# High-Purity Sinewave Oscillators With Amplitude Stabilization

*Application Note* | *March 20, 1998* | *AN1088*

*Author: Barry Harvey*

While a wide variety of circuits and components are used to generate sinewaves, it has always been a challenge to produce spectrally pure and regulated sines in circuits that require no tuning nor adjustments. This article shows a practical method of achieving these goals. The classic system architecture is shown below.

The crystal (or other frequency-selective network) provides the oscillation path around the multiplier or variable-gain amplifier. The multiplier's output is sampled by some amplitude detector, shown here as a rectifier diode. The DC output of the rectifier is filtered by a low-pass filter, and the output of that is compared to a DC reference voltage by the servo amplifier. The gained-up error is then used as the multiplier's gain-control input. The amplitude-control loop serves to set the oscillation path gain to just unity, so that the multiplier's output doesn't grow nor decay, and the loop also maintains oscillation amplitude within the linear range of all components. This gain-controlled oscillator is more complicated than simple overdriven circuits, but it produces very pure sinewaves and has no startup problems.

The EL4451 is a two-quadrant multiplier, whose gain-control input voltage of 0→+2V produces a voltage gain of 0 to 2. The signal input receives a portion of the output signal passed through a series crystal. At resonance, the crystals impedance phase passes through 0° and positive feedback occurs around the multiplier. The crystal has a series resistance of about 100Ω, so with the crystals 510Ω load the multiplier will need to have a gain of 1.2 to sustain oscillation.

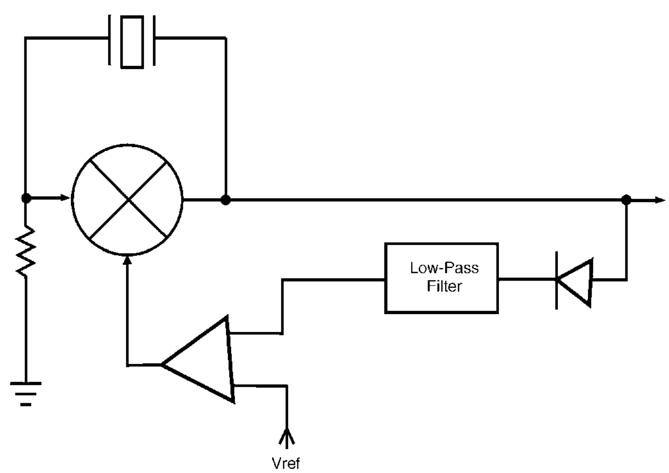


**FIGURE 1. BASIC STABILIZED OSCILLATOR LOOP**

Here is a realization using common components:

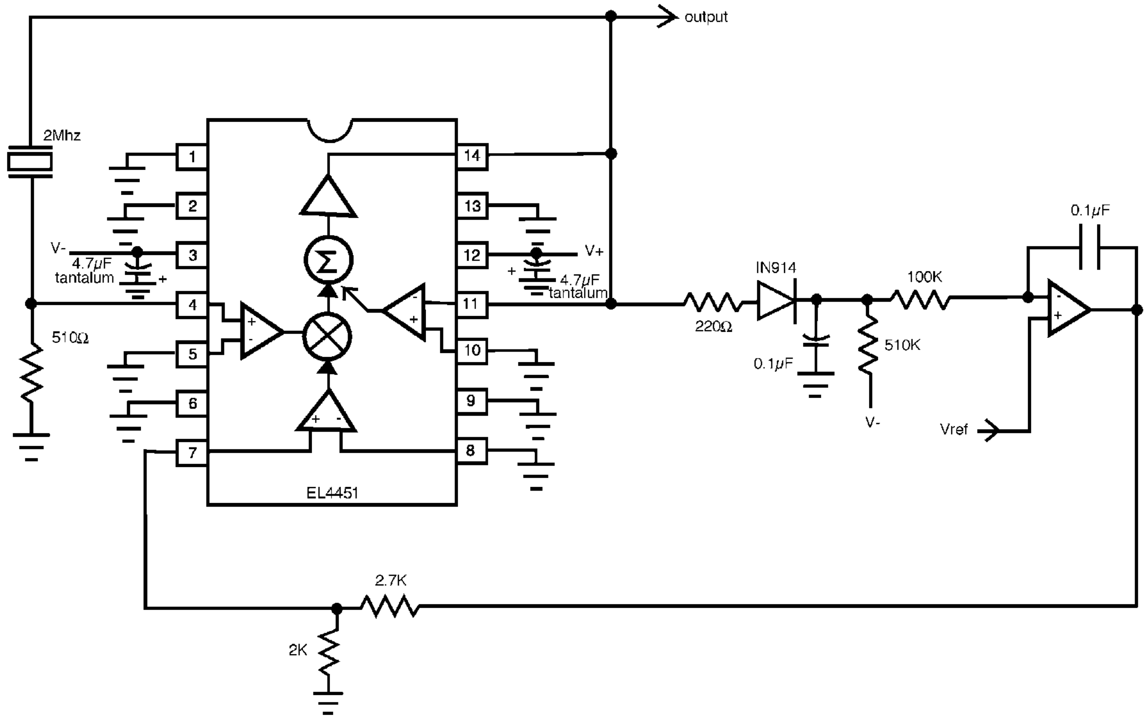


FIGURE 2. BASIC OSCILLATOR WITH AMPLITUDE STABILIZATION LOOP

The output is rectified by a simple diode detector and compared to a reference voltage by an integrating op-amp. The integrators output is attenuated by the 2kΩ and 2.7kΩ resistors so it cannot overdrive the EL4451 gain-control input and cause nonlinear oscillations. The diode detector has a 220Ω resistor in series so as to not cause output distortions due to charging pulses. A pull-down current flows through the 510K resistor to allow proper rectification.

Any crystal, up to about 50MHz fundamental mode resonance, can be used. Overtone crystals will require an added series-tuned circuit to force harmonic oscillation modes. The crystal and 510Ω resistor can be exchanged to put the crystal at ground, using the parallel resonance mode of the crystal.

This circuit generates -53dBc harmonic distortion at 2MHz with ±5V supplies and 1Vrms output into 500Ω. This is mostly due to the output stage nonlinearities of the EL4451, and it drops to -60dBc at ±12V supplies. Reducing the output amplitude further improves distortion levels, although the simple diode detector requires a minimum 0.5Vrms level. Sideband noise is excellent, spanning only 14Hz at -90dBc, the resolution of the spectrum analyzer used.

A series-tuned LC filter can be substituted for the crystal. As long as the loaded Q is greater than about 5, the output distortion will be as good as with the crystal. Sideband noise is worse than with the crystal, however.

This circuit generates very low distortion levels.

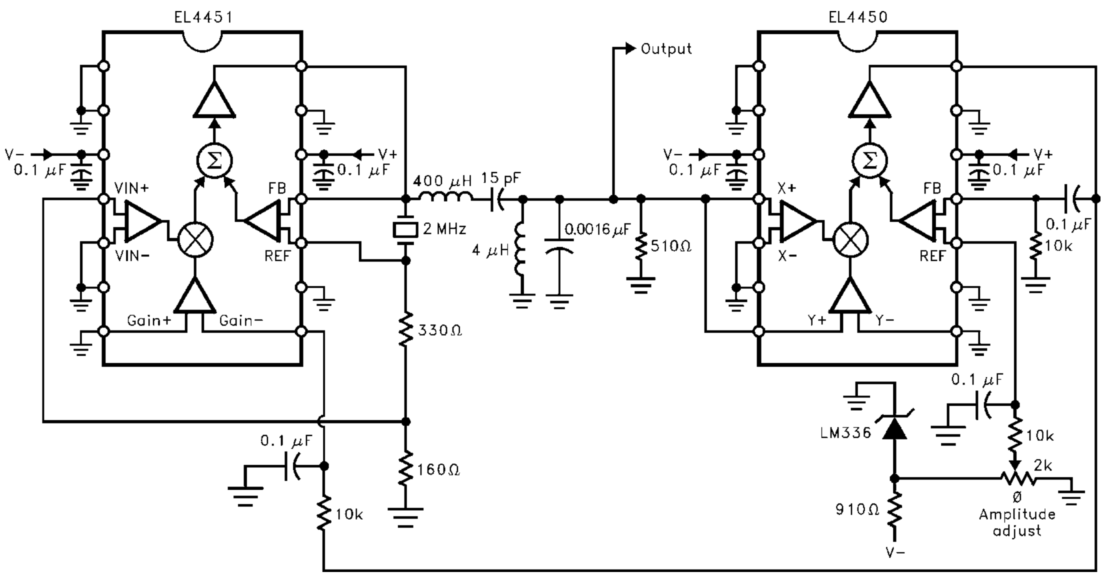


**FIGURE 3. VERY LOW-DISTORTION OSCILLATOR**

The EL4451 is connected in a slightly different way; the majority of crystal feedback is delivered to the REF input of the feedback amplifier, and a smaller amount of signal routed through the variable-gain input port. In this way, most of the signal runs through a simple voltage-follower path with minimal distortion. The total gain of the EL4451 in this connection is 1 + (Vgain/2V) (160Ω/(160Ω + 330Ω)), which needs to be set to about 1.2 for stable oscillation.

The output of the EL4451 is passed through a simple filter to additionally reduce harmonics, then used as the output. For my measurements, I loaded the output with an additional 500Ω, bringing the total load to 250Ω. The EL4451 can drive lower impedances, but the output distortion will rise. Note that no active amplifier nor buffer can be used to drive the output with distortion levels anywhere near that of the passive filter.

Rather than load the filter with a highly nonlinear diode detector, this circuit uses the high-impedance inputs of the EL4450 to sense output amplitude. This is a four-quadrant multiplier, and is used as a mean-square amplitude detector. The advantages include much more precise initial calibration, easier ripple filtering since its at twice the oscillator frequency, and a built-in amplifier which can be used as the servo error amplifier. The X- and Y- inputs of the EL4450 are wired together to produce an internal output$^2$ quantity at the Σ point. Added to this is a static level from the LM336 reference that has a polarity that subtracts from the mean-square quantity. The FB terminal, normally used for DC feedback, is connected as something like an integrator using the 0.1μF capacitor. Thus, the output amplifier of the EL4450 is both the low-pass filter and error amplifier for the servo loop, and attempts to maintain the output mean-squared voltage equal to that of the reference.

Harmonic distortion is -74dB with the circuit running on ±5V supplies, and -80dB with ±12V. As before, reducing the output amplitude improves distortion further.

The error amplifier is not actually required for amplitude stabilization. Since even a minuscule amount of oscillation loop gain more than unity results in a continuously growing amplitude, or a tad less than unity gain creates an ever-shrinking level, we could say that the gain-control input of the oscillating EL4451 already has infinite gain. This circuit makes use of this fact:

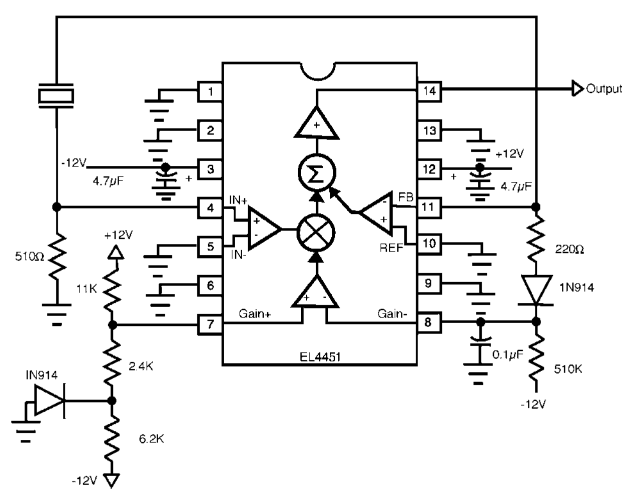


**FIGURE 4. SIMPLE LINEAR OSCILLATOR**

This circuit is very simple and still has the low distortion levels of the previous oscillators, but the output level is not well calibrated, despite the diode forward voltage compensation network connected to the Gain + terminal. Variations in crystal series resistance will vary output amplitude.

In summary, we see that recent multiplier ICs can be employed in simple circuits to generate highly pure sinewaves over wide frequency ranges. The particular devices shown are low-cost, yet well calibrated and flexible.