Bob's TechTalk #32

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Oscillators

If we're going to build a code practice oscillator (CPO), perhaps we should first discuss oscillators. An oscillator is a device that puts out a periodic wave. This periodic wave can take the form of a sine wave, a square wave or something in between. The main requirement is that the wave repeats continuously. Normally oscillators only have an output and no input. Some oscillators have controlling or syncing inputs, but we'll not concern ourselves with these in this discussion.

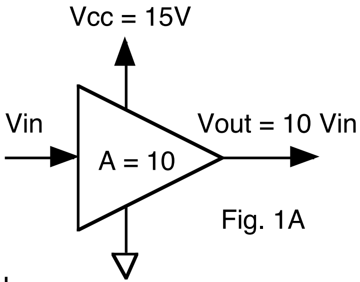


Fig. 1A

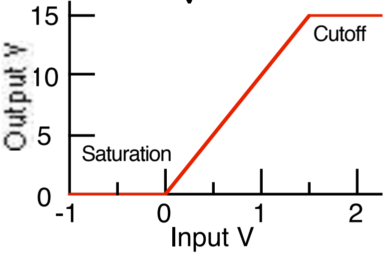


Fig. 1B

What makes an oscillator work? Let's look at Figure 1A. It consists of an amplifier with a gain of 10 and is powered by a +15 volt power supply. The voltage output of this amplifier will be 10 times the input voltage. Because of the size of the power source, the output cannot exceed 15 volts nor be negative (less than zero volts). If the input is increased beyond 1.5 volts then the output will reach 15 volts and stay there; this condition is called *cutoff*. Also, if the input is decreased below zero volts (to a negative voltage) the output will stop at zero; this condition is called *saturation*. See Figure 1B.

(The terms cutoff and saturation refer to the state of the output transistor in the amplifier)

Now, let's connect the output to the input through a resistive attenuator that has an adjustable loss of between nine and eleven. This attenuator provides a *feedback* path from the output to the input. See Figure 2A. Assume for each of the following examples that the initial input to the amplifier is one volt (resulting in ten volts output).

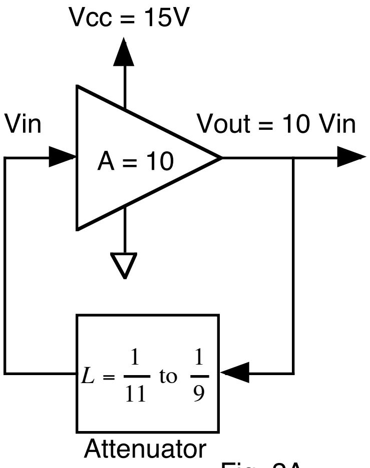


Fig. 2A

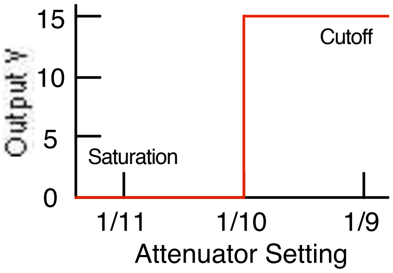


Fig. 2B

If the attenuator is set to a loss greater than ten, then the output voltage will drop to zero (saturation) since the amplifier gain is not enough to make up for the loss in the attenuator.

Likewise, if the attenuator is set to a loss less than ten, then the output voltage will increase to 15 volts (cutoff) since the amplifier gain is greater than the loss in the attenuator.

Should the attenuator be set to ten, then the gain and attenuation will be equal and the output voltage will remain at 10 volts. In the real world this is a very unstable situation since any slight change in gain or attenuation will result in the output moving to one of the two stable states. These are called *latched states*, The steep slope shown in Figure 2B represents the unstable point at an attenuation of 1/10

Let's replace the attenuator with a phase-shift network. We've discussed phase shift networks in a prior ***Techtalk*** column. Our network is designed to have a phase shift of 360° at the design frequency; this is equal to a phase shift of 0°. At the design frequency this network also has a known loss. If the amplifier gain is set near the network loss and some sort of a starting pulse is input to the amplifier, one of three things will occur:

If the gain is less than the network loss, then the output will briefly oscillate at the design frequency with decreasing amplitude until it dies out.

If the gain is higher than the network loss, then the output will oscillate at the design frequency with increasing amplitude until the peaks cause cutoff and saturation resulting is a distorted (almost square) waveform.

However, if the gain is the same as the network loss then the output will oscillate at the design frequency and produce a near sinusoidal waveform. The amplitude will depend on the initial starting signal. Once again, this is a very unstable condition and any small change in conditions will result in one of the preceding conditions.

In order to make real world oscillators stable in amplitude, the gain is usually set near what is required for continuous oscillation, and some special circuit or condition is designed into the oscillator to constantly correct the gain. A good example is a Wein-bridge oscillator[1] that uses the changing resistance of a small lamp to keep the gain (and thus the amplitude) stable.

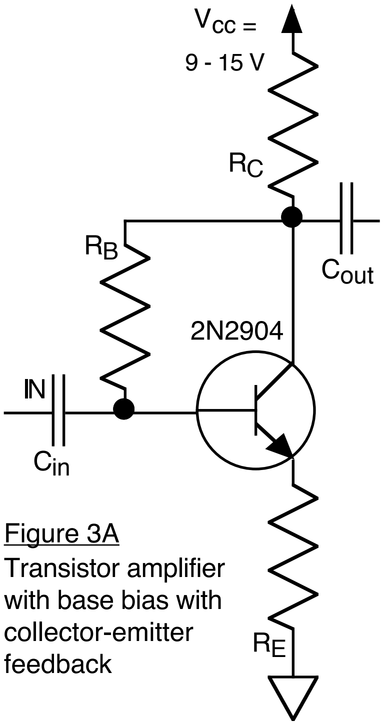


Figure 3A
Transistor amplifier with base bias with collector-emitter feedback

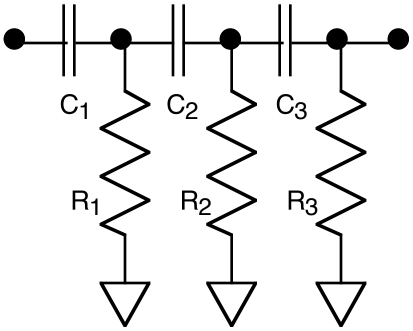


Figure 3B
Three stage high-pass phase-shift network

A real-world way to start an oscillator is also required. Sometimes a special starting circuit is used, but commonly the circuit relies on noise from our imperfect world to start the oscillations. The higher the initial amplifier gain the faster the oscillator will start.

There is a large variety of oscillator circuits that have been designed. Each consists of at least one amplifier and feedback network.

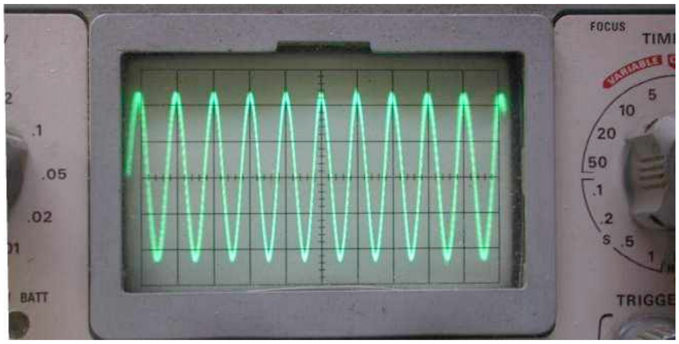
I've chosen to use a phase-shift oscillator as the oscillator for our CPO. It consists of a single transistor amplifier and a three stage phase shift network. Let's look at the amplifier first. It's schematic is shown in Figure 3A. The circuit uses an easily obtained 2N3904 NPN transistor in a common emitter configuration with base bias.[2] The resistors are selected so that the amplifier, with no input, has a collector voltage Vc of about 1/2 of the supply voltage Vcc. The 2N3904 commonly has a beta of more than 100 and the gain of the stage is set by the emitter resistor which is chosen to provide enough gain to cover the loss in the phase shift network and then some. Our amplifier has one other important trait. A positive signal at the input will result in more current flowing in the transistor and in RC. This will result in the output voltage decreasing. Our amplifier thus provides a phase shift of 180° and our phase shift network must only provide an additional 180° of phase shift at the desired frequency of oscillation.

The network used in phase shift oscillators is commonly made up of either three or four high (or low) pass RC networks (Figure 3B). For our design, high pass filters will be easier to integrate with the amplifier circuit as we'll see. If each RC network contains components of equal values then each RC network will provide 60° of phase shift (or 45° if four networks are used) at the frequency of oscillation. Unfortunately, since the RC networks interact with each other you cannot just use the single network values to get the proper R and C, nor can you add the individual RC network losses together to get the total network loss. That requires some complicated matrix mathematics to solve.[3] However, the answers are simple and we'll keep it simple. For a three stage phase shift network the equations for frequency (f) and loss (A) are:

$$f = \frac{1}{2\pi RC\sqrt{6}}$$

$$A = \frac{1}{29}*$$

Figure 6: (Below) is a scope picture of the oscillator's waveform. Vertical gain is 1V/div and the time-base is set at 1mS/div.



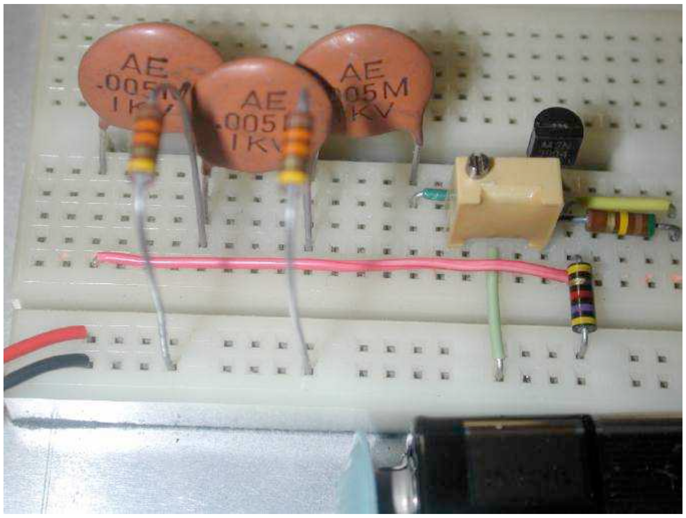


Figure 5: (Left) Is a photo of the phase-shift oscillator breadboard. Q_1 is at the right immediately above the caramel colored trim pot (R_E). The dark object to the lower right is a nine-volt battery.

Now let's connect the two devices together; See Figure 4. Notice that the input capacitor of the amplifier is replaced by one of the capacitors in the network. Also notice that the third resistor (R3) in the network has been removed. We will rely on the input resistance of the amplifier for that resistance. This needs to be taken into account in the design of the amplifier and in selecting R. Since the three RC networks need not be identical, R1 and R2 can be adjusted by trial and error to compensate for the input impedance.

Once the circuit is built, the gain is adjusted by varying RE until the circuit just oscillates. This corresponds to an amplifier gain of 29. The output should be sinusoidal and have a peak-to-peak voltage almost as large as Vcc. If the gain is reduced the oscillations will stop and if it is increased the waveform will distort. The gain should be increased from the initial point until distortion is noted on the waveform and then backed off slightly till the distortion vanishes.

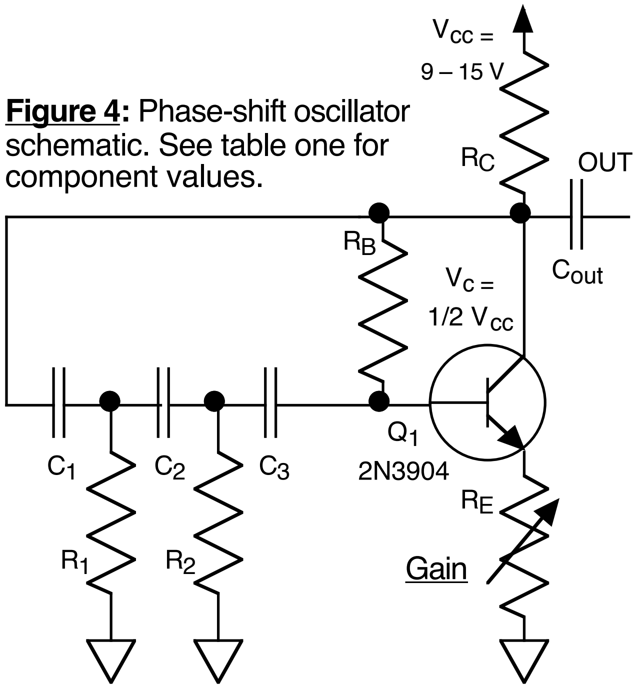


Figure 4: Phase-shift oscillator schematic. See table one for component values.

If you've been following along, you must be asking yourself how the gain is controlled to prevent the instability mentioned previously. The beauty of this circuit is that gain control is built right into the circuit. If you breadboard the circuit you'll notice that the amplitude peaks are near Vcc and zero. As the output of the amplifier approaches saturation and cutoff, the gain decreases. If the gain isn't set too high, this decrease is enough to stabilize the oscillator. This does add some distortion to the sine wave, but if the bias point is set close to midway so that both cutoff and saturation influence the gain, the distortion is minimal.

One other thing needs to be taken into account. The circuit, as shown, is operating without a load. If you want to do something useful with the signal you must couple the output to another circuit. This load will affect the AC gain of the amplifier. The gain should be readjusted with the load connected.

Table 1.
Component values:

R_1, R_2	13KΩ 5%
R_B	510KΩ 5%
R_C	4.7KΩ 5%
R_E	250Ω trim pot
C1, C2, C3	0.005 μf
C_{out}	0.022 μf
Q1	2N3904 NPN

All resistors are 1/4 watt or larger (carbon film preferred)

All capacitors are disk ceramic type, though mylar, polyethylene or paper should work as well.

Experiment with what's in your junk box.

Table 1 gives component values for a phase shift oscillator that operates at about 1 KHz. It will run off of a 12V supply or a nine volt battery, and it draws only a couple of milliamps. Breadboard one up and play with it.

Next month let's look at an follower amplifier that will allow us to drive a small audio amplifier with our oscillator.

Notes:

1. **See any recent ARRL handbook for information on the Wien-Bridge Oscillator.**
2. **A good reference on transistor biasing is: *Transistor Circuit Approximations* by A.P. Malvino, McGraw-Hill, 1968.**
3. **I'd be glad to email the derivation to anyone interested.**

73, from AF6C

This article is based on the TechTalk article that originally appeared in the September 2004 issue of RF, the newsletter of the Orange County Amateur Radio Club - W6ZE.