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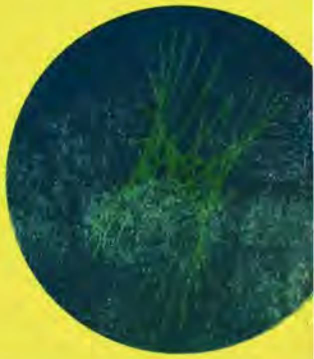

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Experimenting with Circular Sweep

Create Exciting Graphic Designs On Any Oscilloscope

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EXPERIMENTING WITH CIRCULAR SWEEP

Circular-sweep converter provides fascinating scope displays.

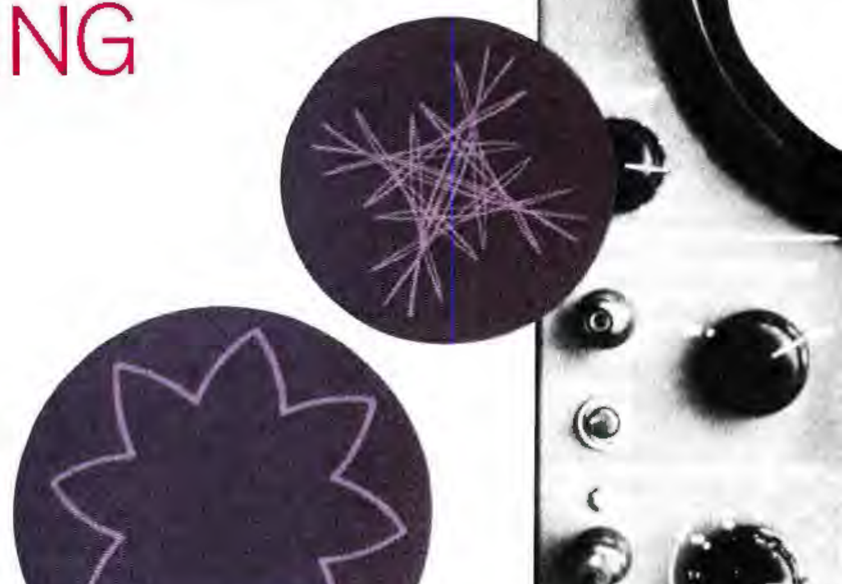
BY RANDALL K. KIRSCHMAN

THE USUAL method of displaying waveforms on an oscilloscope is to sweep the beam horizontally to provide a linear time-base and then deflect it vertically with the waveform to be displayed. In this article, we will discuss another type of display—one in which the beam is swept in a circle and deflected radially (inward and outward from the center) by the waveform to be displayed. This method, called "circular sweep," has some practical advantages. Since the sweep baseline is a closed circle, there is no retrace; and, compared with linear sweep, the baseline can be made longer for an oscilloscope screen of a given size. However, in the author's opinion, practical considerations are of secondary importance to the fact that displaying waveforms with circular sweep creates all sorts of fascinating patterns and effects.

The circular-sweep technique has been used for many years, but early methods were usually limited in performance or were too impractical for the average experimenter. Now, however, with just four IC's, you can make a high-quality circular-sweep converter that connects to the input terminals of a conventional oscilloscope. No modifications of any kind need to be made to the scope.

How It Works. To move the oscilloscope beam in a circle and form the sweep baseline, two sine waves having a 90° phase difference are applied to the two inputs (horizontal and vertical) of the scope. The signal to be displayed is then combined with these two sine waves so that it deflects the beam in a radial direction. This is done with two analog multiplier IC's, as shown in Fig. 1.

An *analog multiplier* (or *operational multiplier*) is a circuit whose output voltage is the product of the two voltages fed into its inputs. The multipliers used here are of the *four-quadrant* type, which means that they can accurately



multiply for all combinations of positive and negative input voltages, a necessary feature for the converter circuit.

To understand how the converter works, think of each multiplier as an amplifier whose gain for the sweep sine wave passing through it is proportional to the voltage fed into its input (in other words, a voltage-controlled amplifier or VCA). The signal to be displayed, plus a constant dc voltage, is also fed to this input. Thus, if the signal is zero, the dc voltage will result in a fixed gain, causing the sine waves to be passed (point A in Fig. 2). This produces a circular baseline on the scope screen.

If the signal voltage increases in a positive direction, the gain of each multiplier is increased, causing the circle to become larger so that the trace is displaced outward from the baseline position (point B). On the other hand, if the signal goes negative, the gain is decreased, causing the trace to move inward (point C). The inward and outward displacement is proportional to the voltage level of the input signal. Thus the beam moves radially in correspondence with the instantaneous voltage of the input waveform, tracing out the waveform as it sweeps around the circle. The result is a circular-sweep display.

Another way of looking at the operation of the circuit, is to realize that each multiplier is acting as a modulator. The sweep sine wave is the "carrier" which is amplitude-modulated by the signal to be displayed. The situation is unusual in that the modulating signal has a *higher* frequency than the carrier for most displays. Also, because four-quadrant multipliers are used, they can "overmodulate" without causing trouble. Instead of clipping the waveform, overmodulation causes the trace to go through the center and come out the other side, as will be shown later.

Circuit Description. The complete circuit of the converter is shown in Fig. 3. A 741 operational amplifier (*IC1*) amplifies and buffers the input signal, which is then fed to one of the "X" inputs of each multiplier (pins 3 of *IC3* and *IC4*). The constant dc offset is added by introducing an offset current into each multiplier (through *R14* and *R15* for *IC3*, *R20* and *R21* for *IC4*).

The sweep sine wave is inverted by another 741 op amp (*IC2*) and applied to the "Y" input of one of the multipliers (pin 5 of *IC4*). The direct sweep input and its inversion drive a phase-shifter consisting of *C5* and *R7* to produce a

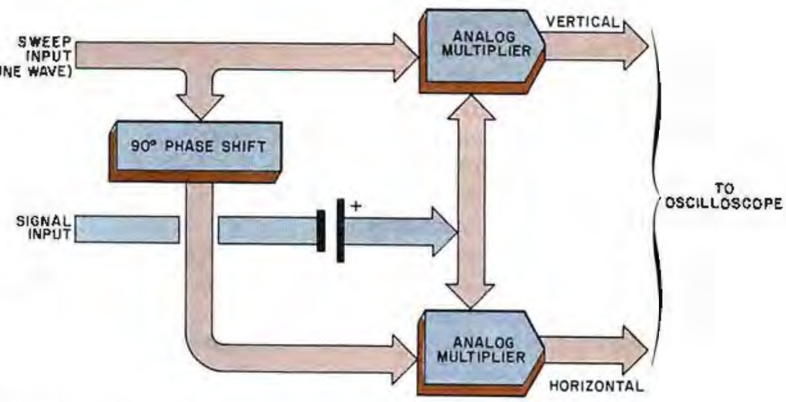


Fig. 1. Block diagram illustrates the basic operation of the circular-sweep converter.

sine wave shifted by 90°, which is then applied to the "Y" input of the other multiplier (pin 5 of *IC3*).

The output of each multiplier (pins 1 and 2 of *IC3* and *IC4*) is connected in a differential configuration to the input of an op amp which is contained in the same IC as the multiplier. The op amps provide amplification and level shifting. The output of each op amp is connected to the corresponding output of the converter. The signal path is entirely dc coupled to display signals with frequencies as low as a fraction of a hertz.

Construction. The converter can be built on perforated board, or assembled bread-board style like the prototype shown in Fig. 4. In either case, leads should be kept fairly short and neatly arranged to avoid high-frequency feedback through the multiplier IC's which have a bandwidth extending to several megahertz. All capacitors, except *C1* and *C2*, should be connected close to the multiplier IC's.

Parts values are not critical, but *R5* and *R6* should be the same value, as should *R22* and *R24*, *R23* and *R25*, *R26* and *R28*, and *R27* and *R29*. Also, the corresponding parts associated with *IC3* and *IC4* should be the same values (*C6* and *C8*, *C7* and *C9*, *R8* and *R9*, *R10* and *R16*, etc.) so that the vertical and horizontal channels of the converter will be matched. Resistors *R25* and *R29* should not be wired in permanently since their values may have to be adjusted slightly as explained in the next section. If sweep frequencies differing appreciably from 60 Hz are used, the values of *C5* or *R7* may have to be changed to get the proper phase shift of 90°. Though the XR-2208 IC is available in several versions, the least expensive, XR-2208CP, was used in the prototype.

The breadboard should be attached to a front panel similar to that shown in Fig. 4, with the appropriate markings. (Use press-on type or some similar means of identification.)

A dual power supply, such as that whose circuit is shown in Fig. 5, is required. Although the prototype used ±12 volts, any supply from ±10 to ±15 volts will work. The converter requires about 20 mA from each side of the supply. Batteries (9 V) can be used for testing purposes.

Checkout and Adjustment. After making sure that the power supply is generating the correct voltages, connect it to the main circuit. Set the SIGNAL AMPLITUDE (*R1*) and SWEEP AMPLITUDE (*R4*) controls for minimum resistance and the four OFFSET controls (*R12*, *R15*, *R18*, and *R21*) at approximately their midrange positions.

Measure the dc voltage between the V OUT connector and ground (center connector) and note that it should be under

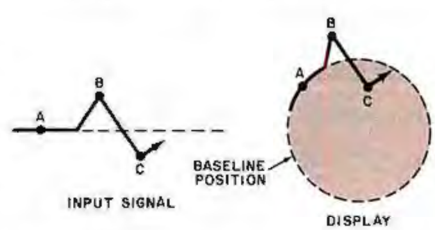


Fig. 2. Converter changes input (left) into circular display.

a few tenths of a volt, either plus or minus. If not, alter the value of *R25* until the minimum is obtained. Repeat this procedure for the H OUT connector, adjusting *R29* if necessary.

Connect the V and H OUT and center ground connectors to the vertical, horizontal and ground connectors, respectively, on the oscilloscope. Almost any scope will suffice if it has a vertical and

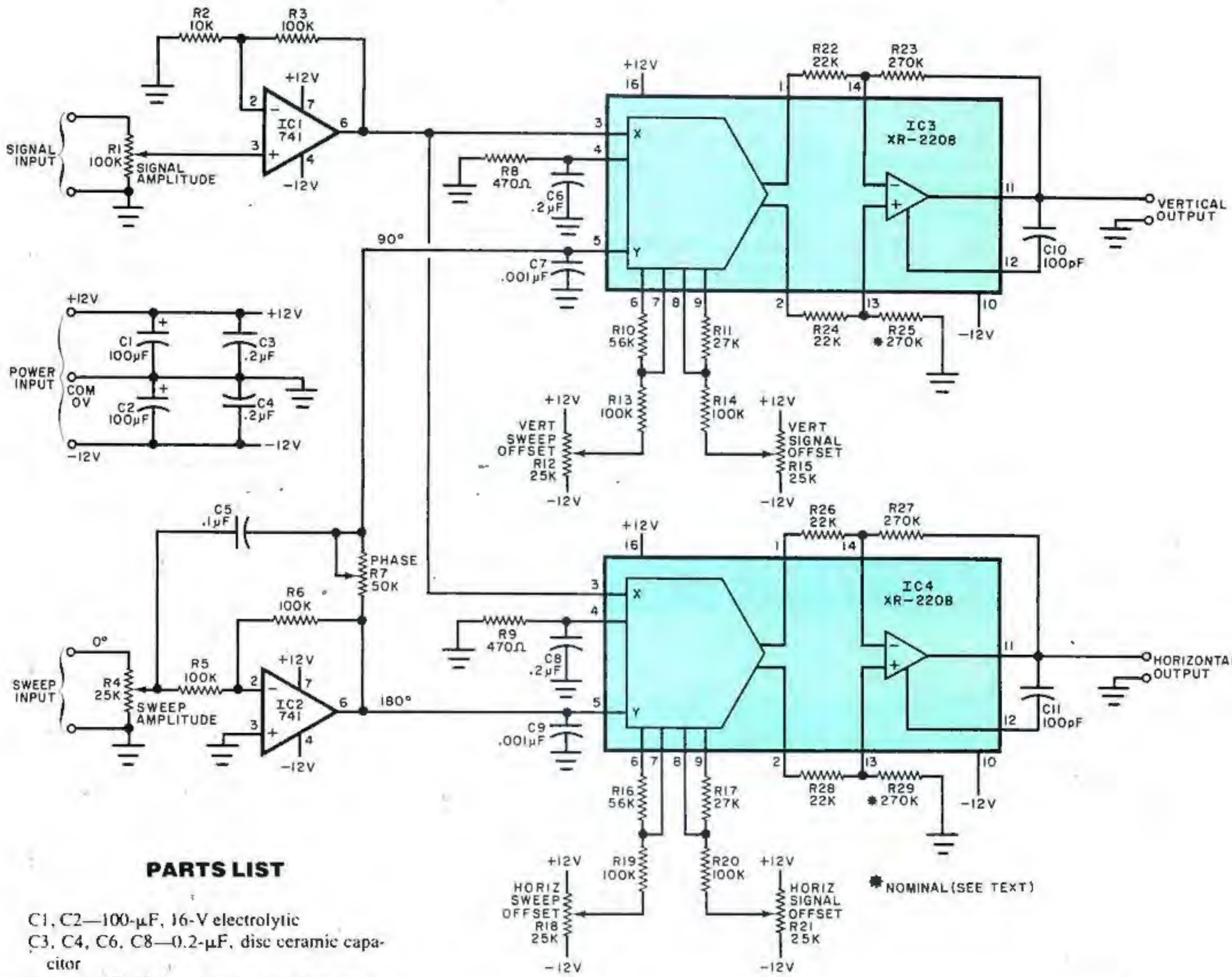


Fig. 3. Input is passed to two four-quadrant multipliers while sweep input to each multiplier is applied 90° out of phase.

PARTS LIST

C1, C2—100-µF, 16-V electrolytic
C3, C4, C6, C8—0.2-µF, disc ceramic capacitor
C5—0.1-µF, Mylar capacitor (not disc ceramic)
C7, C9—0.001-µF, disc ceramic capacitor
C10, C11—100-pF, disc ceramic capacitor
IC1, IC2—741 operational amplifier (or one 747 dual op amp)
IC3, IC4—XR-2208 operational multiplier (Exar)
Unless otherwise noted, the following are ¼-W, 10% resistors:
R1—100,000-ohm potentiometer
R2—10,000 ohms
R3, R5, R6, R13, R14, R19, R20—100,000 ohms
R4, R12, R15, R18, R21—25,000-ohm linear-taper potentiometer
R7—50,000-ohm potentiometer
R8, R9—470 ohms
R10, R16—56,000 ohms
R11, R17—27,000 ohms
R22, R24, R26, R28—22,000 ohms
R23, R25, R27, R29—270,000 ohms (see text regarding R25 and R29)
Misc.—Circuit board; chassis or cabinet; IC sockets; knobs; binding posts or jacks; hardware; etc.

horizontal bandwidth of 50 kHz or more. If your scope has dc coupling, you can work with waveforms having very low frequencies. Ac coupling will, of course, still work. Set the scope vertical and horizontal sensitivities to about 0.4 V/cm (1 V/in.).

Apply the signal to be displayed and the sine-wave sweep to the appropriate input connectors on the converter front panel. The signal to be displayed can be obtained from any waveform source, such as an audio oscillator. Its frequency should be five or ten times that of the sweep. The sweep sine-wave source can be from a conventional 6.3-V transformer or from an audio generator set to approximately 60 Hz. In either case, a good-quality sine wave should be used for best results. Keep both signal and sweep voltages between ±10 volts peak to avoid possible damage to the input integrated circuits.

Keeping the SWEEP AMPLITUDE (*R4*) at a minimum, turn up the SIGNAL AMPLITUDE (*R1*). This will probably produce a line on the scope screen. If excessive input amplitude is used, the converter will be overdriven and abrupt "glitches" will appear on the CRT. Adjust the V OFFSET sweep control (*R12*) and H OFFSET sweep control (*R18*) to reduce the line to a point.

Turn the SIGNAL AMPLITUDE (*R1*) to its minimum position, and adjust the SWEEP AMPLITUDE (*R4*) about half-way up (avoid overdrive). Then adjust the V OFFSET signal control (*R15*) and H OFFSET signal control (*R21*) near their maximums. Adjust PHASE (*R7*) and the scope vertical and horizontal gain controls until a circle approximately one third of the CRT diameter is formed on the screen.

Leave SWEEP AMPLITUDE (*R4*) where

it is, and adjust SIGNAL AMPLITUDE (*R1*). One of two things should occur. You will get either a circular sweep pattern or a diamond-shaped pattern similar to that shown in Fig. 6. If you get the diamond pattern, adjust *R21* to the opposite end of its range to get the circular pattern. This pattern may not be symmetrical. If not, adjust the V OFFSET signal control and the scope vertical gain control (or the H OFFSET signal control and scope horizontal gain).

The PHASE (*R7*), V OFFSET (*R12*) and H OFFSET (*R18*) may also need touching up. Experimenting with the converter front-panel controls will establish the best settings for maximum symmetry and minimum distortion. The "double star" pattern formed by a triangular waveform (Fig. 8C) is a good pattern to use for final adjustments.

When the above steps have been completed, the converter is properly adjusted for circular sweep.

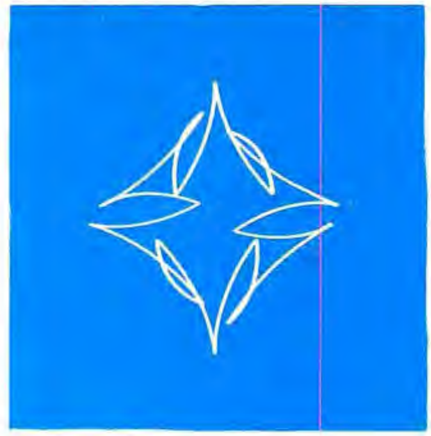


Fig. 6. Diamond-shaped pattern results when offset controls are at opposite settings.

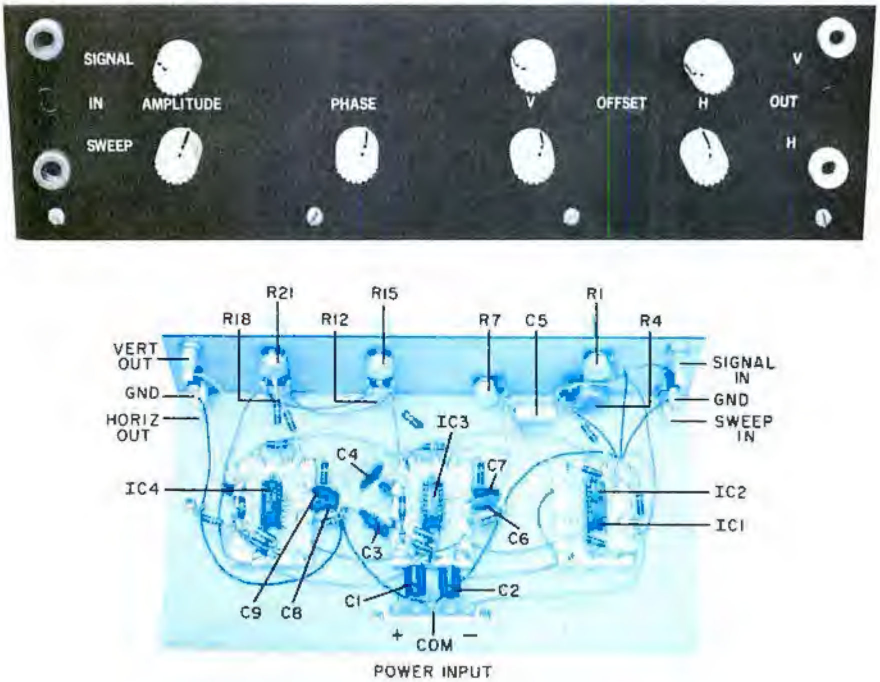


Fig. 4. Photo at top shows front panel of prototype. Below is prototype breadboard. Pc board can be used.

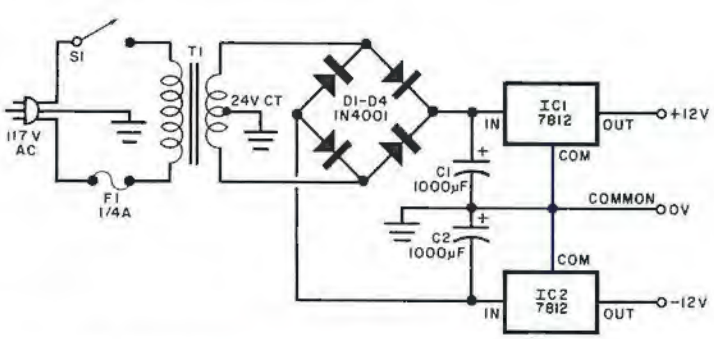


Fig. 5. The dual power supply uses both positive- and negative-voltage regulator integrated circuits.

POWER SUPPLY PARTS LIST

C1, C2—1000-μF, 25-V electrolytic
D1 through D4—Rectifier diode (1N4001 or similar)
F1—¼-A fuse
IC1—Positive 12-V, 100 mA or greater voltage regulator (7812 or equivalent)
IC2—Negative 12-V, 100-mA or greater voltage regulator (7912 or equivalent)
S1—Spst power switch
T1—24-V center-tapped, 100 mA or greater transformer

Use. Some familiar waveforms displayed with the circular sweep converter are shown in Fig. 7. In each case, the waveform frequency was adjusted to give a pattern with a whole number of cycles. The waveforms are sine (Fig. 7A), triangle (Fig. 7B), sawtooth (Fig. 7C), and square (Fig. 7D). As the amplitude of the waveform is increased, the inside of the trace will meet at a point in the center (if the converter has been adjusted properly), as illustrated in Fig. 8A for the triangle waveform. Increasing the amplitude further causes the trace to go through the center and come out the opposite side as shown in Fig. 8B (even number of cycles) and Fig. 8C (odd number of cycles).

The pinwheel pattern in Fig. 9A and the spiral in Fig. 9B are both made with sawtooth waveforms. In Fig. 9A, the waveform amplitude is adjusted so that the traces meet in the center. In Fig. 9B, a low-frequency sawtooth is used. All the patterns illustrated in this article were made using a 6.3-V filament transformer to supply the 60-Hz sweep. The waveforms were obtained from a 8038 waveform generator IC, hooked up as shown in Fig. 10. Hundreds of other patterns can be produced with these basic waveforms. If you exhaust those possibilities, try mixing the outputs of two (or more) waveform generators.

One of the most fascinating displays is that made by music waveforms. Whatever else you do with the converter, be sure to try this. Simply connect the audio from a radio, tuner, phono, etc. to the SIGNAL IN jack. The result is a kaleidoscopic succession of patterns synchronized to the music. No examples are shown because the patterns and effects cannot be satisfactorily captured by still

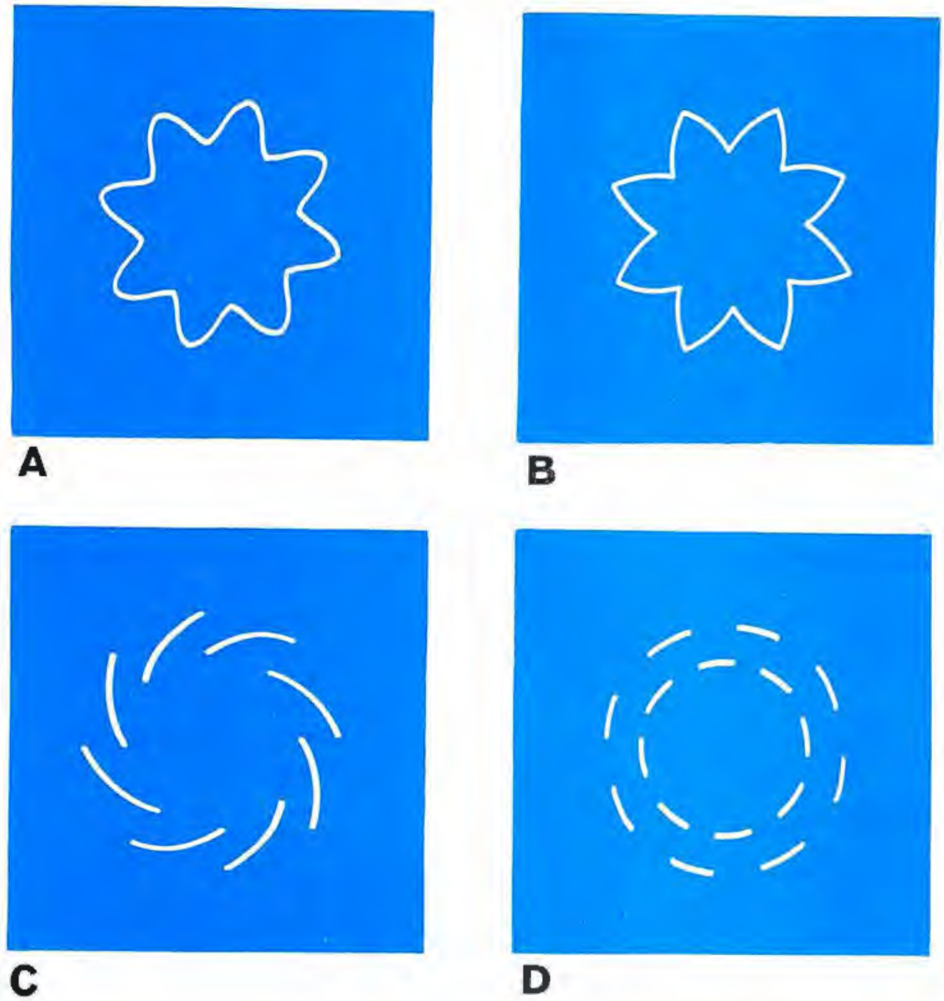


Fig. 7. Appearances of sine (A), triangle (B), sawtooth (C), and square (D) waveforms as displayed by circular-sweep converter system.

A **B** **C**

Fig. 8. Increasing the amplitude of a triangle waveform causes trace to meet in center (A) and come out opposite side with even number of cycles (B) and odd number of cycles (C).

photography. If you use an FM station as the source you may need to insert a low-pass filter (Fig. 11) between the source and SIGNAL IN to eliminate the multiplex and SCA subcarriers. Speech also makes an interesting display.

Frequency Comparison. Using an oscilloscope in the conventional manner, the frequencies of two waveforms can be compared with Lissajous figures. In an analogous way, frequencies can be compared using circular sweep. For example, the traces in Fig. 7 all show eight complete cycles of the waveform, which means that the signal goes through eight cycles while the sweep goes through one cycle. Since a 60-Hz sweep was used, the signal frequency must be 8 times 60 Hz, or 480 Hz. Fig. 9B shows almost the opposite situation. Here the sweep goes through seven cycles while the signal goes through only one cycle. The signal frequency is thus 60 Hz divided by 7, or about 8.43 Hz.

Sometimes the pattern will be more complicated, like the one shown in Fig. 12. It is still relatively easy to determine the frequency as illustrated by the following analysis of the pattern. Starting at one peak on the waveform and following the trace, the next peak that we come to is the fourth one over from the starting point. This means that the sweep goes around four times to make one complete pattern. Note also that there are 11 peaks in all, which means that there are 11 cycles of the triangle waveform in the pattern. Thus, the sweep-to-signal frequency ratio is 4:11. Since a 60-Hz sweep was used, this gives a signal frequency of (11/4) × 60 = 165 Hz.

The frequencies thus determined are exact only if the pattern is stationary. A rotating pattern indicates a slightly higher or lower frequency, depending on the direction of rotation.

Besides circular sweep, the converter can be used for other types of displays which may be less practical and more difficult to analyze, but are just as interesting. For example, you can adjust *R15* (or *R21*) to the opposite end of its range to get the diamond-shaped display mentioned earlier (Fig. 6). For even more variety, all seven controls on the converter can be varied. Combine this with all the different waveforms and combinations which can be used as the signal or sweep and you should be kept busy for a while. Figure 13 illustrates a few possibilities. But be warned—you may become so engrossed that you abandon your color organ, computer graphics, and even television! ◇

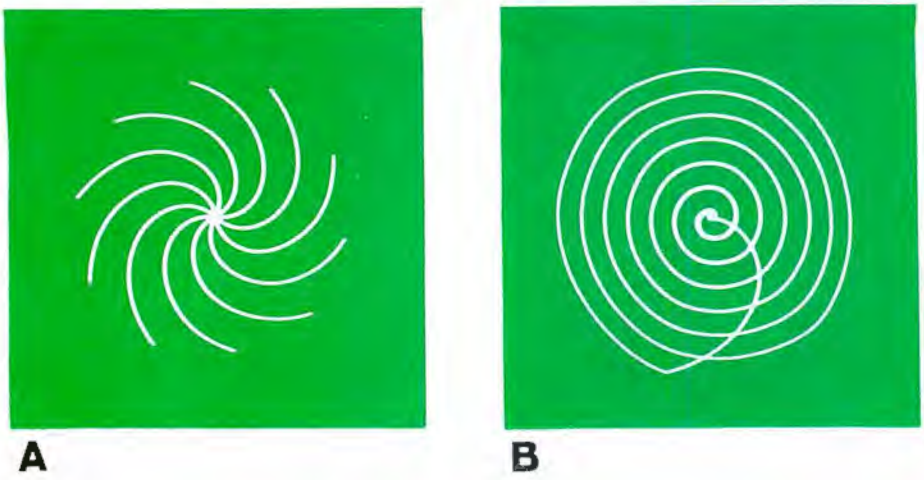


Fig. 9. Pinwheel (A) and spiral (B) patterns are produced by sawtooth waveforms of different frequencies.

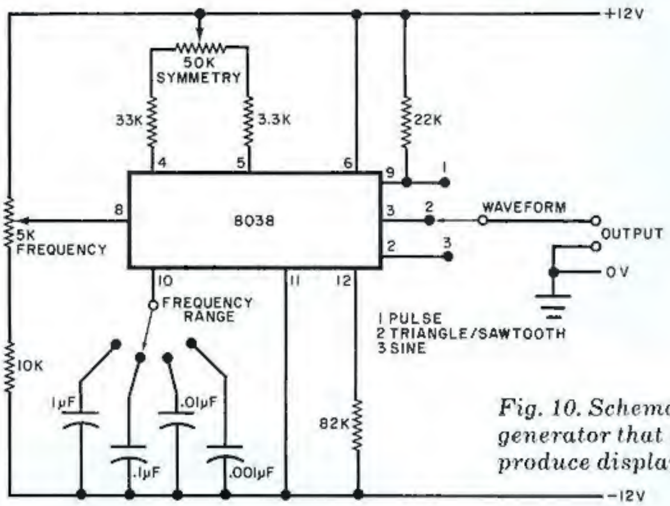


Fig. 10. Schematic of waveform generator that can be used to produce displays shown here.

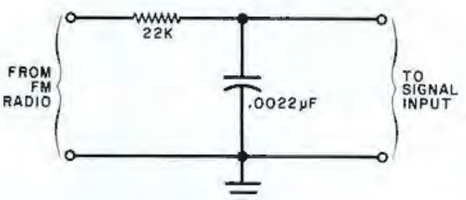


Fig. 11. Filter can be used to remove subcarriers when audio from FM stations is displayed.

Fig. 12. Frequency comparison with circular sweep. Ratio of triangle to sine sweep is 11:4.

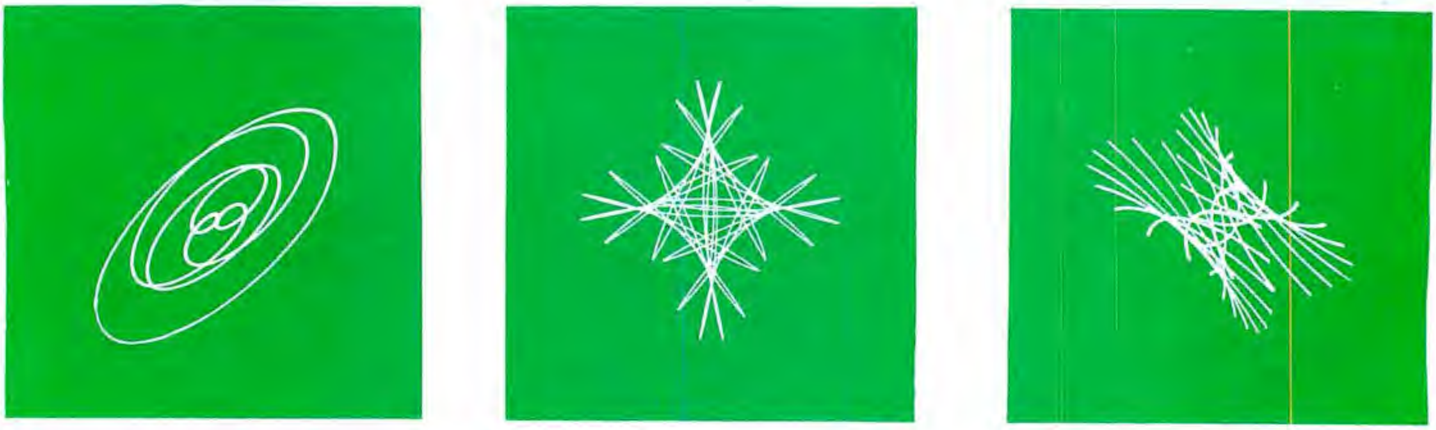


Fig. 13. Three imaginative examples of the thousands that can be generated with the circular-sweep converter.