Enhanced, three-phase VCO features ground-referenced outputs

Harry Bissell Jr, Welding Technology Corp, Farmington Hills, MI

Three-phase VCOs (voltage-controlled oscillators) see service in many applications, including power inverters and in electronic-music synthesis as control and modulation sources. A previous Design Idea describes a basis for a simple, three-phase VCO (**Reference 1**). However, adding a few components enhances the circuit's performance. The original circuit delivers an output of only 600 mV p-p and cannot tolerate substantial loading, especially at low operating frequencies at which the circuit draws the least operating current. Providing ac coupling for the output signals doesn't work well at low frequencies and worsens the loading problem. Finally, the circuit's dc operating point varies with frequency.

The circuit in **Figure 1** elegantly overcomes these limitations. The original circuit uses three of six of a CD4069UB hex inverter's subcircuits. One of the spares, IC_{1A}, senses the complete circuit's dc operating point. Resistor R_2 provides linear feedback around IC_{1A}, forcing the input voltage at Pin 9 to equal the output transition threshold voltage over a range of oper-

ating currents. In other words, the voltage is proportional to the average dc value of the sinusoidal output waveforms.

A voltage follower, IC_{2A}, buffers the averaged voltage at IC_{1A}'s Pin 8. The remaining sections of IC_2 buffer the oscillator's three outputs, equalizing the loading on the oscillator and providing low-impedance drive to three differential amplifiers: IC_{3A}, IC_{3B}, and IC_{3C}. The differential stages subtract the dc offset voltage from IC_{2A} from the buffered three-phase outputs. You can alter the voltage gain of the three differential amplifiers from its nominal factor of five to suit other applications.

Zener diode D_1 limits the voltage to 10V at IC_1's Pin 14. At low frequencies and currents, the oscillator's dc operating point can easily exceed the linear range of IC_2's inputs. You can use rail-to-rail-capable operational amplifiers instead of LM324-family devices. Note that the inputs of IC_1's remaining unused inverters connect to IC_1's Pin 7 and not to circuit ground per normal practice.

Adding an exponential current source eases the task of adjusting the

circuit over a wide frequency range. Transistors Q_1 and Q_2 and their associated components form a simple exponential voltage-to-current converter. For best results, the base-emitter voltages of Q_1 and Q_2 should match at the circuit's nominal operating current—100 µA—and you should thermally couple both transistors. If your application requires precise thermal tracking, replace R_6 with a 2-kΩ temperature-compensating resistor with a coefficient of 3500 ppm/°C, such as a Tel Labs Q81, which is available from such companies as Precision Resistor (www.precisionresistor.com). Place this resistor in thermal contact with Q_1 and Q_2. Temperature-compensating resistors are also available from Micro-Ohm (www.micro-ohm.com), Vishay (www.vishay.com), Ultronix (www.ultronix.com), and KRL Bantry (www.krlbantry.com).

Using the component values in **Figure 1**, the circuit's operating frequency spans 0.1 to 26 Hz. Adding the components in this Design Idea reduces the circuit's dc operating-point shift from 5.5V to less than 25 mV over the frequency range. Most of the frequency
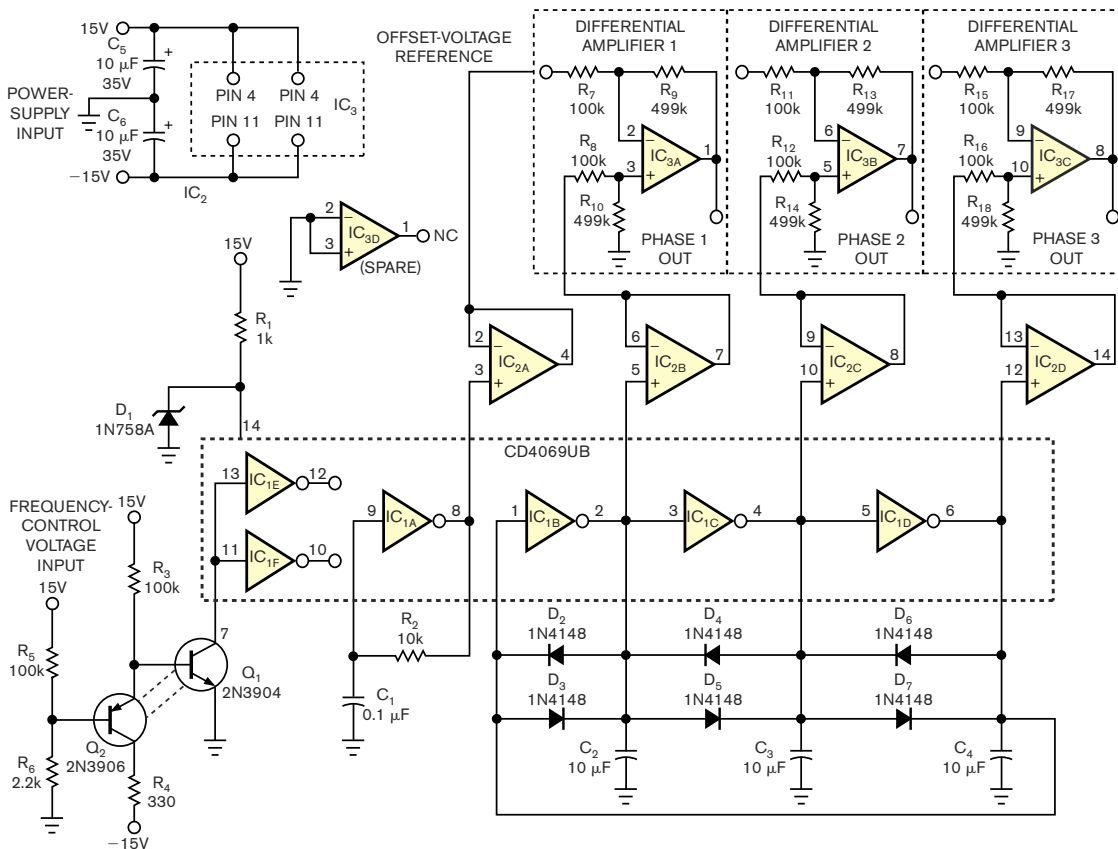
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error occurs at the low end of the frequency range, at which it's the least objectionable.**EDN**

REFERENCE
1 Dutcher, Al, "Inverters form three-phase VCO," *EDN*, Aug 2, 2001, pg 102, www.edn.com/article/CA149120.

NOTES:
PLACE Q₁ AND Q₂ IN THERMAL CONTACT.
FOR BEST STABILITY, USE NONPOLARIZED CAPACITORS FOR C₂, C₃, AND C₄.
DOTTED LINES BETWEEN Q₁ AND Q₂ INDICATE THERMAL CONTACT.

Figure 1 Adding differential and buffer amplifiers and an exponential voltage-to-current converter enhances the performance of a low-frequency, three-phase voltage-controlled oscillator.