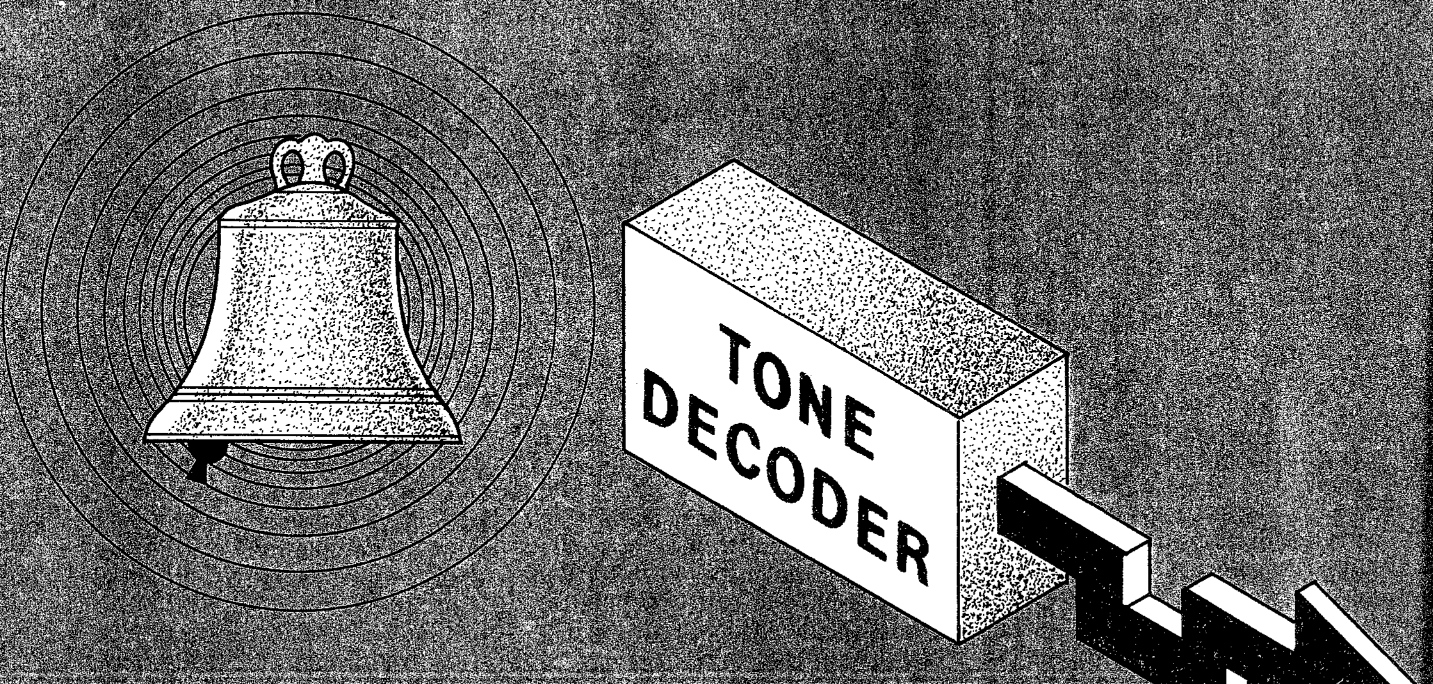

Learn more about designing with the tone decoder, a versatile circuit that includes a phase-locked loop and responds to selected input frequencies

TONE DECODER

RAY MARSTON

THIS ARTICLE, THE FOURTH IN A SEries on phase-locked loops, is about a tone and frequency decoder monolithic integrated circuit. The tone decoder IC contains a stable phase-locked loop and a transistor switch that produces a grounded squarewave when a selected tone is introduced at its input. Tone decoders can decode tones at various frequencies. For example, it can detect telephone Touch Tones. The tone-decoder ICs are also found in communications pagers, frequency monitors and controllers, precision oscillators, and telemetry decoders.

The last three articles in this series explained the basic operating principles of the phase-locked loop and then went on to examine popular PLL ICs. Those included the Harris CD4046B PLL IC, the Philips (formerly Signetics) NE565 PLL IC, and the NE566 function generator IC.

This article is based on the Philips NE567 tone decoder/phase-locked loop. The device is a low-cost commercial version of the 567 packaged in an eight-pin plastic DIP. Figure 1 shows the pin configuration of that package, and Fig. 2 shows the internal block diagram of the device. It can be seen that its principal blocks are the phase-locked loop, a quadrature phase detector, an amplifier, and an output transistor. The phase-locked loop block contains a current-controlled oscillator (CCO), a phase detector and a feedback filter.

The Philips NE567 has an operating temperature range of 0 to +70°F. Its electrical characteristics are nearly identical to those of the Philips SE567, which has an operating temperature range of −55 to +125°. However, the 567 has been accepted as an industry standard tone decoder, and it is alternate-

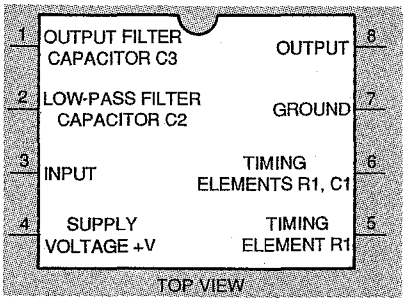

FIG. 1—PINOUT FOR AN NE567 TONE decoder in a eight-pin DIP package.

sourced by many other multinational semiconductor intergrated circuit manufacturers.

For example, Analog Devices offers three versions of its AD567, Exar offers five versions of its XR567, and National Semiconductor offers three versions of its LM567. All of the different brands and models of this device will work in the circuits described in this article. Because of the similarities between these devices, they will be referred to collectively as the "567" for the remainder of this tone decoder article.

The 567 basics

The 567 is primarily used as a low-voltage power switch that turns on whenever it receives a sustained input tone within a narrow range of selected frequency values. Stated in another way, the 567 can function as a precision tone-operated switch.

The versatile 567 can also function as either a variable waveform generator or as a conventional PLL circuit. When it is organized as a tone-operated switch, its detection center frequency can be set at any value from 0.1 to 500 kHz, and its detection bandwidth can be set at any value up to a maximum of 14% of its center frequency. Also, its output switching delay can be varied over a wide time range by the selection of external resistors and capacitors.

The current-controlled oscillator of the 567 can be varied over a wide frequency range with external resistor R1 and capacitor C1, but the oscillator can be controlled only over a very narrow range (a maximum of about 14% of the free-running value) by signals at pin 2. As a result, the PLL circuit can "lock" only to a very narrow range of preset input frequency values.

The 567's quadrature phase detector compares the relative frequencies and phases of the input signal and the oscillator output. It produces a valid out-

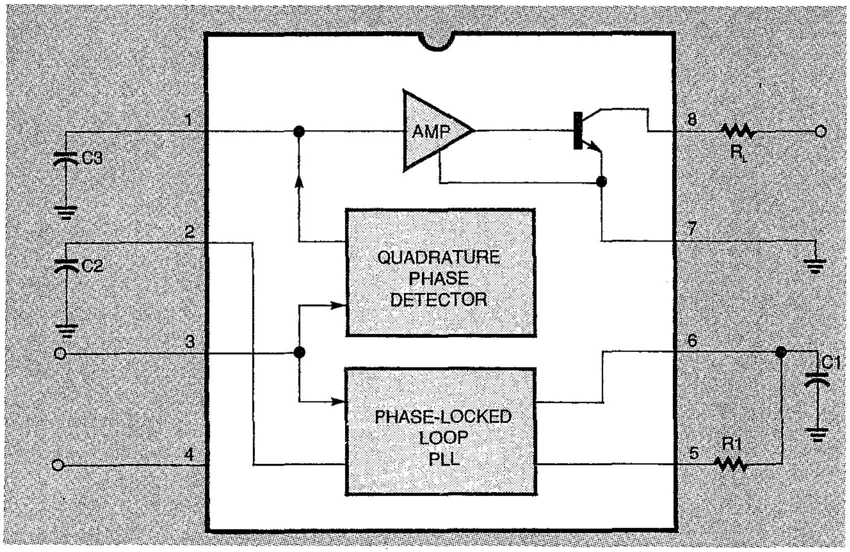

FIG. 2 —BLOCK DIAGRAM OF AN NE567 TONE DECODER.

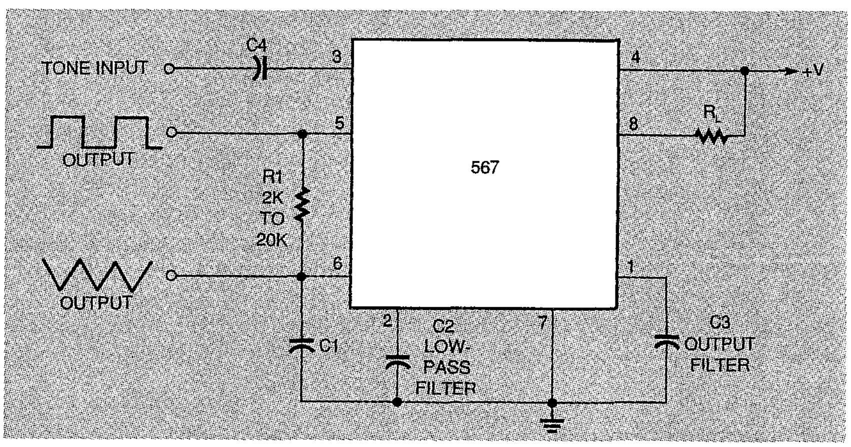

FIG. 3 —TYPICAL CONNECTION DIAGRAM of a 567 tone decoder showing output waveforms at pins 5 and 6.

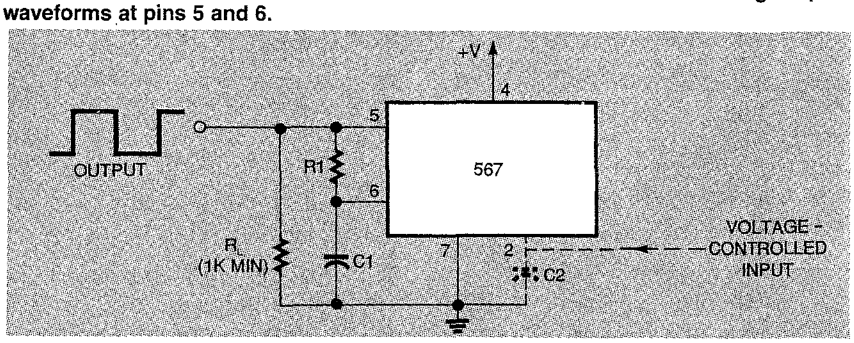

FIG. 4—PRECISION SQUAREWAVE generator based on the 567's 20-nanosecond rise and fall times.

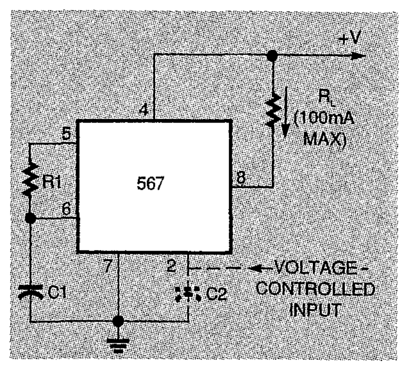

FIG. 5 —PRECISION SQUAREWAVE generator based on a 567 configured for a high-current output.

TABLE 1—ELECTRICAL CHARACTERISTICS

PARAMETER	CONDITIONS	NE567			UNIT
		Min	Typ	Max	
CENTER OF FREQUENCY					
Highest center frequency (f_O)			500		kHz
Center frequency stability	-55 to +125°C		35±140		ppm/°C
	0 to +70°C		35±60		ppm/°C
Center frequency distribution		-10	0	+10	%
Center frequency shift with supply Voltage			0.7	2	%/V
DETECTION BANDWIDTH					
Largest detection bandwidth		10	14	18	% of f_O
Largest detection bandwidth skew			3	6	% of f_O
Largest detection bandwidth—variation with temperature			±0.1		%/°C
Largest detection bandwidth—variation with temperature	V_i = 300mVrms		±2		%/°C
INPUT					
Input resistance		15	20	25	kΩ
Smallest detectable input voltage	I_L = 100mA		20	25	mVrms
Largest no-output input voltage	I_L = 100mA	10	15		mVrms
Greatest simultaneous outband signal to inband signal ratio			+6		dB
Minimum input signal to wideband noise ratio	B_n = 140kHz		-6		dB
OUTPUT					
Fastest on-off cycling rate			f_o/20		
"1" output leakage current	V_8 = 15V		25	0.01	μA
"0" output voltage	I_L = 30mA		0.2	0.4	V
	I_L = 100mA		0.6	1.0	V
Output fall time	R_L = 50Ω		30		ns
Output rise time	R_L = 50Ω		150		ns
GENERAL					
Operating voltage range		4.75		9.0	V
Supply current quiescent			7	10	mA
Supply current—activated	R_L = 20Ω		12	15	mA
Quiescent power dissipation			35		mW

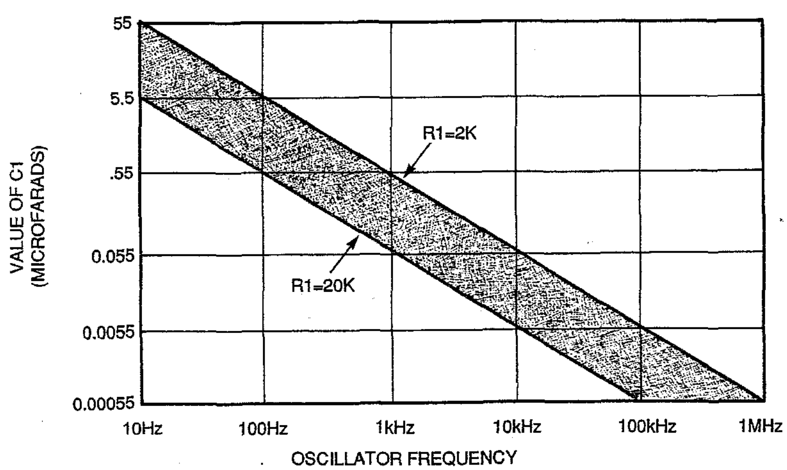

FIG. 6—RESISTOR-CAPACITOR SELECTION GUIDE for the current-controlled oscillator section of the tone decoder.

put-drive signal (which turns transistor Q1 on) only when these two signals coincide (i.e., when the PLL is locked). The center frequency of the 567 tone switch is equal to its free-running oscillator frequency, and its bandwidth is equal to the lock range of the PLL.

Figure 3 shows the basic connections for a 567 organized as a tone switch. The input tone signal is AC coupled through capacitor C4 to pin 3, which has an input impedance of about 20 kilohms. An external output load resistor (R_L) is inserted between pin 8 and a positive supply voltage whose maximum value is 15 volts.

Pin 8 is capable of sinking up to 100-milliampere load currents. Pin 7 is normally grounded, and pin 4 is connected to a positive supply with a minimum value of 4.75 volts and a maximum value of 9 volts. Pin 8 can also be connected to the same power source if that restriction is observed.

The center frequency (f_o) of the oscillator can be determined by the formula:

$$f_o = 1.1/(R1 \times C1) \quad (1)$$

Where resistance is in kilohms and capacitance is in units of microfarads

From this equation the value of capacitor C1 can be determined by transposing terms:

$$C1 = 1.1/(f_o \times R1) \quad (2)$$

With these formulas, values for resistance and capacitance can be determined. The value of resistor R1, which should be in the range of 2 to 20 kilohms, and C1 can be determined from formula 2.

The oscillator generates an exponential sawtooth waveform that is available at pin 6 and a square waveform that is available at pin 5. The bandwidth of the tone switch (and thus the lock range of the PLL) is determined by C2 and a 3.9 kilohm resistor within the IC. The ouput switching delay of the circuit is determined by the value of C3 and a resistor within the IC. Table 1 lists the electrical characteristics of the Philips NE567 which has nearly identical characteristics to all other brands of the 567.

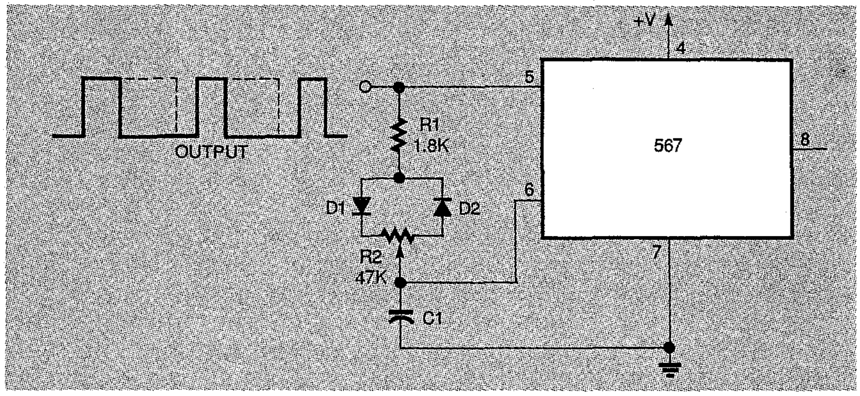

FIG. 7—SQUAREWAVE GENERATOR WITH A VARIABLE mark/space ratio output.

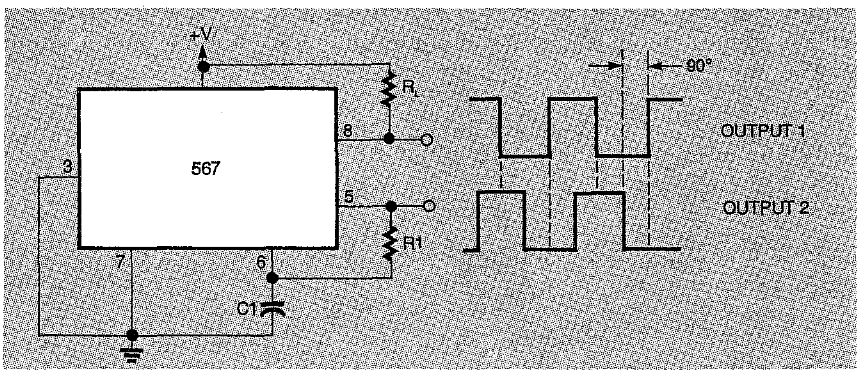

FIG. 8—SQUAREWAVE GENERATOR WITH quadrature outputs.

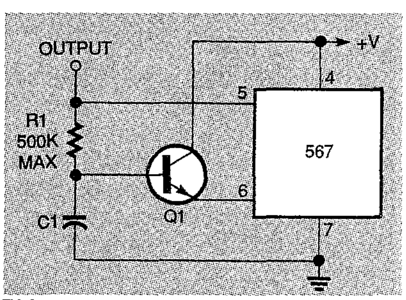

FIG. 9—TRANSISTOR BUFFER increases the permissible value of resistor R1.

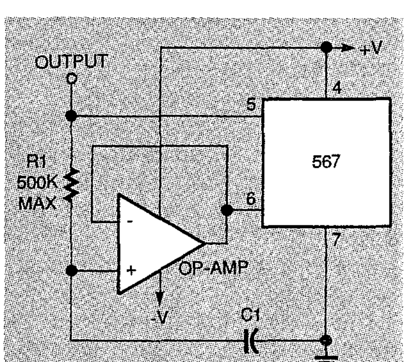

FIG. 10—OPERATIONAL AMPLIFIER buffer increases the permissible resistor value without waveform symmetry loss.

Oscillator design

Figures 4 and 5 illustrate how to obtain various precision squarewave outputs from the 567. The nonlinear ramp waveform available at pin 6 has only limited usefulness, but the squarewave available at pin 5 has excellent characteristics. As shown in Fig. 4, that output can have both 20-nanosecond rise and fall times.

This squarewave has a peak-to-peak amplitude equal to the supply voltage value minus 1.4 volts. It can be externally loaded by any resistance value greater that 1 kilohm without adversely affecting the circuit's function. Alternatively, the squarewave output can be applied (in slightly degraded form) to a low impedance load (at peak currents up to 100 milliamperes at pin 8 output terminal, as shown in Fig. 5

By applying formulas 1 and 2 for oscillator frequency and capacitance, respectively, as presented earlier, various values can be determined. Again, R1 must be restricted to the 2 to 20 kilohm range. To save time in making this determination, component values as they relate to oscillator frequency can be read directly from the nomograph, Fig. 6.

For example, if you want the decoder's oscillator to operate a 10 kHz, the values for C1 and R1 could be either 0.055 microfarads and 2 kilohms or 0.0055 microfarads and 20 kilohms, respectively.

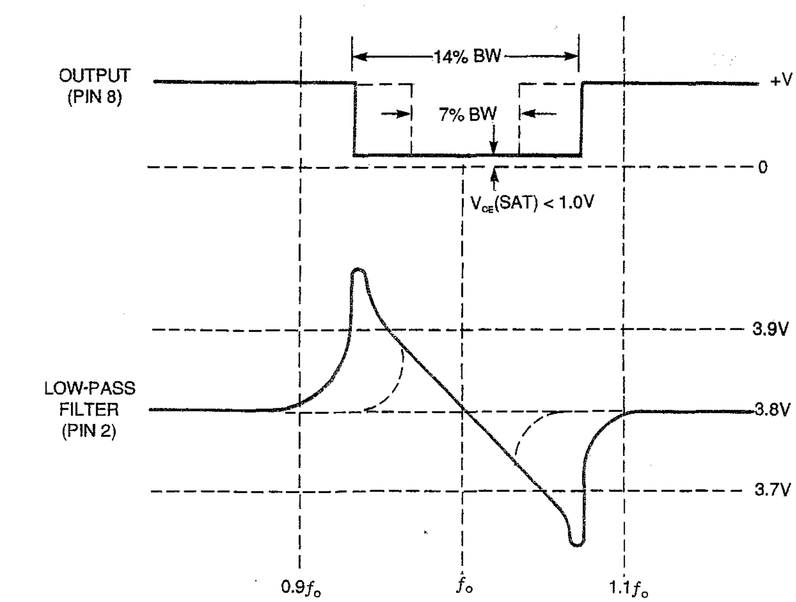

FIG. 11—WAVEFORMS AT PINS 2 AND 8 under in-band input voltage conditions.

The oscillator's frequency can be shifted over a narrow range of a few percent with a control voltage applied to pin 2 of the 567. If this voltage is applied, pin 2 should be decoupled by

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RETRO REMOTE

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dress DIP switches open, address zero with all eight switches closed, or anything in between. Regardless of the address you select, be sure to set the same address on the receiver/decoder board.

Apply power to the receiver and connect a 9-volt battery to the transmitter. Test the training transmitter and receiver by aiming the transmitter at the receiver and pressing the transmit switch. If the circuit is working correctly, the valid transmission LED on the receiver will light up as long as you hold down the transmit switch. The VT LED should light regardless of the settings of the DATA DIP switches (S2 a–d). If the LED does not light, find and repair the mistake.

Follow the manufacturer's instructions for programming the learning remote. Operate the training transmitter as you would any other remote control. As discussed earlier, the power-on command is decoded by the receiver as decimal 15. But, because the training transmitter understands only BCD, set all four data DIP switches at logic high (1111).

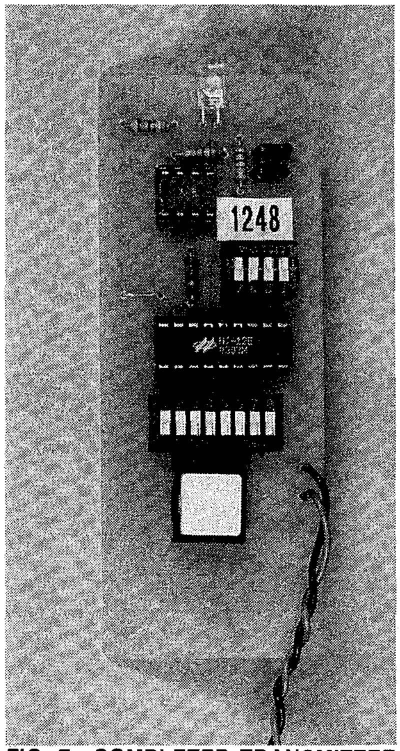

FIG. 7—COMPLETED TRANSMITTER BOARD. This board allows unique coding that won't interfere with nearby remote-controlled equipment.

Now activate the learning remote's learning mode, press the on button, and press the transmit button on the training transmitter until the learning remote indicates that it has received the command. Next set the mute function as decimal 14 (1110), volume-up as decimal 13 (1101), and volume-down as 12 (1100).

How you program the remaining 12 receiver command codes is your choice. You might want to map 0 through 9 to buttons 0 through 9 on the remote. That still allows for two additional commands. Don't forget to program all your other remote controls into the learning remote too. Ω

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C2, whose value should be approximately double that of C1.

The circuits in Figs. 4 and 5 can be modified in several different ways, as shown in Figs. 7 to 10. In Fig. 7, the duty cycle or mark/space ratio of the generated waveform is fully variable over the range of 27:1 to 1:27 with trimmer potentiometer R2. Capacitor C1 alternately charges through resistor R1, diode D1, and the left side of R2, and it discharges through resisor R1, diode D2, and the right side of R2 in each operating cycle. The operating frequency varies only slightly as the mark/space ratio is varied.

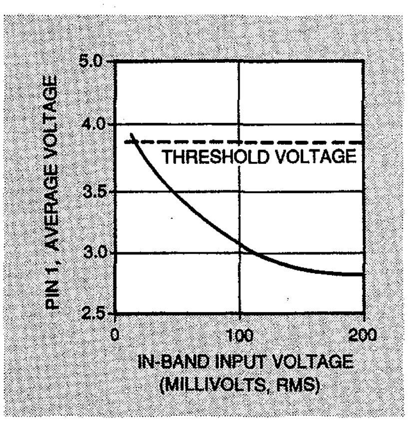

FIG. 12—TRANSFER FUNCTION of average voltage at pin 1 with respect to in-band input voltage.

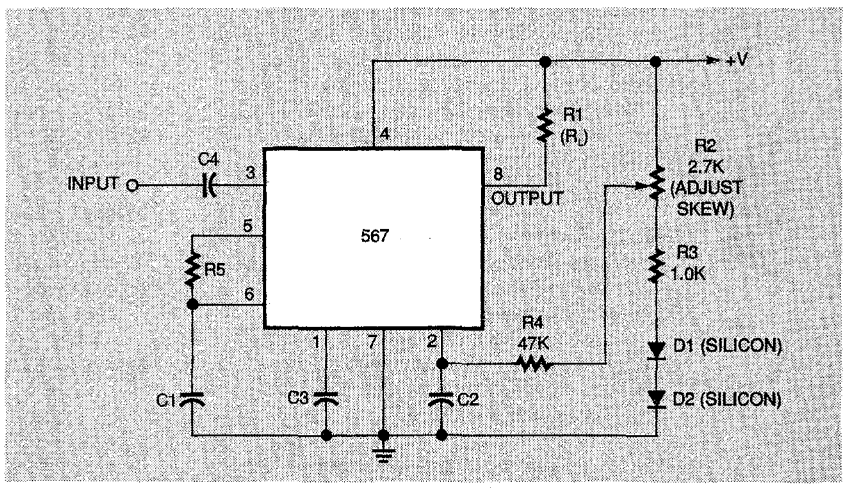

FIG. 13—TONE SWITCH WITH A TRIMMER potentiometer adjustment for skew.

Figure 8 shows how the oscillator generates quadrature outputs. The squarewave outputs of pins 5 and 8 are out of phase by 90°. In this circuit, input pin 3 is normally grounded. If it is biased above 2.8 volts, the square waveform at pin 8 shifts by 180°.

Figures 9 and 10 show how the oscillator circuit can be modified to allow timing resistor values to be increased to a maximum of about 500 kilohms. This permits the value of timing capacitor C1 to be pro-

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portionately reduced. In both circuits, a buffer stage is connected between the junction of resistor R1 and capacitor C1, and pin 6 of the 567.

In Fig. 9 this buffer is an emitter-follower transistor stage. Unfortunately, this stage causes a slight loss of waveform symmetry. By contrast, the circuit in Fig. 10 includes an operational amplifier follower as the buffer. It, however, causes no waveform symmetry loss.

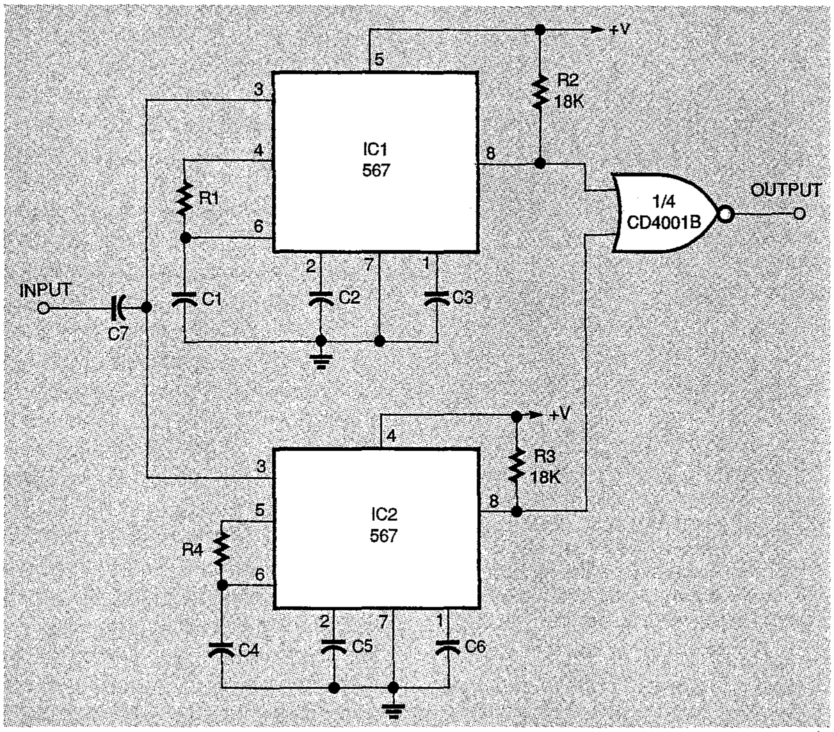

FIG. 14—DUAL-TONE DECODER with a single output.

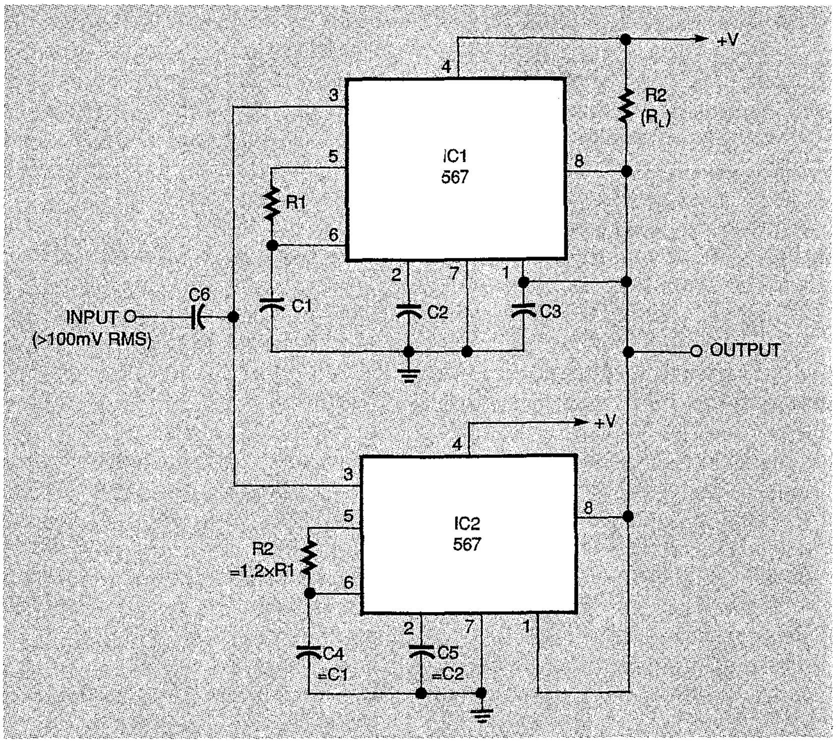

FIG. 15—DUAL-TONE SWITCH with 24 % bandwidth.

Five 567 outputs.

The 567 has five output terminals. Two of these (pins 5 and 6) give access to the oscillator output waveforms. A third (pin 8) functions as the IC's main output terminal, as previously stated. The remaining two outputs are available on pins 1 and 2 of the decoder.

Pin 2 gives access to the phase detector output terminal of the PLL, and it is internally biased at a quiescent value of 3.8 volts. When the 567 receives in-band input signals, this voltage varies as a linear function of frequency over the typical range of 0.95 to 1.05 times the oscillator's free-running frequency. It has a slope of about 20 millivolts per percent of frequency deviation.

Figure 11 illustrates the time relationship between the outputs of pin 2 and pin 8 when the 567 is organized as a tone switch. The relationships are shown at two bandwidths: 14% and 7%.

Pin 1 gives access to the output of the 567's quadrature phase detector. During tone lock, the average voltage at pin 1 is a function of the circuit's in-band input signal amplitude, as shown in transfer graph Fig. 12. Pin 8 at the collector of the output transistor turns on when the average voltage at pin 1 is pulled below its 3.8-volt threshold value.

Detection bandwidth

When the 567 is configured as a tone switch, its bandwidth (as a percentage of center frequency) has a maximum value of about 14%. That value is proportional to the value of in-band signal voltage in the 25 to 200 millivolt RMS range. However, it is independent of values in the 200 to 300 millivolt range, and is inversely proportional to the product of center frequency and capacitor C2. The actual bandwidth (BW) is:

$$BW = 1070\sqrt{V_i/(f_o \times C2)}$$

in % of f_o and $V_i \leq 200$ millivolts RMS

Where V_i is in volts RMS and C2 is in microfarads

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To select a C2 value by an educated trial and error process, start by selecting a value that is twice that of C1. Then either increase its value to reduce bandwidth, or reduce its value to increase bandwidth.

Detection band skew

Detection band skew is a measure of how well the band is centered about the center frequency. Skew is defined as:

$(f_{max} + f_{min} - 2f_o)/2f$

Where f_{max} and f_{min} are the frequencies corresponding to the edges of the detection band.

If a tone switch has a center frequency of 100 kHz and a bandwidth of 10 kHz, and its edge of band frequencies are symmetrically placed at 95 kHz and 105 kHz, its skew value is zero %. However, if its range of band values is highly nonsymmetrical at 100 kHz and 110 kHz, its skew value increases to 5%.

The skew value can be reduced to zero, if necessary, by introducing an external bias trim voltage at pin 2 of the IC with a trimmer potentiometer R2 and 47 kilohm resistor R4, as shown in Fig. 13. Moving the wiper up will lower the center frequency, and moving it down will raise it. Silicon diodes D1 and D2 are optional for temperature compensation.

Tone-switch design

Practical tone-switch circuits based on the typical connection diagram Fig. 3 are easy to design. Select the resistor R1 and capacitor C1 frequency control component values by referring to the nomograph, Fig. 6. Select the value of C2 on an empirical basis as described earlier. Start by making it twice the value of C1 and then adjusting its value (if necessary) to give the desired signal bandwidth. If band symmetry is critical in your application, add a skew adjustment stage, as shown in Fig. 13.

Finally, to complete the circuit design, give C3 a value double that of C2, and check the circuit response. If C3 is too small, the output at pin 8 might pulsate during switching because of transients.

Multiple switching

Any desired number of 567 tone switches can be fed from a common input signal to make a multitone switching network of any desired size. Figures 14 and 15 are two practical two-stage switching networks.

The circuit in Fig. 14 functions as a dual-tone decoder. It has a single output that is activated in the presence of either of two input tones. Here, the two tone switches are fed from the same signal source, and their outputs are NORed by a CD4001B CMOS gate IC.

Figure 15 shows two 567 tone switches connected in parallel so that they act like a single tone switch with a bandwidth of 24%. In this circuit, the operating frequency of the IC2 tone switch is made 1.12 times lower than that of the IC1 tone switch. As a result, their switching bandwidths overlap. Ω