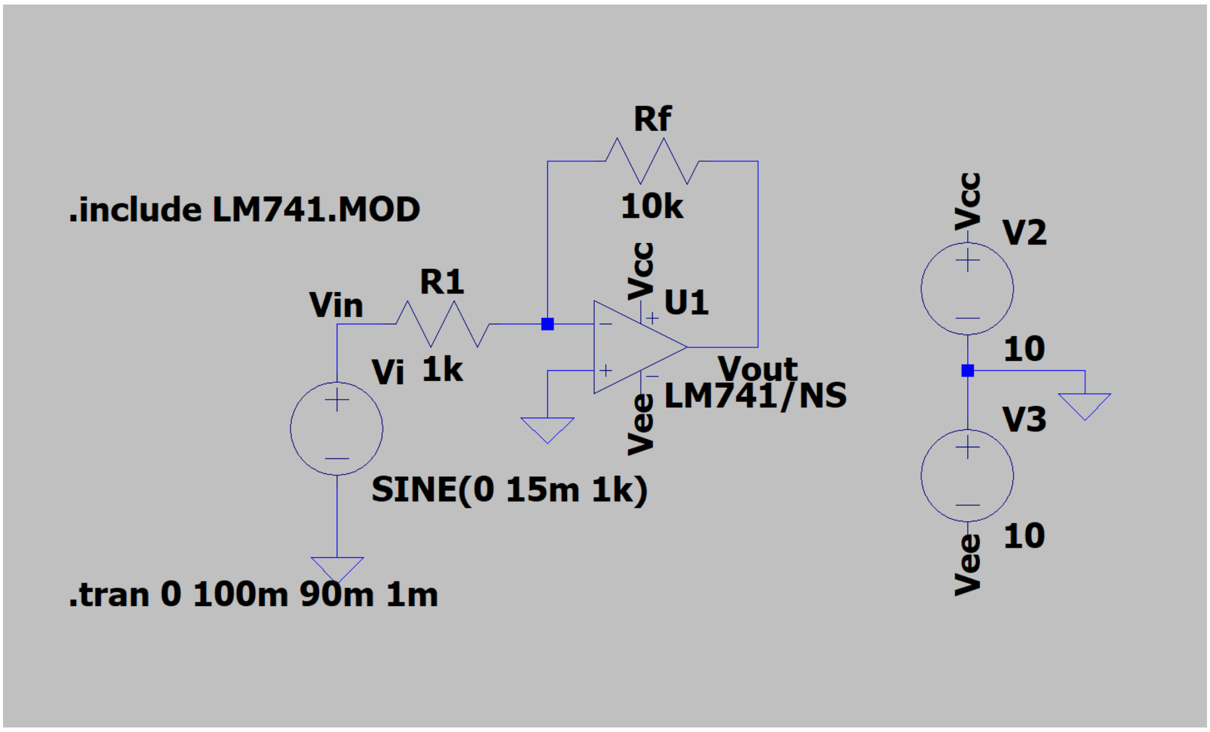
Aim: To study the working of inverting, non-inverting, differentiator and integrator circuits using operational amplifiers.

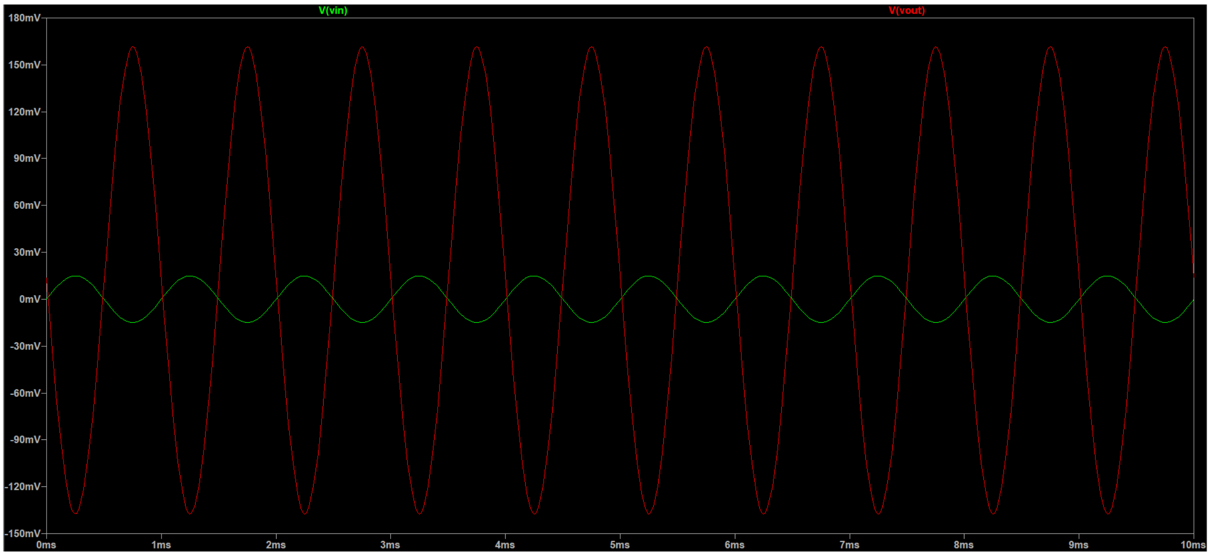
Software used:

Inverting Amplifier:

The simulations are done with three feedback resistances 10k, 100k, 1000k and gain is found to be 10, 100, 1000 respectively. (since, gain = -Rf/R1)

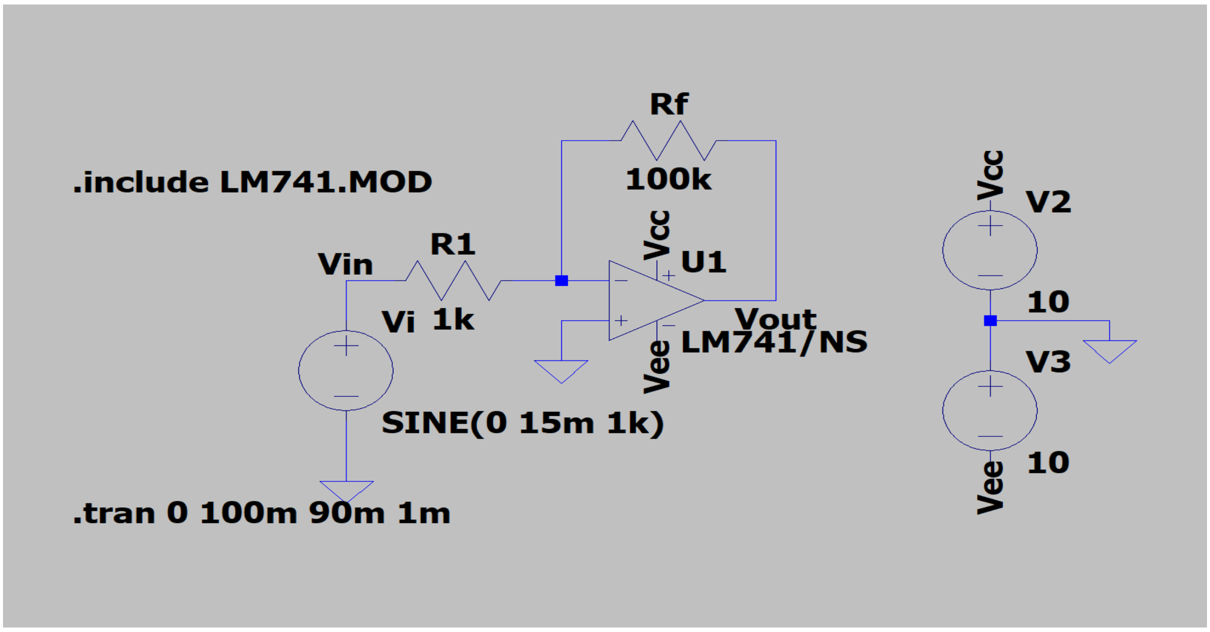
Case 1: Rf = 10k

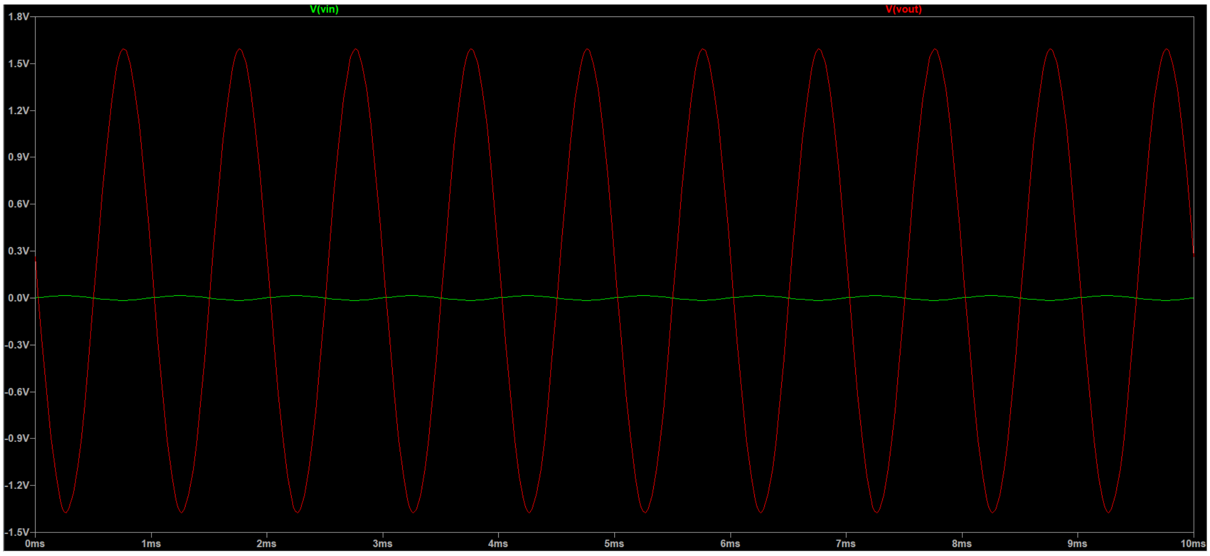




The output is out of phase with the input and has a gain of 10 V/V.

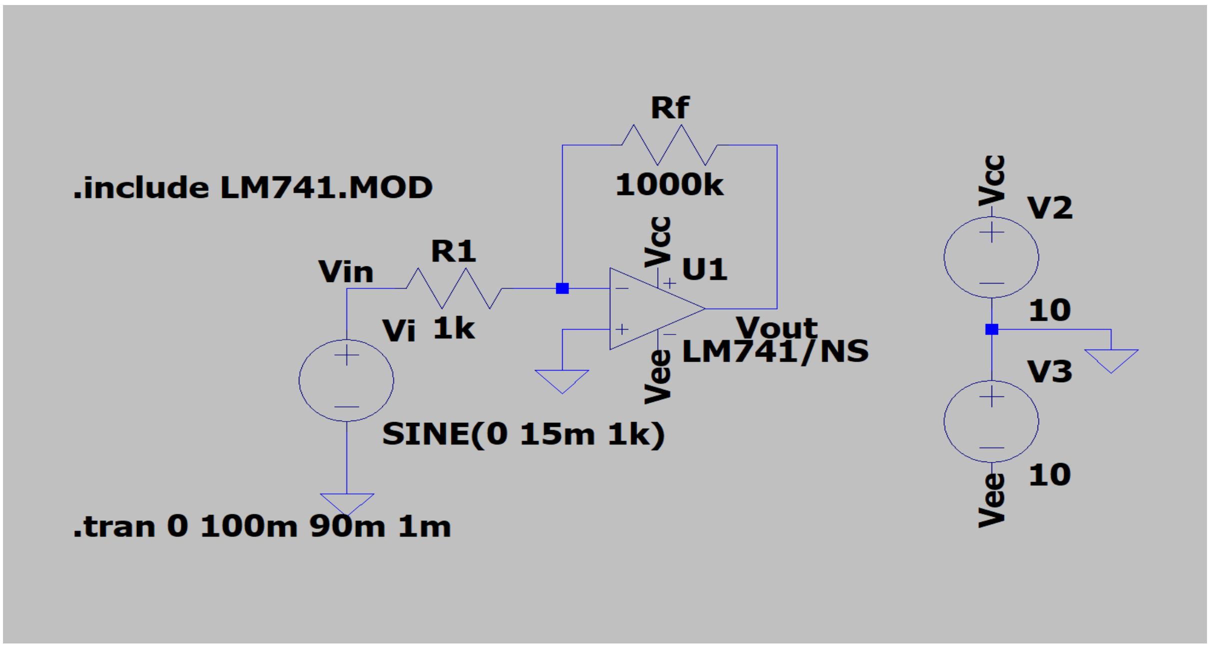
Case 2: Rf = 100k

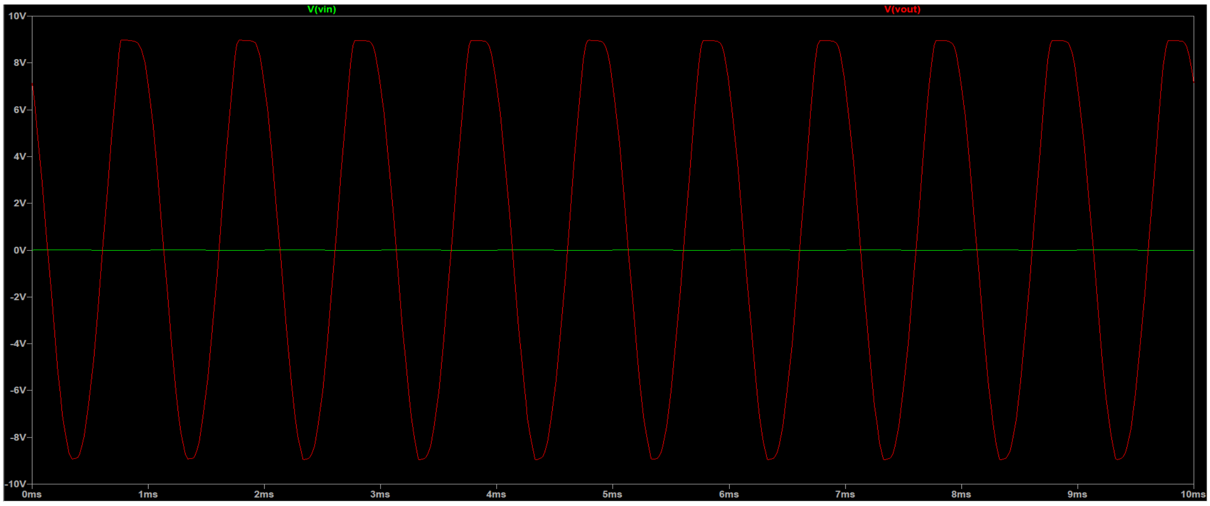




The output is out of phase with the input and has a gain of 100 V/V.

Case 3: Rf = 1000k



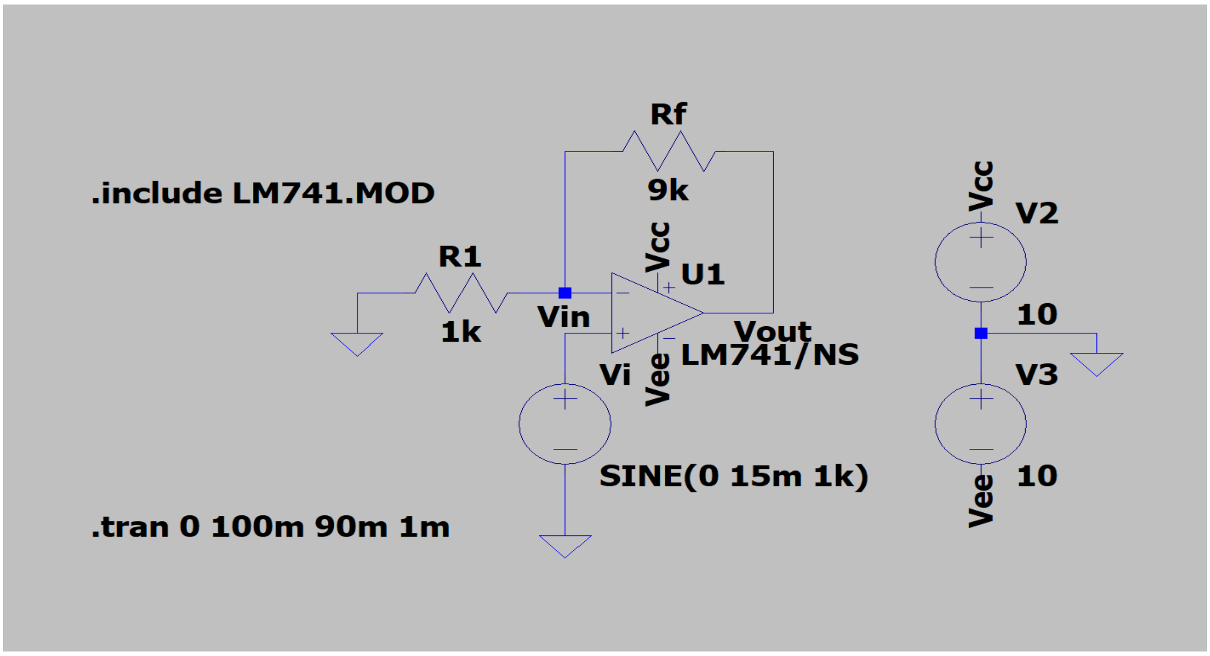


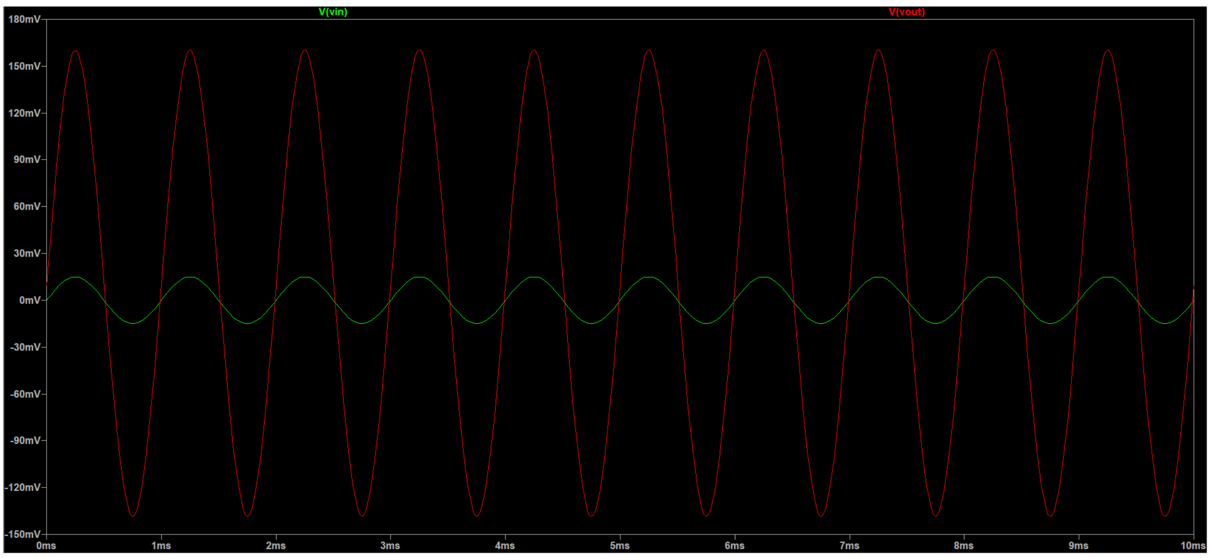
The output waveform here is **clipped off** because the output voltage for those is values is greater than the power supply voltages (i.e., Vcc & Vee).

Non-Inverting Amplifier:

The simulations are done with three feedback resistances 9k, 99k, 999k and gain is found to be 10, 100, 1000 respectively. (since, gain = (1 + Rf/R1))

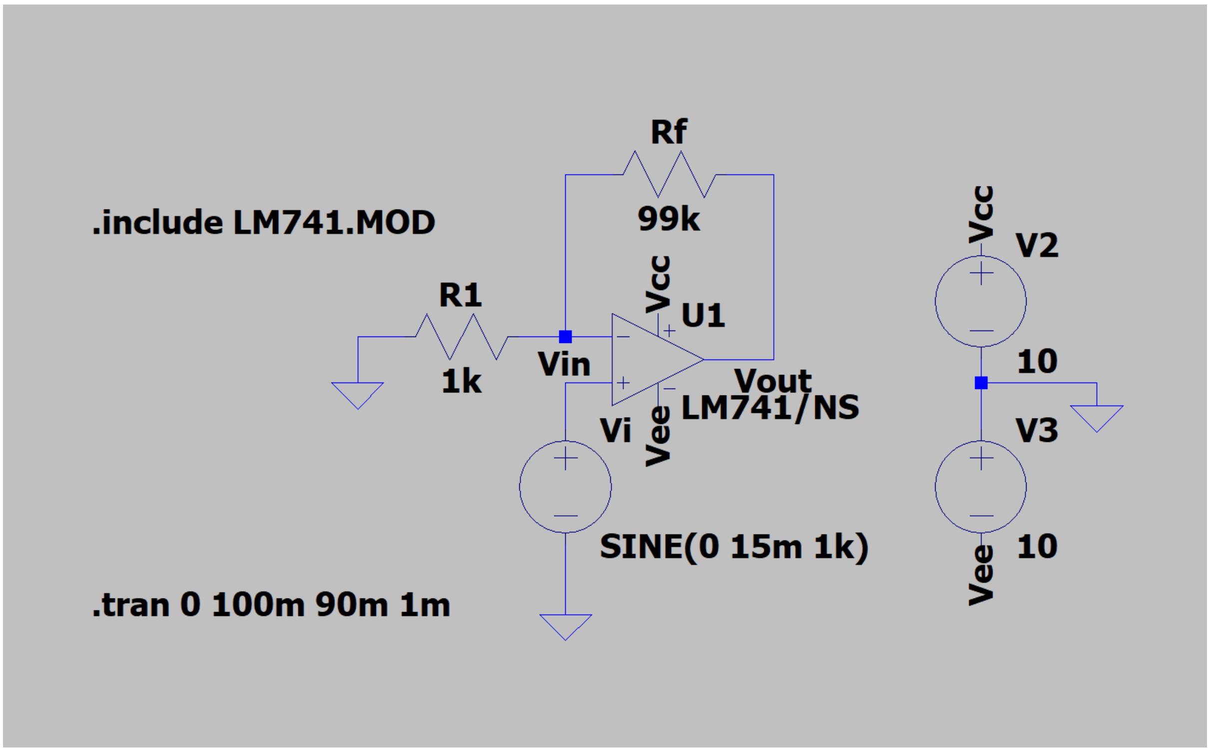
Case 1: Rf = 9k

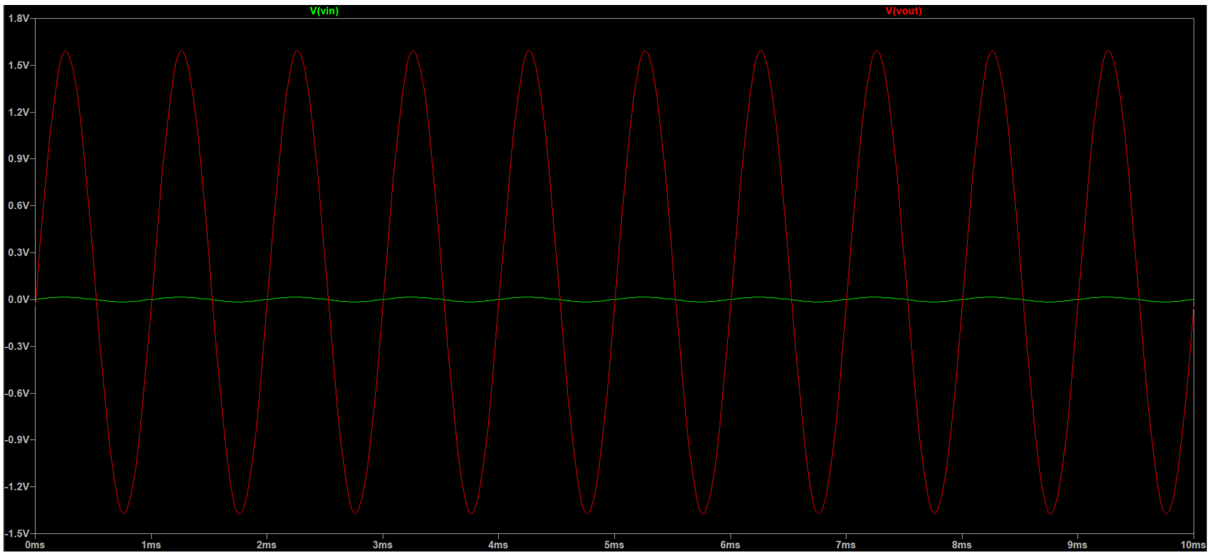




The output is in-phase with the input and has a gain of 10 V/V.

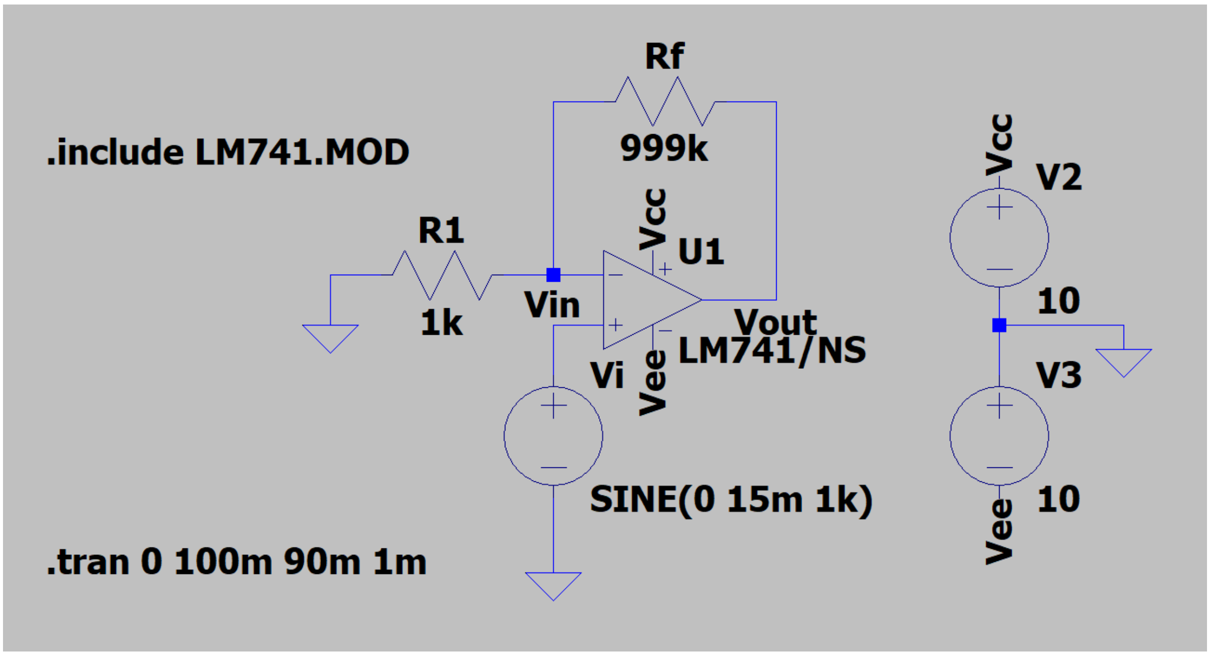
Case 2: Rf = 99k

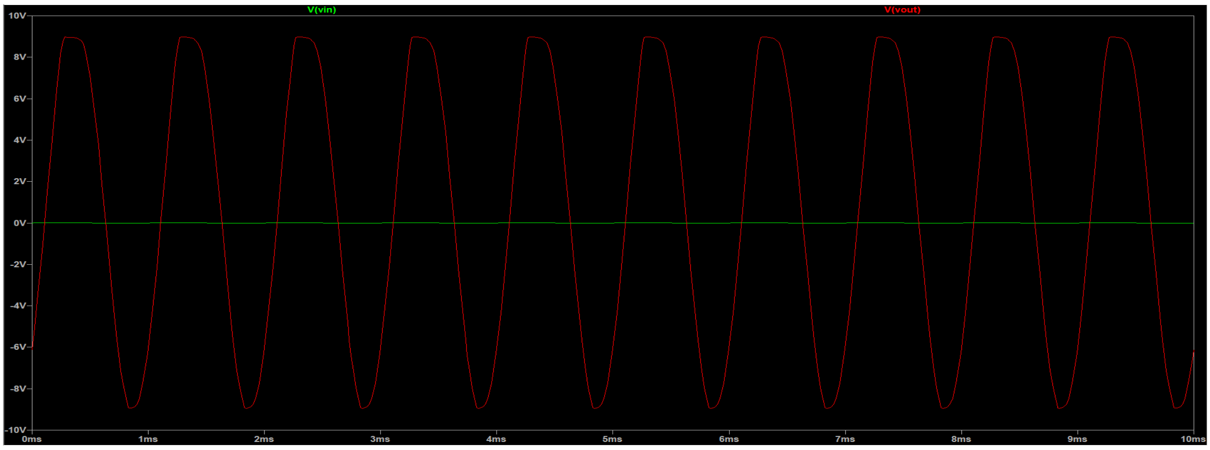




The output is in-phase with the input and has a gain of 100 V/V.

Case 3: Rf = 999k

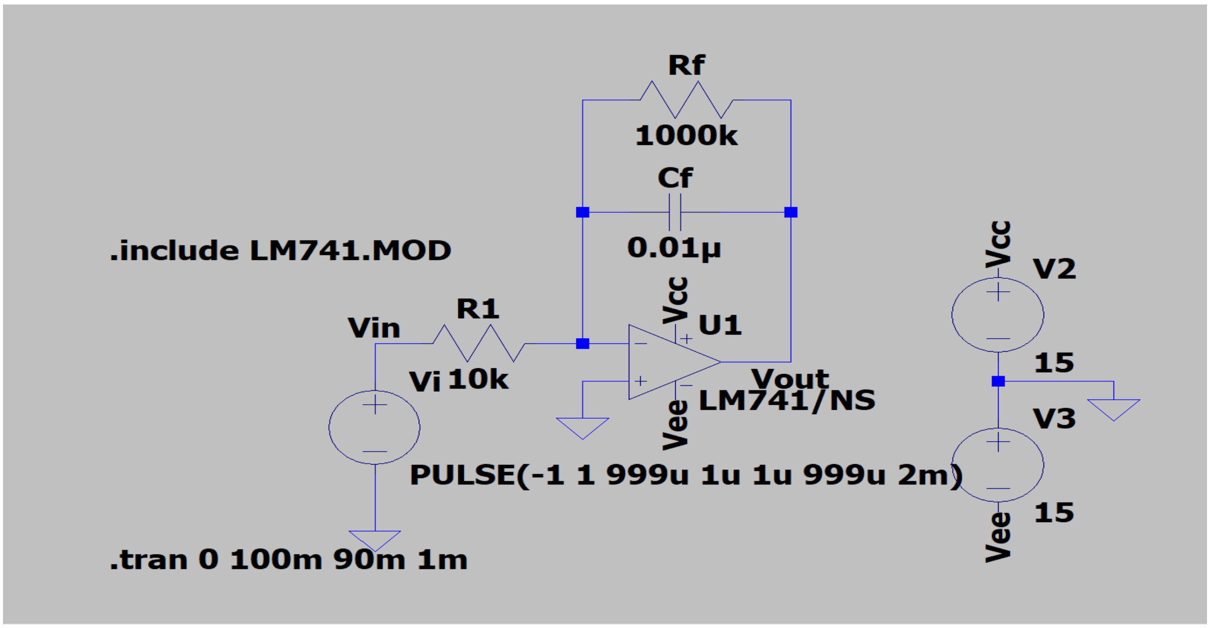


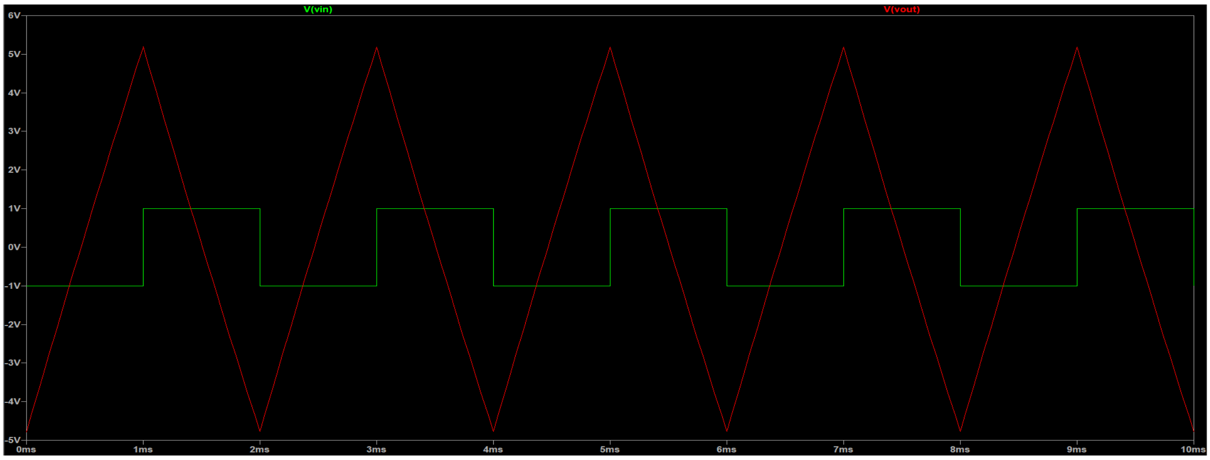


The output waveform here is **clipped off** because the output voltage for those is values is greater than the power supply voltages (i.e., Vcc & Vee).

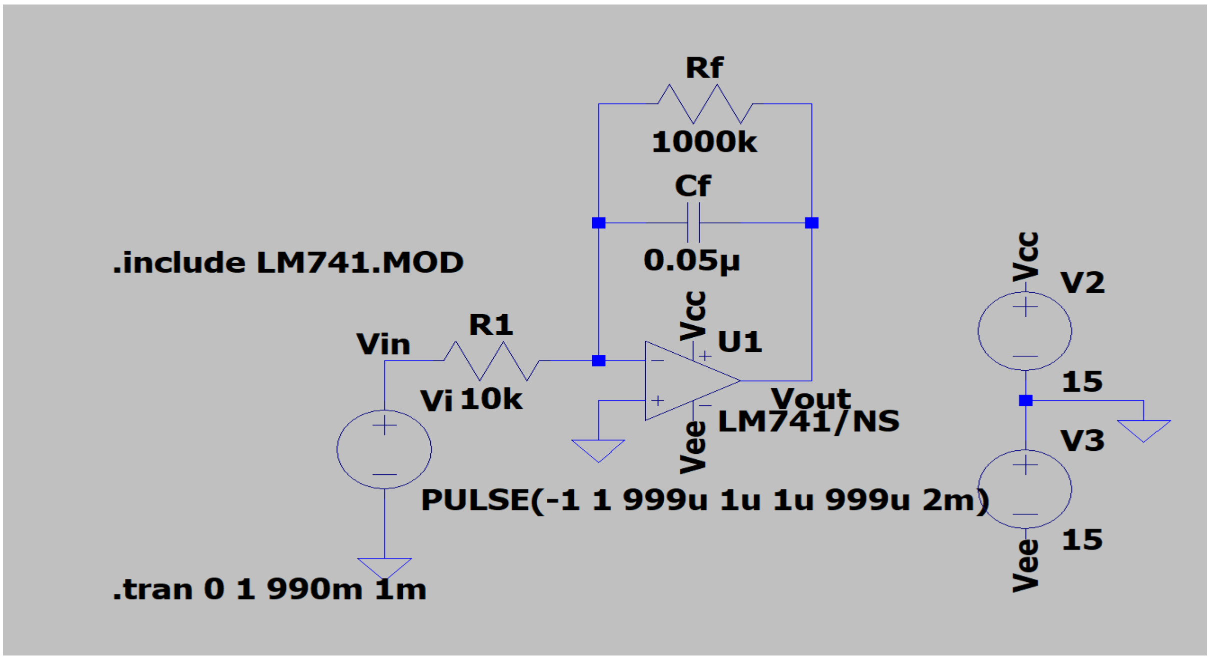
Integrator:

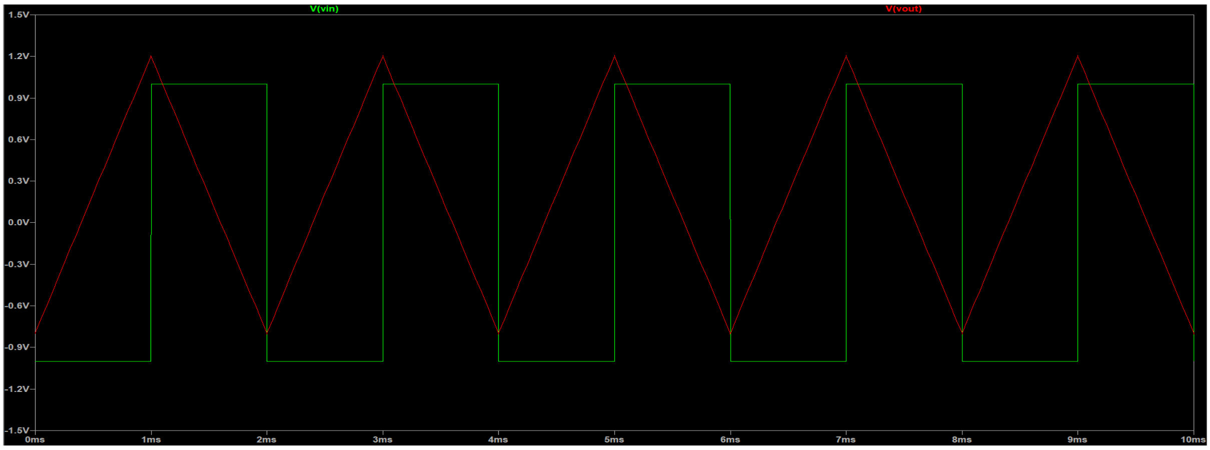
Case 1: Square wave of amplitude 1V as input with R1 = 10k, **Cf = 0.01u**, Rf = 1000k



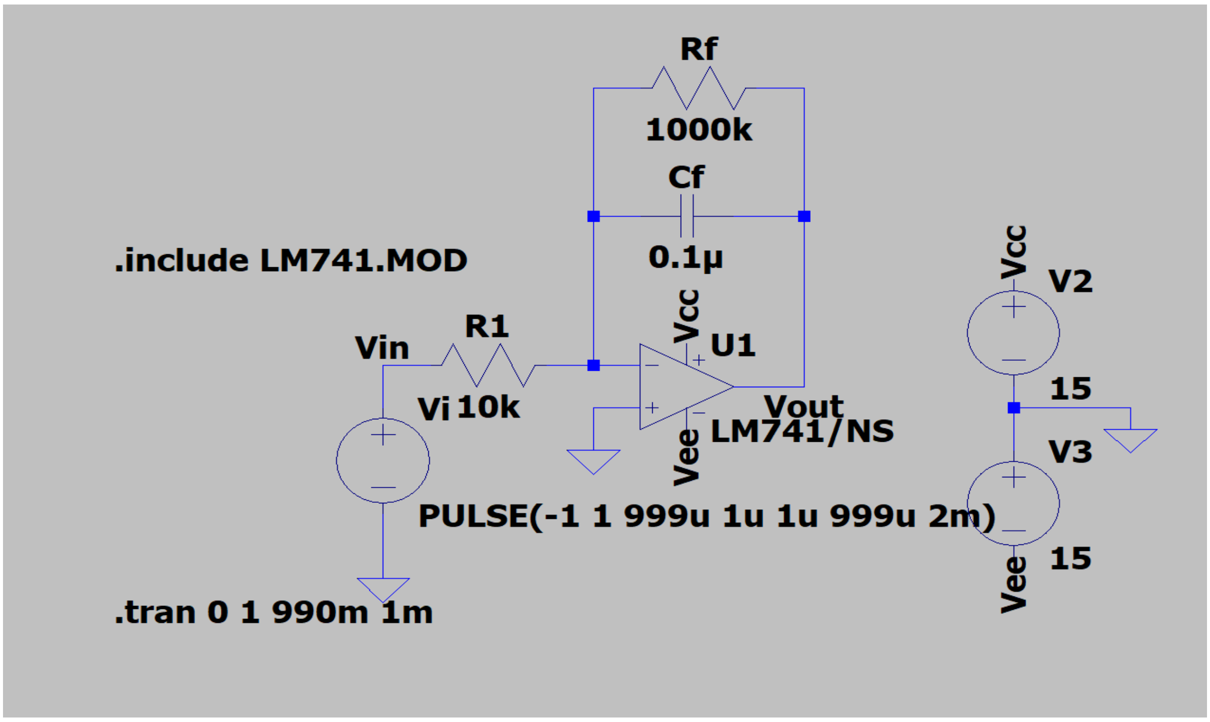


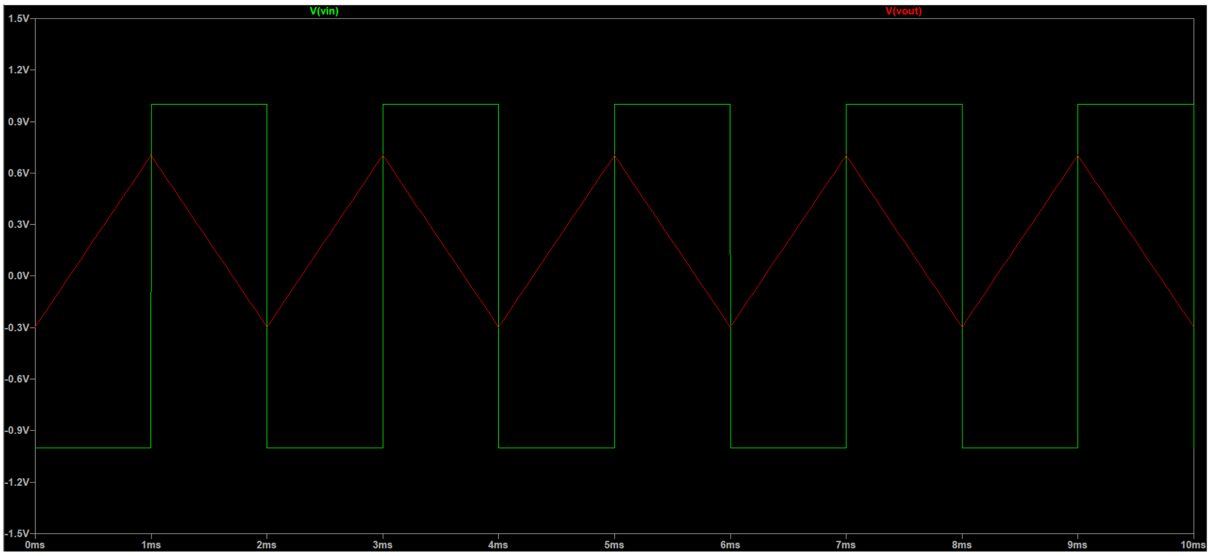
Case 2: Square wave of amplitude 1V as input with R1 = 10k, **Cf = 0.05u**, Rf = 1000k



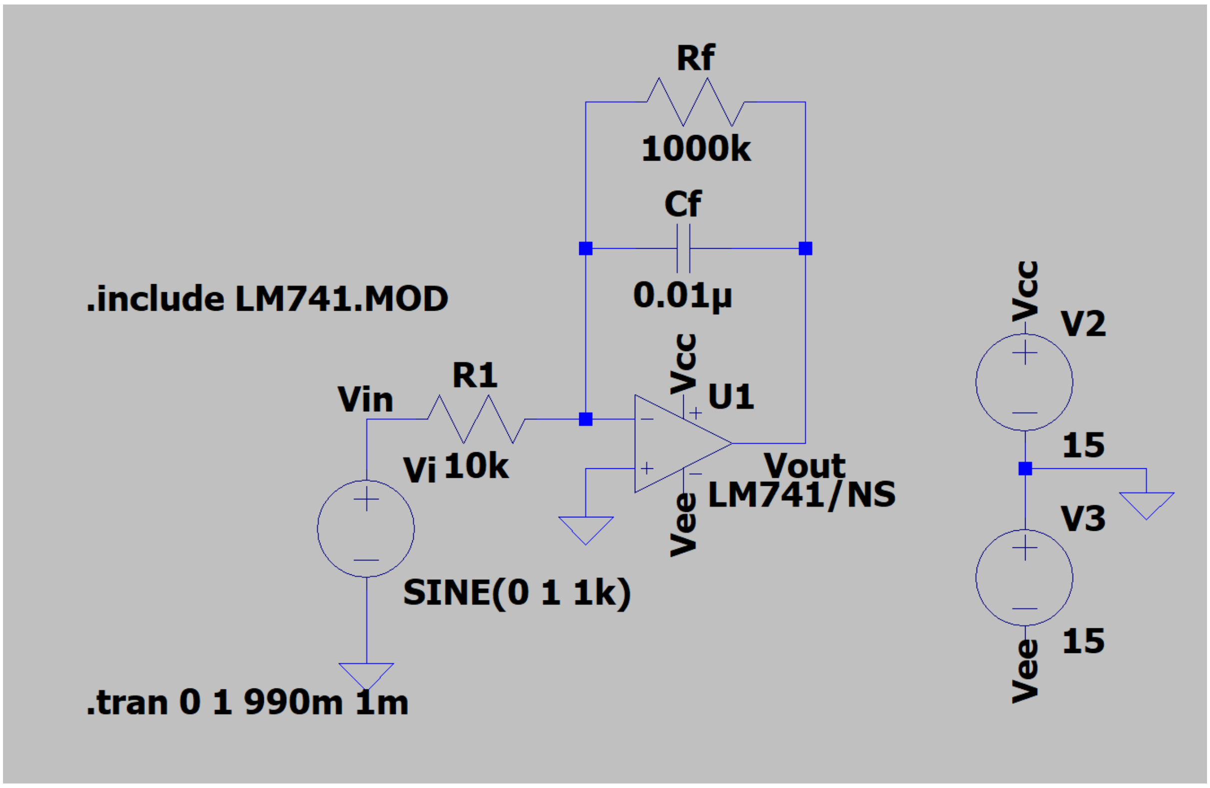


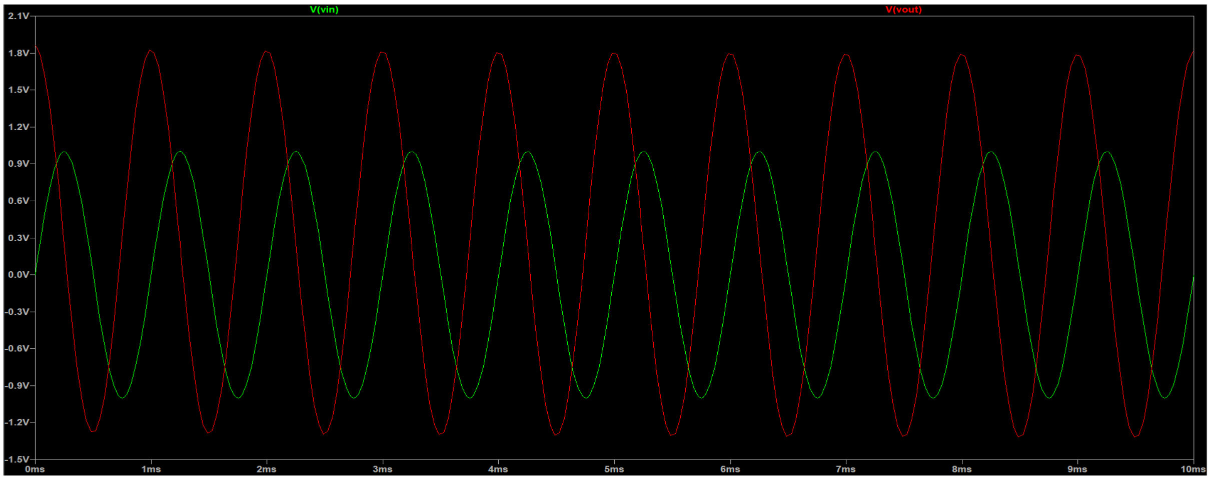
Case 3: Square wave of amplitude 1V as input with R1 = 10k, **Cf = 0.1u**, Rf = 1000k





Case 4: Sine wave of amplitude 1V as input with R1 = 10k, Cf = 0.01u, Rf = 1000k





<u>As can be seen from the above plot,</u>

1) Vout is leading Vin by a phase of 90 degrees
2) Vout = 3.2 V peak to peak sine wave and Vin = 2V peak to peak sine wave.

Transfer function, $\frac{V_o(s)}{V_i(s)} = -\frac{\left(\frac{1}{sC_f} \| R_f\right)}{R_1} = -\frac{\frac{R_f}{1+sR_fC_f}}{R_1} = \frac{-R_f/R_1}{1+sR_fC_f}$

$\Rightarrow$ Gain magnitude, $\left|\frac{V_o(j\omega)}{V_i(j\omega)}\right| = \frac{R_f/R_1}{\sqrt{1+\omega^2R_f^2C_f^2}}$

$\Rightarrow \left|\frac{V_o(j\omega)}{V_i(j\omega)}\right| = \frac{\left(\frac{1000}{10}\right)}{\sqrt{1+(2\pi\times10^3\times10^6\times10^{-7})^2}} = \frac{100}{\sqrt{1+(2\pi\times10)^2}} \approx \frac{100}{2\pi\times10}$

$\Rightarrow$ gain ≈ 1.6 V/V

$\Rightarrow |V_o(j\omega)| = 1.6 \times |V_i(j\omega)|$

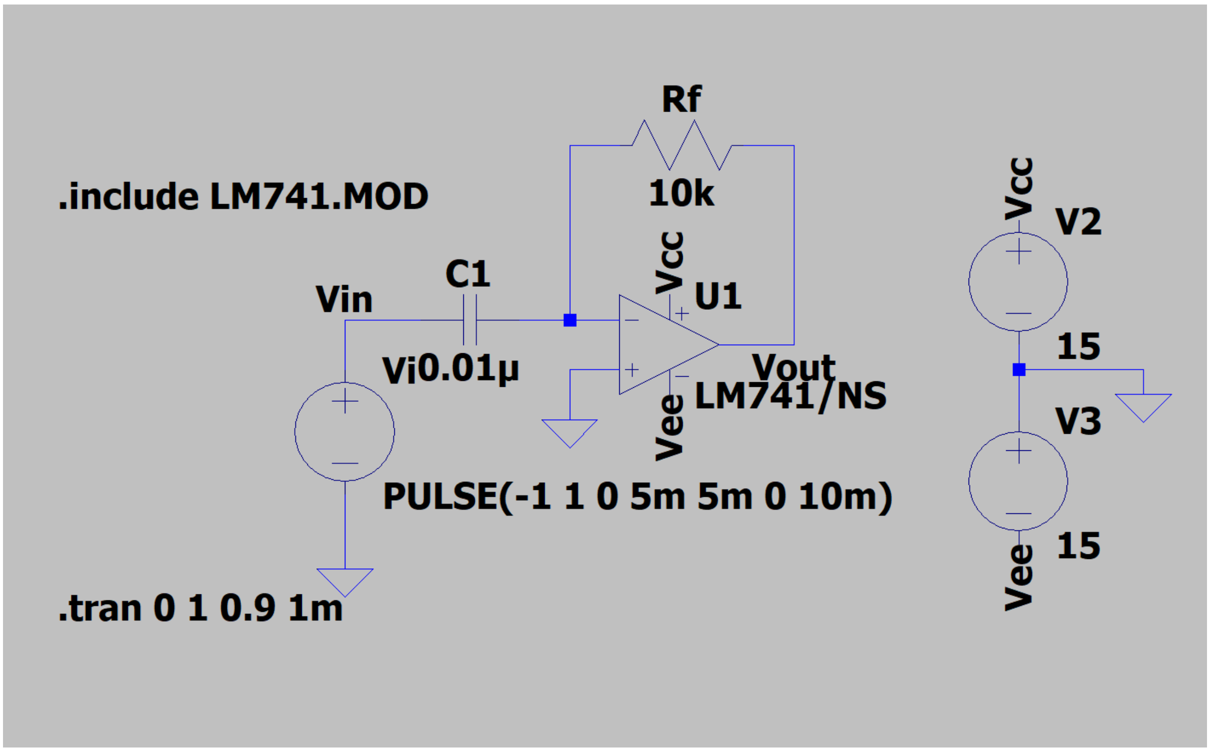
$= 1.6 \times 2$ V peak to peak

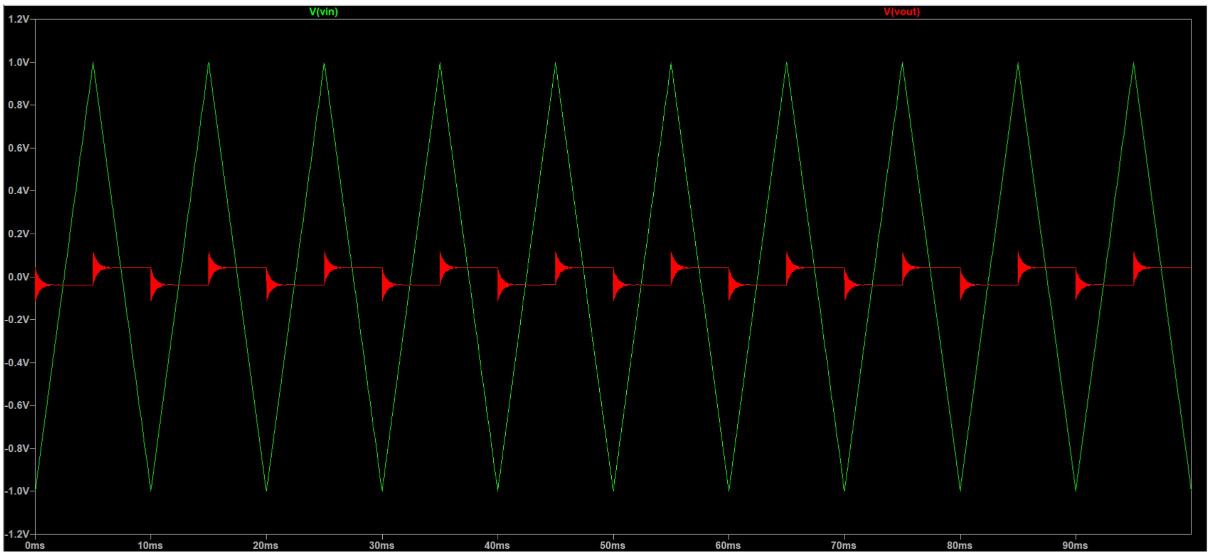
$\Rightarrow |V_o(j\omega)| = 3.2$ V peak to peak

Purpose of resistor Rf: introducing Rf in parallel with capacitor Cf restricts the gain to -Rf/R1 for low frequencies. The gain **without** Rf (i.e., 1/(w*R1*Cf)) for dc voltages would be infinity which implies that for any tiny dc component of input signal would saturate the output voltage.

<u>Differentiator:</u>

Case 1: Triangle wave of amplitude 1V as input with C1 = 0.01u, Rf = 10k





<u>As can be seen from the above plot,</u>

Vin = Triangular wave of amplitude 1V and frequency 100Hz.

Vout = Square wave of amplitude 40mV and frequency 100Hz.

$$V_{out} = -R_f C_1 \frac{dV_{in}}{dt}$$

$$\Rightarrow V_{out} = -(10\times10^{3})\times(0.01\times10^{-6})\times\left[\frac{2}{5\times10^{-3}}\right] \quad \left(\text{when } V_{in} \text{ is changing from } -1V \text{ to } 1V\right)$$

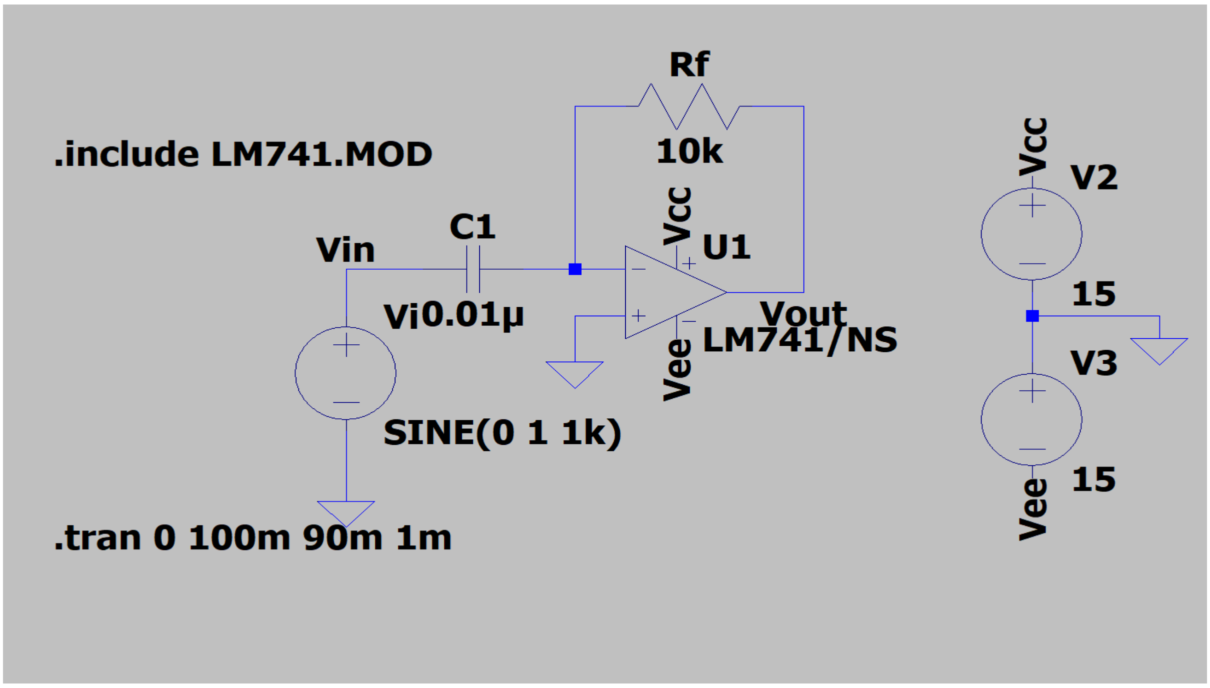
$$\Rightarrow V_{out} = -0.04\ V = -40\ mV$$

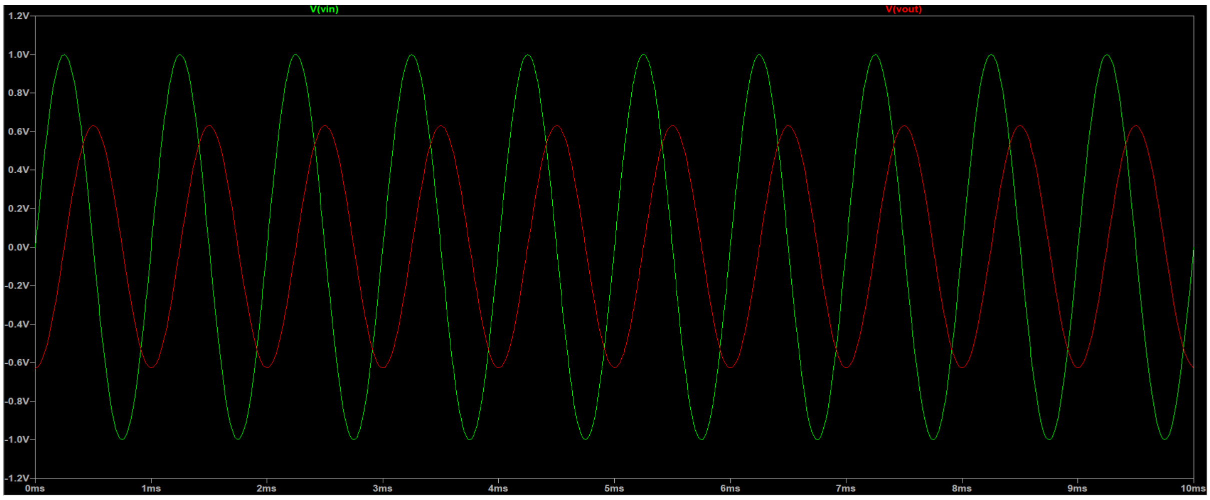
$$\Rightarrow V_{out} = -(10\times10^{3})\times(0.01\times10^{-6})\times\left[\frac{-2}{5\times10^{-3}}\right] \quad \left(\text{when } V_{in} \text{ is changing from } 1V \text{ to } -1V\right)$$

$$\Rightarrow V_{out} = +0.04V = 40\ mV$$

$\therefore$ V_{out} is square wave of amplitude 40 mV.

Case 2: Sine wave of amplitude 1V as input with C1 = 0.01u, Rf = 10k





<u>As can be seen from the above plot,</u>

1) Vout is lagging Vin by a phase of 90 degrees
2) Vin = Sine wave of amplitude 1V and frequency 1kHz.

   Vout = Sine wave of amplitude 0.63 V and frequency 1kHz.

$$V_{out} = -R_f C_1 \frac{dV_{in}}{dt}$$

$$\Rightarrow V_{out} = -(10\times10^{3})(0.01\times10^{-6}) \times \frac{d}{dt}\left(\sin(2\pi\times10^{3}t + \phi)\right)$$

$$\Rightarrow V_{out} = -0.1\times10^{-3} \times 2\pi\times10^{3} \times \cos(2\pi\times10^{3}t + \phi)$$

$$\Rightarrow V_{out} = \underline{0.628} \sin\left(2\pi\times10^{3}t + \phi - \frac{\pi}{2}\right)$$

$\therefore$ V_{out} is a sine wave of amplitude 0.628 V and $f = 1$ kHz

and V_{out} is lagging V_{in} by a phase of $\pi/2$.