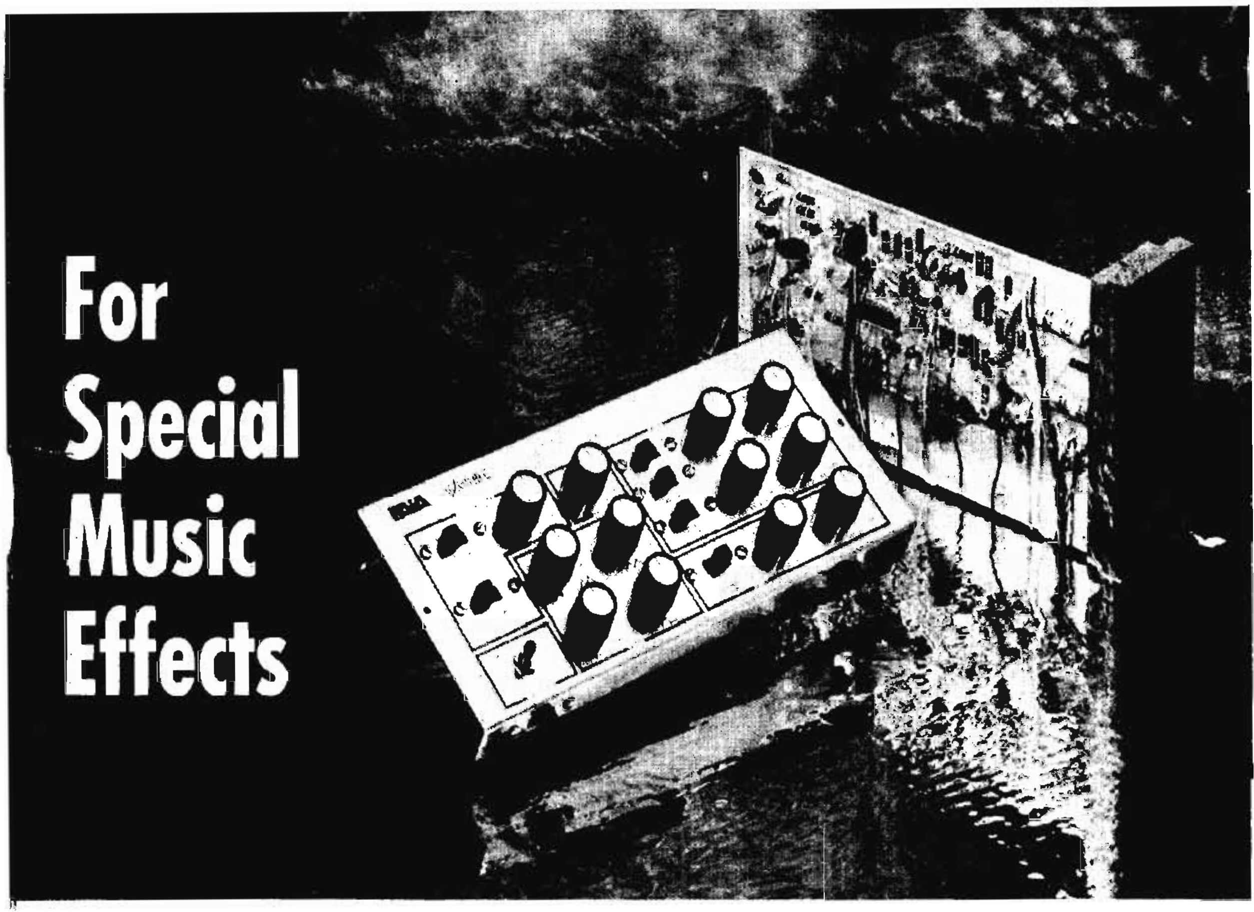

For Special Music Effects

BUILD A PORTABLE SYNTHESIZER

Connect it to a hi-fi amplifier and create your own special music effects.

by JOHN S. SIMONTON, JR.

IF THE TERM "ELECTRONIC MUSIC SYNTHEsizer" calls to your mind a picture of Walter Carlos wandering glassy eyed among a room full of equipment festooned with thousands of knobs and switches and draped with miles of cable, you're a little out of touch.

After years of patching together the amplifiers, oscillator, filters and other individual modules of the early day synthesizers, an interesting pattern began to emerge. Manufacturers and users alike discovered that most of the useful sounds that the equipment could produce were obtainable with a handfull of different patching arrangements. That was the beginning of the "normalized" performing synthesizer.

Basically a normalized synthesizer is one in which the separate elements are pre-arranged in a specific configuration (oscillators feeding amplifiers feeding filters feeding the output, ordinarily) with front panel controls to select various oscillator waveforms and set the level of audio and control signals. Except in studio, University or hobby machines, patch cords are rare and sounds are changed simply by turning a knob or flipping a switch.

To show how normalization works, and to give you a really low cost introduction to synthesis generally, we present the GNOME. The GNOME is a micro-synthesizer that employs the same voltage control techniques that give synthesizers their almost unlimited versatility while featuring controls that are so simple to operate even children can pick out sounds and tunes in the first few minutes.

What's a synthesizer?

The currently fashionable way of thinking of synthesizers is in terms of analog computers. This has the double advantage of giving the electronics technician lacking a musical background a starting point closer to his home stomping ground. It also gives the musician an equivalency between electronic elements and the mechanical counterparts that he already knows. For example, the oscillator of a synthesizer corresponds to the vibrating strings, reeds, or whatever of a musical instrument. The filters correspond to the resonant properties of the body of the instrument. The instrument dynamics (attack and decay) correspond to the voltage-controlled amplifier/function generator combination in the synthesizer.

Once a synthesizer is viewed in these terms, it becomes immediately apparent what the real strengths of the equipment are. It would be difficult to build a mechanical instrument that combined the harmonic structure of a vibrating string with the resonant characteristics of a slide trombone. But with the electronic equivalents of these elements such strange "cross-breeding" is relatively simple.

The GNOME

A block diagram of the normalization scheme is shown in Fig. 1. The built-in controller (a simple voltage divider) provides a control voltage that is proportional to the position of the wiper probe along the strip of conductive elastomer. The front-panel switches routes this control voltage to either the voltage controlled oscillator (VCO) or voltage controlled filter (VCF).

The VCO has two basic output waveforms; a triangle and a square wave. A SKEW control on the input of the oscillator changes the triangular-waveform output to a ramp while the square-wave changes to a short duration pulse, giving the user the option of four waveforms from a low-cost oscillator. Individual level controls

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November, December 1975 and January 1976;

on the oscillator's two outputs allow for selecting or mixing the desired waveforms.

The outputs of the oscillator feed a common audio bus as does the output of the GNOME's internal noise source, also with its own level control. The audio bus always drives the GNOME's VCF, but a switch at the input of the voltage-controlled amplifier (VCA) allows the user to bypass the action of the filter if desired.

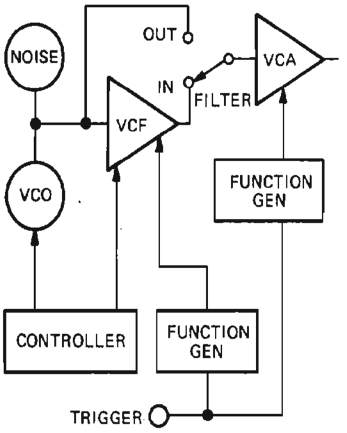


FIG. 1—NORMALIZATION SCHEME of the GNOME.

There are two internal function generators, one dedicated to providing a control voltage for the VCF and the other dedicated to the VCA. Each of these function generators provide for either percussion or sustained envelopes and the VCF's function generator has the added feature of a REPEAT switch that allows it to serve as its own trigger source for low speed cyclic effects similar to tremolo. Both function generators are normally triggered from a front panel TRIGGER button but provision has also been made for external trigger sources such as foot switches or sequencers.

There are many other features to the circuits of the GNOME but these will be covered in the individual circuit discriptions.

Controller

The schematic diagram of the controller, noise source, trigger and power supply is shown in Fig. 2. The "sawtooth" geometry of the conductive elastomer that forms the control strip of the GNOME combines with the paralleling resistors R8 through R11 to produce an exponential voltage distribution along the surface of the strip. The RANGE potentiometer R78 is in series with the effective resistance of the control strip forming a voltage divider. Increasing the resistance of R78 decreases the voltage that appears across the length of the strip.

The wiper probe of the control strip is decoupled by an emitter follower in the VCO to prevent loading of the controller. This probe picks a voltage from the strip that is proportional to the position of the probe along the length of the strip. Switches S2 and S3 allow this voltage to be routed either to the VCO, VCF or both simultaneously.

The diodes at the bottom end of the control strip provide a constant voltage drop of approximately 1.5 volts insuring that there will be sufficient voltage on the strip to drive the VCO regardless of the setting of R78.

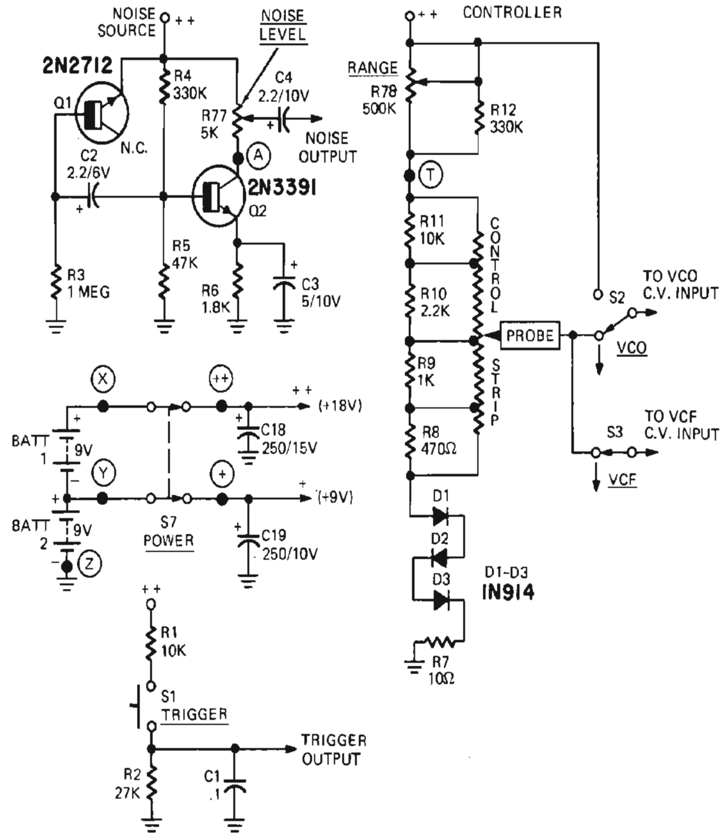


FIG. 2—CONTROLLER, noise source, trigger and power supply schematic diagram.

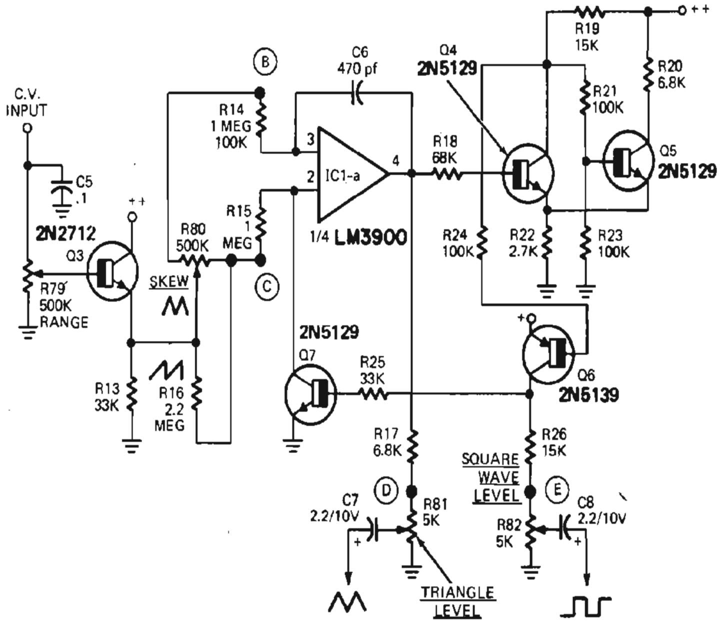


FIG. 3—VOLTAGE-CONTROLLED OSCILLATOR schematic diagram.

Noise source and trigger

The GNOME's noise source (see Fig. 2) is a standard design employing the shot-noise that results from the avalanching process of the reverse-biased base-emitter junction of transistor Q1. The noise appears across resistor R3 and is coupled by capacitor C2 to the single-stage amplifier comprising Q2, R4, R5 and R6. Potentiometer R77 is the level control for the noise source and as the wiper of this control is moved toward the collector of Q2, the amount of noise introduced in to the common audio bus is increased.

The TRIGGER push-button S1 (see Fig. 2) connects the +18-volt supply line to the trigger bus through R1. Capacitor C1 bypasses contact-bounce impulses to ground.

VCO

The schematic diagram of the VCO is shown in Fig. 3. Control voltages are applied to the oscillator at the point marked "c.v. input". Capacitor C5 bypasses to

Parts List

All resistors ½-watt, 10% unless noted.

R1,R11,R34,R36,R40,R41,R61,R69—10,000 ohms
R2—27,000 ohms
R3,R14,R28,R31,R37,R48,R63,R64,R72—1 megohm
R4,R12—333,000 ohms
R5,R35,R51—47,000 ohms
R6,R33—1800 ohms
R7—10 ohms
R8—470 ohms
R9,R53,R76—1000 ohms
R10,R68—2200 ohms
R13,R25,R38,R55,R54,R67,R73,R75—33,000 ohms
R15,R21,R23,R24,R45,R44,R59,R71—100,000 ohms
R16,R46,R49—2.2 megohms
R17,R20,R27,R50,R52,R74—6800 ohms
R18—68,000 ohms
R19,R26,R32,R58—15,000 ohms
R22—2700 ohms
R29,R56,R57—100 ohms
R30,R60—150,000 ohms
R39,R70—470,000 ohms
R42,R66—4700 ohms
R43—22,000 ohms
R47—3.9 megohms
R62—220,000 ohms
R65—680,000 ohms
R77,R81,R82,R84—5000 ohm linear taper potentiometer
R78,R79,R80,R85,R86,R87,R89,R90—500,000 ohm linear taper potentiometer
R83,R88,R91—50,000 ohm linear taper trimmer pot.
C1,C5—.1μF Mylar
C2—2.2 μF 6V electrolytic
C3—5 μF 10V electrolytic
C4,C7,C8,C12,C14,C15,C16—2.2 μF 10V electrolytic
C6—470 pF ceramic disk
C9,C10—.001 μF ceramic disk
C11—33 μF 10V electrolytic
C13,C17—.005 μF ceramic disk
C18—220 μF 15V electrolytic
C19—220 μF 10V electrolytic
D1-D11—1N914 diode
IC1—LM3900 quad current differential amp
Q1—2N2712 selected low noise transistor
Q2,Q12,Q13—2N3391 transistor
Q3,Q14,Q15—2N2712 transistor
Q4,Q5,Q7,Q8,Q10,Q16—2N5129 transistor
Q6,Q11,Q17—2N5139 transistor
Q9—MPF-102 transistor
S1—SPST normally-open push-button
S2,S3,S6,S8—SPDT slide switch
S4,S5,S7—DPDT slide switch
BATT 1,2—9-Volt transistor battery (NEDA 1604 or equal)
MISC.—9-lug terminal strips (2), pin jack, pin plug, miniature phone jack, circuit board, control strip, battery snaps, ¼-in. grommet, knobs (12), wire, solder, hardware, etc.

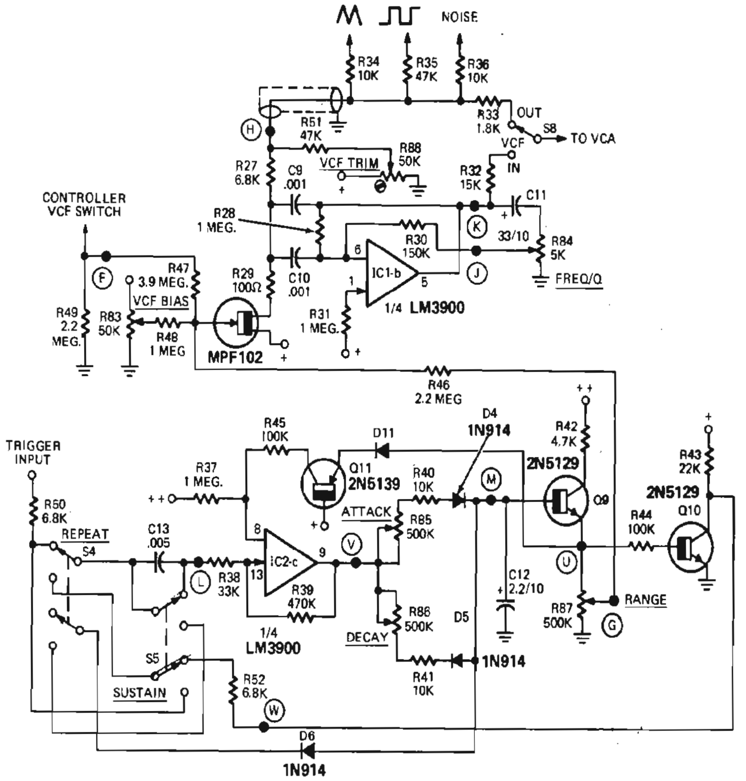


FIG. 4—VOLTAGE-CONTROLLED FILTER schematic diagram.

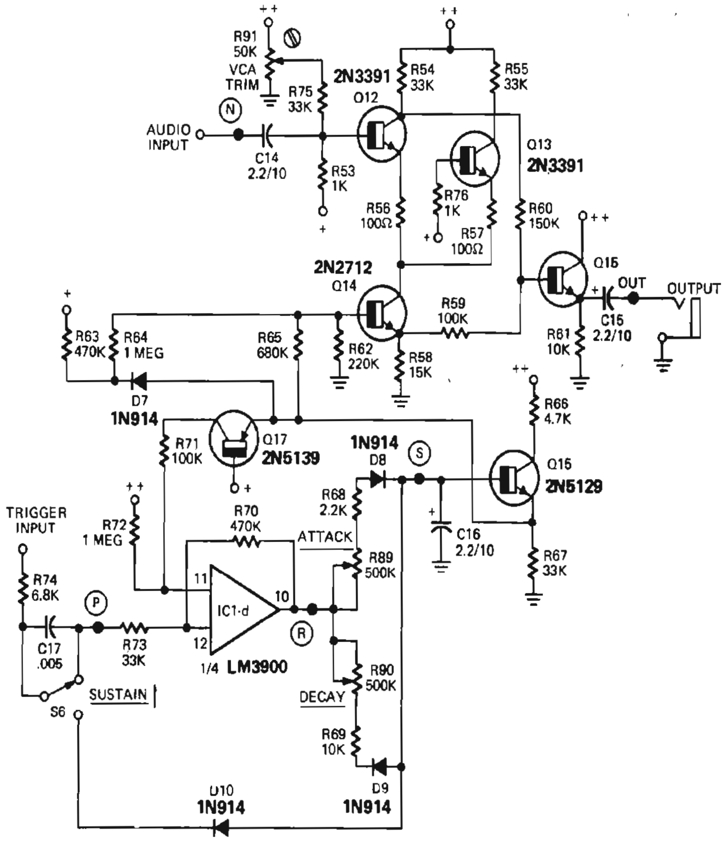


FIG. 5—VOLTAGE-CONTROLLED AMPLIFIER schematic diagram.

ground contact-noise originating at the control strip. The control voltage is then applied to the VCO RANGE control R79 which serves as an attenuator on the control-voltage line. Emitter-follower Q3 serves as an impedance-matching device between the control-voltage input and the oscillator circuitry.

The oscillator is a relatively common type consisting of an integrator (IC1-a) and a Schmitt-trigger comprising discrete transistors Q4 and Q5 and associated components.

(continued on page 100)

MUSIC SYNTHESIZER

(continued from page 39)

The configuration of the integrator is such that the amplifier will work to make identical currents flow into its inverting (IC1-a pin 3) and non-inverting (IC1-a pin 2) inputs. Because of the values of resistors R14, R15 and R80, the current into the non-inverting input will always be at least twice the current into the inverting input except when transistor Q7 is turned on. To make up for this difference in current, the output voltage of the amplifier rises linearly to force current through capacitor C6 into the inverting input. At some point, the integrator output voltage exceeds the threshold established by the Schmitt trigger causing the collector voltage of Q4 to switch from essentially +18 volts to approximately +3 volts. Under these conditions, the base-emitter junction of Q6 is forward biased causing the collector of this transistor to rise to approximately +9 volts. The resulting current flow through R25 into the base of Q7 turns this transistor on. This in turn effectively shunts the current that was previously flowing into the non-inverting input of the integrator to ground. The integrator's amplifier now tries to make up for the surplus current flow into the inverting input by linearly decreasing its output voltage to pull current out of this input through C6. When the amplifier's output voltage falls below the threshold level, the Schmitt trigger resets. The collector voltage of Q4 goes high again and turns off Q6 and Q7 and restores the current flow into the integrator's non-inverting input so that the cycle can start over.

The cycle is identical when the SKEW control is rotated toward the RAMP position except that the decreased resistance in the non-inverting input circuit allows a greater current flow. This causes the integrator's output ramp to rise more quickly. Simultaneously, the decreased resistance in the non-inverting input circuit is added to the inverting input to cause the integrator's output to fall more slowly. The combination of increasing rise-time while decreasing fall-time keeps the total period of the waveform approximately constant.

The ramping output of the integrator is applied to resistor R17 and potentiometer R81. The setting of potentiometer R81 determines the level of the triangle/ramp waveform that is applied to the audio bus. Similarly, potentiometer R82 is in the collector circuit of transistor Q6 and this control adjusts the level of the square wave applied to the audio bus.

VCF

The voltage-controlled filter is a common design built around one amplifier section of the LM-3900 and is tuned by varying the effective resistance of field-effect transistor Q8. The schematic diagram of the VCF is shown in Fig. 4.

The three signals applied to the audio bus are mixed together by resistors R34, R35 and R36 and applied to the input of the filter through resistor R27. Switch S8 allows either the filtered or the unfiltered audio bus signal to be applied to the VCA (*V*oltage-*C*ontrolled *A*mplifier).

The control voltage for the filter can originate at either the control strip or the filter's dedicated function generator. Voltages from the control strip appear across resistor R49 and are applied to the gate of FET Q8 through R47 while voltages from the function generator are applied through R46.

The function generator comprises one section of the LM-3900. Trigger voltages that appear at R38 produce a current flow into the amplifier's non-inverting input that switches the output of the amplifier to a high level. This high output voltage charges the timing capacitor C12 through R40, the ATTACK control R85 and the forward biased diode D4. The voltage across C12 is sensed by the high-impedance emitter-follower Q9 with the voltage at the emitter of this transistor being a diode drop less than the voltage across the capacitor.

Once the amplifier is turned on by the trigger signal, it is held on by feedback current through R39 even if the trigger is removed. As long as the voltage at the emitter of Q9 is low, Q11 is off and there is no current flow through R45 into the inverting input of the amplifier. As soon as the voltage at the emitter of Q9 exceeds two diode-drops (D11 and the base-emitter junction of Q11) above the +9-volt reference at the base of Q11, this transistor starts to conduct causing current to flow through R45 into the inverting input of the amplifier. If the triggering signal has been removed by this time, the amplifier's output resets to a low voltage causing the charge on C12 to drain off through R41, the DECAY control R86 and diode D5 which is forward biased under these conditions. If the triggering signal is still present, it provides enough current into the amplifier's non-inverting input to hold the output high for a sustained interval.

Slide switch S5 provides for either sustained or non-sustained outputs from the function generator by allowing either a direct or capacitively coupled input for the trigger signal. Slide switch S4 provides for a repeat function by allowing the trigger signal from the trigger pushbutton to be replaced by the collector voltage of Q10. Transistor Q10 is a simple inverter stage that changes to a high output voltage when the output of the function generator approaches its lowest level.

Diode D6 provides a discharge path from capacitor C12 back into the triggering network wnen a "mute" function is desired from the function generator (SUSTAIN off, REPEAT on).

VCA

The schematic diagram of the voltage-controlled amplifier is shown in Fig. 5. With the deletion of the components that provide for repeat, the operation of the function generator associated with the VCA is identical to that of the VCF's function generator.

The VCA is a common design employing a differential pair (Q12 and Q13) sharing a common constant current sink in their emitter circuits. Since the gain of a transistor is proportional to its collector current, more current flow through the current sink (Q14) increases the gain of the transistors in the differential stage.

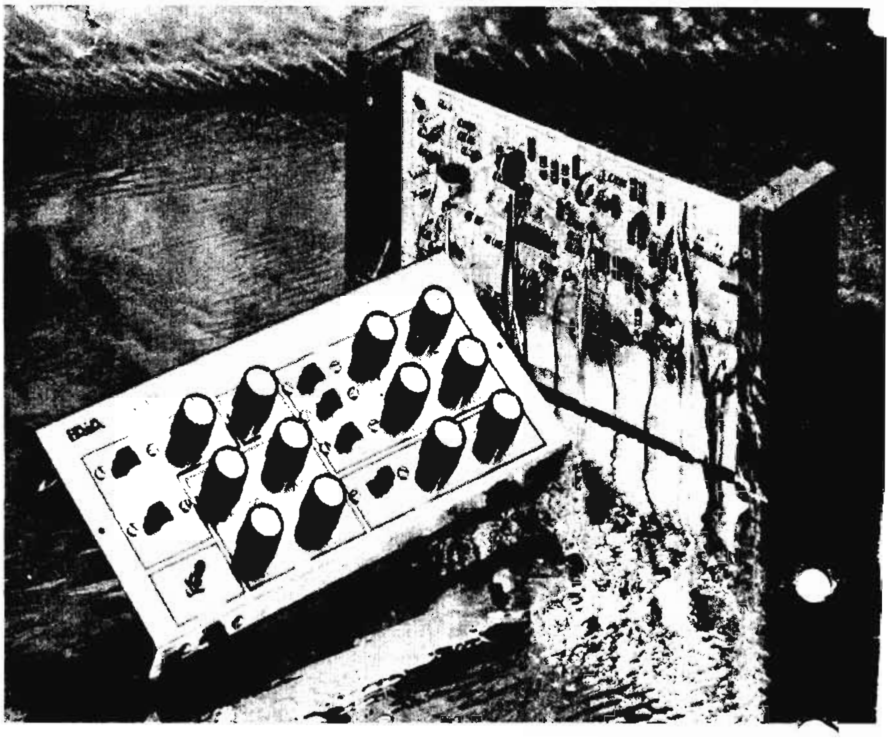
In more expensive VCA's, the differential outputs form the collectors of Q12 and Q13 would be applied to the inverting and non-inverting inputs of an operational amplifier so that the DC voltage level changes associated with increasing and decreasing the gain of the pair would be rejected as a common-mode voltage. In this circuit, the DC voltage changes are cancelled out in R59 and R60 and this is based on the fact that as the voltage at the collector of Q12 drops with increased gain, the voltage at the emitter of Q14 rises by a proportional amount because of current flow through R58. The ratio of R59 to R60 cancels the DC level changes while acting only as an attenuator on the audio signal present at the collector of Q12.

Emitter follower Q15 provides a high input-impedance to the output of the VCA while presenting a desirable low output-impedance to drive the power amplifier being used with the GNOME.

The last two parts of this article will cover the construction details including the foil patterns and component placement diagrams. Also, testing and calibration, and operating procedures will be given.

A short tutorial on synthesizers will also be presented to help the readers understand the principles behind synthesizers.

For Special Music Effects



BUILD A PORTABLE SYNTHESIZER

Part III

Connect this synthesizer to a hi-fi amplifier and you can create your own special music effects.

by JOHN S. SIMONTON, JR.

Last month we covered music synthesizer fundamentals and the operation of the various circuits that make up the GNOME synthesizer.

This month the construction details are presented.

Construction

While complex by virtue of the number of separate elements involved, construction of the GNOME should not be beyond the capabilities of today's average experimenter. For those concerned with the problem of getting all of the electronic and mechanical components together in one place at one time, a kit is offered (see parts list.)

If you decide to go it alone, any of the options available for wiring is appropriate from perf-board to the reproduction of the circuit board shown in Fig. 6. A parts layout for the circuit board is shown in Fig. 7.

Your first step should be to assemble the components mounted on the circuit board, and here all of the standard warnings apply. Watch the polarity of electrolytic capacitors and all semiconductors and be careful of the experimenter's No. 1 gremlin, the heat skunked IC or transistor. Make sure that the circuit board is really clean before you start and use a low-wattage soldering iron (35 watts is more than enough). A socket can be used on the IC, but remember that they really make it easy to get the part in backwards—and once power is applied to an LM3900 that's in a circuit backwards, you'd better start shopping for a new one.

A lot of thought went into eliminating wires running between the circuit board and front panel controls of the prototype. So even if you start from scratch, why not take advantage of some one else's heavy brain work and follow the interconnection scheme shown in Figs. 8 and 9. This means a lot of point to point wiring on the two 9-lug terminal strips illustrated but the alternative is to have a couple of dozen resistors and capacitors on the circuit board that aren't connected to anything but two wires going to a control. Note that in the schematic diagrams, the parts that mount on the front panel rather than on the PC board are enclosed in dashed lines.

In the prototype unit, the case is formed of two pieces of sheet metal; one is U-shaped with a long leg that mounts the controls and point-to-point wiring and the other is L-shaped that covers up the beast's little bottom. The end pieces are wooden blocks cut as shown in Fig. 10. The crossed saw cuts on these end blocks serve the dual purpose of holding the circuit board in the right place and allowing a portion of it to serve as a shelf on which to mount the control strip. At the same time, the front portion of the horizontal cut serves to clamp the control strip in place as shown in Fig. 11.

If you're following the prototype, the control strip should be the last thing that you install. The strip is formed of a material produced by Emerson Cuming, Inc. of Canton, MA. 02021, which they call VF-10. Since these fine people don't sell this material except in 42-inch wide sections (not less than one yard long, please) and since it costs a fortune, you might be better off buying the die-cut strip that is separately available (see parts list). Once you have the strip, thoroughly tin the circuit board control strip contact pads and fasten the strip to the circuit board with double sided tape. Needless to say, make sure that the tape does not cover the control strip contact pads but make sure that it *does* cover the control strip guide line which is etched on the board to assist in alignment of the strip. Note that small screws and nuts mount the "teeth" of the strip down to the circuit board and that this same hardware also mounts the three soldering lugs that are used for connection points for resistors R9 and R10.

To close the unit up, push the wood ends on the circuit board (with sufficient paper shims at the control strip to assure good contact between the strip and the PC board) and fold the top into place. Note that the circuit board mounts in the case upside-down with the foil side of the board facing towards the controls in the top half of the case. Before mounting the bottom panel, go through and check the GNOME with the calibration and verification procedure that follows.

Testing and calibration

There are only three internal adjust-

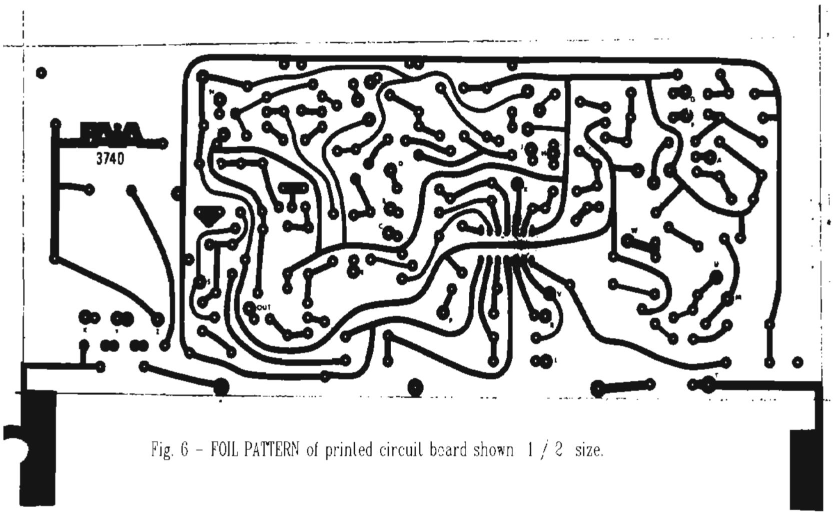


Fig. 6 - FOIL PATTERN of printed circuit board shown 1/2 size.

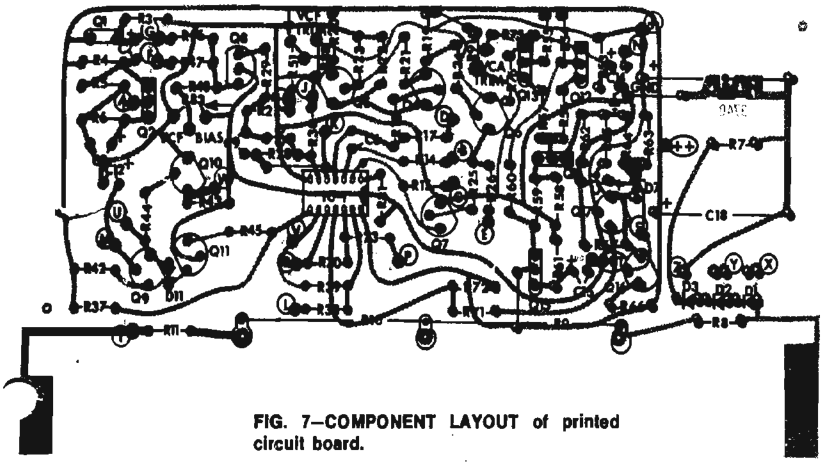


FIG. 7—COMPONENT LAYOUT of printed circuit board.

ments that will need to be made to the GNOME. These adjustments are; balance for the VCA and bias and trim for VCF. The rest of this procedure will be involved with testing the various sections of the GNOME to verify their proper operation.

Snap a pair of heavy-duty 9-volt transistor radio batteries (Eveready #1222 or equivalent) into the battery connectors and use a jumper cable to connect the rear panel output jack of the Gnome to the musical instrument or hi-fi amplifier that you intend using. On most hi-fi amplifiers, either the "aux." or "mag phono" inputs are appropriate.

Before beginning, the calibration procedure, set the controls as follows:

Controller section. Rotate the RANGE control fully counter clockwise to the minimum setting. Set the VCO switch to the off position (opposite direction of arrow in schematic is in all cases considered to be off), VCF switch off.

Noise section. Rotate the NOISE LEVEL control to the minimum position.

VCO section. Rotate SKEW control fully clockwise (CW), RANGE control to minimum, TRIANGLE LEVEL to minimum, SQUARE WAVE to minimum.

VCF section. Set IN-OUT switch to out position, REPEAT switch to off, SUSTAIN switch to off, RANGE control to minimum, FREQ/Q control fully CCW, ATTACK control to minimum, DECAY control to minimum.

VCA section. Set SUSTAIN switch to off, ATTACK control to minimum, DECAY control to minimum.

Turn the external amplifier that you are using on and select the proper input channel. Turn the GNOME on by sliding the front-lip mounted power switch to the on position.

Testing the VCA

Rapidly and repeatedly press the TRIGGER button. You should hear a thump from the amplifier that indicates that the GNOME's VCA is working but needs to

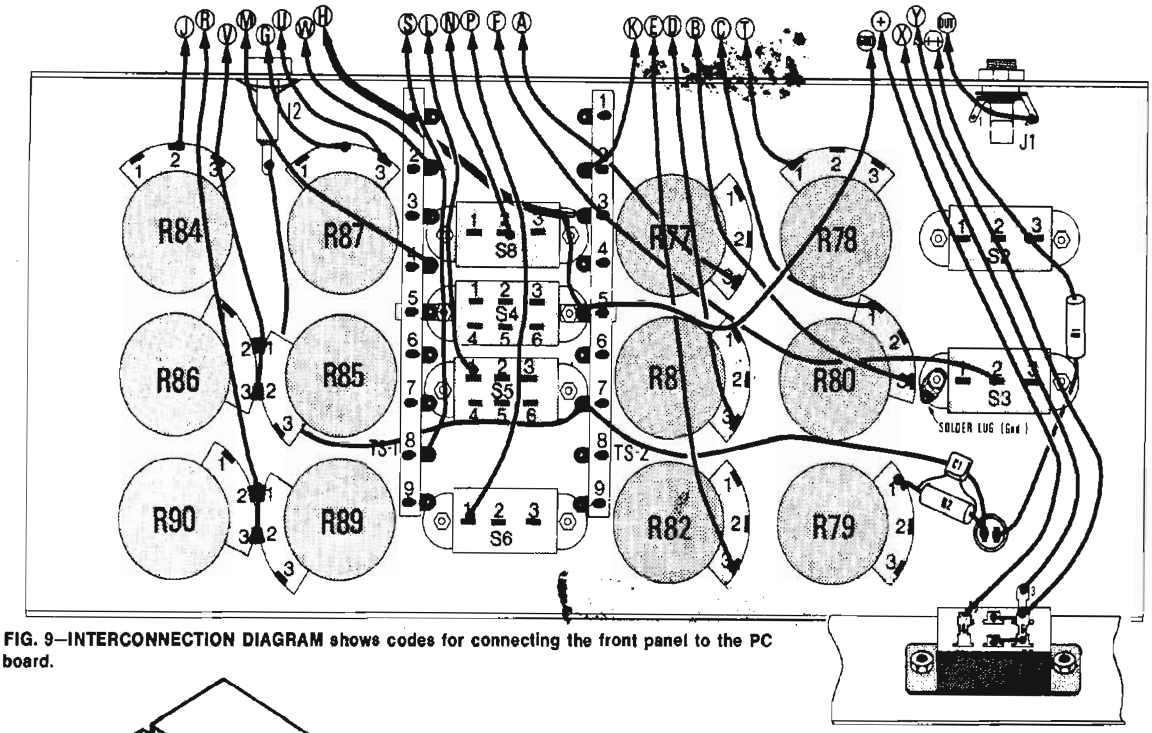


FIG. 9—INTERCONNECTION DIAGRAM shows codes for connecting the front panel to the PC board.

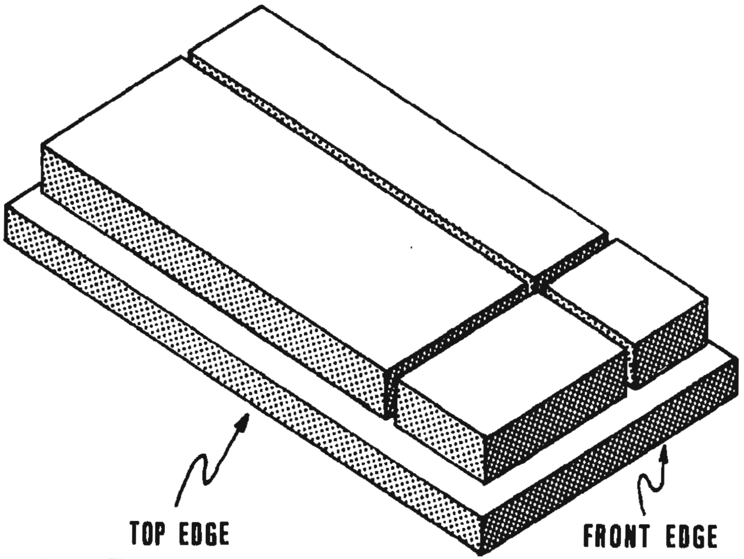


FIG. 10—EDGE PIECES for the GNOME are formed as shown.

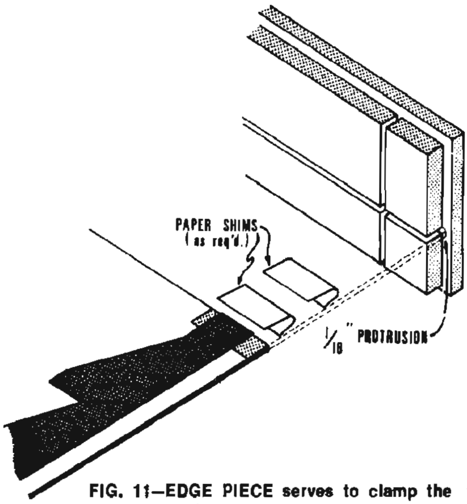


FIG. 11—EDGE PIECE serves to clamp the control strip in place.

be balanced. Again repeatedly press the TRIGGER button while adjusting the circuit board mounted VCA TRIM control. At some point in the rotation of the control, the thump will be minimized. This is the proper setting for this control.

Testing the noise source

Turn the VCA SUSTAIN switch to the on position and set the NOISE control to maximum. Now press the TRIGGER button, you should hear a burst of white noise (hissing similar to inter-station FM radio static) that stays on as long as the TRIGGER button is held down. This indicates that both the noise source and VCA are working properly.

Testing the VCA function generator

Rotate the VCA ATTACK and DECAY controls to maximum and press the TRIGGER button. The noise that you hear should take a little more than a second to build up to a peak volume and then remain at that volume as long as the TRIGGER button is held down. Releasing the TRIGGER button should allow the noise to die away slowly, taking approximately a second to turn off completely.

Turn the VCA SUSTAIN switch off and once again press the TRIGGER button. Observe that now, even though the TRIGGER button is held down, the noise builds to a peak and then immediately begins to die away. Press the TRIGGER button and release it before the entire attack and decay cycle is completed. Observe that as soon as the TRIGGER button is released the sound goes off. This is an automatic muting function that is operational any time the VCA SUSTAIN switch is in the off position. Successful completion of this sequence shows the VCA function generator to be operating properly.

Testing the VCO

Return the NOISE LEVEL control to minimum and advance the VCO SQUARE WAVE LEVEL control to maximum. Return the VCA SUSTAIN switch to its on position and the VCA ATTACK and DECAY controls to minimum. Press and hold the TRIGGER button while advancing the VCO RANGE control toward maximum. During the first 30° or so of the rotation of the VCO RANGE control you should hear nothing. After about 30° of rotation, you should hear a low pitched tone from the amplifier and as the control is advanced further the tone should rise in pitch.

Return the VCO SQUARE WAVE LEVEL control to minimum and advance the TRIANGLE LEVEL control to maximum. Press and hold the TRIGGER button while once again rotating the VCO RANGE control. Once again you should hear a tone that increases in pitch as the VCO Range control goes from minimum to maximum. This tone should be considerably more mellow than the square wave but the frequency range should be the same and you should have the same "dead zone" at the minimum end of the rotation of the RANGE control.

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MUSIC SYNTHESIZER

(continued from page 50)

Leave the VCO RANGE control at some intermediate position so that a steady tone is coming from the amplifier and rotate the SKEW control in a counter clockwise (CCW) direction from the triangle position toward the ramp position. The frequency will increase slightly as the SKEW control is rotated but it should not vary more than a couple of semi-tones. Notice that with the SKEW control set toward the ramp position, the tone is considerably "sharper" than the triangle wave tone.

Set the TRIANGLE LEVEL control to minimum and the SQUARE WAVE LEVEL control to maximum and verify that the resultant tone is the sharpest of all. Successful completion of this sequence verifies the proper operation of the voltage-controlled oscillator.

Testing the VCF

Return the VCO SQUARE WAVE LEVEL control to minimum and the RANGE control to minimum. Slide the VCF switch to the IN position and advance the NOISE LEVEL control to maximum. Set the filter SUSTAIN switch to on. Set the VCF BIAS trimmer R83 fully counter-clockwise as viewed from the *rear* edge of the circuit board (opposite the direction of the arrow) and rotate the VCF TRIM trimmer R88 fully toward you as you look at the circuit board from the rear (opposite direction of arrow). Make sure that the VCF RANGE control is set to minimum and press and hold the TRIGGER button. While listening to the noise, rotate the VCF TRIM trimmer R88 in the direction of the arrow. You should hear the apparent pitch of the noise increase as the passband of the filter sweeps upwards in frequency. Set the VCF TRIM trimmer to the point at which the pitch of the noise just begins to increase.

Rotate the VCF RANGE control to maximum and observe that the pitch of the noise once again increases. Now rotate the VCF BIAS trimmer R83 in a clockwise direction as viewed from the back of the board (in the direction of the arrow) and observe that at some point the pitch of the noise begins to decrease. Leave the VCF BIAS trimmer set at the point at which the pitch of the noise just begins to decrease.

Return the VCF RANGE control to minimum and once again advance the VCF TRIM trimmer in the direction of the arrow until the point is reached at which the pitch of the noise just begins to increase.

Testing the VCF function generator

Set the VCF RANGE control to about half of its rotation and the NOISE LEVEL control to maximum. Slide the VCF REPEAT switch to the ON position and press and hold the TRIGGER button. This setting of the VCF function generator controls (SUSTAIN on, REPEAT on) causes the function generator to trigger itself producing a cyclic sweep of the filter. In this case, the sound produced should be a "swishing" as the filter sweeps up and down over the frequency content of the noise. Observe that the "depth" of this effect increases as the VCF RANGE control is rotated from minimum to maximum.

Note: At this maximum repetition rate (VCF ATTACK and DECAY both minimum) there will probably be some "thumping" from the GNOME. This transfer of the control voltage into the audio channel can be eliminated by reducing the setting of the VCF RANGE control or by slowing the Attack and/or Decay of the VCF function generator.

Observe that as the FREQ/Q control is rotated in a clockwise direction, the overall pitch of the noise increases.

Return the VCF FREQ/Q control to its fully counter clockwise position and the RANGE control to maximum. While holding down the TRIGGER button, advance the VCF ATTACK control to maximum and observe that the pitch of the noise slowly builds up to a peak and then quickly resets and that this effect occurs cyclicly. Return the VCF ATTACK control to minimum and advance the DECAY control to maximum. Observe that now the pitch of the noise goes to a high value and then slowly slides back down scale until again it resets to the high level. Set the VCF ATTACK control to maximum and observe that the filter slowly sweeps up and down scale. **Note:** The VCF RANGE control is designed to have greater effect than is actually needed. If, during this last test, the pitch of the noise seems to increase to a plateau and then hold momentarily before sliding back down scale, it indicates that the RANGE control is too far advanced. Back off on this control slightly and note that the "plateau" is no longer present. Successful completion of this test sequence indicates that both the filter and function generator are operating properly. We will now test the triggering functions associated with the VCF.

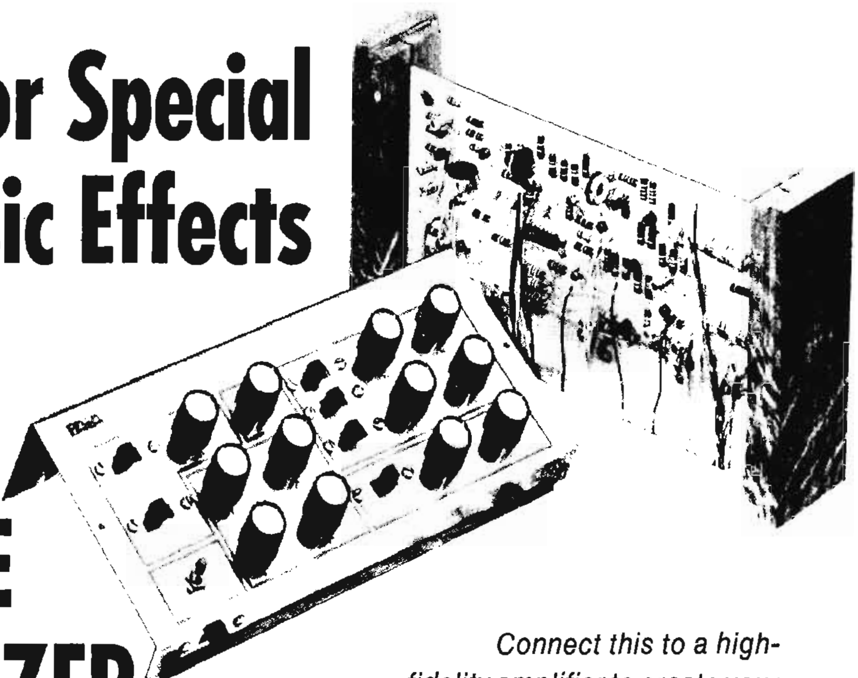
Set the VCF controls as follows: RANGE to maximum FREQ/Q fully counter clockwise, VCF switch to the IN position. REPEAT switch off, SUSTAIN switch off, ATTACK control to minimum, DECAY control to maximum. Press and hold the TRIGGER button. You should hear the noise apparently starting at a high pitch and decaying back to a low pitch, it should not repeat but rather should simply stay at the low pitch until the TRIGGER button is released and pressed again. Set the ATTACK control to maximum and the DECAY control to minimum. Pressing the TRIGGER button should produce a noise that increases in pitch over a period of a second or so followed by a rapid step back to a low pitch. Once again, this pattern should not repeat until the TRIGGER button is released and pressed again. Set the DECAY control to maximum and observe that the pitch of the noise slowly sweeps up and back down each time the TRIGGER button is pressed. Set the VCA DECAY control to maximum, VCF DECAY control to minimum and slide the VCF SUSTAIN switch to its ON position. Press and hold the TRIGGER button. Observe that the pitch of the noise always sweeps up to a high level and remains there until the TRIGGER is released.

Successful completion of these test sequences indicate that the GNOME is working properly.

Next month the article concludes with a short tutorial on synthesizers and the operation of the GNOME synthesizer.

(continued next month)

For Special Music Effects



BUILD A PORTABLE SYNTHESIZER

Connect this to a high-fidelity amplifier to create your own unusual and special music effects.

by JOHN S. SIMONTON, JR.

THE LAST TWO PARTS OF THIS ARTICLE (November and December 1975 issues) covered synthesizer fundamentals, a detailed description of the GNOME and the construction details.

This third and concluding part is a short tutorial on synthesizers.

A short tutorial on synthesizers

Before we get into the operation of the GNOME's controls, a short discussion of synthesizers in general is in order for those whose exposure has been limited.

Every natural sound producing system can be broken down into several separate elements. Ordinarily, the first element in the chain is an energy source. A violin draws energy from the bowing action of the performer, a guitar from the deforming force of the fingers on the strings, and wind and reed instruments from the breath of the musician.

The second element is some means of converting the energy added to the system into periodic oscillations of a pre-determined frequency. In a guitar, the elasticity of the strings cause them to vibrate when deformed and released. In a saxophone the reed converts the steady breath of the musician into a series of pulses.

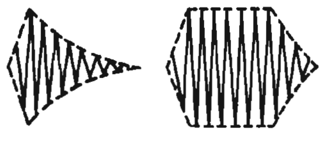
The last element is some means of coupling the oscillations that are occuring in the instrument into the air so that they can be heard. In a guitar, the function is performed by the body of the instrument. In a piano, this is accomplished by the sounding board. The individual characteristics of each of these elements interact to determine how the instrument will sound to a listener.

Dynamics

If the energy is added to the system in a single pulse—as in picking a guitar string or striking the keys of a piano—the instrument is of the percussion family, and all such instruments have the common characteristic of sound intensity at its highest level immediately after the striking action. The period during which the sound output of an instrument is building to its maximum is known as "attack" and this instantaneous rise to a peak is called "percussive attack." In natural percussion instruments, the attack is immediately followed by a "decay" period during which the instrument dissipates the energy that was added by the striking force. During the decay, the sound level falls to zero from the peak it reached during the attack. The decay period may be of short duration as it is in drums or a long duration as it is in pianos. The decay is again a function of the instrument.

If the energy is added in a continuous flow, the attack and decay may be separated by a sustain interval during which time the output of the instrument can be relatively constant. As long as a violinist bows the instrument, sound comes out. As long as the musician's breath holds out he can get a sustained note from his piccolo.

Figure 12 shows an attack/decay and an attack/sustain/decay envelope ("envelope" is a term that designates the behavior of the peak amplitude of the sound). Figure 12-a would be typical of a percussion instrument while Fig. 12-b is the envelope that you would find in wind or brass instruments. Taken together, attack, sustain and decay are known as dynamics and the dynamics of an instrument make by far the largest contribution to how that instrument will be perceived by a listener.



(a) PERCUSSION (b) SUSTAIN

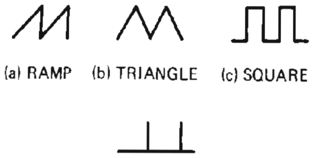
FIG. 12—SOUND ENVELOPES. Percussion envelope is shown in a while sustain envelope is shown in b.

Timbre

But, all instruments that are capable of sustain intervals don't sound alike—a trumpet doesn't sound anything like a flute—so there are obviously other differences as well. Timbre is the term ordinarily used as a label for some of these differences.

The individual timbral characteristics of instruments are the result of two interacting phenomena. First, the "waveshape" of the oscillations produced by the vibrating element and secondly, the resonant characteristics of the coupling device that transfers the energy from the vibrating element to the air.

Not everything vibrates the same way and Fig. 13 shows four examples of the waveforms produced by the "oscillators" in natural instruments. Figure 13-a is typical of the waveform produced by most bowed instruments. This generally is known as a ramp waveform. In a violin, for example, it is caused by the bow grasping a string and deflecting it until the friction of the rosin on the bow is overcome and the string snaps back and is grasped again. Figure 13-b shows a triangle waveform that is typical of the back and forth



(a) RAMP (b) TRIANGLE (c) SQUARE

(d) PULSE

FIG. 13—EXCITATION WAVEFORMS. Ramp waveform shown in a is produced by bowed instruments. Triangle waveform shown in b, square wave shown in c and pulse wave shown in d are produced by wind instruments.

oscillatory motion of the body of air within a flute. Figure 13-c shows a square wave that is usually produced when one or more reeds alternately open and close to allow bursts of the musicians breath to pass into the instrument. Figure 13-d shows a pulse waveform that is often the result of a performer's compressed lips on the mouthpiece of instruments in the brass family. Do not be confused and think that these waveshapes represent the sound of the instrument. These diagrams represent only the way that the vibrating element is behaving, the actual sound results from these waveshapes as modified by the instrument's natural resonator.

Figure 14 shows a sine wave. A sine wave is sort of a strange beast because while there are almost no natural instruments that produce it, it is the only pure tone and all of the waveforms shown in Fig. 13 (in fact any periodic waveform) can be broken down into sine wave components. The number, amplitude, frequency and phase of the various sine waves required to produce non-sinusoidal complex waveforms are ordinarily called the harmonic structure of the waveform. Harmonic structure is a concept that is critical to complete understanding of sound synthesis but in the interest of brevity cannot be covered here.


FIG. 14—SINE WAVE contains no harmonics and is a pure tone. It is not produced by natural instruments.

Every physical object that exists will vibrate when exposed to an energy source. Every physical object has certain frequencies at which it tends to vibrate better than others. The object is said to be "resonant" at these frequencies. If the energy applied to the system is the same as one of the resonant frequencies of the object, then the object will vibrate more energetically than when the energy source is not at one of the resonant frequencies.

The body of the musical instrument contains resonant chambers that filter out the non-resonant frequencies. Because of this filtering property, waveshapes consisting of various sine-wave harmonic-content go into one end of an instrument and come out the other with the sine wave frequencies of the waveshape accentuated if at resonance and attenuated if off resonance. Because the amplitude of the sine wace components are altered, the waveshape is altered. Square waves go into one end of a saxophone and a "ringing" waveform such as the one represented in Fig. 15 comes out (Note: Fig. 15 is an exaggeration for illustration purposes only, the output of a saxophone is much more subtle than that shown). In some instruments, the characteristics of the resonant chamber are constant, as in stringed instruments. In other instruments—wind and brass instruments for example—the parameters of the resonators must be altered to even closely approximate an equally tempered musical scale.

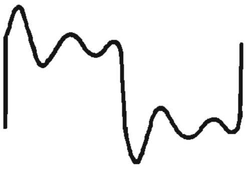


FIG. 15—RINGING WAVEFORM produced by a saxophone excited by a square wave.

Synthesizers

Now that we have some idea of how the mechanical properties of a musical instrument determines the reproduced sound, we will look at how electronic circuits can be used to create those mechanical properties.

The electronic equivalent of vibrating strings, reeds, etc., is the oscillator. Just as the different types of vibrating elements in natural instruments can produce a variety of waveforms, so can the electronic oscillators in synthesizers. Must synthesizer oscillators are capable of producing at least ramp, triangle and pulse waveforms with the added capability of making the pulse so broad that it becomes a square wave. Many synthesizer oscillators can also produce a sine wave, but since a pure tone doesn't appear very often in natural instruments, a sine wave from a single oscillator isn't very interesting in electronic music. In any case, a triangle wave is very close to the same sound as a sine wave.

The pitch of natural instruments is determined by the length of the vibrating string, the pressure on the reeds or the configuration of the musicians lips and

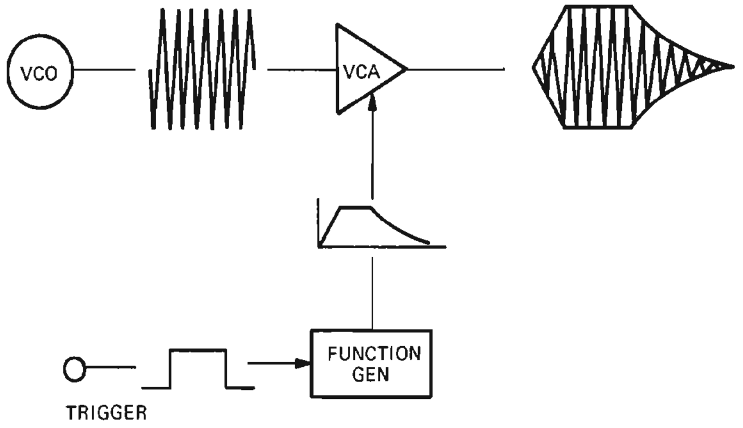


FIG. 16—INSTRUMENT DYNAMICS are simulated by a function generator and a VCA.

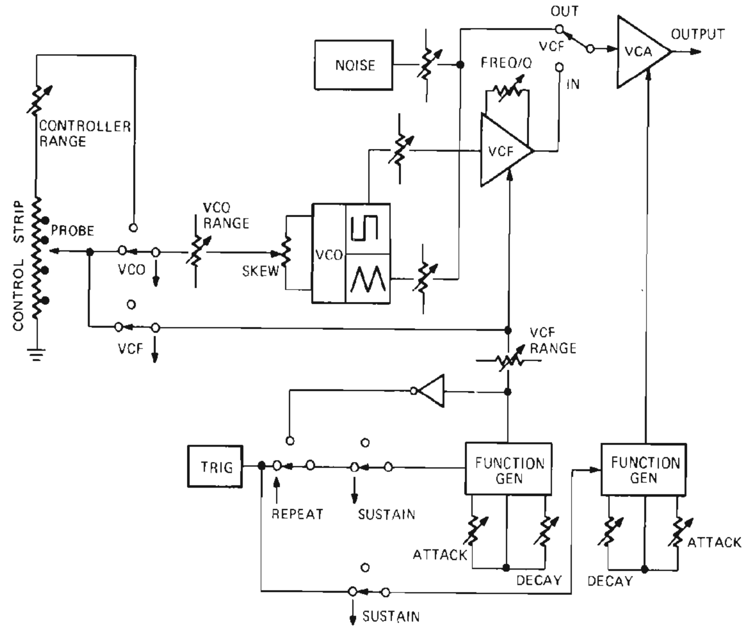


FIG. 17—SIGNAL AND CONTROL PATHS in THE GNOME.

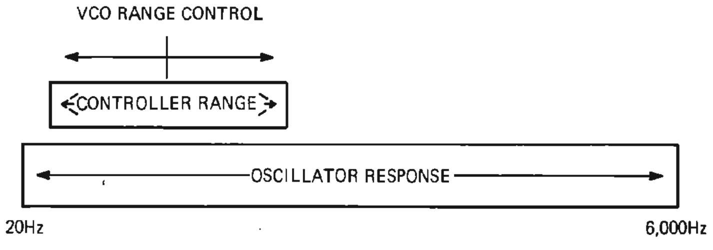


FIG. 18—CONTROLLER CIRCUIT controls the operation of the oscillator.

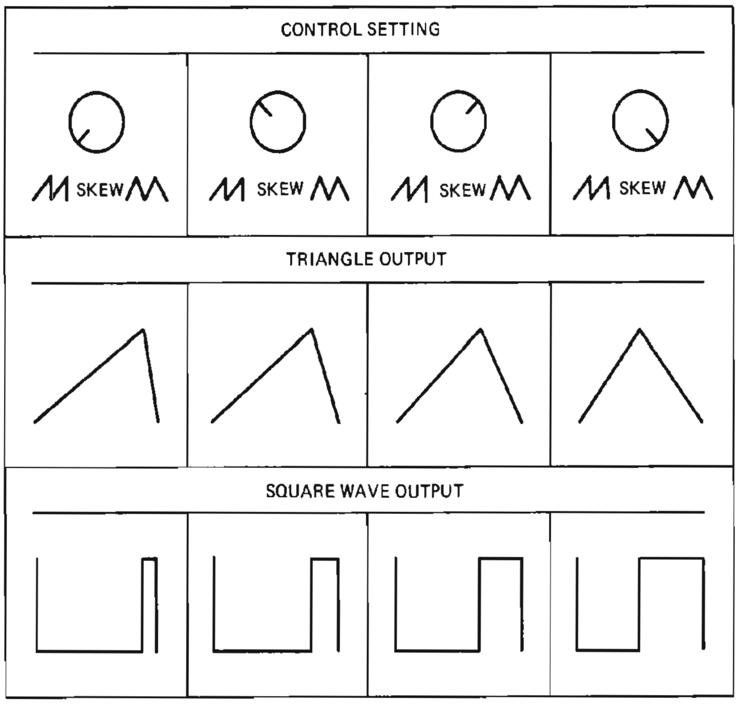
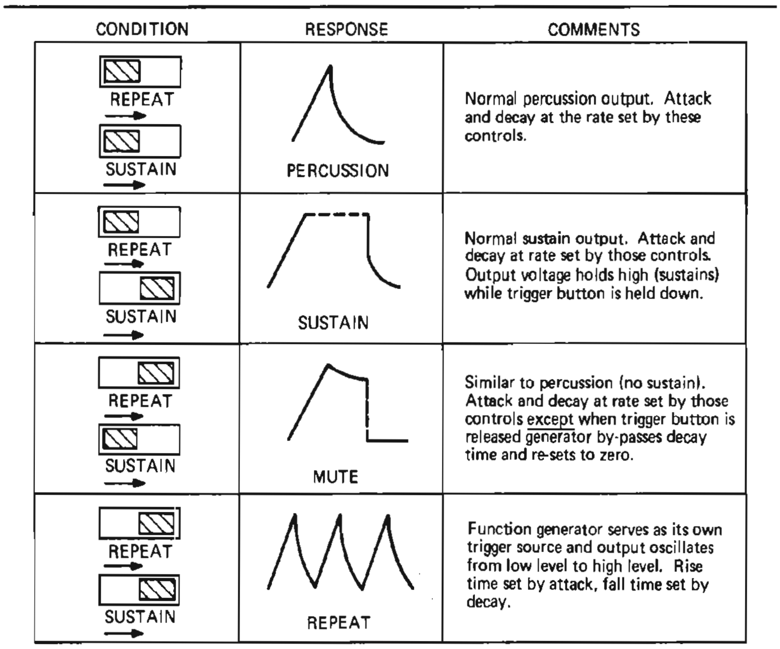
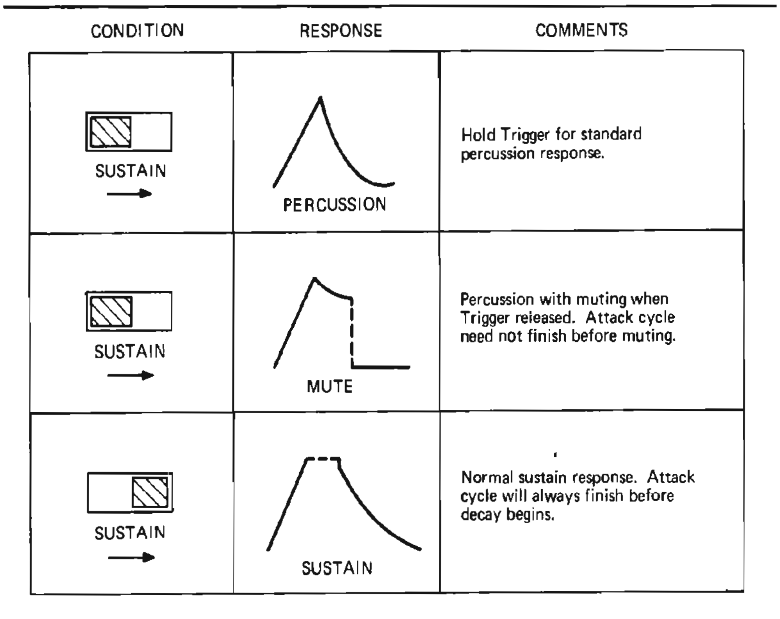


FIG. 19 (top left)—EFFECTS of varying the skew control.



CONDITION	RESPONSE	COMMENTS
REPEAT SUSTAIN	PERCUSSION	Normal percussion output. Attack and decay at the rate set by these controls.
REPEAT SUSTAIN	SUSTAIN	Normal sustain output. Attack and decay at rate set by those controls. Output voltage holds high (sustains) while trigger button is held down.
REPEAT SUSTAIN	MUTE	Similar to percussion (no sustain). Attack and decay at rate set by those controls except when trigger button is released generator by-passes decay time and re-sets to zero.
REPEAT SUSTAIN	REPEAT	Function generator serves as its own trigger source and output oscillates from low level to high level. Rise time set by attack, fall time set by decay.

FIG. 20 (middle left)—EFFECTS of the sustain and repeat switches.



CONDITION	RESPONSE	COMMENTS
SUSTAIN	PERCUSSION	Hold Trigger for standard percussion response.
SUSTAIN	MUTE	Percussion with muting when Trigger released. Attack cycle need not finish before muting.
SUSTAIN	SUSTAIN	Normal sustain response. Attack cycle will always finish before decay begins.

FIG. 21 (bottom left)—EFFECTS of the sustain.

properties of the resonant chamber. In synthesizers, the pitch (frequency) of the oscillator is determined by the magnitude of a control voltage applied to a voltage-controlled oscillator (VCO).

Control voltages can be derived from a number of possible sources including strip controllers (as with the GNOME), keyboards, programmable sources of various types (sequencers, function generators, etc), foot pedals and so on. All of these controllers have in common the fact that some action on the part of the operator produces predictable changes in the controller's output voltage.

In the simulation of an instrument's dynamics, synthesizers diverge slightly from their counterpart mechanical systems. It would be natural to assume that the oscillator is "keyed" or "triggered" in some sort of way to make its attack and decay simulate the natural instrument equivalent. In fact, the output of the oscillator is constant and the building up and dying away of the sound is implemented by varying the gain of an amplifier. As you can imagine, it would be at best cumbersome to twiddle the knob of an amplifier fast enough to simulate percussive attack but here again voltage control comes to the rescue in the form of a voltage-controlled amplifier (VCA).

In synthesizers, the gain of the amplifier is made proportional to the magnitude of a control voltage and in most cases this controlling voltage is generated by a programmable function generator.

A function generator is simply an electronic circuit that in response to a triggering signal produces a voltage that rises to pre-set level in an amount of time set by one control knob (ATTACK) and then falls back to zero in an amount of time set by a second knob (DECAY). Sustain is ordinarily handled by keeping the triggering signal on for the desired sustain interval.

Figure 16 shows a typical example of an oscillator feeding a VCA that is being controlled by a function generator to produce a desired envelope.

This leaves us with only one of the most basic natural properties to simulate—timbre. As with mechanical instruments, many of the timbral properties of a sound are the result of the excitation waveform produced by the vibrating element in the instrument and the remainder of the timbral properties are the result of the characteristics of the resonator that couples those vibrations to the air. Earlier we discussed the filtering characteristics of natural resonators because we were leading up to the use of an electronic filter as an equivalent circuit for this mechanical property.

The type of electronic filter used in the GNOME is the bandpass filter. A sinewave applied to the input of bandpass filter will pass through relatively unchanged if it is at this center frequency of the filter but will be attenuated if at some other frequency. Similarly, the sine

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SYNTHESIZER

(continued from page 48)

wave components of a complex signal that are within the pass band of the filter will be unchanged while the components outside the pass band will be attenuated, thus producing a planned and controlled "distortion" of the complex waveform.

Since many natural instruments depend upon the characteristics their resonators being changed to produce different tones, there must also be some means of controlling at least the center frequency of a synthesizer's filter. As you might expect, voltage control is the answer.

Control voltages for a voltage controlled filter (VCF) can originate from basically the same sources as those that control the oscillators. If the center frequency of the filter is to change with the changing pitch of the oscillator, the same voltage that is controlling the oscillator can also be routed to the filter. For the "waa-waa's" that are characteristic of electronic music, the control can originate in a function generator.

Noise

So far in our analysis we have dealt exclusively with "pitched" sound sources —sources that have a readily discernable frequency and therefore an easily recognized musical pitch. There are also "unpitched" sources.

The concept of an unpitched musical sound may at first seem as esoteric as the sound of a clapping hand, but it is actually very easy to understand. The hiss that you hear from an FM radio that is tuned between stations is an unpitched sound and most synthesizers have provisions for a noise source that produces just this effect. From a technical standpoint, it is the result of summing together randomly varying amplitudes of all possible frequencies within a given frequency band.

The applications of noise are very broad. For example, the sound of the snares of a snare drum is noise with a percussive envelope. By processing noise through the proper filters, the sounds of the surf and wind are easily simulated.

So, now we know a little bit about how musical instruments work and how electronics can be used to simulate the properties of these instruments—let's look at the GNOME and begin applying some of these principles.

The GNOME

In the early days of synthesizers, each element of a system was a free-standing module and the specific electrical connections were made using patch cords. Patch cords allow great flexibility but the laborious task of setting up patches for each voice is a disadvantage to most performing musicians. In a small system that will not be expanded beyond a specific capability, a normalized connection (one in which a specific arrangement of elements is pre-wired) is definitely the way to go.

Figure 17 shows the signal and control paths through the GNOME. The VCO always feeds the input of the VCF and the VCA can get its input either directly from the VCO or from the output of the VCF. The control voltage for the VCA always comes from the function generator. The control voltage for the VCO can come either from the self-contained controller or the power supply and is adjustable with the VCO RANGE control. The VCF control voltages can come either from the function generator or the controller, or both. This is a fairly typical normalization scheme for small synthesizers and while it unquestionably limits the versatility of the machine, the limitations are minimal and entirely consistent with the inherent limitations of the simplified, low cost circuitry of the GNOME.

Controls

The front panel nomenclature of the GNOME is such that the controls are divided into six sections corresponding to the six major circuits that make up the unit. These sections are:

1. Controller
2. Trigger
3. Noise Source
4. Voltage Controlled Oscillator
5. Voltage Controlled Filter
6. Voltage Controlled Amplifier

Controller section

The built-in control strip is nothing more than an exposed resistance element that has one end grounded and a positive voltage applied to the other end. The sawtooth cuts on the resistance strip along with the paralleling resistors inside the case combine to produce a voltage distribution along the control strip that is exponential. If it were not for this exponential voltage distribution at the control strip, semi-tone intervals at the low end of the strip would seem to be bunched together while those at the top end of the strip would be spread apart. This relates back to the distribution of semi-tone intervals in the equally tempered musical scale.

The Controller RANGE potentiometer varies the voltage that appears across the control strip. At the maximum position of this control, the strip is a little less than 4 octaves long while at the minimum setting it is slightly more than ½ octave long. As we shall see later on in this article, the Controller and VCO RANGE controls interact to place the musical "length" of the controller at any desired position within the oscillator's 8 octave range.

The two slide switches within the controller section of the front panel connects the voltage that is picked off the control strip by the wiper probe to either the VCO or VCF, or both. Sliding the switch bat in the direction of the arrow connects the voltage to the element indicated.

Trigger

There is only one control within the trigger section of the front panel and that is the TRIGGER button. Whenever this button is pressed, a voltage is applied to the triggering inputs of the function generators associated with the VCF and VCA. Provisions have been made internally to reduce multiple triggering caused by "noisy" switch contacts, but a firm pressure on the button is needed to prevent contact bounce.

Noise source

The single control within the noise section of the front panel is a LEVEL control that determines the amount of white noise that will appear on the common audio bus. At the minimum position of this control, the noise source is isolated from the bus and the noise level increases with clockwise rotation toward maximum.

VCO

The RANGE control within the VCO section of the front panel is an attenuator on the control voltage input line of the oscillator. It is useful in a number of different ways. When the Controller VCO switch is off, a constant voltage is applied to the VCO RANGE control allowing the oscillator to be set to some constant pitch that is independent of the controller action.

When the Controller VCO switch is on, the VCO RANGE and Controller RANGE controls can be used together to set the highest and lowest pitches available from the control strip. Figure 18 illustrates this by using a bar to represent the total 8 octave range of the oscillator. The double ended arrow above the bar represents the range of the control strip. Rotating the Controller RANGE control toward maximum increases the length of the double ended arrow across the width of the bar. For example, with both controls set to maximum, the range of the controller is approximately from 600 Hz to 6500 Hz. If the Controller RANGE control remains at maximum, the controller will remain a little over three octaves long but reducing the VCO RANGE can cause these three octaves to run from 30 Hz to 350 Hz. **Note:** The same slight non-linearities that in most circumstances make the GNOME oscillator incompatible with keyboards will also make the length of the control strip variable depending on the setting of the VCO RANGE control, but under normal circumstances these errors will not be noticeable or objectionable.

At the minimum setting of the RANGE control, the oscillator is off regardless of the condition of the controller or the setting of the Controller VCO switch.

The SKEW control is a little unusual for synthesizers but it allows the GNOME's simple VCO to produce 4 basic waveforms (triangle, ramp, square wave and pulse) while also making available a wide range of waveforms in between the four. Figure 19 shows the effect of this control. Clockwise rotation changes the ramp wave to a triangle and the narrow pulse to a square wave. There is some shift in oscillator pitch associated with the rotation of this control from one end of its travel to the other. This deviation is maximum toward the center of the range of the control with the two extreme ends being within a semi-tone of the same pitch.

The triangle control determines the amount of ramp/triangle waveform applied to the common audio bus. The level increases with a clockwise rotation of the control.

The square wave control determines the amount of pulse/square wave applied to the common audio bus. The level increases with a clockwise rotation of the control.

VCF

The voltage controlled filter may be eliminated from the audio path entirely by setting the IN-OUT switch to the OUT position.

There are four possible combinations of settings of the REPEAT and SUSTAIN switches and each of these combinations produces a different response. These combinations are most easily explained in tabular form as shown in Fig. 20.

The RANGE control within the VCF section of the front panel is an attenuator on the output of the VCF's function generator. It varies the amount of control voltage applied to the filter from the *function generator only.* Since the response of the filters will vary from one unit to the next, this control is designated so that rotation fully clockwise to MAX provides a control voltage greater than the maximum range of the filter. This assures that maximum range will be available on all units. Voltages originating from the controller when the Controller VCF switch is on are not connected through this RANGE control.

The ATTACK control within the VCF section of the front panel determines the time required for the filter's function generator output to rise to its peak. The range of this control is from .005 seconds at the minimum setting to a little over 1 second at maximum.

The DECAY control determines the time required for the output of the filter's function generator to fall from the attack peak back down to no output. The range of this control is the same as the ATTACK control.

The FREQ/Q control is the only control that actually makes some change to the filter itself. Clockwise rotation of this control raises the frequency of the filter while simultaneously decreasing the Q and increasing the loss of the filter. It is normal for the volume of the sound to decrease as the FREQ/Q control is rotated in a clockwise direction.

VCA

The SUSTAIN switch within the VCA section of the front panel serves roughly the same function as the SUSTAIN switch does for the VCF. With the SUSTAIN switch off (switch to the left), pressing the TRIGGER button will cause the VCA's function generator to attack and then immediately decay. As long as the TRIGGER button is held down, the attack and decay times will be as set by these controls. When the TRIGGER is released, a "muting" function takes over and quickly turns the VCA off.

Turning the SUSTAIN switch on (to the right) causes the function generator to hold at the peak level as long as the TRIGGER button is held down. Releasing the TRIGGER now causes the envelope to decay at the rate set by the DECAY control. These responses are tabulated in figure 21.

The ATTACK control determines the amount of time required for the output of the amplifier to build to a peak. The range of this control is from .002 seconds at minimum to slightly more than one second at maximum.

The DECAY control determines the amount of time required for the amplifier to turn off. The range of the control is from .005 seconds at minimum to slightly more than one second at maximum.

There are two jacks on the back of the GNOME case. The miniature phone jack is the output and it requires a standard miniature phone plug for connections. Coaxial cable should always be used to connect the GNOME output to the input of the amplifier being used.

The black pin jack on the rear edge of the case is an external trigger input. For best operation, the trigger voltage applied to this jack should exceed 8 volts but trigger voltages greater than 4 volts will produce a triggering action (triggers less than 8 volts will not allow the function generators to go to their maximum level). External triggering voltages must be referenced to the GNOME case ground. **R-E**

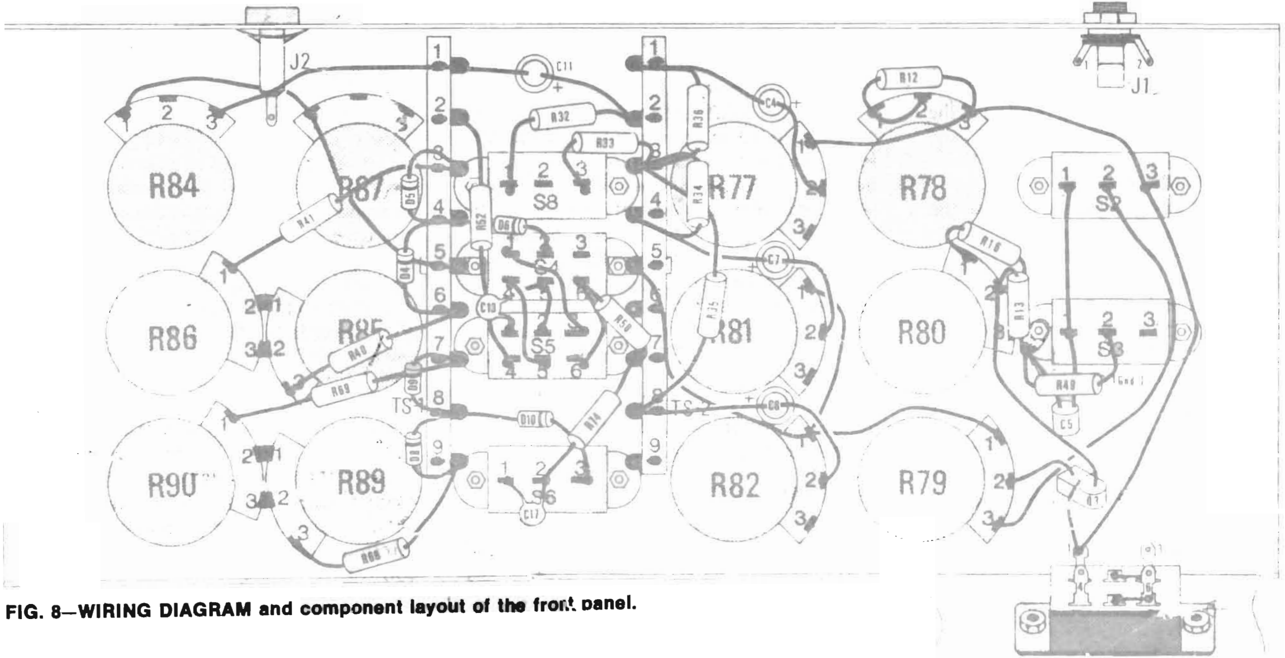

FIG. 8—WIRING DIAGRAM and component layout of the front panel.