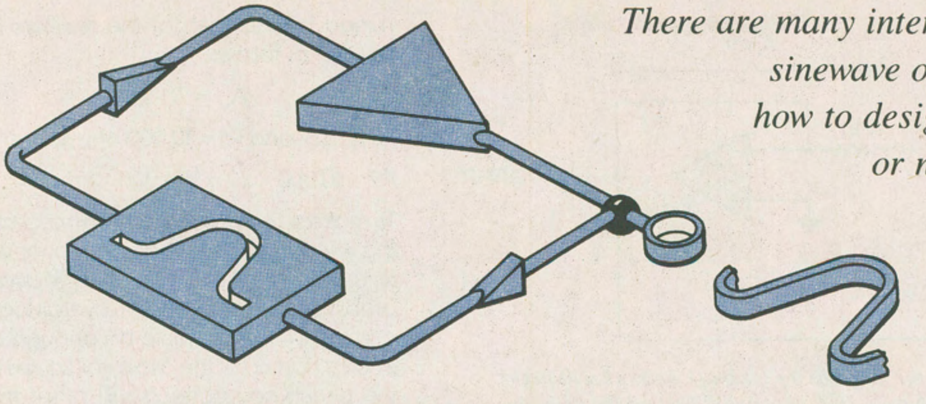

There are many interesting projects that require sinewave oscillators. If you only know how to design square-wave generators, or need a refresher in sinewave generation then this is the article for you.

BY
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All About OSCILLATORS

If you've been involved in electronics as a hobbyist for a while, or even if you're just getting started, no doubt you have seen or heard about various uses for sinewave oscillators. Sound generators, signal sources, radios, televisions, and tape decks use such oscillator circuits to generate signals used in their operation.

So you've encountered sinewave oscillator circuits, but might wonder about how they work? What makes them create an alternating voltage at their output with only DC going in?

That's what we'll be looking at here: the ingredients, if you will, that go into making a circuit oscillate. We'll also take a look at some basic (and some familiar) circuits and how they meet the requirements needed for oscillation.

Sinewave Oscillators. Figure 1 shows the block diagram of the most basic sinewave oscillator. The type of design produces a sinewave at a particular frequency. The top section is an amplifier and the bottom is a frequency-dependent attenuation and phase-shift network. The amplifier is like any other amplifier; its gain produces a copy of the input at the output but with a larger amplitude.

Note that we show the output of the amplifier connected to the attenuator/phase-shift network and the output of the network is connected back to the input of the amplifier. You might be wondering why the output of the amplifier fed back to its own input. That's a good question. Part of the answer is that in order to create an AC signal the amplifier needs a signal to amplify. But that is only a partial answer because, although the resonant feedback network is designed to give maximum output at the chosen frequency, it can't create that signal out of nothing. The amplifier has to supply a signal so the network can do its part. But where is the signal being generated? What came first, the chicken or the egg?

Well, in this case, neither. Obviously, a signal must be generated somewhere to start the whole process. In an actual oscillator that can happen in a couple of ways. One common way is that when the power is switched on, a small voltage spike occurs somewhere in the amplifier. You can think of a spike as a short burst of a range of frequencies or harmonics. Anyway, the amplifier adds gain to the glitch and sends it to the feedback network. The resonant circuit filters out all the harmonics except the ones near its resonant frequency, which it sends to the amplifier. The amplifier in turn amplifies that signal and sends it to the feedback network, and so on. And that's how oscillation starts. However, that explanation is only partially true; we'll clear up the problems with it a little later.

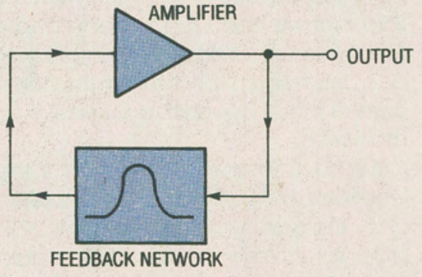

Fig. 1. A sinewave oscillator can be broken down into two key sections: an amplifier and a frequency sensitive feedback network.

Let's Look at the Amplifier. In order for a circuit to oscillate, it must have two important characteristics: The overall gain of the circuit must be 1, and the total "phase shift" through the circuit (which we'll discuss later) must be zero.

First, the gain. Why a gain of one? Let's assume the oscillator is operating normally—outputting a sinewave at some frequency—but the overall gain of the circuit is made greater than one. Each time the signal is fed back around the loop its amplitude would increase by the gain until the maximum output voltage swing of the amplifier was exceeded. At that point, the sinewave would begin to clip causing distortion.

Now let's assume that the loop gain is reduced to less than one. Each time the signal was fed back through the loop, it would decrease until there was no signal left. So, for stable, undistorted operation, the gain of the loop must be one.

But what determines the overall loop gain? If the amplifier has voltage gain, which we call A_V, and the feedback network has attenuation, which is B. The overall loop gain, A_L, can be expressed as:

$$A_L = A_V \times B = 1$$

So we should find out how much attenuation is inherent in a particular feedback loop and set the gain of the amp to offset it so that the overall loop gain is one.

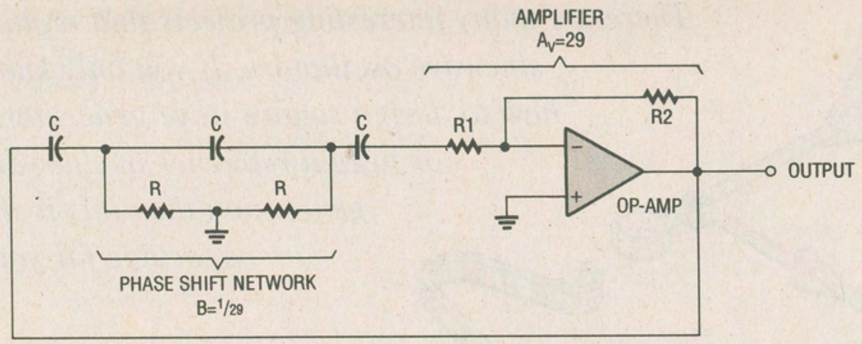

Fig. 2. A phase-shift oscillator relies on the fact that the feedback network will permit only a signal of the desired frequency to have a 360° phase shift around the loop.

Before we leave the topic of total loop gain, one more aspect should be considered: When we talked about how the oscillator gets started, we said that a small signal created by switch-on transients was amplified, fed back, and amplified some more, increasing in amplitude until the desired output signal was obtained. How could that happen with an overall loop gain of one? Sorry, but the answer is that it couldn't.

In practical cases, the overall loop gain at start-up must exceed one in order for the oscillator to operate. In some cases that is accomplished by a portion of the circuit that only operates when the circuit is first turned on. In other cases, the operation of circuit itself limits the gain once the output nears clipping. To do that, the loop gain must be only slightly higher than one.

Phase Shift. Now let's look at the other requirement for oscillation: the total phase shift must be zero. We say "total" phase shift because the amplifier may provide a phase shift. Some amplifiers invert the input signal. That is equivalent to a phase shift of 180°; inverting the signal twice creates a phase shift of 360°, which would put the output back in phase with the input signal.

We need to know the amplifier's phase shift to design the feedback network. We have already said that the job of the attenuator and frequency network is to dictate the frequency at which the oscillator operates. Usually it is some form of resonant or tuned circuit that has a phase-shift of its own. If the phase shift of the network doesn't compliment the phase shift of the amplifier—to make the overall shift 0° or 360°—the waves produced by them will destructively interfere. The circuit will either oscillate at the wrong frequency or fail to oscillate altogether. With that under our belts, let's look at a couple of practical circuits.

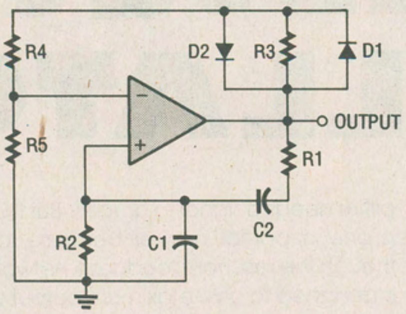

Fig. 3. A Wien-bridge oscillator uses two feedback loops, a negative loop to limit the gain, and a positive loop to set the frequency.

The Phase-Shift Oscillator. The circuit in Fig. 2 is called a phase-shift oscillator. In this particular circuit, an op-amp and two resistors (R1 and R2) form the amplifier. The feedback circuit consists of three capacitors (all with the same value, C) and three resistors (all with the value R) that set the frequency of oscillation. As the signal is fed through the network, a phase shift of 180° occurs. Hence, the name "phase-shift oscillator." The other important aspect of the feedback network is that it gives an attenuation, B, of 1/29.

Since a feedback network has an inherent phase shift of 180°, and we have said that we need the signal in phase (360°), we use an inverting amplifier to add another 180° phase shift. That takes care of the phase-shift requirement for oscillation.

We have to now set the gain. If the feedback network has an attenuation of 1/29, the gain of the amp must be 29 in order to achieve an overall loop gain of one:

$$A_L = A_v x B = 29 \times 1/29 = 1$$

The gain of the amplifier, A_v, is determined by the ratio of the resistors R1 and R2 as follows:

$$A_v = R1/R1$$

if $A_v = 29$ and $R1 = 10{,}000$ ohms:

$R2 = 10{,}000 \times 29 = 290{,}000$ ohms

To make sure the circuit will start oscillating we can choose the next higher resistor value of 330k, which will give us an amplifier gain of 33 and an overall loop gain of 1.14. That should be enough to ensure start up of the oscillator. Losses in the circuit components will offset the extra gain, so once the circuit starts oscillating it shouldn't go into clipping.

We can determine the frequency of oscillation using the following formula:

$$f = 1/(2\pi\sqrt{6}RC)$$

According to that equation, if we used .01-µF capacitors and 10k resistors the frequency is 1.59 kHz.

The circuit is actually quite simple and easy to set up using practically any op-amp. The drawback to the circuit is that it isn't very stable. Temperature variations in the components can cause the frequency to drift so it isn't used very often.

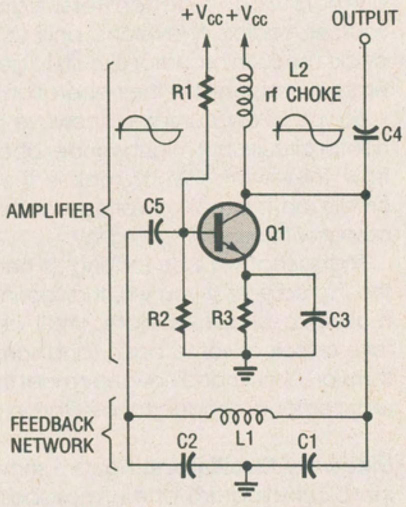

Fig. 4. This basic Colpitts oscillator is built from discrete components, but contains an amplifier and feedback network like the other oscillator circuits.

Next we'll look at a circuit that uses a slightly different technique to achieve the same results.

The Wien Bridge Oscillator. The Wien Bridge uses two feedback loops. One supplies positive feedback through a bandpass filter that has zero phase shift and an attenuation of 1/3 at

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the resonant frequency. The other is a negative feedback loop that is used to limit the gain of the amplifier. Figure 3 shows the schematic diagram.

You'll notice that in the negative feedback loop, (connected to the inverting input of the op-amp), an extra resistor, R3, and two diodes, D1 and D2, are shown. The resistor increases the loop gain during start-up to greater than one. When the output signal reaches a level sufficient to forward bias the diodes (D1 on the positive excursion and D2 on the negative), R3 is shorted out reducing the loop gain to one. Of course, since the attenuation of the positive feedback network is ⅓, the gain of the amplifier circuit is slightly greater than 3 on start-up and about 3 during normal operation.

The main difference between this circuit and the phase-shift oscillator is that the feedback network has a zero phase shift (or 360° phase shift) at the resonant frequency. Since the phase shift of the network meets the requirement for oscillation, the network is connected to the non-inverting input of the op-amp so it provides no phase shift of its own.

The network is made up of two identical resistors and two identical capacitors. One RC pair is arranged as a low-pass filter and the other pair forms a high-pass filter. Together they form a bandpass filter. Components R1 and C1 make up the low-pass filter because at higher frequencies C1 becomes a low

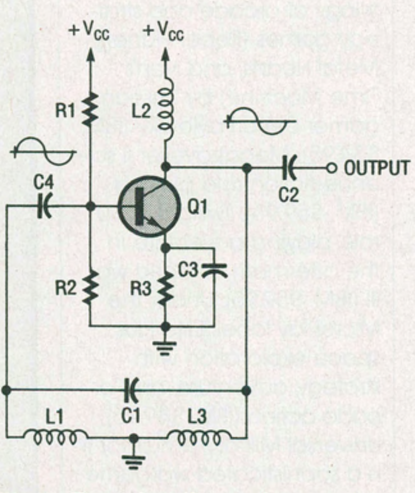

Fig. 5. The only difference between this Hartley oscillator and the colpitts unit presented earlier is the tank circuit. note how the tank's capacitors were replaced with inductors and vice versa.

impedance, shunting the signal to ground. Components R2 and C2 form the high-pass filter, blocking lower frequencies due to C2's high impedance at lower frequencies. The network is also called a lead-lag network because of the phase shifts on either side of the resonant frequency.

The frequency of oscillation and the gain of the op-amp can be determined using the following formulas:

$$f = 1/(2\pi R1C1),$$

and

$$A_v = (R4 + R5 + R3)/R5$$

for the "start-up" gain, and

$$A_v = (R4 + R5)/R5$$

for the operating gain. Again, the overall gain is expressed as:

$$A_L = A_v \times B = 3 \times 1/3 = 1$$

This circuit can also easily be constructed or breadboarded using almost any basic op-amp.

Other Oscillators. There are lots of other feedback-oscillator designs that have been widely used over the years. Due to space limitations, we will only touch on them here; their design will be left as an exercise for the more ambitious reader.

The Colpitts oscillator, shown in Fig. 4, uses a resonant tank circuit made up of an inductor (or sometimes one side of a transformer) and two capacitors. The circuit shown uses a common-emitter transistor amplifier that inverts the output. The grounding point between the two capacitors creates a 180° shift of the signal coming out of the tank making the overall phase shift 360°.

There are several variations on that design. The Hartley oscillator (see Fig. 5) uses two inductors (or a center-tapped inductor) and one capacitor for its tank circuit. The Clapp oscillator, which is not shown, is virtually identical to the Colpitts oscillator of Fig. 4, with one significant difference: a small capacitor is placed in series with the inductor (L1). That capacitor sets the oscillation frequency and reduces the effect of transistor-junction capacitance on the circuit. The list of possible oscillator circuits could go on, but the main requirements for each of them are the same: positive feedback and a gain of one.

I hope that this article has given you enough information for you to design your own oscillator circuits. Good luck with your endeavors, and may all your feedback be positive! ■