Build a Low-Distortion Low-Cost Audio Generator

Generates sine waves with less than 0.02% distortion, or acts as a gyrator.

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MOST function generators use operational amplifiers to generate the basic square and triangle waveforms. The sine waveform is not generated directly; instead, a passive or active shaping network is generally used to "soften up" the triangle wave to produce an approximation of the sine wave, which means that the distortion level leaves much to be desired.

The least expensive way to generate precision sine waves, at only 0.02% distortion, is to use a "gyrator." Using the gyrator, only a single potentiometer is required to cover a 15:1 frequency range. A pair of switch-selectable capacitors can then be used to establish the desired frequency range.

In addition to serving as a precision low-distortion oscillator, the gyrator circuit can also be used as a high-quality variable inductance and as a narrow-band audio pass/reject filter. The schematic is shown on the following page.

About the Circuit. As shown in the schematic diagram, the generator's circuit is arranged as a gyrator, one side of which is referenced to the common or ground point of the split power supply. Operation of the circuit is best understood by observing that *IC3* has a gain of $1/(R4C1\omega)$ and that *IC3* is followed by a current generator made up of *Q1* and *Q2*, which has a transfer function of $1/Rk$. Integrated circuit *IC1* is used as a voltage follower whose gain is unity and input impedance is very high. Integrated circuit *IC2* is operated as a unity-gain inverter, where *R1* and *R2* have similar resistance values.

An input voltage, *E1*, to *IC1* generates a current specified by the formula $I1 = 1/(R4RkC1\omega)$, which can be written as $E1/L = I1$, since dimensionally $L = R^2C$. The statement $1/Rk$ is simply the ratio of the input voltage (from *IC3*) to the total collector current changes referenced to the common point of the power supply. Ignoring the input resistance to the transistors and assuming $\alpha = 1.00$, $Rk = [R7(R6+R5)]/2R5$ and $L = R4RkC1$.

When the circuit is operated as an oscillator, *C2* performs as a low-pass parallel-resonant *LC* network that is driven by *IC5* through *R11*, where the feedback level is determined by the setting of *R9*. Switch *S1* is used to disconnect *IC5* from the inductance to disable the oscillator when only an inductance or an *LC* network is desired. The inductance is linear as long as the peak-to-peak voltage at the junction of the collectors of *Q1* and *Q2* does not exceed about 6 volts for the 18-volt supply illustrated.

With *S2* open, *IC5* serves as a comparator that clips the sine wave to produce a square-wave output from the system. Potentiometer *R3* is used to adjust the square wave's duty cycle.

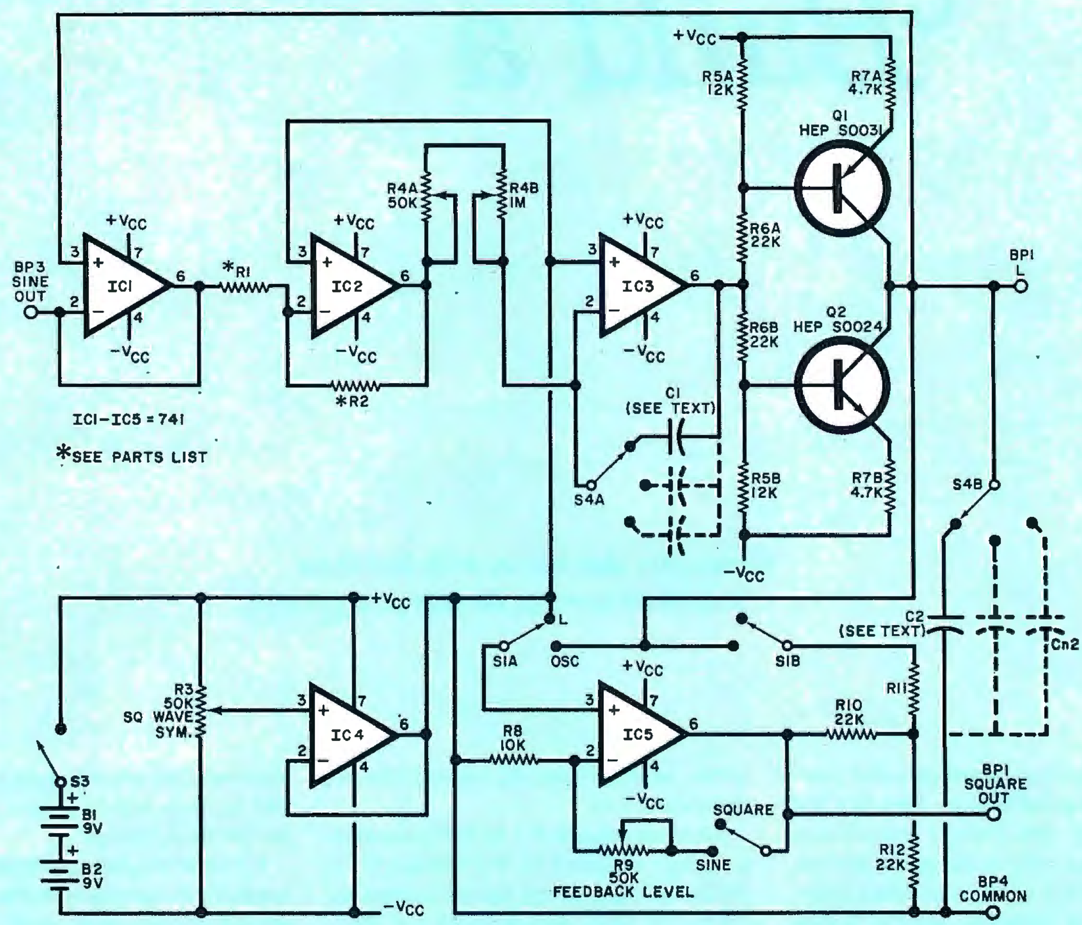
Construction. The circuit can be assembled on perforated board with sockets for the IC's and transistors or on a printed circuit board of your own design. Be sure to note that the pin designation numbers for the IC's in the schematic diagram are for an eight-pin DIP device. You can use any other package style of 741 op amp, but be sure to observe proper pin designations.

For best temperature stability, all fixed resistors should be of metal-film or wire-wound construction, and polystyrene, mica, or Mylar capacitors should be used for *C1*, *C2*, and any other range-determining capacitors. For *Q1* and *Q2*, any reasonable low-leakage, high-gain silicon transistors can be used.

Complementary sine-wave outputs are available from *IC1* and *IC2*, since the 741 op amp is not designed to deliver substantial output power, a buffer should be used if a load impedance of less than 1000 ohms is anticipated.

Range capacitors *C1* and *C2* should be mounted on a multi-position two-deck rotary switch (*S4*), along with any other range capacitors you might decide to use. RANGE switch *S4*, POWER switch *S3*, FEEDBACK control *R9*, FREQUENCY control *R4B*, L/OSC switch *S1*, SINE/SQUARE switch *S2*, and output binding posts *BP1* through *BP4* should all mount on the front panel of the box in which the circuit is to be housed. Mount a piece of heavy white paper or stiff cardboard behind the hex nut that holds *R4B* in place; it will become a scale for the FREQUENCY control. Slip over the shaft of this control a knob with a pointer. Then label all controls and switch positions according to function and/or range.

Setting It Up. For best results, a frequency counter should be used to set trimmer potentiometer *R4A* to provide



Sine-wave generator also serves as a-f filter or simulates inductor from 1 to 1000 H.

PARTS LIST

B1, B2—9-volt battery
BP1 through BP4—Four-way binding post
C1, C2—0.15-μF Mylar capacitor (for 13-to-130-Hz range); 0.015-μF capacitor (for 130-to-1300-Hz range); 0.0015-μF capacitor (for 1300-to-13,000-Hz range)
IC1 through IC5—741 operational amplifier
Q1—HEP S0031 (Motorola) or similar pnp silicon transistor
Q2—HEP S0024 (Motorola) or similar npn silicon transistor
R1, R2—6800-to-8200-ohm, 1% tolerance film resistor (value not critical)
R3, R4A—50,000-ohm trimmer potentiometer
R5A, R5B—12,000-ohm, 1% tolerance film resistor
R6A, R6B—22,000-ohm, 1% tolerance film resistor
R7A, R7B—4700-ohm, 1% tolerance film resistor
R8—10,000-ohm, 5% tolerance resistor
R9—50,000-ohm potentiometer
R10, R12—22,000-ohm, 5% tolerance resistor
R11—470,000-to-600,000-ohm film resistor (Stability more important than absolute value)
S1—Dpdt switch
S2, S3—Spst switch
S4—Two-pole, three-position nonshorting rotary switch.
Misc.—Battery connectors (2); suitable case; perforated board (or pc board); IC sockets (5); transistor sockets (2); control knobs (two round one pointer type); heavy white paper or cardboard; dry-transfer lettering kit; machine hardware; hookup wire; solder; etc.

an exact 10:1 frequency spread over *R4B*'s range, which corresponds to an inductance range of 100:1 (*R4A* = *R4B*/99). Starting at the highest frequency, where the scale is compressed, use the frequency counter to establish convenient frequency intervals on the FREQUENCY control's dial. A different color ink can be used to label the inductance values in accordance with the relationship $L = 1/\omega^2 C$. With the component values specified, the inductance range is from 1 to 1000 H.

When *R4B* is a 1-megohm potentiometer, the values of 0.0015, 0.015, and 0.15 μF for the *C1* and *C2* components provide ranges of 1300 to 13,000 Hz, 130 to 1300 Hz, and 13 to 130 Hz, respectively. If these sets of capacitors are accurately related by powers of 10, switching between ranges should yield frequencies within a few percentage points of the expected values. The frequencies at the scale endpoints can be changed for all ranges simultaneously by trimming the value of *R2*.

FEEDBACK control *R9* should be set to just beyond the point where oscillation begins, at the lowest-frequency setting. The oscillations will rapidly increase in amplitude until *IC5* goes into clipping, establishing an operating point. The value of resistor *R11* must be large to suppress harmonic distortion by minimizing the parallel resistive shunt across *L*/*C2*, thereby increasing its Q. When the circuit is operating properly, the dc potential at *BP1* is within a few millivolts of COMMON binding post *BP4*, and the current demand on the power supply will be approximately 8 mA.

The least distortion occurs when the FEEDBACK control is adjusted to the point where it just barely sustains oscillation. If *R9* were a fixed value to enable operation on all ranges and at all frequencies, the maximum distortion would be about 0.1%. Stray capacitance limits the oscillations to about 40,000 Hz if *R4A* is unchanged from its low-frequency value. ◇