Feature

# Understanding Sound Waves

## Electronic Experiments Using Analog Circuits For Sound Measurement And Control

by Donald Wilcher

Sound allows us to communicate with those about us. The sound of music affects us psychologically using our moods and emotions. The reproduction of sound by radio, movies, record players (i.e. CDs), telephones, televisions, and tape recorders are big business today. Supersonic and ultrasonic are commonly used words to describe very powerful and high-energy sound waves. The so called "sonic boom" is a very powerful sound wave that may strike the earth with a shattering blast when a jet plane pulls out of a supersonic drive.

The material that is to be presented will described in detail the composition and effects of sound. Methods for detection and control will be explained followed by construction projects in which the reader can experiment, thereby understanding the concepts and principles discussed and serving as a final wrap up to this fascinating field of science.

### Physics Of Sound

Sound is composed of longitudinal mechanical energy waves. They can be propagated in solids, liquids and gases but unlike electromagnetic waves, not in a vacuum. Sound propagates faster in liquids and solids than in air. Water cannot be compressed so sound waves propagate by means of lateral motion of the molecules, in a manner similar to wind waves on the surface of a lake. In water, sound is a transverse wave (waves which vibrate at right angles to the direction of propagation of the wave's motion). Sound waves are confined to a range of frequencies which can stimulate the human ear and brain to the sensation of hearing. The audible hearing range is defined from 20Hz to 20KHz. This range is the average response of a high fidelity stereo amplifier, though one can seldom hear sounds as high as 20 KHz. This frequency response corresponds to a wavelength range of 5/8" to 55 ft. (1.7 cm to 17 m, metric). As one becomes older, less and less can be heard at the hight end of the range.

### Infrasonic Waves

As mentioned earlier, sound is comprised of longitudinal mechanical waves. A longitudinal mechanical wave whose frequency is below the audible range is called an infrasonic wave (Infrared light waves are waves below red light).

The longest-wavelength infrasonic waves can affect the normal human ear (20Hz). They are a thousand times as long as the shortest wave to which the ear is sensitive (20KHz). The longest light waves (red) that can affect the eye is less than twice as long as the shortest waves (violet). The ear, however, has a range of ten to twelve octaves: the eye range is but one octave. NOTE: The interval between two frequencies, one of which has twice the frequency of the other, is an octave, e.g., 400Hz to 800Hz.

Infrasonic waves of interest are usually generated by large sources, such as an earthquake. Without resorting to such upheaval as an earthquake, you can sense these kinds of waves while driving behind a large trailer/truck on a highway. The large frontal surface are of the truck (which often is flat) buffers the wind and sets up infrasonic waves which are impressed on the ears as feeling sensations rather than as sound sensation. This buffering also makes steering the car more difficult.

**Methods for detection and control will be explained followed by construction projects...**

As a simple experiment in infrasonic waves, take a trip in a fast elevator in a tall building. You would be going from a position of high air pressure (ground floor) to a position of low air pressure (the highest floor reached) in perhaps 30 to 60 seconds. In order to get a full wavelength, just double the time. Frequency of a wavelength is related to the period (time) by the equation:

$f=1/T$

Where

f is the frequency in hertz

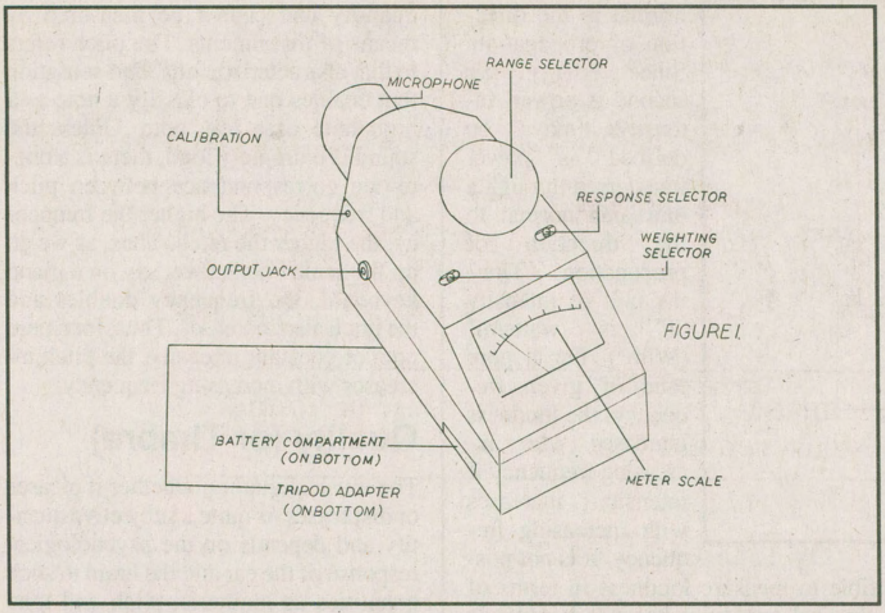

FIGURE I.

T is the period of time in seconds

## Ultrasonic Waves

Frequencies that are above the audible range (>20KHz) are called ultrasonic waves. Ultrasonic waves may be produced by a quartz crystal as is done in certain security intrusion detectors. The devices flood a room or area with silent sound in order to detect an intruder by means of beats set up by the moving object and the original signal. They normally operate at 40KHz and of course cannot be heard by the human ear.

## Periodic Waveforms

Waveforms which are fairly periodic or waveforms which consist of a small number of approximately periodic components give rise to a pleasant sensation, for example, musical sounds. Sounds whose waveform are very irregular, however, are heard as noise.

## Noise

Noise can be represented as a superposition of periodic waves, but the number of components is very large. For example, the noise or static you hear on an AM radio is impulsive in nature, since you hear only a few sferics (atmospheric interferences) per minute, except when there is a storm in the local area with lightening present. The noise you hear and see on a TV set tuned to an unoccupied channel is known as white noise and is made up of many components of audio sine waves. In the same manner, white light is the presence of all frequencies of colour. This, however, is not why the TV screen is white when there is no TV signal coming in. It is due to the type of TV transmitter modulation used in the U.S. and other countries. In the U.S., when an automobile goes by, ignition noise causes black spots to walk across the TV screen. But in England, where the modulation method is reversed, white spots are seen to walk across the screen when an automobile with ignition noise passes by.

## Temperature And Sound

At a temperature of 70 degrees F, the speed of sound in air at sea level is 1130 feet-per-second. Since temperature affects the speed of sound, at high temperatures the molecules transmitting the sound (air or metal, etc.) move faster and the speed of sound is increased. The speed of sound is 1088 feet per-second at 32 degrees F (freezing point of water) because the molecules are slowed down.

## Beat Notes

When two sounds of exactly the same frequency meet, they travel through the air together and form a much stronger or weaker wave then either of them alone. When the two waves are exactly in phase, the maxima and the minima occur at the same time and the two signals are stronger than one by itself. This is called "constructive" interference. When the two signals are exactly out of phase, that is, the maxima of one signal occurs at the same time as the minima of the other signal, we have "destructive" interference and the two waves tend to cancel each other.

If the two waves are of slightly different frequencies, the new wave is sometimes reinforced and diminished, but they never completely cancel each other.

## Components of Sound

Although sound is a longitudinal mechanical wave that can be propagated in solids, liquids and gases, the makeup of this energy wave is comprised of three parts. They are Loud-

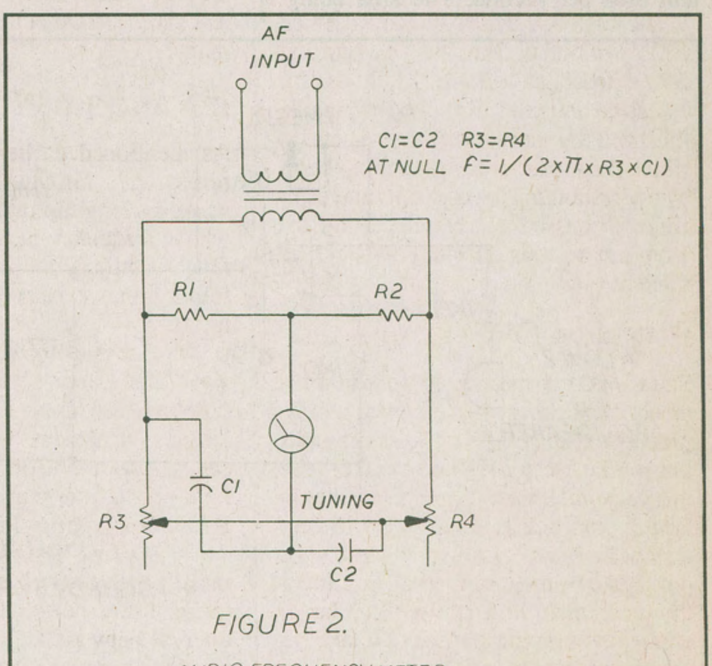

FIGURE 2.
AUDIO FREQUENCY METER

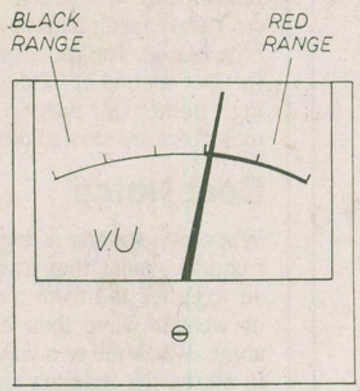


FIGURE 3.
VOLUME UNIT METER

ness, Pitch, and Quality (or Timbre). Musicians rely heavily on these components because the quality of their products (music) determines the amount of profit made on the recorded material. This section will focus on these three key elements and will explain how they interrelate with each other.

## Loudness

The psychological sensation of loudness in the human ear is intimately connected with the intensity of the incident sound wave. The intensity of a sound wave is equal to the energy crossing per unit area per second. The area being normal to the direction of propagation. Since energy per second is power, intensity may be defined as power transferred through a unit area normal to the direction of propagation. Thus, the unit of intensity "I" is watts/m$^2$ (W/m$^2$). For a pure tone of given frequency, the loudness increases with increasing frequency if intensity increases with increasing frequency. It is not possible to measure loudness in terms of physical quantities because it depends upon the response of the ear and the judgement of the individual. For example, two or more observers can easily agree that two sounds are almost equally loud, but they will rarely agree that one sound is twice as loud as another. The loudness of the two sounds may be harder to compare if the frequencies of the two sound sources differ widely.

## Pitch

Pitch is another psychological property of sound that is related to frequency. Just like loudness it is a subjective quantity and cannot be measured by means of instruments. The pitch refers to that characteristic of sound sensation that enables one to classify a note as a high note or a low note. Unless the sound is extremely loud, there is a one-to-one correspondence between pitch and frequency. The higher the frequency, the higher the pitch. Thus, as we go up the scale one octave, say on a piano keyboard, the frequency doubles and the pitch also increases. Thus, for a pure note of constant intensity, the pitch increases with increasing frequency.

## Quality (or Timbre)

The musical quality, whether it pleases or displeases, is quite a subjective quantity and depends on the psychological response of the ear and the brain to such quantities as loudness, pitch and tone quality. Two of these quantities have been discussed previously; tone quality will be explained in the following paragraph.

If a musical instrument could be made that had only the fundamental frequency and constant intensity, it would not produce a pleasant musical sound. The tone quality of any musical sound is determined by the number of overtones and their relative intensity.

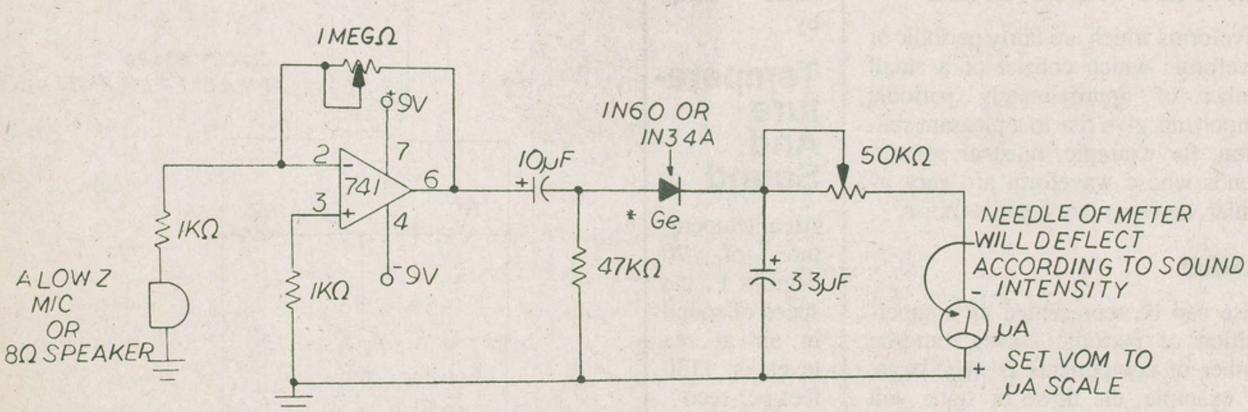


FIGURE 4.
SOUND LEVEL METER

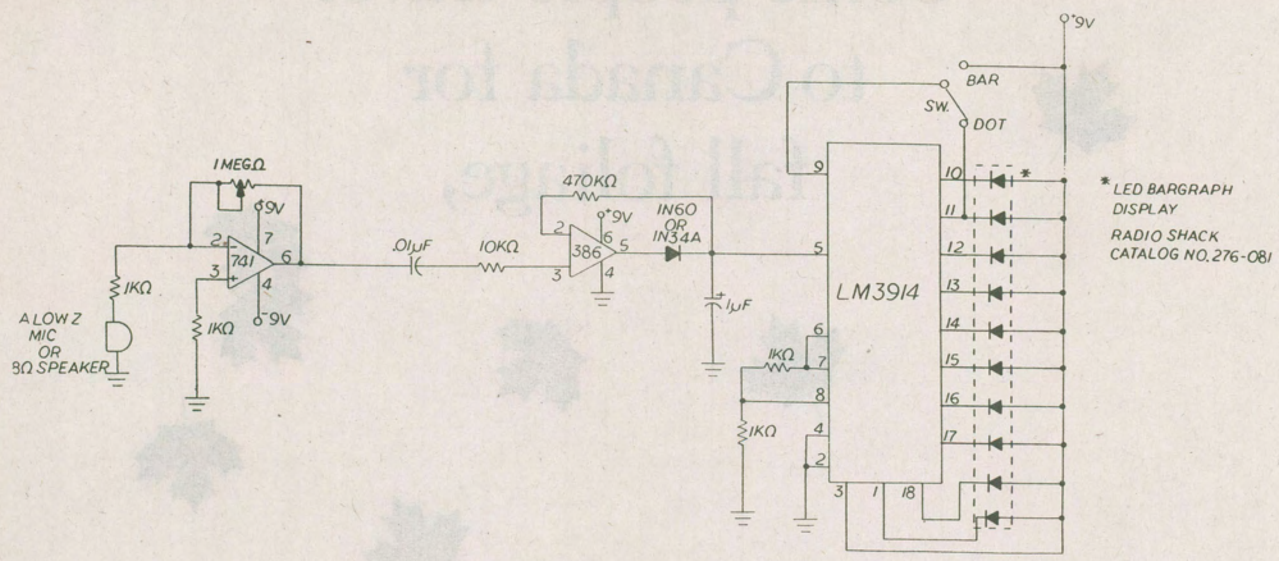


FIGURE 5.

SOUND LEVEL METER WITH BARGRAPH DISPLAY

## Sound Detection and Measuring Devices

Now that the fundamentals of sound in terms of composition and elementary science have been explained, how can this physical parameter (sound) be measured and used to control "real" world devices? Well, the following paragraphs will explain how measuring instrumentation may be used for sound detection and control of infrasonic sound waves.

## Sound Level Meter

Basically, a sound level meter is a portable instrument for measuring the intensity and other characteristics of sound. To best describe the versatility of this instrument, the Tandy Corporation's sound level meter will be used as an example to explain the meter operation.

As shown in Figure 1, the Realistic Sound Level Meter is an extremely versatile device for measuring sound intensity ($W/m^2$) in just about any acoustic environment — loud or soft, high pitch, low pitch or broad band, intermittent or continuous. This unit has scores of practical applications for professional and home use: measuring noise levels in factories, schools, offices, airports, checking acoustics of studios, auditoriums, and home stereo installations.

The precisely calibrated meter features a large, easy-to-read indicator for taking quick measurement anywhere.

This sound level meter has a phono type output jack for connection to a stereo or to test equipment. For example, the meter can be connected to a stereo system via an audio patch cord to the aux or high level input of the system. NOTE: The meter response will not be flat, due to the A and C weighting networks. The RANGE selector switch is set so that a maximum needle deflection is never greater than +4, to prevent the built-in amplifier from clipping. The A weighting is used for voice recording/measurements and the C weighting for full-range musical material. A motion detector will shortly be constructed using the output jack feature of the sound level meter and a few associated electronic components.

## Audio Frequency Meter

An instrument for measuring frequencies in the audio frequency spectrum (20Hz to 20KHz) is known as an Audio Frequency Meter. Three types of meters are commonly used: analog, digital, and the bridge. The analog type frequency meter gives direct indications of frequency on the scale of a D'Arsonval meter. The usual range that can be measured with this unit is 20Hz to 100KHz. The digital frequency meter gives direct indication of frequency by means of a readout of lamps or LED/LCD displays. Frequency range for this meter is 1Hz to 15MHz. This meter can be used in radio frequency measurement applications as well. The bridge type audio frequency meter consists of a frequency sensitive bridge such as a Wein Bridge, with a null indicating meter. The operator of this device balances the bridge and reads the unknown frequency from the dial of the balance control. Figure 2 illustrates the wiring diagram of the bridge type audio frequency meter.

## Volume Unit Meter

A volume unit (VU) meter is an instrument for measuring the root mean square (RMS) volume level in an audio amplifier. The VU meter is calibrated in decibels relative to +4dBm. Most VU meters are fast acting instruments with just enough damping to allow easy reading. In a sophisticated stereo amplifier, each channel has a VU meter. The scale is marked off in black and red numerals with a black and red reference

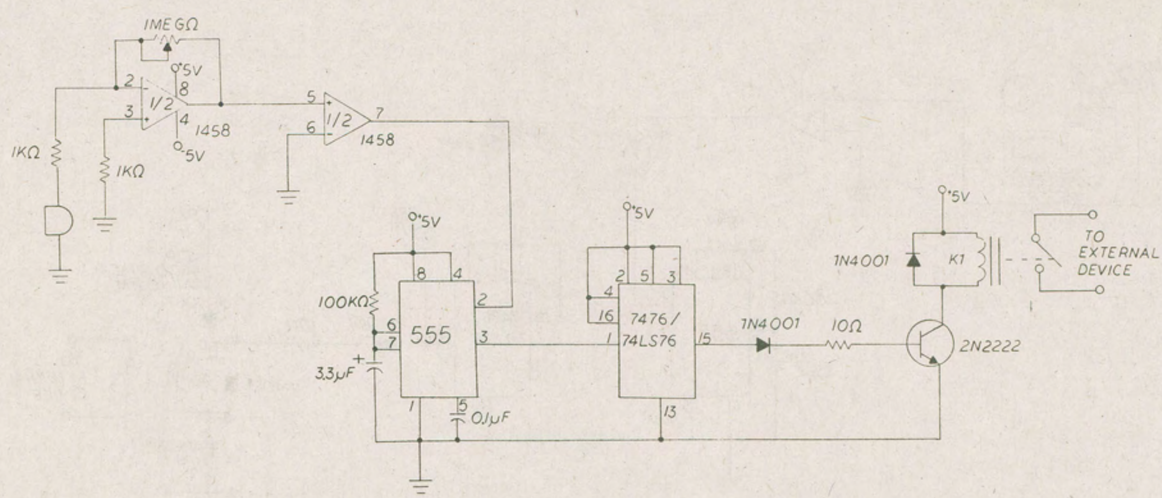


FIGURE 6.

VOICE/SOUND ACTIVATED SWITCH

line. The amplifier gain should normally be set so that the meter needle never enters the red range indicating that distortion is likely to occur on audio peaks. Figure 3 shows the face of a typical VU meter.

## Motion Detector

A motion detector is a device for sensing the movement or stopping of a body such as a rotating shaft or a moving car. As discussed earlier, ultrasonic waves along with a quartz crystal can be used for detecting such motion. By using the combination of ultrasonics and a quartz crystal, an intrusion alarm can be constructed.

## Experimental Sound Detection/Measurement and Control Circuits

Now, here comes the fun part of this article, electronic experiments and projects. The projects that will be explored in this section are, a sound level meter (both an analog and a LED Bargraph Display unit), a voice/sound activated switch and an experimental motion detector. So, warm up the soldering iron and blow the dust off of those electronic parts and get ready for some old fashioned electronics tinkering with a "high tech" twist.

## A Sound Level Meter

Figure 4 shows the schematic diagram of an analog sound level meter. The 741 op-amp operates as an inverting amplifier. It amplifies the voltage (sound) microphone. The speaker or microphone is used to detect any sound or noise input signal. The feedback resistor, a 1 MΩpotentiometer can be used to vary the gain of the amplifier — it determines the sensitivity of the amplifier circuit. The 10μf and 47kΩ resistor form a timing circuit for the meter deflection response. This circuit establishes the timing between each sound voltage peak level and the analog meter showing the response. The germanium diode and the 3.3μf capacitor provide a rectification and filtering network for the meter's needle deflection. The 50K pot provides meter sensitivity to the flow of current that it is monitoring.

Once the circuit has been constructed, both the 1MΩ and 50KΩ pots should be adjusted for best sound level detection response reading on the meter. NOTE: Adjust the 50K pot so that maximum meter response will not peg the needle of the meter. If a professional sound level meter is available, see if you can calibrate this circuit to the standard unit. Try various locations around your home and see what the sound level is at the location of measurement. Record your results in a log book and make a plot between location versus sound level intensity (dbM).

## Sound Level Meter With an LED Bargraph Display

This circuit in Figure 5 operates in a similar fashion to the previous circuit with the exception of the output display unit. This circuit will illuminate the appropriate LED(s) depending on the sound level signal received at pin 5 of the LM3914 Bar/Dot Display IC. This chip was designed to function in a logarithmic manner based on the concept of decibels (dB). Upon the input signal being received at pin 5 of the chip, the device will convert the signal into its equivalent log number. Therefore, the LED Bargraph will display a true dB reading. The LM386 IC provides further amplification to the LM3914 IC. The germanium diode and 1μf capacitor provide rectification and filtering of the output signal from the

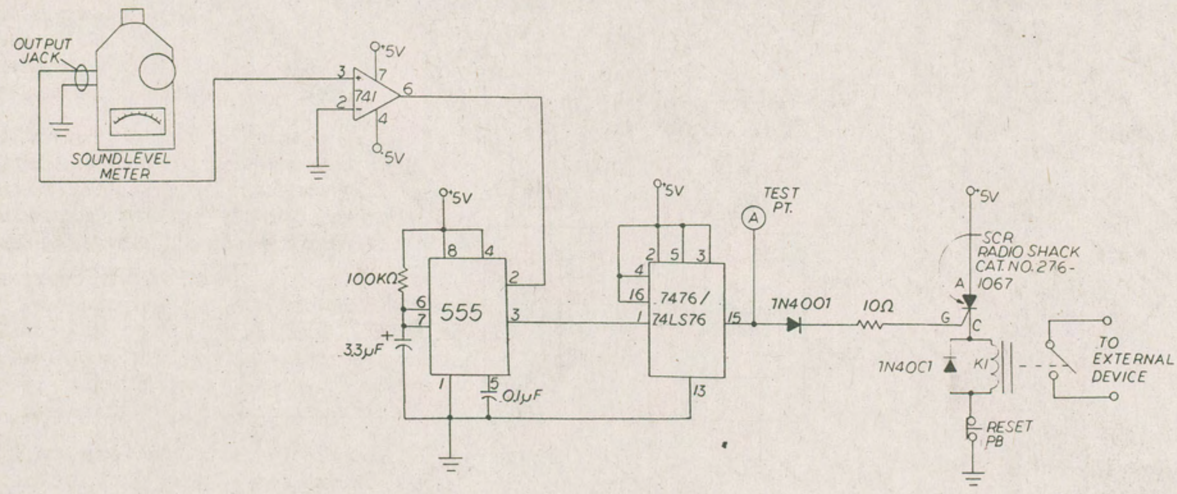


FIGURE 7

AN EXPERIMENTAL MOTION DETECTOR

LM386 chip NOTE: If the switch is in the BAR position, several LEDS will be illuminated according to intensity of sound level. If the switch is in the DOT position, each individual LED will be illuminated according to intensity level.

## A Voice/Sound Activated Switch

With electrical impulses being produced by the microphone via sound detection, the 1st 1458 op-amp is configured as a non-inverting pre-amplifier. This amplifier will amplify the signal to a level compatible with digital logic which will do the switching and control of external devices. The 2nd 1458 op-amp is used as a square wave converter. The pulse produced by the converter is compatible with the 555 Timer and the 7476/74LS76 J-K flip-flop circuits. The 555 IC is wired as a one-shot timer to provide a delay, thereby allowing the 7476 adequate time in receiving and processing the square wave input pulse. The delay established by the 555 is important because the output latch circuit (7476) requires a few milliseconds in order to receive and process this data for switching applications. The 555 circuit is configured for a delay of 363 milliseconds. The 7476 chip upon receiving this 363mS signal will then turn on or off an external device via the transistor relay driver. The J-K flip-flop was used as opposed to using just a transistor relay driver because once the output signal of the J-K flip-flop is high it needs to remain in that state until it receives another input pulse from the one-shot timer. The transistor relay driver connected at the output of the flip-flop IC is used for switching external devices (e.g. motors, lamps, robots, etc.) on or off. Figure 6 is the complete diagram of a voice/sound activated switch.

## An Experimental Motion Detector

The circuit shown in Figure 7 is of an experimental motion detector. The circuit functions exactly as the voice/sound activated switch with the exceptions of the sound level meter and the SCR relay driver circuit. The sound level meter acts as a pre-amplifier by detecting the sound via microphone and then amplifying the sound and sending it to the square wave converter circuit via the output jack of the meter. The 555 IC and the 7476/74LS76 establish the time delay and output latching functions respectively. Upon receiving a flow of current into the gate of the SCR, the relay is energized and remains energized until the RESET PB is depressed, at which time the driver circuit is ready to switching on the external alarm. In order to reset the circuit, the following steps are required:

1. Clap your hands or make a loud noise so that the sound level meter can detect it.
2. By connecting a volmeter or using an LED at TEST PT A, there should be no voltage or LED on.
3. Depress the RESET PB.
4. The circuit is ready for detection.

Sensitivity of this circuit is adjusted using the Range Selector Switch for the correct dB level on the meter.

## Summary

It is hoped that the material presented in this article has furthered your knowledge about sound and the various methods used to monitor, measure and control this natural energy form. As a design challenge, see if you can interface some of the circuits that were discussed to a personal computer for data logging the dB levels measured in various environments. GOOD LUCK!!! ❒