A.5 Oscillators

This section describes some general op amp sinewave oscillator circuits that fall under three main categories: Wien bridge, phase shift, and quadrature. A brief description and of each type is provided, along with one or two variations. Op amp sinewave oscillators are used to create references in applications such as audio and function/waveform generators.

A.5.1 Basic Wien Bridge Oscillator

When $\omega = 2\pi f = 1/RC$, the feedback is in phase (this is positive feedback), and the gain is 1/3, so oscillation requires an amplifier with a gain of 3. When $R_F = 2R_G$ the amplifier gain is 3 and oscillation occurs at $f = 1/2\pi RC$. Normally, the gain is larger than 3 to ensure oscillation under worst case conditions.

V_{REF} sets the output dc voltage in the center of the span.

The output sine wave is highly distorted because limiting by saturation and cutoff is controlling the output voltage excursion. The distortion decreases when the gain is decreased, but the circuit may not oscillate under worst-case low gain conditions.

$$V_{REF} = \frac{\frac{V_{CC}}{2}}{1 + \frac{R_F}{R_G}} \qquad \text{A–42}$$

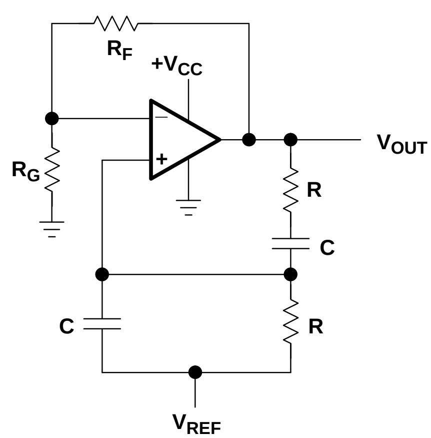

Figure A–37. Basic Wien Bridge Oscillator

A.5.2 Wien Bridge Oscillator with Nonlinear Feedback

When the circuit gain is 3, $R_L = R_F/2$.

Substituting a lamp (R_L) for the gain setting resistor reduces distortion because the non–linear lamp resistance adjusts the gain to keep the output voltage smaller than the power supply voltage. The output voltage never approaches the power supply rail, so distortion doesn't occur. R_F and R_L determine the lamp current (see Equations A–43 and A–44).

$$I_{LAMP} = \frac{V_{OUT(RMS)}}{R_F + R_L} \qquad \text{A–43}$$

$$R_F = \frac{2\left(V_{OUT(RMS)}\right)}{3\left(I_{OUT(RMS)}\right)} \qquad \text{A–44}$$

The lamp is selected by examining lamp resistance curves until a lamp with a resistance approximately equal to $R_F/2$ at $I_{OUT(RMS)}$ is found. The output voltage swing should be less than 75% of the maximum guaranteed voltage swing, and 3 R_L must be greater than the load resistance specified for the voltage swing specification. V_{REF} should be $V_{CC}/5$.

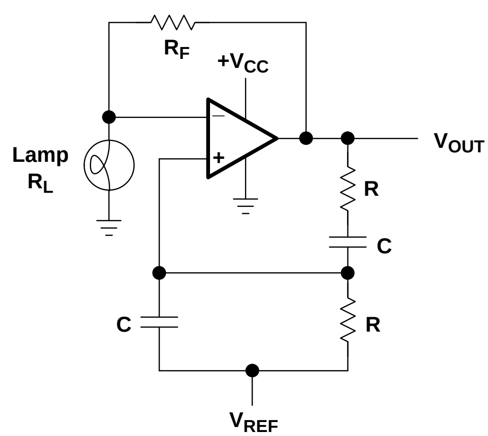

Figure A–38. Wien Bridge Oscillator with Nonlinear Feedback

A.5.3 Wien Bridge Oscillator with AGC

The op amp is configured as an ac amplifier to ease biasing problems. The gain equation for the op amp is given below. R_{G1} or R_{G2}, but not both resistors, is required depending on the selection of the Q_1.

The diode, D_1, half-wave rectifies the output voltage and applies it to the voltage divider formed by R_1 and R_2. The voltage divider biases Q_1 in its linear region, and they eventually set the output voltage. C_1 filters the rectified sine wave with a long time constant so that the output voltage stays constant. C_2 must be selected large enough to act as a short at the oscillation frequency.

As the output voltage increases, the negative voltage across the gate of Q_1 increases. The increased negative gate voltage causes Q_1 to increase its drain-to-source resistance. This results in increased op amp gain and an output voltage decrease. When the voltage divider and FET are selected properly, the output voltage swing is less than the guaranteed maximum swing, so distortion doesn't occur.

$$G = \frac{R_F}{R_{G1} + R_{G2} \parallel R_{FET}} \qquad \text{A–45}$$

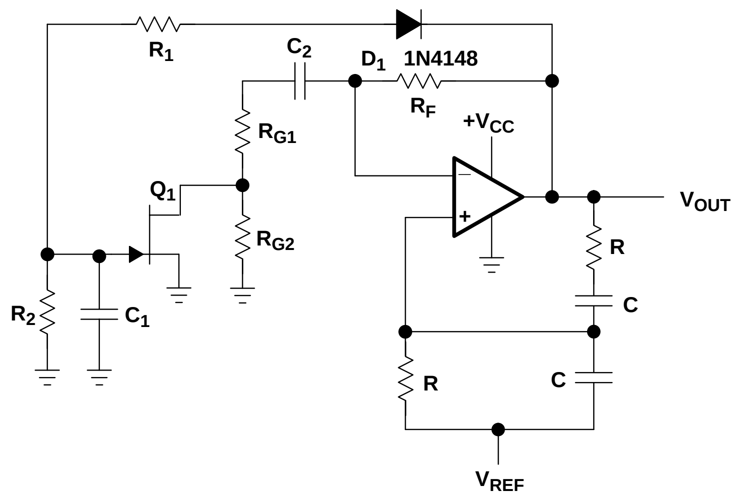

Figure A–39. Wien Bridge Oscillator with AGC

A.5.4 Quadrature Oscillator

Quadrature oscillators produce sine waves 90° out of phase, so they output sine/cosine, or quadrature waves.

When $R_1C_1 = R_2C_2 = R_3C_3$, the circuit oscillates at $\omega = 2\pi f = 1/RC$. Both op amps act as integrators causing two poles at 1/RC, thus the circuit oscillates when the loop gain crosses the 0-dB axis. The integrators ensure that gain is always sufficient for oscillation. There is a slight bit of distortion at the sine output, and it is very hard to eliminate this distortion.

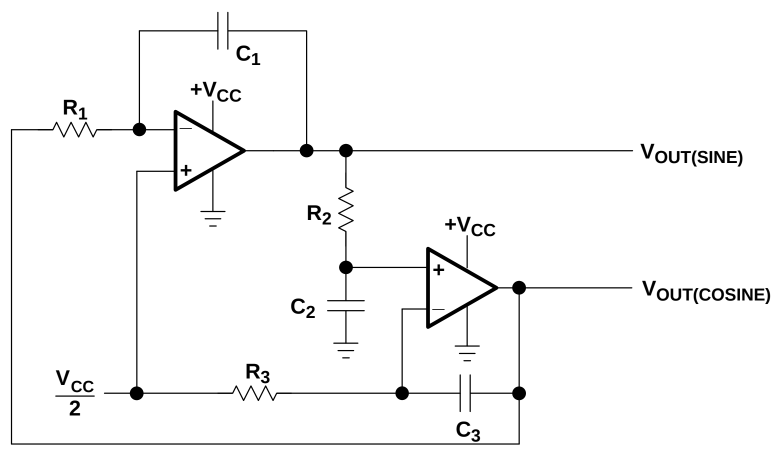

Figure A–40. Quadrature Oscillator

A.5.5 Classical Phase Shift Oscillator

Theoretically, the three RC sections do not load each other, thus the loop gain has three identical poles multiplied by the op amp gain.

The loop phase shift is –180° when the phase shift of each section is –60°, and this occurs when $\omega = 2\pi f = 1.732/RC$ because the tangent of 60° = 1.73. The magnitude of β at this point is $(1/2)^3$, so the gain, $A = R_F/R_G$, must be greater or equal to 8 for the system gain to be equal to 1.

The assumption that the RC sections do not load each other is not entirely valid, thus the circuit does not oscillate at the specified frequency, and the gain required for oscillation is more than 8. This circuit configuration was very popular when an active component was large and expensive, but now that op amps are inexpensive, small, and come quad packages, the classical phase shift oscillator is losing popularity.

The classical phase shift oscillator has an undistorted sine wave available at the output of the third RC section. This is not a low-impedance output, and the signal amplitude is smallest here, but these sacrifices have to be made to get away from distortion. An undistorted output can be obtained from the op amp if an AGC circuit similar to the one shown in Figure A–39 is employed. The reference voltage is set according to the equation $V_{REF} = V_{CC}/\ 2(1+R_F/R_G)$ to center the output voltage at $V_{CC}/2$.

$$A\beta = \left(\frac{1}{RCs + 1}\right)^3 \qquad \text{A–46}$$

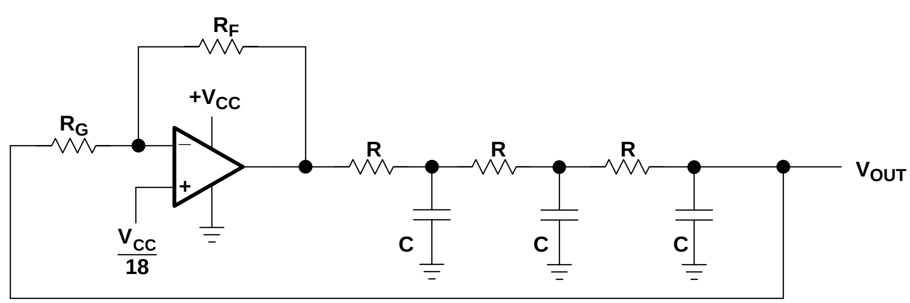

Figure A–41. Classical Phase Shift Oscillator

A.5.6 Buffered Phase Shift Oscillator

A noninverting op amp buffers each RC section in this oscillator. Equation A–46, repeated below, truly represents the transfer function of this circuit if $R_G >> R$.

$$A\beta = \left(\frac{1}{RCs + 1}\right)^3 \tag{A–47}$$

The loop phase shift is –180° when the phase shift of each section is –60°, and this occurs when $\omega = 2\pi f = 1.732/RC$ because the tangent 60° = 1.73. The magnitude of β at this point is $(1/2)^3$, so the gain, $A = R_F/R_G$, must be greater or equal to 8 for the system gain to be equal to one.

The buffered phase shift oscillator has an undistorted sine wave available at the output of the third RC section. This is not a low-impedance output, and the signal amplitude is smallest here, but these sacrifices have to be made to get away from distortion. An undistorted output can be obtained from the op amp if an AGC circuit similar to the one shown in Figure A–39 is employed.

There are three op amps, so the gain can be distributed among the op amps at the expense of a few resistors, and the distortion is reduced. Another method of reducing distortion is to limit the output voltage swing softly with external components. The limiting technique does not yield as good results as the AGC technique does, but it is less expensive. The reference voltage is set according to the equation $V_{REF} = V_{CC}/\,2(1+R_F/R_G)$ to center the output voltage at $V_{CC}/2$.

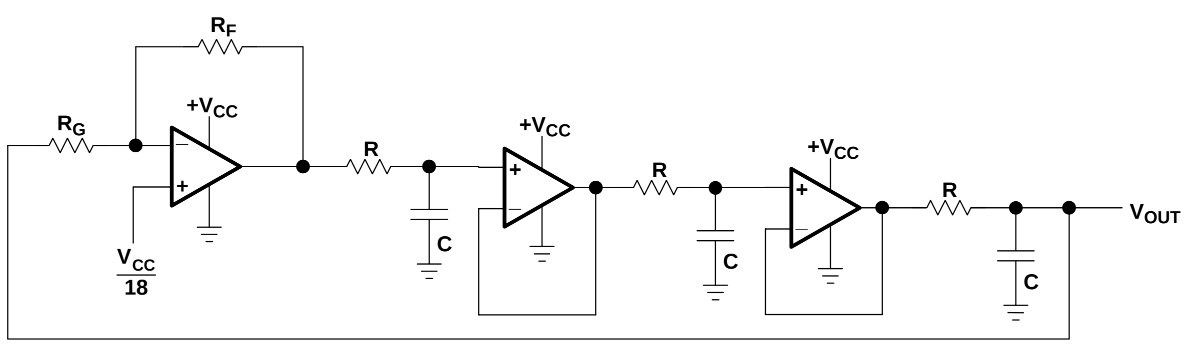

Figure A–42. Buffered Phase Shift Oscillator

A.5.7 Bubba Oscillator

The Bubba oscillator is another phase shift oscillator, but it takes advantage of the quad op amp package to yield some unique advantages. Each RC section is buffered by an op amp to prevent loading. When R_G >> R there is no loading in the circuit, and the circuit yields theoretical performance.

Four RC sections require –45° phase shift per section to accumulate –180° phase shift. Each RC section contributes –45° phase shift when $\omega = 1/RC$. The gain required for oscillation is $G \geq (1/0.707)^4 = 4$. Taking outputs from alternate sections yields low-impedance quadrature outputs. When an output is taken from each op amp, the circuit delivers four 45° phase-shifted sine waves.

The gain, A, must equal 4 for oscillation to occur. Very low distortion sine waves can be obtained from the junction of R and R_G. When low-distortion sine waves are required at all outputs, the gain should be distributed among the op amps. Gain distribution requires biasing of the other op amps, but it has no effect on the oscillator frequency. This oscillator has the best dφ/df of the phase shift oscillators, so it has minimum frequency drift. The reference voltage is set according to the equation $V_{REF} = V_{CC}/\ 2(1+R_F/R_G)$ to center the output voltage at $V_{CC}/2$.

$$A\beta = \left(\frac{1}{RCs + 1}\right)^4 \qquad \text{A–48}$$

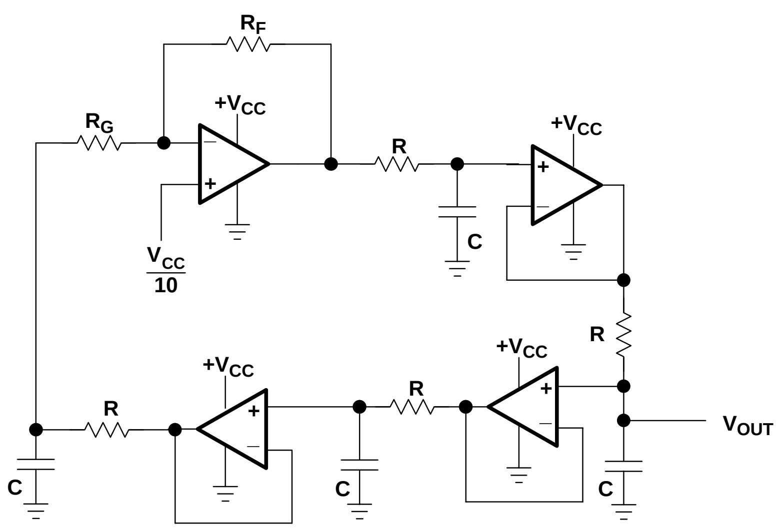

Figure A–43. Bubba Oscillator

A.5.8 Triangle Oscillator

The triangle oscillator produces triangle waves and square waves. The op amp functions as an integrator. When the output voltage of the comparator is low, the output of the op amp charges C until the output voltage exceeds the hysteresis voltage set by R_1 and R_F and the reference voltage ($V_{CC}/2$). At this point, the comparator output switches to a high state and the op amp integrates the voltage in a negative direction. The triangle wave (op amp output voltage swing) is given in Equation A–49. The frequency of oscillation is given in Equation A–50.

$$V_{OUT} = \frac{V_{CC}}{2} \pm \frac{V_{CC}R_1}{2R_F} \tag{A–49}$$

$$f = \frac{R_F}{4CRR_1} \tag{A–50}$$

The op amp reference voltage can be adjusted to equalize the triangle rise and fall times.

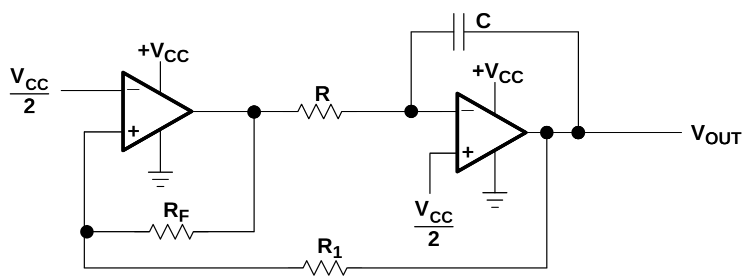

Figure A–44. Triangle Oscillator