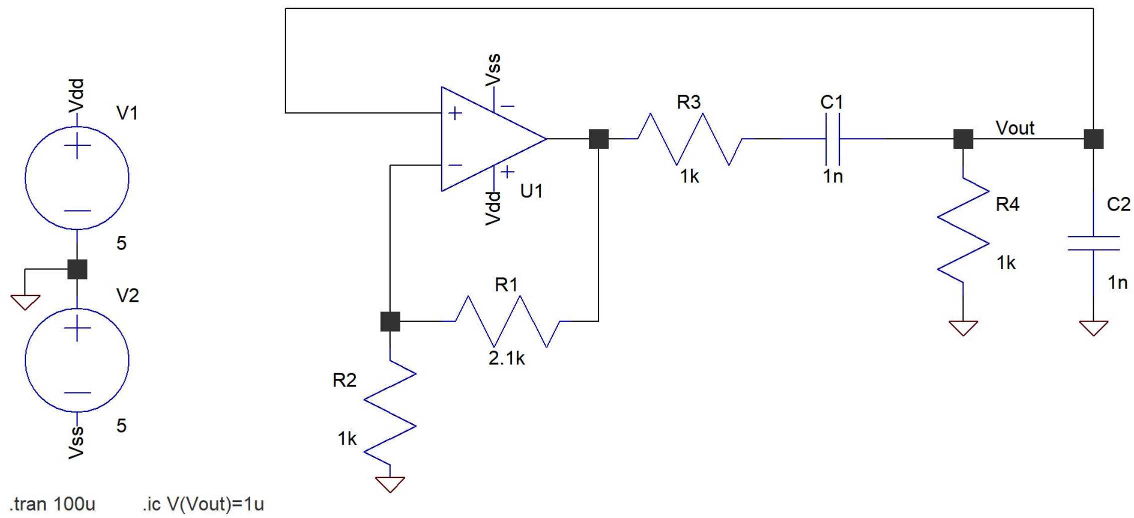
- To get a better idea of the waveform generated, we can see its Fourier transform. Click on *View->FFT* (When the plot pane is selected) and plot the FFT of *Vout*.



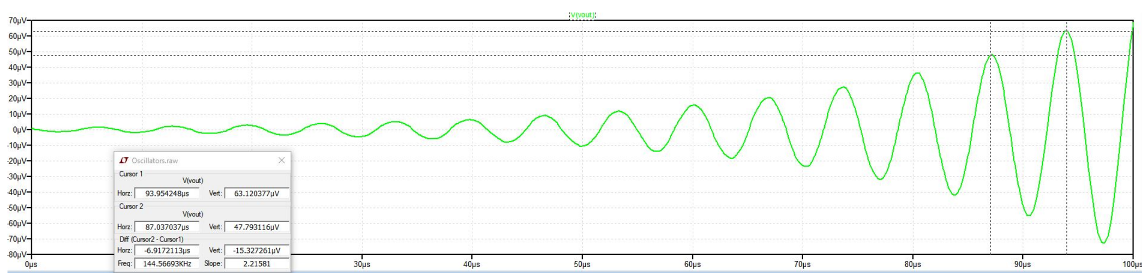


We find that the sinusoid is reasonably pure with a small amount of distortion.

- We can sustain the sinusoid by slightly adding more gain. Modify the circuit as shown below. Now, the *open loop* gain at the center frequency will be more than $0dB$. Hence, even a small disturbance will get amplified and sustain the circuit. Set the initial condition to $1\mu V$



- Run the transient simulation for $100\mu s$



We see that the amplitude keeps increasing in this time window. Run the transient simulation for $1000\mu s$.
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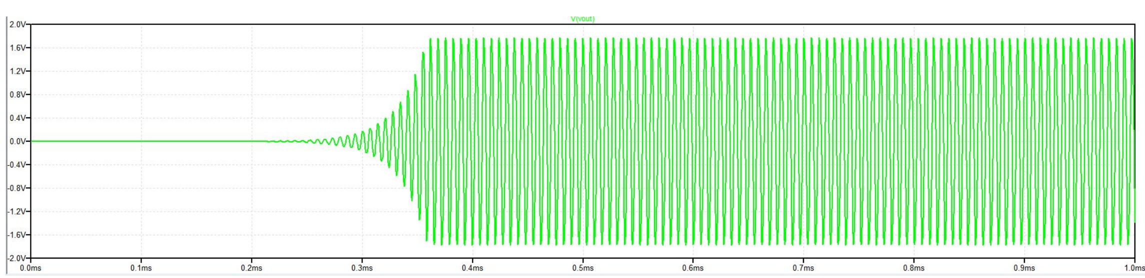
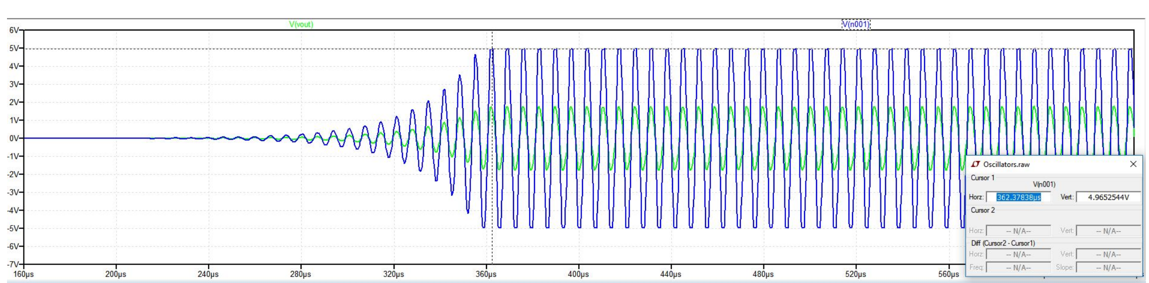


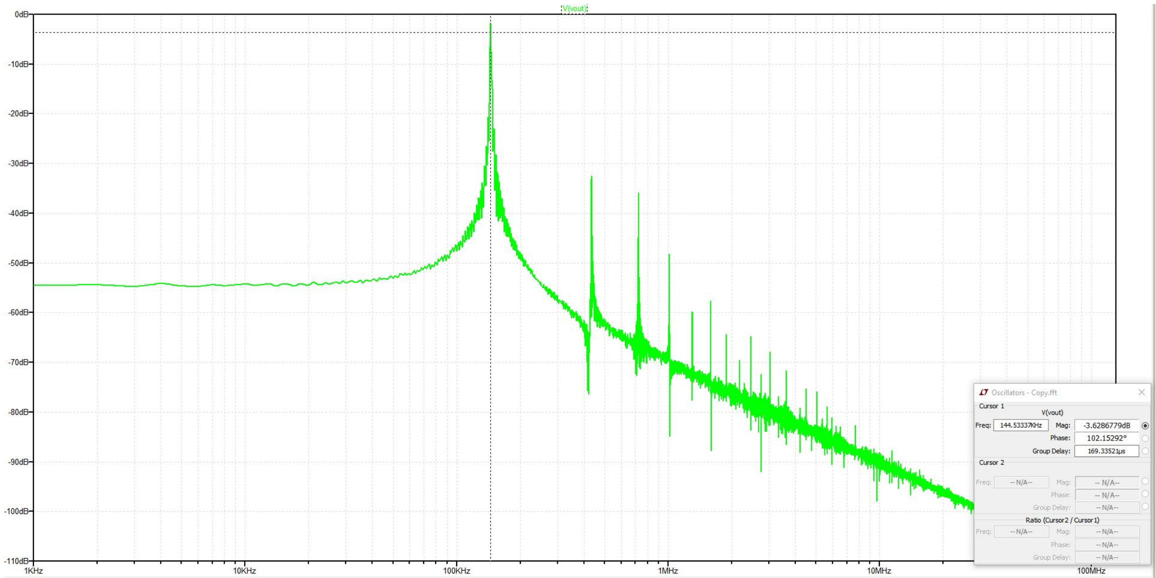
We see that even a $1\mu V$ disturbance is sufficient to start the circuit. Noise in the circuit will be sufficient to do this, and hence we do not need any other circuit components to start this circuit.

- Note that now the circuit would actually be unstable if all the components were ideal. This is because a sinusoid at the center frequency will get amplified in the loop without any bounds (There is positive feedback). Here the opamp is non-ideal, which results in its output voltage getting clipped. Probe the output of the opamp to see this.



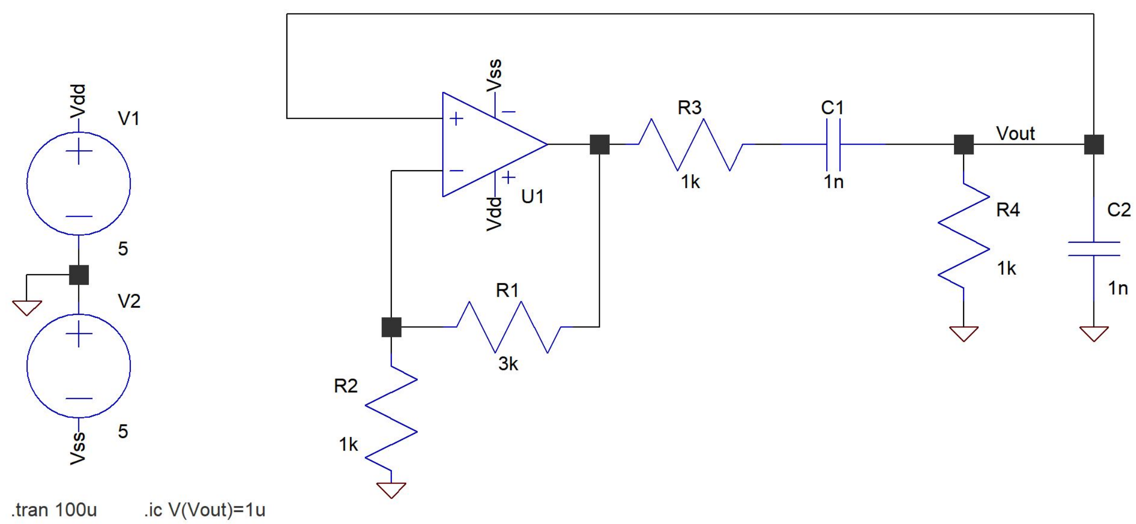
The opamp output saturates at $\pm 5V$. Note the time it takes for saturation to begin, which is the time the circuit needs to start up.

- Generate the FFT of the waveform at *Vout*

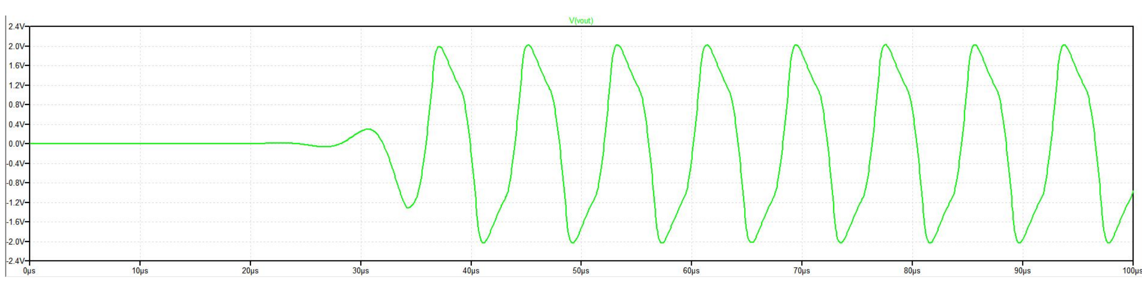


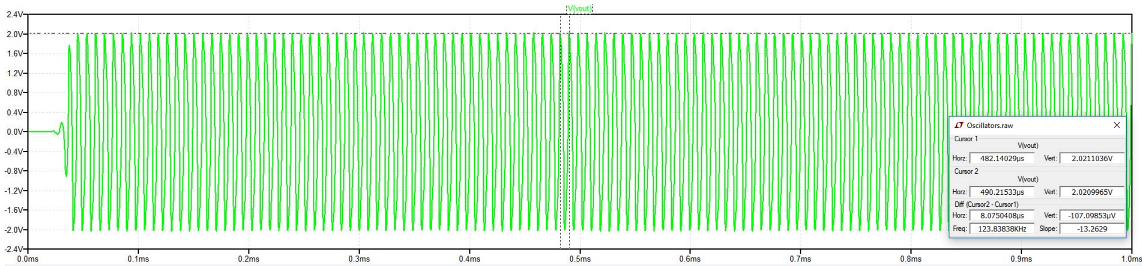
We can see that there is harmonic distortion . This is due to the fact that the opamp is getting saturated.

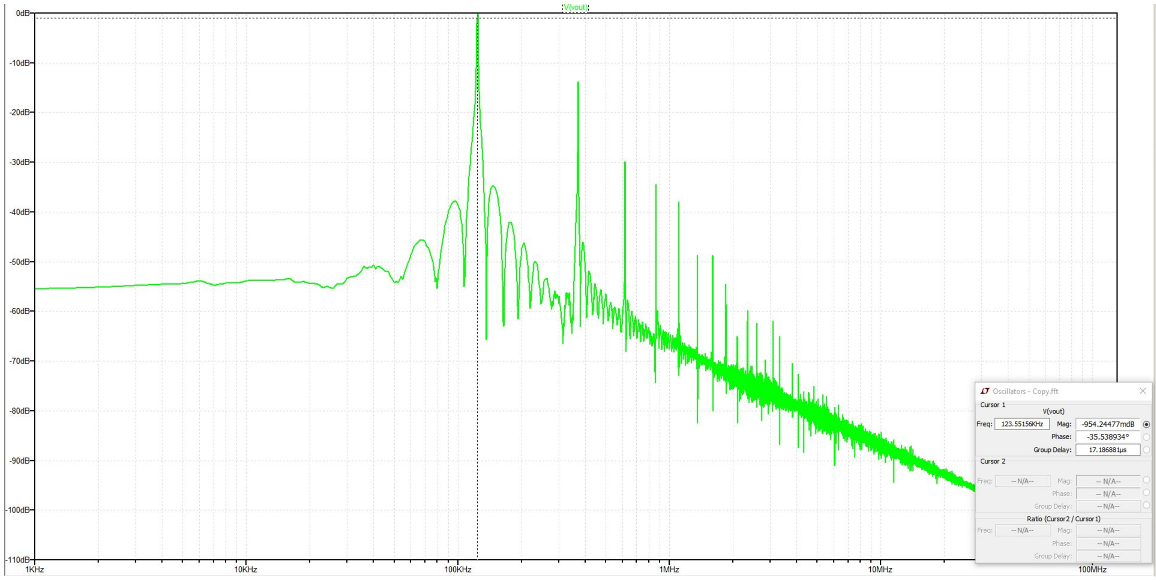
- Let us add more gain to this circuit. Modify the circuit as shown below.



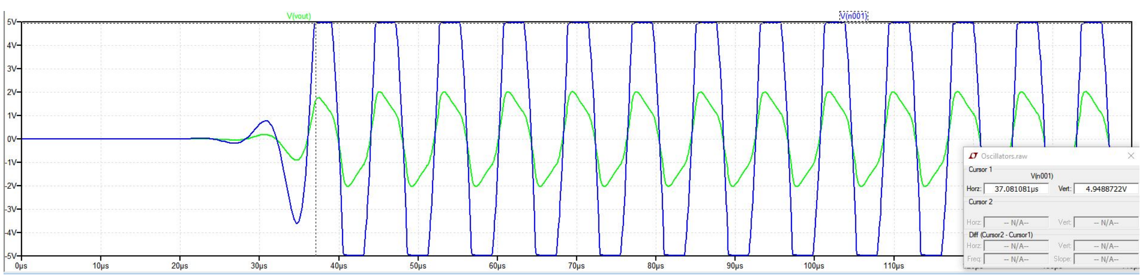
- Run the transient simulation and view the output waveform and its FFT





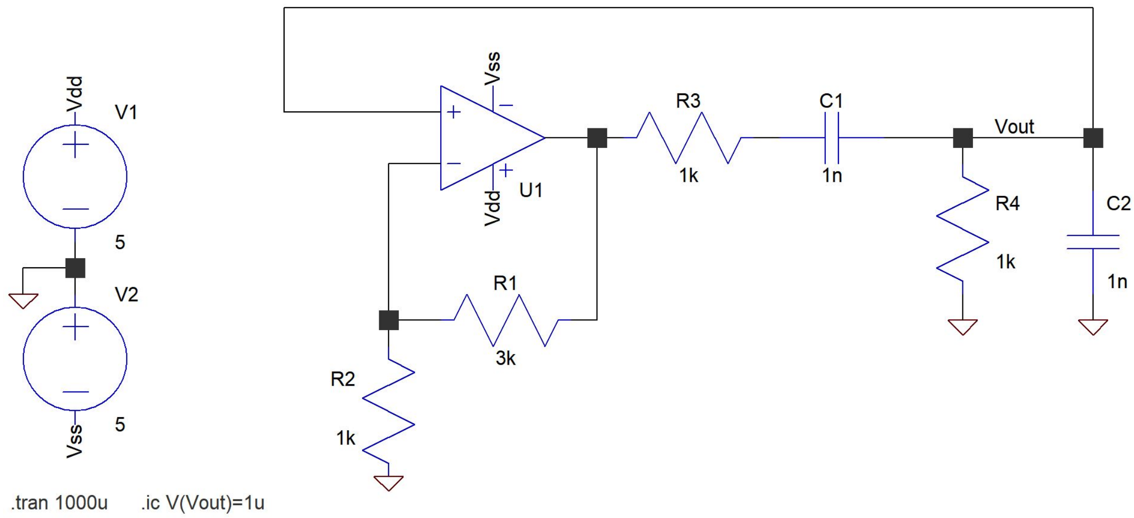


You can see that the output waveform is significantly distorted. The FFT shows significant harmonic distortion. Probe the opamp output voltage also.



We see that the circuit starts up in a much smaller amount of time.

- We see that if we set a lower gain, the circuit cannot sustain stable oscillations (they will die down). On the other hand if we set higher gain, the opamp will saturate and we get harmonic distortion at the output. Further, lower gain means that the circuit will take longer to start up. Negative feedback techniques are used to set the gain to just the right amount to sustain the output waveform at a certain amplitude without saturating the opamp.
- The final circuit is shown below



- Note that we actually want an *unstable circuit* for *stable oscillations*.