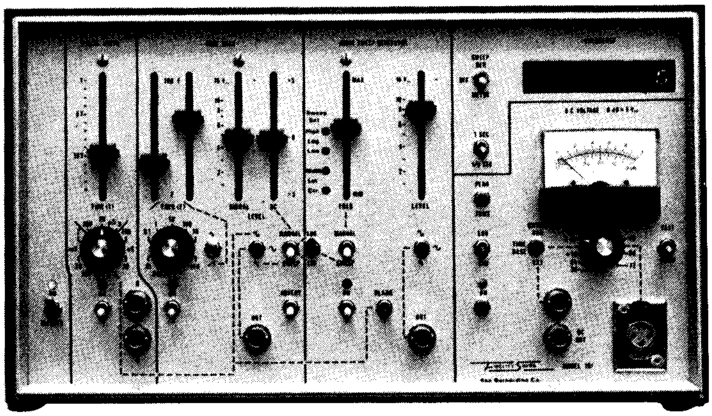
BUILD THIS

Audio Test Station



A host of precision instruments are required by anyone wanting to put high-quality audio equipment through its paces. This test station has everything you'll need. You can build it from a kit.

RAY DAVISON

THIS IS THE FIRST IN A SERIES OF ARTIcles describing the operation, design and construction of Fidelity Sound's *model 101* Audio Test System. This first article presents the functions that are available and gives detailed information on the power supplies. Subsequent articles will cover the other major circuit blocks. A kit of all components is being offered.

The unit consists of a power supply, two sine/square/triangle function generators, pulse generator, frequency counter and AC voltmeter. In its simplest form it can be thought of as several pieces of independent test equipment in a common cabinet. They are all basically familiar test equipment and can be used in the normal manner. In addition, when the various sections are properly connected to each other and to an X–Y plotter or scope, the system will generate a frequency-response plot.

The controls and the Audio Test System are grouped within solid black lines on the front panel as can be seen in Fig. 1. Each of the areas should be thought of as a separate piece of equipment with the capability of being internally connected. Each section has its own power switch. Figure 2 is a block diagram that shows the various circuits and their interrelationships.

Basic to audio testing is a three-decade, three-function generator. This is contained in the area labeled Audio Sweep Generator. This basic generator has three controls besides the power switch: Slide pots for frequency and amplitude and a toggle switch to select one of the three available waveforms. The amplifier output impedance is less than one ohm and it will supply 15 volts peak-to-peak into 500 ohms or 10 volts peak-to-peak into 8 ohms. By having the output impedance very low the user can add resistance either internally or externally where necessary to match a particular application. The other three toggle switches in the sweep generator section are used to interface to the timebase section that will be discussed next.

The next step of sophistication beyond a basic function generator is generally a sweep generator. This requires some type of second oscillator to generate a sweep signal for the primary generator. Often the secondary oscillator is a simple fixed or possibly selectable frequency ramp generator.

In the case of the *model 101* we decided to give you wide latitude in the choice of both sweep and return times. The basic waveform of the timebase is a triangle. The two slide pots (R1 and R2) on the left side of the timebase section control the leading and trailing sides of that triangle independently. A switch (S4) deactivates one of the pots and allows the remaining one to control the frequency of a symmetrical triangular waveform. Use of the two frequency control pots allows the leading or trailing side to be up to 100 times as long as the other side. Rotary switch S3 steps the frequency range. In the slowest setting, with the slide pots at their minimum, the timebase will produce a triangular waveform of three minutes on each ramp. This would be used for maximum resolution for such things as plotting standing waves in an auditorium on an X–Y recorder.

Slide pot R3 is the amplitude adjustment and R4 is a ±5-volt DC offset. Below the DC offset pot there are two toggle switches. The one to the left (S5) selects one of the three waveforms. The timebase is capable of providing the three basic waveforms and hence, rather than merely a secondary oscillator to sweep the audio generator, it is a complete second function generator. The separate leading and trailing edge frequency controls allow it to produce nonsymmetrical waveforms. Combining the frequency, amplitude and DC offset controls will provide wide latitude in generating a pulse train.

Toggle switch S8 inverts the output, while S9 provides for manual setup of the timebase/sweep generator system.

The triangle output from the timebase generator (independent of the setting of the output waveform switch) sweeps the audio generator through the LOG/LINEAR sweep select switch (S12) of the sweep generator section when SWEEP/MANUAL switch S9 in the timebase section is set on SWEEP. When this switch is set to MANUAL the DC offset pot replaces the triangle timebase generator. This allows the timebase signal, which would drive the X-axis of a plotter and simultaneously sweep the audio generator, to be manually moved to any point and stopped. While the timebase signal is stopped, the audio generator frequency can be read off the counter. This mode provides for setting of the sweep end points and calibrating the chart paper.

The sweep frequency end points are set by multiturn trimmers with a screw driver through the four small holes to the left of R6, the sweep generator manual frequency slide pot.

The timebase also triggers the blanking mode of the audio sweep generator. In the blanking mode when the timebase is on the negative-going side of the ramp, the audio oscillator is turned off. Also, the holding capacitors in the AC to DC converters of the voltmeter are discharged. This results in a zero reference line during retrace. The purpose of this will be more apparent when the unit is discussed as a system.

With the sweep generator SWEEP/MANUAL switch S9 set to MANUAL and blanking mode activated, the sweep generator functions as a tone-burst generator. The left-hand timebase frequency select pot controls the on-time of the

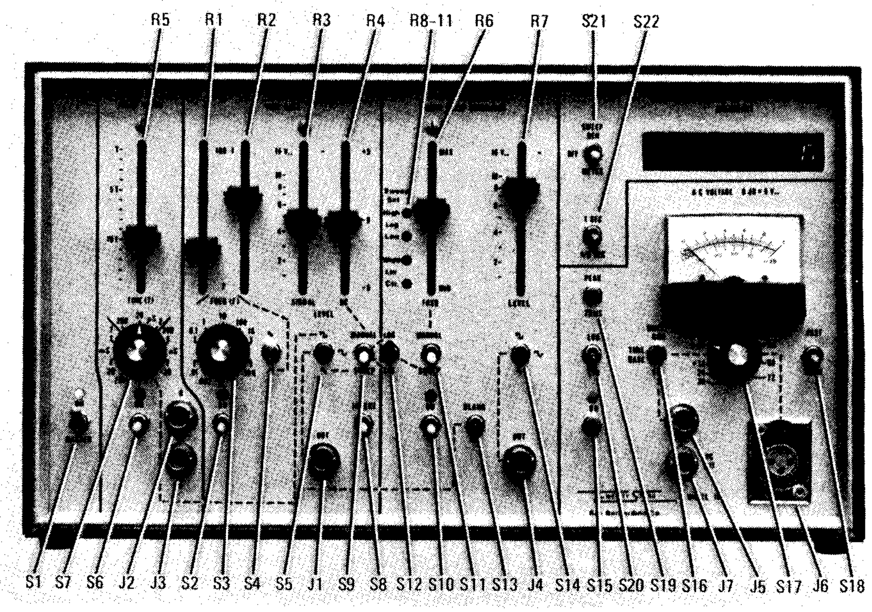


FIG. 1 THE MODEL 101 AUDIO-PLUS SYSTEM consolidates several audio test instruments.

Radio-Electronics

WITH MORE AND MORE AUDIO SERVICE centers, dealers and design laboratories making repetitive and comprehensive measurements of audio equipment (including everything from preamplifiers to loudspeakers and tape decks), their goal is to make such measurements as quickly as possible, with as few pieces of test equipment as practical. For this reason, The Fidelity Sound *model 101*, shown in Fig. 1, combines various signals and test

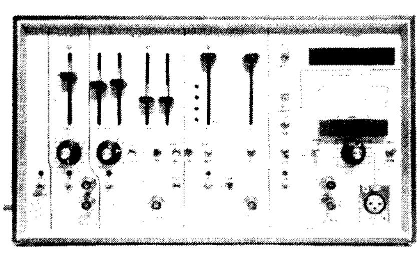


FIG. 1

functions into a single, compact instrument. It won't tell you everything you ever wanted to know about a piece of audio equipment but, when combined with a decent oscilloscope and/or an X–Y plotter, it produces some very excellent response measurements of virtually any kind of audio gear where frequency response is important. Its many signal outputs, built-in frequency counter and built-in audio voltmeter can prove useful in making a variety of other tests besides frequency response.

The *model 101* consists of two sine/square/triangle-wave function generators, a pulse generator, a frequency counter and an AC voltmeter. In its simplest form, the unit can be thought of as several pieces of independent equipment in a compact cabinet. In addition, when these various sections are properly interconnected (many of these interconnections are internal, thanks to the front-panel switching arrangements) and if an X–Y plotter or scope is used, the system generates a frequency-response plot. When the unit is combined with an efficient speaker, a quality microphone and a hard-copy plotter, it will produce a written record of room acoustic analysis including standing waves, which, because of their low spectral energy, are often missed by other types of sweep analysis.

There are several applications for which the unit is *not* suitable. For example, its sinewave output is too high in distortion to be used to check preamplifier or power amplifier distortion, although the amplitude response of the sweep generator, used in either its manual or sweep mode, is certainly flat enough for meaningful frequency-response measurements.

The frequency-counter section, shown in Fig. 2, is a useful addition. The counter

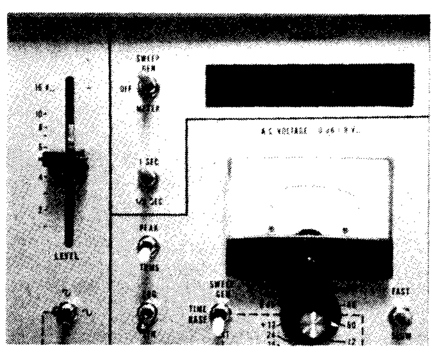


FIG. 2

reads the repetition rate of whatever signal is selected from the sweep-signal generator section. It would have been more useful if the counter could also read externally connected signal frequencies.

The functions and controls of the different sections are described in the article dealing with the construction of the *model 101*. Our purpose here was to check out

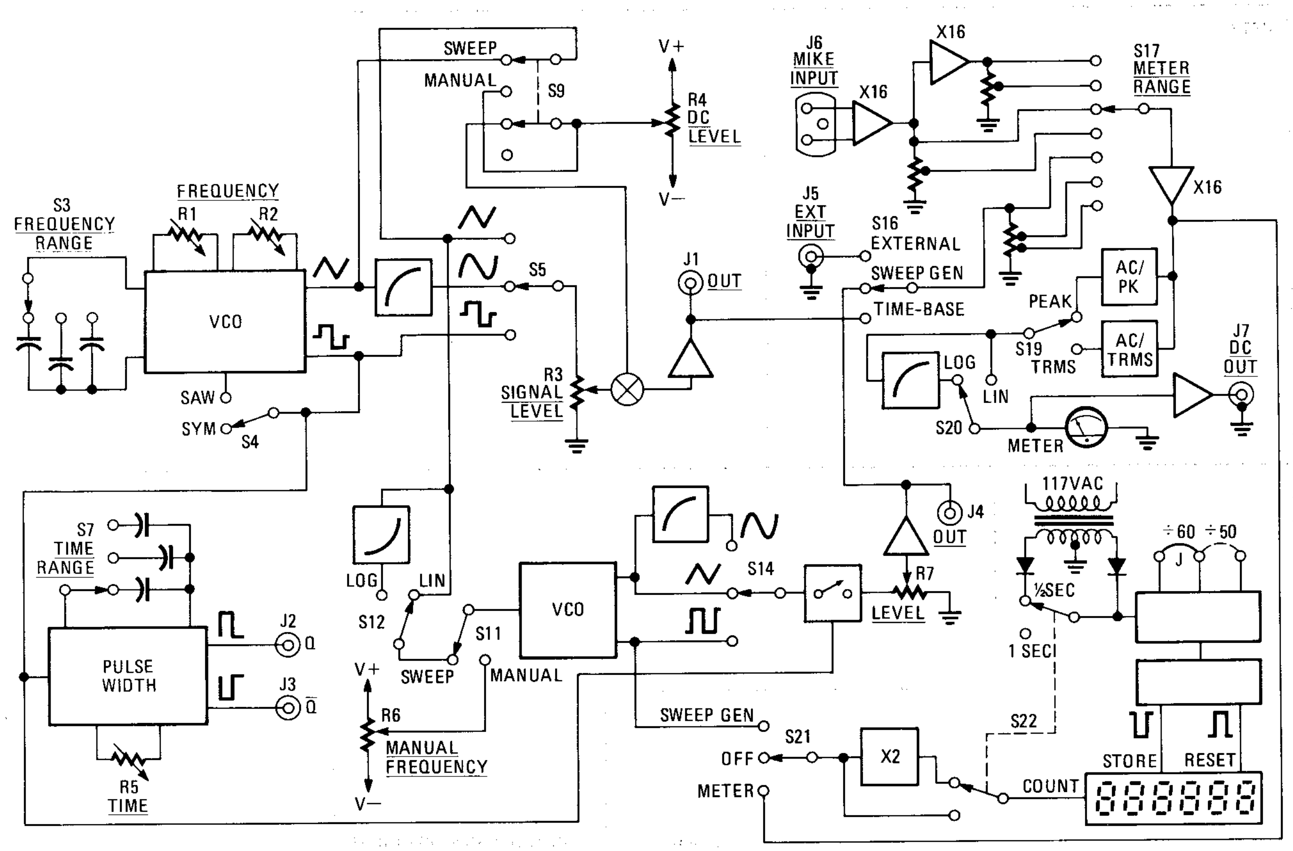


FIG. 2—BLOCK DIAGRAM shows inter-relationship of the different instrument sections. Use it along with Fig. 1 to follow text description of the system's operation.

Tests It

LEN FELDMAN
CONTRIBUTING HI-FI EDITOR

the various specifications of the instrument and to examine some of the output waveforms it is able to deliver. Table 1 summarizes the manufacturer's specification claims as well as our own measurements and results. In general, most of the published specifications were either met or exceeded. One notable exception was the total harmonic distortion of the sweep-generator sinewave output. This THD measured 1.8% for a 1-kHz output signal, as opposed to the 1.0% claimed by the manufacturer.

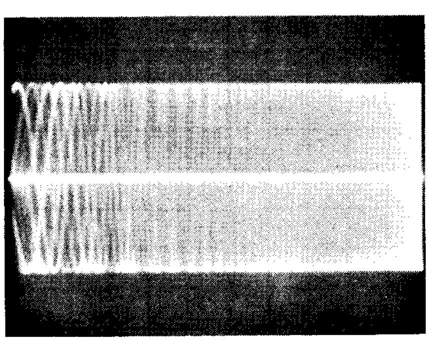


FIG. 3

Output signal waveforms

We photographed several types of waveforms that can be taken from the various output terminals of the *model 101*. Figure 3 shows a sweep-frequency signal output, logarithmically swept from 20 Hz to 20 kHz. The center line seen from left to right is the retrace signal between successive sweeps and is, of course, adjustable as to duration. The total sweep time can be adjusted from its slowest speed of around 3½ minutes for a full sweep to about 4 seconds—the minimum time required to "get all the frequencies in" for at least one cycle of each.

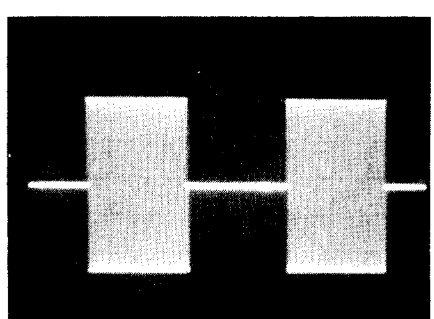


FIG. 4

Figure 4 shows how a wide variety of tone bursts can be generated with the combined use of the timebase generator and the audio sweep generator operated in its manual mode (under which conditions any frequency within the audio range can be selected and remains fixed).

Figure 5 shows positive- and negative-going sharp pulses. Besides being useful in and of themselves, these pulses are also timed to occur at the start of a timebase

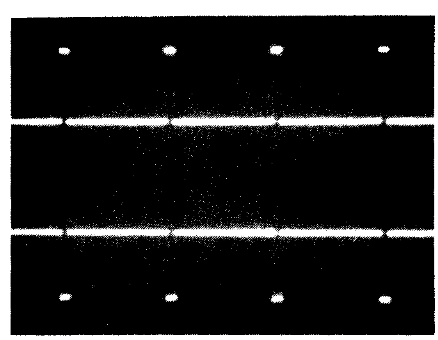


FIG. 5

ramp generated by the timebase section. Since the ramp voltage generated by the timebase section also sweeps the frequencies generated by the sweep-generator section, these dual-polarity pulses provide a ready means for triggering a scope burst and the right-hand pot controls the off-time. The blanking circuit is coordinated with the zero crossing of the sweep generator waveform; therefore, the tone burst produces only integral cycle waveforms, beginning and ending at zero.

To the left of the timebase section is a pulse output and pulse-width control. Each time the timebase begins its positive-going ramp the pulse section provides a single pulse. The width is controlled independent of timebase frequency by range switch S7 and slide pot R5. The outputs are complementary TTL.

An AC voltmeter is in the lower right-hand corner of the unit. Rotary switch S17 under the meter is the range switch. The high-sensitivity ranges (−36 to −72 dB) apply only to the mike connector. Toggle switch S16 selects either the sweep or timebase function generators or the external BNC connector (J5) below it. The other three toggle switches provide fast or slow tracking rate (large or small damping), peak or true RMS, and linear or log scales.

A six-digit frequency counter is above the voltmeter. Toggle switch S21 is the power switch and also selects the signal to be counted. It will count either whatever signal is selected by the voltmeter select switch, or it will count the audio generator internally. This latter selection allows stable counting of the audio generator when the signal coming from the system under test may be very distorted or of very low amplitude. The second toggle switch (S22) selects either a one-second or a one-half-second counter update. The counter is line-triggered and may be programmed for either 50 or 60 Hz.

Next month, we will present an in-depth discussion of the power supply and timebase circuits as well as the construction details for these two circuits. **R-E**

TABLE I

PERFORMANCE SPECIFICATIONS

	Manufacturer's Claim	R-E Measurement	Comments
TIMEBASE SECTION			
Timebase frequency range	0.002 Hz–800 kHz	Confirmed	
Vernier control of ± ramp side	100 X	Confirmed	
Sinewave THD	Less than 1.5% at 1 kHz	0.9%	
Squarewave rise & falltime	0.5 µs, 8 volts P-P	0.7 µs	
Timebase amplitude	16 volts P-P	Confirmed	Includes DC offset
DC offset	±5.0 volts	Confirmed	
PULSE SECTION			
Pulse-width total range	40 ns–4 seconds	Confirmed	In 10X steps
Pulse-width vernier	14 X per range	Confirmed	
SWEEP-GENERATOR SECTION			
Manual frequency range	20 Hz–20 kHz	18 Hz–20.2 kHz	
Sinewave THD	Less than 1.0%, 8 volts P-P	1.8%	At 1 kHz
Squarewave rise & falltime	0.5 µs	0.7 µs	0–90% at 8 volts P-P
Output level	16 volts P-P/500 ohms; 10 volts P-P/8 ohms	17.0 volts P-P, 500 ohms; 12 volts P-P/8 ohms	
AC VOLTMETER SECTION			
0-dB reference	8.0 volts P-P = 0 dB	Confirmed	
Internal or line-in range	+36 dB to -24 dB	Confirmed	In 12-dB steps
Microphone input range	-36 dB to -72 dB	Confirmed	In 12-dB steps
External input impedance	1 megohm	Confirmed	
Microphone input impedance	600 ohms	Confirmed	
Voltmeter output impedance	100 ohms	Confirmed	
Meter system response	20 Hz–100 kHz, +0, -¼ dB	18 Hz–110 kHz, ±0.25 dB	
FREQUENCY-COUNTER SECTION			
Sensitivity	10% of selected meter scale	Confirmed	
Reading update	0.5 or 1.0 seconds	Confirmed	Switch-selectable
GENERAL SPECIFICATIONS			
Dimensions	14 W × 8 H × 3-inches D	Confirmed	
Shipping weight, assembled	9 lbs.	Confirmed	
Price	$650		

sweep or initiating the action of an X–Y plotter in sync with the frequency sweep to be plotted.

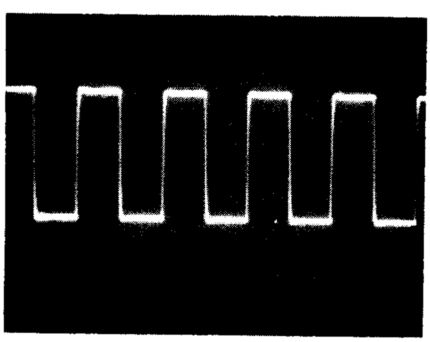


FIG. 6

Figure 6 shows a 20-kHz squarewave output. This particular squarewave was observed at the output terminal of the timebase generator section, but equally steep squarewaves can be obtained at the sweep-generator output terminals.

Figures 7 and 8 are scope photos taken of the triangular and ramp-shaped waveforms at the output jack of the timebase generator section. A sinusoidal timebase is also available from this output terminal.

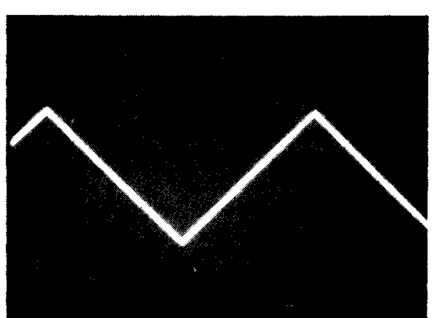


FIG. 7

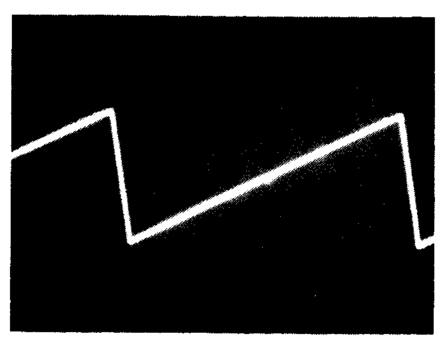
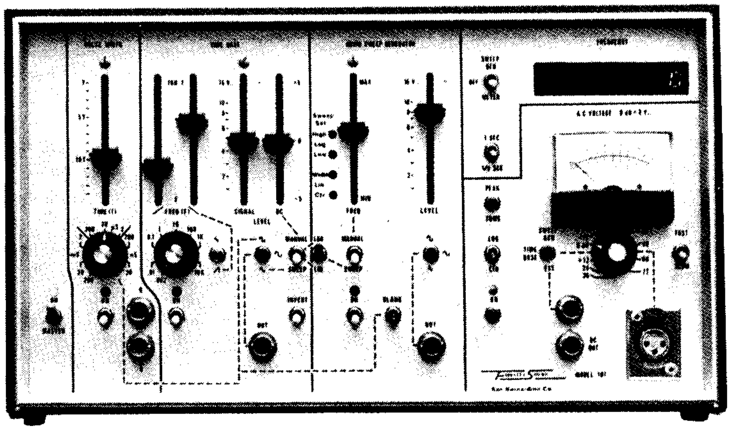


FIG. 8

Based on our tests and measurements, we conclude that the *model 101* Audio-Plus Test System would be a useful addition to anyone's audio test bench. **R-E**

Audio Test Station



Part 2—A host of precision instruments are required if you want to put high-quality audio equipment through its paces. This month we cover the test station's power supply and timebase circuits.

RAY DAVISON

THIS, THE SECOND ARTICLE DESCRIBING Fidelity Sound's *model 101* Audio Test System describes the power supply and timebase circuits and presents the construction details for these sections. Last month, we presented the overall block diagram and described the general operation of the model 101.

The traditional straightforward and largely self-explanatory power-supply circuit is shown in Fig. 3. The timebase and audio-generator output amplifiers are supplied by single-stage regulated supply. The rest of the analog circuitry is double-regulated. The pulse and counter sections have individual regulators. The diode/R-C circuits coming directly from the secondary of the transformer provide the trigger for the counter timebase.

The timebase circuit is shown in Fig. 4. The basis of this section is oscillator IC201. It is an emitter-coupled multivibrator that can be considered as an integrator and a comparator in a closed loop. The output of the comparator will always be one of two possible voltages. The output of the integrator will be a straight line whose slope is a function of the

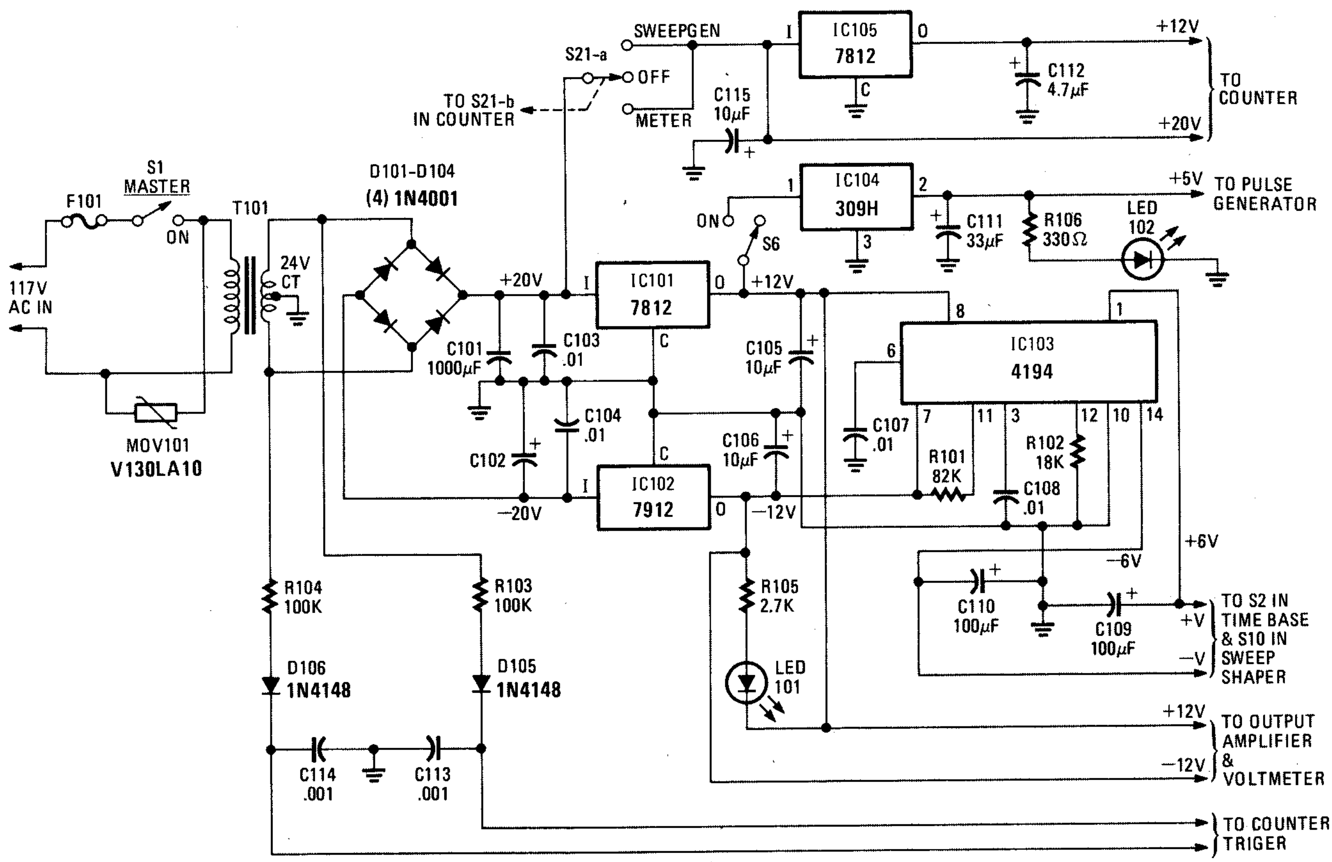


FIG. 3—THE POWER SUPPLY delivers all the operating voltages required by the various internal circuits. Some supply sources are double-regulated.

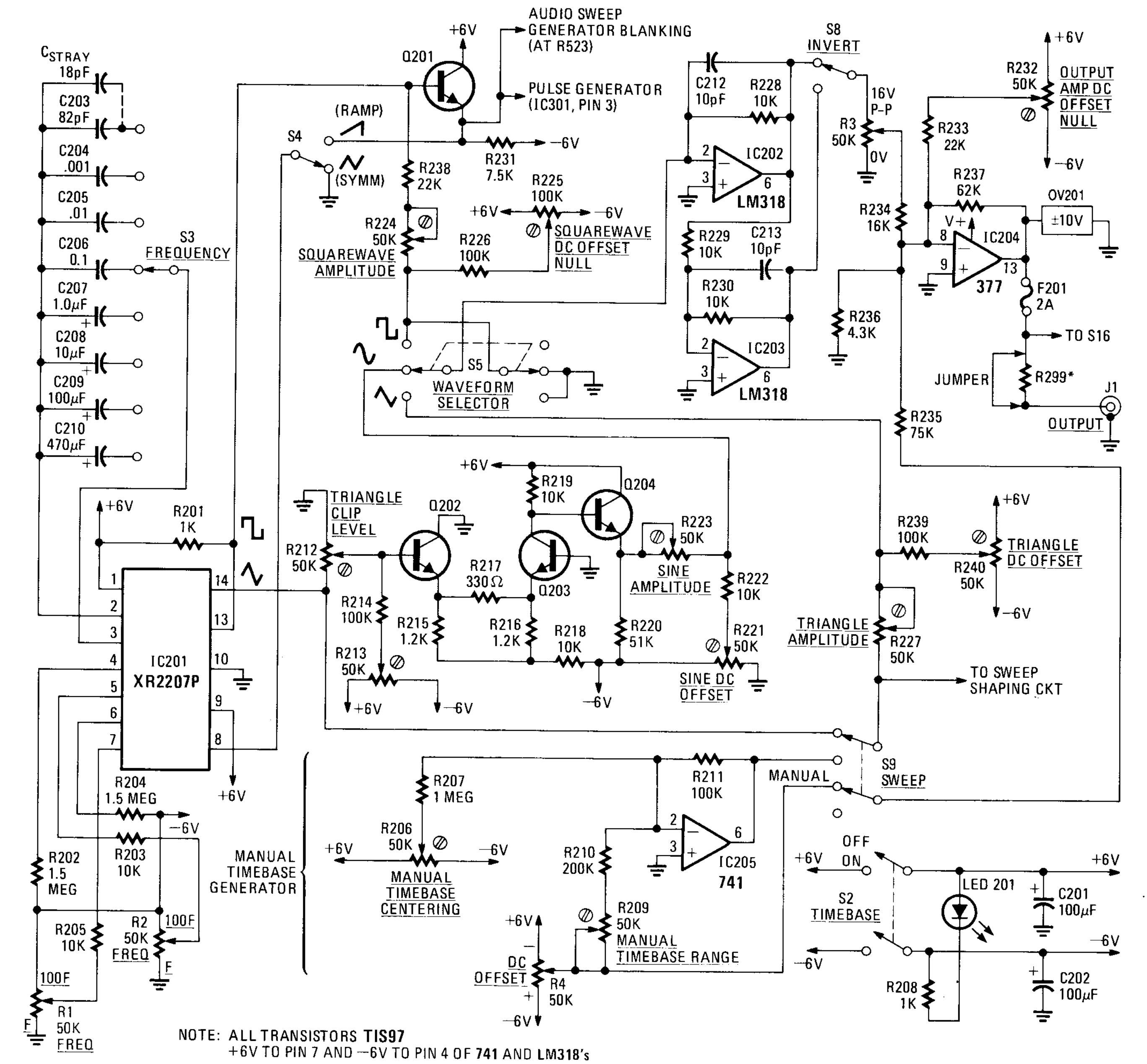


FIG. 4—THE TIMEBASE GENERATOR is designed around the Exar 2207 current-controlled oscillator. Frequency is determined by switchable capacitors and two slide pots on the front panel.

TIMEBASE

Resistors, ¼ watt, 5% unless otherwise specified
R201, R208—1000 ohms
R202, R204—1-5 megohms
R203, R205, R218, R219, R222, R228-R230—10,000 ohms
R206, R209, R212, R213, R221, R223-R225, R227, R232, R240—50,000 ohms, trimmer
R207—1 megohm
R210—200,000 ohms
R211, R214, R226, R233, R239—100,000 ohms
R215, R216—1200 ohms
R217—310 ohms
R220—51,000 ohms
R231—7500 ohms
R234—16,000 ohms
R235—75,000 ohms
R236—4300 ohms
R237—62,000 ohms
R238—22,000 ohms
R299—See text

Capacitors
C201, C202—100 µF, 10 volts
C203—82 pF
C204—0.001 µF
C205—0.01 µF
C206—0.1 µF
C207—1.0 µF, aluminum electrolytic, low voltage, low leakage. See text.
C208—10 µF, aluminum electrolytic, low voltage, low leakage. See text.
C209—100 µF, aluminum electrolytic, low voltage, low leakage. See text.
C210—470 µF, aluminum electrolytic, low voltage, low leakage. See text.
C212, C213—10 pF
Q201-Q204—TIS97
IC201—XR-2207
IC202, IC203—LM318
IC204—LM377
IC205—LM741
OV201—LA10 over-voltage limiter
F201—2-amp fuse
S2, S9—SPDT toggle switch
S3—SPDT rotary switch
S4, S8—SPDT toggle switch
S5—DPDT toggle switch
J1—BNC panel jack

POWER SUPPLY

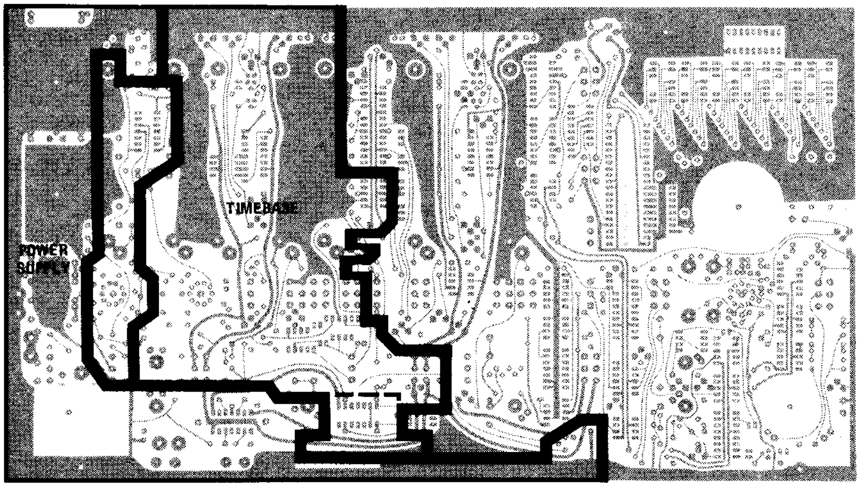
Resistors ¼ watt, 5% unless otherwise noted
R101-82,000 ohms
R102—18,000 ohms
R103, R104—100,000 ohms
R105—2700 ohms
R106—330 ohms

Capacitors
C101—1000-μF, 16-volt, electrolytic (two 500 μF in parallel)
C102—500 μF, 16-volt electrolytic
C103, C104, C107, C108—0.01-μF disc
C105, C106, C115—10-μF, 16-volt electrolytic
C109, C110—100-μF, 16-volt electrolytic
C111—33-μF, 16-volt electrolytic
C112—4.7-μF, 16-volt electrolytic
C113, C114—0.001-μF disc

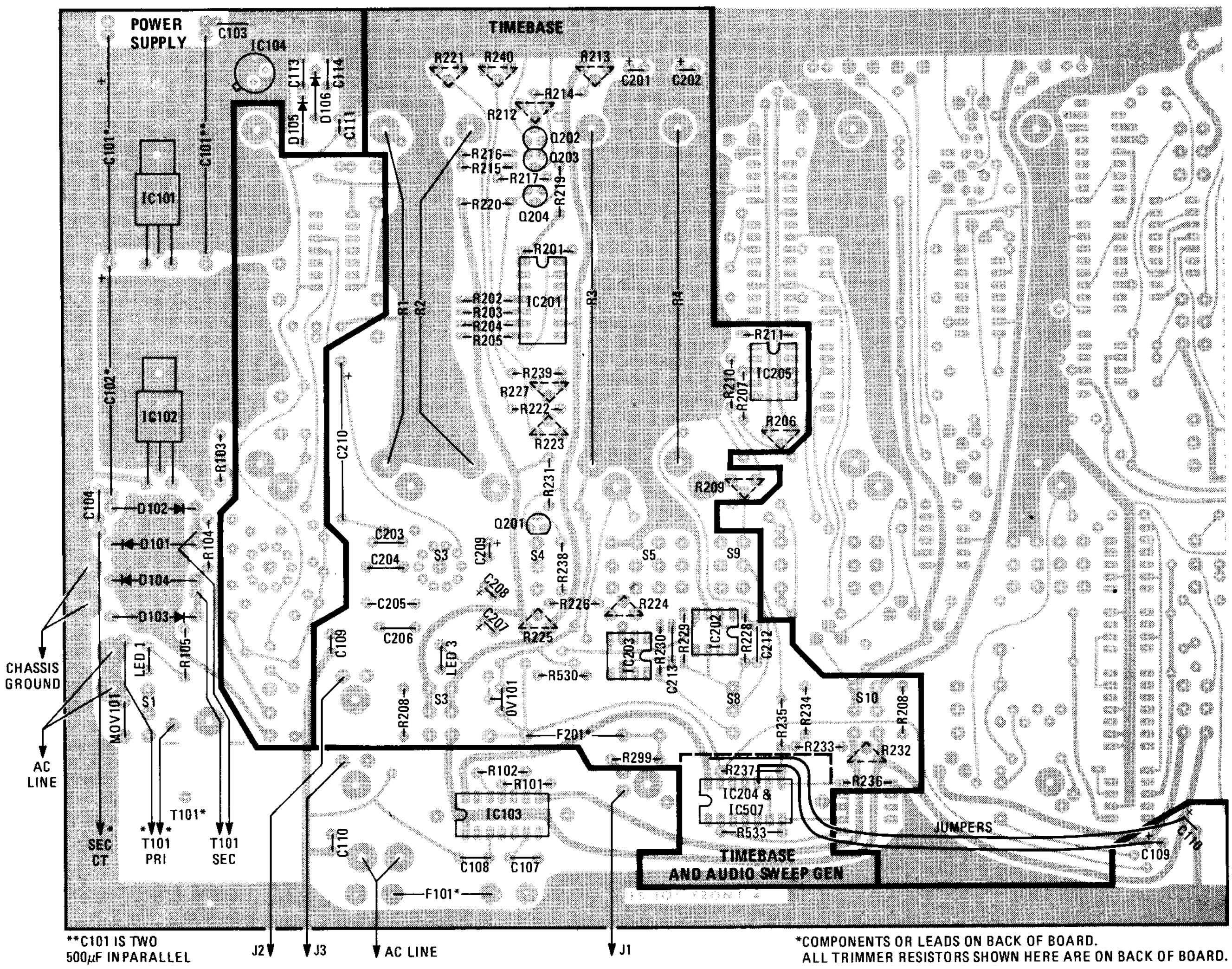
Miscellaneous
MOV1-V130LA10 thyristor
D101-D104—1N4001
D105-D106—1N4148
IC101, IC105—7812
IC102—7912
IC103—4194
IC104—309H
LED1, LED2—
T101—24-volt, 1-amp transformer
F101—
S1—SPST toggle switch
S21—DP3T toggle switch

The following are available from FSI, 1894 Commercenter W., No. 105. San Bernadino, CA 92408: Complete kit, $495.00; cabinet and circuit board, $115.00. Set of semiconductors, $195.00; seven slide pots with knobs, $17.00, set of trimmers including four multiturn pots, $17.00.

California residents add state and local taxes as applicable.



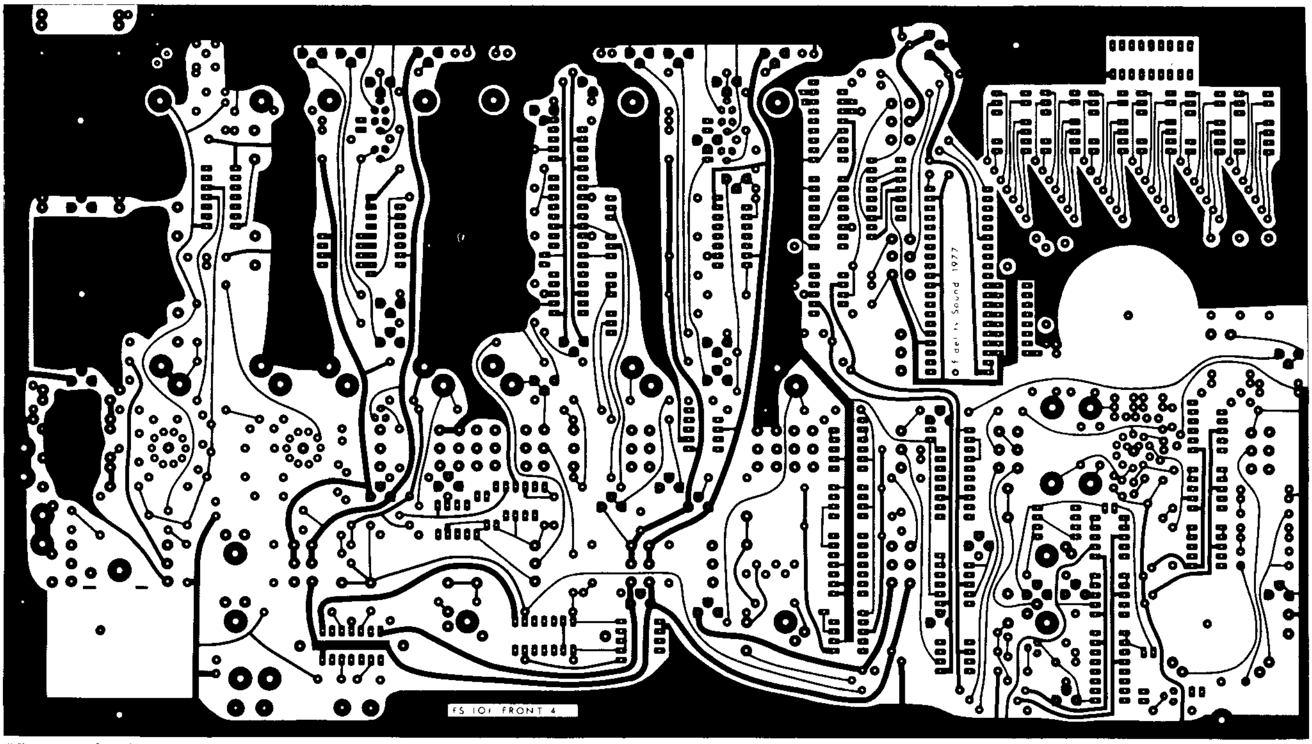
FOIL PATTERN of the component side of the PC board overlayed with the outlines of the power supply and timebase sections that are shown in the parts-placement illustration below.



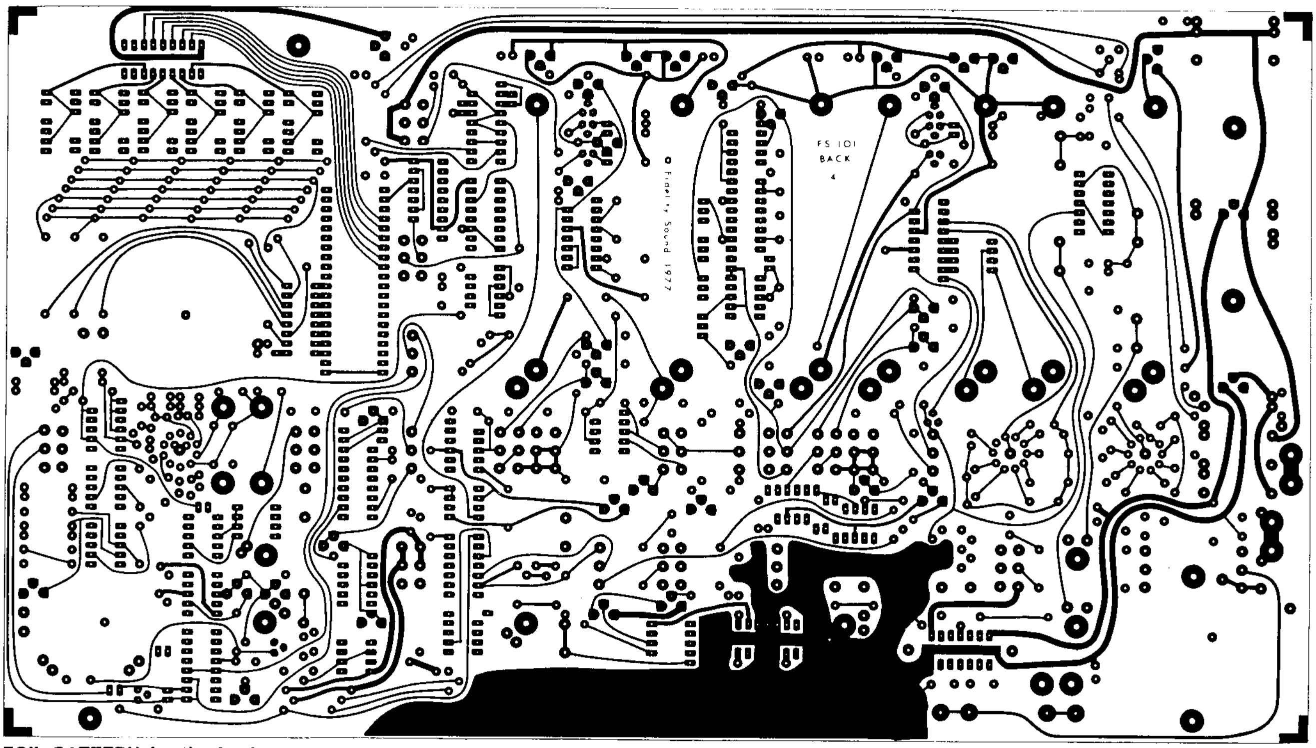
**C101 IS TWO 500μF IN PARALLEL

*COMPONENTS OR LEADS ON BACK OF BOARD.
ALL TRIMMER RESISTORS SHOWN HERE ARE ON BACK OF BOARD.

COMPONENT LAYOUT for the power supply and timebase generator are shown. Power supply parts are coded in the 100 series and timebase parts in the 200 series. Components on the front panel have codes beginning with 1.



PRINTED CIRCUIT PATTERN for the front side of the PC board shown half size. Most components are on this side.



FOIL PATTERN for the back surface of the board shown half size. It carries the fuses and most trimmers.

charging current supplied to the capacitor. The output of the integrator is then fed back to the comparator.

The integrator is essentially a constant-current source applied to a capacitor. If the current applied to the capacitor is constant, the change in voltage across that capacitor will also be constant. When power is applied, the output of the comparator begins to charge the capacitor through the constant-current source. This causes the voltage across the capacitors to rise linearly. When that voltage, which is applied back to the comparator, reaches a predetermined point, the comparator switches states and begins to charge the capacitor in the reverse direction. This causes the voltage across the integrating capacitor to change linearly in the opposite direction.

The result is that the output of the integrator is a triangle wave and the output of the comparator is a squarewave. The peaks of the triangle wave align with the edges of the squarewave since it is these edges that cause the integrator to change its output slope. If the charging rates represented by the plus and minus slopes of the integrator are equal, the slopes will be of equal magnitude and opposite sign, and, hence, both the triangle wave and the squarewave will be symmetrical.

The output of the integrator is at IC201 pin 14, and the comparator output is at pin 13. Both these outputs are buffered and do not represent the actual oscillator voltages.

continued on page 78

Rotary switch S3 selects the integrating capacitor, and the charging current is determined by the networks connected to IC201 pins 4 through 7. Small-value capacitors charge faster than larger capacitors for the same charging current so a smaller capacitor selected by S3 will produce a higher frequency. Also for a given capacitor, increasing the charging current by varying R1 and R2 also increases the frequency.

The comparator or squarewave output from pin 13 is applied to Q201, an external buffer. The buffer is necessary because the internal squarewave buffer is an open collector, and the output impedance on the positive edge of the squarewave is equal to R201. Therefore, any significant change in the external load on pin 13 alters the amplitude of the positive edge of the squarewave.

The two resistor networks connected to pins 4 through 7 each control a separate current source for charging the integrating capacitor. These sources can be used singly or in pairs. When used in pairs, the currents of each are added. The voltages applied to IC201 pins 8 and 9 determine which of these current sources is active.

The outputs of both pins 13 and 14 are approximately symmetrical around 0. The output of Q201 ranges from approximately 0 to +V (+6 volts). With S4 in the SYMM position, IC201 pin 8 is at level 0 and pin 9 at +V. This enables both pins 6 and 7 and, therefore, the charging current from the integrating capacitor for both the positive and negative ramps is the total current drawn from pins 6 and 7. When the wiper of R1 is at ground, only a very small current is drawn from pin 7, and the charging rate, or frequency, is determined by R204. Resistor R204 therefore determines the low frequency point when R1, the front panel frequency-adjust slide pot is at the minimum setting. When the wiper of R1 is at −V (−6V), most of the charging current is provided by R205, since it is much smaller than R204. Resistor R205 then determines the high frequency limit when R1 is at the maximum setting. With these values for R204 and 205, the frequency range of R1 is 100:1. The reason that R204 and R205 are not also 100:1 is because even with R1 at ground, R205 contributes slightly to the charging current and therefore R204's contribution must be reduced to compensate. When R1 is at −V, the R204 contribution is negligible compared with that of R205.

When S4 is in the RAMP position and the output from IC201 pin 13 is high, pin 8 is also high. In this case, pins 4 and 5 are activated and they perform exactly as do pins 6 and 7. Remember that the squarewave output of pin 13 is at a constant voltage during rise of the ramp voltage of pin 14. Therefore, during the positive-going ramp of pin 14, the current is controlled by pins 6 and 7. During the negative portion of the ramp, current is controlled by pins 4 and 5; or, as viewed from the front panel, R1 controls the time of the positive-going ramp and R2 controls the time of the negative-going ramp. If R1 and R2 are in extreme opposite positions, the result is positive and negative ramps with a 100:1 time ratio. With S4 in the ground (symmetrical) position, R1 controls the time of a symmetrical triangular waveform. The result of all this (looking at the front panel), is that R1 and R2 provide a 100:1 change of frequency, and each step of S3 provides a 100:1 change.

We know that the timebase section derives its name from the fact that its primary function is to sweep the audio generator and the time (actually the inverse of time—frequency) base of an X–Y display. To accomplish this, the timebase only has to provide a variable-symmetry triangle wave at low frequency. However, once the basic oscillator is established, it is relatively easy to let it provide other useful functions.

For instance, an effective way to check the proper action of a mixer is to apply two triangle waves, one, high-amplitude at a low frequency; the second, a lower amplitude at a higher frequency. If the mixer is functioning properly, each input retains its individual characteristics at the output, but one input will be riding on the other. The timebase section was designed to provide the three basic waveforms over at least the full spectrum of needed audio frequencies.

A piece of test equipment that many classify as "nice to have" but difficult to justify as a separate purchase is a pulse generator. Again, however, since there is already a basic oscillator in the timebase section, it is relatively simple to shape it into a pulse output. Therefore, the total frequency range of the timebase oscillator is made as wide as the capabilities of the basic oscillator can provide.

You then have a three-function generator with a useful frequency range of 0.002 Hz to 100 kHz and a pulse repetition rate of 0.002 Hz to about 800 kHz. The pulse-shaping section will be covered next month.

To provide the maximum possible versatility to the timebase oscillator, the range of integrating capacitors has been made as wide as practical. There is no DC bias across the integrating capacitor, and the manufacturer of IC201 has specified that the capacitors be nonpolar. This requirement is easily implemented for small-value capacitors; however, large-value nonpolar capacitors are rare and usually large sized.

The problem with using a polarized-type capacitor in a bipolar circuit is that the polarized capacitor tends to leak when you try to charge it in the reverse direction. If the leakage represents a significant portion of the charging current, the voltage rise across the capacitor (and hence across the output triangle wave) will be an exponential rather than a linear rise. This is because the leakage current increases with the charging voltage. If the leakage is significant, then at some voltage level, the leakage current and charging current will be equal, the voltage will cease to rise and oscillation will also cease. Additionally, some types of polarized capacitors can be damaged by reverse voltage.

Actually, this circuit works quite well with some aluminum electrolytic capacitors. With a supply voltage of ± 7, the charging voltage is only about ± 1.5. Aluminum electrolytic capacitors can tolerate the 1.5-volt reverse voltage. However, low-leakage capacitors, and only those with the lowest voltage ratings, should be used in this circuit.

Note that the integrating capacitors are all evenly spaced one decade apart except for the largest and smallest capacitors. The 470-μF value capacitor is simply the largest value that will consistently work in this circuit. Also note that the smallest capacitor (C203) must be reduced from its nominal value by an amount that is equal to the stray capacitance of the board and switch circuit.

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Accuracy and stability are mainly dependent on the components' cost and the amount of care taken during calibration. The oscillator is quite stable, and the timing components can be stable and either precision or trimmable. We decided that the components should be stable but that absolute accuracy was not important. The frequency counter can read down to approximately 1 Hz. By noticing the last digit bobble, it is even possible to interpolate to a sensitivity of less than 1 Hz. Frequencies of less than 1 Hz should perhaps be selected as subjective rather than absolute values. Therefore, the resistors, similar to most of the resistors throughout the rest of the system, are 5% carbon film; the capacitors are as temperature stable as readily available with the tolerance of the smaller values at ±5% and that of the electrolytic capacitors at ±20%.

Timebase output circuitry

The output of Q201 serves four functions: One has already been discussed; the other functions will be covered as they apply to other circuits. Transistors Q202 and Q203 form a triangle-to-sinewave converter. Each transistor logarithmically clips one peak of the triangle wave. Resistor R212 determines the degree of rounding of the peak, and R213 makes sure that the peaks are clipped equally. Transistor Q204 buffers the common-collector output of Q203.

Trimmer resistors R224, R223 and R227 as selected form the input resistor to inverter IC202. Each of the three basic waveforms are generated with different signal levels; therefore, these resistors provide that each waveform has the same amplitude at the output of IC202. Trimmers R225, R221 and R240 provide offset nulling for each waveform, with R226, R222 and R239 controlling the sensitivity of those adjustments.

Switch S5 selects one of the three signal lines to be applied to IC202. Note that the squarewave line when it is not selected is grounded through the other half of switch S5. This minimizes squarewave crosstalk into the sinewaves or triangle waves at time of selection. The rise- and falltimes of the squarewave are fast enough to cause a spike waveform to propagate across the contacts of S5 or across the circuit board.

The output of IC202 goes to IC203, which is connected as a unity-gain inverter. Switch S8 then inverts at the output whatever waveform was selected by S5. This is valuable for interfacing with certain other types of equipment and can also help provide a stable scope-trigger for internal calibrations.

Resistor R3 is the front-panel-amplitude slide pot, and IC204 is one-half of an

LM377. This device is generally considered only as a driver for low-power speaker systems, to be used with a single power supply. However, it is far more versatile and actually easier to implement with a split power supply than with a single power supply. Also, from the speaker-driver applications it is not always obvious that this is an operational amplifier suitable for op-amp applications. It is fast enough for the full audio spectrum.

One of the most powerful audio applications for an operational amplifier is as a mixer. The negative inputs of IC204 and IC201–IC203 are connected as a summing junction. This creates a perfect mixer; that is, several independent signals can be added together each with independent gain or loss, without any signal affecting any other signal.

A first encounter with this circuit is often rather mysterious. When you troubleshoot a signal-processing system, you often take an oscilloscope, start at the input and then walk through node-by-node to the output, observing the waveforms and watching for any change from node to node. Normally, the only change from input to output is a change in amplitude. If a node in the chain does not have a signal, you can generally assume that something has either interrupted or grounded the signal since you checked the previous node; also you would not

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observe that signal in any subsequent node. However, in this circuit (if R3 is not at ground) there is a signal at the left side of R234, but the right side of R234 shows just 0 volt.

This phenomenon is called a *virtual* ground. The input impedance of IC204 (as seen from the wiper of R3) is simply R234. For any signal from R3 that might attempt to pass back through R235, it's as if the right side of R235 were grounded. Turning up the sensitivity control on the scope may reveal a very severely clipped remnant of the signal. However, the output of IC204 is the original signal with a gain of R237 divided by R234.

In addition, there is a DC level that is the voltage at the left of R233 times R237 divided by R233. In this case, the voltage should be zero since R233 provides the offset null of IC204. Front-panel DC offset is applied through R235.

Resistor R236 is necessary for frequency compensation. OP-amp IC204 is internally compensated to be stable at gains greater than 10 (the gain being determined by the ratio of feedback resistor R237 to input resistors R234, etc.). Resistor R236 can be calculated, but is most easily determined empirically. Substitute a variable resistor for R236, set S5 to the squarewave position, observe the output of IC204, and adjust R236 for both minimum risetime and minimum overshoot at 1 kHz.

Resistor R4 is the front-panel DC offset. With S9 in the SWEEP position, the R4 output mixes with the signal from R3 to provide a ±5-volt DC offset of that signal.

Switch S9 provides the manual timebase mode. With S9 in the SWEEP position, the triangle-wave output of the oscillator is used to sweep the frequency of the audio sweep generator as well as the timebase of an X–Y display. Setting S9 switch to the MANUAL position opens the direct connection between R4 and IC204. The triangle wave is removed from its sweep function, and R4 is substituted for it—both for the sweep circuitry and for the timebase output. Switch S5 must be in the TRIANGLE position. Resistors R209 and R206 adjust the output of IC204 so that the signal from R4 that arrives at the upper half of S9 will exactly replace the triangle wave at switch S9.

The LM377 IC has both overcurrent and thermal shutdown. It can apply at least ±5 volts to a less than 10-ohm load. If a higher signal or power level is required, an LM378 or an LM379 can be substituted, as these IC's are equivalent.

The LM377 is rated at a total supply voltage of 26. The LM378 and LM379 are both rated at 35 volts. The only way to differentiate between those devices that can tolerate a higher voltage from those that can't is to experiment. (The premium price of the LM378 pays for destroying a lot of good LM377's to locate some of the higher voltage units we need.) The LM379 is an LM378 with a metal heat sink on top. A tab at each end lets you solder it into a circuit board; the device is also drilled and tapped so that you can mount an additional heat sink or mount the unit to a chassis.

Although the LM377 is quite immune from self-destruction, it can be damaged by applying a large external voltage at J1. Overvoltage sensor OV201 protects the output of IC204 from external damage. If ±10 volts or more is applied to the output terminal, OV201 shorts to ground and prevents the external voltage from reaching IC204. If this voltage is present for any significant time, F201 blows, thereby protecting OV201 from excess dissipation.

The external overvoltage protection is optional. There are several devices on the market designed to limit voltage, and the PC board is set up to accept several different types. The recommended LA10 device costs approximately $20. Even though this $20 is there to protect a $3 output amplifier, **the value lies in eliminating repair costs and downtime.**

Resistor R299 establishes the output impedance. The jumper around R299 is on the circuit board. Normally, R299 is omitted in which case the output impedance is less than 1 ohm. If some other output impedance is desired, it is inserted as R299 and the jumper on the board is cut. The jumper is on the reverse side of the board readily accessible in a finished unit, which makes it easy to attach R299.

Timebase calibration

Connect a reasonably well-calibrated oscillator scope to J1. (The scope is the only calibration standard that will be used and it is assumed that amplitude calibrations are not critical.)

Set the scope input to DC.
Set all trimming resistors to their center positions.
Turn on master power switch S1 and S2.
Set S5 to TRIANGLE and S8 to NOT INVERT.
Set R3 to maximum and R4 to 0.
Set S3 to 1 kHz.
Set S4 to symmetrical.
Set R1 to lower position.
The output should show a clean triangle wave at about 1 kHz.
Set R3 to zero.
Make sure that R4 is at 0.
Adjust R232 for zero offset.
Set R3 to maximum.
Adjust R227 for 16 volts peak-to-peak.
Adjust R240 for zero offset.
Switch S5 to squarewave.
Adjust R224 for 16 volts peak-to-

peak.

Adjust R225 for zero offset.

Switch S5 to sinewave.

Adjust R223 for approximately 16 volts peak-to-peak and R222 for approximately zero offset. Both these resistors will be readjusted later.

Switch the scope input to AC.

Adjust R212 for slight clipping.

Adjust R213 for symmetrical waveform.

With the scope set to AC, adjusting R213 will cause the average level of the waveform to shift; therefore, symmetry is achieved when the positive-going and the negative-going peaks are exactly the same distance from the center line on the scope.

Adjust R212 for minimum sinewave distortion. A sinewave plotted on the face of the scope can greatly assist in this. Use an 8 × 8-centimeter overlay, and a harmonic distortion analyzer can be used if one is available.

Adjust R223 for 16 volts peak-to-peak.

Switch the scope input to DC.

Adjust R222 for zero offset.

Set S5 to triangle wave.

Check the waveform quality at each position of S3.

At the 10K position, the waveform will be distorted; however, the 10K position is only intended to trigger the pulse generator. When you initially check the low-frequency ranges, set R1 to 100 F. Any deviation from strict linearity indicates a leaky capacitor. A slight curving of the waveform is acceptable for most applications. However, if curving is severe, the circuit may not oscillate at all at low currents. For the lowest positions of S3, set the horizontal timebase of the scope to external; this will produce just a vertical trace. Then, follow the oscillator through at least a couple of cycles to insure there is no excessive leakage. At the 0.002 setting of switch S3, a single cycle is approximately 8 minutes. If the scope beam stops while approaching one peak, increase R1 slightly. This increases the charging current. The beam should continue slightly, which indicates excessive leakage. Increasing R1 past some point should cause the oscillator to restart. Replace the capacitor that is leaky.

Then,

Set R3 to maximum.
Set S9 to manual.
Set R4 to zero.
Set R206 for zero output.
Move R4 to +5 volts.
Set R209 for a +8-volt output.
Move R4 to −5 volts.

The output should be approximately −8 volts. Resistors R206 and R209 will be fine-tuned later on.

The combination of 50K (R3) and 16K (R234) produces a taper similar to the audio taper in most controls.

That's it for now. Next month, we'll cover the pulse generator, sweep shaper and audio sweep generator. **R-E**

Audio Test Station

PART 3—A continuation of the series describing the operation and construction of the model 101 audio test system. This month we cover the pulse generator, sweep shaper and audio sweep generator.

RAY DAVISON

THIS IS THE THIRD OF A SERIES OF ARTIcles describing the *model 101* Audio Test System by Fidelity Sound. In the January issue we presented an overall picture of this versatile instrument. Last month we began with a technical description and construction details on the power supply and timebase generator.

This month we will cover the pulse generator, sweep shaper and the audio sweep generator—providing technical discussions, assembly details and calibration and alignment instructions.

Pulse generator

The pulse generator (Fig. 5) is simply a monostable multivibrator (one-shot) that produces a single pulse at the beginning of each cycle of the timebase. The one-shot is triggered by the output from timebase squarewave buffer Q201. The one-shot has complementary outputs; that is, they are always at an opposite logic level. When the one-shot is triggered by Q201 the outputs change state. They remain in this new state for a period of time that is determined by the combination of the capacitor selected by S7 and the total resistance between pin 11 and the positive supply.

After this period of time has elapsed, the outputs return to their original state. This is why the device is called a monostable. It is stable in one state. It can be forced to change state and held in that new state. However, it returns to its original state after the charge on the capacitor, which was holding it in the new state, has sufficiently diminished.

With the components shown, the pulse generator is capable of providing pulse widths ranging from about 40 nanoseconds to about 3 seconds. The front-panel controls show a minimum pulse width of 20 nanoseconds. However, the rise and falltimes converge at about 30 nanoseconds and this establishes the minimum pulse width.

Pulse-width accuracy is a simple function of the cost of the timing components. Slide potentiometer R5 is quite linear and therefore poses no inherent restriction. The remaining variable then is the capacitor selected by switch S7.

These capacitors need not be of any particular type. For the values from 10 pF thru 0.1 μF 5% ceramic or film is probably adequate for most applications. For the values of 1 μF to 100 μF, aluminum electrolytics are the smallest and least expensive. They are available in tolerances from ±10% to −20% and +100%. If greater accuracy is demanded in these ranges, then tantalum is probably the best choice.

Both outputs have over-voltage sensors to protect against the application of an external voltage, as was discussed in the timebase section. The recommended devices are $20 each. They are optional and not part of the standard parts kit, and the circuit board has been set up to accommodate several different types.

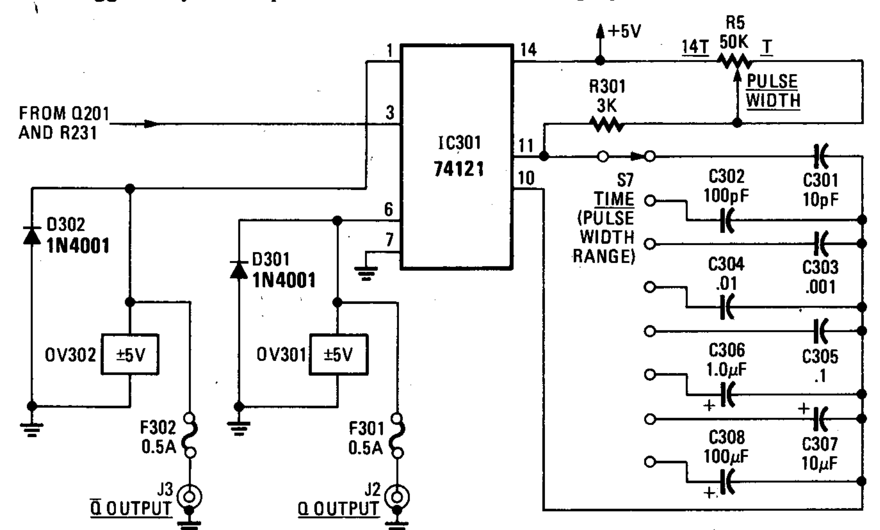

FIG. 5—THE PULSE GENERATOR is perhaps the simplest of the system's circuits. Pulse widths are adjustable from 40 nS to 3 seconds.

The sweep shaper

The audio sweep generator shown, in Fig. 6, has both log and linear sweep modes. One of these is selected by switch S12. The oscillator produces a frequency change proportional to the sweep voltage applied to it. Therefore, for a linear sweep, the sweep shaper (the timebase-to-sweep-generator interface) need only provide the proper amplitude and offset. Trimmers R10 and R409 establish the magnitude of the sweep signal while R11, 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.

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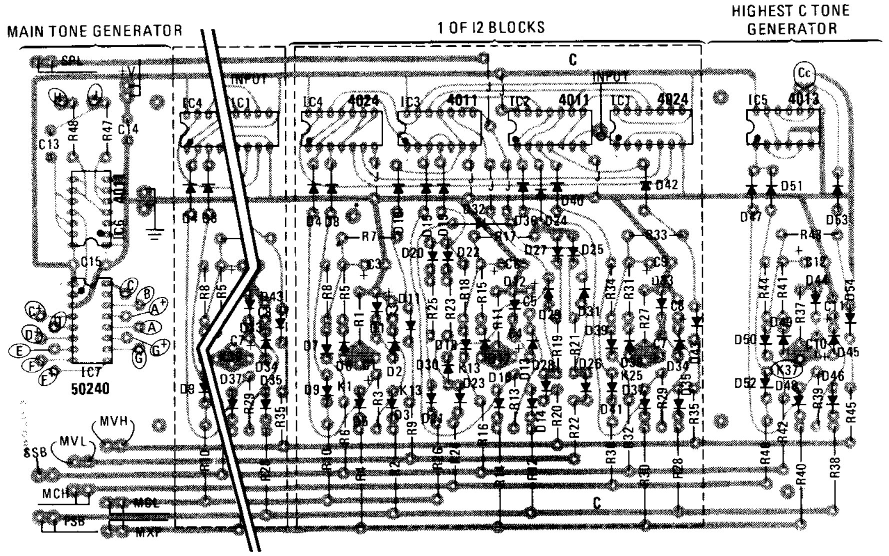


FIG. 12—PARTS PLACEMENT diagram shows the location of components on each of the twelve tone blocks and the main tone generator and the high-C generator on the ends of the 1550A board.

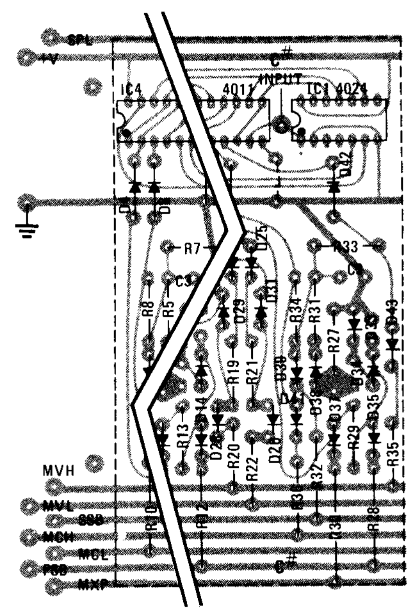


FIG. 13—CONNECTIONS that are to be made on the left end of the 1550B circuit board.

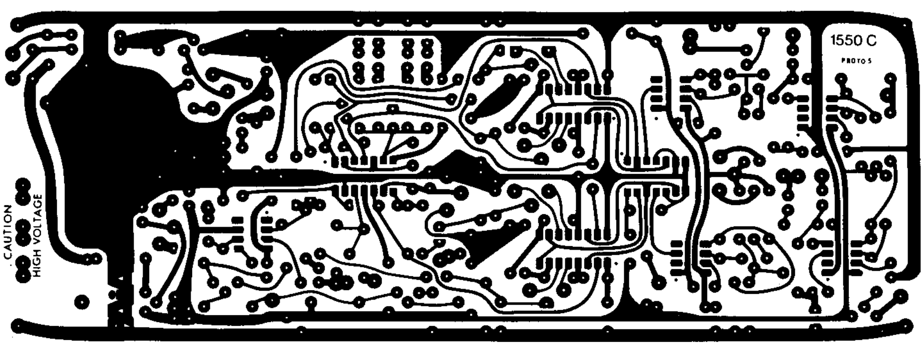
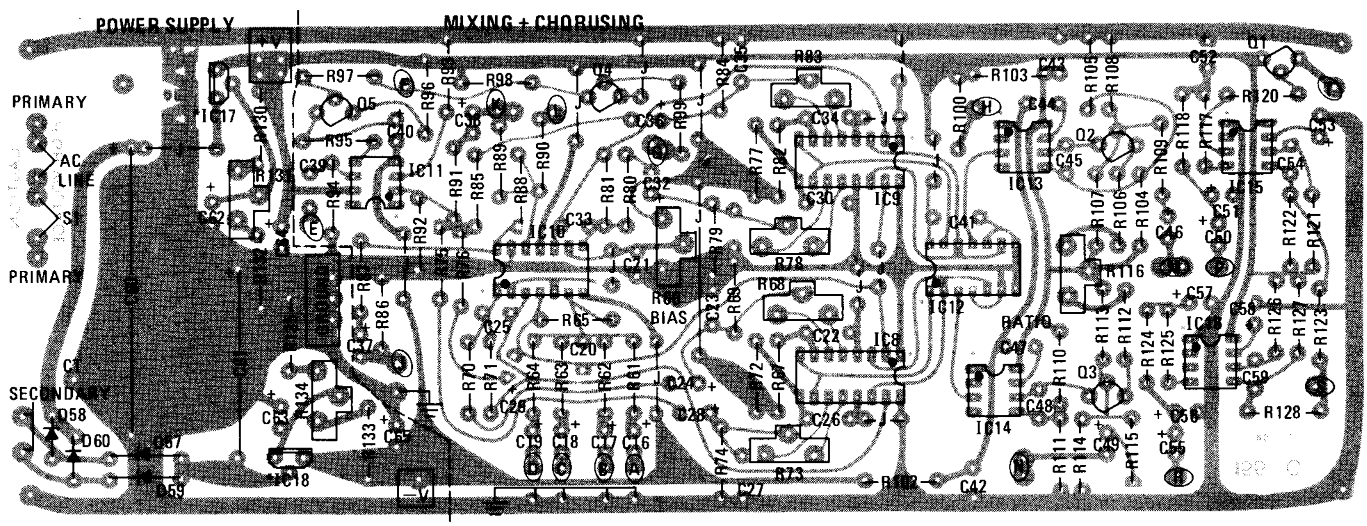


FIG. 14—HALF-SIZE FOIL PATTERNS for the 1550C board. Power supply components are on the extreme left edge. Mixing and chorusing circuits occupy the balance of the board.

PARTS LIST FOR ONE OF 12 IDENTICAL TONE BLOCKS

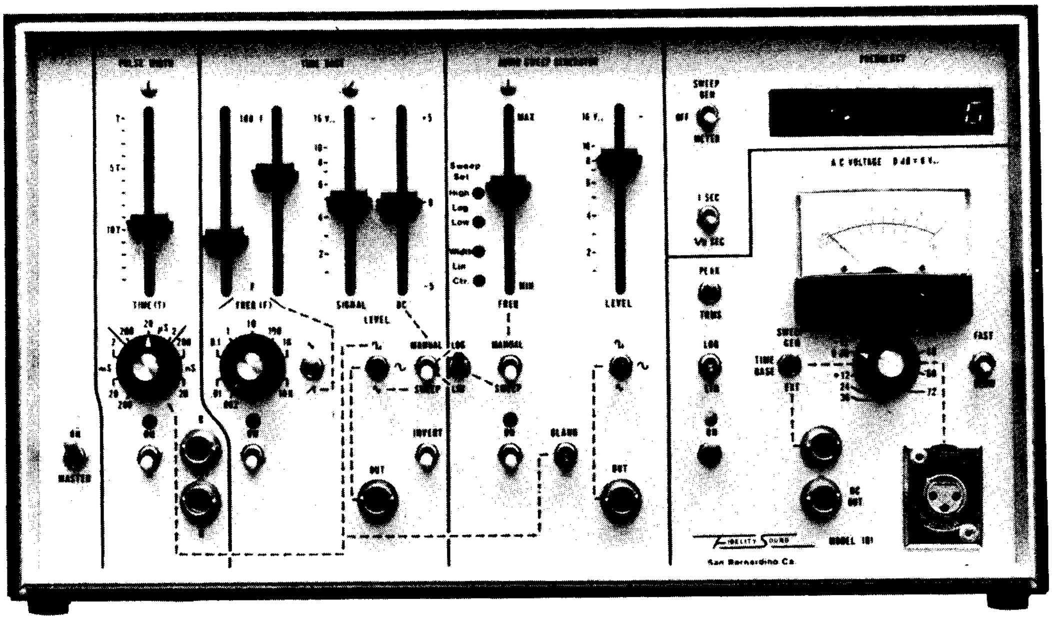
Resistors ¼ watt, 10% or better

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.



R410, and R411 establish the offset. Resistors R10 and R11 are 20-turn trimmers accessible through the front panel. Resistor R10 is labeled LINEAR SWEEP WIDTH and R11 is LINEAR SWEEP CENTER frequency.

For a log sweep, the change in frequency at any point on the frequency scale is proportional to the frequency at that point. For example, if a straight line is divided into 10 equal length segments, there will be 11 marks including the one that closes off the 10th segment. If the first mark is labeled 20 Hz, then each successive mark is twice the frequency of the preceding mark. The end marks will have a frequency of 20 Hz and 20,480 Hz. The change in frequency between the first two marks is only 20 Hz. The change between the last two marks is 10,240 Hz. This then is a *10-octave range* because the frequency doubled 10 times. This function is generally referred to as a log sweep.

For linear sweep voltage to sweep a linear VCO (voltage-controlled oscillator) in the above manner, the sweep voltage must be conditioned so that it changes very slowly at the beginning of the sweep and increases the rate of change as the sweep continues. The action just described is *not* a log function but an *antilog* function. Therefore, to convert a linear sweep to a log sweep we need an antilog converter not a log converter.

IC402 is an antilog amplifier. Op-amp IC401 inverts the incoming control voltage before it is applied to IC402, the antilog amplifier. Pots R8 and R9 are the log sweep set trimmers. The output of IC402 is effectively clamped at zero. Therefore, R8 effects primarily the peak amplitude of the waveform and hence the high-frequency end point of the sweep. Trimmer R9 adjusts the base of the waveform around zero. It shifts the entire waveform, but we call it the low-frequency sweep end-point control because its effect on the high-frequency end-point is relatively insignificant compared to its effect on the low-frequency end-point. Trimmer R412 provides a slight amount of linear sweep at the beginning of the sweep to compensate for a slight lag in the overall sweep generator circuit.

Audio sweep generator

The schematic in Fig. 7 shows the audio sweep generator circuit. The waveforms are generated by oscillator IC502. The frequency range is set by C501 connected between pins 2 and 30. The minimum frequency is established by R507. The frequency is increased by applying a negative control voltage to R506. This resistor changes the voltage signal to a current signal. With switch S11 in the SWEEP position, the linear or log signal, as selected by S12, is applied to the inverting input of IC501. Feedback resistor R505 combines with the various output resistors of the sweep-signal conditioning section to provide the desired

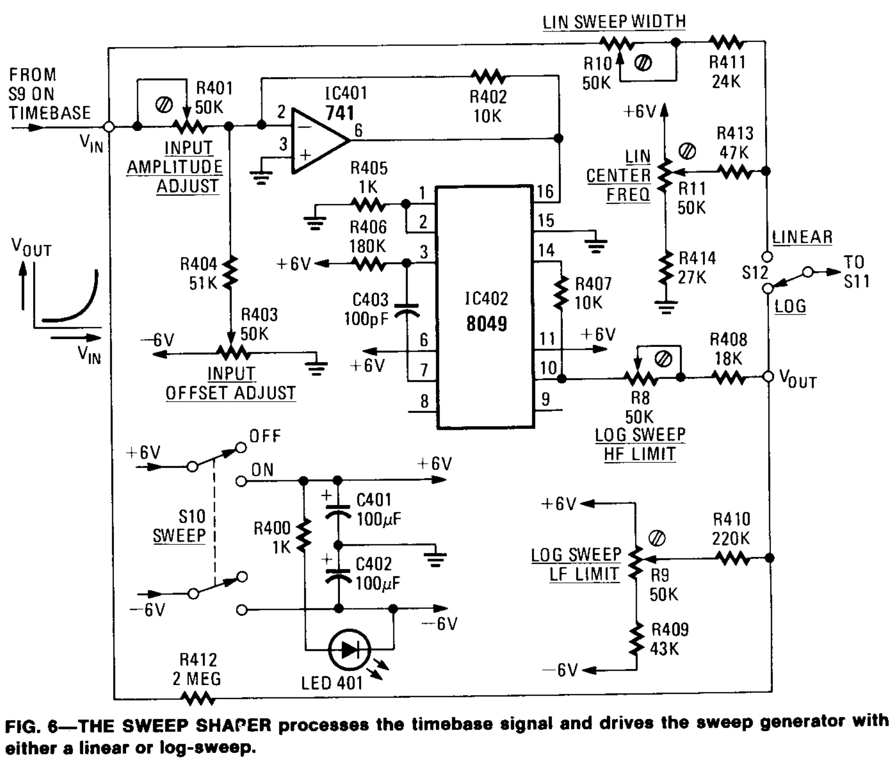
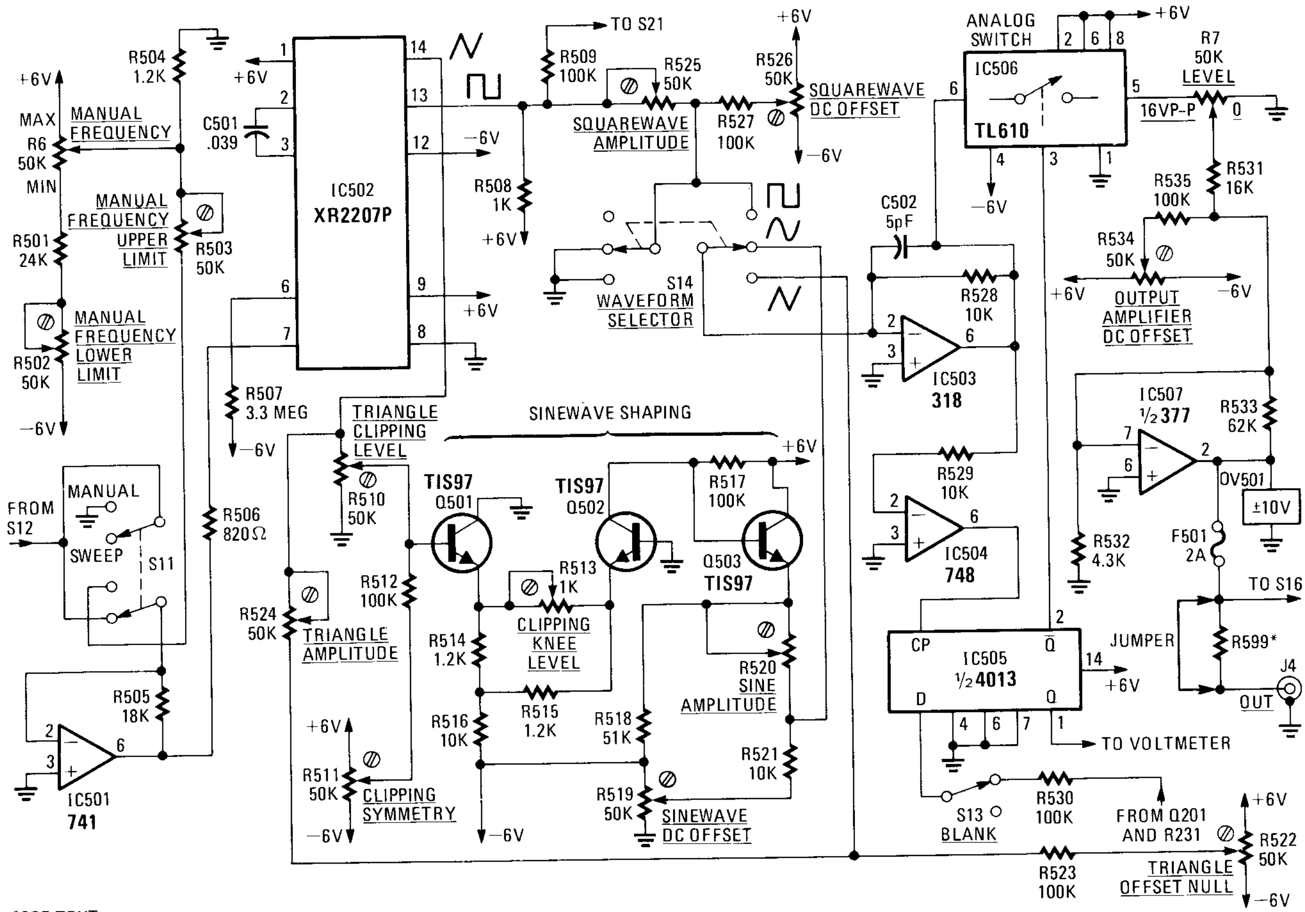


FIG. 6—THE SWEEP SHAPER processes the timebase signal and drives the sweep generator with either a linear or log-sweep.



*SEE TEXT

FIG. 7—THE AUDIO SWEEP GENERATOR is basically a voltage-controlled function generator that provides sine, square and triangular waveforms.

current to the oscillator sweep input.

When S11 is switched to MANUAL the sweep voltage is provided by R6, the MANUAL frequency control on the front panel. The other half of S11 grounds the timebase sweep signal when it is not being used. Otherwise, this signal can be coupled across the contacts of S11 and modulate the oscillator frequency.

The front-panel markings on frequency control R6 have no numerical calibration, but rather just minimum and maximum points. It is customary for a function generator to have a calibrated frequency-control dial. However, with this system, the built-frequency counter gives far greater accuracy and resolution than would be possible with a calibrated dial. Trimmers R502 and R503 allow the user to select his own minimum and maximum points. For instance, if the unit is going to be used for telephone frequencies, the sweep can be narrowed to that spectrum. Resistor R504 is in parallel with R501, R502 and the bottom portion of R6. With R502 set for a 20-Hz low-frequency limit, the result is a logarithmic frequency control from R6. The various signals, thru their respective trimmers,' are summed into IC503 to provide equal amplitude waveforms with zero offset.

The circuit at the output of the oscillator provides a tone burst. The oscillator output passes thru analog switch IC506 and on to the IC507 output stage. The signal used to gate analog switch (IC506) originates at Q201. Flip-flop IC505-a is a data or D-type flip-flop. It will pass data from the D input to the output only during the positive transition of the clock input. Op-amp IC503 is connected as a comparator that is used as a zero-crossing detector. The 748 op-amp, incidentally, makes an excellent comparator. It will do an excellent job at 20-kHz, whereas most of the comparators that have been considered standard for some time cease to function well below that.

That data to be transferred by IC505 is the tone-burst gating signal from the timebase section. The clock is a squarewave corresponding to the zero-crossings of the waveform or burst to be gated. Assume that the gating signal at the D input switches from high to low. This is ignored until the output of IC504 switches from low to high, thus indicating that a waveform out of IC503 has crossed zero in a negative-going direction. At this point the outputs of the flip-flop change state: $\overline{Q}$ goes high. This causes analog switch (IC506) to close and pass the output of IC503 as it crosses zero in the negative direction.

When the gating signal and flip-flop output go high, this data is likewise held until the output of IC504 switches from low to high. This indicates that a waveform from IC503 has again crossed zero in a negative-going direction. Thus, the tone-burst circuit produces only complete waveforms with the beginning at zero and ending at zero.

Note that IC504 is an inverting comparator and that IC507 is also an inverter. Thus, the waveforms as seen at the output start and end in a positive-going direction, which isn't any more useful but seems more "comfortable" when viewed on the scope.

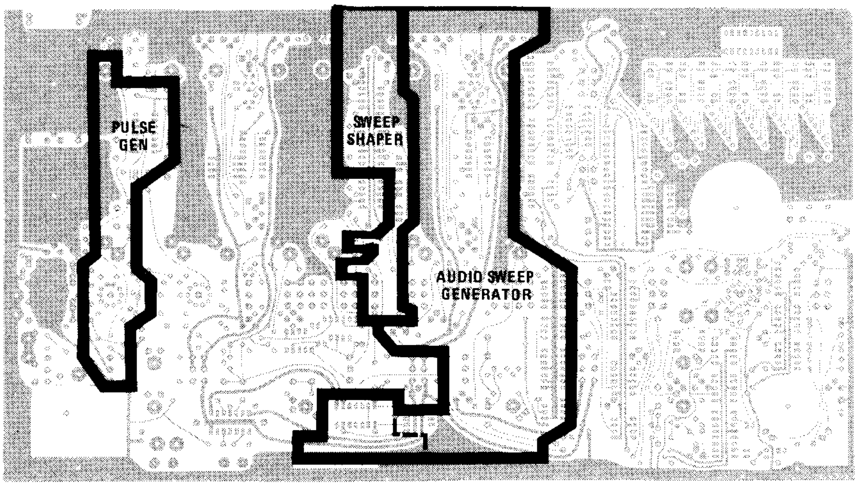
Note that switch S13 on the front panel is labeled BLANK. Its function is to blank the output of the audio sweep generator during the return sweep to provide a zero reference line and to avoid overlaying a retraced plot. Recall that IC506 is switched on when the gating signal at S13 goes low. The output of Q201 (in the timebase generator, Fig. 4) goes low as the ramp output of the timebase begins a positive-going ramp. Therefore, with switch S13 in the BLANK position the output of the audio sweep generator is on during a positive-going timebase ramp.

The output of IC506 goes to R7, the front-panel LEVEL or amplitude control. The output circuitry is identical to that of the timebase section, except that there is no DC offset. The combination of R531 and R7 produces an audio taper at R7. This produces a potentiometer curve similar to a volume control. Again the output over-voltage protection is optional, and the board accepts alternate devices.

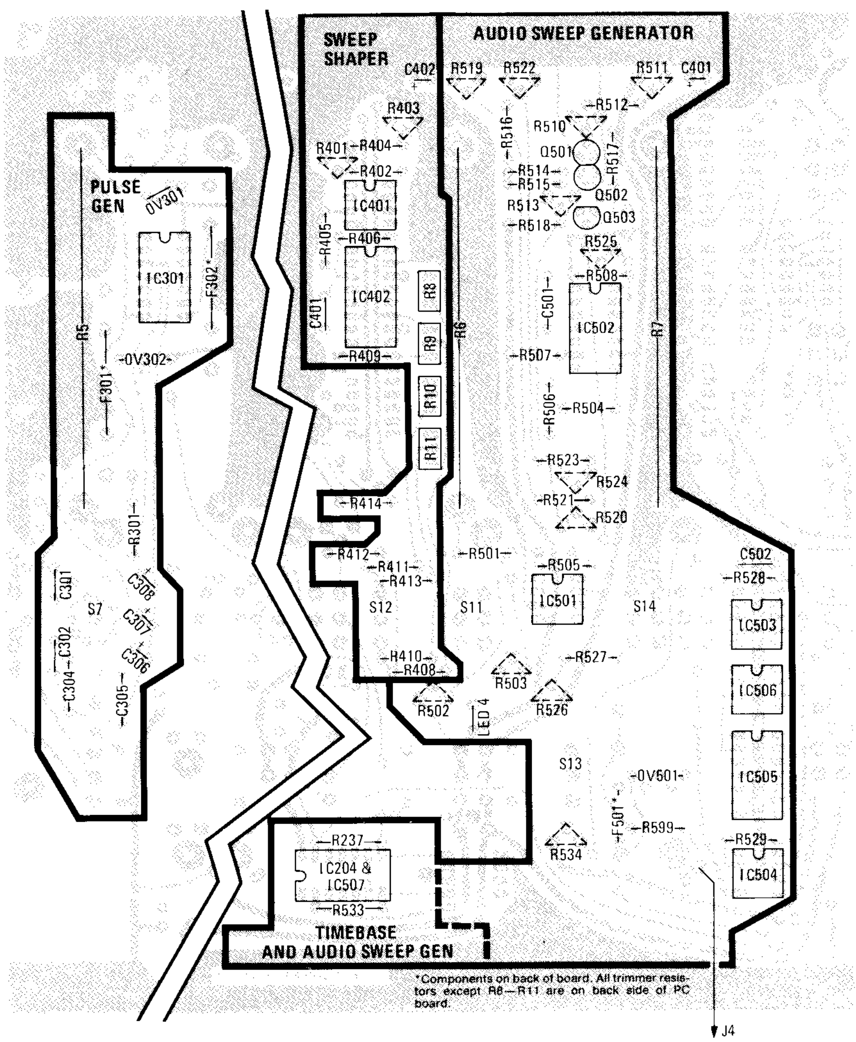
(continued on page 81)

PARTS LIST FOR PULSE GENERATOR

R5—50,000 ohms, linear pot
R301—3000 ohms
C301—10 pF
C302—100 pF
C303—.001 μF
C304—.01 μF
C305—0.1 μF
C306—1 μF
C307—10 μF
C308—100 μF
IC301—74121 monostable multivibrator
D301, D302—1N4001
OV301, OV302—LVC-1A5.1 (MCG Electronics, 160 Brook Ave., Deer Park, NY 11729)
F301, F302—0.5 amp fuse
J2, J3—panel-mount BNC connectors
S7—single-pole 10-position rotary switch



CIRCUIT LOCATION of the pulse generator, sweep shaper and audio sweep generator with respect to the entire PC board.



COMPONENT LOCATION. Use the diagram above to locate these sections on the PC board.

PARTS LIST FOR SWEEP SHAPER

All resistors ¼-watt, 5% carbon film unless otherwise noted.

R8-R11—50,000 ohms, 10-turn pot
R400—1,000 ohms
R401, R403—50,000 ohms, linear slide pot
R402—10,000 ohms
R404—51,000 ohms
R405—1000 ohms
R406—180,000 ohms
R407—10,000 ohms
R408—18,000 ohms
R409—43,000 ohms
R410—220,000 ohms
R411—24,000 ohms
R412—2 megohms
R413—47,000 ohms
R414—27,000 ohms
C401, C402—100 μF, 16 volts or higher
C403—100 pF disc
IC401—741
IC402—8049 (Intersil)
LED401—
S10—DPST toggle
S12—SPDT toggle

PARTS LIST FOR AUDIO SWEEP GENERATOR

All resistors ¼-watt, 5% carbon film unless otherwise noted.

R6, R7—50,000 ohms, linear slide-type potentiometer
R501—24,000 ohms
R502, R503, R510, R511, R519, R520, R522, R524-R526, R534—50,000 ohms, trimmer pot
R504, R514, R515—1200 ohms
R505—19,000 ohms
R506—820 ohms
R507—3.3 megohms
R508—1000 ohms
R509, R512, R517, R523, R527, R530, R535—100,000 ohms
R513—1000 ohms, trimmer pot
R516, R521, R528, R529—10,000 ohms
R518—51,000 ohms
R531—16,000 ohms
R532—4300 ohms
R533—62,000 ohms
C501—.039 μF disc
C502—5 pF disc
IC501—741
IC502—XR2207P
IC503—LM318
IC504—LM748
IC505—4013
IC506—TL610 (Texas Instruments)
IC507—377
Q501-Q503—TIS97 (Texas Instruments)
OV501—LA10 (MCG Electronics)
F501—2 A fuse
J4—panel-mount BNC connector
S11—DPDT toggle switch
S13—SPDT toggle switch
S14—DP 3-position toggle switch

The following are available from FSI, 1894 Commercenter W., No. 105. San Bernadino, CA 92408: Complete kit, $495.00; cabinet and circuit board, $115.00. Set of semiconductors, $195.00; seven slide pots with knobs, $17.00, set of trimmers including four multiturn pots, $17.00.

California residents add state and local taxes as applicable.

MASTER PARTS LIST

The following is a list of all the components and the quantity necessary to build the complete *model 101* Test Station. However, it is not necessary to build a complete Test Station. Each section will work independently of the other sections (except for the power supply) so that you can build any or all of the sections you desire. Subtract any components you already have. What you will need to complete the *model 101*.

All resistors ¼-watt, 5% carbon film unless otherwise noted

1—100 ohms
2—310 ohms
7—330 ohms, 1 watt
2—820 ohms
9—1000 ohms
5—1200 ohms
1—1500 ohms
2—2200 ohms
1—2700 ohms
2—300 ohms
2—4300 ohms
5—7500 ohms
19—10,000 ohms
1—12,000 ohms
3—15,000 ohms
2—16,000 ohms
3—18,000 ohms
2—22,000 ohms
2—24,000 ohms
1—27,000 ohms
2—30,000 ohms
1—43,000 ohms
1—47,000 ohms
3—51,000 ohms
2—62,000 ohms
1—75,000 ohms
1—82,000 ohms
17—100,000 ohms
1—180,000 ohms
1—200,000 ohms
1—220,000 ohms
1—330,000 ohms
1—1 megohm
2—1.5 megohms
1—2.0 megohms
1—3.3 megohms

Trimmer pots

31—50,000 ohms, MuRata type RVA0911H 306-7 503M
2—1000 ohms, MuRata type RVA0911H 306-7 102M
4—50,000 ohms, Weston type 8501

Slide pots

7—50,000 ohms linear, Alps type LD14R 50K B

Resistors ¼-watt, 1% or better

1—1000 ohms
1—3000 ohms
2—10,000 ohms
1—12,000 ohms
2—30,000 ohms
1—48,000 ohms
1—192,000 ohms
1—768,000 ohms

Capacitors

5—5-pF disc
4—10-pF disc
1—82-pF disc
3—100-pF disc
1—680-pF disc
9—0.001-μF disc
2—0.005-μF disc
7—0.01-μF disc
1—0.039-μF disc
3—0.1-μF disc
1—5-15-pF trimmer
1—7-40-pF trimmer
1—2.5-10-pF trimmer
2—100-400-pF trimmer

Electrolytic capacitors, 16 volts or higher

3—1 μF
1—2.2 μF
1—4.7 μF
1—22 μF
10—10 μF
3—33 μF
9—100 μF
1—470 μF
3—500 μF

Semiconductors

4—741 operational amplifier
4—748 operational amplifier
6—318 precision high-speed operational amplifier (Fairchild, National)
2—XR-2207 VLO (Exar)
1-TL610 analog switch and driver (Texas Instruments)
1—8048 logarithmic amplifier (Intersil)
1—8049 antilogarithmic amplifier (Intersil)
1—LH0091 true RMS-to-DC converter (National)
1—ULN2004 10-channel printer/driver (Sprague)
1—UDN2982 digit driver (Sprague)
1—4013 dual "D" flip-flop
1—MK50395 counter/display driver (Mostek)
1—4194 dual-tracking voltage regulator
2—7812 positive 12-volt regulator (TI, National, Motorola)
1—309H positive 5-volt regulator (Motorola, National, Signetics)
1—7912 negative 12-volt regulator (Fairchild, National, TI)
1—377 2-watt dual-channel audio amplifier (National)
1—74121 monostable multivibrator
1—4528 dual monostable multivibrator (TI, Fairchild)
1—14556 timebase generator (Motorola)
1—4030 or 4070 quad exclusive OR gate
9—TIS97 NPN silicon transistor
8—1N4001 diode
9—1N4148 diode
5—LED's
6—MAM-72 7-segment LED display
1—VP130A10 transient-suppressor varistor
2—LA10 overvoltage protector
2—LVC01A5.1 overvoltage protector
1—LA5.1 overvoltage protector

Miscellaneous

3—single-pole, 10-position rotary switch Alco MRB-1-10-PC
1—SPST toggle switch C & K 7101L1C
7—SPDT toggle switch C & K 7101SC
1—DPDT toggle switch C & K 7211SC
7—DPDT toggle switch C & K 7201SC
2—DP3T toggle switch C & K 7411SC
1—SP3T toggle switch
1—transformer, 24-volt secondary, Triad F45X
6—panel-mount BNC connectors
1—panel-mount 3-conductor microphone connector
6—fuse holders
3—250-volt ½-amp fuse
2—2-amp fuse
1—35-volt 15-amp fuse
1—PC board
1—cabinet
1—voltmeter with linear, log and dB scales.

Calibration

Most of the audio sweep circuitry is identical to the timebase section so the same calibration procedure applies. Output level and symmetry calibration proceeds from the output circuits back. That is, set R7 to zero and adjust R534 for zero DC level. Then set R7 to maximum (with switch S13 set to not-blank) and adjust the trimmers between oscillator IC502 and S14. The only difference in this area is that R513 must be adjusted, whereas its counterpart in the timebase was fixed. Interaction between R510 and R513 is rather subtle. It is not enough to adjust each independently for minimum distortion. Often by actually increasing the distortion with one of these pots subsequent adjustment of the other pot will result in lower distortion.

The optimum calibration procedure uses a harmonic distortion analyzer and a dual-trace scope. First, a sinewave is mathematically plotted on the face of the scope and the output of the function generator is adjusted so that the period and amplitude correspond to the peaks and zero-crossing points of the plotted sinewave. This same signal is simultaneously fed to the input of the distortion analyzer. The output of the distortion analyzer is applied to the second trace of the scope. The first adjustments are made with a screwdriver in each hand, and R510 and R513 are adjusted simultaneously to provide the best visual fit between the generator waveform and the plotted waveform. Observing the output of the distortion analyzer at the same time provides some understanding of the effect and interaction of these two controls. The final adjustment is made by the meter on the distortion analyzer. However, if there is a visual deviation between the generator waveform and the plotted waveform, this indicates that further improvement is possible.

A simpler but less precise test is to use only a single-trace oscilloscope with a sinewave plotted on its screen. This single waveform should cover as much of the CRT face as possible. (See Fig. 8) On most scopes this would be 8 × 8 centimeters. A visual match between the generated and plotted waveforms will produce distortion components that are low enough to be insignificant in frequency-response measurements.

Frequency sweep

The following procedure will calibrate the manual frequency sweep. This involves both the timebase and audio sweep generator sections since both can provide a manual frequency sweep of the audio sweep generator. Recall that during the discussion of the timebase section, fine tuning of the manual timebase mode was set aside until a later time. That function will now be covered as well.

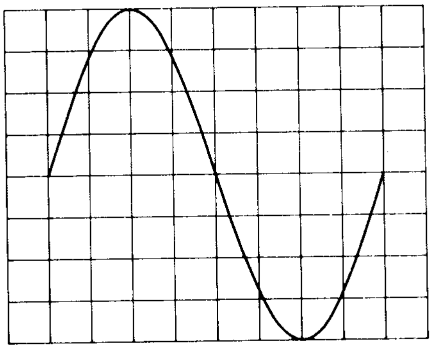


FIG. 8—SINE FUNCTION can be plotted on the CRT screen and used to adjust the sweep generator for minimum distortion.

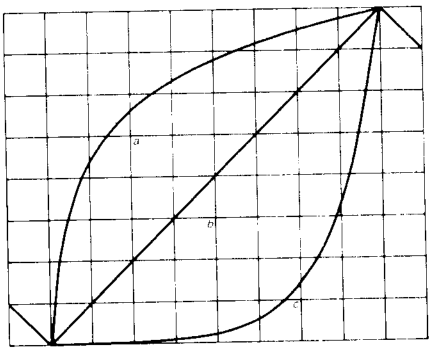


FIG. 9—CALIBRATION WAVEFORMS. Log function is shown in *a*, triangular wave is shown in *b* and antilog function is shown in *c*.

This procedure assumes that the frequency counter is already part of the overall system. It will provide the calibration standard for the sweep circuit because it measures the ultimate result of those circuits. Since it is voltage levels that are to be calibrated, the frequency counter can be thought of as a digital voltmeter.

Set S11 to manual

Sweep R6 thru its maximum travel.

Observe the end-point frequencies.

Adjust R502 and R503 for the desired end-points.

R503 sets the total sweep width.

R502 affects mainly the low-frequency end-point.

If a full 20-Hz to 20-kHz sweep is desired, the voltage at the output of IC501 goes slightly positive so as to cut off the current from pin 7 of oscillator IC502. This voltage will pass thru zero at approximately 30 Hz. With the output of IC501 at zero volts, check the symmetry of the oscillator by observing the triangle wave. This is a test that the manufacturer of the oscillator IC does not perform and, hence, a relatively large number of devices are significantly nonlinear at this point. The devices can be very linear at 20 Hz and at 40 Hz but quite nonlinear at 30 Hz.

Place a scope on the output of IC501.

Set the vertical amplifier for 1 volt-per-division and move the trace to one division from the top of the screen with no input.

Run R6 thru full travel and note the end-point voltage levels.

Set the timebase frequency for 1 kHz.

Set S4 to symmetrical.

Set S9 to SWEEP.

Set S12 to LINEAR and S11 to SWEEP.

There should now be a triangle wave that can readily be positioned and scaled, using R10 and R11, so that its peaks correspond to the end-point voltages that were produced by sweeping R6 thru its full travel.

Switch S12 to LOG.

Run R8 (the front-panel high-frequency log sweep set) to the end of its travel at maximum sweep width and then back off three turns.

Plot an antilog function as shown in Fig. 9-a on the face of the oscilloscope and align the generated waveform with that plot. (An 8 × 8-centimeter film overlay of log, antilog and sine functions is available from Fidelity Sound for $5.00). To provide a stable overlay of the plotted and generated waveforms, it is generally helpful to trigger the scope from the triangle output of the timebase generator. Use the manual trigger level rather than automatic. Also it is often helpful to switch S8 to INVERT. A dual-trace scope is also helpful here. The peak of the antilog function is easy to locate, the low point of the valley is not. If the triangle wave is adjusted on the scope as shown (Fig. 9-b), it establishes the end-points of the antilog function.

Adjust R401 and R403 so that the antilog waveform has approximately the same span as the R11 sweep voltage and has no clipping at the peak.

Use the variable vertical amplifier attenuator on the scope to scale the generated antilog waveform to that of the plotted antilog function.

Adjust R401 and R403 for best visual match between the plotted and generated waveforms. Note what effect each direction of each pot has on the generated waveform. This accomplishes the approximate adjustment of the antilog waveform. Final adjustment will occur later in this section.

At this point everything is at least approximately calibrated so that the timebase will sweep the audio generator either manually or automatically, and linear or logarithmic. The following will calibrate the manual sweep control:

Set S3 to 100 and R1 to its lowest position.

Set S4 on symmetrical.

Set S9 to SWEEP.

At this point we are going to use the audio sweep generator and the counter as a digital voltmeter. The sweep generator then acts as a voltage-to-frequency converter. This will be used to match the manual and sweep modes of the timebase. Since the log sweep has the greatest resolution at low frequency and the linear sweep has the greatest resolution at high frequency, that is how they will be set.

Set the horizontal amplifier on the oscilloscope to external.

Apply the timebase triangle wave to the vertical and horizontal scope inputs simultaneously. If a line is traced from the lower left to the upper right, this indicates the positive voltage drives the horizontal amplifier in a right-hand direction. A line from upper left to lower right indicates that a positive voltage drives the horizontal amplifier in the left-hand direction. In this case switch S8 to INVERT so that there is a line traced from lower left to upper right. That way a response plot will have the low frequencies at the left and the high frequencies at the right.

Set R4 at zero.

Switch S3 to 10 Hz. Use R3 to establish a 10-centimeter sweep (it may be necessary to use horizontal-expand mode on scope).

Switch S3 to .002.

Set S22 to ½ second.

With the beam traveling to the right and the counter increasing in frequency and with S12 in linear, observe the end point of the beam and the highest frequency attained.

With the beam traveling toward the left side and the frequency of the audio sweep generator decreasing and (with S12 set to the LOG position), note the turn-around point of the beam and the lowest frequency reached by the audio sweep generator. It is possible to interpolate fractions of a Hz by observing the bobble of the counter between two frequencies. If, for instance, it bobbles between 20 and 21 Hz every time the counter refreshes, which is one-half second, then the frequency is 21.5 Hz. Or if it stays on one number longer than the other, then it is closer to the displayed number at which it stays the longest.

Repeat the slow sweep a couple of times to confirm the end-point frequencies. Remember to switch S12 when the trace switches directions.

Switch S9 to manual.

Turn R4 thru its full travel. The frequency of the audio sweep system generator should track the movement of R4.

Set S12 to LOG and R4 to its lowest position. Note the frequency of the audio generator.

Switch S12 to LINEAR and move R4 to its upper position. Note the frequency of the audio generator.

Adjust R206 and R209, in the timebase section, so that as R4 is moved thru its travel and S12 is switched, the same end-point frequencies are produced as were produced during the automatic sweep mode. Trimmer R209 establishes the total sweep width and R206 sets the

continued on page 113

AUDIO TEST STATION

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centerpoint. When this is accomplished, R4 (with S9 in the manual mode) will produce the same sweep as the triangle timebase did with switch S9 in the sweep mode.

Set S9 to MANUAL.

Sweep the horizontal amplifier of the scope by running R4 thru its full travel. Be sure that when R4 is at its end-points, the beam rests on an end vertical line on the CRT graticule.

Switch S12 to LINEAR.

Set R4 to zero.

Adjust R11 for the desired center frequency.

Move R4 to its lowest position.

Set R10 for the desired low-frequency limit.

Move R4 to its upper position. Check for desired high-frequency limits. Several adjustments of R10 and R11 may be necessary.

Adjust R9 to its low frequency and then back off three turns.

Run R4 thru its full travel. Watch the beam as it moves horizontally across the scope and stop at each centimeter mark. Observe the frequency of each mark. A perfect log sweep would have the frequencies shown in Table 1.

Adjust R401 and R403 for best fit with those frequencies listed. It is valuable to be able to occasionally look at the waveform at the output of IC501 as was done when the first approximate adjustments of R401 and R403 were made. This is because it is easy to grossly misadjust R401 or R403. Looking at the output waveform out of IC501 provides a close approximation from which to perform final adjustments.

With S9 on SWEEP, run R4 on its lowest position. Set the desired low-frequency end-point by using R9.

Move R4 to its upper position and set the upper frequency end-point using R8.

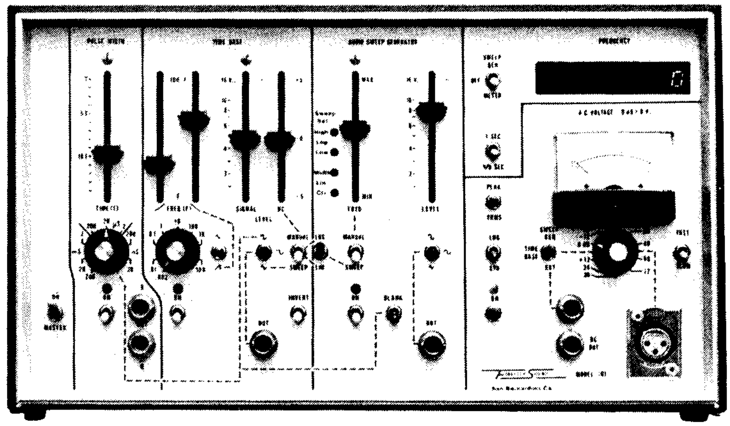
TABLE 1

cm	Hz
0	20
1	40
2	80
3	160
4	320
5	640
6	1280
7	2560
8	5120
9	10,240
10	20,480

Recheck the lower end-point.

This wraps it up for this month. We still have to cover the voltmeter and frequency counter sections and will then conclude with additional calibration data and application details. **R-E**

Audio Test Station



Part 4—This month we discuss in detail the theory of operation and the construction of the voltmeter and digital frequency meter that are essential to maximum usage of this audio test station.

RAY DAVISON

THIS MONTH, WE CONCLUDE THE CONstruction details of the Audio Test Station with the voltmeter and frequency counter sections.

Voltmeter section

The voltmeter circuit shown in Fig. 10 has two separate inputs. One is labelled EXT INPUT, which is a high-impedance low-gain input for line-level signals and the other is labelled MIKE INPUT, which is a low-impedance, high-gain input for low-level low-impedance signals. The front panel connector for the MIKE INPUT (J6) is a standard XLR type. The mike input circuitry consists of IC601 and its associated components, which form a balanced-line receiver. Resistor R601 terminates the line and R603 and R602 set the gain of IC601. The gain as seen from pin 3 of J6 is 16. The gain of the + input of IC601 is 16 + 1 or 17. Therefore, R603 and R604 are added to form a voltage divider so the overall gain of a signal applied at J6 pin 2 is the same as for a signal applied at J6 pin 3. This satisfies the basic purpose for having a balanced transmission line, namely common-mode rejection.

The balanced transmission line reduces the effect of stray signals picked up by interconnecting cables. The most susceptible stray pickup point in sound systems is a microphone cable. It is not that the mike cable itself is more susceptible, but rather that the microphone supplies such a low-level signal that it is relatively easy to pick up enough of a stray signal to be audible when mixed and amplified with the mike signal. The stray signal is often induced into a mike cable when the cable is in the presence of an electric or magnetic field.

The mike input circuitry inverts the signal applied to J6 pin 3, while the signal applied to pin 2 is not inverted. The actual mike signal that is applied to J6 pin 3 is of equal magnitude and opposite polarity of that which is applied to pin 2. Op-amp IC601 inverts the negative signal at pin 3, and adds this to the positive signal at pin 2.

When stray signals that are induced into the cable arrive at J6 pins 2 and 3 in phase, the signal at pin 3 is inverted and added to that at pin 2. However, this is subtraction. The result is what is known as common-mode rejection. A signal that was common to both inputs is rejected.

This circuit is normally shown with the four resistors of high precision and fixed value. In this circuit the common-mode rejection is simply trimmed by R604. To do this, connect a signal simultaneously at J6 pins 2 and 3. A mid-frequency sinewave at about a half a volt peak-to-peak is suitable. Set S17 to −72 dB, adjust R604 for minimum output from IC603. The signal at the output of IC603 should be about the same magnitude as the input signal. Note that the same signal applied to either input alone would have been amplified by about 4,000 or 72 dB. Therefore, since the signal was passed with a gain of approximately 1, the common-mode rejection ratio is the 72 dB that the signal would ordinarily have been amplified by.

We have used this type of mike preamp in sound systems with mike cable lengths of well over 100 feet without any apparent extraneous pickup. However, for sound system use, the 748 is much too noisy. This can be easily remedied though by replacing the 748 with something like TI's TL071. The two parts are pin-compatible, and the 5-PE compensation capacitors used for the 748 can even be left in place when switching to the TL071. The difference in noise levels is dramatic.

A second-stage preamp consisting of IC602 is included. Having the preamp in two stages accomplishes a couple of things. First, the supply voltages are rather close to the maximum output voltage. A single amplifier with 48-dB gain and with an attenuator at the output would clip at signal amplitudes intended for the low-gain attenuator setting. In fact a signal which yields full scale on the −30-dB setting causes IC602 to clip.

Another reason for cascading is that the overall bandwidth is increased. This allows two common op-amps to be used in place of a single high-frequency unit.

Switch S16 selects one of three high-level inputs. The sweep generator and timebase pickup points are on the inboard side of the fuse that is used in conjunction with the output overvoltage sensors. Therefore, if there is no output from the sweep generator or timebase but its level can be read on the meter, it indicates a blown fuse. Capacitor C603 blocks any DC component present at S16. Resistors R610 through R615 form the actual input attenuator. Consider for the moment just this resistor string and S17. There is stray capacitance between every node of that resistor string and every other node. The result is a very complex R–C filter. At low frequencies, it is a simple voltage divider whose transfer function can be easily determined by simple arithmetic. Higher frequencies, however, travel from node to node in a manner that is quite difficult to predict accurately.

Capacitors C604 through C609 are added as an attempt to swamp out the internodal stray capacitance. This is

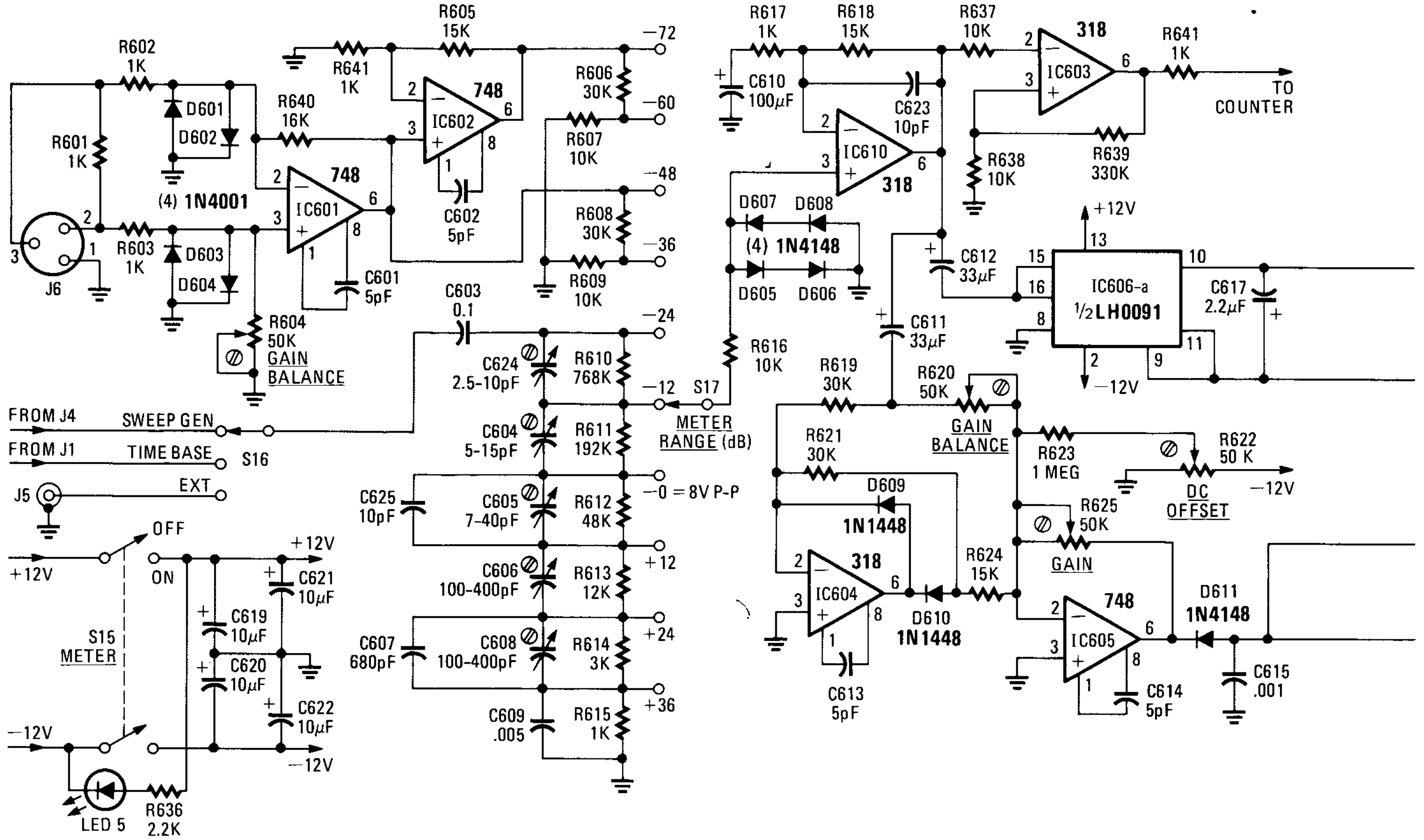


FIG. 10—SCHEMATIC DIAGRAM of the voltmeter. Its input circuitry uses frequency compensation. The separate preamp is for low-level inputs. The 1.5K resistor near the meter is R643, not R635.

called attenuator compensation. For purposes of simple compensation, the absolute capacitance values are relatively unimportant except that they must properly relate proportionately to the resistors that they are parallel with and the stray capacitances they are combining with. However, it is generally desirable to keep these capacitors small so as to minimize the total capacitance seen from the input.

If this were the input attenuator to an oscilloscope where waveform purity is of great importance, a low capacitance switch would be necessary. This is typically a large open-frame type with relatively large intercontact spacing. In this system, the problem is somewhat intensified by the use of a miniature switch where all nodes are in very close proximity. However, it is quite satisfactory up to at least 100 kHz. which should satisfy the needs of the system.

To adjust the compensating capacitors, monitor the output of IC603 with a scope. Apply a 10–15-kHz squarewave to the input and move S17 through each of the relevant positions. Adjust the capacitor immediately below the selected switch position for best squarewave response. Initial calibration of the attenuator will require several trials to bring the trimmers into proper relationship with each other. Once the adjustment is made with a squarewave input, a sinewave can be applied and swept from 10 kHz to 100 kHz to verify the overall response. Some fine tuning may be helpful at this time.

Assuming the sinewave from the timebase would be used for this last check, recall that the timebase begins a noticeable rolloff around 100 kHz. So be sure that any compensation adjustments made with the sinewave input are not compensating for timebase rolloff.

An additional gain stage and attenuator buffer consisting of IC603 is provided. Diodes D605 through D608 provide protection against excessive voltage applied to the external input. With S17 in the −24-dB position, IC603 is connected essentially straight to the external input. The diodes conduct at about 1 volt and are capable of 50 milliamps. Resistor R616 is intended to limit the diode current to a safe level. However, R616 cannot be arbitrarily large since it combines with the capacitance at the input of IC603 to form a low-pass filter. Since the diodes can handle 50 milliamps, 500V can be applied without damaging them. However, the power-handling capability of R616 must be considered at a fraction of that voltage level. If R616 is a half-watt resistor, it will tolerate 70 volts. The resistor can tolerate larger voltage levels than that for short periods of time. Since even a much smaller level will cause the meter to peg, if the operator is attentive, a 10K half-watt resistor should be adequate.

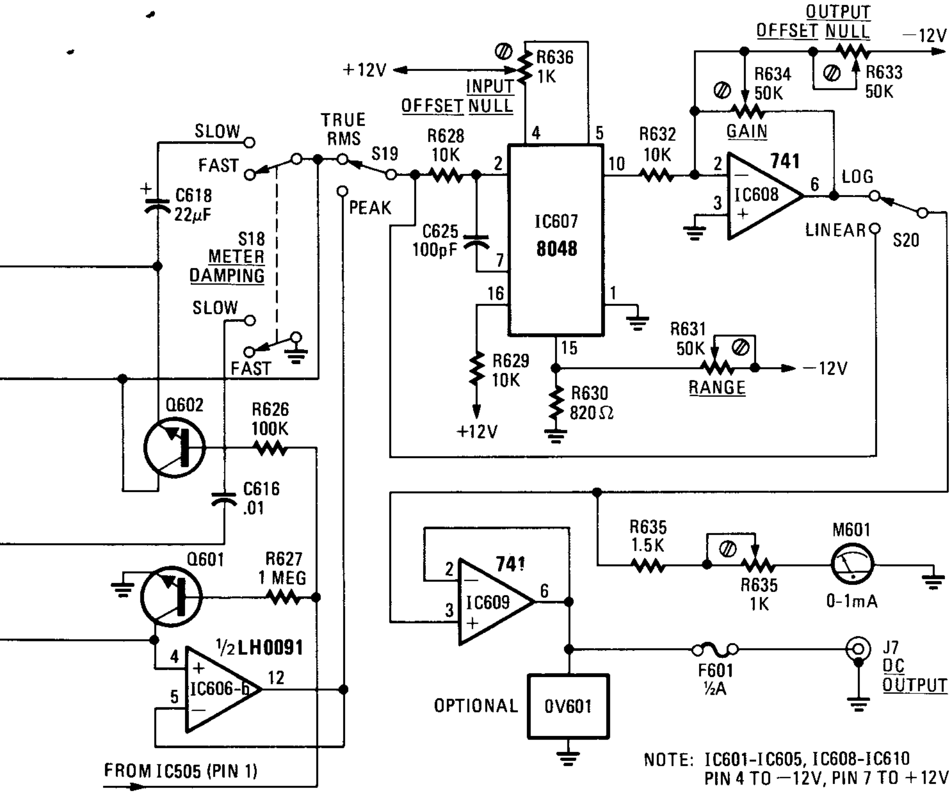
However, for insured safety R16 can be replaced with a positive temperature coefficient thermistor of approximately 10,000 ohms cold resistance. Such a device is a self-protecting resistor, since as excessive power causes it to heat, its resistance increases, which decreases the power and hence the heating effect. Also, keep in mind that R616 is of no particular value and need only be large enough to protect the diodes and small enough not to degrade high-frequency performance.

IC610 is a comparator with hysteresis. A zero-crossing dejector is formed by applying a signal through an isolation resistor to the negative input. Applying positive feedback causes the detection point to shift, which results in a circuit that ignores signals smaller than the detection levels.

This circuit preconditions the voltmeter signal before it is applied to the counter. For the circuit shown, the overall result is that the counter will count an input whose magnitude is 10% of the full-scale setting selected by S17.

IC604 through IC607 form the AC-to-DC converter. IC604 and IC605 are a full-wave rectifier. One-half of an applied waveform is inverted and added to the noninverted half. Resistor R630 adjusts the relative gain of the inverted and noninverted parts of this waveform. Trimmer R625 adjusts the overall gain of the rectified waveform.

Components D611, C615 and IC606 form a peak detector. When the signal from IC605 goes positive, diode D611 conducts charging C615. Capacitor C615 is small and hence charges as fast as the voltage from IC605 rises. When the output of IC605 passes a peak and starts to decrease, diode D611 cuts off and IC606 is left with charged C615 on its input.



Capacitor C615 discharges through the input of IC606. The rate at which C615 discharges is called the droop rate. Note that when D611 is cut off, IC606 has no DC bias on the + input. This results in a negative offset from IC606 equal to 1 diode-drop. Trimmer R622 shifts the output of IC605 enough to compensate for this and hence zero the output of IC606.

Note that the three diodes in the circuit do not exhibit the 7/10-volt threshold normally associated with a diode. The threshold is reduced to a negligible level by the active circuitry with which the diodes are associated.

The result so far then is a full-wave peak detector that will track an increasing amplitude instantaneously and track a decreasing amplitude at a slower rate, this rate being determined by the capacitor, and hence the droop rate is rather arbitrary and is based on the system under test.

If the acoustics of a large reverberant room are being analyzed, standing waves can cause wide fluctuation in amplitude. Tracing these rapid fluctuations requires a fast droop rate and hence a small capacitor. On the other hand, a fast droop rate will tend to track individual waveforms of a low-frequency signal. Therefore, to provide for difference response time requirements, S18 is provided to switch in a parallel capacitor, C616.

Also recall from the generator sections that there is a blanking mode that switches off the output of the audio generator at the end of a sweep. The same trigger that switches off the output of the audio generator turns on Q601, which rapidly discharges the capacitor at the input of IC606. Therefore, a clean cutoff is provided at the end of a plot.

The same signal that is applied to the peak detector is also applied to IC607. This is a true RMS-to-DC converter. Capacitor C617 controls the amount of filtering of the DC output. Unlike the peak detector, the response of IC607 is equal regarding both increasing and decreasing signal levels. Again S18 provides for a variable response time by adding C618 in parallel. Also the blanking trigger turns on Q602 to rapidly zero the output at the end of a sweep.

IC607 is a linear-to-log converter. Voltage gain in dB is defined as 20 times the log of the linear voltage gain. There is a linear voltage at S19 that is zero for a zero level input and ranges up to 4 volts for either a 4-volt peak or RMS input. Since a true log function cannot be physically implemented because it is of infinite length, a decision must be made to use only part of the function and eliminate the region that extends below some practical limit.

To help select an appropriate range; note the effect of a log converter on a linear input signal. Input variations slightly above zero produce very large output variations. Therefore, such things as ripple from the peak detector would be greatly magnified at low levels. Eliminating the lower portion of the function produces a dead zone, for any input voltage below the cutoff point is ignored. The cutoff-point trade off is between low-level excessive sensitivity and total dynamic range, which is the remaining portion of the function. Thus, it was rather arbitrarily decided to cut off the function at minus 40 dB.

VOLTMETER PARTS LIST

Resistors, ¼ watt, 5% or better

R601, R603, R617, R641—1000 ohms
R604, R620, R622, R625, R631, R633, R634, R640—50,000 ohms, trimmer
R605, R624—15,000 ohms
R606-R608—30,000 ohms, ¼ watt, 1%
R607, R609—10,000 ohms, ¼ watt, 1%
R610—768,000 ohms, ¼ watt, 1%
R611—192,000 ohms, ¼ watt, 1%
R612—48,000 ohms, ¼ watt, 1%
R613—12,000 ohms, ¼ watt, 1%
R614—3000 ohms, ¼ watt, 1%
R615—1000 ohms, ¼ watt, 1%
R616, R628, R629, R632, R637, R638—10,000 ohms, ½ watt
R618, R621—30,000 ohms
R623, R627—1 megohm
R616—100,000 ohms
R630—820 ohms
R635, R636—1000 ohms, trimmer
R639—330,000 ohms
R642—2200 ohms
R643—1500 ohms

Capacitors

C601, C602, C613, C614—5 pF disc ceramic
C603—0.1 µF disc ceramic
C604—5—15 pF trimmer
C605—7—40 pF trimmer
C606, C608—100—400 pF trimmer
C607—680 pF disc ceramic
C609—.005 µF disc ceramic
C610—100 µF electrolytic, 16 volts or higher
C611, C612—33 µF, electrolytic, 16 volts or higher
C615—.001 µF disc ceramic
C616—0.01 µf disc ceramic
C617—2.2 µF electrolytic or tantalum
C618—22 µF electrolytic, 16 volts or higher
C619-C622—10 µf electrolytic, 16 volts or higher
C623—10 pF disc ceramic
C624—2.5—10 pF disc ceramic
C625—100 pF disc ceramic
C626—10 pF disc ceramic

Semiconductors

IC601, IC602, IC605—748
IC603, IC604, IC610—318
IC606—LH0091 (National)
IC607—8048 (Intersil)
IC608, IC609—741
D601-D604—1N4001
D609-D611—1N4148
Q601, Q602—TIS97

Miscellaneous

S15, S18—DPDT toggle switch
S16—SP3-position toggle switch
S17—SP10-position rotary switch
S19, S20—SPDT toggle switch
J6—3-terminal microphone connector
J7—BNC connector
M601—1-mA DC meter
OV601—LA10 overvoltage limiter (MCG Electronics)
F601—0.5-amp fuse

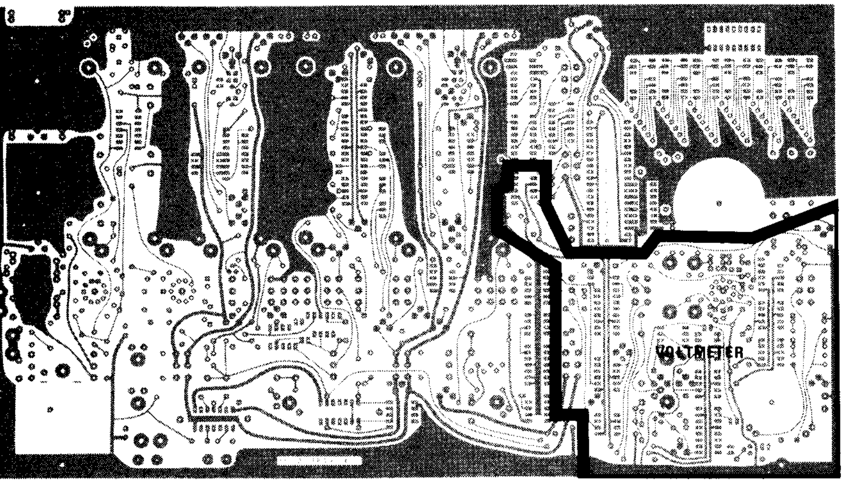


FIG. 11—FOIL PATTERN of the component side of the PC board overlayed with outlines of the area occupied by the voltmeter. The figure below shows the parts that are installed in this area.

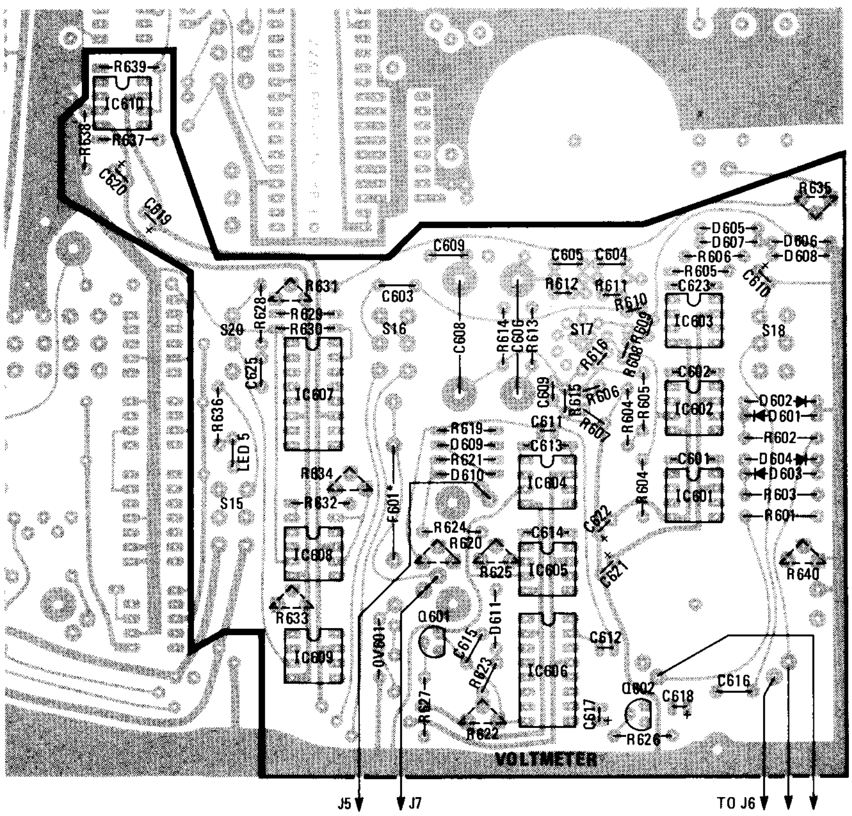


FIG. 12—COMPONENT LAYOUT diagram for the voltmeter. Parts used in this section are coded with numbers in the 600 series. See Fig. 10 for the schematic diagram.

The next task is to physically eliminate the lower portion of the function. To accomplish this, R631 applies a negative voltage to the inverting input of the output stage of IC607. This drives the log waveform up against a positive supply rail, which limits the transition or deflection. IC608 and its associated components provide proper polarity as well as gain and zero set.

Switch S20 selects the log signal, which was just described, or the linear signal, which is simply a bypass of the log converter. Resistor R635 converts the voltage signal to a current signal to drive the meter. A one-milliamp movement is quite satisfactory. Since audio measurements can sometimes be quite dynamic, it is preferable that the movement be critically damped.

IC609 is a very low-impedance output buffer. When connected in this manner, the impedance, looking back into the device, is that of the negative input, which is a virtual ground. IC609 is not really necessary but it does provide lower output impedance, isolation of the signal to the meter and better output protection than the circuit would have without it.

Overvoltage limiter OV601 limits the effect of the application of an external voltage; the same type optional unit is recommended here as was recommended for the other sections. Fuse F601 protects the overvoltage protector from excessive dissipation.

Assembly of this section is straightforward. Figure 11 shows the location of the voltmeter section with respect to the entire PC board and Fig. 12 shows the location of the components.

Counter section

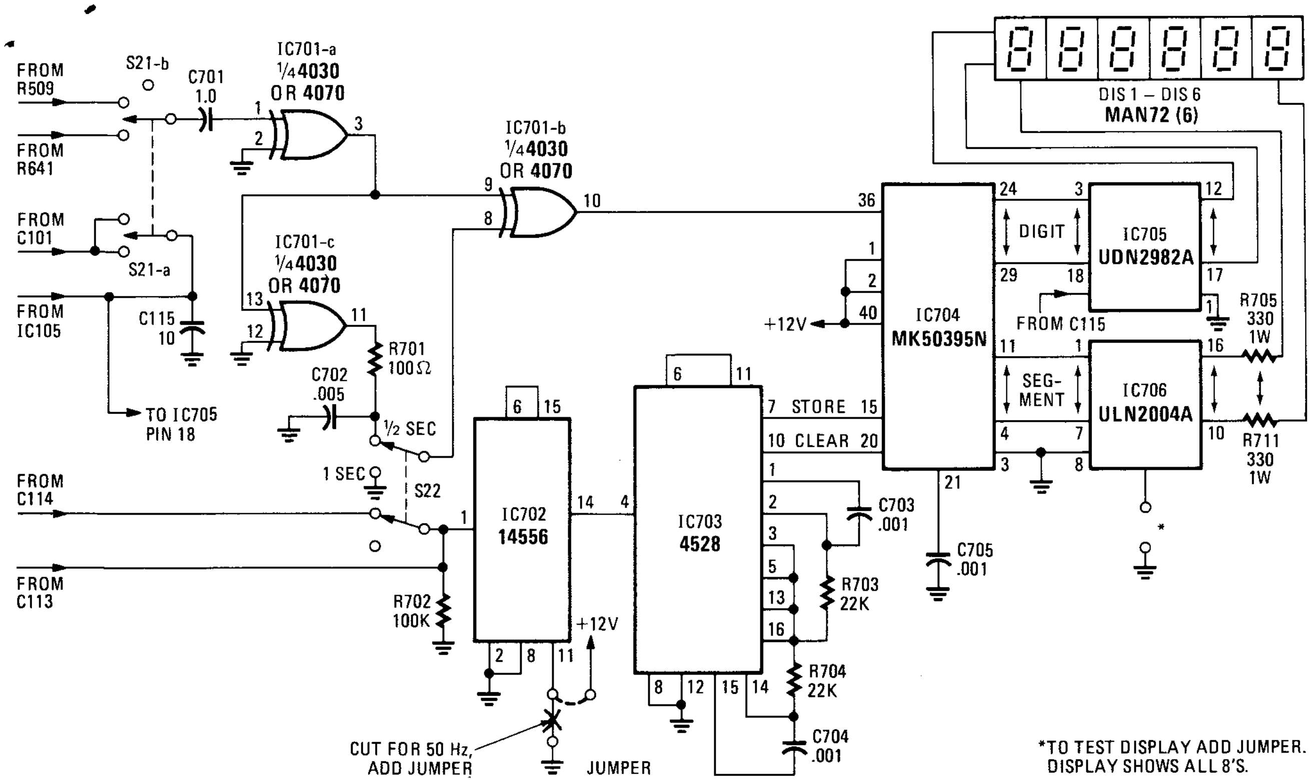
The schematic diagram of the frequency counter is shown in Fig. 13. Section b of S21 is the counter power switch; switch S21-a selects the signal to be counted. In one position the counter counts whatever signal is applied to the voltmeter. The voltmeter signal, however, can possibly be very low amplitude or altered in some way by the system under test so that it does not provide true and stable triggering of the counter. Therefore, S21-b can alternately select an internal signal from the audio sweep generator section. Stable counting of the sweep generator signal is thus always assured regardless of what happens to that signal as it is processed by the system under test.

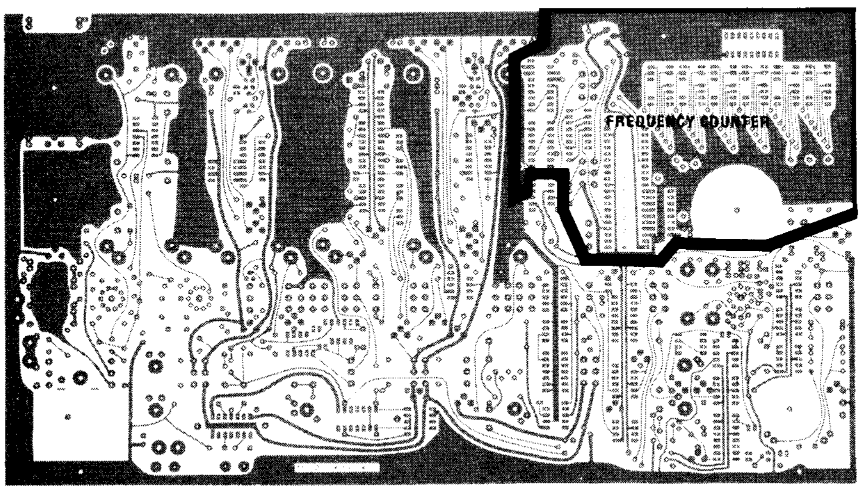
The counter timebase establishes the counting period or window. The counting circuit counts each cycle of the input waveform that occurs during the time the window is open. If the counting window is 1 second, the total number of cycles counted is the average frequency of the input signal during that second in Hz.

This system uses both 1-second and ½-second counting windows. The one-half second window is more useful for tracking a swept frequency.

The timebase, which establishes a counting window, is derived from the power line and selected by switch S22. Resistor R702 is a pull-down resistor for the input of counter IC702. With pin 11 connected to ground, IC702 divides by 60. With pin 11 connected to V+ (which for the counter section is 12V), it divides by 50. On the circuit board, pin 11 is connected to ground. To convert the unit to a 50-cycle power line, it is only necessary to cut a circuit on the back side of the board and install a short bus wire jumper between two pads, which are provided for this purpose. Cutting the circuit disconnects pin 11 from ground. Adding the jumper connects pin 11 to V+. The output of IC702 then is a pulse train whose frequency is either 1 or 2 times the power-line frequency.

IC703 is a dual one-shot. For each input pulse, IC703 provides a negative going store pulse. This store pulse is about 10-μs wide. This time is determined by C703 and R703. As the store pulse terminates, it triggers the second one-shot, which produces a positive going clear pulse. The width of the clear pulse is determined by C704 and R704 and is also about 10 μs. The counting window then is from the end of the clear pulse to the beginning of the next store pulse. These two pulses shorten the counting window by about 25 μs, inducing an error of 25 parts-per-million for a one-second update time or 50 parts-per-million for a half-second update. This error is insignificant in comparison to the normal power-line frequency variation. Line frequency er-





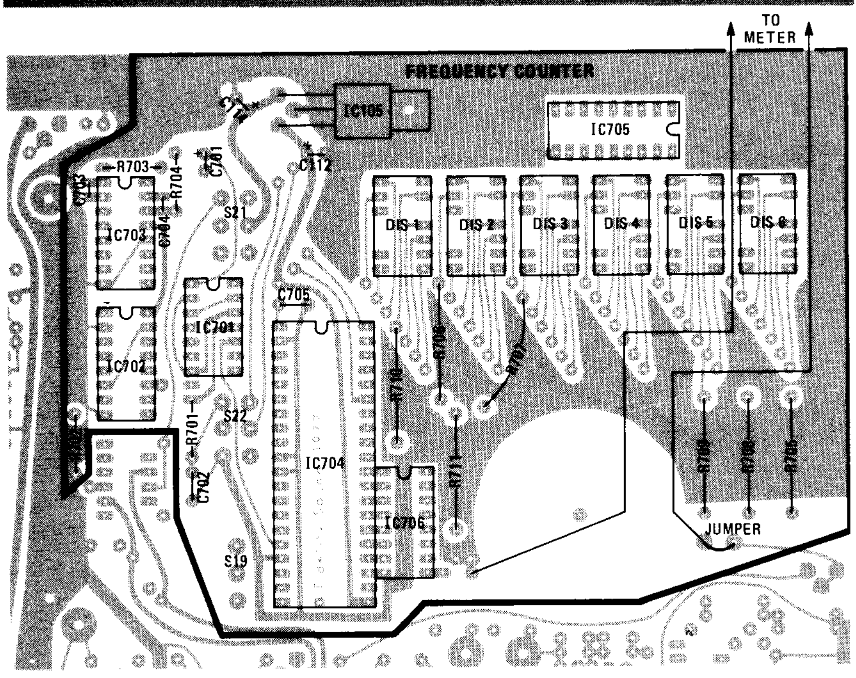


FIG. 13 (above)—THE SCHEMATIC of the digital frequency meter. FIG. 14 (left)—THE AREA OCCUPIED by the frequency meter. FIG. 15 (lower left)—LAYOUT OF PARTS in the frequency counter. IC105 at top center is a voltage regulator that is a part of the power supply.

COUNTER PARTS LIST

R701—100 ohms, ¼ watt, 5% or better
R702—100,000 ohms, ¼ watt, 5% or better
R703, R704—22,000 ohms, ¼ watt, 5% or better
R705-R711—330 ohms, 1 watt, 5% or better
C701—1 μF electrolytic, 16 volts or higher
C702—.005 μF disc ceramic
C703-C705—.001 μF disc ceramic
IC701—4030 or 4070
IC702—4566
IC703—4528
IC704—MK50395
IC705—UDN2982 (Sprague)
IC706—ULN2004 (Sprague)
DIS1-DIS6—MAN72 7-segment display
S21—DP3-position toggle switch
S22—DPDT toggle switch

The following are available from FSI, 1894 Commercenter W., No. 105. San Bernardino, CA 92408: Complete Kit, $495.00; cabinet and circuit board, $115.00. Set of semiconductors, $195.00; seven slide pots with knobs, $17.00, set of trimmers including four multiturn pots, $17.00.

California residents add state and local taxes as applicable.

rors are a fraction of a percent. The overall result is a timebase-caused error in the fourth or fifth significant figure of the displayed frequency.

IC701 is a quad exclusive OR gate connected as a frequency doubler. Gate

continued on page 105

Audio Test Station

PART 5—The utility and overall accuracy of the Audio Test Station will depend on the skill and care used in its calibration. This article "walks you, step-by-step," through the calibration process.

RAY DAVISON

IF YOU HAVE COMPLETED THE AUDIO TEST System, your next step is proper calibration so you can take full advantage of its many features. Calibration steps will be performed stage-by-stage so the precision of the sections calibrated during the initial stages can be used in later procedures. Figure 16 shows the locations of the various trimmers that you will be adjusting.

Timebase calibration

Connect a reasonably well calibrated scope to jack J1. (The scope is the only calibration standard that we will be using and it is assumed that amplitude calibrations are not critical for most applications.)

Set the scope input to DC.
Set all trimmer resistors to their center positions. See Fig. 16.
Turn on power switches S1 and S2.
Set R5 to TRIANGLE and S8 to NOT INVERT.
Set R3 to maximum and R4 to 0.
Set S3 to 1 kHz.
Set S4 to SYMMETRICAL and R1 to its lower position.

The scope should show a clean triangle wave at about 1 kHz.

Set R8 to 0—make sure R4 is still at 0.
Adjust R232 for zero offset.
Set R3 to maximum.
Adjust R227 for 16 volts P-P.
Adjust R240 for zero offset.
Switch S5 to SQUAREWAVE.
Adjust R223 for approximately 16 volts P-P and R222 for approximately zero offset. These two controls will be readjusted later.
Switch the scope input to AC.
Adjust R212 for slight clipping.
Adjust R213 for a symmetrical waveform.

When the scope is set to AC, adjusting R213 will cause the average level of the waveform to shift. Symmetry is reached when the positive-going and negative-going peaks are *exactly* the same distance from the center line on the scope.

Adjust R212 for minimum sinewave distortion.

A sinewave plotted on the face of the scope screen is a valuable aid in completing this step in the calibration. (An 8 × 8 cm clear plastic overlay (Fig. 17) is available from Fidelity Sound.) Naturally, if you have access to a harmonic distortion analyzer, you can use it in adjusting for minimum distortion.

Adjust R223 for 16 volts P-P output.
Switch the scope to DC input.
Adjust R222 for zero offset.
Set S5 to TRIANGLE.

Check the waveform quality at each position of S3. At the 10K position the waveform will be distorted; however, this is not too important because this position is used only to trigger the pulse generator.

For initial checks on the low-frequency ranges, set R1 to 100F. Any deviation from strict linearity indicates capacitor leakage. A slight curvature of the waveform is acceptable for most applications. However, if curving is severe, the circuit may not oscillate at all at low currents.

For testing at the lowest positions of S3, set the scope's horizontal timebase for external sweep. This will produce just a vertical trace. Follow the oscillator through a couple of cycles to insure that there is no excessive leakage. At the .002 position of S3 a single cycle takes approximately 8 minutes. If the scope beam stops while approaching one peak, increase R1 slightly to increase the charging current. The beam should advance slightly. This action indicates excessive leakage in the capacitor involved. Increasing R1 beyond some point should cause oscillations to resume. **Replace the faulty capacitor.**

Set R3 to maximum.
Set S9 to MANUAL.
Set R4 to 0.
Set R206 to 0 output.
Move R4 to +5 volts.
Set R209 for +8 volts output.
Move R4 to −5 volts.

The output should be approximately −8 volts. This is simply a functional check. Trimmers R206 and R209 will be fine-tuned later.

Sweep generator calibration

Waveforms: Most of the circuitry is identical to that used in the timebase section and the same calibration procedure applies. The output levels and symmetry proceeds from the output (J4) back. That is, set R7 to zero and adjust R534 for 0 volts DC level. Now, set R7 to maximum, S13 to NOT BLANK, and adjust the trimmers between oscillator IC502 and switch S14.

The only difference in this area is that R513 must be adjusted; whereas its counterpart in the timebase is fixed. Interaction between R510 and R513 is rather subtle. It is not enough to adjust each independently for minimum distortion. Often, by actually increasing the distortion with one of these pots, readjustment of the other pot results in lower distortion.

The optimum calibration procedure requires a harmonic distortion analyzer and a dual-trace scope. First, a sinewave is

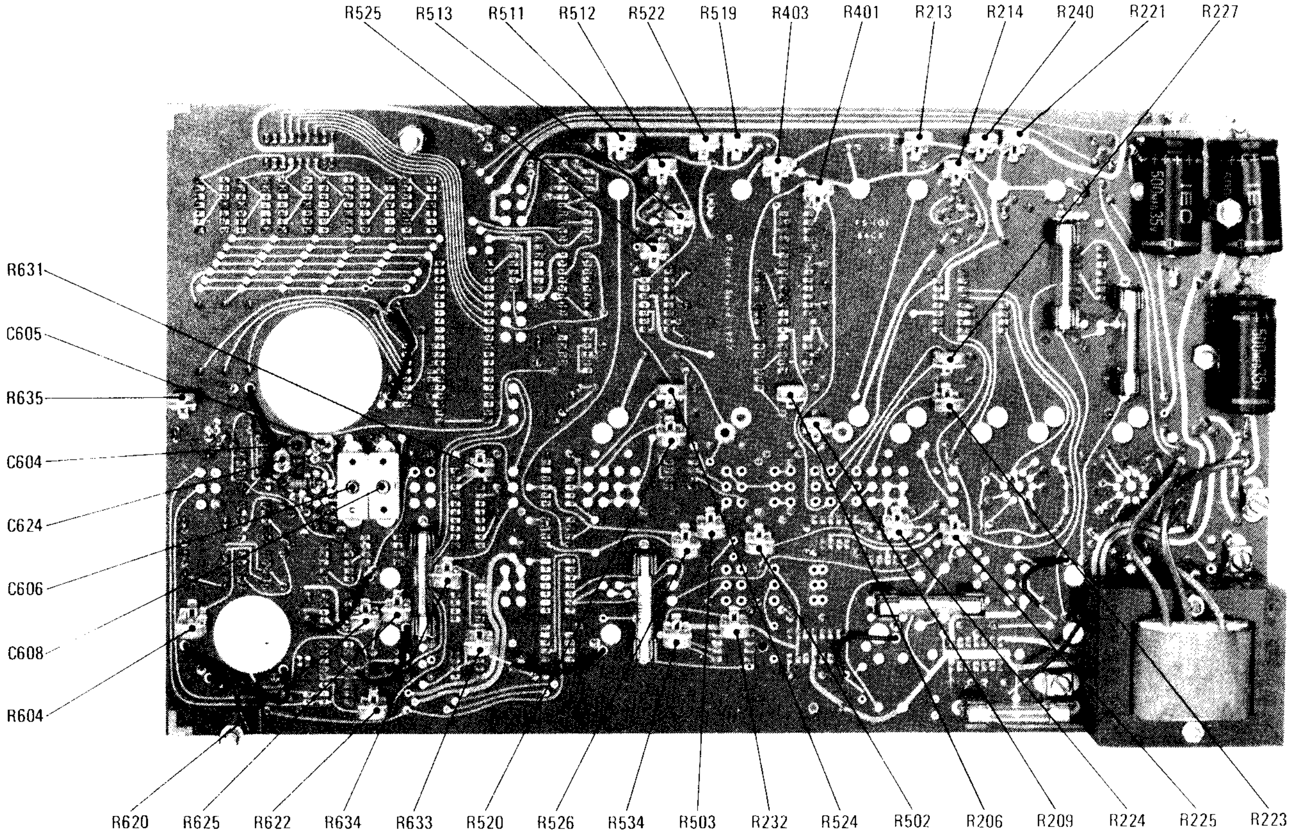


FIG. 16—VIEW OF THE BACK SIDE OF THE PC BOARD showing the locations of the fuses, a couple of large capacitors and, most important of all, the locations of the trimmer capacitors and trimmer resistors. Their placement simplifies calibration.

mathematically plotted on the face of the scope tube (the sinewave pattern (Fig. 17) available from Fidelity Sound may be fastened to the tube screen) and the output of the AF sweep generator is adjusted so that the period and amplitude correspond to the peaks and zero-crossings of the plotted sinewave.

This same signal is simultaneously fed to the input of the distortion analyzer. The output of the distortion analyzer is applied to the second trace of the scope.

The first adjustments are made with a screwdriver in each hand. Simultaneously, adjust R510 and R513 to provide the best visual fit between the generator waveform and the plotted pattern. Watching the output of the distortion analyzer as you make the adjustments will help you understand the interaction of these two controls. The final adjustments are made while watching the meter on the distortion analyzer. However, if there is a noticeable deviation between the generator output and the reference waveform, it indicates that a further improvement is possible.

A simpler, but less precise, test is to use a single-trace scope with a sinewave pattern superimposed on the screen. A visual match between the plotted and generated waveforms will produce a signal having distortion components that are low enough to be insignificant in frequency-response measurements.

Calibrating the manual frequency sweep involves both the timebase and audio sweep generator sections since either can be used to provide a manual frequency sweep of the audio sweep generator. Earlier, we set aside fine-tuning of the manual timebase. We will take that up now.

This procedure uses the frequency counter as the calibration standard for the sweep circuit. It is the voltage levels that will be calibrated so the frequency counter can be considered as being a digital voltmeter. Proceed as follows:

Set S11 to MANUAL.
Sweep R6 through its maximum travel and check the end-point frequencies.
Adjust R502 and R503 for the desired end-points.
R503 sets the total sweep width; R502 affects mainly the low-frequency end-point.
Connect the scope to the output of IC501.
Set the vertical amplifier for 1 volt-per-division and adjust the trace for one division from the top of the screen with no input.
Run R6 through its full range and note the end-point voltage levels.
Set the timebase frequency to 1 kHz.
Set S4 to SYMMETRICAL and S9 to SWEEP.
Set S12 to LINEAR and S11 to SWEEP.

You should now see a triangle wave that can be positioned and scaled by R10 and R11 so its peaks correspond to the end-point voltages developed by sweeping R6 through its full travel.

Switch S12 to LOG.
Run R8—the front panel HIGH LOG set control—to the end of its travel at maximum sweep width. Now back off 3 turns.

Plot an antilog function (Fig. 18) on the scope screen and align the generated waveforms with the pattern. To provide a stable overlap of the generated and plotted patterns, you will find it helpful to sync the scope from the triangle output of the timebase generator. Use the manual trigger level rather than auto. Also, try switching S8 to INVERT. If your scope has a dual-trace feature, try it. The peak of the antilog function is easy to locate; the low point of the valley is not. The method used here makes it easy to establish the end-points of the antilog function.

Adjust R401 and R403 so that the antilog waveform has approximately the same span as that provided by R11 sweep voltage without clipping at the peaks.
Use the scope's vertical attenuator to fit the generated waveform to the plotted antilog function.
Adjust R401 and R403 for the best visual match between the generated and plotted waveforms. Note the effect each movement of each pot has on the generated waveform.

This completes the rough adjustment of the antilog waveform. Fine-tuning comes later.

At this point, everything is at least approximately calibrated so that the timebase will sweep the audio sweep generator either manually or automatically in linear and logarithmic modes. Now, to calibrate the manual sweep control.

Set S3 to 100 and R1 to its lowest position.
Set S4 to the SYMMETRICAL (upper) position.
Set S9 to SWEEP.

At this point we will use the audio sweep generator and the counter as a digital voltmeter. The sweep generator then acts as a voltage-to-frequency converter. This will be used to match the manual and sweep modes of the timebase. The log sweep has the greatest resolution at low frequencies and the linear sweep has the greatest resolution at the high end; so this is the way we will set them up.

Set the scope horizontal amplifier to EXTERNAL INPUT.

Apply the timebase triangle waveform to the scope's vertical and horizontal inputs simultaneously. If a line is traced from lower left to upper left across the screen, this indicates that a *positive* voltage drives the scope beam toward the *right*. Similarly, a line from upper left to lower right shows that a positive horizontal input voltage drives the beam toward the *left*. In this case, throw S8 to INVERT so the trace extends across the screen from lower left to upper right. This insures that frequency-response plots will have the low-frequency end at the left and the high-frequency end on the right.

Set R4 to 0.
Switch S3 to 10 Hz. Use R3 to establish a 10-cm sweep. (It may be necessary to use the scope's expanded-sweep mode.)
Switch S3 to .002.
Set S22 to ½ SEC.

With the beam traveling left-to-right and the counter increasing in frequency and with S12 set for linear operation, note the end-points of the beam and the highest frequency attained.

As the beam is returning to the left side of the screen and the frequency of the audo sweep generator is decreasing (S12 in the LOG position), note the turn-around point of the beam and the lowest frequency reached on the frequency counter. Note that it is possible to interpolate fractions of a hertz by observing the "bobble" of the counter between two frequencies. If, for instance, it "bobbles" between 20 and 21 Hz every time the counter refreshes (every half second) the frequency is 20.5 Hz. Or, if the reading stays on one number longer than the other, the frequency is closest to that figure.

Repeat the slow sweep a couple of times to confirm the end-point frequencies. (Remember to switch S12 as the trace switches directions.)

Set S9 to MANUAL.
Sweep R4 through its full travel. The frequency of the audio sweep generator should track R4.
Set S12 to LOG and drop R4 to its lowest position. Note the frequency of the audio generator.
Adjust R206 and R209, in the timebase section, so that R4, as it is moved through its travel range and S12 is switched, produces the same end-point frequencies as those produced during the automatic-sweep mode. Trimmer R209 establishes the total sweep width and R206 sets the center point. When these trimmers are properly set, R4, with S9 in the MANUAL position, will produce the same sweep as the triangle timebase did with S9 and the sweep mode.
Set S9 to MANUAL.

Sweep the scope horizontal amplifier by running R4 through its full range. Make sure that when R4 is at its end-points, the beam is on an end vertical line.

Switch S12 to LINEAR.
Set R4 to 0.
Adjust R11 for the desired center frequency.
Move R4 to its lowest position.
Set R10—through the front panel—for the desired low-frequency limit.
Move R4 to its upper position. Check for the desired high-frequency limits. Several readjustments of R10 and R11 may be necessary.
Adjust R9 to the extreme low-frequency end and then back off 3 turns.
Run R4 through its full travel.

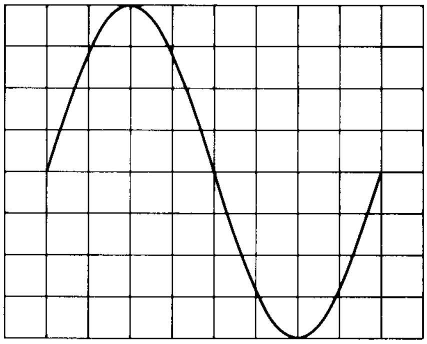


FIG. 17—SINE FUNCTION can be plotted on the CRT screen and used to adjust the sweep generator for minimum distortion.

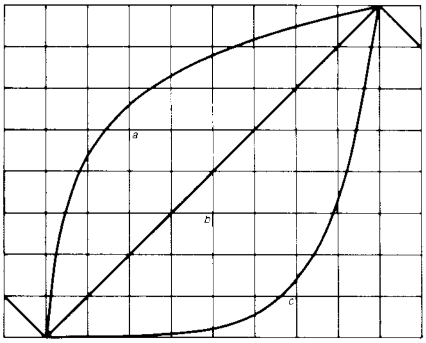


FIG. 18—CALIBRATION WAVEFORMS. Log function is shown in *a*, triangular wave is shown in *b* and antilog function is shown in *c*.

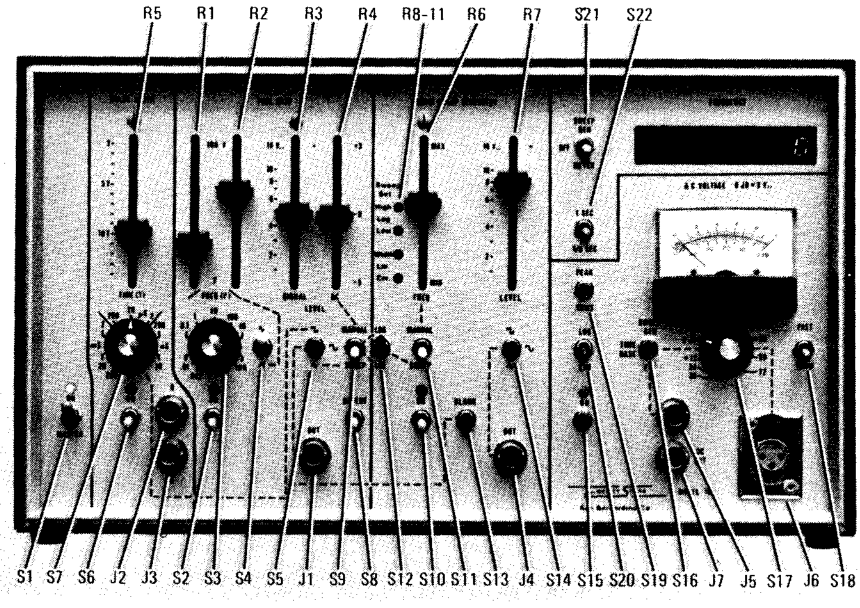
Watch the beam as it moves horizontally across the scope screen. Stop at each vertical centimeter division and note the frequency. A perfect log sweep will have the frequencies indicated in Table 1.

Adjust R401 and R403 for the best fit at the frequencies listed.

It is important to be able to occasionally look at the waveform at the output of IC501 as was done when the first approximate adjustments of R401 and R403 were made. This is because it is easy to grossly misadjust R401 and R403 and keeping an eye on the waveform at the

TABLE 1

cm	Hz
0	20
1	40
2	80
3	160
4	320
5	640
6	1280
7	2560
8	5120
9	10240
10	20480



LOCATIONS AND DESIGNATIONS of the controls mounted on the front panel.

output of IC501 will make fine adjustments more precise.

With S9 on SWEEP, run R4 to its lowest position. Set the desired low-frequency end-point by adjusting R9.
Move R4 to its upper position and set the upper frequency end-point with R8.
Recheck the lower end-point.

Voltmeter adjustments

Start by calibrating the input attenuator.

Set S16 to TIMEBASE.
Set S3 to 1K.
Set S5 to SINEWAVE.
Set METER RANGE switch S17 to −24 dB.
Monitor the output of IC610 with the scope.
Set R4 to 0.
Set R3 to produce 3 to 4 volts peak at the output of IC610.
Move R1 through its full travel.
Adjust trimmer capacitor C604 for minimum deviation from the 1-kHz level.

Repeat the steps outlined above to adjust the appropriate compensating capacitors for the −12 through +24 dB positions of S17.

Apply a 1-kHz sinewave simultaneously to pins 2 and 3 of mike jack J6.
Set S17 to −72dB.
Monitor the output of IC610 while adjusting trimmer resistor R604 for minimum output. This adjusts the common-mode rejection for the mike preamp.

AC to DC converter

The following procedure is for setting up the AC-to-DC converters:

Set the METER RANGE switch (S17) to 0 dB.
Set S16 to TIMEBASE.
Adjust the timebase section for a 1-kHz 4-volt peak sinewave at the output of IC610.
Set S19 to PEAK.

Monitor the output of IC605 with the scope. It should display a full-wave rectified sinewave.

Adjust R620 for equal amplitude in both halves of the waveform.
Adjust R625 for approximately 4 volts peak.
Check to be sure that it is possible for each half of the waveform to reach at least 4 volts peak without clipping.

Increase the timebase frequency to 100 kHz while checking the rectified sinewave. Some degradation of the valleys is acceptable; however, the peaks should not be affected.

Reduce R3 to 0.
Adjust R622 for 0 volt at the output of IC609.
Adjust R3 so the output of IC609 is exactly 4 volts peak.
Adjust R625 so the output of IC609 is 4 volts DC.
Monitor the signal at the arm of S19.
Place S19 in the TRMS (true RMS).

The DC voltage should drop to approximately 2.8 volts. Now, reduce the timebase frequency to around 20 Hz.

With S18 in the FAST position, a definite droop should be noted when S19 is at PEAK. An approximately equal amount of ripple should be noted when S19 is set returned to TRMS.

Placing S18 in the SLOW position should significantly reduce both the droop and the ripple.

Log converter

The procedure for calibrating the log converter is as follows:

Set the timebase for a 1-kHz triangle waveform.
Set R3 for 4 volts P-P (peak to peak).
Set R4 to +2 volts. This will produce a triangle wave between 0 and 4 volts.
Set S16 to EXTERNAL with nothing connected to jack J5. There should be 0 volt at the output of S19.
Connect the output of J1 through a 10K resistor to the output end of R628, the input of IC607.
Set the scope timebase so that half of the triangle wave cuts diagonally across an 8 × 8 centimeter grid.

Monitor the output at J7. If possible, use a dual-trace scope so the input and output of the log converter can be observed simultaneously.

Plot an 8 × 8 centimeter log function on the face of the scope screen (see Fig. 18) or use the preplotted transparency mentioned earlier.

Adjust trimmer resistors R631, R633, R634 and R636 for the best fit of the output at J7 to the plotted log pattern.

Trimmer R631 adjusts the total range of the log function as evident by the sharpness of the knee. Trimmer R633 adjusts the DC offset so that a zero volt input produces a zero volt output. Trimmer R634 is used to adjust the overall gain so a 4-volt input produces a 4-volt output.

Remove the timebase signal and the 10K resistor.
Turn off the timebase generator.
Set S16 to SWEEP GEN.
Set S11 to MANUAL.
Set R6 to approximately 1 kHz.
Set S19 to PEAK.
Set S20 to LINEAR.
Set R7 for 8 volts P-P.

The signal at J7 should read 4 volts.

Set R7 for 0 volt.
The voltage at J7 should read 0.
Set S20 to LOG.
Adjust R633, if necessary, to keep the voltage reading at J7 at zero.
Switch S20 to LINEAR.
The output of J7 should be 4 volts. If it is not, touch up R634.
Adjust R635 for 100% meter deflection.

Well, that wraps up the calibration procedure. Next month we will conclude this series with some hints and application notes on using the Audio Test System. **R-E**