BUILD THIS

SONIC *MOTION* DETECTOR

Here's a unique project that uses sound to detect motion. Use it with a burglar alarm, a door opener, or in a number of other applications.

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IN THIS ARTICLE, WE'LL BE LOOKING AT A low-cost motion-detector sensor suitable for a wide variety of applications. Among other things, the project can be used to detect intruders, turn on the lights when someone enters a room, or open a door when it is approached. Presently, five of the units, controlled by a KIM computer, are being used in various rooms of the author's home as a burglar alarm system. They have been in use successfully for over a year.

Theory of operation

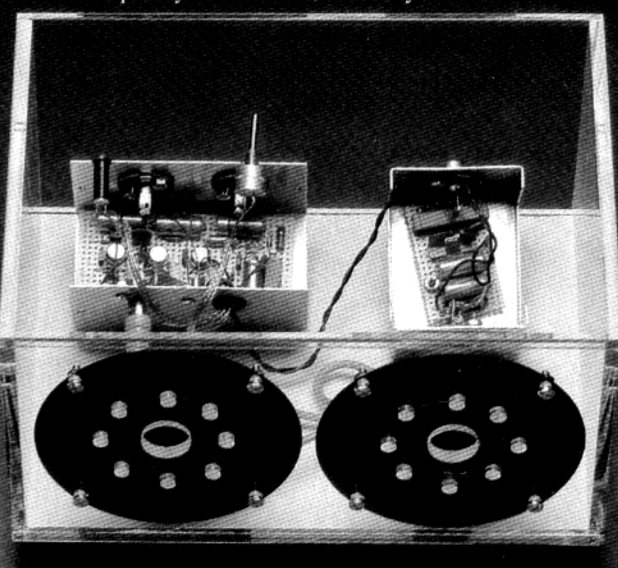
The theory behind this project is not new. In fact, the original idea for it came about while discussing police-radar fundamentals. The basic principle behind the operation of both police radar and this project is the doppler shift. Most people have observed that effect at one time or another. Remember that train whistle or car horn that sounds high pitched while coming toward you, and drops to a lower pitch as it moves away? That phenomenon is caused by the doppler shift, and the change of frequency of the sound can be expressed mathematically for reflection from a moving object as follows:

$$f_R = f_S \frac{V_M}{V_M \pm V_O}$$

where f_R is the frequency of the return wave, f_S is the frequency of the source wave, V_M is the velocity of a sound wave at 70°F at sea level and is equal to 1119 feet/second, and V_O is the velocity of the moving object.

That same formula applies to any type of wave by substituting the correct V_M; i.e. for radar using radio waves, V_M is 186,300 miles per second. The above formula simply means that if a wave of known frequency is sent out, the reflected wave will be different in frequency if the reflecting object is moving. Therefore by having a device that is able to determine if the reflected wave is different in frequency from the one sent out, moving objects in the range of the device can be detected.

The above formula provides important information for the choice of bandwidths and cutoff frequencies. The value for f_S for the project was chosen as 17 kHz because that is about where the inexpensive tweeters used start to roll off and because that frequency is inaudible, or barely audible, to most people.



Seven miles-per-hour (or ten feet-per-second) is a reasonable maximum speed for a walking person. Substituting those values in the above equation, we can find the range of return frequencies. If moving toward the source:

$$f_R = 17{,}000 \times \frac{1119}{1119 - 10} = 17153.9 \text{ Hz}$$

If moving away from the source:

$$f_R = 17{,}000 \times \frac{1119}{1119 + 10} = 16849.4 \text{ Hz}$$

The above values are used to determine several component values in the circuit. Referring to Fig. 1, a block diagram of the circuit, the high-frequency bandpass amplifiers must be able to pass frequencies from about 16.5 kHz to 17.5 kHz while attenuating all other frequencies. They must be able to pass and amplify the source and reflected frequencies, while rejecting other tones such as talking, outside noise, etc. The low-frequency amplifier must be able to pass the frequencies of 17.2 kHz − 17.0 kHz and 17 kHz − 16.8 kHz, or frequencies from 0 to 200 Hz.

The amount of audio power needed to drive the transmitter and amount of amplification needed in the receiver, were determined experimentally. Incidently, be sure to use high-frequency tweeters capable of operating at 17 kHz. Do not substitute small radio replacement-speakers, as they generally do not have the proper frequency response. The project was almost abandoned in its early stages, due to insufficient sensitivity of those small speakers.

Circuit description

The circuit operates in a fairly straightforward manner. Turning first to the receiver (see Fig. 2), the first stage is a high-Q, high-gain bandpass amplifier. It provides a voltage gain of about 100. The active-filter components were scaled to 17 kHz and bandpass characteristics suitable to pass the desired 16.5 kHz to 17.5 kHz, while maintaining high attenuation at higher and lower frequencies. Note the decoupling circuit at R2 and C1, used to ensure stability and to isolate the op-amp from any supply noise. Capacitor C2 is

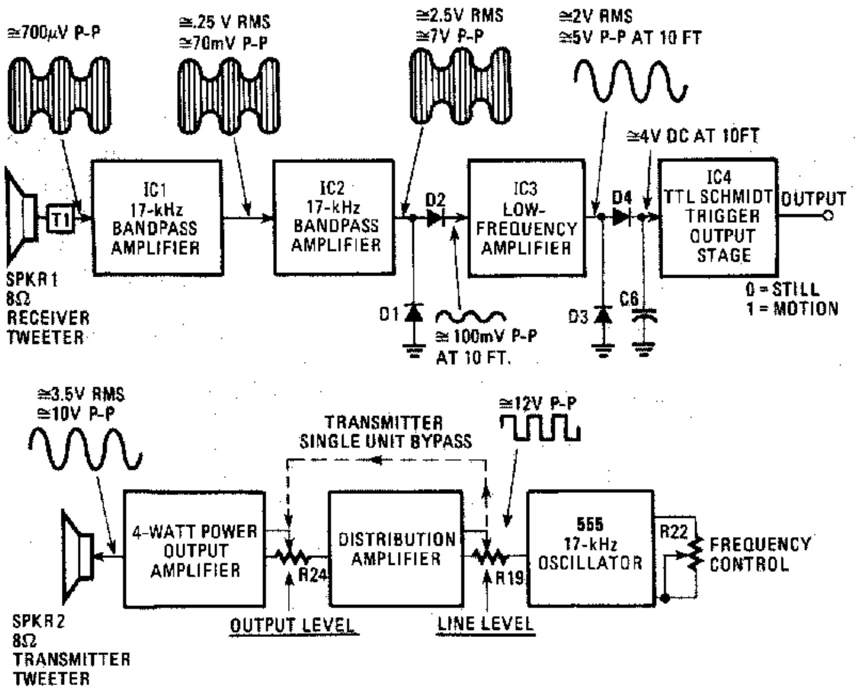


FIG. 1—BLOCK DIAGRAM of the sonic motion-detector system. Voltages given assume an object located 10 feet away.

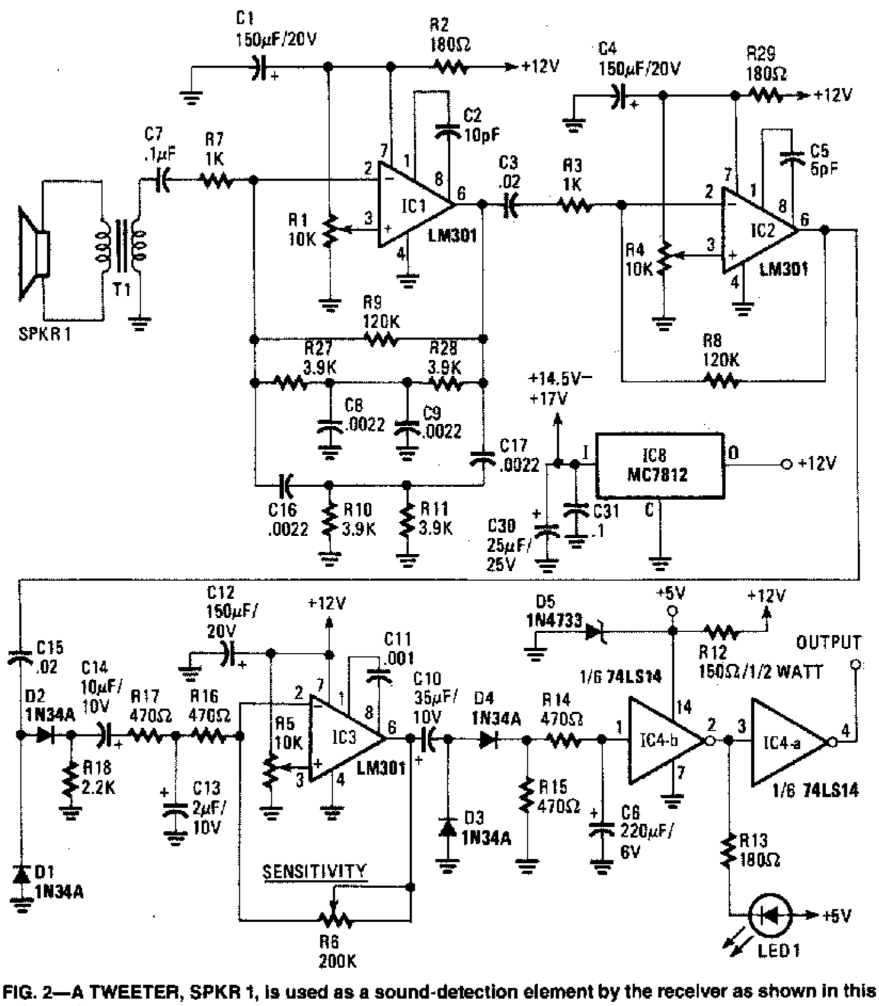


FIG. 2—A TWEETER, SPKR 1, is used as a sound-detection element by the receiver as shown in this schematic.

used to set the high-frequency rolloff characteristics of the op-amp and helps prevent IC1 from oscillating. Integrated circuit IC1 should be a fairly high-frequency op-amp; the same holds true for IC2 and IC3. If you are substituting a device other than the one specified, check the manufactures data sheet to be sure it has sufficient gain at 17 kHz. For instance, a 741 op-amp would not work here since its gain drops to a maximum of about 40 at 17 kHz. Impedance matching and voltage step-up between the tweeter (used here as a sound detector rather than a sound source) and the first stage is done by T1, an 8-ohm/1000-ohm audio transformer. That transformer is placed in the circuit so that the 8-ohm side is connected to the speaker.

The second stage is a high-frequency amplifier with a gain of about 100. Low-frequency attenuation is provided by C3 and R3. High-frequency attenuation and stability is provided by C5. Power-supply decoupling is taken care of here by R5 and C4. The magnitude of the received 17-kHz signal at this point should be about 4 to 8 volts P-P.

If there is a moving object in the range of the device, there will be another frequency present at the output of that stage. In addition to the 17 kHz being reflected from the walls, doors and other stationary objects, there is also a weaker signal whose frequency is determined by the speed of the moving object. Those two signals (a strong 17-kHz signal and a weaker ± doppler signal) appear as an amplitude-modulated waveform. Germanium diodes D1 and D2 are used to detect that AM signal, much like a crystal radio.

The third stage is a variable-gain low-frequency bandpass amplifier that rolls off slowly below 15 Hz and above 200 Hz. Those frequencies represent the average range of doppler-shifted frequencies as determined earlier in the article. That stage uses a potentiometer, R6, to control unit sensitivity; it varies gain from 1 to about 200. The output of that stage should be about 5 volts P-P, if there is motion in the range of the device.

That AC signal is rectified by D3 and D4. The DC produced by those diodes is fed to an integrator. The integrator makes sure that motion is detected for about two-tenths of a second before setting off the Schmitt trigger (the fourth stage). That ensures that random system noise and room noise will not trip the unit. In addition, by placing C6 on the input of the TTL Schmitt trigger, the unit will always power up in the "not tripped" or still mode.

The transmitter circuit (see Fig. 3) is quite simple in operation. A 555 timer is used as an oscillator to produce the 17-kHz carrier. It is a good idea to use a polystyrene capacitor for C26 (the .01μF

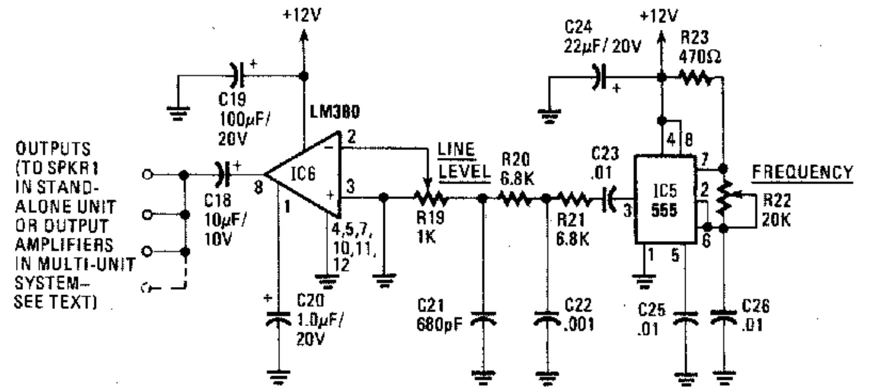


FIG. 3—THE OUTPUT OF the LM380, IC1, is used to either drive a speaker in a stand-alone system, or an output amplifier in a multi-unit system.

in the 555-oscillator timing circuit) to reduce frequency drift with temperature. The signal can take one of two paths after that depending on whether a single- or multiple-unit setup is involved.

In single-unit systems, a 555 timer and a single LM380, or other suitable audio power-amplifier, are used to drive the tweeter directly (see Fig. 3). An LM380 is a high-gain audio-power amplifier capable of producing about 3 watts of audio power. Other desirable characteristics of that amplifier are that it requires only one power supply, and its inputs are ground referenced.

In the author's set-up, which uses units in five different rooms, the LM380 shown in Fig. 3 serves as a distribution amplifier. Its output is fed to a second LM380, which serves as an output amplifier, in each unit (see Fig. 4).

The project requires 12 volts. Here, that voltage was derived by feeding 14.5–17 volts from a wall-plug supply to a 12-volt regulator housed in the receiver case.

One problem with that set-up is that the system becomes disabled if power in the house is interrupted. A solution to that problem is to supply a battery back-up as shown in Fig. 5. The circuit shown in that figure will enable B1, a battery pack made up of 10 NiCd cells in series, to cut in any time that power is interrupted. It will also trickle charge the cells so that the batteries will not become depleted during the long (hopefully!) periods between uses.

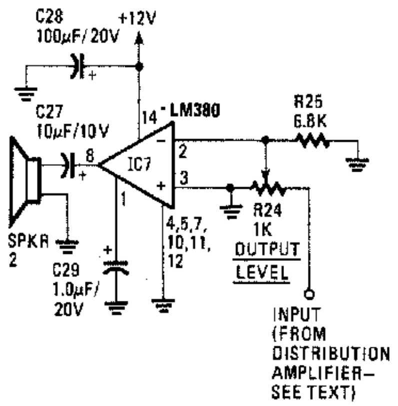


FIG. 4—IN MULTI-UNIT SYSTEMS, only a single oscillator/distribution-amplifier is used. The output from that circuit (shown in Fig. 5) is fed to an output amplifier, such as the one shown here, located in each unit.

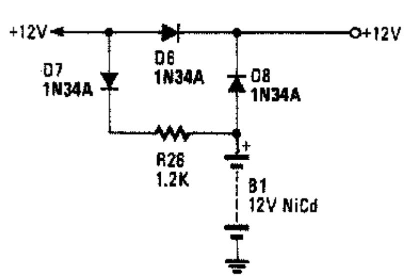


FIG. 5—A BATTERY BACK-UP will keep the system active in case of a power interuption.

Construction

Although there is little that is critical about the circuit, good construction practices should be followed. The author's prototypes were built on perforated construction board and point-to-point wiring was used with good results. Figure 6 shows the receiver and output-amp board layout used by the author. Note that R6 and LED1 are brought outside of the box housing the receiver circuit and are cemented to the cover of that box. Also ⅛-watt resistors were used in the prototype. As those resistors can be difficult to come by, we suggest using ¼-watt units instead.

Here are some tips: The ground leads should be of heavier wire to reduce inductance. Make an attempt to separate inputs from outputs on the gain stages. Keep leads short. Make absolutely sure to use a regulated, filtered power supply as shown; remember, the three stages have a combined gain of around 1,000,000. It is a good idea to house the receiver in a shielded box separate from the transmitter. And be sure to use shielded cable from the tweeter to the receiver.

Common parts are used in this design, and they are easy to obtain from a number of sources. Where performance would not be compromised, the least expensive suitable components were used. With careful shopping, the cost of building a unit should run about $35.00, or less if you have a well stocked junkbox.

The cabinet shown here and on the cover was made out of acrylic plastic for appearance reasons. The author's prototypes, however, were made from plywood, which is cheaper and easier to work with. When you make your cabinet, be sure that it is large enough to accommodate the two tweeters and the two boards. The tweeters can be mounted on the front panel of the cabinet with either

PARTS LIST

All resistors ¼-watt, 10% unless otherwise noted

R1, R4, R5—10,000 ohms, trimmer potentiometer
R2, R13, R29—180 ohms
R3, R7—1000 ohms
R6—200,000 ohms, potentiometer
R8, R9—120,000 ohms
R10, R11, R27, R28—3900 ohms
R12—150 ohms, ½ watt
R14–R17, R23—470 ohms
R18—2200 ohms
R19, R24—1000 ohms, multi-turn trimmer potentiometer
R20, R21, R25—6800 ohms
R22—20,000 ohms, multi-turn trimmer potentiometer
R26—1200 ohms

Capacitors

C1, C4, C12—150 μF, 20 volts, electrolytic
C2—10 pF, ceramic disc
C3, C15—.02 μF, ceramic disc
C5—5 pF, ceramic disc
C6—220 μF, 6 volts, electrolytic
C7—0.1 μF, ceramic disc
C8, C9, C16, C17—.0022 μF, polystyrene
C10—35 μF, 10 volts, electrolytic
C11, C22—.001 μF, ceramic disc
C13—2 μF, 10 volts, electrolytic
C14, C18, C27—10 μF, 10 volts, electrolytic
C19—100 μF, 20 volts, electrolytic
C20, C29—1 μF, 20 volts, electrolytic
C21—680 pF, ceramic disc
C23, C25—.01 μF, ceramic disc
C24—22 μF, 20 volts, electrolytic
C26—.01 μF, polystyrene
C28—100 μF, 20 volts, electrolytic
C30—30 μF, 25 volts, electrolytic

Semiconductors

IC1–IC3—LM301 operational amplifier
IC4—74LS14 hex Schmitt trigger
IC5—555 timer
IC6, IC7—LM380 operational amplifier
IC8—MC7812 12-volt regulator
D1–D4, D6–D8—1N270 or 1N34A
D5—1N4733 Zener
LED1—green LED with holder (Radio-Shack 276-019 or equivalent)
T1—transformer, 1000-ohm primary, 8-ohm secondary (Radio-Shack 273-1380 or equivalent)
SPKR1, SPKR2—tweeter (Radio-Shack 40-1270 or equivalent)

Miscellaneous: Perforated construction board, metal project boxes (2), cabinet materials (see text), wire, solder, etc.

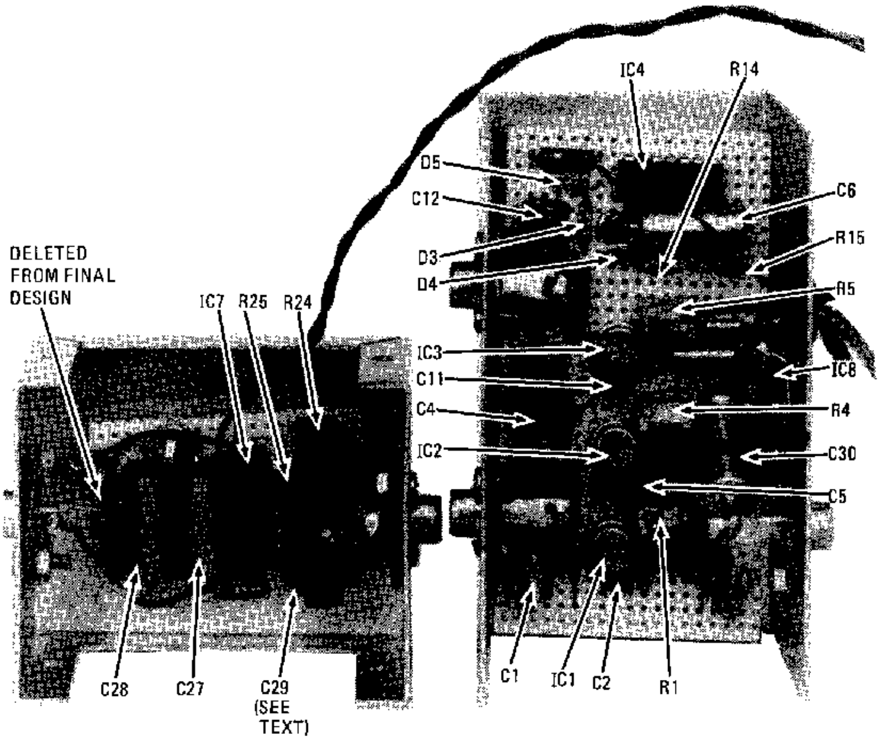


FIG. 6—THE AUTHOR'S PROTOTYPE was built on perforated construction board. Note that the unit shown here, the receiver/output-amplifier combination used in multi-unit systems, is a prototype and differs slightly from the final design.

screws or glue. Be sure to cut holes out of the front piece to allow sound to leave or reach the tweeters unimpeded.

Circuit alignment

The easiest way to align the circuit is with an oscilloscope, although it can also be done with a VOM or VTVM.

Let's first check out the transmitter, referring back to Fig. 3 as we go. Power up the transmitter with the speaker connected. If the circuit is operating, there is a good chance a loud high-pitched tone will be emitted from the tweeter, so you may want to do this part of the checkout in a secluded part of your house! Connect your test instrument to pin 3 of the 555 timer. If using a scope, you should see a 12-volt P-P squarewave. If using a VOM, you should see about 6 volts on the DC scale. Moving on to the output of the LM380, connect to the speaker side of the output coupling capacitor. When using a scope, you should see a fairly distorted sinewave of about 10-volts P-P. If using a VOM, there should be about 3.5 volts on the AC scale. The level control of the line driver and/or output amplifier should be adjusted to obtain the above values. If you have a frequency counter, adjust the frequency potentiometer to get about 17 kHz. If you don't have a counter, a rough adjustment can be made by turning the frequency potentiometer so that a loud high pitched tone is heard. Then adjust the potentiometer so that the tone gets higher in frequency. Continue turning the pot until you can barely hear the tone produced. For the average ear, you should now be adjusted to around 17 or 18 kHz.

Receiver alignment is almost as straightforward as the transmitter. You probably noticed that T1 is not located on the receiver board. To save room on the circuit board, it is mounted on the receiver tweeter. Connecting the receiver tweeter to the receiver board and applying power to the unit, we are ready to proceed. Note: to align the receiver, the transmitter must be operating as it is the signal source. It will help to have both tweeters pointing in the same direction and away from moving objects. Also, try to point them toward a wall or surface that is no less than 10 feet away.

First of all, the DC-level potentiometers, R1, R4, and R5 on all the op-amps, should be adjusted. Disable the transmitter for those measurements since they are DC adjustments. Starting with IC1, a scope or meter should be connected to pin 6 of each respective op-amp. Adjust IC1 and IC2 to read about 5.25-volts DC. Adjust IC3 to get about 6-volts DC.

Now turn on the transmitter. Looking at signal at pin 6 of IC1 with a scope, you should see some indication of a 17-kHz sinewave. You should be able to see some small amount on the AC scale of your VOM or VTVM. Depending on your meter, you may need to put a 1-µF capacitor in series with the meter to block the DC level at the measurement points. If you see no signal at that point, it is time to adjust the transmitter frequency to obtain maximum signal. It will help to point the transmitter tweeter directly toward the receiver tweeter.

Assuming you have a 17-kHz signal at IC1, we can now check out IC2. Connect your scope or meter to pin 6 of IC2. You should see several volts of 17-kHz signal at that pin. Next we'll set the 555 frequency and the transmitter-output level. Point both speakers in the same direction, away from nearby objects. Observing your scope or meter, make sure the signal level is less than 7-volts P-P on the scope or less than 2.5-volts RMS on the AC meter. Adjust the transmitter-level control to obtain those voltages. Now adjust the transmitter-frequency control for maximum indication on your scope or meter. That is the final setting for the frequency potentiometer. Be sure to have the level potentiometer set for about 7- volts P-P at IC2. It is interesting at this point to observe the amplitude modulation of the 17-kHz signal that is caused by movement.

On to the final amplifier stage. Detector diodes D1 and D2 and the following low-frequency bandpass filter feed a signal to IC3 that is proportional to the low-frequency amplitude variations of the 17-kHz carrier. IC3 amplifies that voltage to a useful level. Connect your scope or meter to pin 6 of IC3. With the sensitivity control set to mid-range, you should see about 1-volt P-P or ⅓-volt RMS, which represents circuit noise etc. Moving your hand in front of the speakers should cause the output of this stage to hit both rails. Your scope should see a squarewave down to about 1 volt and up to about 11 volts when a moving object is near the tweeter. An AC voltmeter should see greater than 3 volts with nearby movement.

The last stage of the receiver is a 74LS14 Schmitt trigger, IC4. Its signal comes from diodes D3 and D4, which rectify the low-frequency AC of the previous stage. The output of the diodes is connected to an integrator, which is connected to the input of the 74LS14. If all is well, when the voltage at that point reaches about 1.7 volts, pin 4 of IC4 will go high and LED1 will light, indicating movement in front of the detector.

Interfacing

Interfacing the unit to the outside world is a matter of preference. Using an intruder alarm as an example, the easiest way to do something useful with the circuit would be to connect the output directly to a "noise maker" of some type. You would probably want to have an outside hidden or key switch to turn the unit on or off.

A more sophisticated approach would be to drive a one-shot (possibly made from the unused sections of the 74LS14 and some capacitors) to keep the alarm on for a minute or so to ensure that the intruder leaves! In the author's home, a KIM computer and interface provides power and monitors the outputs of five units. A one-key code on the KIM keypad enables the units when the house is empty, and a six-key code turns off the units when the house is occupied. **R-E**