BUILD THIS

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String Synthesizer

An introduction to the latest innovation in electronic music synthesizers. The string synthesizer gives the soloist and small groups the background needed to enhance the performance.

MARVIN JONES

STRING SYNTHESIZERS, AND THEIR RECENT popularity, represent the culmination of over a decade's worth of work in developing and improving electronic music synthesizers. String synthesizers are the first of what we expect will be a long line of special-purpose instruments designed to avoid the clutter of patch cords and a strong technical background required to run the early breeds of synthesizers. Recent surges of interest in guitar and drum synthesizers indicate that these instruments will follow in the string synthesizers' path.

It is very natural that the string synthesizer was the first special-purpose synthesizer to come along. Since the inception of popular music, one of the staples of the "[illegible] record" sound has been the lush, flowing orchestrated backgrounds. Unfortunately, few vocalists and solo musicians do well enough to allow hiring orchestras to perform live. Thus, the lush background was always missing in concerts. Organs helped, but weren't quite the same. Then there's always the problem of being able to afford an orchestra for the recording session in the first place! String synthesizers have changed all that. Now musicians are using these units to perform anything from country music to avant garde, in locations ranging from your neighborhood bar to Madison Square Garden!

Strangely enough, the basic circuitry in a string synthesizer is more a result of combo organ technology than of synthesizer technology. The rich moving sounds they produce are so powerful that most anyone (musician or not) gets a kick out of playing with them. And all the commercially available units use the same basic circuitry to achieve the effect of violins and cellos 'en masse.'

This article will describe how to build a professional-quality string synthesizer, but first let's take a look at how these magical machines are used, and then discuss how the circuitry works. The model 1550 synthesizer is of particular interest since it is available in kit form as well as assembled, and there are a number of options available such as stereo outputs and a microprocessor interface card. The instrument also produces a percussive electric-piano voicing.

How it is used

The majority of the features on string synthesizers can be found on the front

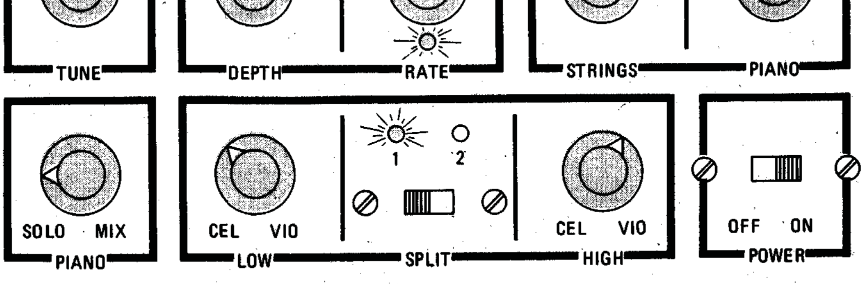


FIG. 1—LAYOUT OF THE CONTROL PANEL. It is operated with the left hand. Five jacks are provided for output and interfacing connections.

panel of the instrument. The front panel of the model 1550 is shown in Fig. 1. All connection points for outputs and interfacing are in the top row of the panel, and are provided via five ¼-inch phone jacks. The bottom two rows of the panel provide the multiple user controls which alter and mix the various voices of this instrument.

The GATE jack provides a voltage which steps from 0 to about +9 volts whenever a key is pressed on the keyboard. This allows the instrument to trigger external effects or processing equipment such as synthesizer modules. Many of the standard synthesizers manufactured today have an array of "systems interfacing" jacks to allow external signals to be processed and become the basis for more complex sounds with polyphonic synthesizer textures. When string synthesizers are used in this way, it is easy to synthesize "brass" sounds, and other special effects using the circuitry inside the synthesizer in conjunction with the string synthesizer.

There are two signal outputs on the stock synthesizer. The first is the MIX output, or the master output. At this jack will appear the sustained string voices plus a variable mix of the electric piano sound. The second output provides only the PIANO signal. This output is useful if you wish to use separate mixing, equalization, or special effects for the two different voicings. When using a standard ¼-inch 2-conductor phone plug in the PIANO jack, the piano signal is automatically removed from the composite signal at the MIX jack. This allows complete separation of the two types of signals if desired. Alternatively, you could use a ¼-inch 3-conductor phone plug which has no connection made to the ring section of the plug. The piano signal will appear now at both output jacks, with the user selecting either or both outputs with the PIANO mix control (explained later).

The SUSTAIN jacks allow provisions for remote control of the amount of time it takes for a signal to fade out once the key is released. For those of you familiar with synthesizer terminology, this would actually relate to the "release" control on an ADSR (*A*ttack, *D*elay, *S*ustain, *R*elease) envelope generator. Note that there are separate, fully variable sustain controls for each of the two types of signals—string and piano. Some commercial units have only a long/short sustain switch, or no control at all. The most common use of the sustain jacks will be for sustain foot switches, which will operate much like the sustain pedal on an acoustic piano. When the two conductors of the jack are shorted together, the front panel sustain control will operate normally to set the minimum sustain time. When the foot switch contacts are opened, the sustain time increases to maximum as though the front panel control were turned to maxim[illegible] For the foot switch itself, a norma[illegible]

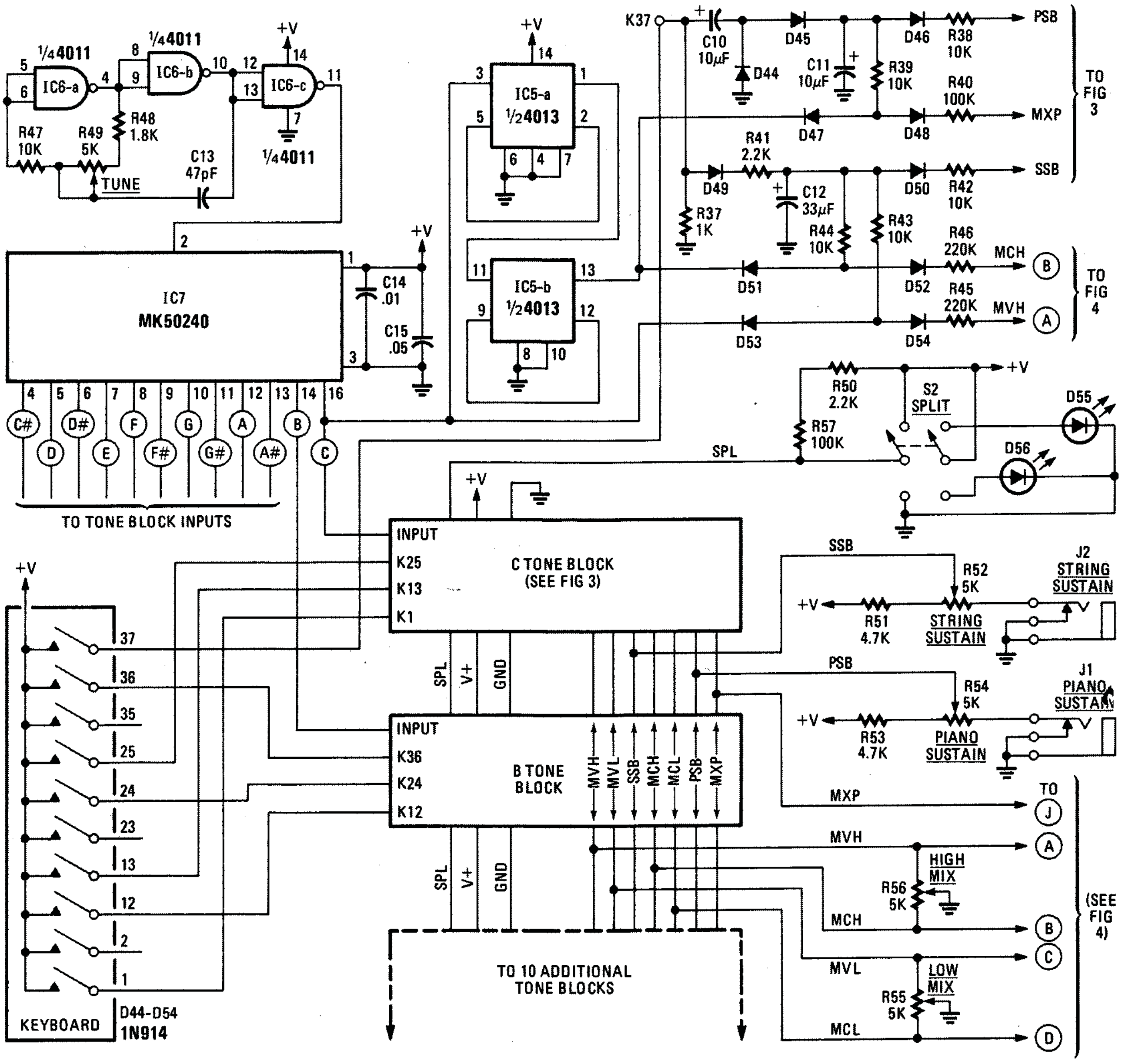


FIG. 2—BASIC SCHEMATIC for the main section. This circuit contains the twelve identical tone blocks that develop the shaping, keying and mixing for the three octaves of each note.

closed momentary-contact switch can be used to provide action similar to acoustic piano sustain pedals, or a positive contact switch can be used to provide push-on, push-off sustain control action.

Internal design of the model 1550 synthesizer allows for use of variable foot pedals (such as pedal volume control voltage (0 to +5 volts) to remotely program the sustain times for either of the voices. This allows all the versatility of the front panel controls without requiring the musician to remove his hands from the keyboard.

The TUNE control is fairly standard. It allows the instrument to be tuned to other instruments, yet provides a full octave of transposition so you can extend the range of the instrument for special compositions. With a little practice, the TUNE control can even be used as a performance device, allowing orchestral glides or pitch bends for special effects.

Perhaps the most important and powerful controls on the model 1550 (or any string synthesizer) are those controls that allow the user to modify the operation of the chorusing and vibrato circuits. These controls are important in allowing each musician to alter the basic string sound to suit musical requirements or individual tastes. Unfortunately, this is where many commercial units fall short in the eyes of musicians. The chorusing circuitry is responsible for taking the single "reedy" voice of the organ circuitry and making it sound as if there are a great number of simultaneous voices occurring. This effect is obtained by using analog delay lines to generate two "echoes" of the original signal. The time delay is so short (constantly varying between 0.5 ms and 20 ms) that it is not heard as a distinct echo. Rather, it appears as if there is another instrument playing in unison with the original voice. With two delay lines, we can generate three-voice chorusing which is sufficient to confuse the human ear into believing it is hearing a large number of voices. By now you should see why this circuitry is so important to the effective generation of orchestral effects.

This synthesizer provides two controls for user alteration of chorusing effects. DEPTH determines the amount of chorusing in the effect. At minimum setting, there is no frequency modulation occurring at all, yielding a bland reed-organ voice. This would be useful for basic combo organ effects, or for external processing as mentioned earlier. As the DEPTH control is advanced, the two delayed voices are frequency modulated by an increasing amount. At approximate mid-rotation, the typical string chorus with vibrato is achieved. Further rotation of the control creates very heavy vibrato and pitch deviations of about a semi-tone for special effects.

The RATE control varies the speed of pitch fluctuations (vibrato) in the chorusing circuitry. At minimum, the vibrato is so slow that it is not heard as actual pitch variations but as a rich, ethereal rolling effect similar to several phase shifters or flangers sweeping simultaneously. This control setting provides a thick pipe-organ effect that is actually spine-tingling! As it is advanced, the vibrato rate increases through normal settings to fast quivering vibrato for special effects. The adjacent LED indicates the speed of one of the low-frequency vibrato oscillators for use as a visual guide of control settings when you are on stage or in the studio.

The PIANO SOLO/MIX control is used to send the piano voice to either the master MIX output, or to the solo PIANO output. The control acts as a panning control, so the signal can be applied to the two outputs in any blend. When using only the MIX output, the PIANO control will act as a volume control for the amount of piano signal available in the master mix. When a standard 2-conductor ¼-inch plug is used to carry the piano signal from the PIANO jack, the piano signal is disabled from the MIX jack and the PIANO MIX control will act as a volume control for the amount of signal appearing at the PIANO jack. When a 3-conductor plug is used (with no connection to the ring) for the piano output, the PIANO MIX control acts as a panning control to send variable amounts of piano signal to the two outputs. Interesting stereo imaging effects can be obtained with this configuration.

The large box of controls centered in the bottom of the panel is used to design the string voicing you desire. The SPLIT switch is used to select the point at which the keyboard can be divided. At position 1, the keyboard voicing will be split at the first octave. In position 2, the keyboard will split at the second octave. LED's show the selected split location at a glance. Once the split function is selected, the LOW mix control will set the desired blend of violins and cellos for all keys *below* the selected split position. The performer can select violins only, cellos only, or any combination of the two. It should be mentioned here that the cellos are 2 octaves lower than the violins.

The HIGH mix control serves a similar function for all keys *above* the selected keyboard split point. With these controls, you can easily configure the keyboard for the type of music you will be playing. For example, if the composition uses simple droning cello parts, but a violin part that moves and jumps over a wide range, then you would set the split switch for the first octave, and set the LOW mix for cellos and HIGH mix for violins. An infinite variety of voicings are available with these controls. The string mix and split controls take on added power when the stereo output is added to the unit. With the option installed, the selected split location can also become the point at which the stereo effect is split. Or, in an alternate stereo operation mode, the violins can be routed to one side and cellos to the other side. In this mode, the LOW and HIGH mix controls are instrumental in determining the "width" of the stereo effect by determining the violin/cello content of each half of the keyboard.

How it works

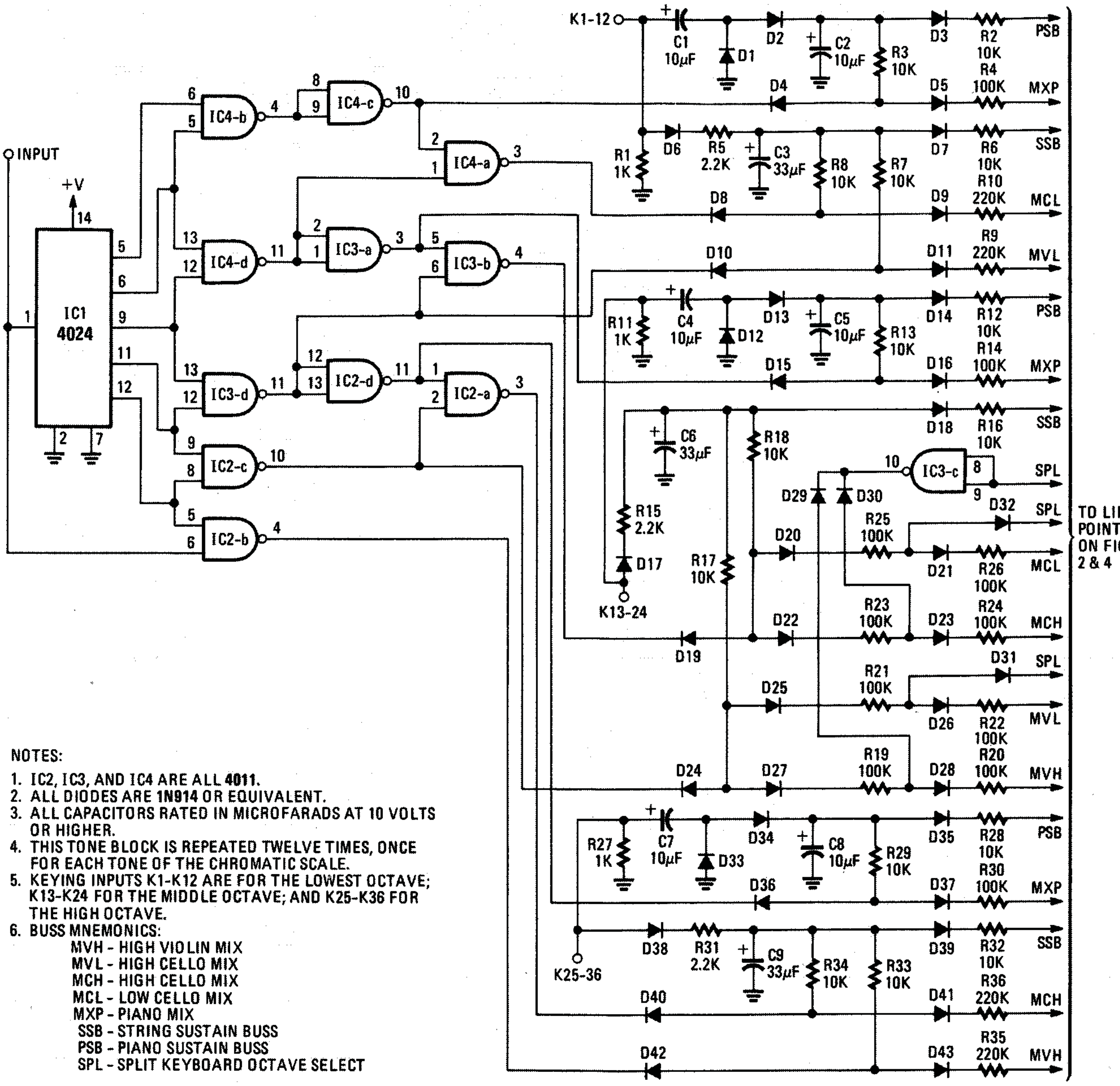
The schematic for the main circuit is shown in Fig. 2. Three of the four gates in IC6 generate a high-frequency clock signal (around 1 MHz.) This clock signal is applied to the Top-Octave Generator, IC7, where it is divided by the twelve integers required to produce the twelve equally tempered frequencies of a scale. These frequencies will be divided into the lower octaves inside each of their respective tone blocks. Since the keyboard used in this synthesizer is actually 3 octaves plus one note (the highest "C"), additional circuitry must be provided for the tone generation of that extra note.

IC5 and associated resistors, capacitors, and diodes provide this function. This circuitry works exactly like the circuitry in the Tone Blocks, and will be discussed later. The additional circuitry in Fig. 2 shows the operation of the various front panel controls. The SPLIT switch, S2, generates a high (+V) or low (ground) logic signal which represents a high or low keyboard split location, respectively. The second section of S2 controls the LED SPLIT function indicators. Sustain controls, R52 and R54, generate control voltages that are variable from 0 to about +5 volts.

The selected control voltage is applied to the buses that run along the edge of the tone block circuit boards. Thus, this voltage is a master control that effects the sustain time of all thirty-seven notes of the keyboard. The sustain jacks, J1 and J2, provide an interrupt function for the sustain control voltage. When a plug is inserted into a jack, the voltage on that sustain bus can be remotely varied or switched (shunted) for variable sustain function. The MVH, MVL, MCH and MLH string voice signal buses (*M*ix *V*iolins *H*igh, *M*ix *V*iolins *L*ow, *M*ix *C*ellos *H*igh, and *M*ix *C*ellos *L*ow) are applied to mix controls, R55 and R56.

With these controls, the signals can be shunted to ground in the desired proportions. The resulting mixtures of string voices, as well as the raw piano-bus signal, is fed to additional circuitry for final processing.

In Fig. 2, also note that +V is applied to the common bus of the keyboard, and depression of any key provides, in effect, a logic signal to the tone block circuitry. A positive voltage designates a key being played. The open circuit of a released key is pulled back to ground by an input pull down resistor at each keying input of each tone block. Master buses running throughout the tone blocks also distribute +V, ground, and the split logic signal.



NOTES:

1. IC2, IC3, AND IC4 ARE ALL **4011**.
2. ALL DIODES ARE 1N914 OR EQUIVALENT.
3. ALL CAPACITORS RATED IN MICROFARADS AT 10 VOLTS OR HIGHER.
4. THIS TONE BLOCK IS REPEATED TWELVE TIMES, ONCE FOR EACH TONE OF THE CHROMATIC SCALE.
5. KEYING INPUTS K1-K12 ARE FOR THE LOWEST OCTAVE; K13-K24 FOR THE MIDDLE OCTAVE; AND K25-K36 FOR THE HIGH OCTAVE.
6. BUSS MNEMONICS:
   - MVH - HIGH VIOLIN MIX
   - MVL - HIGH CELLO MIX
   - MCH - HIGH CELLO MIX
   - MCL - LOW CELLO MIX
   - MXP - PIANO MIX
   - SSB - STRING SUSTAIN BUSS
   - PSB - PIANO SUSTAIN BUSS
   - SPL - SPLIT KEYBOARD OCTAVE SELECT

FIG. 3—CIRCUIT OF ONE OF THE TWELVE TONE BLOCKS. These identical circuits provide the necessary waveshaping, keying and mixing for all notes. The mixing and chorusing circuit (Fig. 4) will be presented next month.

The circuitry for one of the twelve tone blocks is shown in Fig. 3. This circuitry generates the waveshaping, keying, and mixing for three octaves of any chromatic note. The twelve tone blocks are identical and all are contained on two large PC boards in addition to the top octave and highest "C" circuitry discussed in the main schematic.

The whole process begins with the input of a high-pitched squarewave from the top-octave generator. This waveform switches between +V and ground, and directly drives the input of the tone block circuitry. IC1 is a 4024 7-stage counter which divides the input frequency into lower octaves. Only the first five divisions, plus the original input, will be used. The first bank of NAND gates (IC4-b and -d, IC3-d and IC2-b and -c) are driven by the counter and used to convert the squarewave signals to pulse waves with a 25% duty cycle.

The harmonic content of this type waveform more closely approximates the sound of a violin. The high-octave violin signal is obtained at pin 4 of IC2-b, while the middle-octave violin appears at pin 10 of IC2-c, and the low violin at pin 11 of IC3-d. The three lowest octaves of NAND gate outputs are additionally fed through inverters consisting of IC4-c, IC3-a, and IC2-d. This inversion maintains proper phase relationships so the remaining waveshaping circuit will operate correctly.

Immediately after inversion, these waveforms are selected for use as the piano signal. At this point, these waveforms still have a 25% duty cycle. Finally, NAND gates IC4-a, IC3-b, and IC2-a are used to mix the inverted waveform with the non-inverted waveform which originated one octave higher. The result is a pulse wave with a 12.5% duty cycle. The extremely wide harmonic spacing occurring in this waveform very closely approximates a cello waveform, and is consequently used as the signal source for this voicing.

The remaining keying and mixing circuitry is roughly divided into three sections, one for each octave that will be keyed by the keyboard. Additionally, each of these three sections is further divided into a section for strings and another for the piano effect. The input terminal labelled K1–K12 is the lowest octave keying input. NOTE that there is actually only one input at this point to each tone block. However, this one point will be labelled differently for each chromatic tone block. For example: K1 will be in the "C" tone block, K2 in the "C♯" tone block, and so on through K12 in the "B" tone block.

When a key is depressed, the keying input jumps to a positive voltage. The first thing to happen is the piano keying.

PARTS LIST

The following lists the components according to type and quantity and is included as an aid to help you acquire the parts necessary to build the model 1550.

Resistors—¼-watt, 10% unless otherwise noted
5—10 ohms
1—100 ohms
5—470 ohms
46—1000 ohms
1—1800 ohms
37—2200 ohms
6—2700 ohms
6—4700 ohms
1—8200 ohms
205—10,000 ohms
1—15,000 ohms
3—22,000 ohms
147—100,000 ohms
50—220,000 ohms
1—170,000 ohms

Potentiometers
—100 ohms, trimmer
5—1000 ohms, trimmer
1—50,000 ohms, trimmer
7—5000 ohms, linear taper
1—100,000 ohms, dual-section, linear taper

Capacitors
—47 pF disc ceramic
2—100 pF disc ceramic
1—500 pF disc ceramic
10—.001 μF disc ceramic
3—.01 μF disc ceramic
7—.05 μF disc ceramic
1—0.1 μF Mylar
12—1 μF, 10 volts, electrolytic
2—2.2 μF, 10 volts, electrolytic
4—5 μF, 10 volts, electrolytic
82—10 μF, 10 volts, electrolytic
37—33 μF, 10 volts, electrolytic
1—250 μF, 20 volts, electrolytic
1—1000 μF, 20 volts, electrolytic

Semiconductors
12—CD4024 7-stage divider (RCA, National, Motorola)
37—CD4011 quad NAND gate (RCA, Motorola, National)
1—MK50240 top-octave generator (Mostek, AMI)
2—CD4013 Dual D-type flip-flop (Motorola, National, RCA)
1—7805 positive 5-volts regulator (Motorola, National, Signetics)
1—7905 negative 5-volts regulator (Motorola, National, Signetics)
1—CA3080 transconductance amplifier (RCA)
2—SAD-1-24 analog delay line (Reticon)
4—566 voltage-controlled oscillator (Signetics, National)
4—2N5139 or similar NPN transistor
1—2N5129, 2N3904 or similar PNP transistor
4—1N4003 rectifier diodes
527—1N914 silicon switching diode
3—TIL209 red light-emitting diode

Miscellaneous
1—power transformer, 24 VCT, 1A
40—flea clips
2—socket, 16-pin DIP (for SAD-1024's)
control knobs, mounting hardware, case, line cord, etc.

Note: The following are available from Paia Electronics, 1020 W. Wilshire, Oklahoma City, OK 73116:
1550A PC board $30.00 postpaid
1550B PC board $30.00 postpaid
1550C PC board $10.00 postpaid
1550LED PC board $2.00 postpaid
(All boards are etched, drilled and screened with parts placement layout.)
Set of four PC boards $70.00 postpaid
A 37-note (3-octave) organ keyboard (Order No. AGO-37) $60.00 plus $5.00 postage and handling
Complete kit of parts including case, keyboard and step-by-step instructions (Order No. 1550) $295.00 shipped freight collect
Fully assembled unit (order No. 1550AS) $600.00 freight collect.

The positive step-voltage that is dropped across R1 is differentiated by C1. The positive spike generated is sufficient to forward bias D2 and dump a charge on C2. Simultaneously, C1 is charging to absorb that +V which has been applied to it. By the time the positive charging spike for C2 falls and C1 has a full charge, D2 has become reverse biased, eliminating the front end of this circuit as a possible discharge path for the charge on C2. The only possible discharge is through R3 and R4 to the virtual ground of the piano mix bus (MXP). This R—C combination (R3, R4, C2) sets the maximum sustain time for the piano signal.

To get a variable amount of shorter sustain time, the voltage on the piano sustain bus (PSB) can be lowered from about +5 volts to ground with the front panel control. If this bus is anywhere lower than the peak charge of C2 (about +5 volts), D3 becomes forward biased, offering C2 a lower impedance discharge path through R2. This causes the charge on C2 to fall more rapidly than normal thus making the sustain time shorter. When the key is released, the drop in keying voltage across R1 causes a negative spike to be generated by C1. Diode D1 becomes forward-biased by the spike and shorts it to ground. Resistor R1 will then serve to quickly discharge C1, preparing the piano keying circuit for the next key depression.

The only remaining section of the piano circuit is the signal-gating (envelope or amplitude contour) circuitry built around D4 and D5. This circuit is the standard diode-keying configuration that has been used in electronic organs for quite some time. The pulse wave being used as the piano-signal source is being continuously applied to the cathode of D4. While the piano circuit is at rest, C2 is discharged leaving the anode of D4 at ground. This leaves D4 continuously reverse-biased and stops any signal transmission through it. When a key is pressed, a pattern of rising and falling DC voltage is generated across C2 as described earlier. This voltage will now forward bias D4 and allow the piano signal to pass. When the piano signal happens to be at a high level (the top of the pulse wave), the voltage at the junction of D4 and D5 will be pulled up to a DC voltage equivalent to the charge remaining on C2. When the piano pulse wave switches to a low level (near ground), D4 conducts and the junction of D4 and D5 will be pulled nearly to ground.

This high-speed (audio frequency) switching continues until the C2 charge has been depleted via the discharge path through R3 and R4. From the previous discussion, we see that the charge on C2 has a sharp increase followed by a long decay. The audio signal passed through D4 and D5 takes on the same attack and decay characteristics, thus duplicating the effect of a plucked or hammered piano string.

Diode D5 is used primarily to avoid interaction with other notes which may be simultaneously applied to the audio mix buses. In addition to being one of the major determinants of the timing for the piano effect, R4 is also used as a mixing resistor and gain-setting component for this one piano note.

The same low-octave keying input we have been discussing for the piano circuits will also be used to gate a violin and cello sound at the same time. The keying voltage applied to R1 will forward bias D6 and cause C3 to charge via R5. The larger value of C3 and the current limiting of R5 cause C3 to charge more slowly, generating a "softer" attack, to more closely imitate the build-up that occurs when a section of strings bows a new note. This DC voltage is concurrently applied to two diode keying sections. Resistor R8, D8, and D9 are used to gate the low-octave cello signal being applied to D8. Resistor R7, D10, and D11 impose envelope control on the violin signal.

The entire keying section for the top octave of the tone block is identical to the circuitry we have just covered. The high-octave keying inputs are K25 through K36, and the high-octave signal sources are tapped from higher frequency outputs of the NAND gate waveshaping circuit. Also, the violin and cello outputs from the high-octave keying are permanently connected to the high-violin and cello-mix buses. Otherwise, the circuits are the same.

Next month we will discuss the power supply and the middle-octave mixing and chorusing circuits and then go on to construction details. This will include foil patterns for the PC boards and diagrams showing parts placement. **R-E**

String Synthesizer

Part 2—Continuing the discussion of the electronic string music synthesizer. This unique instrument gives the soloist and small groups the background needed to enhance performance

MARVIN JONES

BEFORE PRESENTING THE CONSTRUCTION details, we will conclude the circuit discussion started last month with a description of the middle-octave mixing and chorusing circuit and the power supply.

The middle-octave piano keying circuit is exactly like the high- and low-octave circuits, but the middle-octave strings section is slightly different to accommodate the switchable split-keyboard feature. The string keying starts off the same; C6 charges through R15 and D17, and the sustain control affects the discharge time of C6 via R16 and D18. Resistors R17 and R18 apply the envelope voltage of C6 to two diode keying networks—one for violins, one for cellos. Here the differences begin. The two diode keying circuits are designed to each provide two identical outputs. The basic philosophy behind the split keyboard circuitry is: "Feed an identical signal to both the upper AND lower mix buses, and remove the one you DON'T want."

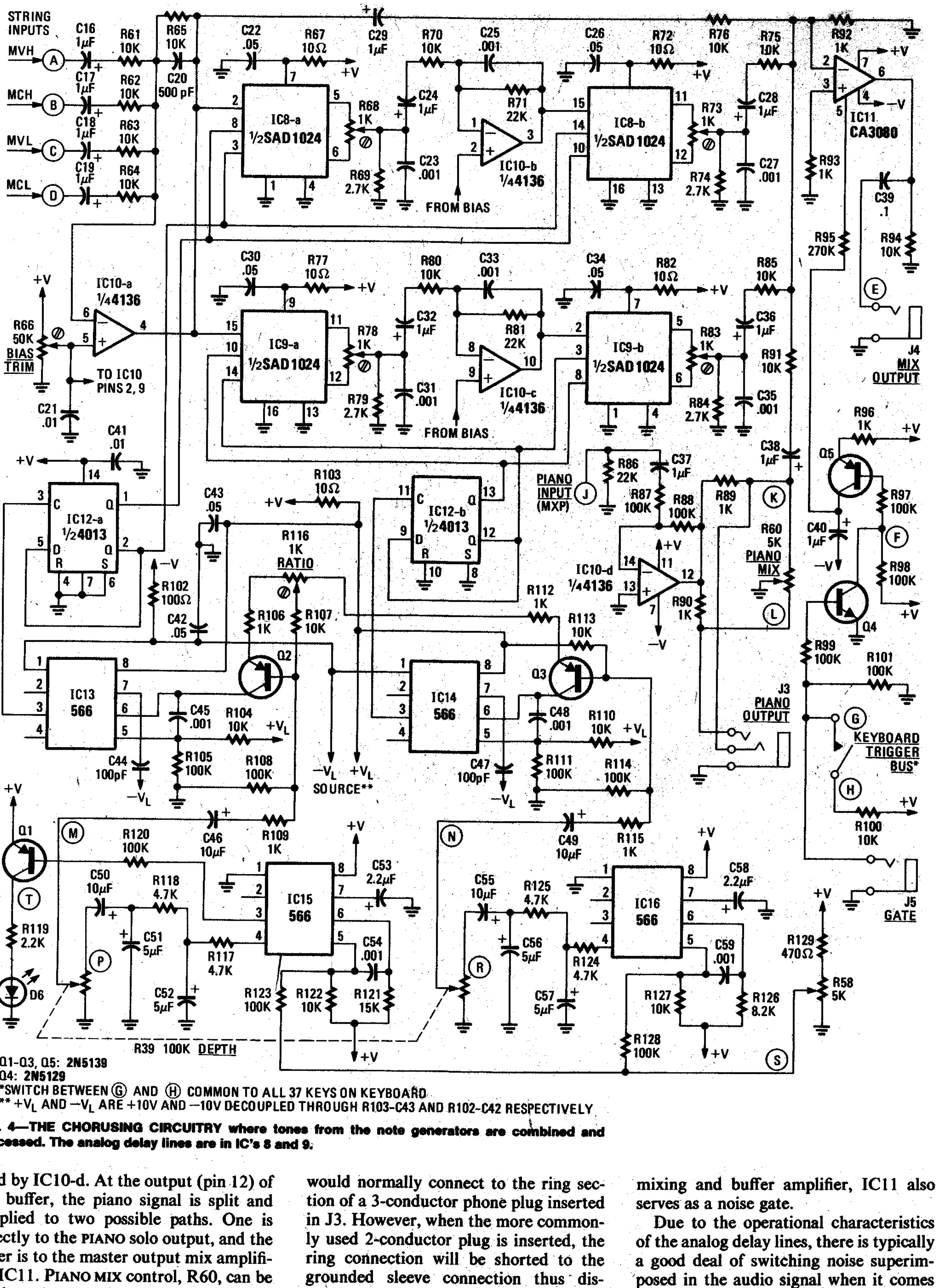
So where the low-octave strings are connected to the appropriate low-mix buses and the high-octave strings are connected to the high-mix buses, the middle-octave strings are simultaneously applied to both. The logic level available on the split select bus (SPL) is used to determine which of the two signals will be grounded out. The voltage levels on the SPL bus are directly related to the front panel switch position. Low-octave split point is represented by a low voltage. High-octave split point is represented by +V appearing on the SPL bus. The single NAND gate (IC3-c) remaining from the waveshaping circuit is used to invert the SPL signal. When the front panel split switch is at position 1, the keyboard is being split between the low and middle octaves. Thus, you want the middle octave to be applied to the high-mix bus.

So, the ground potential appearing at the SPL bus is used to forward bias the shunt diodes, D31 and D32, causing the low-string mix signals from the middle octave to be shunted to ground. The diodes connected to the high-string mix buses, D29 and D30, are being driven by the SPL inversion which is now at a high level. Thus, the diodes are inactive. When the SPLIT switch is in the high, or No. 2 position, the SPL bus is at a high level allowing the signal to pass to the low-mix bus. The inverter now produces a low output, shunting the high-mix signals to ground.

The chorusing circuitry is shown in Fig. 4. Most of this circuitry is contained on one PC board, with the exception of front panel controls, jacks, and so on. The resultant signal mixes from the front panel HIGH and LOW mix controls are applied to string inputs A, B, C and D. IC10-a serves as a unity-gain mix and buffer amplifier. Capacitor C20 rolls off the high-frequency content of the input signal to avoid any intermodulation with the clocking frequency of the analog delay lines. Bias trimmer, R66, sets a DC level at the output of the buffer (IC10-a) so the analog delay lines will be biased for minimum distortion and maximum dynamic range. The buffered input signal is applied to two delay lines (IC8 and IC9) plus the output amplifier, IC11.

Thus, the composite string signal at the output consists of one original signal and two independently delayed and modulated signals. In one path, the signal is delayed by IC8-a and dropped across the delay line load, R69. Capacitor C23 eliminates the high-frequency clocking signal that is superimposed on the audio signal as it passes through the delay line. Op-amp IC10-b is a gain stage to make up for losses encountered in the delay line and C25 provides additional filtering of high frequencies to help smooth the audio signal. The output of IC10-b, which also rides the bias level determined by R66, is passed through another stage of analog delay, IC8-b. The delay line output is again filtered and applied to the output mix amplifier, IC11. Delay time IC9 and its associated circuitry operates identically to the delay line circuitry of IC8. This second independent delay line has its signal also applied to the output mix amplifier.

The remaining stage of IC10 is used to buffer and drive the piano signal outputs. The signal from the piano mix bus (MXP) is dropped across R86, and buff-



Q1-Q3, Q5: 2N5139
Q4: 2N5129
*SWITCH BETWEEN Ⓖ AND Ⓗ COMMON TO ALL 37 KEYS ON KEYBOARD
** +V_L AND −V_L ARE +10V AND −10V DECOUPLED THROUGH R103-C43 AND R102-C42 RESPECTIVELY

FIG. 4—THE CHORUSING CIRCUITRY where tones from the note generators are combined and processed. The analog delay lines are in IC's 8 and 9.

ered by IC10-d. At the output (pin 12) of the buffer, the piano signal is split and supplied to two possible paths. One is directly to the PIANO solo output, and the other is to the master output mix amplifier, IC11. PIANO MIX control, R60, can be used to shunt various amounts of either signal path to ground. Also note that the on-board piano signal path that leads to the master output mix is connected to the piano jack via point K. This connection would normally connect to the ring section of a 3-conductor phone plug inserted in J3. However, when the more commonly used 2-conductor plug is inserted, the ring connection will be shorted to the grounded sleeve connection thus disabling the piano signal at the MIX OUTPUT. The combination of three string signals and one piano signal which are to be applied to output amplifier IC11 are dropped across R92. As well as being a mixing and buffer amplifier, IC11 also serves as a noise gate.

Due to the operational characteristics of the analog delay lines, there is typically a good deal of switching noise superimposed in the audio signal when it comes out of the delay IC's. This translates into a "hissing" effect which is normally masked by the larger amplitude signal. However, when there is no signal present at the delay lines the hissing output can be annoying—especially if you are on stage, running the synthesizer through several hundred watts of amplification. So the noise gate action of IC11 allows a signal to pass to the output ONLY when a key is depressed on the keyboard. Normally, C40 will be discharged and there will be no control current being applied to pin 5 of the CA3080, IC11. With no control current applied to the IC, there is no amplification by the IC—and thus no output. When any key of the keyboard is pressed, the trigger bus switch contacts will close. The resultant shorting of points "G" and "H" causes a voltage to appear at the GATE output jack, J5, and at the base of Q4.

When Q4 conducts, Q5 will also turn on. When Q5 conducts, C40 will charge through R96 towards +V. The charging time constant of C40/R96 is selected to be slightly less than the attack time of the diode keying in the string sections of the tone blocks. When C40 is fully charged, the current through R95 to IC11 drives the output to the desired level for interface with most guitar amplifiers or PA systems. When all keys on the keyboard are released, Q4 and Q5 turn off. The impedance looking back into the collector of Q5 is very high, thus leaving R95 as the only discharge path for C40. The discharge time constant of R95/C40 is selected to be slightly longer than the longest sustain times available from the string tone block circuitry. Therefore, the long sustained string passages should never be "cut off" by the output noise gate.

The circuitry shown in the lower half of Fig. 4 is the control circuitry for the analog delay lines. Front panel RATE control R58 sets the desired control voltage to be applied to low-frequency vibrato oscillators IC15 and IC16. The variations in voltage drive the vibrato oscillators to selected frequencies. Although the timing capacitors for these oscillators (C53, C58) are the same, the timing resistors (R121, R126) are slightly different. This causes the pseudo-random beating and chorusing required to get the string effects. Capacitors C54 and C59 suppress parasitic oscillations at each oscillator IC.

Since the pitch deviations generated within the analog delay lines are related to the mathematical derivative of the signal used to modulate the high-frequency clock, we need to have a sinewave modulation signal in order to obtain the common smooth sinewave type (actually cosine would be mathematically correct) vibrato. The closest thing available as an output from the vibrato oscillator IC's is a triangle wave at pin 4. This signal is run through a 2-pole passive filter to smooth it into a sine shape, and the resulting signal from each oscillator is applied to a section of the dual-section DEPTH control, R59. The squarewave output of IC15 at pin 3 is used to control the LED driver Q1 for a visual indication of vibrato rate.

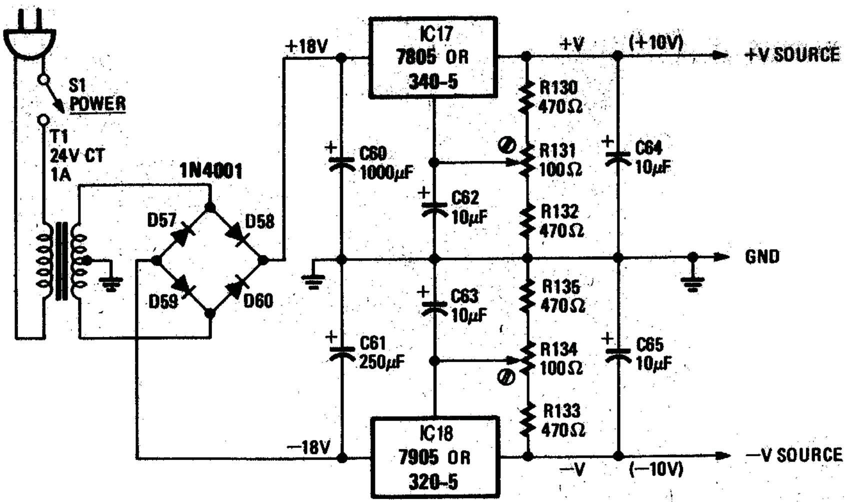


FIG. 5—POWER SUPPLY for the synthesizer uses center-tapped transformer and a full-wave bridge rectifier to deliver equal positive and negative voltages.

The selected amount of low-frequency modulation signal is fed to the high-frequency delay line clocks, IC13 and IC14. Transistors Q2 and Q3 serve as current sources which replace the customary timing resistors at pin 7 of the high-frequency oscillators. The small value timing capacitors, C44 and C47, result in clock frequencies up around several hundred kHz.

With the use of current sources to drive the timing resistor inputs of these IC's, a fairly small voltage fluctuation can be used to effectively sweep the clock frequency over a wide range, as opposed to the modulation inputs of the IC's at pin 5 which typically only cause deviations of about 2:1.

The delay lines require a bi-phase clock signal, preferably providing squarewaves and generating as little overlap during switching periods as possible. To accomplish this, the squarewave outputs of the high-frequency oscillators are fed through a CD4013 D-type flip-flop. With the flip-flop connected as a frequency divider, the two output pins (pins 1 and 2 for one divider, pins 12 and 13 for the other) provide nice, clean complementary squarewaves to drive the delay lines.

The continuous changing of the clock speeds for the delay lines causes a periodic shifting of the pitch of the audio signal applied to the delay line. The input signal for the delay line is sampled periodically at a rate determined by the delay-line clock frequency. If, when the signal gets to the end of the delay line, the clock happens to be running faster than when the signal was clocked in, the pitch of that signal will be shifted up slightly. The signal is being pushed OUT of the IC faster than it was taken in. Similarly, if the clock happens to be running slower than when the signal was clocked in, the pitch will be shifted down slightly.

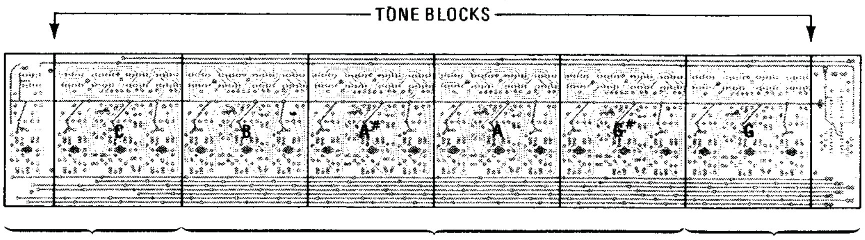
Ratio trimmer, R116, is a means of providing slight adjustments in the center frequencies of the two high-frequency clocks. Since these two clocks are contained on the same circuit board near each other and near the audio circuitry of IC10 and IC11, it is possible that the two independent clocks could beat against each other and induce or transmit audible beat frequencies into the signal path. With R116, you can slightly alter the ratio of one clock frequency to the other, thus setting up a ratio where the beat frequencies fall outside audibility and make the chorusing circuit even quieter.

Networks R102/C42 and R103/C43 provide current limiting and supply line decoupling for the high-frequency circuitry. The current limiting also reduces the power consumption of the 566 high-frequency oscillators and puts them in a safer operating range.

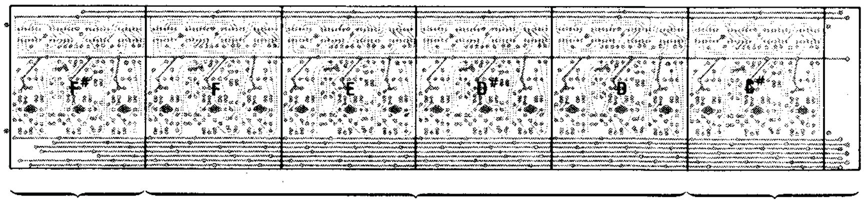
The power supply for the entire string synthesizer is shown in Fig. 5. All active components for the supply are contained on the same PC board that contains the chorusing circuitry. A 24-volt RMS center-tapped transformer drives a bridge rectifier (D57-D60) and primary filters C60 and C61 to initially provide ±18 volts DC. Transistors Q6 and Q7 provide regulation of the supply. Although these are 5-volt regulators, the resistive network at the outputs biases the regulators up to around 10- or 12-volt outputs, depending on resistor tolerances. Capacitors C64 and C65 increase the transient response of the supply, while C62 and C63 help stabilize the new reference voltages which are increasing the output voltage of the regulators. A small degree of trimming is allowed for in the power supply. The ratios of supply voltages can aid in achieving minimum switching noise and intermodulation from the chorusing circuit. This is a relative adjustment and is interactive with the ratio trimmer, R116. In most cases, the supply trimmers can be left at mid-position.

The PC boards

Most of the circuitry and construction techniques are straightforward so little explanation is required. Note well that



1550A BOARD, FOIL SIDE



1550B FOIL SIDE

FIG. 6—HOW THE TONE BLOCKS ARE ARRANGED on the two large PC boards. On board 1550A there is additional circuitry at the ends of the six tone blocks.

this is a **BIG** project. There are four PC boards—two are approximately 24 by 6 inches. You'll need all your prior experience as well as larger etching equipment. Your best bet may be to order the PC boards from the source listed in the parts list.

The two large boards are almost identical as each contains six of the twelve identical tone blocks. The block drawings in Fig. 6 show the order of the tone blocks

PARTS LIST FOR POWER SUPPLY

Resistors ¼ watt, 10% or better
R130, R132, R133, R135—470 ohms
R131, R134—100 ohms trimmer pot
C60—1000 μF, 20 volts
C61—250 μF, 20 volts
C62-C65—10 μF, 10 volts
D57-D60—1N4001
S1—SPST switch
T1—power transformer, 24 VCT, 1A
IC17—LM340-5 or 7805
IC18—LM320-5 or 7905

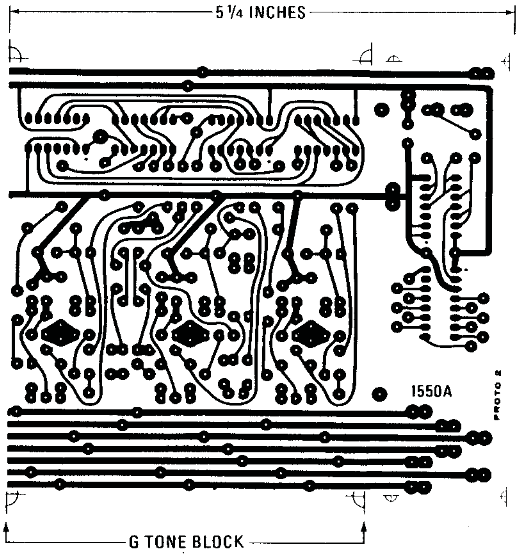


FIG. 7

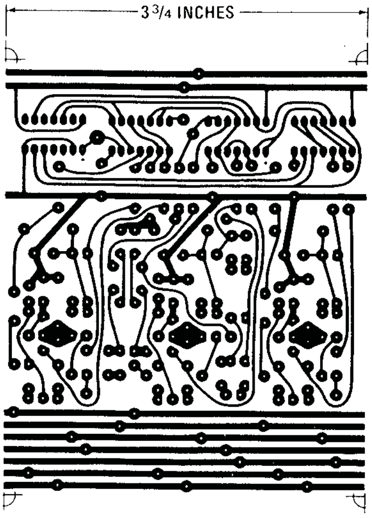


FIG. 9

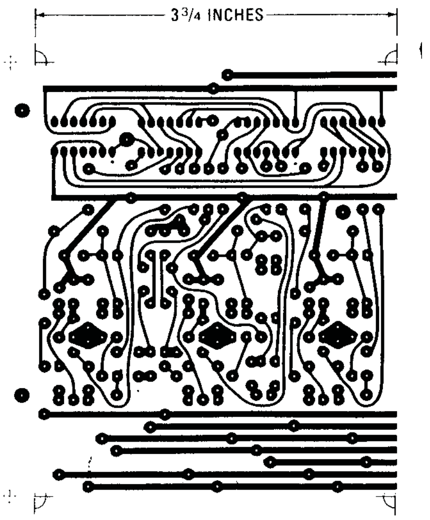


FIG. 10

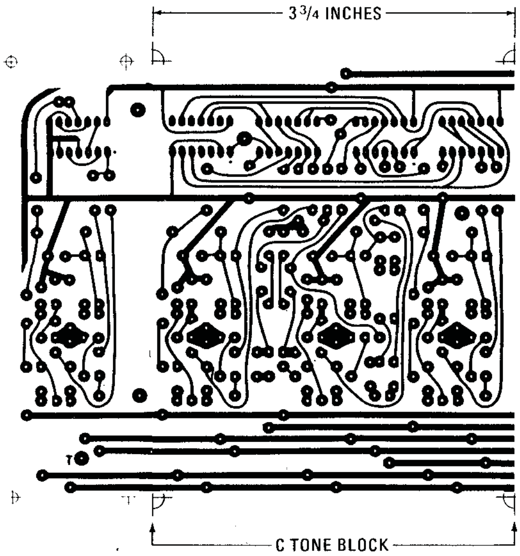


FIG. 8

HALF-SIZE SECTIONAL FOIL PATTERNS. Figs. 7 and 8 are right and left ends, respectively, of the "A" board. Fig. 9 pattern is used when making the four tone blocks in the center of boards "A" and "B". Fig. 10 is the F# block and Fig. 11 the C# block on the "B" board.

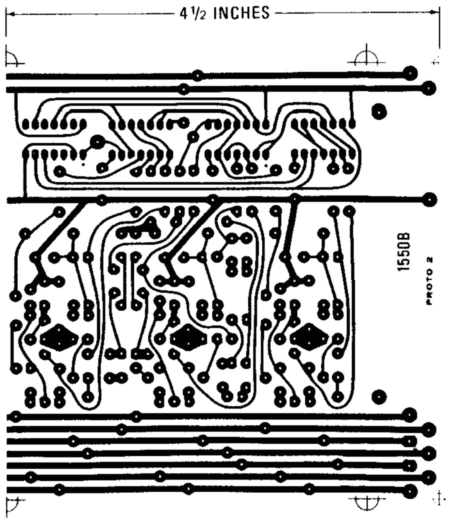


FIG. 11

on the 1550A and 1550B PC boards. The 1550A board has some additional circuitry on each end and so is a little longer than the 1550B board. Figures 7 and 8 show the foil patterns for the circuitry at the right and left ends and for the G and C tone blocks. The foil pattern in Fig. 9 is repeated four times between the G and C tone blocks.

Similarly, Figs. 10 and 11 are the foil patterns for the F and C tone blocks at the ends of the 1550B board. The pattern in Fig. 9 is repeated four times as on the 1550A board. Figure 12 shows the parts placement on the ends of the 1550A board. The components in all twelve tone blocks are positioned as in the C-note block in Fig. 12. Figure 13 shows the connections to the left end of the B board.

continued on page 104

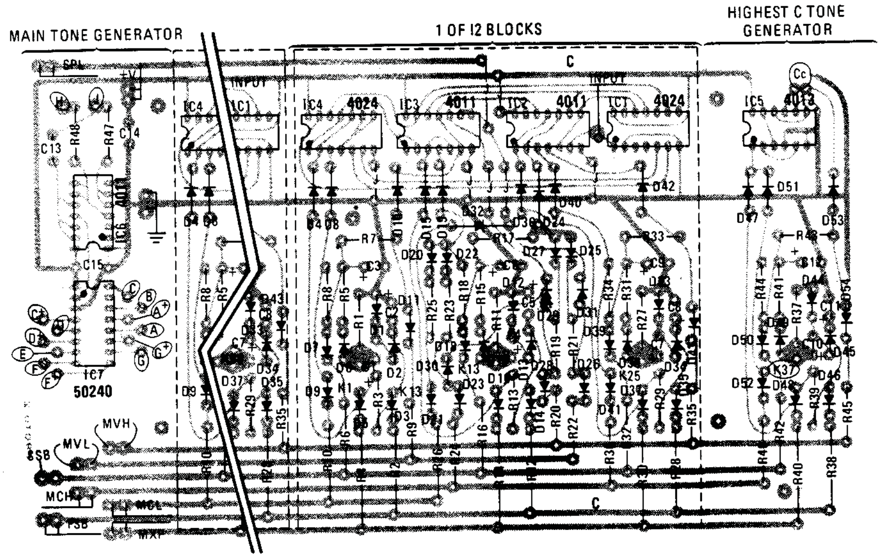


FIG. 12—PARTS PLACEMENT diagram shows the location of components on each of the twelve tone blocks and the main tone generator and the high-C generator on the ends of the 1550A board.

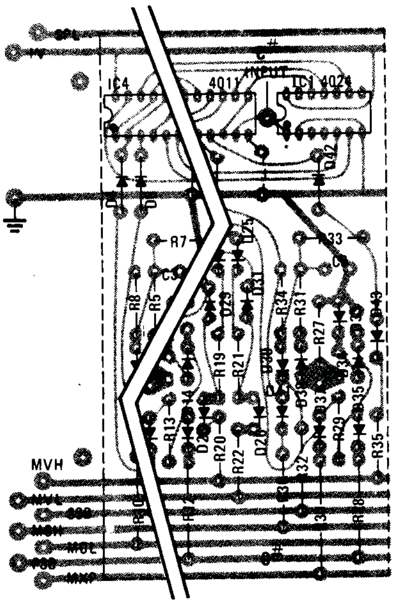


FIG. 13—CONNECTIONS that are to be made on the left end of the 1550B circuit board.

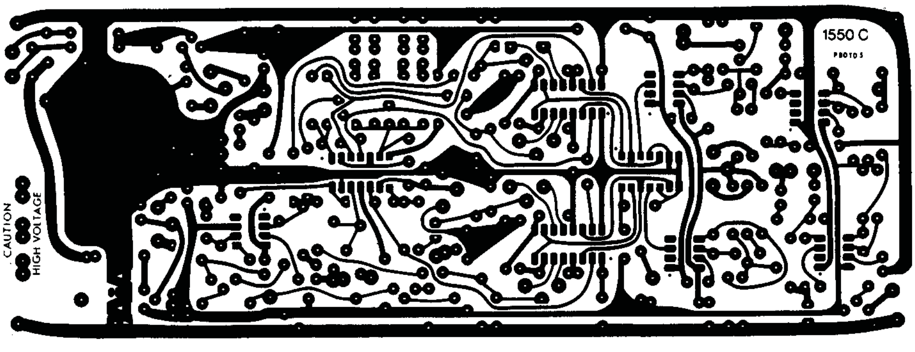
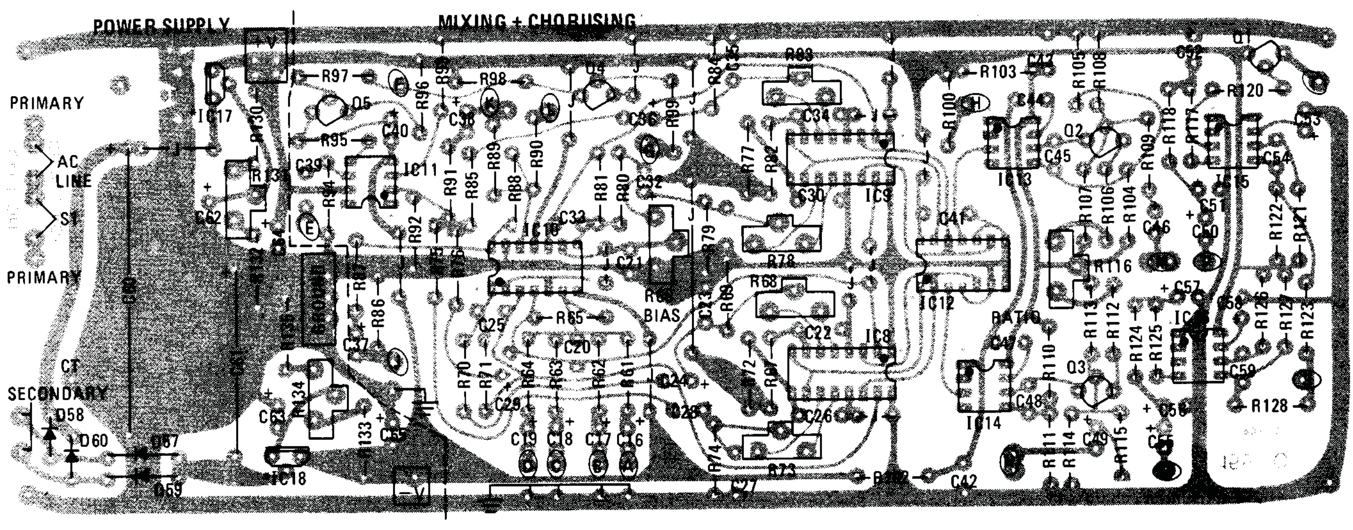


FIG. 14—HALF-SIZE FOIL PATTERNS for the 1550C board. Power supply components are on the extreme left edge. Mixing and chorusing circuits occupy the balance of the board.

PARTS LIST FOR ONE OF 12 IDENTICAL TONE BLOCKS

Resistors ¼ watt, 10% or better

R1, R11, R27—1000 ohms
R2, R3, R5, R7, R8, R12, R13, R16-R18, R28, R29, R32-R34—10,000 ohms
R4, R14, R19-R26, R30—100,000 ohms
R5, R15, R31—2200 ohms
R9, R10, R35, R36—220,000 ohms
C1, C2, C4, C5, C7, C8—10 µF, 10 volts electrolytic
C3, C6, C9—33 µF, 10 volts electrolytic
D1-D43—1N914 diode



NOTES: *IC17 AND IC18 REQUIRE HEATSINKS.
TERMINALS MARKED BY CIRCLED LETTERS CONNECT TO SIMILARLY MARKED TERMINALS ON OTHER BOARDS.

FIG. 15—PLACEMENT OF COMPONENTS on the "C" board. All points marked by letters enclosed in circles must be connected to similarly indicated points on other boards.

There are three points where each tone block differs from the others. These points are the coded markings for the connections to coded points on the keyboard. There are thirty-seven terminals marked 1 to 37 which connect to correspondingly marked (K1 to K37) on the tone blocks. Terminal pads K1, K13 and K25 are on the C tone block as you can see in Figs. 2 and 12. Terminal pad markings for the twelve keys are, reading left to right from the component side of the boards:

Tone Block	Pad Markings
C	K1, K13, K25
B	K12, K24, K36
A#	K11, K23, K35
A	K10, K22, K34
G#	K9, K21, K33
G	K8, K20, K32
F#	K7, K19, K31
F	K6, K18, K30
E	K5, K17, K29
D#	K4, K16, K28
D	K3, K15, K27
C#	K2, K14, K26

Figures 14 and 15 are foil pattern and parts layout for the 1550C board. Figure 16 is the foil pattern for the 1550LED board that is mounted on the shaft of R58, the MODULATION RATE control. Figure 17 shows the component location. The board is mounted with the foil side facing the body of R58 and away from the rear surface of the control panel. The three LED's are mounted from the component side of the LED board. The resistors and all other connections are tack-soldered to the foil on the etched side of the board. Note that the flat side of the LED casing identifies the *cathode* lead which corresponds to the *negative* markings on the placement diagram.

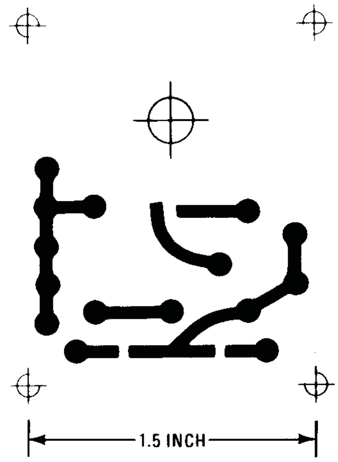
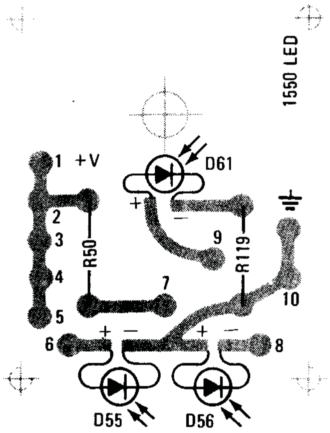


FIG. 16—FOIL PATTERN for the LED board that mounts on the shaft of potentiometer R58.



SMALL HOLES (#60)
AT (+) AND (−)
(6 PLACES)

NOTE: SEE FIGS 18 AND 19
FOR CONNECTIONS TO
LED BOARD

FIG. 17—PARTS PLACEMENT on the LED board. Note the LED's are on the component side; the resistors are tacked to foil side of board.

Figure 18 shows the positioning of the controls on the panel along with interconnections between the various components. The connections shown should be made before adding the connections from the control panel to the PC boards as shown in Fig. 19. Note that the first on-board connections have been deleted for clarity. The coding at the end of each lead indicates the point of origin of that lead. The letters in parenthesis denote the board from which the wire originates. Be sure to use shielded cable or small-diameter coax where indicated in Fig. 19.

Putting it all together

The assembly of the 12 chromatic tone generator blocks involves a lot of repetitive assembly work. Be forewarned that it's boring during this stage of assembly, and remember to get up and take a break when you feel yourself getting tired. Attention to detail will save a lot of troubleshooting in the final stages. Second, notice that there are a lot of CMOS IC's used in this instrument. Thus, remember to use handling precautions with the IC's. Store them in conductive foam or tinfoil; don't wear synthetic materials (nylon, rayon, etc); use a grounded or DC soldering iron if possible, or let your standard iron warm up before unplugging and then solder a few IC's while the iron is still warm. Alternatively, use sockets on the IC's to help eliminate much of the handling. Observe orientation markings on all IC's and the many diodes required for this circuit.

There are seven bare-wire jumpers in each tone block on the 1550A and 1550B circuit boards, and fourteen jumpers on the 1550C board. In each tone block, the input signal comes from the appropriate tone output of the top octave generator IC7 on the 1550A board. These connections should be made with insulated wire. Note that the A and B boards are designed to be "stacked" over each other. The B board is mounted above the A board using No. 4 × 1-inch or 1½-inch machine screws and ¾-inch spacers. Once these boards are sandwiched, the connections from the inputs of the 6 tone blocks on the B board can be connected to the appropriate tone outputs of IC7. Also, there are 10 buses that run the length of each board. Short insulated jumpers are used to tie the B-board buses to similar points on the A board. The duplicate holes on the A board are then used to make the connections to various points on the front panel and C board. The four audio signal buses should have their connections made with shielded wire to avoid noise pickup (MVH, MVL, MCH, MCL).

On the 1550C board the CMOS and semiconductor soldering precautions still apply. The two voltage regulators mounted on this board have small clip-on heat sinks (Thermalloy 6043 or similar) to aid in heat dissipation.

In addition to five jacks, eight controls, and two switches, the front panel should serve as mounting for R101, R119, R50, R129, R51, R53, and R57. The small 1550LED board will hold R119 and R50 in addition to the three LED's. This board is mounted on the shaft of R58 and positioned to allow the LED's to protrude through front panel holes. See Figs. 17, 18 and 19.

In preparing the organ keyboard, note that two switch buses are required. In each case there should be a common bus running the length of the keyboard. One set of switches on each note provides for 37 independent terminals to contact a main bus rod. The other set of switches are all common, such that ANY key being pressed will cause a switch closure between the second "trigger" bus and a 38th terminal. The trigger bus is used to enable the output noise gate and gate trigger, and connects to board C at points G and H. The individual key outputs are connected to the proper tone blocks of the A and B boards. The bus associated with these key outputs is connected to +V.

PARTS LIST FOR MAIN AND HIGHEST C TONE GENERATORS

Resistors, ¼ watt, 10% or better
R37—1000 ohms
R38, R39, R42, R44, R47—10,000 ohms
R40, R57—100,000 ohms
R41, R50—2200 ohms
R45, R46—220,000 ohms
R48—1800 ohms
R49, R52, R54-R56—5000 ohms pot
R51-R53—4700 ohms
C10, C11—10 μF, 10 volts electrolytic
C12—33 μF, 10 volts electrolytic
C13—47 pF disc
C14—.01 μF disc
C15—.05 μF disc
D44-D54—1N914 or 1N4148 diode
D55, D56, D61—TIL209B LED
IC5—4013 dual flip-flop
IC6—4011 quad NAND gate
IC7—MK50240 top-octave generator
S2—SPDT switch
J1, J2—closed-circuit jack

Testing and calibration

After completing assembly, double check for cold solder joints, loose wire clippings and so on. Apply power and look for a pulsing rate LED and one of the split select LED's as a power indicator. Check the voltages on the C board at points "+V" and "−V." These should be about ±10 or 11 volts. The actual voltage is not as important here as the fact that it is regulated. Resistors R131 and R134 should give a voltage variation of about 1 or 2 volts. Set these trimmers to midpoint and proceed.

Connect the MIX output to a standard guitar or hi-fi amplifier. Set all controls to midrange except PIANO, which should be at minimum. Playing a few notes on the keyboard should now yield a reedy organ-type tone. Adjust BIAS trimmer R66 on the C board. At one point during the rotation, you should notice a considerably fuller sound as the chorusing circuits come into bias and add another two voices to the overall sound. Set R66 for the center of the "fullness" area and proceed.

The four trimmers near IC8 and IC9 on the C board are primarily for the perfectionists among us. If you do not have access to a scope, set R68, R73, R78

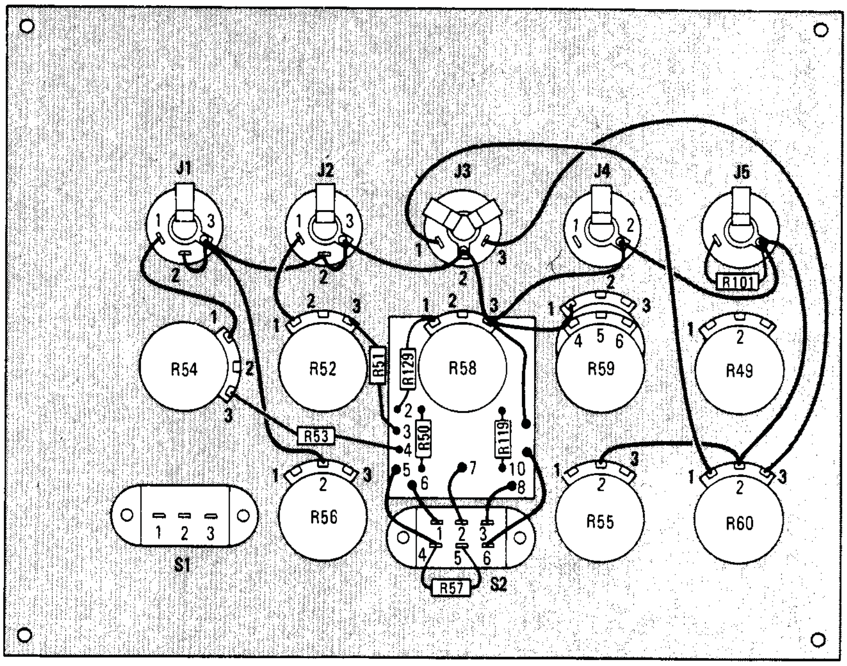
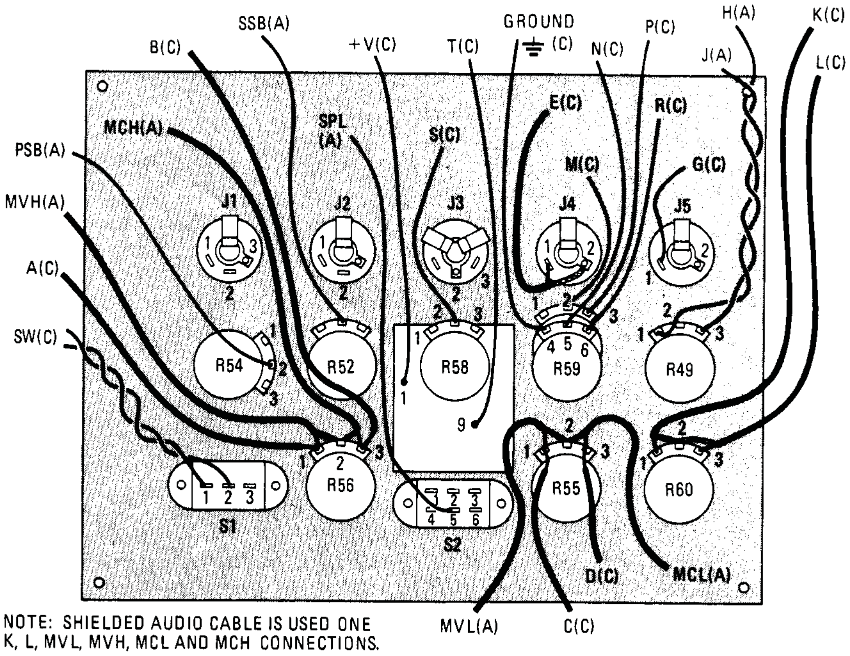


FIG. 18—COMPONENTS ON THE CONTROL PANEL—where they are mounted and how they are interconnected. Be sure LED board mounts with foil side to the rear.



NOTE: SHIELDED AUDIO CABLE IS USED ONE K, L, MVL, MVH, MCL AND MCH CONNECTIONS.
LETTERS IN PARENTHESIS DENOTE BOARD FROM WHICH WIRE ORIGINATES

FIG. 19—ON-BOARD CONNECTIONS eliminated so you can clearly see interconnections. Letters in parenthesis designate destination PC board.

PARTS LIST FOR MIXING AND CHORUSING CIRCUIT

Resistors ¼ watt, 10% or better

R61—R65, R70, R76, R78, R80, R88, R91, R94, R100, R104, R107, R110, R113, R122, R127—10,000 ohms
R66—50,000 ohms trimmer pot
R67, R72, R77, R82, R103—10 ohms
R69, R74, R79, R84—2700 ohms
R71, R81, R86—22,000 ohms
R87, R88, R97, R99, R105, R108, R111, R114, R120, R123, R128—100,000 ohms
R89, R90, R92, R93, R96, R106, R109, R112, R115—1000 ohms
R95—270,000 ohms
R102—100 ohms
R117, R118, R124, R125—4700 ohms
R121—15,000 ohms
R126—8200 ohms
R130, R132, R133, R135—470 ohms
R68, R73, R78, R83, R116—1000 ohms trimmer pot
R131, R134—1000 ohms trimmer pot

Capacitors, electrolytic, 10 volts or greater unless otherwise noted

C16-C19, C24, C29, C32, C36, C37, C38, C40—1 µF
C46, C49, C50, C55—10 µF
C51, C52, C56, C57—5 µF

Capacitors, disc ceramic unless otherwise noted

C20—500 µF
C21, C41—0.1 µF
C22, C26, C30, C34, C42, C43—.05 µF
C23, C25, C27, C31, C33, C35, C45, C48, C54, C59—.001 µF
C39—0.1 µF Mylar
C44, C47—100 pF

Semiconductors

Q1-Q3, Q5—2N5139
Q4—2N5129
IC8, IC9—SAD-1024 delay line
IC10—4136 quad op-amp
IC11—CD3080 transconductance amplifier
IC12—4013 dual flip-flop
IC13-IC16—NE566 VCO

and R83 to mid-rotation and proceed. These trimmers are used to balance the outputs of the delay lines, a process which minimizes distortion and clock feed-through. To set these trimmers, view the signal at the wiper of the trimmer. At either end of the trimmer's rotation, you will see two representations of the audio signal, each riding at a different DC level. Near the middle of the trimmer's rotation, the two signals will converge and appear as one. This is the correct setting. Repeat the procedure for the remaining three trimmers.

The final trimmer on the C board is the RATIO trimmer, R116. This adjustment is interactive, and best made over a period of time to allow optimum adjustment for all applications and environments. In order to actually hear the effect of this control, a small clip lead should be used to jumper point G to +V. This will turn on the output noise gate without having any keyboard signal present. You will hear two noises. One is a hissing due to the clocking and switching occurring in the delay lines. This is normal and easily masked when keyboard tones are present. The second noise will be a periodic popping or ticking. This is actually an audio beat frequency which is caused by the two high-frequency clocking oscillators that are being independently modulated for the chorusing effect. If the ratio between these two oscillators is just right, the beat frequencies dip into the audio passband. Slight adjustment of R116 will shift the frequencies of the VCO's in an inverse proportion. Listen for the quietest point and leave the trimmer. Note that this adjustment may need to be altered after about 20 hours of operation. This is due to the aging of components which may cause slight changes in values and slight changes of frequencies, etc. The power supply trimmers, R134 and R131, are interactive with the RATIO trimmer. If you have trouble finding a quiet spot along the rotation of R116, the power supply voltages can be shifted very slightly to throw the RATIO trimmer into a whole new range. However, in most cases, the voltage trimmers may be left at mid-point.

At this point you are ready to experiment with the front panel controls, and begin experiencing the versatility they offer. **R-E**