FET op amp adds new twist to an old circuit

Need a wide-range sine-wave oscillator with one-control frequency selection? Try this modified Wien-bridge oscillator.

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The Wien-bridge oscillator has long been favored for single frequency applications because of its simplicity and flexibility. But its flexibility can easily be increased. Add just a single op amp to the circuit and you get a wide-range oscillator with one-control frequency selection.

The basic oscillator circuit is often analyzed as a bridge with two reactive and two resistive arms in the feedback circuit of a high-gain amplifier; hence, the name Wien-bridge circuit. However, it may also be looked at as a reactive feedback circuit and a fixed-gain amplifier. **Fig. 1** shows the reactive network (R_S, C_S, R_P and C_P,) and the fixed-gain amplifier (the high-gain op amp and negative feedback network R_1 and R_2). The gain of the feedback amplifier is $1 + R_2/R_1$.

When the gain (A) = $1 + R_S/R_P + C_P/C_S$, you have neutral stability. Setting R_1 and R_2 to give exactly this gain will result in oscillation requiring a minimum of distortion to stabilize its amplitude. But if the gain falls below this value, the oscillation will stop. If it rises above this value, the oscillation amplitude will grow until it is limited by nonlinear distortion. Should a stable sine wave output be required, the gain **must** be held at the proper value as the frequency is changed.

The oscillation frequency is given by:

$$f = 1/\sqrt{2\pi R_S C_S R_P C_P}$$

Observe that the frequency of oscillation can be adjusted by changing any one of the values in the reactive networks. Unfortunately, the gain expression shows that either the gain must change to accommodate the change in one component or components must be changed in pairs. Usual practice is to change both R_S and R_P so that their ratio stays constant as their product is changed. Thus the gain remains fixed while the frequency is adjusted.

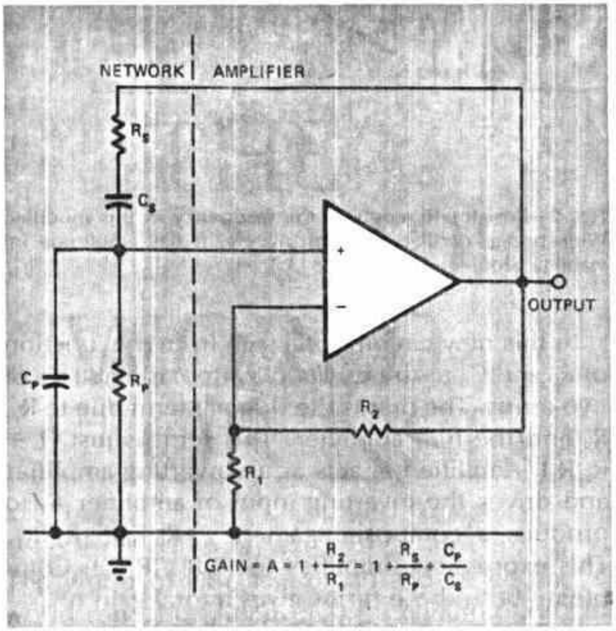

Fig. 1—Classic Wien-bridge oscillator consists of a reactive feedback circuit and a fixed-gain amplifier. It is normally used to generate a single frequency.

Separate adjustment of R_S and R_P is made difficult by their interaction. Therefore, due to the cost and difficulties associated with using precision ganged potentiometers, the Wien-bridge circuit is seldom used as a variable-frequency oscillator.

Frequency-compensate the gain

The circuit shown in **Fig. 2** uses a variable-gain amplifier in which one of the frequency-determining resistors sets the gain. In this way the gain is exactly compensated for changes in one of the frequency-determining resistors, R_P. Once the circuit is optimized at a single frequency, the frequency can be swept through a wide range by changing R_P alone.

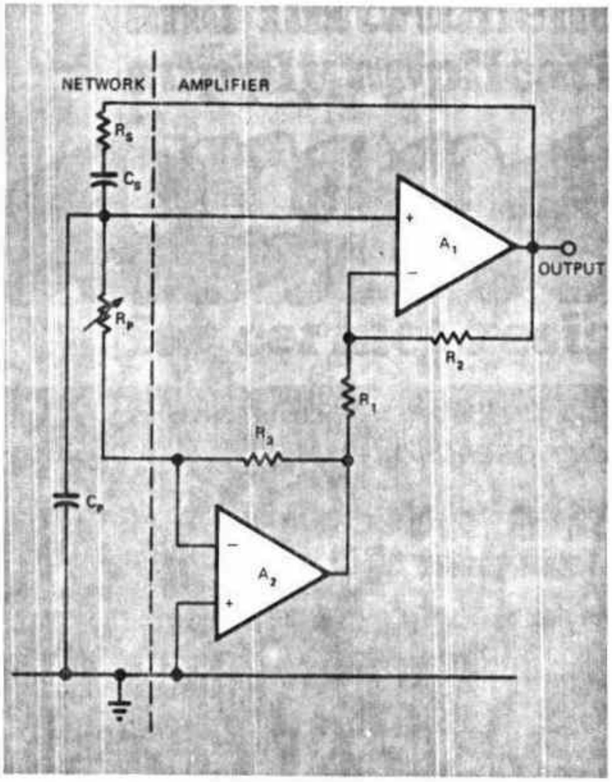

Fig. 2—Resistor R_P controls the frequency in this modified Wien-bridge oscillator. Unfortunately, it has amplitude instability problems.

In this new circuit, total gain from the junction of R_P and C_S to the oscillator output is made up of two terms. The first is the original term due to R_1, R_2 and the first amplifier. This term is just $(1 + R_2/R_1)$. Amplifier A_2 acts as an inverting amplifier and drives the inverting input of amplifier A_1 to produce a composite gain of $(-R_3/R_P)(-R_2/R_1)$. This expression simplifies to $(R_2R_3)/(R_1R_P)$. Combining both these terms gives a total gain A'.

$$A' = 1 + R_2/R_1 + (R_2R_3)/(R_1R_P) \qquad \textbf{(1)}$$

Substituting this into the original gain equation for the Wien-bridge and reducing gives:

$$R_2/R_1 + (R_2\,R_3)/(R_1\,R_P) = R_S/R_P + C_P/C_S \qquad \textbf{(2)}$$

This equation is the condition which must be satisfied to obtain neutral stability. To satisfy the condition, set $R_2/R_1 = C_P/C_S$. This equality reduces **Eq. 2** to:

$$(R_2\,R_3)/(R_1\,R_P) = R_S/R_P$$

which can be further reduced to:

$$R_3 = R_S\,R_1/R_2 \qquad \textbf{(3)}$$

It is important to note that the constraint for neutral stability given in **Eq. 3** does not involve R_P. Further, since R_P is terminated in a virtual ground, the frequency response of the R_SC_S, R_PC_P network is unchanged. Therefore the frequency of this oscillator can be adjusted by changing R_P without otherwise disturbing the circuit gain.

You need amplitude stabilization

In principal, at neutral stability the amplitude of the oscillations neither increases nor decreases (neglecting noise in the circuit). Unfortunately, in practice the slightest deviation from ideal values will result in amplitude instability. In general, if the gain is slightly above the ideal value, oscillation amplitude grows until nonlinearity in the system lowers the "average gain" and stabilizes the amplitude. The theory indicates that if $C_P = C_S$ then R_1, R_2, and R_3 can all be made equal to R_S for neutral stability.

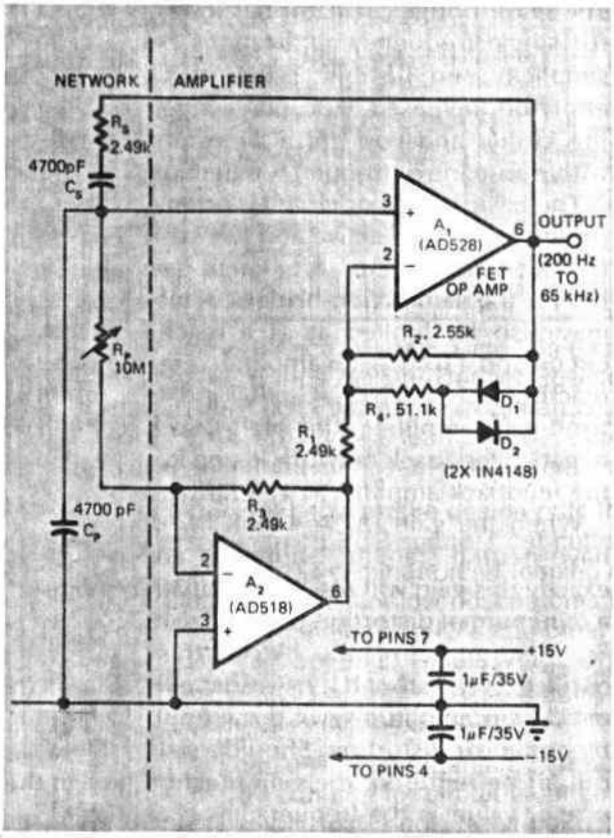

Fig. 3—Practical variable-frequency oscillator uses extra components to achieve amplitude stability. A small resistor in series with R_P makes the circuit "fool proof."

A practical oscillator using the new circuit is shown in **Fig. 3**. Here R_2 is made slightly larger than nominal to insure that the oscillation amplitude will not decay. Resistor R_4 and diodes D_1 and D_2 stabilize the output amplitude by providing a controlled nonlinearity which reduces the gain at large signal levels.

As R_P is reduced, the closed loop gain of amplifier A_2 is increased. The gain bandwidth of this amplifier puts the lower limit on R_P and the upper end on the frequency adjustment range. The Analog Devices AD518 wideband amplifier illustrated gives performance more than an order of magnitude better than 741-type amplifiers.

Input current for amplifier A_1 flows through R_P and can produce a substantial input offset voltage when R_P is large. This will offset the oscillator output and result in significant distortion. Therefore, to obtain the maximum range for R_P, a FET input amplifier should be used. The AD528 shown is a FET-input complement to the AD518 and has the bandwidth required for a wide output frequency range. Using a FET op amp for A_1 makes this circuit practical up to the resistance limits of conventional potentiometers.

The single R_P adjustment of the circuit of **Fig. 3** can sweep the output from 200 Hz to 65 kHz. Since oscillation frequency is inversely proportional to the square root of R_P, the frequency changes very rapidly near the low resistance end of the potentiometer. This adjustment sensitivity can be reduced by using a nonlinear potentiometer characteristic such as an audio or logarithmic taper.

To make the circuit "fool proof," a small resistor can be added in series with potentiometer R_P to limit the frequency adjustment range in accordance with the frequency response of A_1.

Should it be inconvenient to use closely matched capacitors for C_S and C_P, the circuit can be optimized by adjusting the ratio of R_1 to R_2. If this is done, R_3 can then be separately adjusted to give a flat amplitude characteristic over the frequency range.

Obviously this modified Wien-bridge oscillator is not limited to manual adjustment applications. For example, a useful preamplifier/signal conditioner (VFO) can be produced by replacing R_P by a photo-resistor or thermistor. You can search your imagination for other new classes of application. □

Author's biography

A. Paul Brokaw is manager of advanced development at Analog Devices Semiconductor, Wilmington, MA. He received his B.S. degree in physics from Oklahoma State and is an IEEE member. Twelve patents and numerous published articles attest to his creativity. Paul's favorite leisure time activities include swimming, skiing and writing.