Analog Engineer's Circuit

Sine wave generator circuit

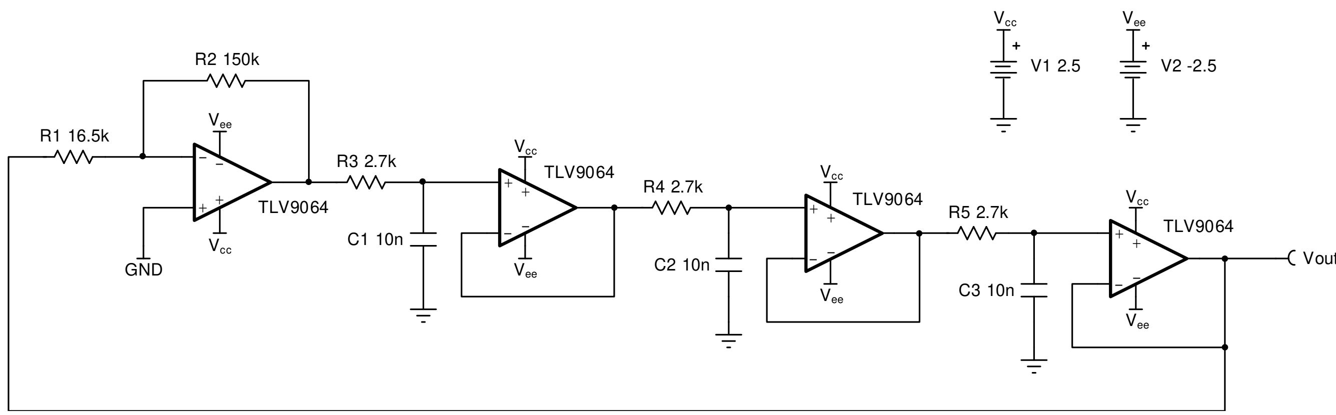
Amplifiers

Design Goals

AC Specifications		Supply	
AC Gain	$f_{oscillation}$	V_{cc}	V_{ee}
8V/V	10kHz	2.5V	–2.5V

Design Description

This circuit uses a quad channel op amp with ±2.5-V supplies to generate a 10kHz, low-distortion sine wave. The amplifiers buffer each RC filter stage, which yields a low-distortion output.



Design Notes

1. Using excessively large feedback resistors, R_1 and R_2, can lead to a shift in oscillation frequency, and an increase in noise and distortion.
2. The first stage resistors, R_1 and R_2, must be selected to provide a sufficiently large gain. Otherwise, oscillations at the output will dampen. However, an excessively large gain at the first stage will lead to higher output distortion and a decreased frequency of oscillation.
3. Heavy loading of the output leads to degradation in the oscillation frequency.
4. At higher frequencies (> 10 kHz), the phase delay of the amplifier becomes significant. The result will be a frequency of oscillation that is lower than calculated or expected. Thus, some margin must be included when selecting values for the loading elements of the first, second, and third stages (R_3, R_4, R_5, C_1, C_2, and C_3) for higher-frequency designs to ensure the desired oscillation frequency is achieved.
5. Choose an amplifier with at least 100 times the required gain bandwidth product. This will ensure the actual and calculated oscillation frequencies match.
6. For more precise control of the oscillation frequency, use passive components with lower tolerances.

Design Steps

For a classical feedback system, oscillation occurs when the product of the open loop gain, A_{OL}, and the feedback factor, β, is equal to –1, or 1 at 180°. Therefore, each RC stage in the design must contribute 60° of phase shift. Since each stage is isolated by a buffer, the feedback factor, β, of the first stage must have a magnitude of $(1/2)^3$. Therefore the gain (1/β) must be at least 8V/V.

1. $$A_{OL} \times \beta = A_{OL} \times \left(\frac{1}{RCs + 1}\right)^3$$

   Select the first stage feedback resistors for the gain necessary to maintain oscillation.

   $$\text{Gain} = \frac{R_2}{R_1} \geq 8\frac{V}{V}$$

   $$R_1 = 16.5k\Omega,\ R_2 = 150k\Omega \text{ (Standard Values)}$$

2. Calculate components R_3, R_4, R_5, C_1, C_2, and C_3 to set the oscillation frequency. Select C_1, C_2, and C_3 as 10nF.

   $$f_{oscillation} = \frac{\tan(60°)}{2\pi \times R \times C} = 10\text{kHz}$$

   $$C_{1,2,3} = 10\text{nF (Standard Values)}$$

   $$R_{3,4,5} = \frac{\tan(60°)}{2\pi \times C \times f_{oscillation}} = \frac{1.73}{2\pi \times 10\text{nF} \times 10\text{kHz}} = 2757\Omega \approx 2.7\text{k}\Omega \text{ (Standard Values)}$$

3. Ensure the selected op amp has the bandwidth to oscillate at the desired frequency.

   $$f_{oscillation} \ll \frac{GBW}{Gain} = \frac{GBW}{\left(\frac{R_2}{R_1}\right) + 1}$$

   $$10\text{kHz} \ll \frac{10\text{MHz}}{\left(\frac{150\text{k}\Omega}{16.5\text{k}\Omega}\right) + 1} \cong 991\text{kHz}$$

4. Ensure the selected op amp has the slew rate necessary to oscillate at the desired frequency. Use the full power bandwidth equation to calculate the necessary slew rate and ensure it is less than the slew rate of the amplifier. While the exact amplitude of oscillation is difficult to predict, you can ensure that our amplifier is fast enough to generate the needed sine wave by ensuring that the output can swing from rail-to-rail.

   $$SR_{req} = V_{peak} \times 2\pi\, f_{oscillation} = 2.5V \times 2\pi \times 10\text{kHz} = 0.157\frac{V}{\mu s}, \text{ given } V_{cc} = V_{peak}$$

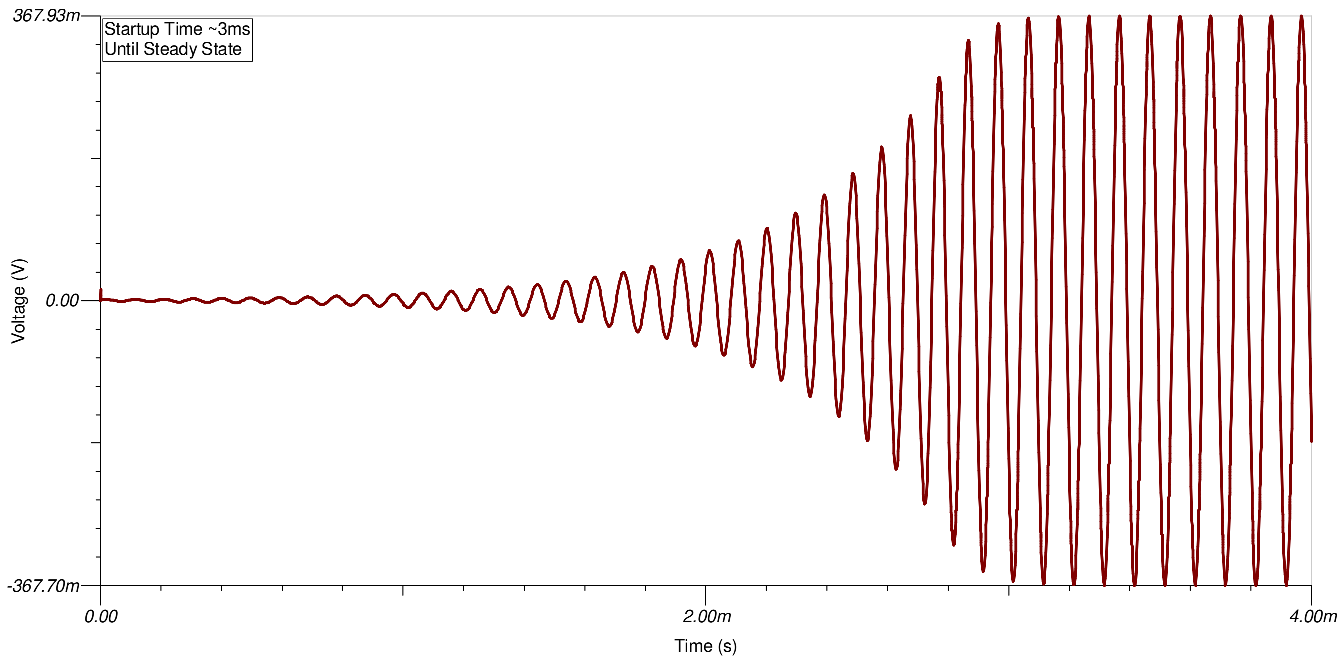
   $$SR_{req} < SR_{TLV9064}$$

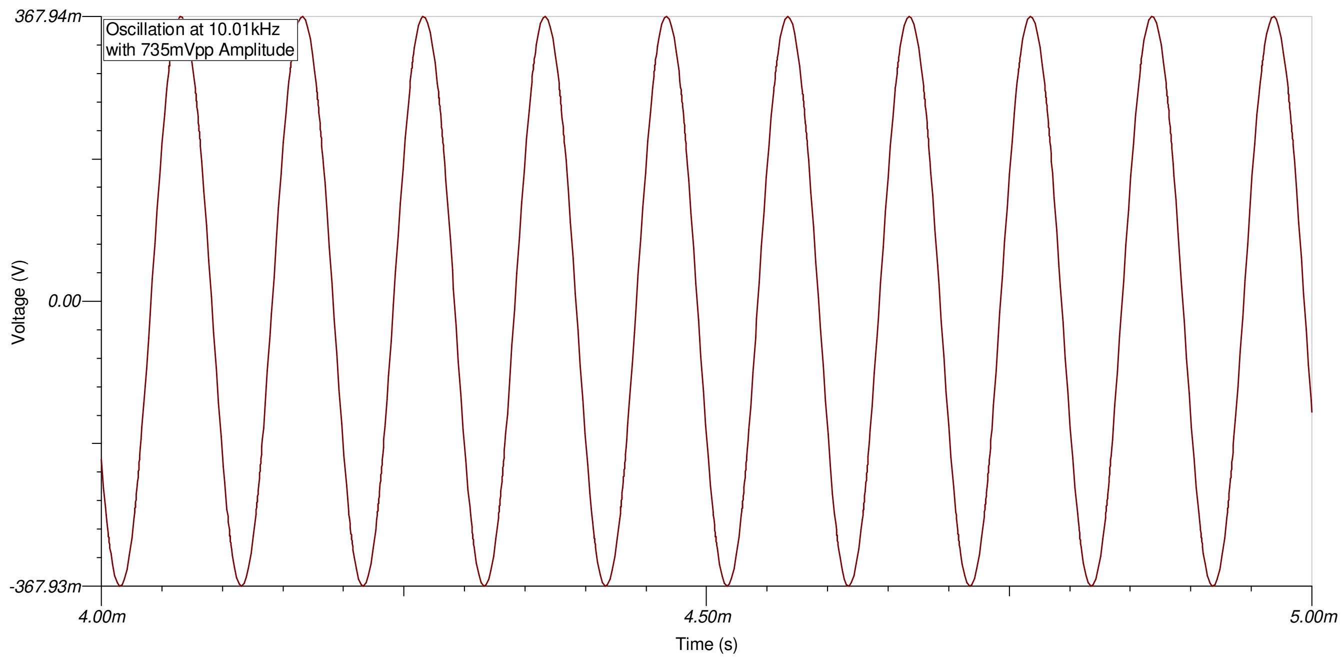
   $$0.157\ \frac{V}{\mu s} < 6.5\frac{V}{\mu s}$$

Design Simulations

The resulting simulations demonstrate a sinusoidal oscillator that reaches steady state after about 3ms to a 10.01-kHz sine wave with a 735-mV_{pp} amplitude.

Transient Simulation Results





Design References

1. See Analog Engineer's Circuit Cookbooks for TI's comprehensive circuit library.
2. SPICE Simulation File: SLOC355.
3. TI Precision Labs
4. *Sine-Wave Oscillator Application Report*
5. *Design of Op Amp Sine Wave Generators Application Report*

Design Featured Op Amp

TLV9064	
V_{ss}	1.8V to 5.5V
V_{inCM}	Rail-to-rail
V_{out}	Rail-to-rail
V_{os}	300µV
I_q	538µA
I_b	0.5pA
UGBW	10MHz
SR	6.5V/µs
#Channels	1, 2, 4
www.ti.com/product/TLV9064	

Design Alternate Op Amps

	TLV9052	OPA4325
V_{ss}	1.8V to 5.5V	2.2V to 5.5V
V_{inCM}	Rail–to–rail	Rail–to–rail
V_{out}	Rail–to–rail	Rail–to–rail
V_{os}	330µV	40µV
I_q	330µA	650µA
I_b	2pA	0.2pA
UGBW	5MHz	10MHz
SR	15V/µs	5V/µs
#Channels	2	4
	www.ti.com/product/TLV9052	www.ti.com/product/OPA4325