Electronic 'Spirograph'

A. Sharp.

The circuit will generate 'Spirograph' patterns on a conventional oscilliscope. The circuit consists of two sinewave generators followed by allpass filters which we use to phase shift the input signals by 90°. Applying a sinewave to the y input gives a circular trace. If a second set of sin and cos signals are mixed in, a 'Spirograph' pattern is obtained. A block diagram of the system is shown in Fig 1.

RV1 is a balance control which varies the contribution of each oscillator to the pattern without affecting the size, so that once set up there is no need to readjust the gain controls on the oscilliscope. This type of control can only be used if the oscillators have a low impedance output.

SW1 is a reversing switch which has the effect of turning the pattern inside out.

An existing sinewave oscillator can of course be used and the 50 Hz mains could be employed (attenuated to about 2 V RMS from a low voltage transformer secondary) as the fixed oscillator. However flickering is a problem with lower frequencies (complex patterns requiring four or more cycles to complete will flicker at about 10 Hz using the mains frequency as an oscillator. I found 150 Hz to be a good compromise (higher frequencies require more critical tuning).

The allpass filter is recommended for phase splitting as it has a unity gain for all frequencies and settings of RV5.

First connect the y input of the scope to the output of an oscillator and adjust RV2 until a two volt RMS sinewave is obtained, repeat for second oscillator. Then connect up the x and y inputs as shown in Fig 1, turn the balance control to one end so as to look at the output of the fixed oscillator then adjust the 100.k pot until a circle is obtained (with suitable x and y gains). Now put the balance control in the middle and adjust the frequency controls until a stable pattern is produced. SW1 and RV1 the balance control can be used to alter the nature of the pattern without affecting its overall size, stability or symetry. Adjust RV5, the phase control (following the variable oscillator) for symmetry. — Have fun!

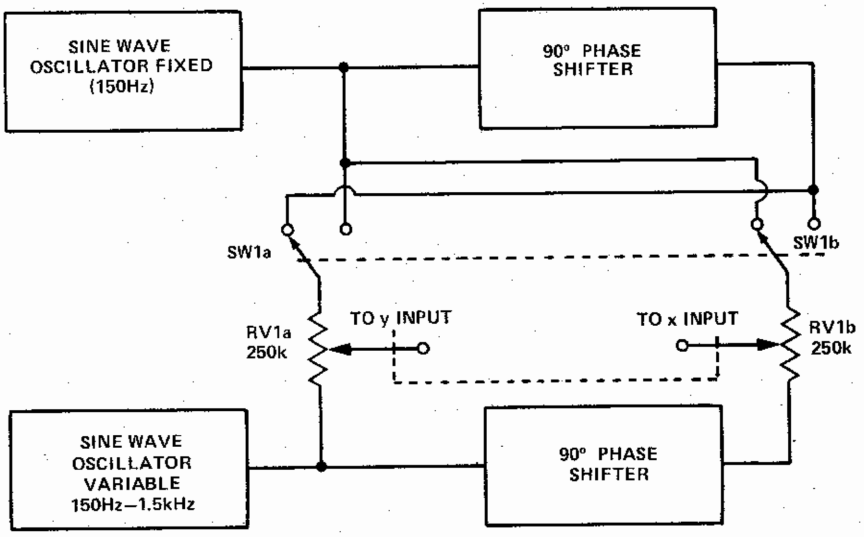


Fig. 1. Block diagram of the 'spirograph'

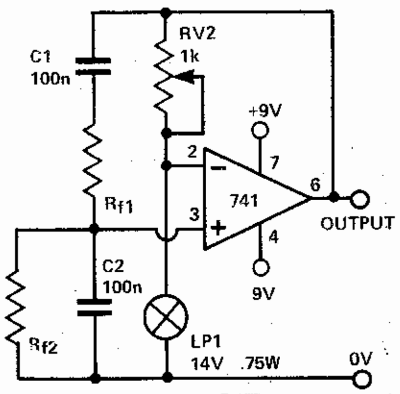


Fig. 2 (a) suitable oscillator for the 'spirograph'

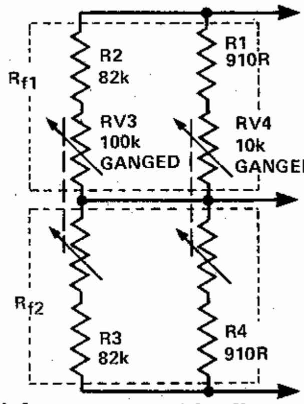


Fig. 2 (b) Arrangement to give fine control of the frequency of the oscillator shown in Fig. 2 (a). For 150 Hz fixed frequency use Rf1 = Rf2 = 10k

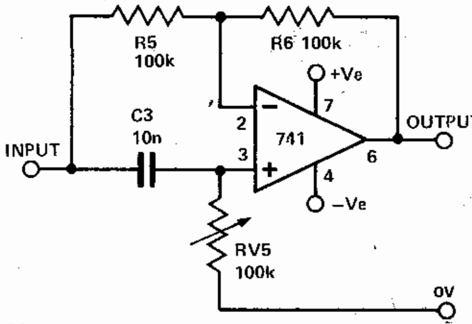


Fig. 3. Phase shifter circuit for use in 'spirograph' circuit.

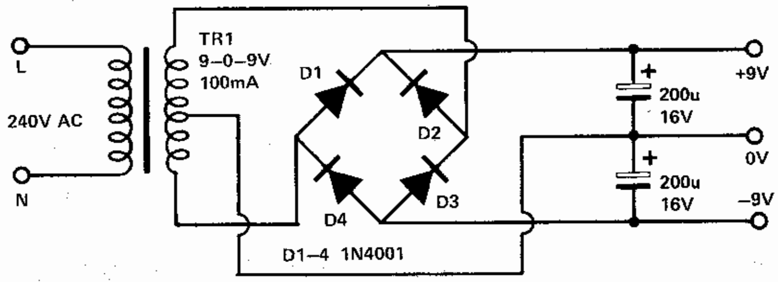
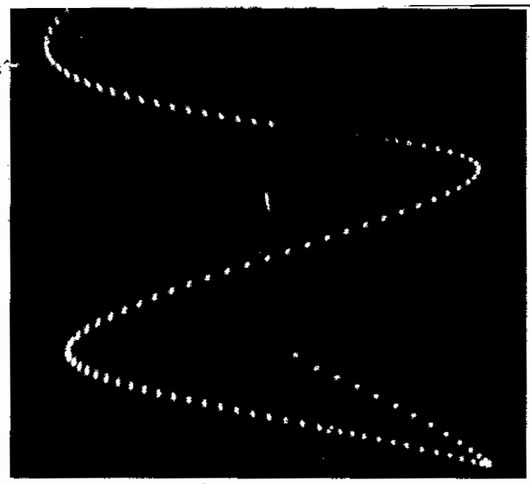
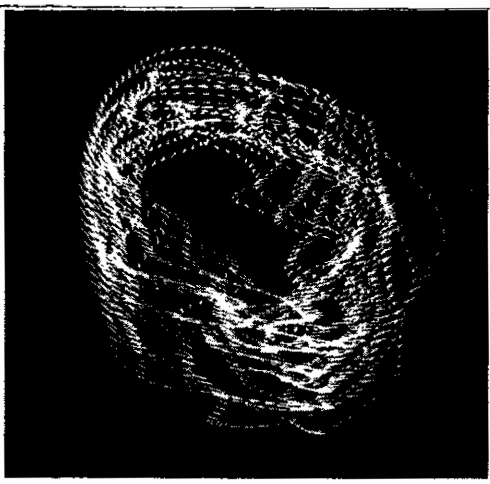
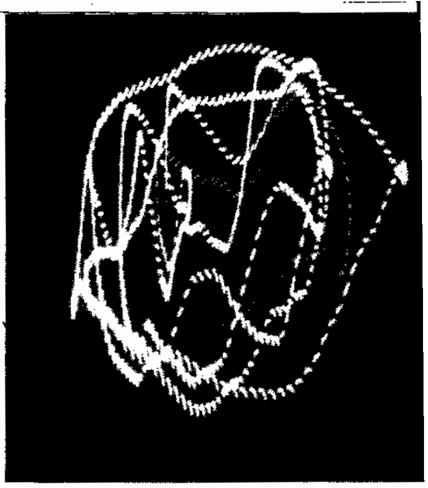
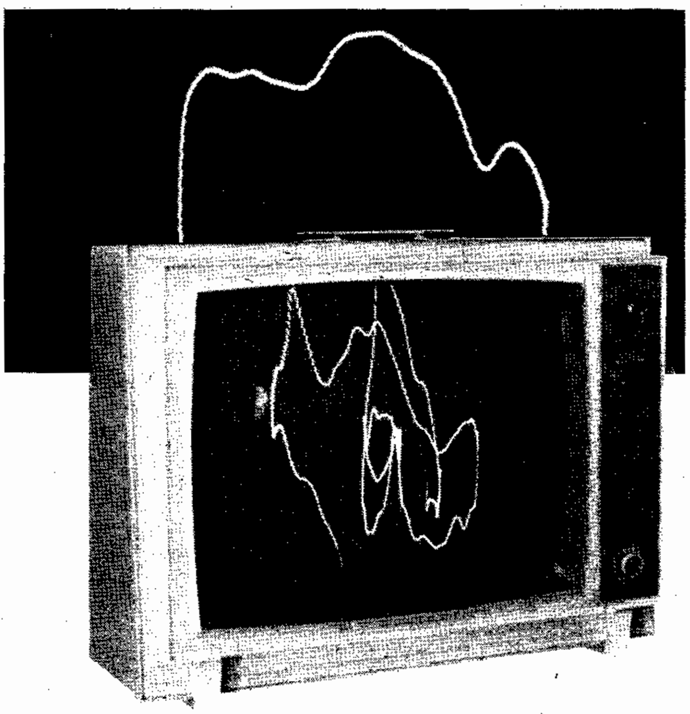


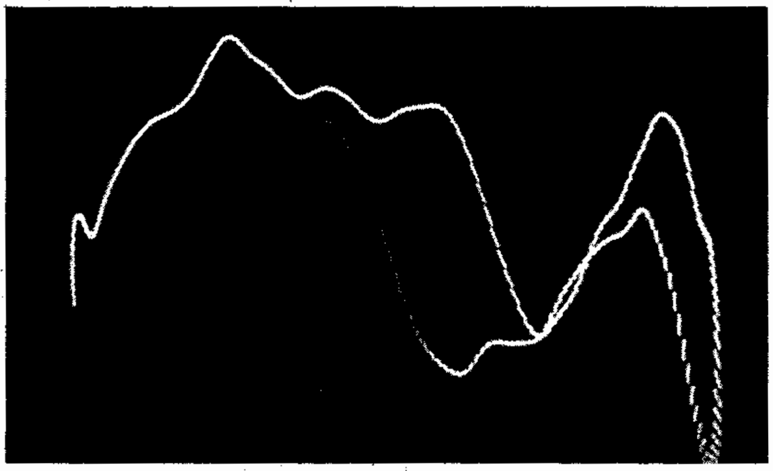
Fig. 4. PSU for 'Spirograph'











LISSY, THE TV LIGHT PEN

Lissajous patterns on your old TV add excitement to stereo.

by Dean Hock

☐ Are you an avid stereo enthusiast looking for a new way to experience your favorite music? Have you tried conventional "color organs" and found them fun for a few minutes, but dull as dishwater thereafter? Have you perhaps seen an oscilloscope hooked up with a microphone on its input and watched in fascination as the sound waves dance on the screen in perfect synchronism with your voice?

If you'd like something new to stretch your visual sense and expand the aural connection with your eyes, look no further. *Lissy*, the adapter which turns any beat-up old TV set into an oscilloscope for stereo sound, displays myriad sound patterns on the receiver screen. Its *Lissajous* patterns respond to both right and left-hand stereo signals—although it can also work with just one channel—providing an infinitely-variable light/sound display for your friend's pleasure and amazement.

What's a Lissajous? Let's go back to basics for just a minute, and review what a Lissajous figure is. Those of you who read our Basic Course in the March/April issue (*Using the Oscilloscope,* pages 83-88) will recall that Lissajous figures are 'scope displays of *two* signal inputs to the display screen —not just the usual vertical input signal which we use when we want to measure the amplitude of a voltage or watch how its amplitude changes with respect to time (the most common use of the oscilloscope).

With signals going to both the vertical *and* the horizontal inputs of an oscilloscope we can measure the relationship with respect to time (it's called *phase*) between the two signals.

For example, if a known signal is applied to the horizontal input and an unknown signal is applied to the vertical input, the resulting Lissajous pattern shows the phase relationship of the two signals.

Lissajous patterns can also be used to measure frequency. A known frequency is applied to the horizontal amplifier and an unknown frequency is applied to the vertical. By counting the number of tangency points at the top and at one side, a ratio of unknown-to-known frequency can be obtained. By multiplying the ratio times the known frequency, you can determine the frequency of the unknown.

A Simple Pattern. The drawing shows a Lissajous pattern for two sine waves. Numbers have been assigned to corresponding voltage points on the two signals Extensions of these points are brought to the screen. The intersection of corresponding numbered lines is the position of the electron beam at that instant of time. In this case the two sine waves are in phase.

In the figure below, voltage/time relationships are different; corresponding voltage points are 45° apart. Therefore the waveforms are 45° out of phase.

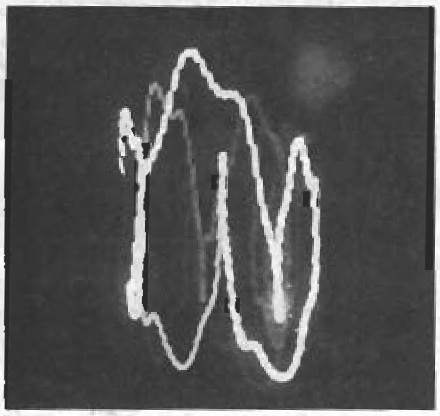
Lissy's Pictures. A continually shifting Lissajous pattern results when the phase relationship between the two input signals is constantly changing. The more complex the pattern (resulting from a frequency ratio having large numbers, such as 17/13) the harder it is to interpret. But since were not trying to *analyze* Lissy's pictures, we can just lean back and enjoy. *(Please turn page)*

LISSY TV LIGHT

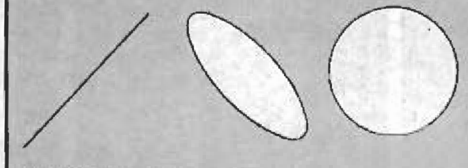
How Lissy Does It. By connecting the parts of an old TV set so that the output from one channel of a stereo set (for example, the left) drives the electron beam of TV tube vertically, and the output of the stereo set's right channel drives the beam horizontally, we can use the TV set to display Lissajous figures created by the signals from the two stereo channels. What we do is make the old TV set/stereo amplifier combination into an uncalibrated oscilloscope. Then we feed it the two signals without worrying what they mean.

Putting It Together. Begin with an old television set. You can use one in which the tuner, IF, and sound sections do not work since they will not be used. You'll also need an extra deflection yoke from another old set. Most of the older tube-type black and white sets have yokes the same size. As long as the extra yoke will fit over the neck of the set's picture tube it can be used. A junked TV is the best place to look. You must also have a stereo set with amplifiers capable of producing 12-15 watts of output power per channel. Even better is a spare (second) stereo set. This will insure better results and will also allow you to adjust the tone, volume and balance controls to the TV set without upsetting your listening pleasure, by changing the volume setting while you listen.

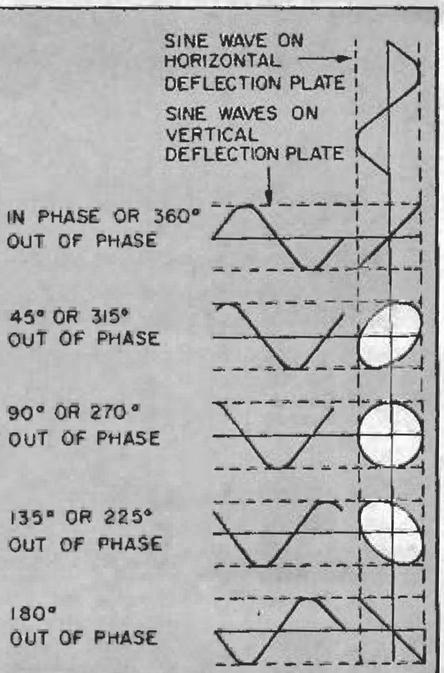
Begin by removing the back from the old TV set. Disconnect the socket from the rear of the picture tube. Loosen the clamps holding the deflection yoke and slide it off the neck of the tube. Do not disconnect any of the wires from the



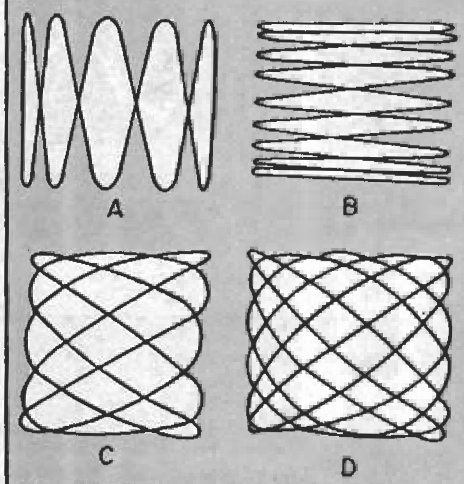
These patterns appear from moment to moment on the TV screen when it's being driven by signals from music. To see what they really look like you'd have to have motion pictures.



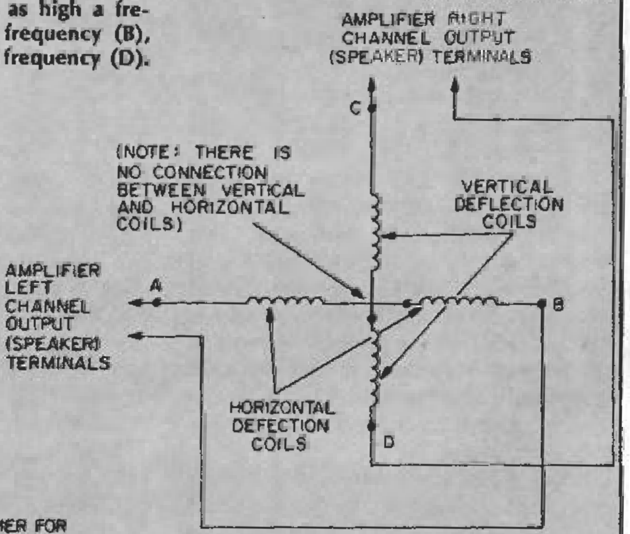
Simple Lissajous figures like these result from putting the same (or almost same) signal voltages on horizontal input and vertical input of oscilloscope (or TV picture tube).



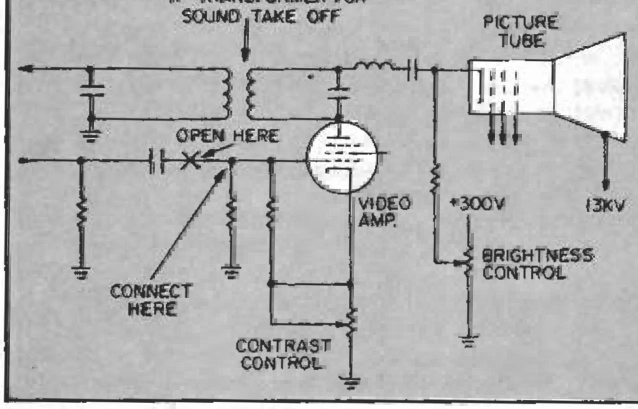
If your two stereo channels put out exactly the same signals (or you put a mono signal into both) you should get a straight (diagonal) line on the screen. If not, adjust gain of one channel. Other Lissajous patterns like these will result from out-of-phase signals. Music waveforms are extremely complex compared to the signals used to derive simple patterns shown here.



These more-complex Lissajous patterns are created by feeding a simple sine wave to the horizontal input of a scope and sine waves of exactly five times as high a frequency (A), one-ninth the frequency (B), 3/5 frequency (C), and 5/6 frequency (D).



The added deflection yoke from second TV set is connected as shown above to the two stereo channels of an amplifier or receiver. Using a separate amp (from the one you listen to) is recommended, but not essential.



This schematic shows a typical video amplifier tube for TV sets six to 15 years old. Disconnect the video input signal on the grid side of the grid-coupling capacitor and connect your Lissy oscillator at the same point to make Lissy do extra tricks.

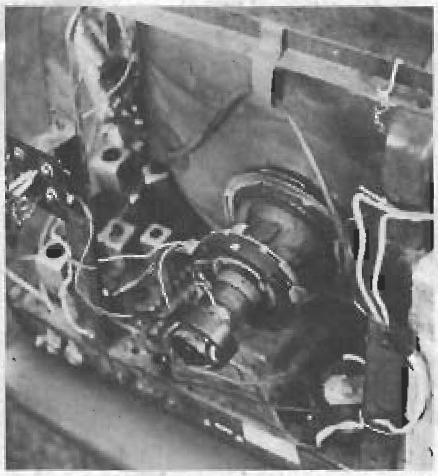
yoke since it is part of the circuit for putting the beam on the screen. Secure the old yoke to the chasis of the TV somewhere out of the way, taking care in seeing that it does not short circuit.

Preparing the Deflection Yoke. There are two coils in the deflection yoke of a TV set. One is called the horizontal and one the vertical.

Each of these two coils is divided into two sections, and we must eliminate any extra parts such as a small resistor or capacitor which are often connected to one or both of the yokes. They are usually connected to the midpoint of the horizontal coil or vertical coil. Simply remove any resistor or capacitor connected to any parts of the yoke, and if this separates the two sectional parts of either the horizontal or vertical coil, put a jumper between the two sections. Check with a voltmeter to be sure which terminals are connected (through the two coils) together. Mark them in some way so that you'll know which two leads of each coil are connected together (through each coil). Solder 2 three-foot lengths of speaker wire to the terminals of the vertical and horizontal coils.

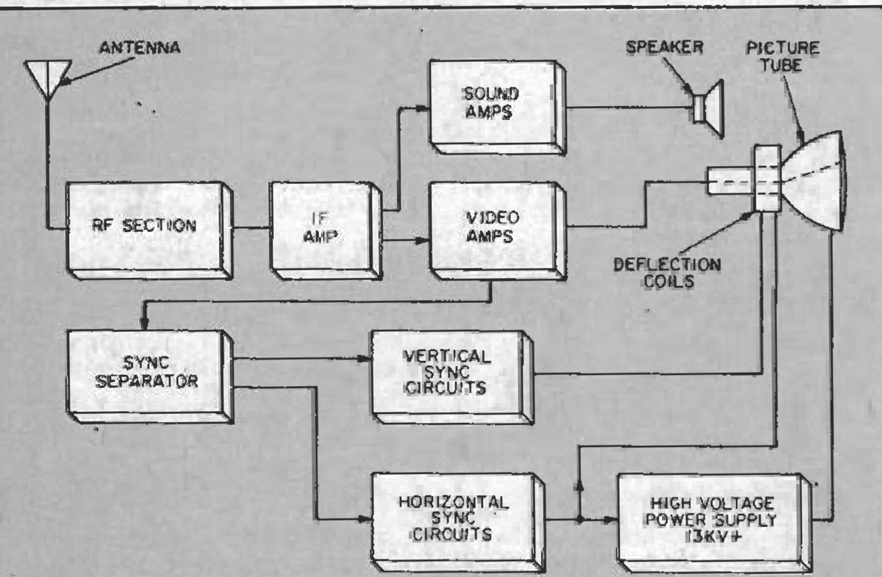
Putting It Together. Take the yoke and slide it on to the neck of the picture tube securing it with a clamp. Return the socket to the back of the tube along with any magnets that may have been removed. Put the magnets back exactly where they were. (Adjust to center beam, later.) Route the speaker wire out the back of the TV set as you put the cover back on. Run wires from the speaker outputs on your stereo to the TV set and connect the two sets of wires together using a terminal strip.

You are now ready to test out Lissy. Leave your stereo off and turn on the TV set. After warmup a small dot should be visible in the middle of the screen. Adjust the magnets, if any, to

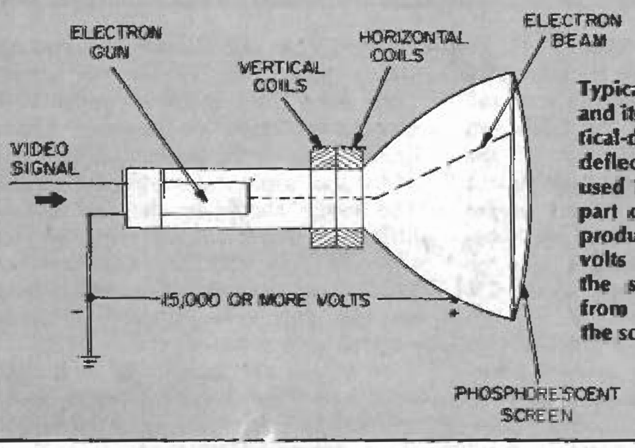


Here's how the back of author's set looks with the new picture tube yoke (deflection coils) on neck of picture tube. Original deflection yoke is removed from tube but kept hooked up because it's also used in the circuit which generates high voltage for picture tube. It's tied out of way at upper right, atop high voltage cage.

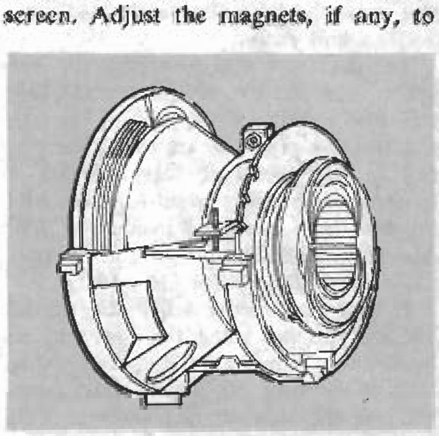
Closeup of picture tube neck shows large circular positioning magnet which some sets have behind yoke. Be sure to replace any magnets your set had into their original position after you replace the yoke.



Simplified block diagram of TV set shows how vertical and horizontal sweep currents are derived from the synchronizing signals sent from the transmitter. Vertical and horizontal sweeps feed vertical and horizontal deflection coils.



Typical TV picture tube and its horizontal and vertical-deflecting coils. Old deflection yoke is still used in Lissy because it's part of the circuit which produces thousands of volts required to attract the stream of electrons from the electron gun to the screen.



Most old TV sets have deflection yokes which look like this. Large end (left here) goes snug up against the flare of the picture tube. May require loosening of screw which secures clamp around coils.

LISSY TV LIGHT

center the beam. If necessary turn the brightness control up or down. Now turn on the stereo set and turn up the volume slowly until you start to notice the dot moving. By adjusting the balance control you should be able to make the dot move about an equal amount horizontally and vertically. It may be necessary to disconnect the speakers in order to move the beam enough. Adjust the brightness for a pleasing light level without burning the screen phosphor. Low bass notes will show up as rotating circles. Each tone has its own pattern which intensifies with the volume.

Now that you are finished sit back and enjoy the added dimension of the music TV in a dark room. It will provide you with many hours of listening and viewing pleasure.

More Fun With Lissy. Once your Lissy is working you may want to add an extra circuit which will strobe the moving pattern on and off, making a more unusual and interesting light display. By connecting the output of an oscillator to the grid of the TV set's video amplifier tube you can turn on and off the electron beam in the picture tube. This will produce dots and dashes as the beam is moved around on the screen. The effect is quite pleasing. A stop-action type of display (called "strobe") is only one interesting improvement you'll see.

The added circuit is a simple two-transistor oscillator. The switches and potentiometers allow you to select different dot line lengths and frequencies. By connecting the output of the oscillator to the grid of the video amplifier you force the tube alternately into conduction and cutoff.

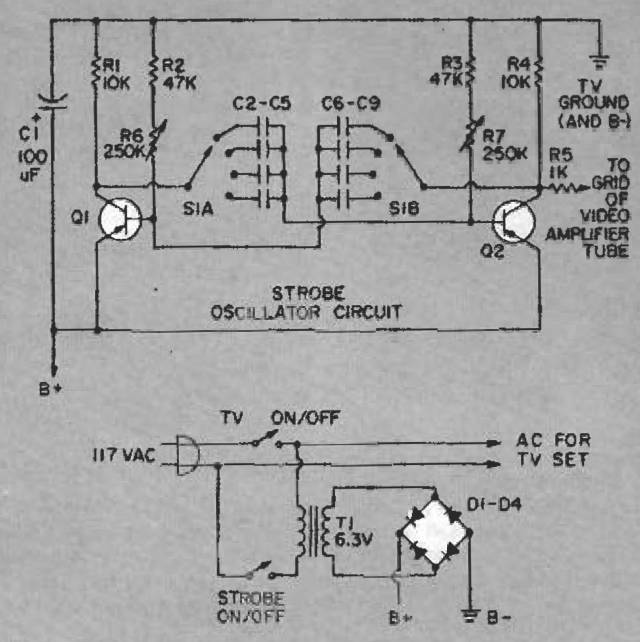
The oscillator and power supply are not critical and can be constructed any way that is convenient, as long as safe construction practices are used. The circuit in the prototype was built on a terminal strip using point-to-point wiring and then mounted inside the TV. Almost any general purpose PNP transistors can be used for Q1 and Q2.

If you can't get a schematic of the TV set you are using the best way to locate the video amplifier tube is to look at the tube placement chart (usually on the side or back of the TV) and find the tube which is labeled *Video Amp.* If the video amp tube also contains other elements in the glass envelope you will have to trace down that part of the tube which has its plate connected to the sound trap transformer (usually a metal can type) and its cathode connected to the contrast control. This may vary slightly in your set.

Once you have found the video amplifier cut one of the leads of the capacitor going to the grid and replace it by connecting the oscillator output to the tube in its place, (see the schematic). Connect the negative lead on the oscillator's power supply to the TV common ground.

Fire Her Up. Now you are ready to test the circuit. Look it over for any wiring errors. Set the potentiometers to maximum resistance and set the rotary switches at the .01 uF capacitors. Turn on the TV set and allow it to warm up. Get a music display on the screen. Turn down the brightness control until you can no longer see the raster (white lines). Turn on the strobe oscillator and adjust the brightness control as needed. The display should be chopped up into little line segments. By adjusting the controls you can get different line lengths and frequencies—anything from star-like dots to a pulsating array of stopped action traces.

Now you can lean back and enjoy your Lissy—the TV light organ which will amuse and amaze your friends for many evenings ahead. ■



PART LIST FOR LISSY—THE TV LIGHT ORGAN

TV receiver—which has light (raster) on the picture tube. It need not have a working tuner or IF section, nor sound.
Picture tube deflection yoke—in working condition. (Most are—this is a part that rarely fails in TV sets.)
Speaker wire—8-10 ft.
Stereo amplifier or receiver—preferably 12-15 watts or more per channel.
Misc.—Solder, wire, switches, etc.

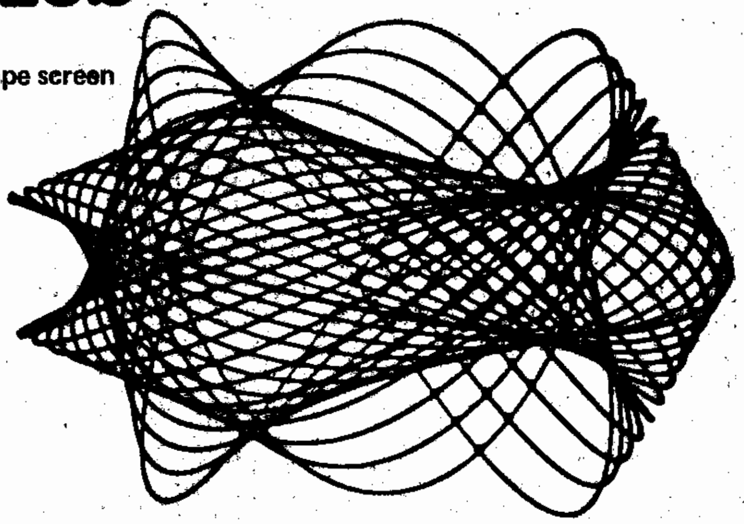
PARTS LIST FOR STROBE CIRCUIT FOR LISSY

C1—100-uF, 16-VDC electrolytic capacitor
C2, 6—.002 or .22-uF capacitor
C3, 7—.01-uF capacitor
C4, 8—.1-uF capacitor
C5, 9—1-uF capacitor
D1, 2, 3, 4—rectifier diodes, 30 PIV or better, any amperage
R1, 4—10,000-ohm, ¼-watt resistor
R2, 3—47,000-uF, ¼-watt resistor
R5—1000-ohm, ¼-watt resistor
R6, 7—250,000-ohm potentiometer (or 500,000 if 250,000 not available)
S1—Single-pole, 4-position (or more) rotary switch
Q1, 2—General-purpose PNP silicon transistors, HEP-242 or similar
T1—Power transformer, 117 VAC primary, 6.3 VAC secondary, any amperage

You can call Lissy's designs Lissajous patterns, but your friends will call them "out-of-sight"! The twisting, convoluted, ever-changing, swirling designs are truly a visually exciting wonder which can't fail to draw the viewer's eye into almost hypnotic attention. You can convert almost any old television from a boob tube to a groove tube with just a little effort, and at almost no cost at all. Just an evening's work, and your place will be jumping like never before.

oscillographics

Fascinating geometrical patterns on an oscilloscope screen



An oscilloscope can be used not only as a test instrument; with the aid of the following circuit it can be made to generate a multitude of fascinating and attractive geometrical patterns.

M. Zirpel

The accompanying illustrations give some idea of the variety of different patterns that can be generated by the 'spirator' (spirographics generator). As can be seen, they are similar to the patterns which can be produced by hand using the popular 'Spirograph™' outfit, and also to the type of figures often produced by computer graphics.
The patterns are derived from certain basic geometrical functions, and are known as 'Lissajous' figures. They are to be found in nature, for example in the path described by an object fixed to the end of a rope which is oscillating. In geometrical terms a Lissajous figure is obtained when a point describes a sinewave on both the X- and Y-axes.
The circuit of the spirator produces two sinewave voltages, the frequency of each being independently variable. Both sinewaves are damped, i.e. after the waveform has been started, the function will decay exponentially to zero.

Block diagram

The function of the spirator can be explained simply be referring to the block diagram of figure 1.
The circuit is built round two damped-sinewave oscillators, one of which is responsible for the vertical deflection (Y-signal) of the spot on the screen, the other for the horizontal deflection (X-signal). Both the frequency and the degree of damping of the two oscillators are independently variable by means of potentiometers. It is also possible to modulate either oscillator frequency by an external signal, so that the patterns are continuously changing.
Since the oscillators are not free-running but have to be started, there is an astable multivibrator which ensures that both oscillators are triggered simultaneously. The trigger frequency is 60 Hz. Whilst the oscillators are being started the spot on the screen is blanked by means of the brightness signal Z, thereby suppressing unwanted lines produced by the normal scan of the scope.

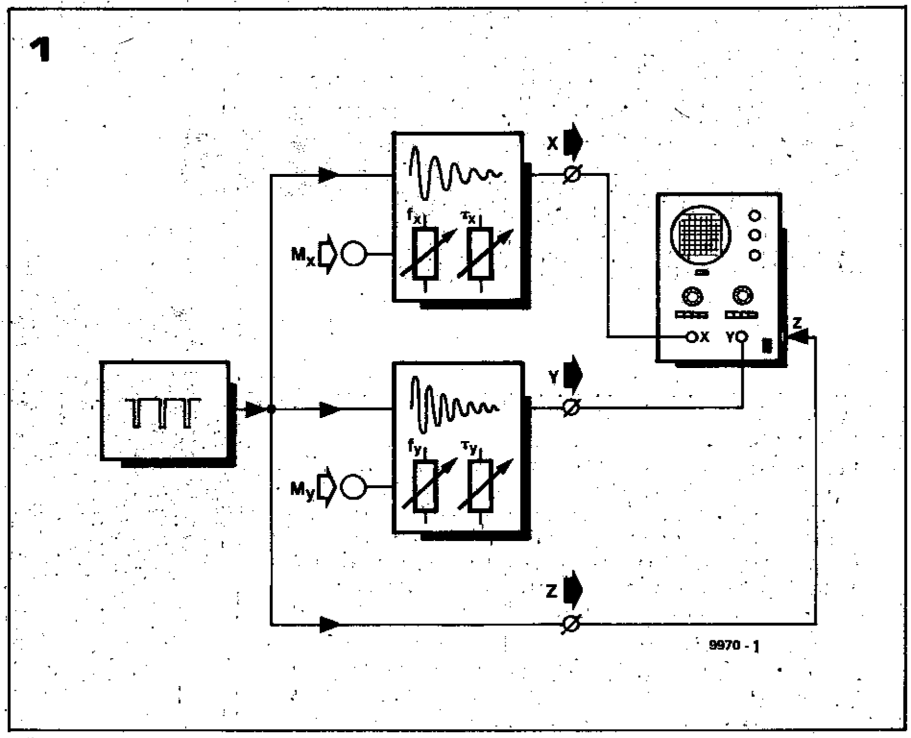
Circuit diagram

The complete circuit diagram of the spirator is shown in figure 2.
The astable multivibrator which provides the trigger pulses for the two damped-sinewave oscillators is formed by the simple circuit round opamp IC1. As was already mentioned, the frequency of the multivibrator signal is 60 Hz, sufficiently high to ensure a flicker-free picture on the scope screen. The period for which the output of IC1 is high is much longer than the period for which it is low. During the latter portion of the signal the trace is blanked via the brightness input. The next positive-going edge at the output of IC1 triggers the sinewave oscillators.
The two oscillators are identical and consist of three 741 opamps. IC2, IC3 and IC4 comprise the oscillator for the horizontal (X-)signal, whilst IC5, IC6 and IC7 form the vertical (Y-)signal oscillator. To see how they work let us take the example of the X-oscillator.
Opamps IC2 and IC3 are both connected as integrator and thus, at a certain frequency, produce a phase-shift of 180° in sinewave signals. A further phase-shift of 180° is introduced by IC4, which functions as an inverter. The three opamps together therefore have the total phase-shift of 360° required for oscillation. The total gain of the 3 cascaded opamps can be varied by means of P1 and is always less than unity. Thus, once started, the oscillator generates a damped sinewave. The degree of damping can be varied by means of P1 (P3 in the case of the Y-signal), and the frequency of the

Figure 1. The spirographics generator consists of two damped-sinewave oscillators which are triggered by an astable multivibrator. Both the frequency and damping of the sinewaves can be varied independently. The oscillator output signals are used to control the X- and Y-deflection of an oscilloscope trace; the result is a fascinating display of Lissajous figures.

Figure 2. The complete circuit diagram of the spirator. Two extra modulation inputs allow the patterns to be continuously varied. Various different types of oscillator (sinewave- or triangle-) can be used to provide the modulation inputs. Waveforms with steep edges (sawtooth, squarewave etc.) result in an abrupt transition from one pattern to another).

1



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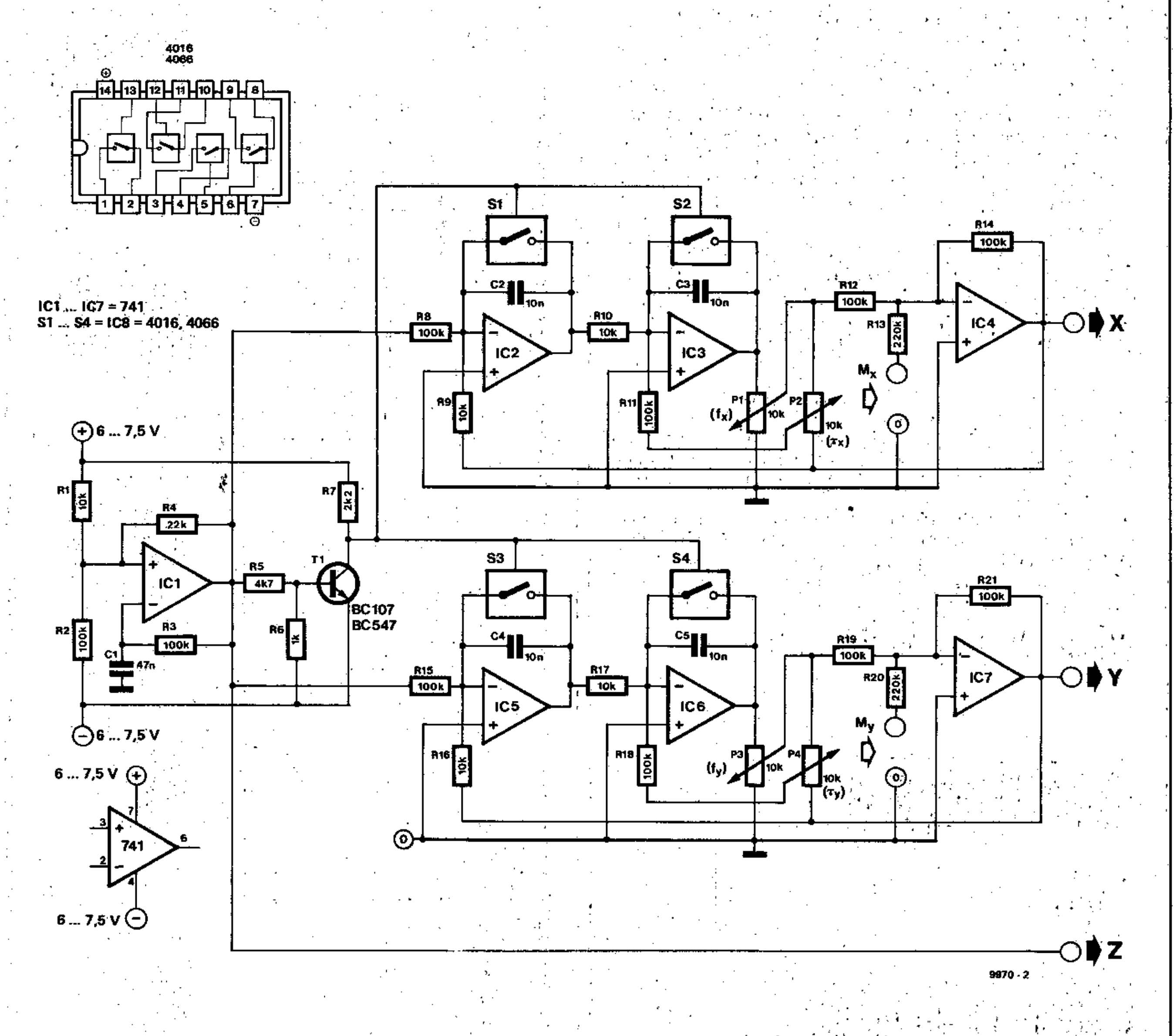

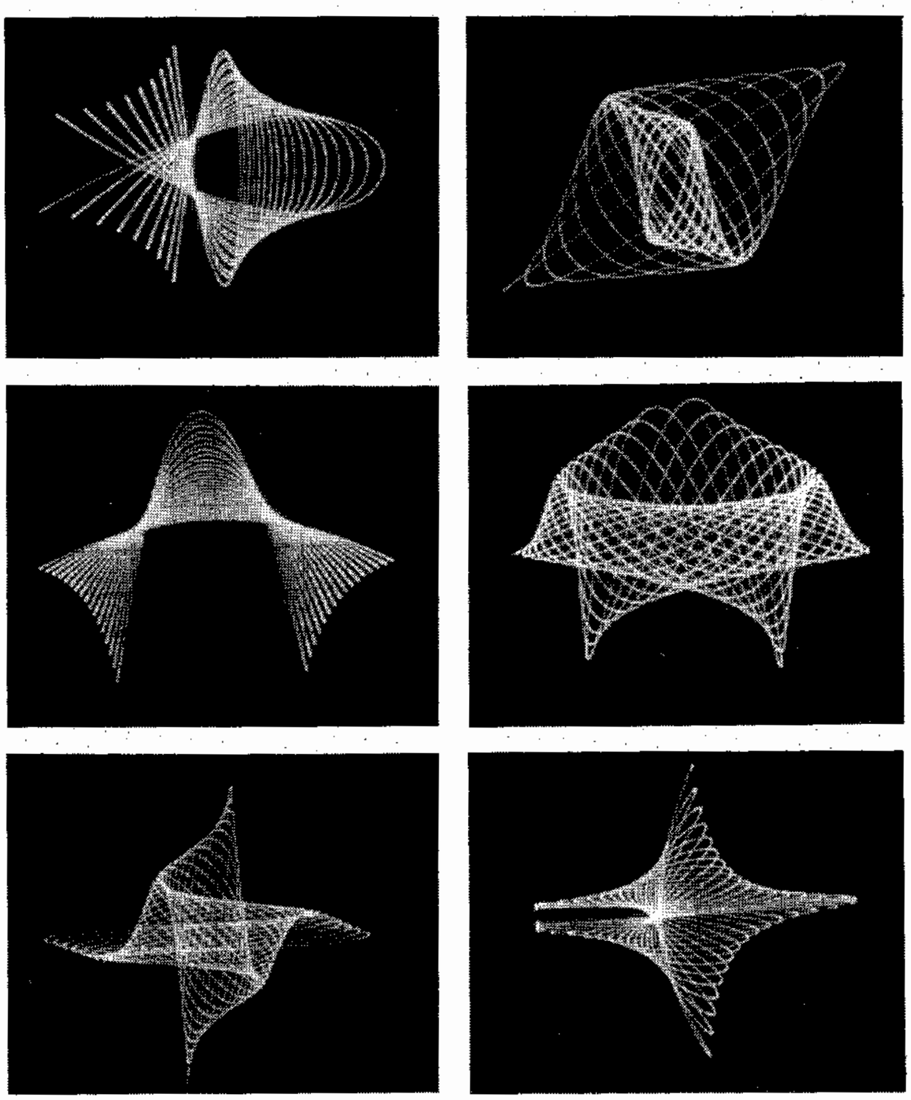

Figure 3. These photographs give some idea of the type of patterns which can be obtained from the spirator.

oscillator can be adjusted by means of P2.

In order to obtain a stable picture on the screen, both oscillators must, of course, be triggered simultaneously. This is ensured by means of electronic switches S1 . . . S4. At each positive-going edge of the output signal of IC1 they cause the capacitors C2 . . . C5 in the feedback loops of the opamps to be discharged. This sets the initial conditions of each opamp, i.e. that the output always starts from the same voltage. Thus each successive pattern written on the screen appears at exactly the same point thereby producing a completely stable image. Without this precaution, integrator drift would cause the same pattern to appear at slightly different positions on the screen — a highly undesirable effect.

The circuit also offers the particularly aesthetic possibility of displaying moving patterns by varying the frequency and/or damping of one or both oscillators. To this end the circuit provides extra control inputs (M_1 and M_2) for low frequency modulation signals (from, e.g. a sinewave generator). Naturally enough, various types of signal (squarewave, triangle etc.) of varying amplitude and frequency can be used. The type of waveform will determine the design of the resulting pattern, the frequency will determine the speed at which it changes, whilst the amplitude affects the extent to which the pattern varies. The only constraint upon the modulation signal is that it should not contain a DC component (i.e. it should be symmetrical and AC coupled), otherwise there is the possibility that part of the pattern will be off the screen. The maximum amplitude of the modulation signal is 15 V_{pp}. If desired the value of R14 and R21 can be altered to suit input levels greater than this.

Depending upon the type of oscilloscope used, it may be necessary to invert the Z-signal, in which case the signal can be taken from the collector of T1.

If the picture is not completely flicker-free, then the value of C1 should be reduced accordingly. ◀

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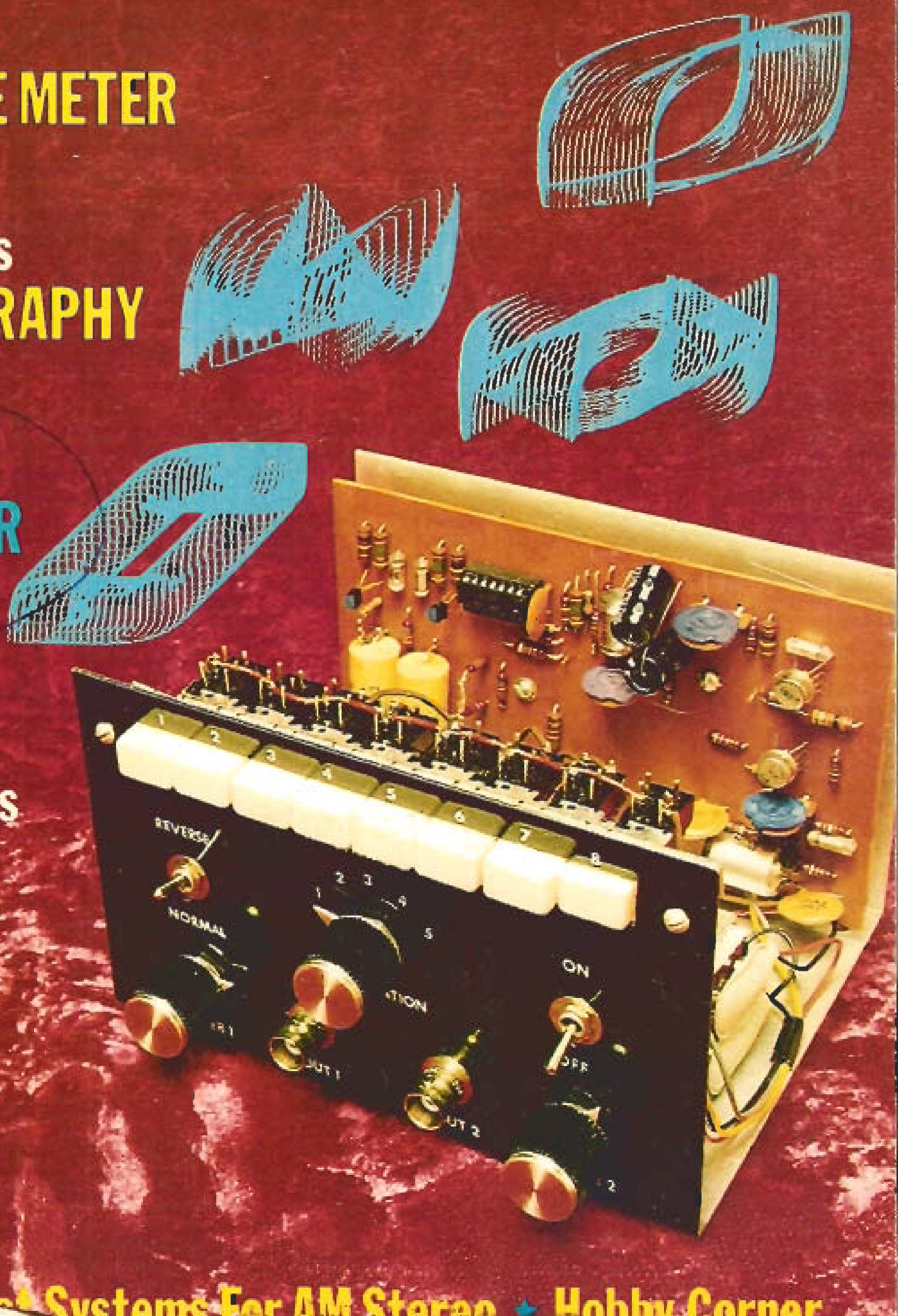

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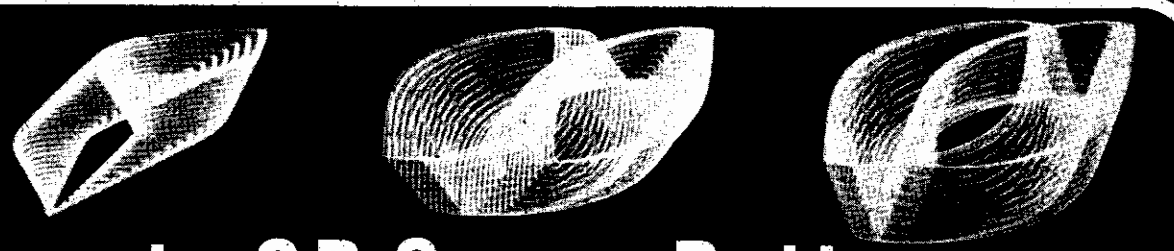
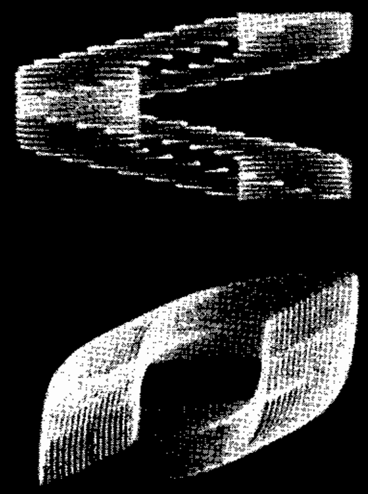


Create 3D Scope Patterns

Build Optical Synthesizer



With you at the controls of this oscilloscope add-on, an enormous variety of seemingly three-dimensional traces can be displayed

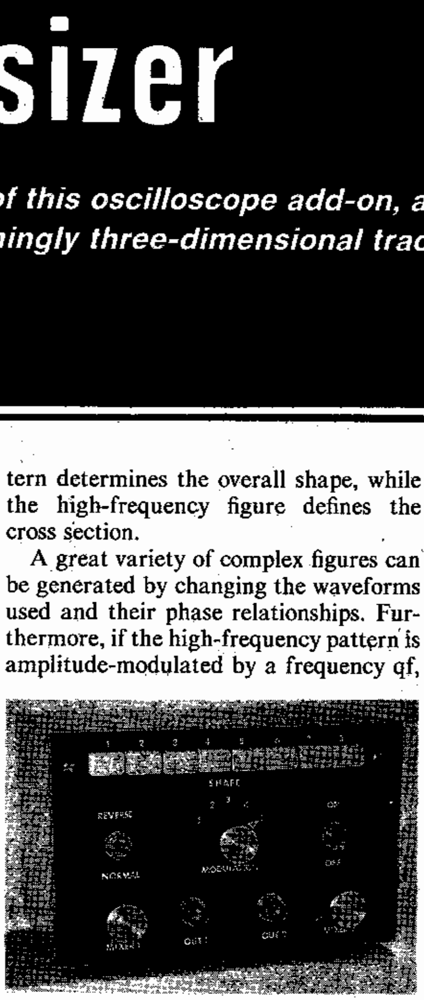
WALTER SIKONOWIZ

ANYONE WITH A NEW OSCILLOSCOPE HAS observed a Lissajous figure, which is a line pattern that is generated by various harmonically related waveforms applied to an oscilloscope's X and Y inputs. This article describes an Optical Synthesizer that uses Lissajous principles to create seemingly three-dimensional figures of extraordinary beauty and intricacy. Front panel controls are provided that vary these figures and permit the user to create an enormous variety of effects. The cost of the Optical Synthesizer is approximately $30.

About the circuit

The secret lies in summing together one low-frequency and one high-frequency Lissajous figure. The low-frequency Lissajous figure comprises a fundamental frequency f and its harmonic mf, while the high-frequency figure is defined by frequency components nf and pf. Here m, n and p are integers, with n and p both much larger than m. Imagine that the low-frequency Lissajous figure is a large circle and that the high-frequency figure is a small square. When the two are summed, as the electron beam rapidly traces small squares, it also slowly describes a large circle, resulting in a "doughnut" shape with a square cross section. The low-frequency Lissajous pattern determines the overall shape, while the high-frequency figure defines the cross section.

A great variety of complex figures can be generated by changing the waveforms used and their phase relationships. Furthermore, if the high-frequency pattern is amplitude-modulated by a frequency qf,



OPTICAL SYNTHESIZER has pushbuttons and rotary switch to select different patterns. Two potentiometers rotate the pattern about the vertical and horizontal axis.

in which q is some small integer, the cross-sectional area can be made to vary through space. To sum the two Lissajous patterns, the two X components and the two Y components must be summed independently. These two composite signals are then applied to the oscilloscope's X (horizontal) and Y (vertical) inputs, respectively.

How it works

The schematic diagram of the Optical Synthesizer is shown on Fig. 1. Transistors Q1 and Q2, and associated components comprise an astable multivibrator. The output of the multivibrator appears at Q2's collector, which drives IC1, a CD4024BE binary ripple divider. There are seven synchronized, harmonically related squarewaves that appear at IC1's output pins 3, 4, 5, 6, 9, 11 and 12. Pin 12 has the highest frequency signal (3840 Hz), and pin 3 has the lowest frequency signal (60 Hz). From pin 12 down to pin 3, signal frequencies are successively divided by two. This provides a set of even harmonics from which to construct the Lissajous patterns. Odd harmonics can also be used, although trying to obtain a more complete harmonic spectrum is more costly. Besides, there are sufficient harmonics to make an excellent Optical Synthesizer.

The squarewaves from IC1 must be shaped into waveforms that can be used to create Lissajous patterns. Six synthesized waveforms are shown at points A through F in Fig. 1. Triangular waves, formed by integrating the squarewaves, are available at points B, D and E. At points A and C the triangular waves have been clipped, but Fig. 2 shows that these waveforms are not only clipped but also

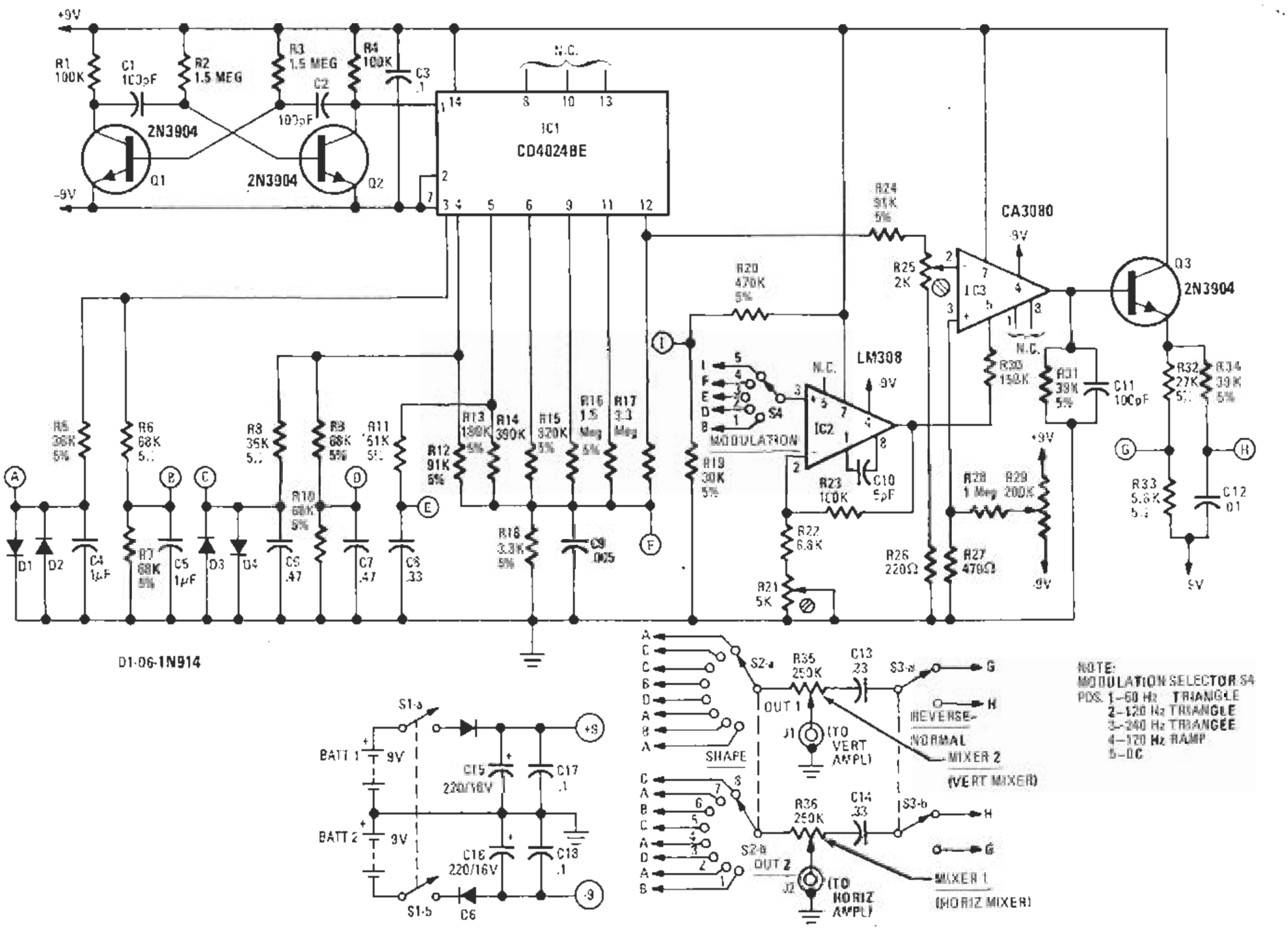


FIG. 1—OPTICAL SYNTHESIZER uses oscillators, mixers, waveshaping and phase shifting techniques.

PARTS LIST

All resistors are ½-watt, 10%, unless noted.
R1, R4, R23—100,000 ohms
R2, R3, R16—1.5 megohms, 5%
R5, R8—36,000 ohms, 5%
R6, R7, R9, R10—68,000 ohms, 5%
R11—51,000 ohms, 5%
R12, R24—91,000 ohms, 5%
R13—180,000 ohms, 5%
R14—390,000 ohms, 5%
R15—820,000 ohms, 5%
R17—3.3 megohms, 5%
R18—3,300 ohms, 5%
R19—30,000 ohms, 5%
R20—470,000 ohms, 5%
R21—5,000-ohm trimmer
R22—6,800 ohms
R25—2,000-ohm trimmer
R26—220 ohms
R27—470 ohms
R28—1 megohm
R29—200,000-ohm trimmer
R30—150,000 ohms
R31, R34—39,000 ohms, 5%
R32—27,000 ohms, 5%
R33—5,600 ohms, 5%
R35, R36—250,000-ohm linear potentiometer
C1, C2, C11—100 pF, polystyrene
C3, C17, C18—0.2 µF, ceramic
C4, C5—1.0 µF, paper or Mylar, 10%
C6, C7—0.47 µF, paper or Mylar, 10%
C8, C13, C14—0.33 µF, paper or Mylar, 10%
C9—.005 µF, paper or Mylar
C10—5 pF, polystyrene
C12—.01 µF, polystyrene
C15, C16—220 µF, 16-volt, electrolytic
D1-D6—IN914 diode
Q1-Q3—2N3904
IC1—CD4024BE ripple divider
IC2—LM308 op-amp
IC3—CA3080 op-amp
J1, J2—BNC or binding-post output jacks
S1—DPST toggle
S2—double-pole 8 position, rotary or pushbutton
S3—DPDT toggle
S4—single-pole 5 position rotary
BATT 1, BATT 2—9-volt transistor batteries

phase-shifted. Finally, there is a digitally synthesized staircase waveform at point F.

The low-frequency Lissajous patterns discussed earlier will have waveforms A, B, C and D as the X and Y components. For example, if waveform A is used as the X component and waveform B is used as the Y component, plotting the result on a piece of paper would show the Lissajous figure to be a parallelogram. Other combinations of A, B, C and D yield more complex and unusual images.

Only one high-frequency Lissajous figure is used in the synthesizer. This figure

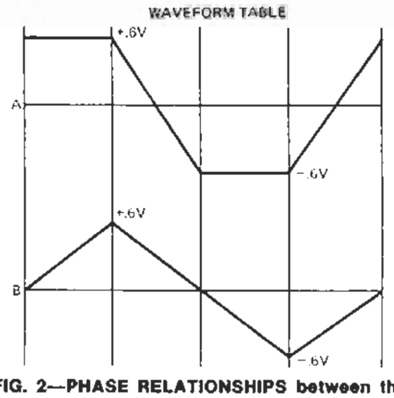


FIG. 2—PHASE RELATIONSHIPS between the 60-Hz signals at circuit points A and B.

is generated by amplitude-modulating the 3840-Hz squarewave (IC1 pin 12). This squarewave signal is fed via R24, R25 and R26 to input pin 2 of IC3, which is a CA3080 operational amplifier. The gain of IC3 is a function of the current passing through R30 into pin 5; this current is, in turn, a function of the voltage at output pin 6 of IC2, which is connected as a noninverting feedback amplifier. Operational amplifier IC2 is an LM308 chosen because of its low-supply current drain. The modulating signals, routed to the input of IC2, consist of triangular waveforms B, D and E;

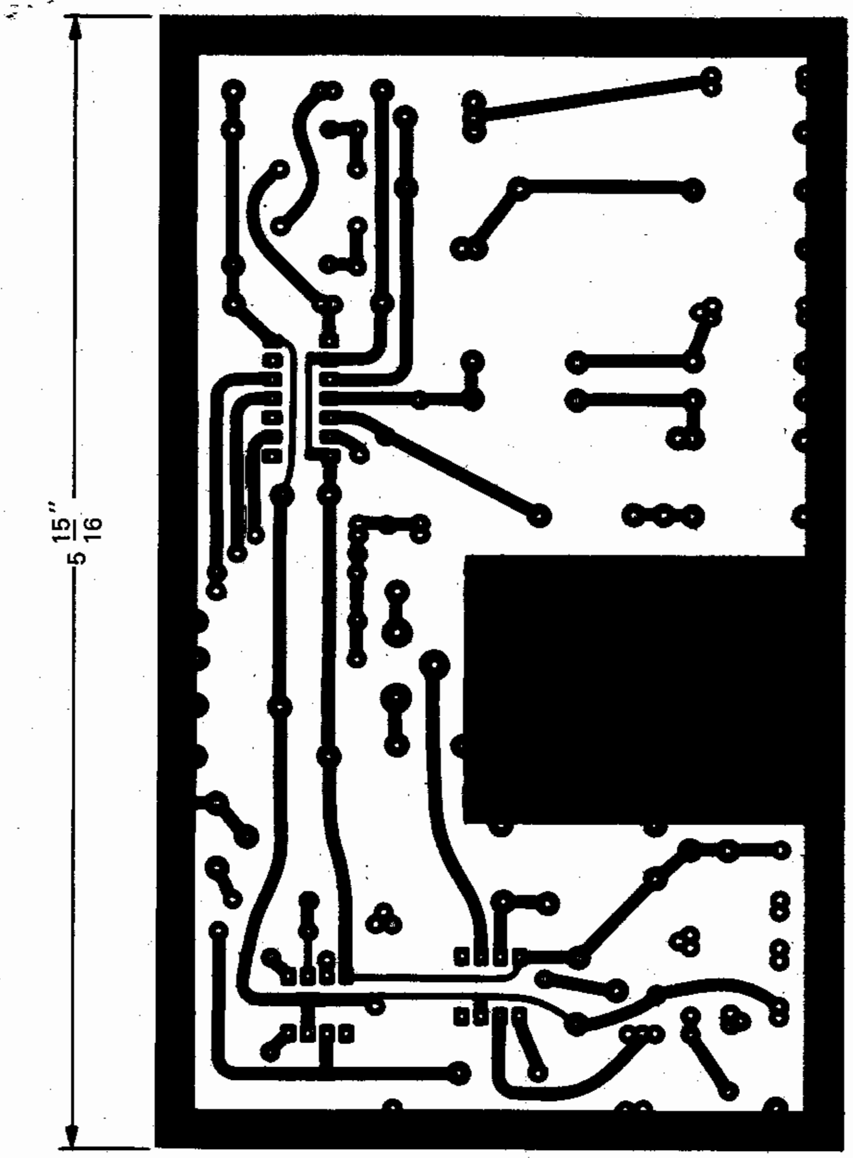
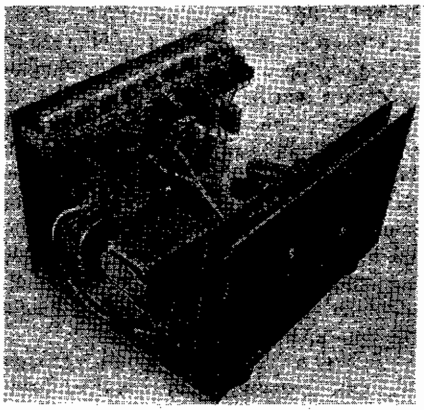


FIG. 3—FOIL PATTERN of single-sided board shown full-size.

staircase waveform F; and fixed DC potential I.

An amplitude-modulated squarewave appears at output pin 3 of IC3. When switch S4 selects the DC voltage from point I, IC3's output will be a squarewave of constant amplitude, i.e., unmodulated. Resistors R28 and R29 cancel IC3's input offset voltage. Capacitor C11, connected across R31, lengthens the transition times of the modulated squarewave in order to improve the display. In addition to being part of IC3's load, resistor R31 supplies bias current to emitter follower Q3. Transistor Q3 is necessary to reduce IC3's very high output impedance.

The load for transistor Q3 consists of R32, R33, R34 and C12. An amplitude-modulated, slightly rounded squarewave is available at point G, and at point H there is an amplitude-modulated triangular waveform. If modulation is constant and if points G and H are connected to the X and Y inputs of an oscilloscope, a rectangle with two rounded corners appears.



REAR VIEW OF FRONT PANEL shows pushbuttons, switches and potentiometers. Battery holder is formed from an aluminum strap.

Now, all that remains is the summation of the low-frequency and high-frequency Lissajous patterns. The Y components of the two figures are mixed in R35, while the X components are summed in R36. Capacitors C13 and C14 block the DC supply so that only AC signals are mixed. Switch S2, the SHAPE selector, chooses various low-frequency waveform combinations, and switch S3 reverses the high-frequency signal connections. Output jacks J1 and J2 must feed high-impedance loads (1 megohm or greater) for proper mixing action, and although J1 connects to the vertical scope channel and J2 connects to the horizontal scope channel, the connections to the scope can be reversed. When the mixers are terminated with a high-impedance load, each output is the weighted average of the two input signals. All such input signals (waveforms A through G) have the same nominal 1.2-volt peak-to-peak magnitude. Therefore, the peak-to-peak output of each mixer remains a constant 1.2 volts as each potentiometer is rotated. This means that the area occupied by the display on the oscilloscope screen also remains constant, regardless of mixer settings.

Two 9-volt transistor batteries power the circuit. Diodes D5 and D6 protect against incorrect battery installation and, at the same time, slightly reduce the supply voltage since fresh 9-volt batteries may actually supply 10 volts. The diodes insure that the maximum supply voltage limit of IC1 is never exceeded, even with fresh batteries. Capacitors C15 and C16 provide a low-frequency supply bypass, and capacitors C17 and C18 provide high-frequency bypassing.

Construction

It is relatively easy to build the Optical Synthesizer, but you must be careful because any errors will be visible on the display. The safest procedure is to use a printed-circuit board. The foil pattern is shown in Fig. 3 and the component placement diagram is shown in Fig. 4. If you don't use a printed circuit board, it is important that you follow the layout shown in Fig. 4 as closely as possible.

A socket should be installed for IC1, which, since it is a CMOS unit, should be installed only after all soldering is completed. Furthermore, be sure to use a CD4024BE for IC1; devices with an "AE" suffix cannot supply enough output current. Install capacitor C10 as close as possible to IC2. Although most components mount on the PC board, capacitors C13 and C14 are wired point-to-point.

Pay attention to polarities for all IC's, transistors and diodes as well as electrolytic capacitors C15 and C16. In addition, do not confuse IC2 with IC3; the former is an LM308, and the other is a CA3080. For best results use 5%-tolerance resistors and 5% polystyrene capacitors where specified.

The front panel layout is not critical. Switch S2 in the prototype was a pushbutton unit that happened to be around at the time of construction. You can just as well use a rotary switch that will probably be more readily available and less expensive. Output jacks J1 and J2 should match the oscilloscope connectors. Generally, these connectors will be either BNC or binding-post types.

Make a battery holder for BATT1 and BATT2 with a 16-gauge aluminum strap, bent to fit the battery dimensions. Use two fresh, high quality batteries. If the battery voltages are unequal, triangular waveforms B, D and E will not be symmetrical with respect to ground, and some signal clipping will result. While this sort of clipping may produce some interesting visual effects, battery voltages should be as equal as possible when the initial adjustments are made on the synthesizer.

Note how switch S2 is wired. One position of the switch may send waveform signal A to the vertical mixer and waveform signal B to the horizontal mixer, but the next switch position will reverse these connections. Such a connection reversal results in an image reversal on the screen. This doubles the number of possible displays. By means of switch S3, the high-frequency mixer inputs can also be reversed. Interchanging the high-frequency components produces interesting and sometimes dramatic changes in the display, depending upon the settings of the mixers and of S2.

When wiring mixer potentiometers R35 and R36, connect them so that their actions are similar. Wire them so that when each wiper advances fully counterclockwise, it directly contacts a low-frequency input. Advancing both controls together in a clockwise direction then causes the simultaneous increase in high-frequency content of both outputs. Of course, the controls will usually be manipulated independently, but they are easier to correlate if the actions have a similar effect.

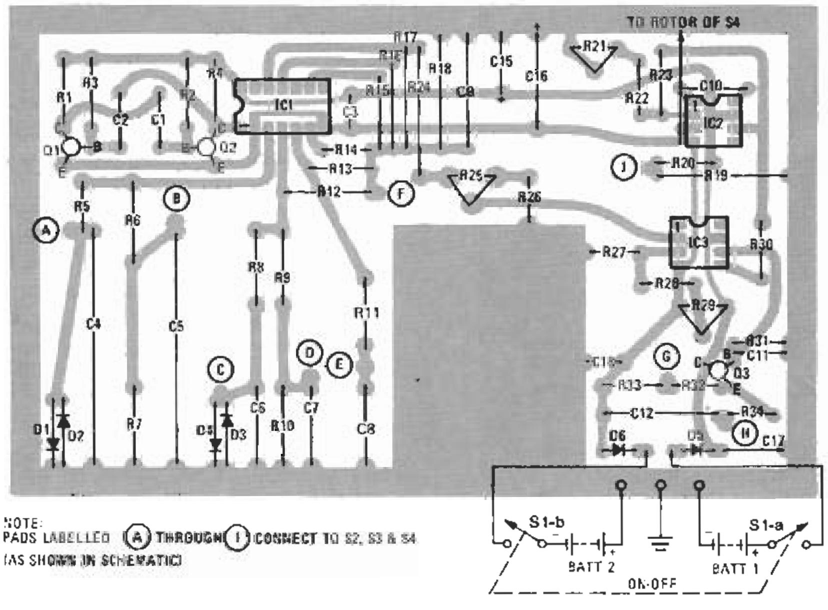
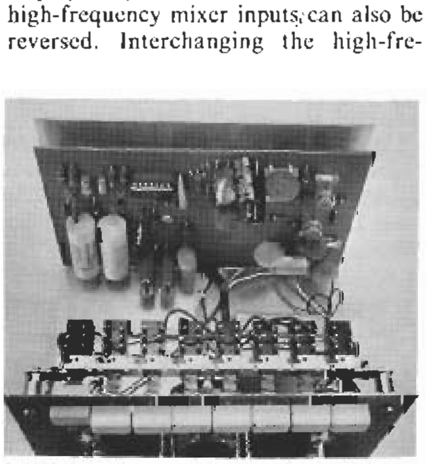


FIG. 4—COMPONENT PLACEMENT diagram for the PC board.



PC BOARD is mounted vertically against rear panel and held in place with stand-offs. Trimmer adjustments are easily accessible.

Calibration

After construction is complete, install IC1 and apply power. Use your oscilloscope to verify waveform signals A through F, which should all have a peak-to-peak amplitude of about 1.2 volts. Now, adjust S4 so that the 60-Hz triangle waveform B is applied to IC2. Attach a probe to IC2 output pin 6 and adjust trimmer R21 for the largest possible unclipped triangular waveform, which will have an amplitude of around 15 volts peak-to-peak.

Now, leaving S4 where it is, ground IC3 pin 2 using a short jumper lead. Attach your scope probe to IC3 output pin 6 and adjust trimmer R29 to eliminate the 60-Hz triangular waveform. You will probably be picking up some low-level, high-frequency signals at the same time. This pickup is unavoidable and should be ignored. After the 60-Hz triangular wave has been cancelled, disconnect the probe and remove the ground lead from IC3 pin 2.

Reconnect the scope probe to point G in the circuit. Set S4 so that the DC potential at point I is applied to IC2. Adjust trimmer R25 so that the peak-to-peak voltage of the 3840-Hz squarewave at point G is 1.2. Since the potential at point G is always more negative than ground, set the vertical amplifier for a DC input signal. When a 1.2-volt peak-to-peak signal has been obtained at point G, check point H, where you should observe a triangular wave of the same magnitude. Now dial in the various modulating waveforms via S4, and verify that modulation occurs at points G and H. This completes the calibration procedure and the synthesizer is ready for use.

Using the synthesizer

The Optical Synthesizer is easy to use. First, connect the outputs to the X and Y scope inputs. After the scope has warmed up, center the dot on the screen. If you wish, remove the scope's graticule, as it can be distracting.

Set modulation selector S4 so that the IC2 input connects to point I. Turn both mixing potentiometers fully counterclockwise so that their wipers directly contact low-frequency inputs A, B, C or D. Now apply power to the synthesizer, and adjust the scope's X and Y sensitivity controls so that the image fills the oscilloscope screen.

Use the focus and astigmatism controls on the oscilloscope to obtain a sharp display over the entire screen. Use all eight positions of shape-selector switch S2 to obtain the four low-frequency Lissajous patterns plus their four reversed counterparts.

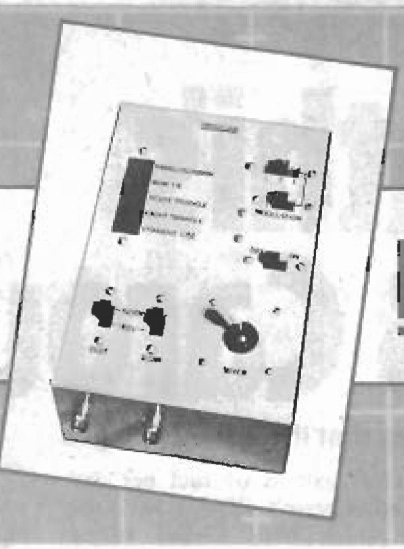
Set S2 so that there is a parallelogram on the screen, and rotate the scope's intensity control to maximum. Advance both mixers, stopping when you have some degree of three-dimensionality in the display. Next, dial in the various modulating waveforms via switch S4 to notice the effects. You can now experiment with the rest of the controls to note their effect on the display.

The mixers are the most important controls on the synthesizer, and careful mixing will yield many fascinating displays. The visual effects include a change in the size relationships between various parts of an image plus apparent rotations about two axes. As a display rotates, certain lines may coincide, causing the display to take on a whole new character.

As more of the high-frequency signal is mixed with the low-frequency signal, various sections of an image overlap. Consequently, the distinction between the overall shape of the image and the shape of the cross section is lost as a new pattern emerges.

When you have become familiar with the mixing procedure, you can create dynamic displays that twirl and change shape on the screen as the two mixers are slowly rotated. Experiment with the controls until you become familiar with their effects. **R-E**

With a little help, your scope becomes an electronic canvas



IMAGICIAN

by Walter Sikonowiz

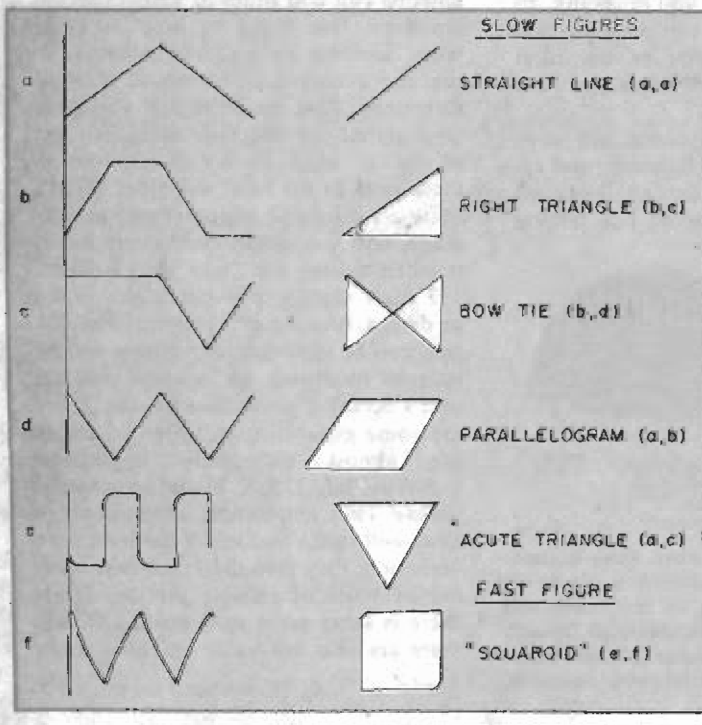
HOW WOULD YOU LIKE TO be able to generate beautiful geometric line drawings electronically? And what if these figures could be made to look 3-dimensional, with forms that expand, rotate, and flow under the command of a joystick? Sounds expensive and complicated, doesn't it? If you've seen some of the graphics produced by hobby-type digital computers, you're probably skeptical and rightfully so. Small digital computers generate simplistic graphics with a chunky appearance. Generating smooth lines and complex figures with a digital computer requires much more memory than most computer hobbyists can afford.

But if a few ideas are borrowed from the *analog* computer, a device rarely mentioned anymore, it's possible to generate dazzling graphics with simple, inexpensive circuitry. That's the principle of the Imagician, a simple, two-IC project that transforms your oscilloscope's screen into a window on a magic land of animated geometric figures.

The Lissajous Figure. Before delving into the workings of the Imagician's circuit, let's talk about Lissajous figures. If you own a scope, no doubt you are familiar with them. A Lissajous figure is a closed curve that results when two harmonically related signals are applied to a scope—one signal to the vertical input, the other to the horizontal input. The most familiar figure occurs when a sine wave is applied to one input, and a phase-shifted sine of the same magnitude and frequency is fed to the other input. On the scope's screen there appears either an elliptical or circular trace, depending upon the phase relationship between the two signals. With non-sinusoidal waveforms driving the X and Y inputs, other geometrical displays can be created.

Let's examine the various waveforms synthesized within the Imagician (Figure 2). From just these six signals, thousands of fascinating displays can be produced. Waveforms *a*, *b* and *c* all oscillate at 60 Hz; signal *a* is a triangle wave, *b* is a symmetrically clipped triangle, and *c* is trapezoidal. Signal *d* is another triangular waveform, but with a frequency of 120 Hz. For reasons that will be apparent later, let's call figures *a* thru *d* "slow" figures.

It stands to reason that there must be some fast signals, too. Waveforms *e* and *f* are the fast ones, with a frequency equal to 3840 Hz (64 times faster than 60 Hz). Signal *e* might be called a "soft-shouldered square wave," while *f* just begs to be called a "shark-fin wave."



This chart depicts the basic waveforms (lettered a thru f at left) generated by Imagician's oscillator. The slow and fast waveforms are created by pairing two of the basic waveforms together (b, d for the bow tie, etc.). The table of switch positions on the last page of the article shows which positions are used for selection of figures.

What are the simplest Lissajous figures that can be generated by selected pairs of the above six waveforms? Figure 3 shows these fundamental figures along with the X and Y components necessary for their generation. It is assumed that the X and Y components are of equal magnitude; if such is not the case, the shapes will be distorted to new forms. Note that these fundamental Lissajous figures are segregated into slow and fast classes. The slow figures have slow waveforms (*a* through *d*) as components, while the fast figure has fast components (*e* and *f*). The slow figures include familiar geometric shapes: a straight line, a right triangle, a parallelogram, an acute triangle and the perhaps not-so-familiar bow tie. Were it not for a slight slope to the sides and a pair of rounded corners, the fast figure would almost appear to be a square. In recognition of the similarity, let's call the fast figure a "squaroid."

New complex Lissajous figures, some of which will appear to be 3-dimensional, can be synthesized by adding together one of the slow figures and the squaroid. This is accomplished by summing the X- and Y-component waveforms of the two figures independently. Furthermore, it's not necessary to mix signals in a one-to-one ratio. Different mixing ratios yield new and fascinating displays in a manner that's often hard to predict. As a final touch, the components of the fast figure (squaroid) can be amplitude-modulated. The type of modulation used here was specifically chosen to enhance the illusion of perspective in those displays that appear 3-dimensional.

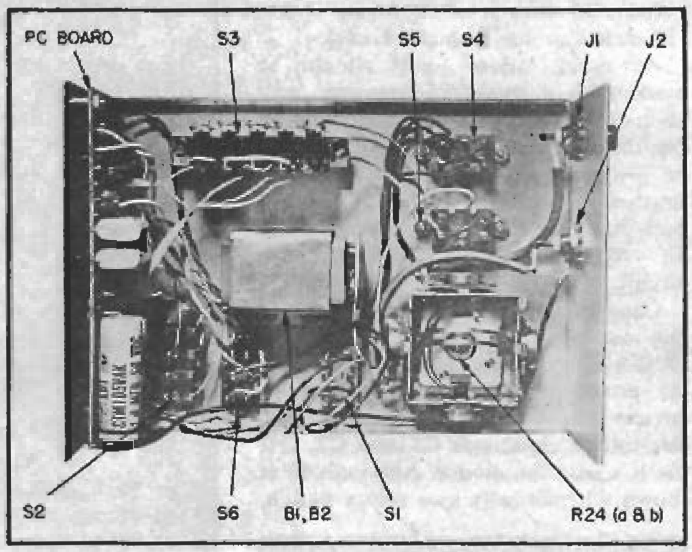
The Circuit. Let's consider the Imagician's circuit in detail. Two batteries, B1 and B2, provide +9V and −9V supply potentials for the circuit when power switch S1 is closed. Diodes D1 and D2 protect the ICs from incorrect battery installation and also drop the supply potential slightly, which is desirable here. Capacitors C1 through C4 provide :spply bypassing.

Q1, a programmable unijunction transistor (PUT), works together with R1, R2, R3 and C5 to form an oscillator that feeds pulses to the clock input (pin 1) of U1, a 4024B seven-stage binary frequency divider. U1 divides the input frequency by 2, seven times in succession to yield seven harmonically related square-wave outputs. We need harmonics in order to generate Lissajous patterns, but square waveforms do not yield interesting displays. Consequently, the greater portion of the Imagician's circuitry is devoted to the shaping of square waveforms into other more useful signals.

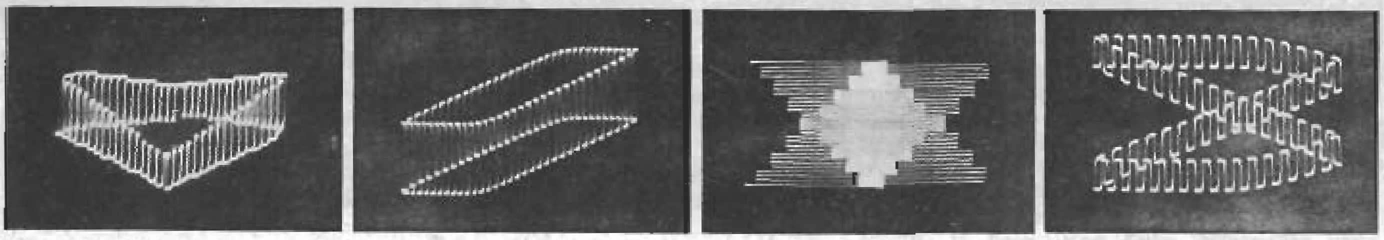
At pin 3 of U1, we find the lowest-frequency square wave (60 Hz), while pin 4 supplies the second harmonic (120 Hz). R15 and C6 integrate the 60 Hz signal to a triangular waveform (*a*). Diodes D3 and D4 together with integrating network R16/C7 produce the symmetrically-clipped 60 Hz triangle (*b*). Driven by both the 60 and 120 Hz signals, the D5/D6/R17/R18/C8 network yields a 60 Hz trapezoid (*c*). Finally, the last slow waveform, triangle wave *d*, is generated when R19 and C9 integrate the 120 Hz square-wave signal.

Fast waveforms *e* and *f* are formed with the aid of shaping networks R22/C10 and R23/C11, respectively. When S6 is flipped to the left, as indicated in the schematic, amplitude-modulated currents at 3840 Hz are fed to the shaping networks just discussed. As a result, waveforms *e* and *f* are also amplitude-modulated. The manner in which modulation is obtained here requires further explanation: U2, a 4070B quad EXCLUSIVE-OR gate, taps harmonically related signals from frequency divider U1. The gates within U2 are connected so as to yield a sort of digital multiplier when the various outputs are summed together (by R5/R9 and R10/R14). Switch S2 controls the shape of the modulation envelope, with three choices available. If S6 should now be flipped to the right, an unmodulated 3840 Hz square-wave current will be fed to each R/C shaping network. Consequently, signals *e* and *f* will be of constant amplitude.

The rest of the circuitry serves only to combine signals *a* through *f* in various ways. Switch S3 selects pairs of X and Y components for the 5 slow Lissajous figures. These signal pairs are routed to the vertical (R24a) and horizontal (R24b) mixers via reversing switch S4. (When a Lissajous figure's X and Y components are interchanged, it flips to a new orientation on the screen.) Switch S5 performs the same function as S4, but it operates on the components of the fast figure instead. Addition of the X components of the slow and fast figures occurs in the horizontal mixer; the vertical mixer sums their Y components. R24a and R24b are part of a joystick assembly; north-south movement of the stick controls R24a, while east-west motion affects R24b. Thus, a single control manipulates two pots independently of one another. If desired for reasons of economy, however, two separate potentiometers could be used for R24a and R24b. Jacks J1 and J2 send the mixer output signals to the appropriate high-impedance (1 Megohm) scope inputs.



This underside view of the chassis shows the positions of the panel switches and joystick control. As usual, this should only serve as an example of how you can go about building your own model. There are no critical component placements in Imagician.



Here are a few examples of the designs which can be produced by mixing of the basic waveforms. What we can't show are the moving figures and the shifts which are possible. From left to right are: acute triangles, parallelograms, inverted acute triangles, and a double bow tie formed in a dot pattern instead of solid lines. With experimentation, you can come up with many more.

Construction. Printed-circuit construction of the Imagician is recommended, and complete details of the board can be found in Figures 4 and 5. For the sake of shielding, an aluminum cabinet should be used to house the circuit. Furthermore, the chassis should be connected to system ground at some point. Connections between the Imagician and your oscilloscope should be effected by means of relatively short, (18-inches or less) shielded cables.

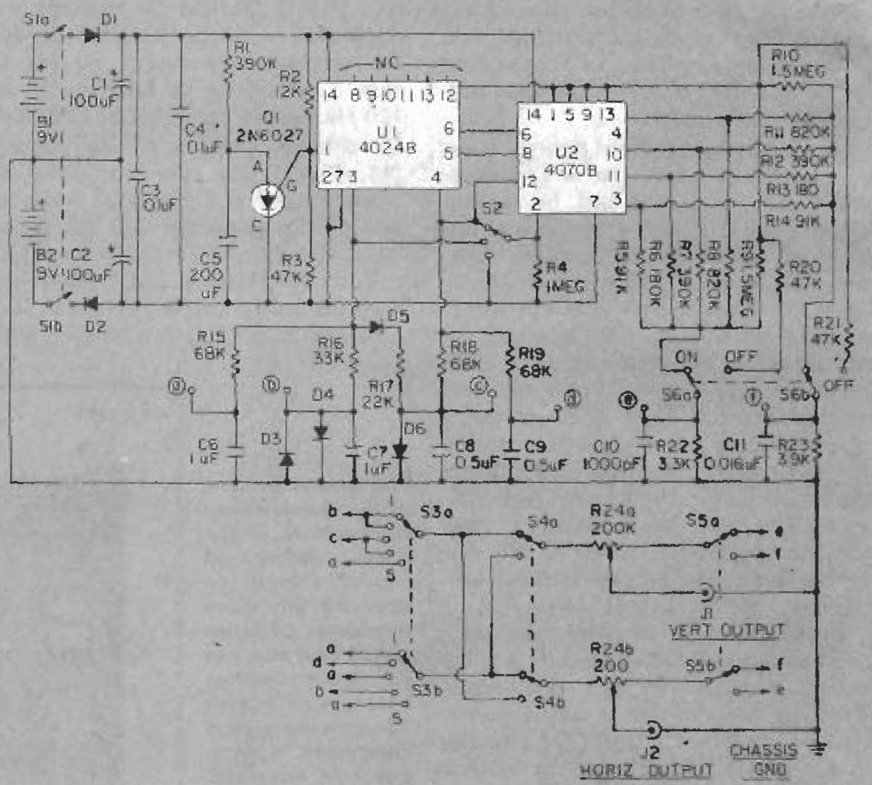
As usual, solder joints should be made with a small, 25-watt iron and resin-core solder. Sockets are required for the two CMOS ICs, which should be installed only after all soldering is finished. Be certain that U1 and U2 both have the "B" suffix—devices with an "A" suffix will not work in this circuit.

Capacitor C5 must be a polystyrene (or mica) unit to ensure that your oscillator's frequency is close to that of the prototype. Be careful with those devices requiring proper orientation—electrolytic capacitors C1 and C2, Q1, the ICs, and the diodes. Although S3 is shown schematically as a rotary switch, it's obvious from the photos that a pushbutton unit was used in the prototype. You can use whatever is most convenient.

Current consumption is on the order of 1-milliampere, so batteries will last a long time. Be sure that both batteries are fresh—if they are not, lop-sided displays will result.

When wiring the joystick, you'll find that it comes equipped with four pots. Use any two pots on adjacent sides of the square support assembly. The potentiometers on opposite sides are ganged together and cannot be adjusted independently.

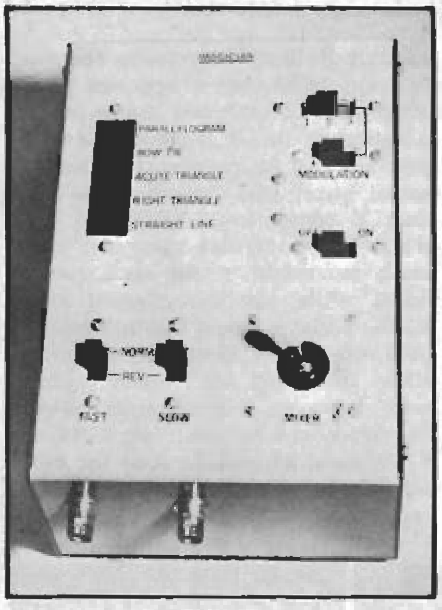
Checkout and Operation. After construction is complete, the circuit should be given a thorough workout to make sure that everything is in order. Begin by turning on your scope and allowing 15 minutes warm-up time. If the grati-



PARTS LIST FOR IMAGICIAN

B1, B2—9-volt transistor battery
C1, C2—100-uF, 16-VDC electrolytic capacitor
C3, C4—0.1-uF ceramic disc capacitor, 100-VDC
C5—200-pf polystyrene capacitor 100-VDC
C6, C7—1.0-uF mylar capacitor, non-polarized
C8, C9—0.5-uF mylar capacitor 100-VDC
C10—1000-pf polystyrene capacitor 100-VDC
C11—0.016-uF mylar capacitor 100-VDC
D1 thru D6—1N914 diode
J1, J2—BNC jack
Q1—programmable unijunction transistor—2N6027, 2N6028 or HEP S9001. (Note: 2N6028 Available from SOLID STATE SALES, BOX 74A, Somerville, MA 02143.)
R1, R7, R12—390 K, ½-watt resistor, 5%
R2—12 K, ½-watt resistor, 5%
R3, R20, R21—47 K, ½-watt resistor, 5%
R4—1 Megohm, ½-watt resistor, 5%
R5, R14—91 K, ½-watt resistor, 5%
R6, R13—180 K, ½-watt resistor, 5%
R8, R11—820 K, ½-watt resistor, 5%
R9, R10—1.5 Megohm, ½-watt resistor, 5%
R15, R18, R19—68 K, ½-watt resister, 5%
R16—33 K, ½-watt resistor, 5%
R17—22 K, ½-watt resistor, 5%
R22—3300-ohm, ½-watt resistor, 5%
R23—3900-ohm, ½-watt resistor, 5%
R24a, b — two, linear-taper 200K-ohm pots mounted in a joystick assembly (Herbach & Rademan #TM21K167; address is 401 E. Erie Ave., Philadelphia, PA 19134)
S1—DPST slide switch
S2—SP3T rotary or slide switch
S3—DP5T rotary or pushbutton switch
S4, S5, S6—DPDT slide switch
U1—4024B binary ripple counter
U2—4070B quad EXCLUSIVE-OR gate
Misc: aluminum cabinet, IC sockets.

Note: An etched and drilled printed circuit board for the Imagician is available from *LECTRO-GRAPHIX* P.O. Box 537, Auburn, NY 13021, for $5.90 postpaid to U.S. and Canadian residents. Foreign and overseas orders should include an additional $1.50 for postage and handling, and should remit the cost in the form of a money order or other drafts payable in U.S. currency. Allow 2 to 3 weeks for delivery. NY residents add 7% sales tax.

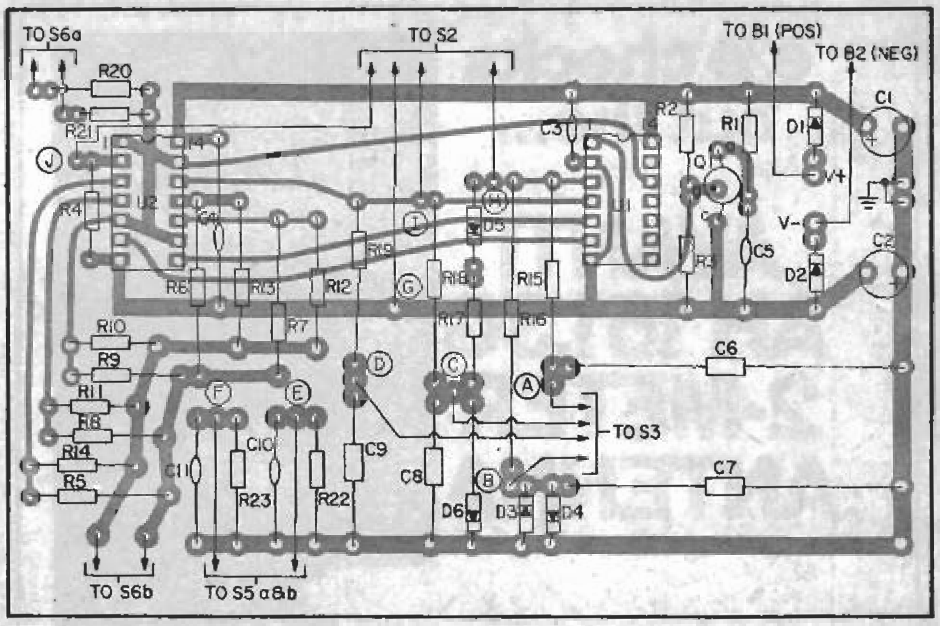


This front panel closeup shows the relative positions of all the controls, and the dry transfer lettering we utilized to achieve a more professional appearance for the prototype. We positioned the input and output coaxial jacks at the bottom front rather than at the top, so as to minimize the effects of body capacitance when one's hand is brought into proximity of the input and output cables. This feature also allows much more freedom of access to the controls as opposed to top mounting of the jacks.

cule on your scope is removable, as on the older Heath and B&K models, it might be a good idea to take it off; the gridwork of lines serves no useful purpose in this application, but it may distract attention from the display. If the graticule cannot be removed, just turn the GRATICULE ILLUMINATION control completely off.

Both the X and Y inputs should have an impedance of about 1-Megohm. This almost universally is the case, but check your scope's specifications to be sure—especially if a very old model is being used. With the horizontal and vertical inputs grounded, center the dot on your screen. Signals from both channels of the Imagician have peak-to-peak amplitudes of 1.2-volts; set your vertical and horizontal gain controls so that a 1.2-volt signal would roughly span the screen.

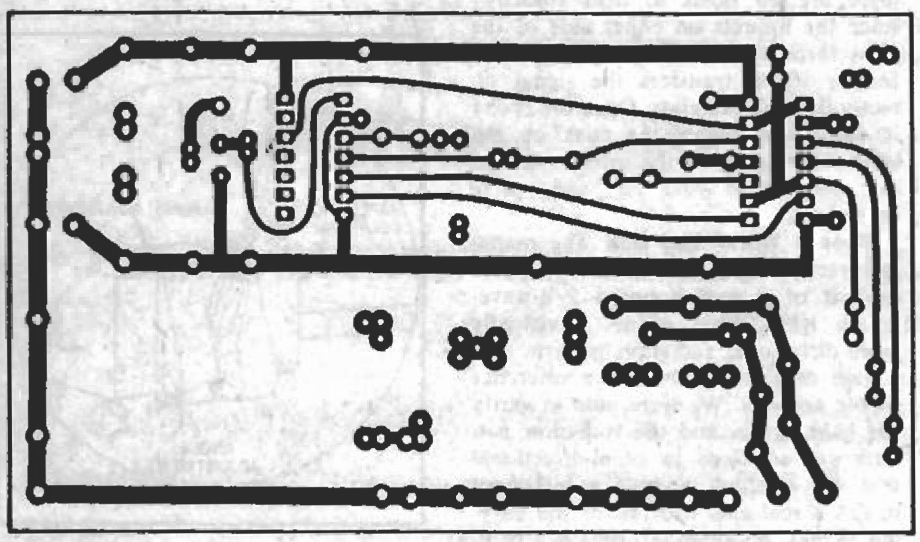
On the Imagician, turn MODULATION switch S6 to OFF, and set SLOW-FIGURE SELECTOR S3 to its PARALLELOGRAM position. Connect the outputs of the Imagician to the appropriate scope inputs with short shielded cables. After turning on the power with S1, you should see an image of some sort on your screen. The display will probably be faint, so rotate your scope's INTENSITY control to maximum. (However, when centering the dot as described above, you should use only *minimal* intensity to avoid burning the scope's screen.) Now, readjust the scope's vertical and horizontal gain controls so that the image just fills the screen. Finally, adjust the ASTIGMATISM and FOCUS controls, if your scope has them, for an image that is sharp and clear at all points on the screen.



This is the component location guide used with the printed circuit board. Just about all of the components used in Imagician, with the exception of the switches, jacks and R24, are mounted directly on the board. Use IC sockets and be sure to orient them properly. Take special note of the takeoff points that lead away to the switches.

S1—Power
S2—Modulation Selector
S3—Slow-Figure Selector:
 1 = parallelogram
 2 = bow tie
 3 = acute triangle
 4 = right triangle
 5 = straight line
S4—Slow-Figure Reversing Switch
S5—Fast-Figure Reversing Switch
S6—Modulation ON/OFF
R24a, b—Mixer

This table shows which switches perform what functions and, for S3, what figures are generated in each switch position.



This is the etching guide for the PC board, shown in exact scale. If a project of this magnitude is beyond your abilities, you can obtain a ready-made circuit board from LECTROGRAPHIX. Their address and ordering information is shown beneath the parts list.

Bend your Imagician's joystick until you reach the position where a simple parallelogram fills the screen. Next, flip S3 to its four other positions so that the rest of the slow figures may be observed. After viewing them all, return to the parallelogram. Use the joystick now to create new images. Note that this is a "high-powered" control—a seemingly slight adjustment can lend a whole new character to the display. With practice, you'll learn to make images dance and change form at will through skillful manipulation of the stick.

Still using the parallelogram, adjust the joystick until the resultant display has a 3-dimensional character. Turn on the modulation via S6, and check out the various effects produced by MODULATION SELECTOR S2. Manipulate the joystick, too, in order to get different views.

Conclusion. By now, you should be somewhat familiar with the controls on the Imagician. You can proceed to create 3-D patterns based on the remaining four slow figures. Also, check out the effects of the reversing switches, S4 and S5; the effects of S5 are subtle and depend upon the setting of the joystick, so watch closely. If you wish, it's possible to capture some of your prize creations on film with the aid of a Polaroid scope camera, which you might be able to borrow from a school science department. With a little imagination in the photodeveloping process, you may become the first electronic Picasso! ■

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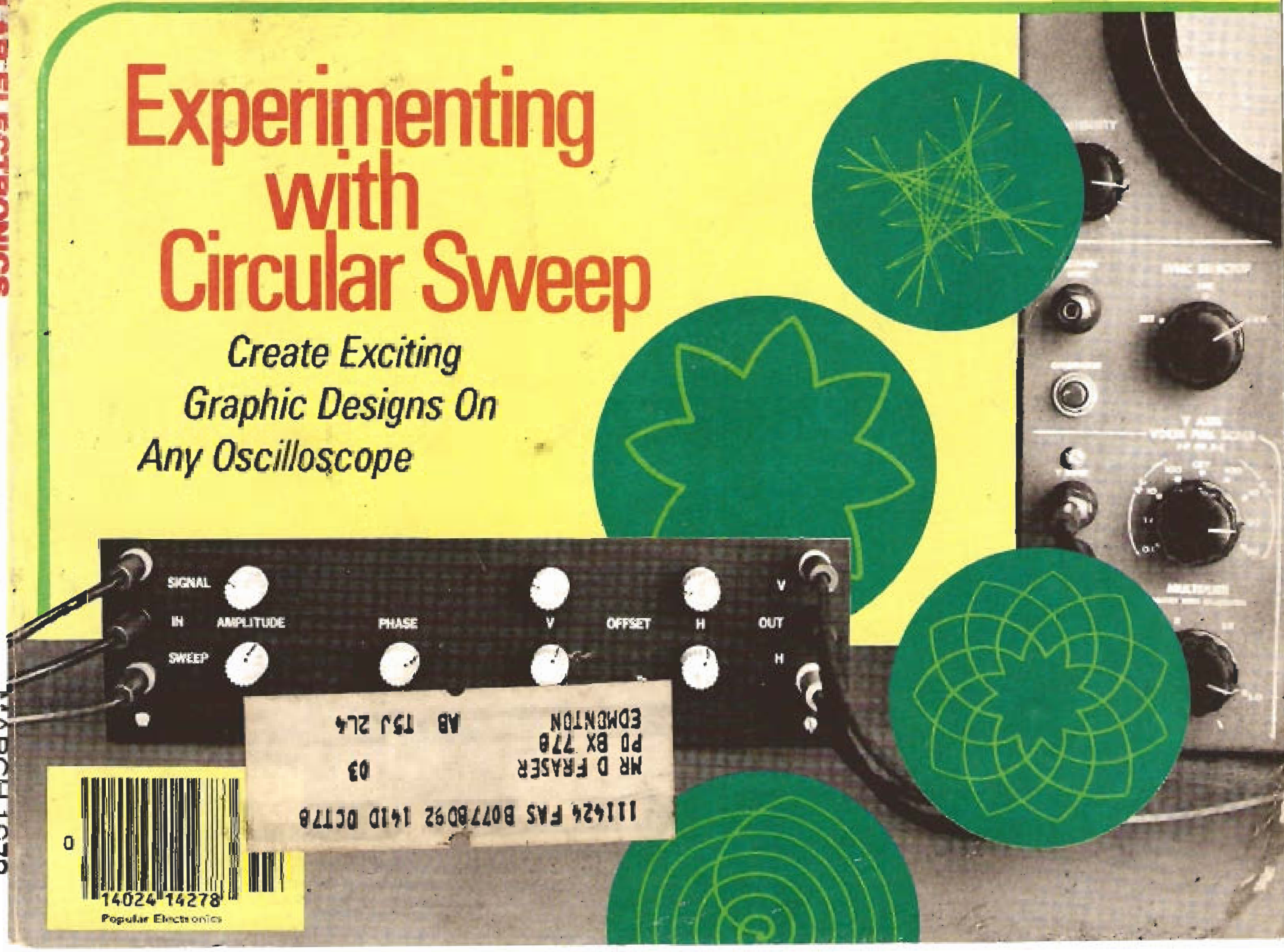

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EXPERIMENTING WITH CIRCULAR SWEEP

Circular-sweep converter provides fascinating scope displays.

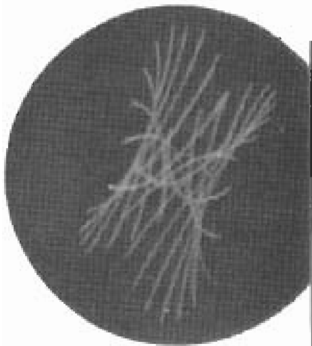
BY RANDALL K. KIRSCHMAN

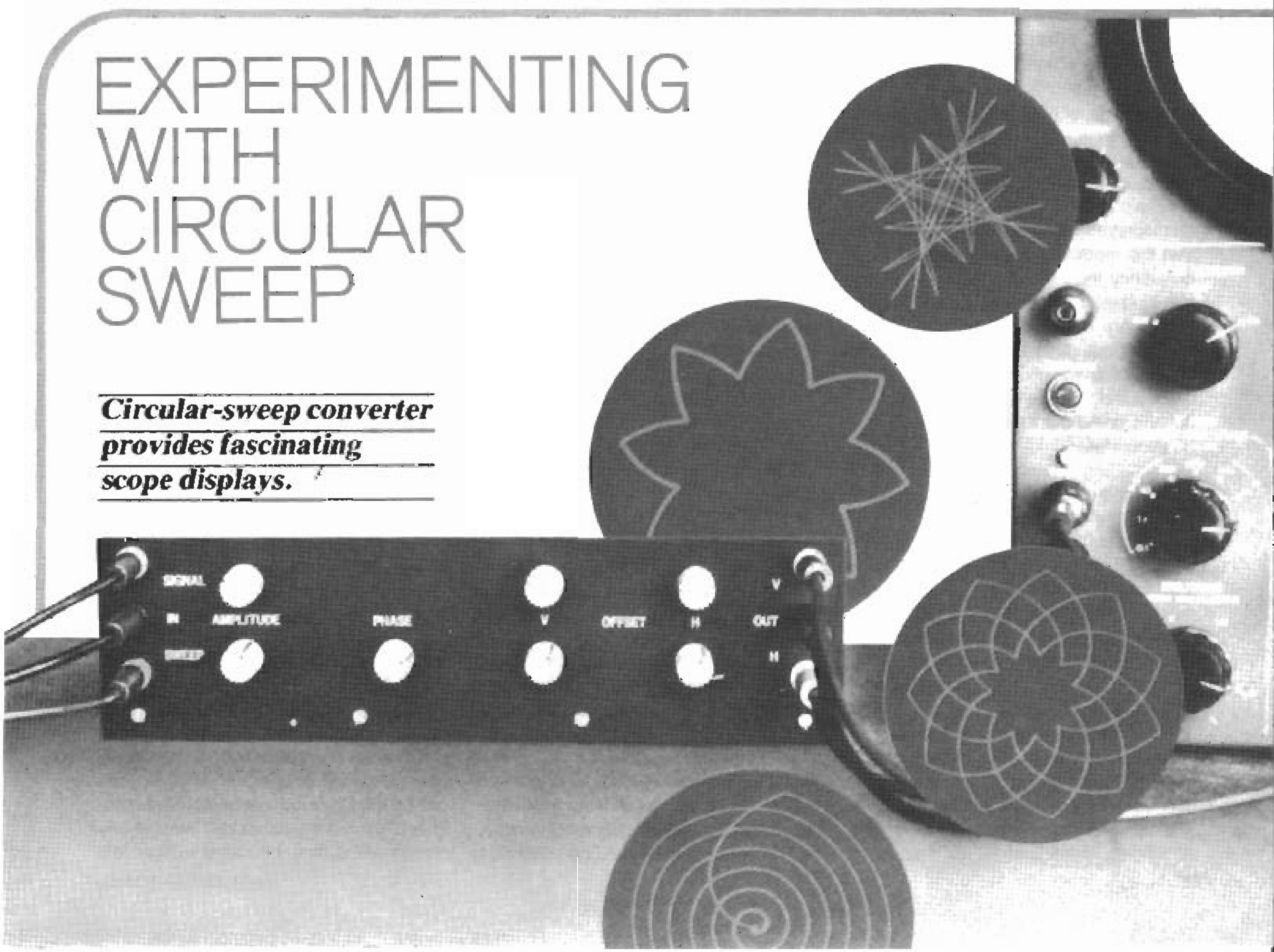
THE USUAL method of displaying waveforms on an oscilloscope is to sweep the beam horizontally to provide a linear time-base and then deflect it vertically with the waveform to be displayed. In this article, we will discuss another type of display—one in which the beam is swept in a circle and deflected 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

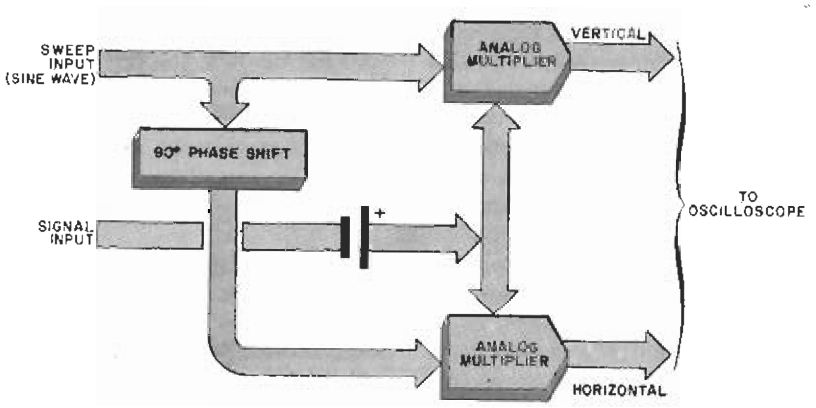


Fig. 1. Block diagram illustrates the basic operation of the circular-sweep converter.

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

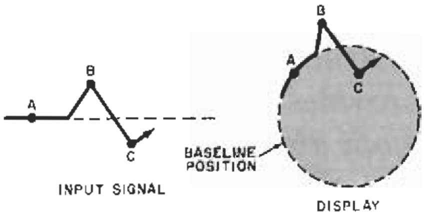


Fig. 2. Converter changes input (left) into circular display.

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

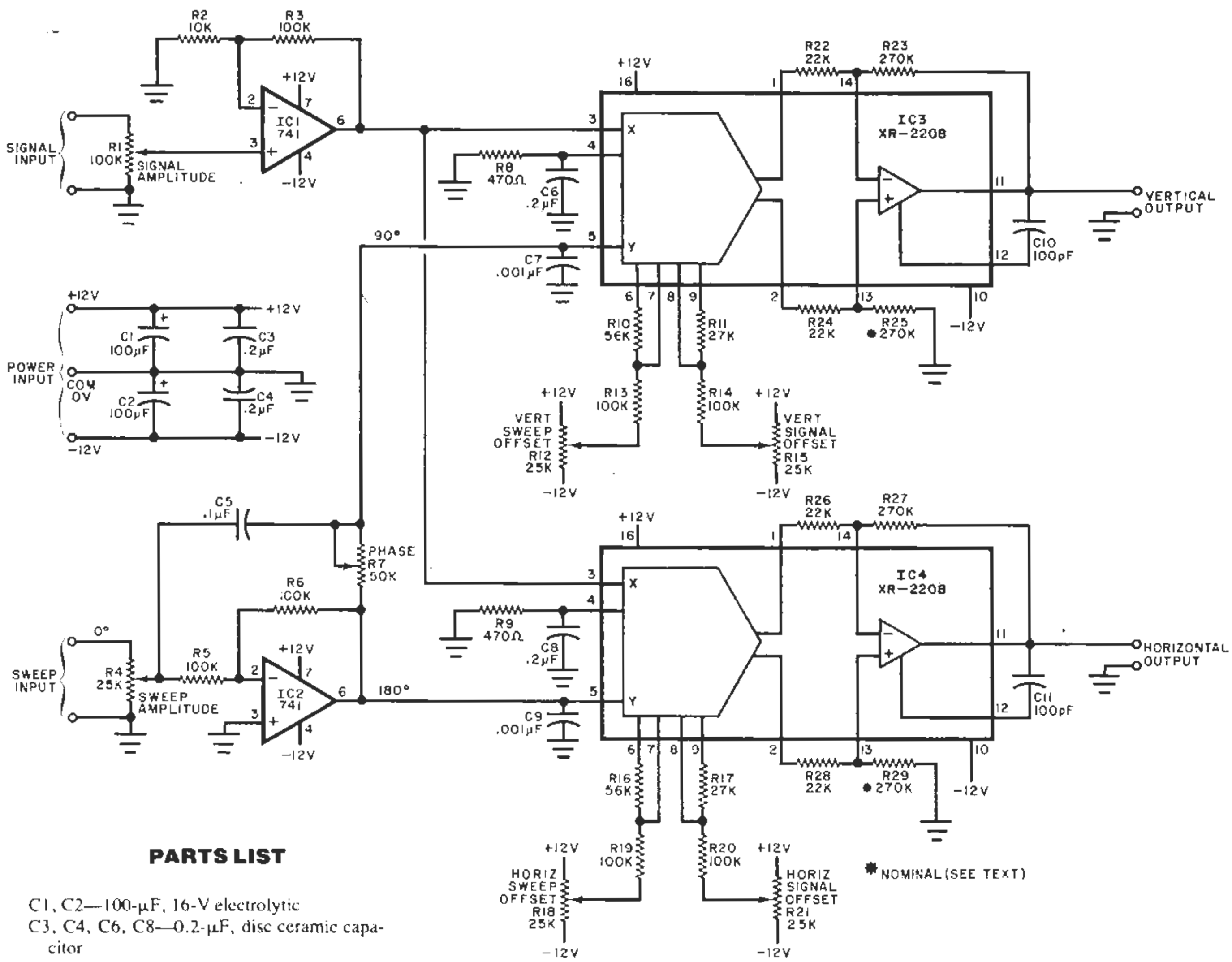


Fig. 3. Input is passed to two four-quadrant multipliers while sweep input to each multiplier is applied 90° out of phase.

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-wav 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.

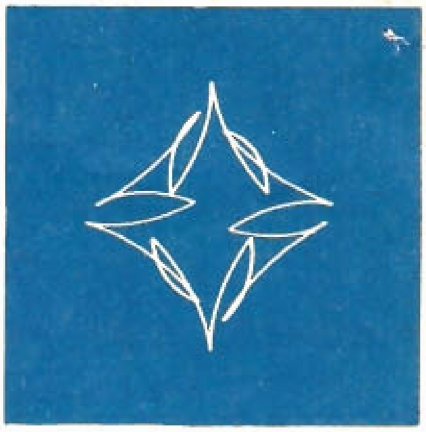


Fig. 6. Diamond-shaped pattern results when offset controls are at opposite settings.

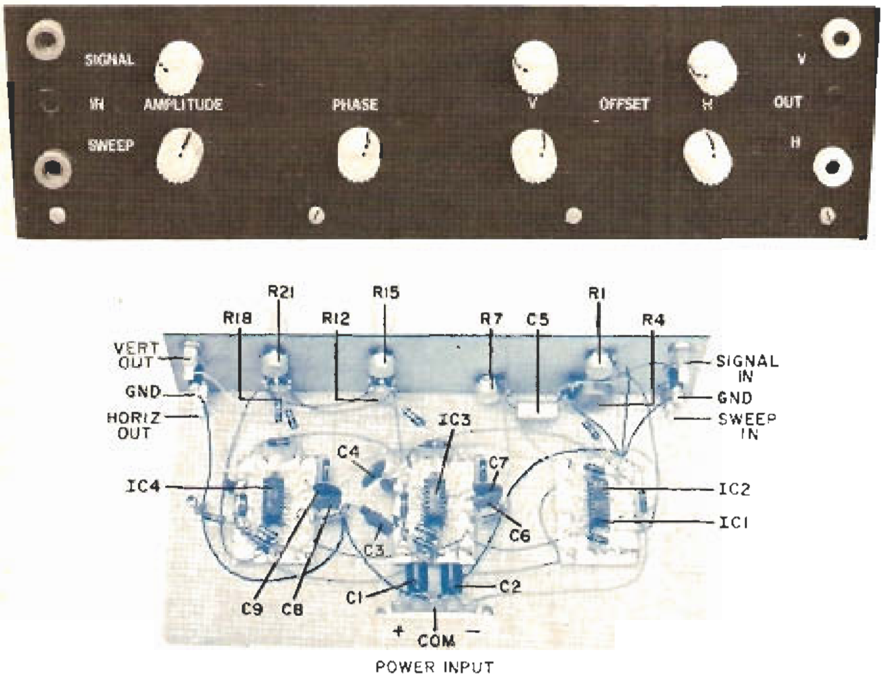


Fig. 4. Photo at top shows front panel of prototype. Below is prototype breadboard. Pc board can be used.

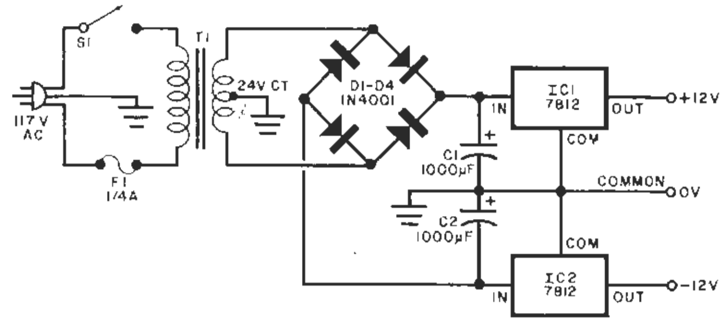


Fig. 5. The dual power supply uses both positive- and negative-voltage regulator integrated circuits.

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

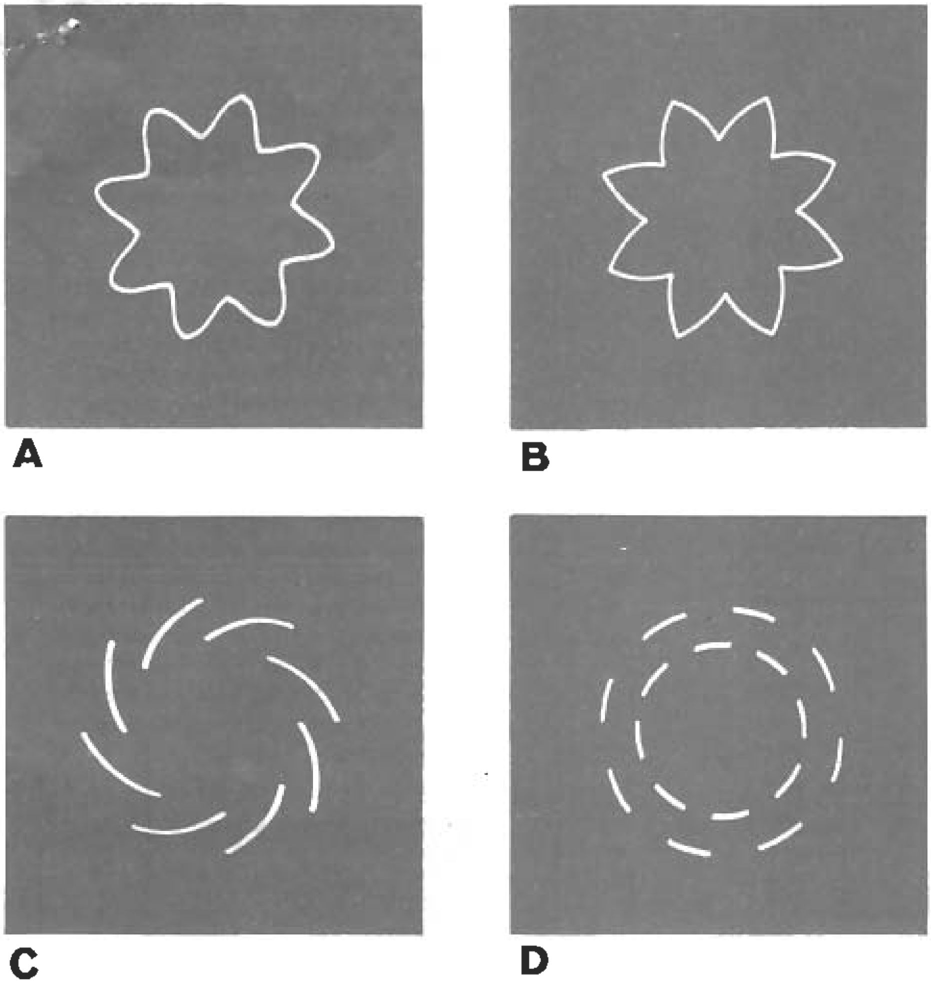


Fig. 7. Appearances of sine (A), triangle (B), sawtooth (C), and square (D) waveforms as displayed by circular-sweep converter system.

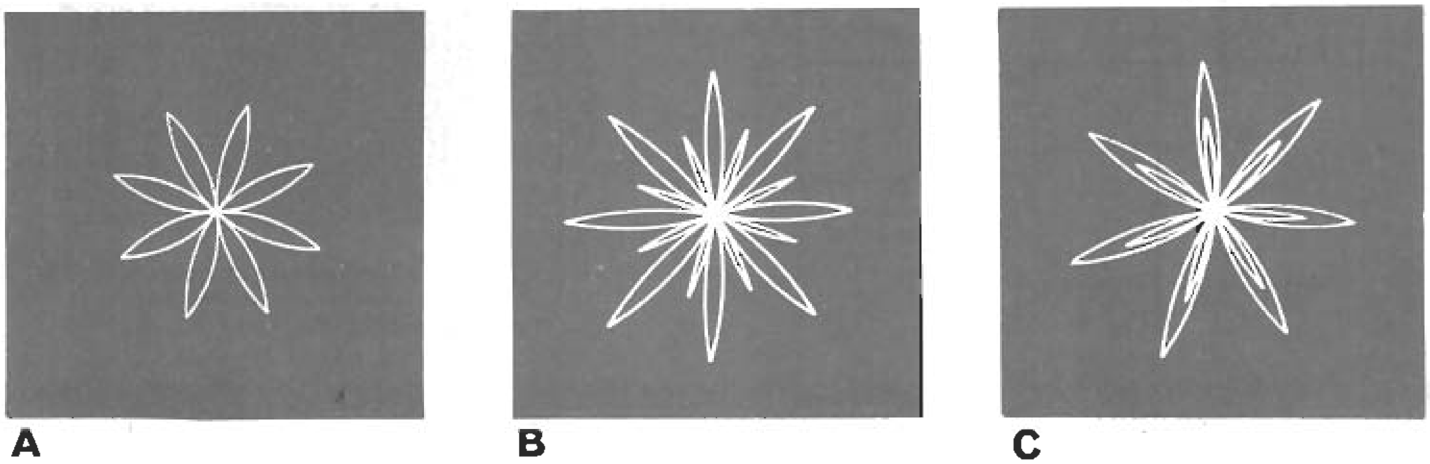


Fig. 8. Increasing the amplitude of a triangle waveform causes trace to meet in center (A) and come out opposite side with even number of cycles (B) and odd number of cycles (C).

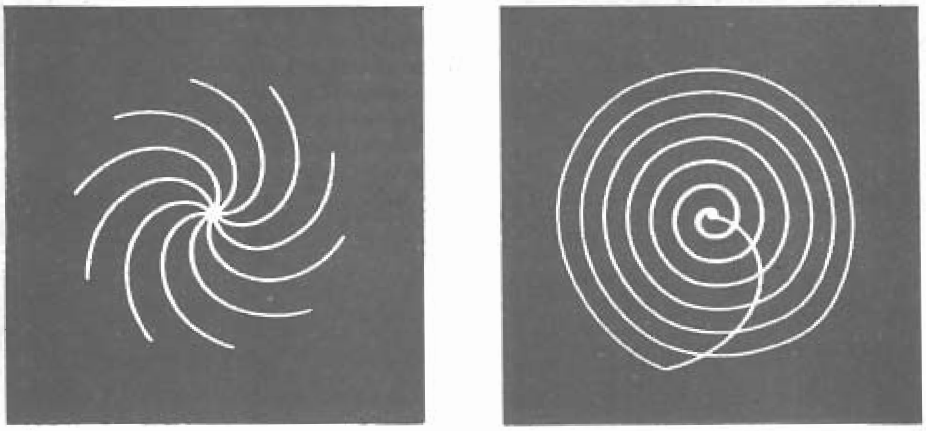
photography. If you use an FM station as the source you may need to insert a low-pass filter (Fig. 11) between the source and SIGNAL IN to eliminate the multiplex and SCA subcarriers. Speech also makes an interesting display.

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! ◇



A **B**

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

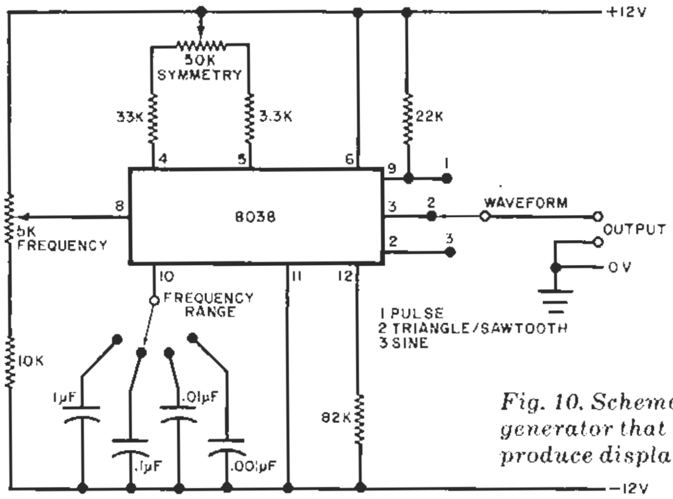


Fig. 10. Schematic of waveform generator that can be used to produce displays shown here.

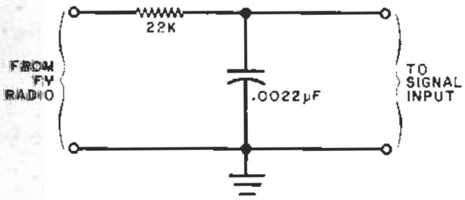


Fig. 11. Filter can be used to remove subcarriers when audio from FM stations is displayed.

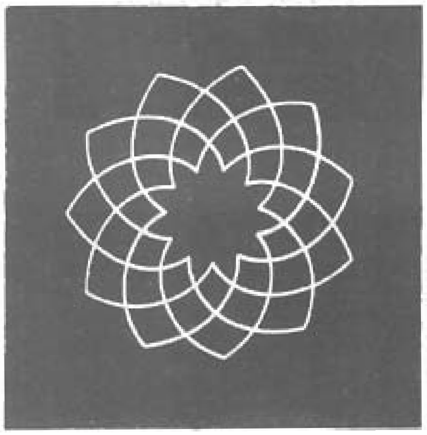


Fig. 12. Frequency comparison with circular sweep. Ratio of triangle to sine sweep is 11:4.

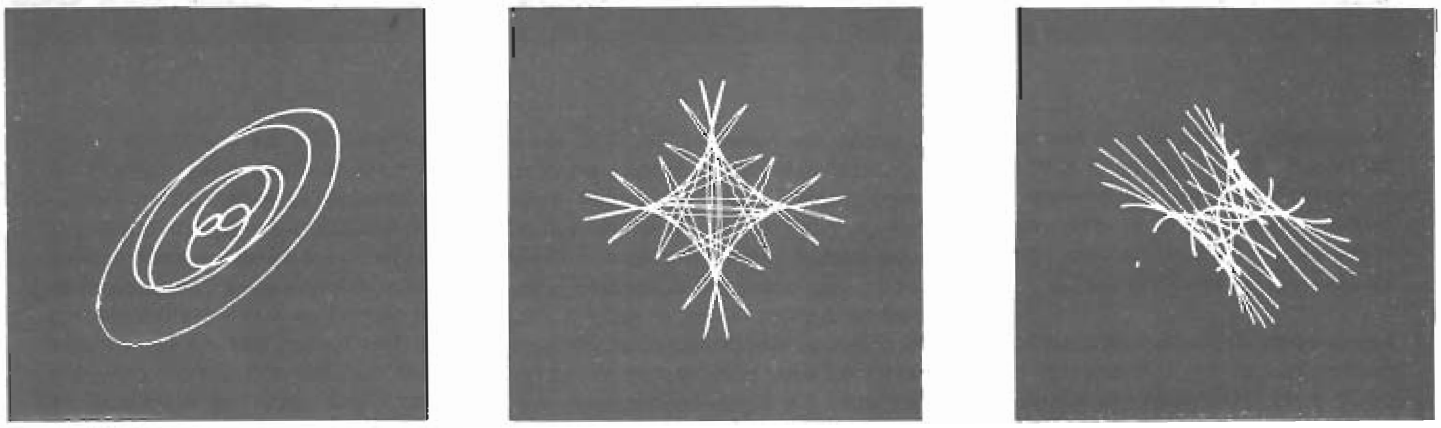
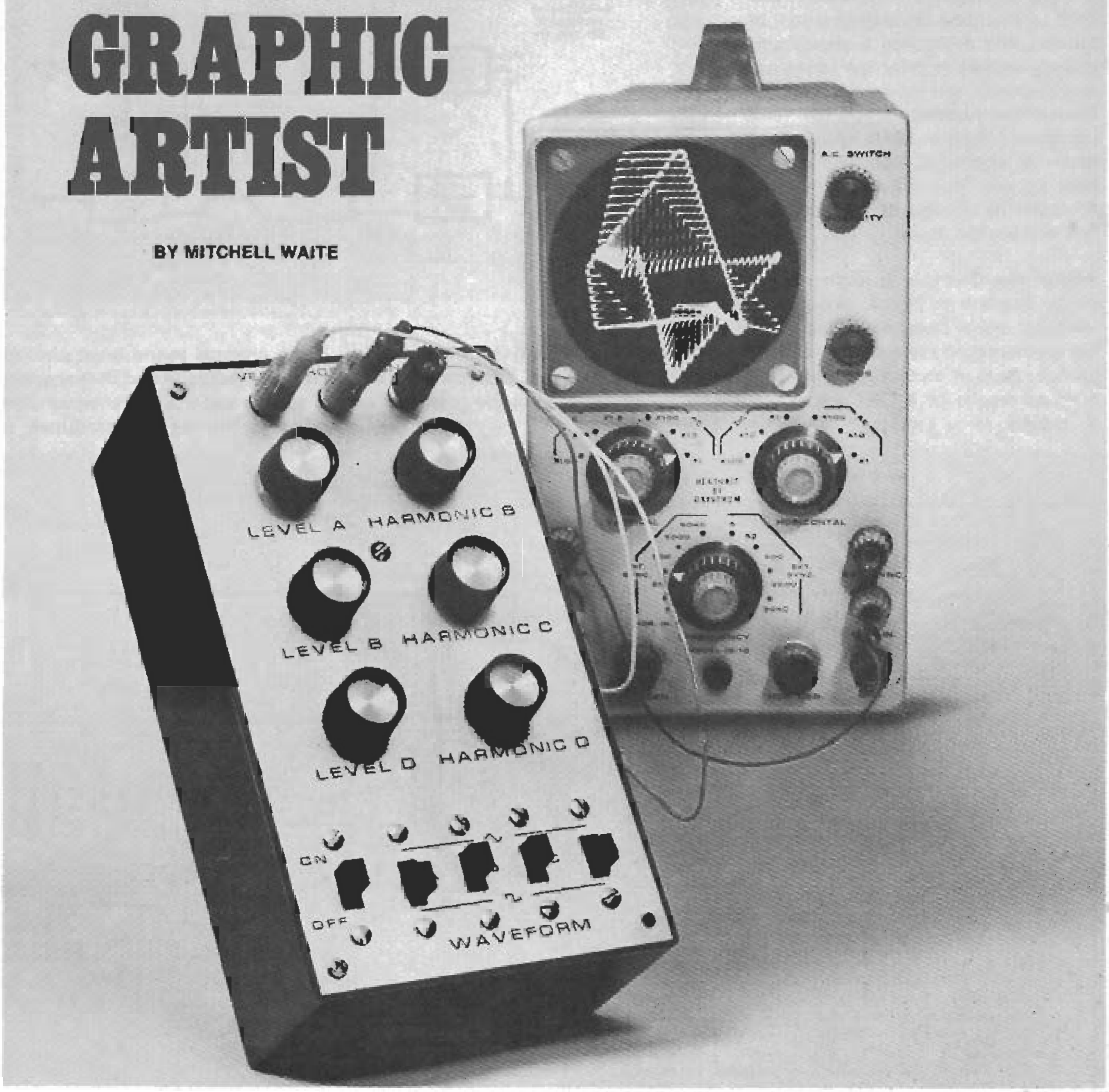


Fig. 13. Three imaginative examples of the thousands that can be generated with the circular-sweep converter.

THE OSCILLOSCOPE GRAPHIC ARTIST

BY MITCHELL WAITE



Create exciting, computer-generated, three-dimensional drawings on your oscilloscope

A DIM light traces a delicate pattern of geometrical lines on the screen of an oscilloscope. The lines form a rectangle that suddenly tilts back and transforms into a revolving ring of diamonds. You can produce these, plus many more, effects by operating the controls on the Graphic Artist project described here. You can easily make an image rotate in three dimensions, compress and expand, break up into other shapes, or slowly oscillate.

The Graphic Artist is a visual pattern generator that is designed to use the CRT screen of an oscilloscope as a "canvas" and its electron beam as a high-speed "brush." The real-time three-dimensional display on the CRT screen has all the delicate geometric beauty and detail of the computer-generated three-dimensional drawings with which we are all familiar.

The beam in an oscilloscope is forced to follow two complex, harmonically related signals in producing the geometeric patterns. Phase-shift networks, working in concert with a simple modulator, in the Graphic Artist add a signal that produces a depth and volume cue for the scope image.

If you're into electronic music, you might try feeding the output signal of the Graphic Artist into a stereo amplifying system to hear the tones associated with the on-screen images. Even more interesting, you can feed harmonics from a music source into the Artist's circuit in place of the oscillator signals. This allows you to view the patterns created by harmonically related musical notes.

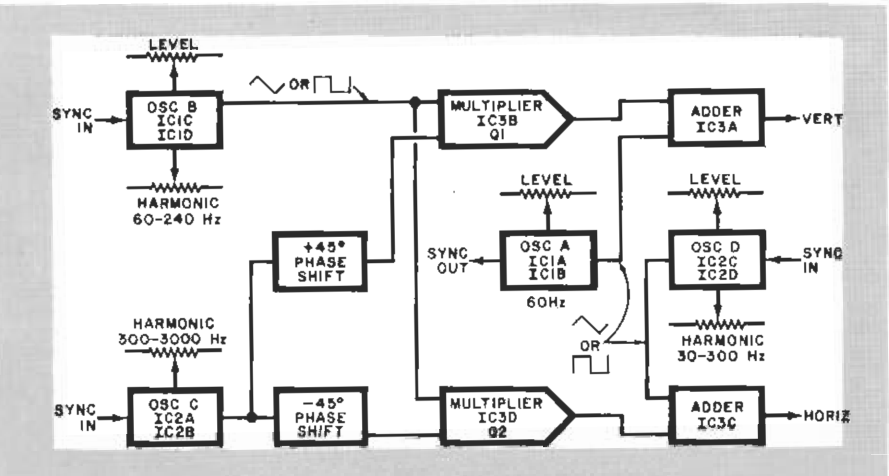


Fig. 1. Block diagram of Graphic Artist.

About the Circuit. As shown in the block diagram in Fig. 1, two almost identical signal channels in the Artist are connected to the vertical and horizontal inputs of an oscilloscope. This hookup results in a CRT trace that is known as a Lissajous figure—a circular-like trace that is proportional to the vertical and horizontal displacement of the scope's electron beam.

Each channel in the Artist consists of two oscillators (A and D) that generate square and triangular waveforms. Added to the signals produced by

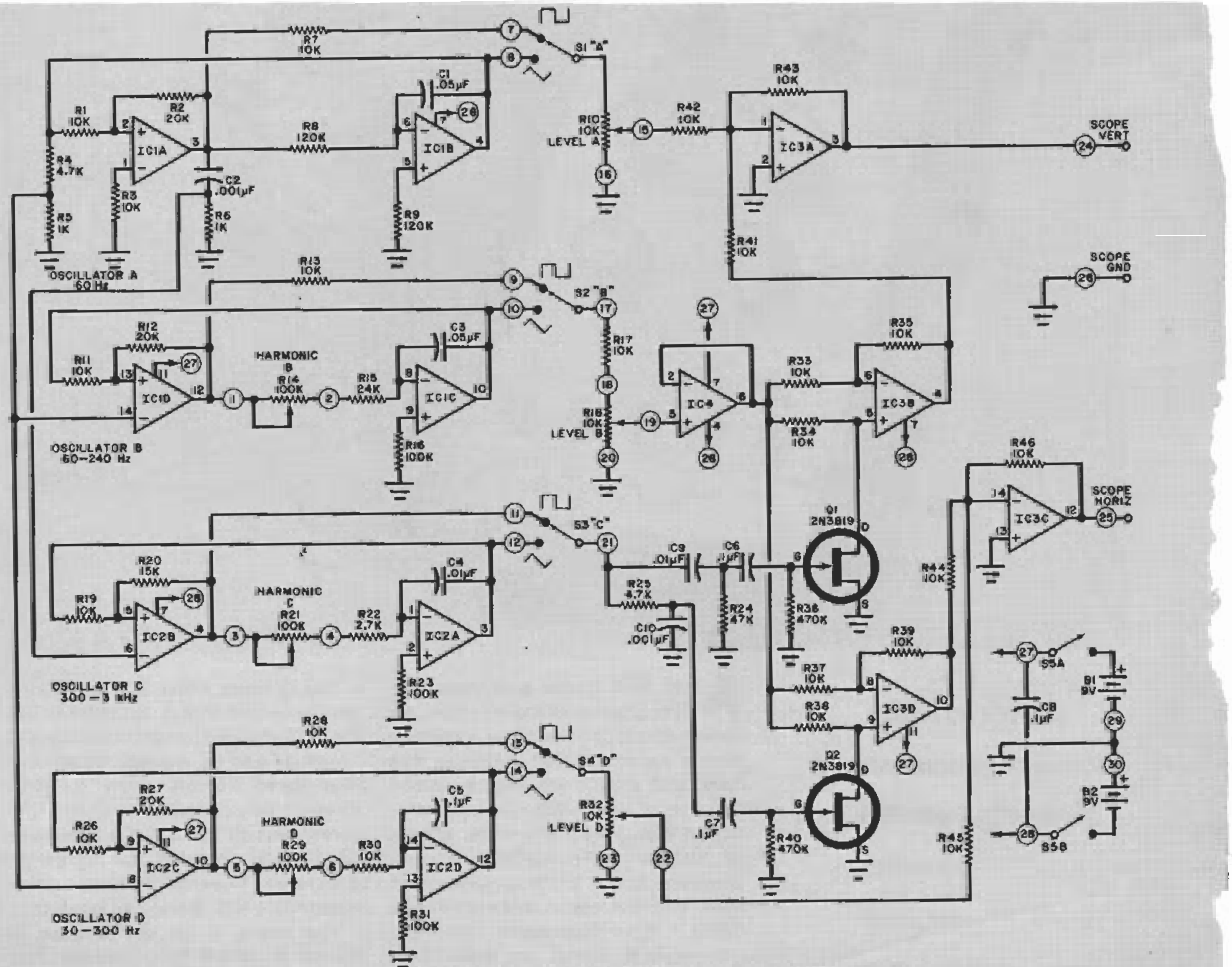


Fig. 2. Oscillators are identical except for frequency-determining elements.

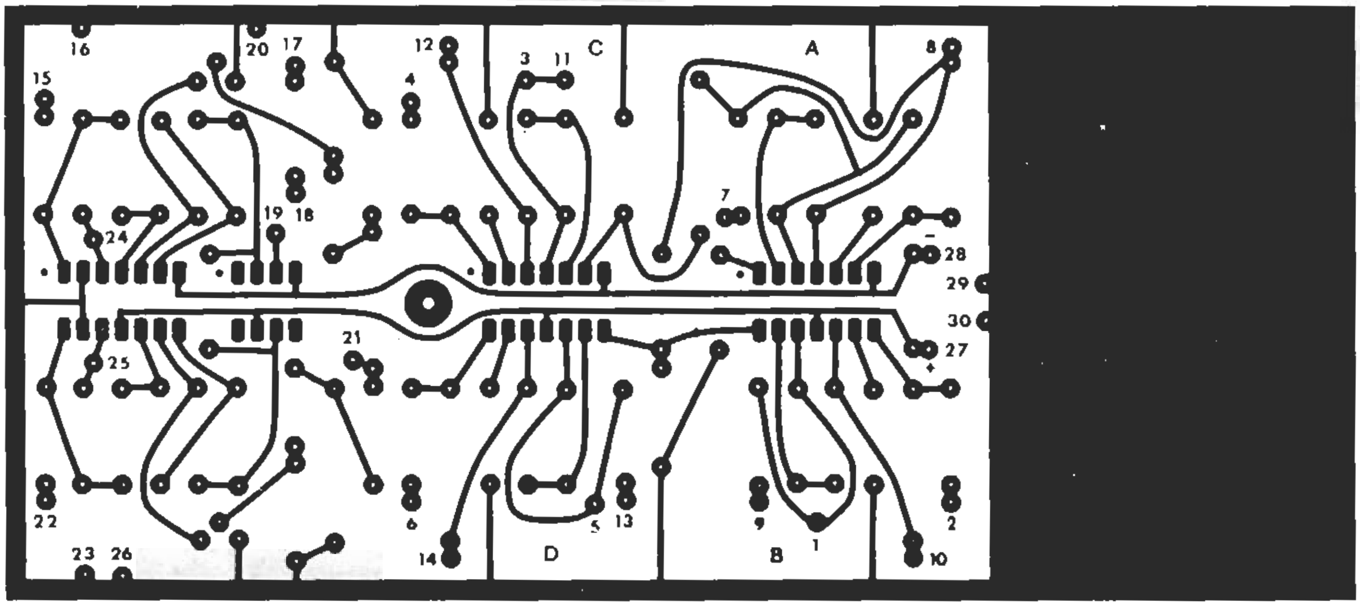
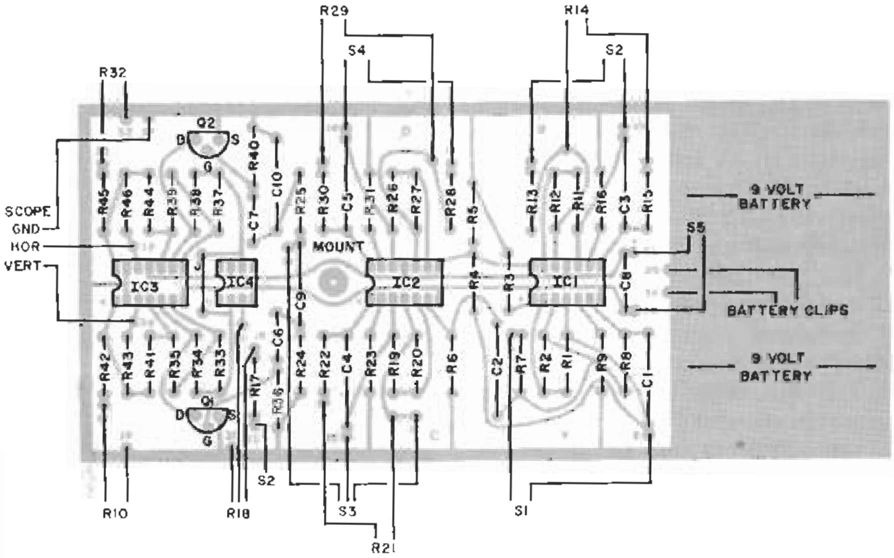


Fig. 3. Etching and drilling (above) and component (right) guides.



PARTS LIST

B1,B2—9-volt battery
C1,C3—0.05-μF Mylar capacitor
C2,C10—0.001-μF Mylar capacitor
C4,C9—0.01-μF Mylar capacitor
C5,C6,C7,C8—0.1-μF 100-volt Mylar capacitor
IC1, IC2,IC3—Quad 741 operational amplifier integrated circuit (Raytheon RC4136DB)
IC4—741 operational amplifier integrated circuit
J1, J2, J3—Five-way binding post
Q1,Q2—2N3819 junction field-effect transistor
The following resistors are ¼-watt 10% tolerance:
R1,R3,R7,R11,R13,R17,R19,R26,R28, R30,R33,R34,R35,R37,R38,R39,R41, R42,R43,R44,R45,R46—10,000 ohms
R2,R12,R27—20,000 ohms
R4,R25—4700 ohms
R5,R6—1000 ohms
R8,R9—120,000 ohms
R15—24,000 ohms
R16,R23,R31—100,000 ohms
R20—15,000 ohms
R22—2700 ohms
R24—47,000 ohms
R36,R40—470,000 ohms
R10,R18,R32—10,000-ohm linear taper potentiometer
R14,R21,R29—100,000-ohm linear-taper potentiometer
S1 thru S4—Spdt slide or toggle switch
S5—Dpdt slide or toggle switch
Misc.—Printed circuit or perforated board; 7½"L × 4¼"W × 2"D (19 × 11 × 5.1 cm) case; knobs (6); battery clips (2); lettering kit; hookup wire; machine hardware; solder; etc.

Note: The following are available from CalKit, P.O. Box 38, San Rafael, CA 94901: Complete kit #GA-1 (includes components, board, case, but not battery) at $55; p.c. board #GA-3 at $7.50. All orders postpaid. California residents, add 6% sales tax.

these oscillators is a common modulated signal derived from oscillators B and C. The overall shape of the Lissajous pattern is set by the signals from oscillators A and D. (For example, a simple rectangle results when triangular waveforms make up these signals.)

The modulation component is comprised of a variable high-frequency carrier from oscillator C and a variable medium-frequency envelope from oscillator B. The carrier is shifted in phase by ±45°. The +45° component is modulated by waveform B in the multiplier and summed with the waveform from oscillator A in an adder. Likewise, the −45° carrier is modulated by waveform B but is summed with the waveform from oscillator D. When the phase-shifted components interact in the scope, they form another Lissajous pattern that is perpendicular to the major rectangle pattern, creating the three-dimensional illusion of volume.

Each oscillator can be switched to generate square waves. Depending on which oscillator is switched to square waves, the pattern will either break up into multiple images or change the character of its surface composition. There are three level controls, which tilt or expand the image and change the relative sizes of the modulating components. The harmonic controls are frequency setting potentiometers that are used to adjust the ratio between the various harmonic signals. The ratios of the signals in turn control the "family" of images you see.

To prevent the patterns from revolving on the screen (this occurs whenever the patterns are derived from uncorrelated oscillators), one of the four oscillators is fixed in frequency. The output from this "master" oscillator is used to synchronize the remaining oscillators, forcing them to run at an exact multiple of the syncing frequency.

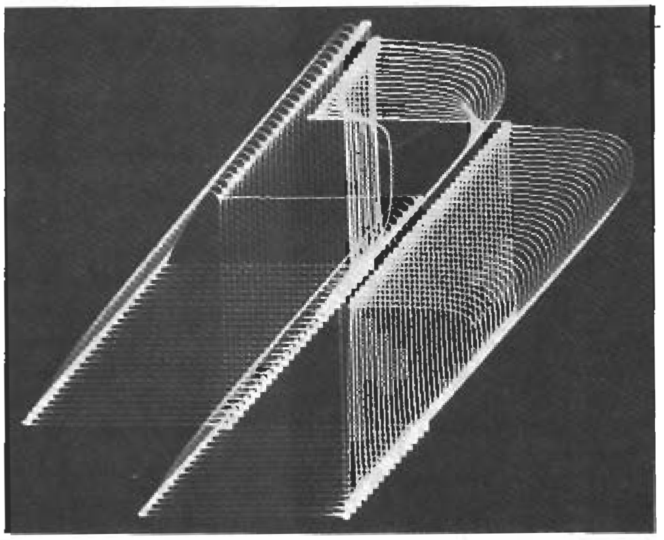
In addition to using the controls on the project, you can also use the vertical- and horizontal-gain controls on the scope to adjust the width and height of the images.

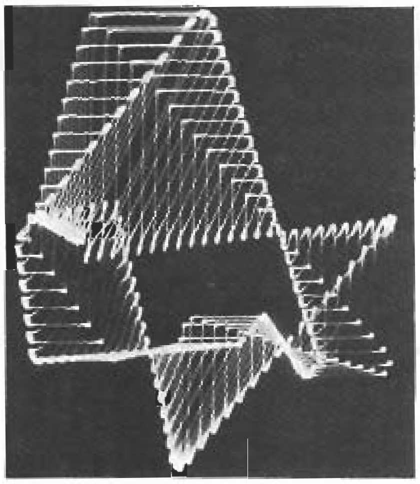
Circuit Details. As shown in Fig. 2, the four oscillators are identical except for their frequency-determining elements. Oscillator A is fixed at approximately 60 Hz by *R8* and *C1;* oscillator B is variable from 60 to 240 Hz; oscillator C is variable from 300 to 3000 Hz; and oscillator D is variable from 30 to 300 Hz. The oscillators are arranged in a classical comparator-integrator configuration.

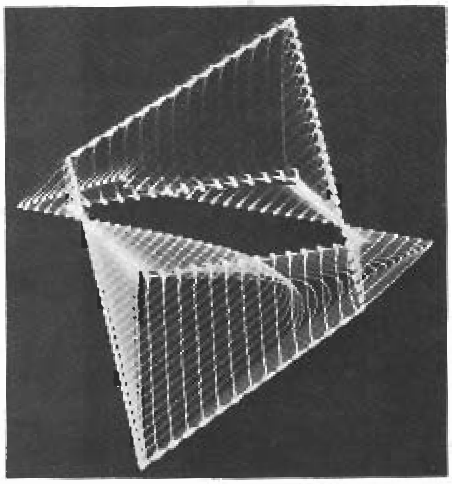
Taking oscillator A as an example, *IC1A* uses *R1* and *R2* to set the trip point at about $\pm V_{cc}/2$. The output of this comparator connects to integrator *IC1B*, which in turn, connects back to *IC1A's* input. When *IC1A's* output is at −9 volts, *IC1B* linearly charges *C1* through *R8*. Hence, the output of *IC1B* is a positive-going ramp. As soon as the ramp reaches $V_{cc}/2$, *IC1A* changes to the positive state and *IC1B* linearly discharges *C1* to initiate a negative-going ramp. When this ramp reaches $-V_{cc}/2$, *IC1A* trips to the negative state and the cycle repeats itself.

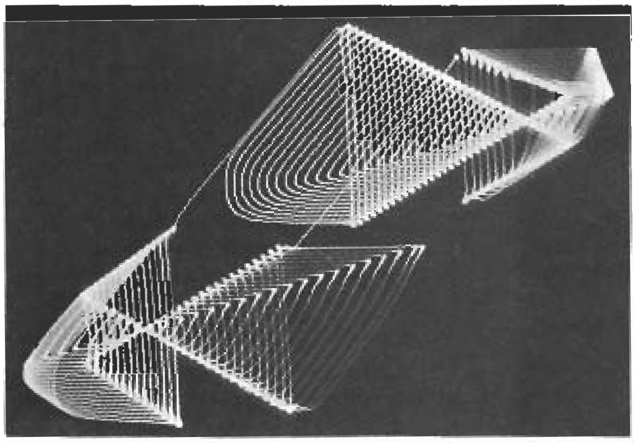
Potentiometers are used to set the frequencies in the three variable-frequency oscillators by varying the charging currents. The outputs from the comparators (*IC1D*, *IC2B*, and *IC2C*) are symmetrical square waves, while the outputs from the integrators (*IC1C*, *IC2A*, and *IC2D*) are triangle waves. Resistor *R10* in fixed-frequency oscillator *IC1A*/*IC1B* sets the amplitude of the two waveforms. Level controls are provided for all but oscillator C. Oscillator C has no level control because only one signal need be variable if both signals go to the inputs of a multiplier to cause the output of the multiplier to vary.

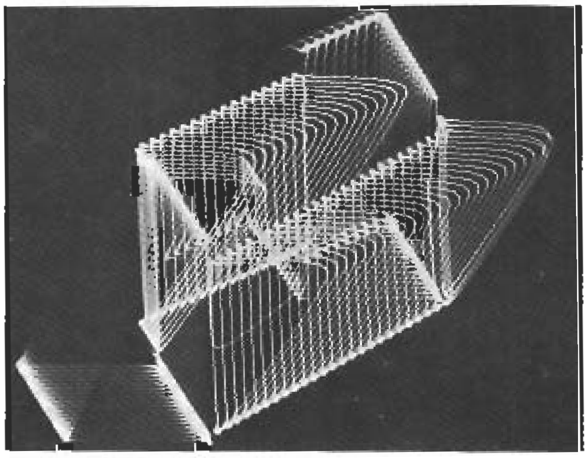
The square-wave output from oscillator A is differentiated by *C2* and *R6* to create a sync pulse. This pulse is fed to the inverting (−) input of *IC2B* to force oscillator C's operating frequency to be an exact multiple of the operating frequency of oscillator A. To sync the remaining oscillators, the triangle-wave output from oscillator A is attenuated by *R4* and *R5* and fed to the inverting inputs of *IC1D* in oscillator B and *IC2C* in oscillator D. The 60-Hz











Photos illustrate only five of the countless varieties of waveform displays possible.

triangle wave forces oscillators B and D into exact sync. Resistor *R7* in oscillator A makes the square and triangle waves in this oscillator equal in amplitude. Switches *S1* through *S4* provide means for selecting the desired waveforms.

Integrated circuit *IC4* is an op amp follower, used here to reduce the source impedance to chopper-type multipliers *IC3B* and *IC3D*. In this type of multiplier, a bipolar transistor or JFET is used to switch the op amp between a noninverting (+) and an inverting (−) unity-gain buffer. Transistor *Q1* serves this purpose in this circuit.

When the signal in oscillator C goes positive, *Q1* conducts and *IC3B* reverts to an inverting amplifier. When oscillator C goes negative, *Q1* starts to cut off, and *IC3B* becomes a noninverting amplifier with unity gain. This switching action results in suppression of the carrier, and the output of *IC3B* is a balanced four-quadrant signal.

The signal from oscillator C is shifted in-phase by +45° in network *C9-R24* and by −45° by network

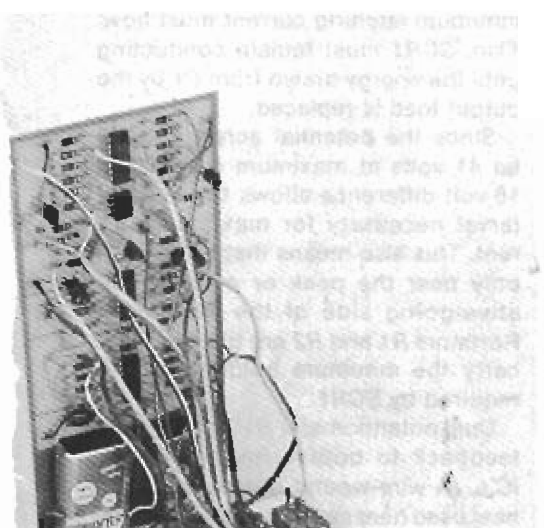


Fig. 4. Construction details.

C10-R25. So, the waveform to each JFET (*Q1* and *Q2*) is out-of-phase, resulting in a modulated output from the multiplier also being out-of-phase. Networks *C6-R36* and *C7-R40* provide dc restoration for *Q1* and *Q2*.

The output from multiplier *IC3B* is summed with the signal from oscillator A in adder *IC3A*. The output from multiplier *IC3D* is summed with the signal from oscillator D in adder *IC3C*. Finally, the outputs from the two adders are fed to the oscilloscope to form the complex Lissajous patterns.

Power is supplied to the Artist by two standard 9-volt batteries (*B1* and *B2*). Capacitor *C8* aids in reducing instability in the IC op amps.

Construction. The project can be built on either printed circuit or perforated board. The actual-size etching and drilling guide and components-placement diagram are shown in Fig. 3. After preparing or buying a ready-to-use pc board (see Parts List for supplier), mount the components on it as shown in the placement diagram, paying particular attention to the orientations of the IC's and transistors. Place *B1* and *B2* on the blank end of the board, terminals pointing away from the components, and fasten them in place with loops of wire passed between the batteries. Temporarily set aside the board assembly.

Next, machine the front panel for the six potentiometers, five switches, three binding posts, and a No. 6 machine screw. The last hole should line up exactly with the large hole in the pc board assembly. Mount the pots, switches, and binding posts in their respective locations (see Fig. 4). Pass a 6-32 × 2" machine screw (to support the circuit board assembly) through the remaining hole, slip over its threads a length of plastic spacer, and follow with a No. 6 machine nut. The spacer should be just long enough that, when the nut is in place, about ¼" of screw thread is still visible. Label the controls, switches, and binding posts.

Referring back to Fig. 2 and Fig. 3, finish wiring the project.

Operation. The oscilloscope used with the Graphic Artist must have an external horizontal input. Connect test-lead cables from the output binding posts on the Artist to the appropriate inputs on the scope. Set all waveform switches to triangle. Switch on the project and scope.

Set time LEVEL B control fully counterclockwise (off). Because oscillator B connects to both multipliers, making LEVEL B zero eliminates the modulated component on the screen. You should now see a simple rectangular or square Lissajous pattern. Adjust the horizontal- and vertical-gain controls on the scope so that, when LEVEL A and LEVEL D controls are set to midrange, the image just fills most of the screen.

Slowly turn up LEVEL B. This adds the modulated waveform to the existing pattern. Readjust LEVEL A and LEVEL D for a pleasant balance and to keep the image from drifting off-screen. Adjust HARMONIC B to sync the modulated envelope with the image. In essence, this control sets the number of "lobes" riding on the primary Lissajous pattern.

Next, adjust HARMONIC C so that the high-frequency carrier is in sync with the image. You should now have a display similar to those shown in the photos. The next thing we can do is alter the Lissajous "family" by using combinations of the waveform switches. For example, switching WAVEFORM A to the square-wave position and setting WAVEFORM D to the triangle-wave position causes the image to break up into separate shapes. There are 16 combinations for the four waveform switches. Add to this the effects of the six HARMONIC and LEVEL controls, and chances are you will never see the same pattern twice.

After you've familiarized yourself with the operation of the controls (it does take some skill), you might try connecting a pair of stereo headphones to the two output channels. The sounds of the four oscillators mixing and adding produces beat notes that are fascinating in themselves. You can even "play" the sounds by twisting the various controls.

Some very different and interesting effects can be produced by running the Graphic Artist in reverse. Take a signal from an external source, such as an electronic organ, and connect it in place of one of the oscillators. You can do this by disconnecting one waveform switch input and connecting your signal in its place. Choose your notes to be exact even or odd harmonics of oscillator A, which operates at approximately 60 Hz. The images will appear to stop their motion and their actual shape will depend on the particular waveform of the note being played. ◈