

# Analog Engineer's Circuit

## Sine wave generator circuit



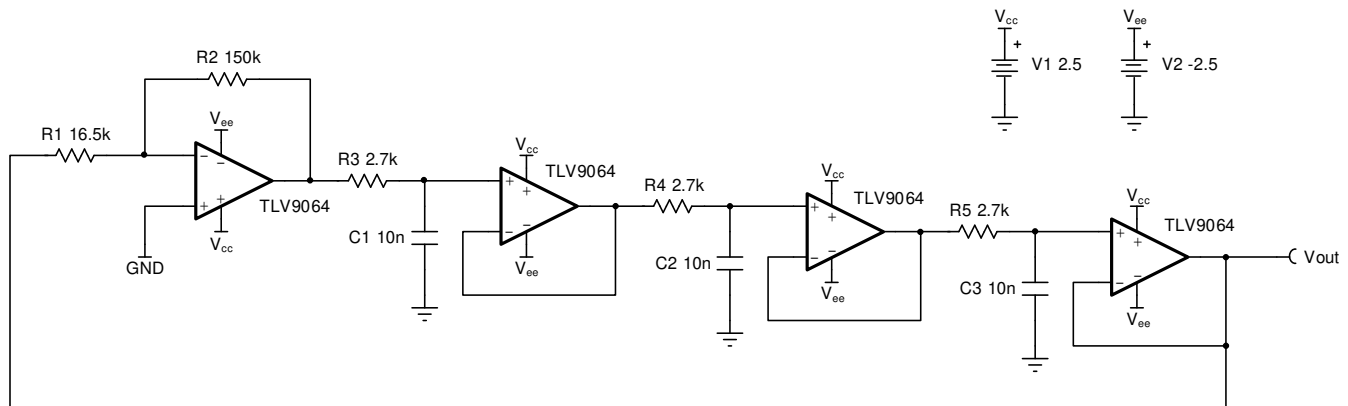
### Amplifiers

### Design Goals

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

### Design Description

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



### Design Notes

- 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.
- 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.
- Heavy loading of the output leads to degradation in the oscillation frequency.
- At higher frequencies ( $> 10\text{ kHz}$ ), 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.
- Choose an amplifier with at least 100 times the required gain bandwidth product. This will ensure the actual and calculated oscillation frequencies match.
- 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,  $\beta$ , is equal to  $-1$ , or  $1$  at  $180^\circ$ . Therefore, each RC stage in the design must contribute  $60^\circ$  of phase shift. Since each stage is isolated by a buffer, the feedback factor,  $\beta$ , of the first stage must have a magnitude of  $(1/2)^3$ . Therefore the gain  $(1/\beta)$  must be at least  $8V/V$ .

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

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

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

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

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  $10nF$ .

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

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

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

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

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

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

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.

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

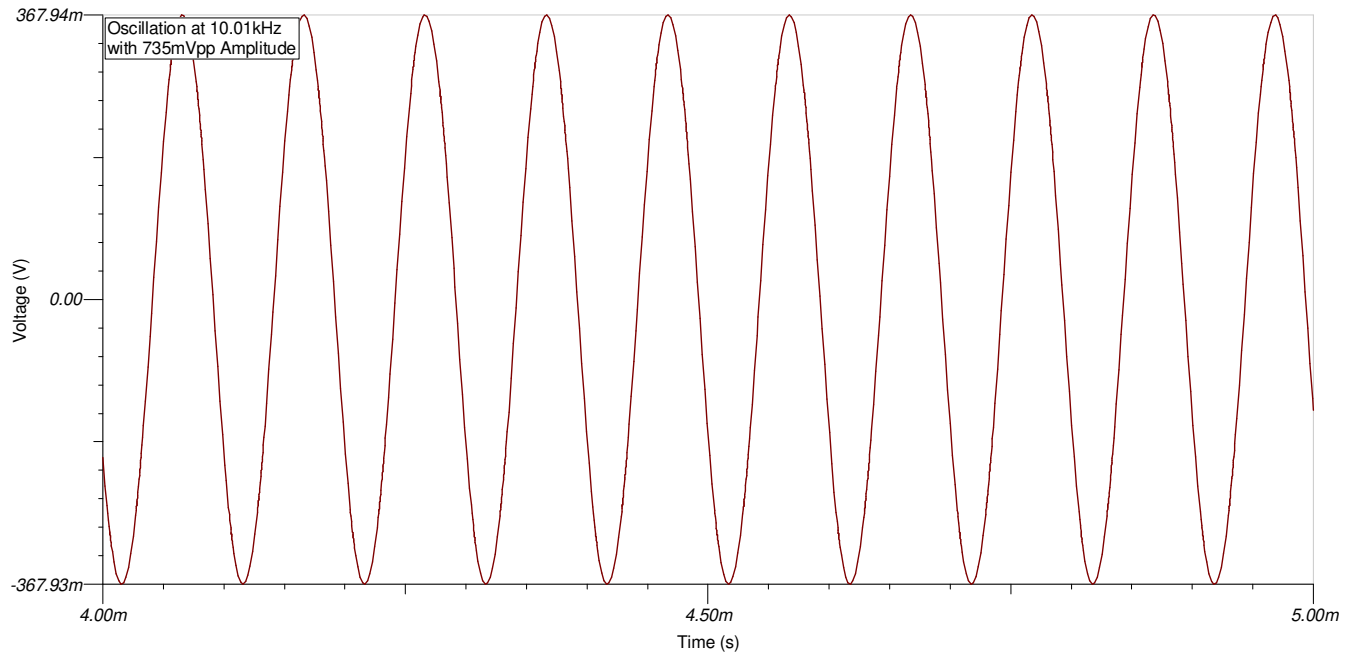
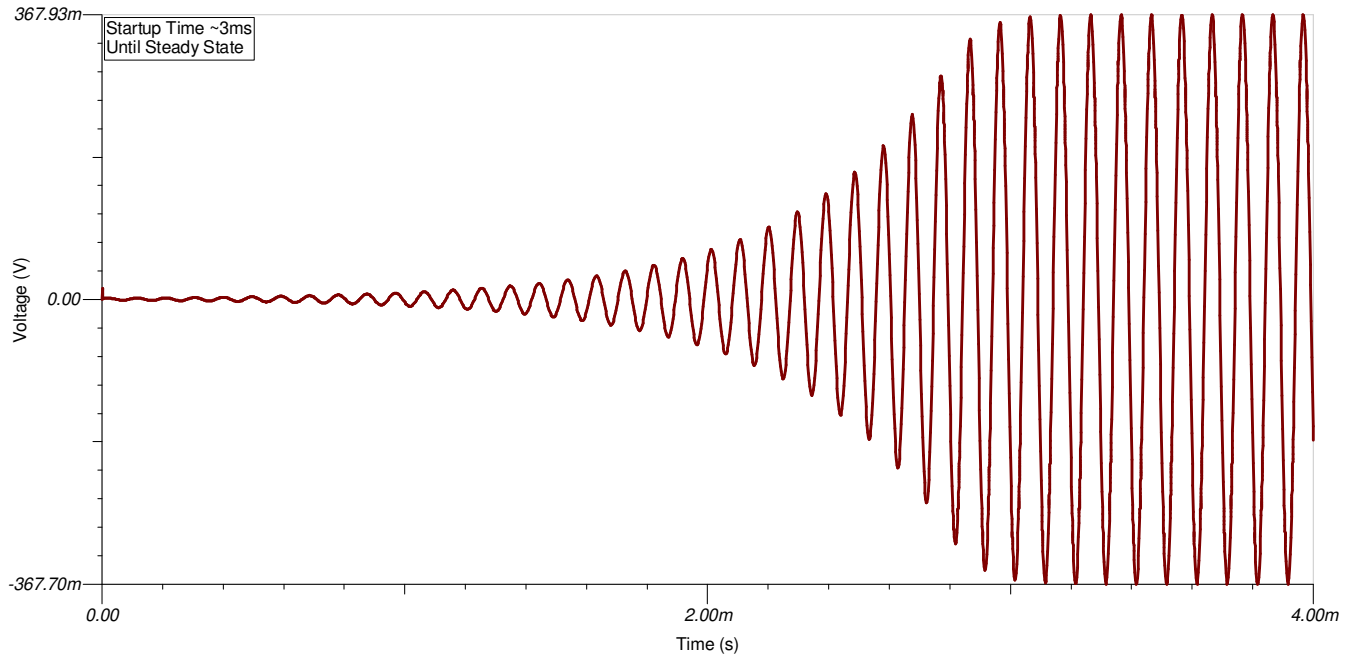
$$SR_{\text{req}} < SR_{\text{TLV9064}}$$

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

## 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<sub>pp</sub> 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
$V_{os}$	300 $\mu$ V
$I_q$	538 $\mu$ A
$I_b$	0.5pA
<b>UGBW</b>	10MHz
<b>SR</b>	6.5V/ $\mu$ s
<b>#Channels</b>	1, 2, 4
<a href="http://www.ti.com/product/TLV9064">www.ti.com/product/TLV9064</a>	

## 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
$V_{os}$	330 $\mu$ V	40 $\mu$ V
$I_q$	330 $\mu$ A	650 $\mu$ A
$I_b$	2pA	0.2pA
<b>UGBW</b>	5MHz	10MHz
<b>SR</b>	15V/ $\mu$ s	5V/ $\mu$ s
<b>#Channels</b>	2	4
	<a href="http://www.ti.com/product/TLV9052">www.ti.com/product/TLV9052</a>	<a href="http://www.ti.com/product/OPA4325">www.ti.com/product/OPA4325</a>

## IMPORTANT NOTICE AND DISCLAIMER

TI PROVIDES TECHNICAL AND RELIABILITY DATA (INCLUDING DATASHEETS), DESIGN RESOURCES (INCLUDING REFERENCE DESIGNS), APPLICATION OR OTHER DESIGN ADVICE, WEB TOOLS, SAFETY INFORMATION, AND OTHER RESOURCES "AS IS" AND WITH ALL FAULTS, AND DISCLAIMS ALL WARRANTIES, EXPRESS AND IMPLIED, INCLUDING WITHOUT LIMITATION ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE OR NON-INFRINGEMENT OF THIRD PARTY INTELLECTUAL PROPERTY RIGHTS.

These resources are intended for skilled developers designing with TI products. You are solely responsible for (1) selecting the appropriate TI products for your application, (2) designing, validating and testing your application, and (3) ensuring your application meets applicable standards, and any other safety, security, or other requirements. These resources are subject to change without notice. TI grants you permission to use these resources only for development of an application that uses the TI products described in the resource. Other reproduction and display of these resources is prohibited. No license is granted to any other TI intellectual property right or to any third party intellectual property right. TI disclaims responsibility for, and you will fully indemnify TI and its representatives against, any claims, damages, costs, losses, and liabilities arising out of your use of these resources.

TI's products are provided subject to TI's Terms of Sale (<https://www.ti.com/legal/termsofsale.html>) or other applicable terms available either on [ti.com](https://www.ti.com) or provided in conjunction with such TI products. TI's provision of these resources does not expand or otherwise alter TI's applicable warranties or warranty disclaimers for TI products.

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265  
Copyright © 2021, Texas Instruments Incorporated