



BUILD THIS Hobby Spectrum Analyzer

*At less than \$100 to build,
this spectrum analyzer is
a must for every hobbyist!*

BOB KOPSKI

The project described in this article was inspired by a need to analyze the radio-frequency spectrum for hobby applications related to radio-controlled (R/C) model planes. The author suspected that some microprocessor-controlled R/C accessories were causing interference with the onboard guidance radio. Those problems were tracked down by using a borrowed Smith Design "Spectrum Probe" and very expensive HP spectrum analyzer. (Smith Design is located in North Wales, PA.) That experience prompted the author to design and build this inexpensive, yet effective, Hobby Spectrum Analyzer (HSA).

What is it? A spectrum analyzer might be perceived as an automatically-tuned visual radio. To envision this, connect the audio output from a radio to an oscilloscope's vertical input. Spin the tuning dial slowly; every time you tune through a station the output will show up as a random vertical blip on the oscilloscope. Now imagine you are able to tune the radio and synchronize the oscilloscope's horizontal sweep in step with it. The horizontal axis on the oscilloscope would simulate a radio tuning dial. Radio signals would show up on the display at their frequency locations. In addition, the size of the blip could be an indication of the radio

signal's relative strength.

The HSA can do all of the above and be built for less than \$100 using commonly available parts. The HSA tunes from low MHz frequencies to 100 MHz. With a few inches of antenna wire connected to the input terminal, the HSA routinely displays RF signals within its operating range on an inexpensive oscilloscope. Those detected signals include CB and amateur-radio activity, wireless phone, RC signals, local TV stations, and a significant portion of the FM band; plus any local EMI, all *at the same time and on one display!*

The HSA is actually a double-conversion superhetrodyne radio. The tuning sweep is electronically and repeatedly generated by an internal sweep circuit that linearly tunes the frequency range in a 10-mS time period. If the oscilloscope time base is set to 1 mS per-major-division, then each division represents a 10-MHz segment of the tuning range. This is the "frequency dial" analogy and the blips on it are received radio-frequency signals. The HSA outputs a trigger pulse to initiate the internal sweep of the oscilloscope coincident with the beginning of the frequency sweep. This assures solid synchronization between the HSA's frequency tuning and the oscilloscope display.

The HSA is an excellent relative RF voltmeter or power meter. It has a sen-

sitivity of better than -80 dBm which is about 22 microvolts rms on a 50-ohm line. It has an amplitude dynamic range exceeding 50 dB, which can be further increased with built-in RF and IF attenuators. A built-in comb generator allows accurate calibration of both frequency and amplitude performance. When the HSA is aligned, it has a frequency accuracy within ± 1 MHz, and the prototype has an amplitude flatness/accuracy better than ± 2 dB across the entire range. The HSA is battery powered with eight alkaline AA cells in an internal battery pack.

Almost any inexpensive, one-channel oscilloscope with a triggered-sweep feature can serve as the HSA's companion unit. A two-channel oscilloscope, or one with a time-base magnifier adds versatility, but is not necessary. The HSA is easy to align and use. What is needed to align the HSA is the companion oscilloscope, plus a DVM, an adjustable DC power supply, an audio or function generator producing a 10-kHz (or so) sine-wave signal, and a source of 145 MHz for IF alignment.

While the HSA will be more than adequate for hobbyist or other "less demanding" applications, remember that it is not intended to be a "lab-grade" instrument. For example, the HSA has no input filter, so signals beyond 100 MHz may sneak in as im-

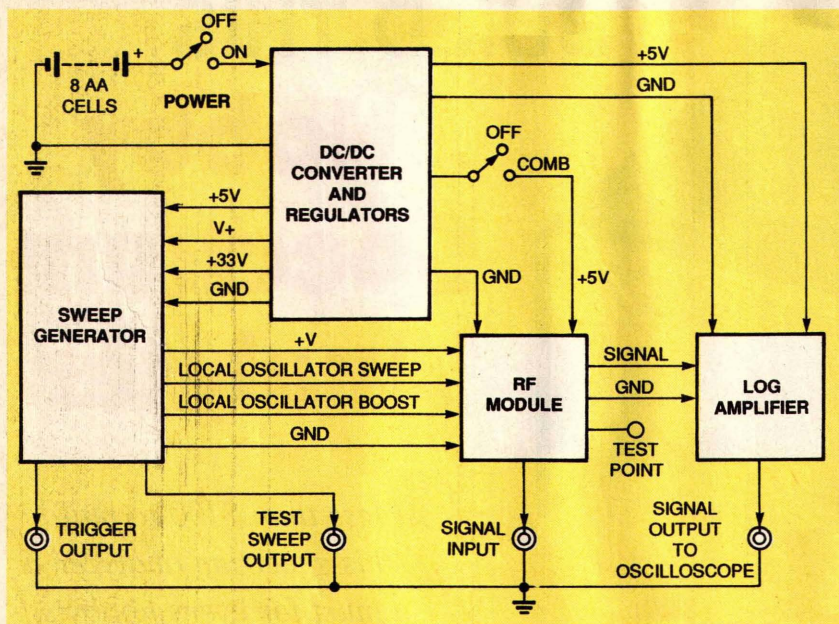


FIG. 1—SIMPLIFIED BLOCK DIAGRAM for the Hobby Spectrum Analyzer. Functional blocks are actual circuit boards which make circuit understanding and construction easier for the hobbyist.

ages and appear on the display. Also, the HSA uses a simple heterodyne detector technique and the resulting spectral lines are actually swept-through zero beats. This results in some amplitude display jitter. You just have to look a bit more carefully at the oscilloscope display for more accurate readings.

How it works. The Hobby Spectrum Analyzer's four main functional blocks (see Fig. 1) are the sweep generator, RF module, log amplifier, and DC/DC converter and regulators. All four blocks are constructed as individual assemblies. They are tested individually for basic operation, then interconnected with short cables, and housed in a metal case.

RF circuit module. The RF circuit module schematic diagram is shown in Fig. 2. The RF input signal first reaches the INPUT SWITCH S1, which is a three-pole, three-throw slide switch. It selects either a HIGH Z input, a 50 OHM input, or a -20-DB input for the first mixer/converter. The HIGH Z input is very useful with a short-wire antenna connected to the SIGNAL INPUT jack while the latter two options are useful for more accurate amplitude measurements in 50-ohm cable systems. (The same basic idea can be extended to 75-ohm systems if that is your preference.) The comb generator block is the built-in

calibrator function mentioned earlier and will be discussed in detail in the alignment section.

The signal from S1 flows to the first converter IC1, a Signetics NE602 oscillator-mixer. The local oscillator is a varactor-tuned Colpitts configuration. A sweep voltage of about 4 to 30 volts is applied to varactor D1 and that causes the local oscillator to vary from about 145 MHz to about 245 MHz. Thus, the first converter is an "up converter". For example, when an incoming signal is at 50 MHz, it is mixed with the swept local oscillator signal. At some point in the timed local-oscillator sweep signal, the 195-MHz point of the sweep mixes with the 50-MHz signal to produce the mixer output signal at 145 MHz, which is the first IF frequency. This spot frequency signal is then processed by the remainder of the HSA functions. The LO (local oscillator) boost input shown in Fig. 2 is a finer detail and will be discussed later.

The first converter is followed by a simple double-tuned, 145-MHz band-pass filter and then the IF ATTN switch. The latter uses a double-pole, double-throw slide switch and permits the filtered 145-MHz signal to flow either directly into the second converter or to first experience 20 dB of attenuation. Since the second converter is the first circuit to overload with high input levels, the IF attenuator is aptly located.

PARTS LIST FOR THE RF CIRCUIT MODULE (Fig. 2)

SEMICONDUCTORS

D1—MV209 varactor diode
IC1, IC2—NE602A oscillator-mixer, integrated circuit (Signetics)

RESISTORS

(All resistors are 1/4-watt, 5% units.)
R1, R3—60.4-ohm, 1%, metal film
R2—249-ohm, 1%, metal film
R4—49.9-ohm, 1%, metal film
R5—100-ohm
R6—22,000-ohm
R7—10,000-ohm
R8—1300-ohm
R9—150-ohm

CAPACITORS

(All capacitors are ceramic discs unless otherwise noted.)
C1, C2, C4, C5, C8—C11, C20, C21, C25, C28—0.001- μ F
C3, C22—0.1- μ F
C6, C13, C17, C18, C27—2.5–7.5-pF trimmer, 6 millimeter
C7—4-pF
C12—15-pF
C14, C16—7-pF
C15—1-pF
C19—100-pF
C23—5-pF
C24—2-pF
C26—12-pF

ADDITIONAL PARTS AND MATERIALS

L1, L5—Ferrite bead (Panasonic EXC-L351390)
L2, L6—5 turns of #30, solid, enameled wire, 3/32-in. i.d., air-core, spread turns as required (see text)
L3, L4—5 turns of #20, solid, tinned wire, 1/4-in. i.d., air-core, spread turns as required (see text); L4 is tapped (tack soldered) at 1 turn above ground to lead from C15
S1—Three-pole, three-throw, slide switch (Digi-Key SW336, or equiv.)
S2—Two pole, two-throw slide switch (Digi-Key SW335, or equiv.)
Double-sided PC board material (unetched) plus scrap pieces from PC universal prototyping board (RadioShack 276-168); BNC male connector, flange mount; 6-pin, straight, male plug with 0.1-in. centers; metal and plastic spacers; screws; nuts; washers; copper foil; etc.

The second converter has a fixed local oscillator frequency of 145 MHz. Thus, its input signal from the at-

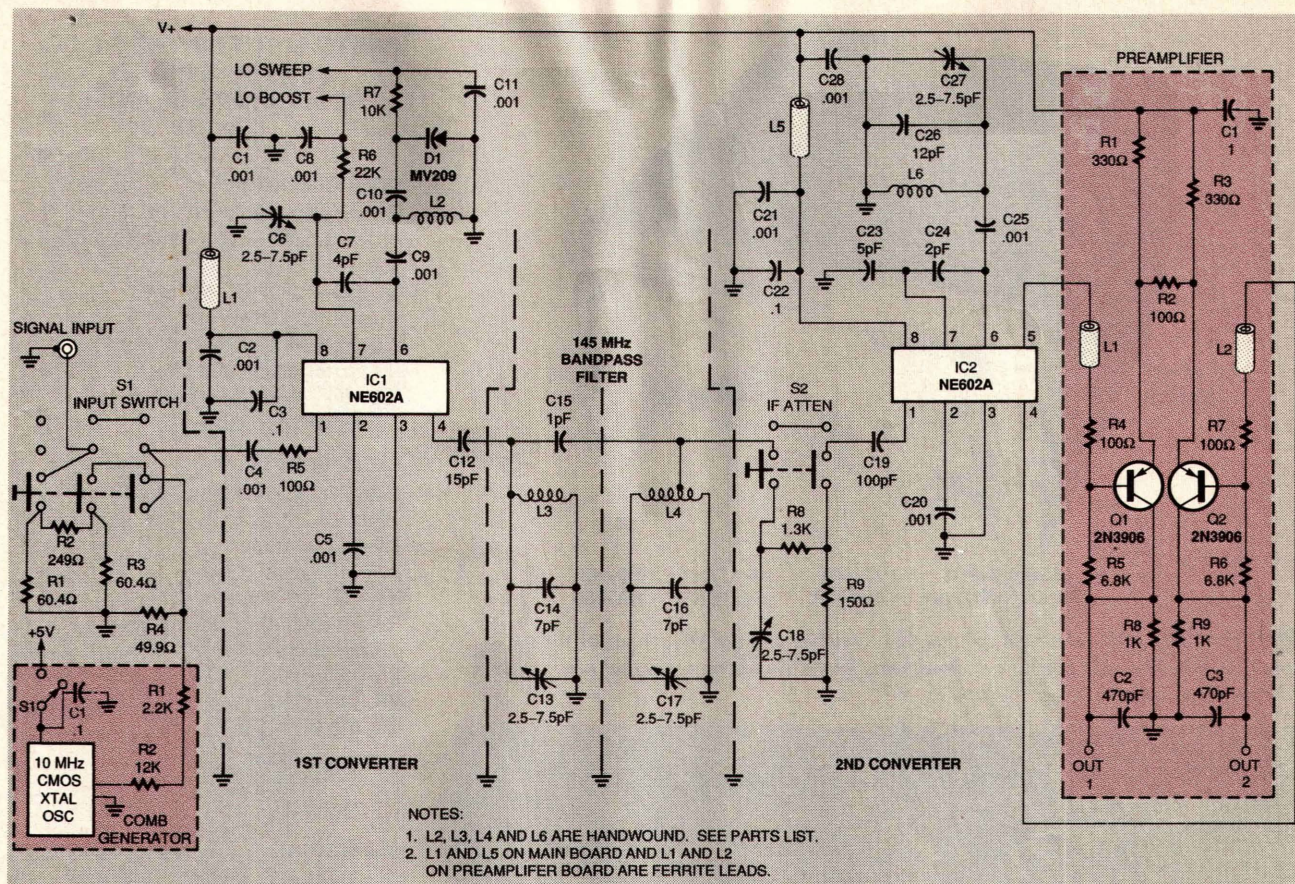


FIG. 2—SCHEMATIC DIAGRAM for the RF circuit module. Note that the circuit includes two subassemblies—comb generator and preamplifier—each of which is assembled on its own board. Since the parts symbol for each assembly section begins with "1," there are three R1s, etc., in the diagram. The text clearly separates discussion on each section so there is no confusion.

tenuator and its own oscillator signal heterodyne (mix) to produce swept zero-beat signals with incoming signals.

The second converter also uses a Signetics NE602, and its balanced output drives a preamplifier. The heterodyne output signals are low frequencies that range from zero at "beat" upwards to low 100s of kHz during the heterodyne sweep. The pre-

amplifier and the log amplifier need only be low-frequency circuits. A bandwidth of 100 kHz for the second IF is adequate.

DC/DC converter and regulators module. The DC/DC converter and regulators module (See Fig. 3) receives 12-volt DC from the eight AA dry-cell pack and provides three regulated output voltages to operate the HSA. What are those outputs and why are they needed? A separate +5 volt regulated supply powers the sweep generator, log amplifier, and comb generator boards. There is also a V+ output which only powers the RF and preamplifier circuits. The V+ output is adjusted during alignment to between 5 and 7 volts to optimize HSA performance. Finally, there is a +33-volt DC output. This high voltage powers the sweep generator output system for varactor tuning. The voltage is obtained from a simple, regulated voltage multiplier powered directly from the 12-volt battery. While

PARTS LIST FOR THE PREAMPLIFIER SUBASSEMBLY (Fig. 2)

SEMICONDUCTORS

Q1, Q2—2N3906, PNP, RF amplifier transistor

RESISTORS

(All resistors are 1/4-watt, 5% units.)

R1, R3—330-ohm
R2, R4, R7—100-ohm
R5, R6—6800-ohm
R8, R9—1000-ohm

CAPACITORS

C1—1.0-μF, 16-WVDC, tantalum
C2, C3—470-pF, ceramic disc

ADDITIONAL PARTS AND MATERIALS

L1, L2—Ferrite bead (Panasonic EXC-L351390)

PC universal prototyping board (RadioShack 276-168), wire, hardware, etc.

PARTS LIST FOR THE COMB GENERATOR SUBASSEMBLY (Fig. 2)

C1—0.1-μF, disc, ceramic capacitor

R1—2200-ohm, 1/4-watt, 5% resistor

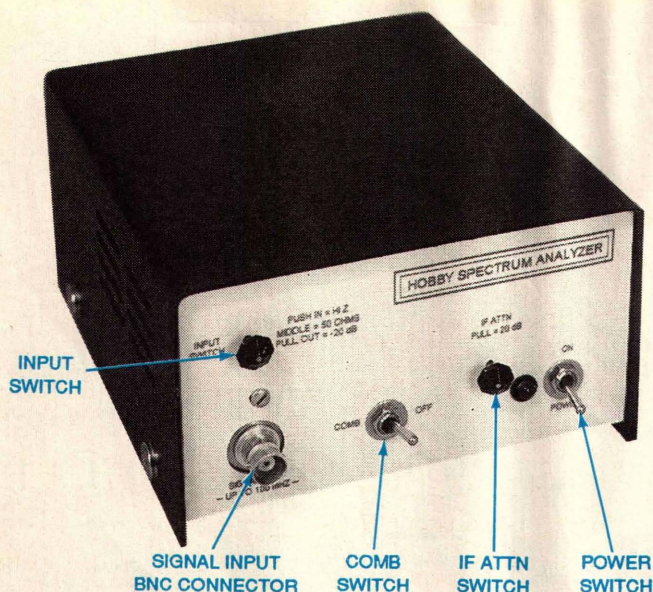
R2—12,000-ohm, 1/4-watt, 5% resistor

S1—Single-pole, single-throw, toggle switch

10.0-MHz crystal-controlled, CMOS oscillator integrated circuit (Digi-Key CTX114); piece of PC universal prototyping board (Radio Shack 276-168); wire, etc.

the +5 volts and the V+ voltages are obtained from common-type 78L05 three-terminal regulators, the +33-volt generator deserves some expanded explanation.

The DC/DC converter and regulators module uses a classic diode



FRONT PANEL OF THE HSA mounts four switches and a BNC connector for the input signal. The rear panel (not shown) has four RCA phono jacks that provide three output signals and a battery test point.

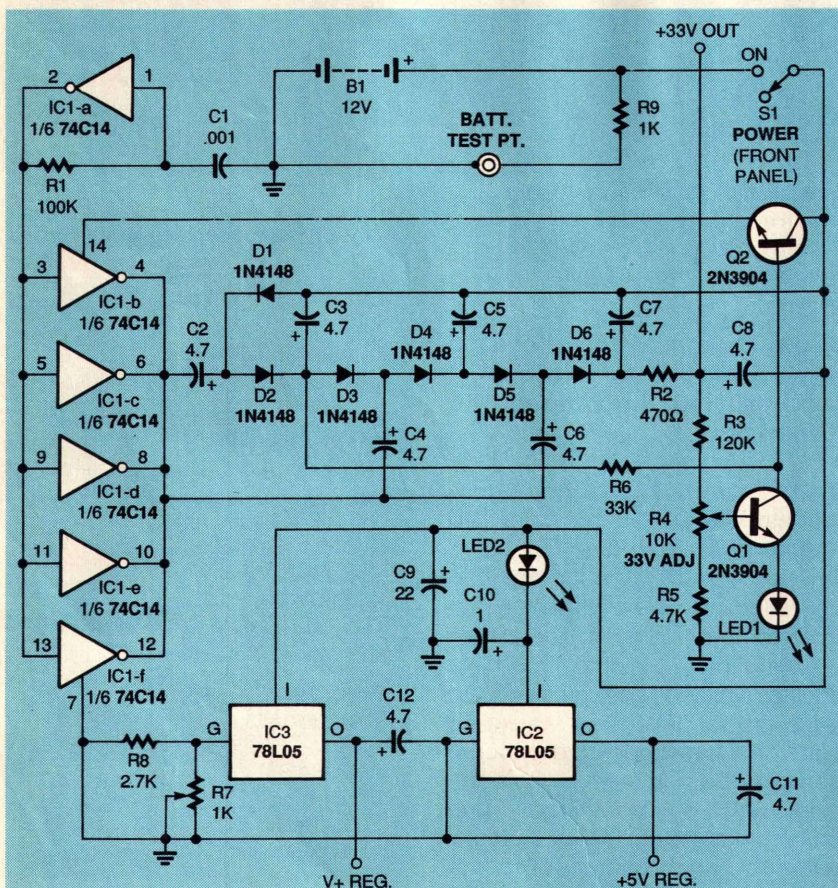


FIG. 3—SCHEMATIC DIAGRAM for the DC/DC converter and regulators module. The $V+$ -volt DC supply is used in the RF module where the final voltage setting of $R7$ is made for optimum performance. The +33-volt DC output is used in the sweep circuit module to generate the output log sweep.

and capacitor voltage multiplier chain with some *tricks* added in. Integrated circuit IC1 contains six CMOS

Schmitt inverters with IC1-a wired as an astable squarewave oscillator. The oscillation frequency is set by $R1$ and

PARTS LIST FOR THE DC/DC CONVERTER AND REGULATORS MODULE (Fig. 3)

SEMICONDUCTORS

D1-D6—1N4148 diode, or equiv.
LED1, LED2—Light-emitting diode, red
Q1, Q2—2N3904, NPN, RF amplifier transistor
IC1—74C14 CMOS hex Schmitt inverter, integrated circuit
IC2, IC3—78L05 +5-volt regulator, integrated circuit

RESISTORS

(All fixed resistors are 1/4-watt, 5% units.)
R1—100,000-ohm
R2—470-ohm
R3—120,000-ohm
R4—10,000-ohm, PC-mount, potentiometer
R5—4700-ohm
R6—33,000-ohm
R7—1000-ohm, PC-mount, potentiometer
R8—2700-ohm
R9—1000-ohm

CAPACITORS

C1—0.001- μ F, Mylar
C2-C8—4.7- μ F, 35-WVDC, aluminum electrolytic
C9—22- μ F, 16-WVDC, tantalum
C10—1.0- μ F, 16-WVDC, tantalum
C11, C12—4.7- μ F, 10-WVDC, tantalum

ADDITIONAL PARTS AND MATERIALS

B1—+12-volt battery (see text)
S1—Single-pole, single-throw, toggle switch
PC universal prototyping board (RadioShack 276-168), 8 AA-cell holder (RadioShack 270-387, or equiv.), battery snap (RadioShack 270-324, or equiv.) phono jack, copper foil, etc.

C1 to about 65 kHz. The remaining five Schmitt inverter sections are wired in parallel to form a power amplifier. This combination of Schmitt triggers delivers squarewave current to the diode-capacitor multiplier string (D1-D6 and C2-C7).

The DC/DC voltage-multiplier converter would output about 45 volts were it not for transistors Q1 and Q2. Those semiconductors and their associated circuitry form an adjustable DC-voltage regulator wherein Q1 serves as an error amplifier. Transistor Q1 compares the voltage at wiper of

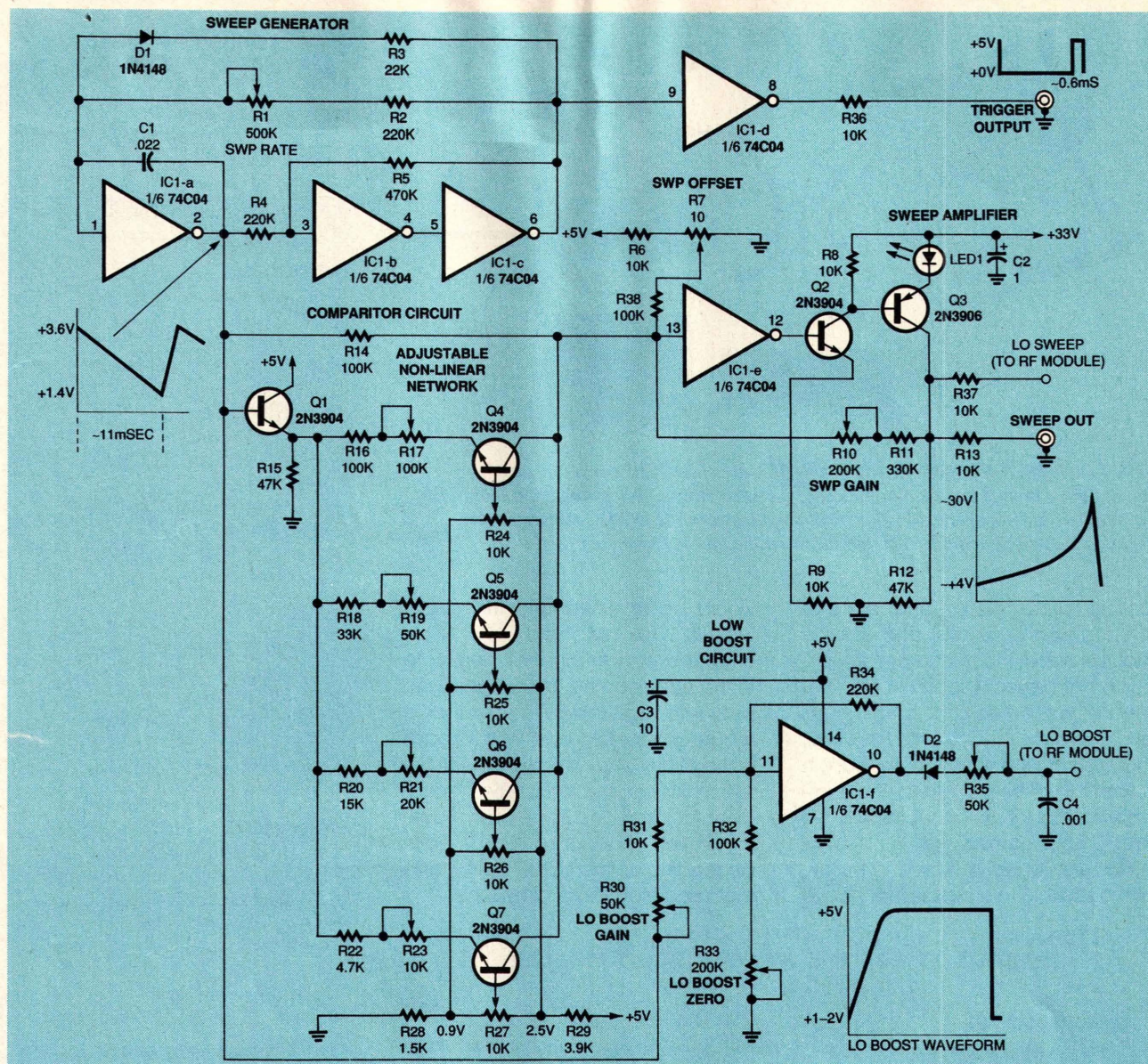


FIG. 4—SCHEMATIC DIAGRAM for the sweep-circuit module. This module provides the "curvy" sweep voltage for the first-converter local oscillator to make the frequency sweep (radio dial) linear, and also provides the oscilloscope's trigger signal.

R4 to the reference pedestal of its own base-emitter junction and LED1 in the emitter circuit (which is about 2.4-volts DC equivalent).

In operation, an error signal is amplified by Q1 which controls series-pass transistor Q2 (Fig. 3). Thus, a variable voltage is supplied to power IC1 as needed to control the squarewave amplitude that drives the voltage multiplier in the first place! For example, if for some reason the +33-volt level would tend to drop, Q1 would conduct less and its collector voltage would rise. This would increase the voltage powering IC1, which in turn would make the squarewave drive to the multiplier chain increase, pre-

empting the precipitating voltage drop! Should the +33-volt level increase, the opposite occurs.

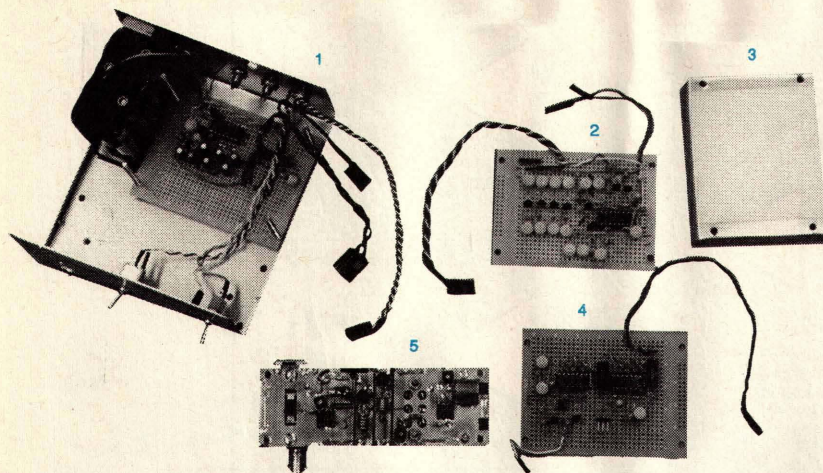
The nominal value of +33-volts DC is adjusted by trimmer R4 and that value holds over the useful range of the battery voltage (+13 when *fresh* to +10 volts when *dead*). Light-emitting diode LED1 will glow rather dimly, but light-emitting diode LED2, which is in the supply path to regulator IC2, glows brightly and serves as the HSA's POWER indicator.

The sweep circuit. The schematic diagram for the sweep circuit is shown in Fig. 4. A CMOS hex inverter, IC1, has four sections wired as operational

amplifiers. Section IC1-a is configured as an integrator circuit. With capacitor C1 connecting from the inverter's output to input, a linear voltage ramp will appear at the output, pin 2, for a step change in the DC voltage (astable squarewave) applied to a resistor on input pin 1.

Inverters IC1-b and IC1-c are wired as a comparator circuit, which is not a linear system. The inverters here have outputs that are either high or low and *nothing* in-between. This is assured by the positive feedback connection via R4 and R5. Thus, a switched waveform at pin 6 of IC1-c will either be +5 volts or 0 volts.

To visualize operation of the com-



THE FOUR MAJOR ASSEMBLIES of the HSA are: 1—DC/DC converter and regulators, which is mounted in the case, 2—sweep circuit, 4—log amplifier, and 5—RF circuit. The aluminum shield (3) is positioned between the DC/DC converter and regulators and log amplifier assemblies when the unit is assembled.

parator circuit, assume that pin 6 of IC1-c is high (+5 volts) and assume that resistor R4 in the comparator circuit is not present (open circuit). That means that the input at pin 3 is high, and thus pins 4 and 5 are low (0 volts), thus assuring the high condition at pin 6, which is where we started. The comparator made up of sections IC1-b and IC1-c is *latched* high.

Had we started with pin 6, IC1-c low, all voltage levels described above

would be reversed and the circuit would be latched low. The changeover from one latched state to the other can be forced by driving pin 3 to approach mid-voltage range, or about 2.5 volts. With R4 back in the circuit and ramp voltages from IC1-a pin 2 driving it, the 2.5-volt condition at pin 3 occurs at ramp waveform levels of about 1.3 and 3.7 volts, depending on the state of pin 8 and the associated ramp direction.

PARTS LIST FOR THE SWEEP CIRCUIT MODULE (Fig. 4)

SEMICONDUCTORS

IC1—74C04 or CD4069, CMOS hex inverter
Q1, Q2, Q4—Q7—2N3904, NPN, RF amplifier transistor
Q3—2N3906, PNP transistor
D1, D2—1N4148, fast-switching, silicon diode (or equiv.)
LED1—Light-emitting diode, red

RESISTORS

(All resistors are 1/4-watt, 5% units unless otherwise noted.)
R1—500,000-ohm PC-mount trimmer potentiometer
R2, R4, R34—220,000-ohm
R3—22,000-ohm
R5—470,000-ohm
R6, R8, R9, R13, R31, R36, R37—10,000-ohm
R7, R23—R27—10,000-ohm PC-mount trimmer potentiometer
R10, R33—200,000-ohm PC-mount trimmer potentiometer
R11—330,000-ohm
R12, R15—47,000-ohm

R14, R16, R32, R38—100,000-ohm
R17—100,000-ohm PC-mount trimmer potentiometer
R18—33,000-ohm
R19, R30, R35—50,000-ohm PC-mount trimmer potentiometer
R20—15,000-ohm
R21—20,000-ohm PC-mount trimmer potentiometer
R22—4700-ohm
R28—1500-ohm
R29—3900-ohm

CAPACITORS

C1—0.022-μF, Mylar
C2—1.0-μF, 35-WVDC, tantalum
C3—10-μF, 10-WVDC, tantalum
C4—0.001-μF, ceramic disc

ADDITIONAL PARTS AND MATERIALS

PC universal prototyping board (RadioShack 276-168); phono jacks (2 required); 5-pin 0.1-in. centers, right-angle male connector; 6-pin 0.1-in. centers, female connector; wire, solder, etc.

PARTS LIST FOR THE LOG AMPLIFIER MODULE (Fig. 5)

SEMICONDUCTORS

IC1, IC2—74C04 or CD4069, CMOS hex inverter, integrated circuit
Q1, Q2—2N3904, NPN, RF amplifier transistor

RESISTORS

(All fixed resistors are 1/4-watt, 5% units.)
R1—10,000-ohm
R2—20,000-ohm, PC-mount, potentiometer
R3—27,000-ohm
R4—68,000-ohm
R5, R8, R11, R14, R17, R20—39,000-ohm
R6, R9, R12, R15, R18, R22—150,000-ohm
R7, R10, R13, R16, R19, R23—100,000-ohm
R21, R25—5100-ohm
R24, R31—2200-ohm
R26—10,000-ohm, PC-mount, potentiometer
R27—3900-ohm
R28—5000-ohm, PC-mount, potentiometer
R29—2700-ohm
R30—1000-ohm

CAPACITORS

C1—4.7-μF, 10-WVDC, non-polarized, aluminum, electrolytic
C2—18-pF, ceramic disc
C3—2.2-μF, 10-WVDC, non-polarized, aluminum, electrolytic
C4—100-pF, ceramic disc
C5—0.01-μF, Mylar
C6—10-μF, 10-WVDC, tantalum

ADDITIONAL PARTS AND MATERIALS

PC universal prototyping board (Radio Shack 276-168), Connector, 3-pin, male, 0.1-in. centers, right angle, phono jack, wire, solder, etc.

The ramp motion is caused by pin 6 of IC1-c driving integrator inputs via R1 and R2 or D1 and R3. The ramp voltages corresponding to crossover are determined by the ratio of R5/R4. Thus, for the pin 6 high condition we began with, the integrator's pin 2 voltage is decreasing, and when it hits about 1.3 volts, the comparator pair of IC1-b and IC1-c changes state. This drives pin 6 low, and the integrator output ramps upwards. When it hits approximately 3.7 volts, the comparator pair again changes state, and the process begins over. The repetitive waveform

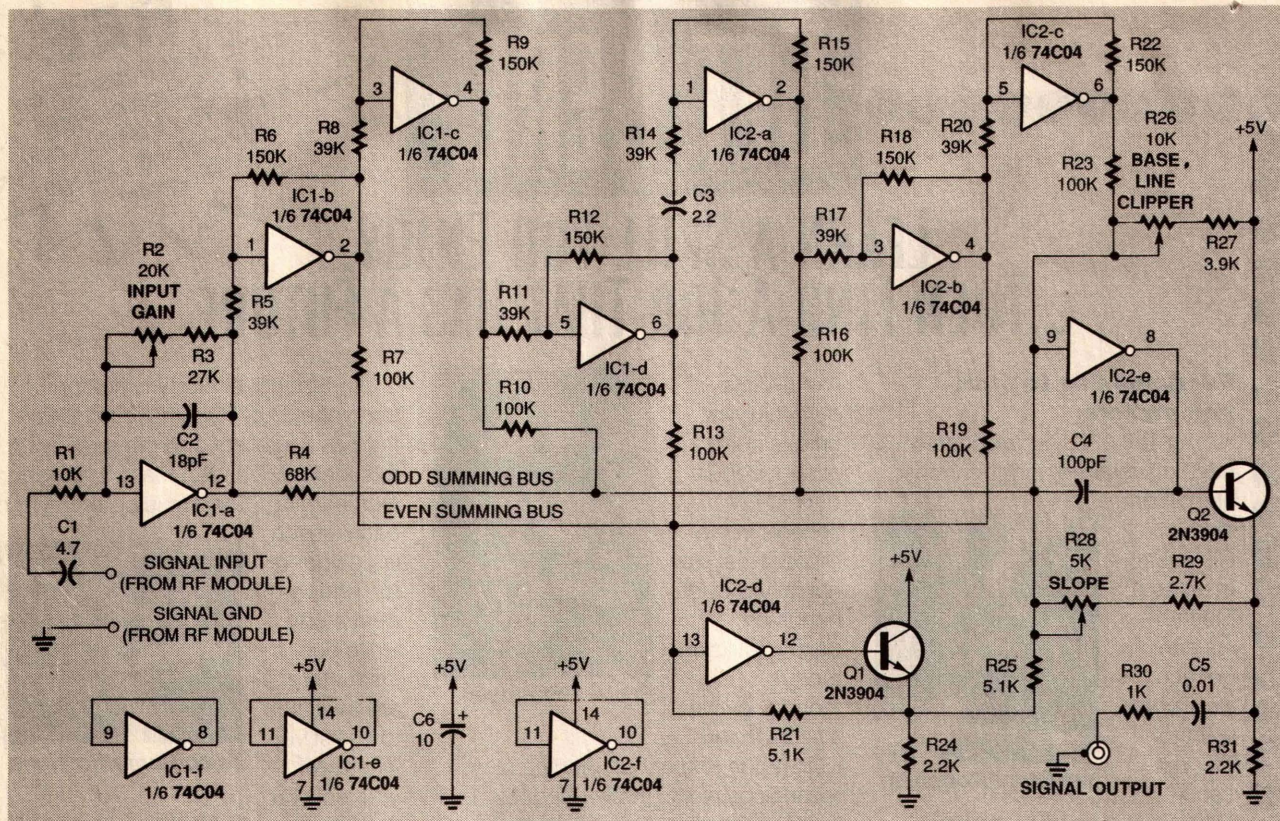


FIG. 5—SCHEMATIC DIAGRAM for the log amplifier module. The log amplifier provides the accurate non-linear transfer function needed to make the oscilloscope's graticule read out in dB instead of linear voltage.

MATERIALS LIST FOR THE HSA CASE ASSEMBLY

- 1—3 × 5 × 5 7/8 metal cabinet (RadioShack 270-253)
- 4—6-32 × 2-in. machine screws
- 23—6-32 × 1/4-in. hex nuts
- 4—Plastic or metal spacers (see text)
- 4—#6 outside star washers
- 4—1/4-in. × 1 3/4-in. plastic or metal standoffs, 4-40 thread
- 12—4-40 × 1/4-in. cap head screws
- 1—Sheet of 0.010 to 0.020-in. aluminum for formed shield cover (see text)
- 1—Sheet of copper tooling foil, 36 gauge (craft store)
- 1—5-in. brass (or comparable) 1/16-in. dia. rod stock (hobby shop)
- 4—1/16-in. metal wheel collars w/set screws (hobby shop)
- 2—Decorative beads, 1/16-in. bore for pull knobs (craft store)
- 2—6-32 × 1/4-in. machine screws (to mount slide switch)
- 2—6-32 × 3/8-in. machine screws (to mount slide switch)
- 2—4-40 × 3/8-in. threaded spacers
- 1—1/4-in. × 3/4 × 2 1/4-in. wood or foam spacer block
- 1—3/4-in. × 2 1/2-in. double-stick Velcro (to mount battery holder)

at pin 2 is depicted in Fig. 4 as an asymmetrical triangular wave. It's a fast positive ramp followed by a slower negative going ramp. The latter is what's ultimately used to sweep the local oscillator's first converter.

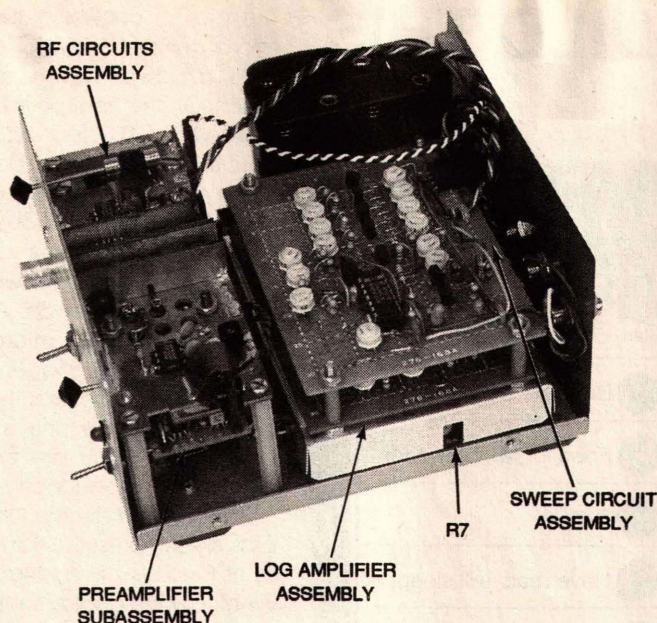
In all the above, the waveform at pin 8 is a rectangular waveform which is buffered by inverter IC1-d. This waveform is the trigger output used to initiate oscilloscope sweep on the negative going slope of the pulse. This sweep is time coincident with the beginning of the slow negative ramp at pin 2 of IC1-a.

The triangle waveform voltage at IC1-a, pin 2 is about 2.4 volts peak-to-peak. Varactor D1 in the first converter local oscillator (Fig. 2) requires about a 28-volt swing to effect a local oscillator frequency change of about 100 MHz. Thus, the limited ramp levels at pin 2 of IC1-a (Fig. 4) must be amplified to much higher levels. Not only that, but the change in frequency of the first converter is non-linear with respect to varactor D1's bias drive, so the drive shape must be "bent" into shape. Those dual requirements are met with the sweep amplifier and ad-

justable nonlinear network in Fig. 4.

The sweep amplifier assembly consists of IC1-e, Q2, and Q3, which are configured as an operational inverter whose basic gain is established by the ratio of three resistors: $(R10 + R11) \div R14$. Gain is adjustable by adjusting trimmer R10. The output transistor, Q3, is powered from the +33-volt line, so it is capable of swinging the high voltage needed by varactor D1 (Fig. 2). The sweep voltage at Q3's collector and SWEEP OUT jack is shown in Fig. 4. Remember, the first converter local oscillator needs a "curvy" sweep voltage to make the frequency sweep ("radio dial") linear.

Sweep voltage shaping is obtained by "piecewise linear waveform shaping" as brought about by the circuitry of Q1, Q4 through Q7, and their related components. Given that the ultimate output voltage at Q3 collector is governed by the sweep drive to vary the sweep drive dynamically in a nonlinear manner. In effect, what's needed is to equivalently "lower" the value of R14 during the driving ramp time. However, there is no resistive val-



RIGHT-SIDE VIEW OF THE HSA shows part of the preamplifier subassembly under the RF circuits assembly. The small slot cut in the shield that covers the DC/DC converter and regulators permits adjustment of potentiometer R7, which sets the V+ voltage.

ue change. Rather, transistors Q4 through Q7 sink more and more current from the IC1-e input node as a sweep progresses, simulating what appears to be lowered resistance in R14.

Transistor Q1 buffers the ramp waveform at IC1-a, pin 2, and drives the four resistive networks shown in Fig. 4. Transistors Q4 through Q7 have base biases adjusted by their individual base-voltage-divider potentiometers, R24 through R27. Emitter currents (and collector currents) in those transistors can only flow for Q1 emitter voltage levels falling lower than the emitter voltages of Q4 through Q7. The magnitude of those currents is then controlled by resistors R16 through R23. As Q1's emitter ramp voltage sweep moves in a negative going direction, and with the transistor base biases properly adjusted, transistors Q4 through Q7 sequentially come into conduction and progressively sink more current from the IC1-e input node. As that sequence takes place the sweep output voltage at Q3's emitter increases nonlinearly. The exact shape of the resulting waveform is easily adjusted (tuned) during the HSA alignment.

LO boost. Now for that elusive LO-boost function mentioned earlier. Dur-

ing the development of the HSA, several RF modules were built and tested. In each, the amplitude response rolled off about 5 dB from about 30 MHz to zero. The output display suffered response flatness at the lower third of the frequency sweep. This problem was fixed by time-varying the local oscillator power level in the first converter. Thus, from sweep initiation to about one-third the frequency

range, the local oscillator power of the first converter is adjusted "on the fly" to yield an overall flat frequency response. The circuitry of IC1-f and associated adjustment trimmers perform that mission, and those tuneup details are discussed later.

The log amplifier module. A log amplifier module output is the mathematical logarithm of the input signal. The log amplifier displays a diminishing gain as its input signal increases. A good log amplifier has an accurate "log transfer characteristic". The log amplifier function in the HSA is accomplished with 74C04 CMOS hex inverter logic circuits operating in linear/limiting fashion (See Fig. 5).

The HSA transfer function will be set to 100 mV per 10 dB during alignment. Then a 10 dB increase in input signal will cause a 100 mV output increase. So does the next 10 dB. And the next. And so on. The HSA has a nominal 60 dB log amplifier. This means that the output changes only about 0.6 volt for an input signal range of 1000:1 (60 dB).

The log amplifier module schematic diagram shown in Fig. 5 is a configuration known as a "piecewise linear synthesized log amplifier". This means that the overall 60-dB transfer is "constructed" of individual short quasi-linear transfer segments strung end to end to look like a smooth log function. While that may sound like a "bumpy-curve" technique, the resulting circuit behavior is actually very smooth. In fact, the log linearity of the HSA circuit is better than ± 1 dB over the entire range.

Seven sections from two hex inverter ICs are connected as amplifiers in series. Except for the first stage (IC1-a), all stages have a fixed voltage gain of about 10 dB. This is primarily established by the 150,000-ohm and 39,000-ohm resistors around each stage. The 7-stage amplifier has over 70 dB of gain. A very small input signal causes a large output signal at the last stage (IC2-c). This last stage quickly saturates with increasing input. More input causes the next-to-the-last stage to similarly saturate. Eventually all the preceding stages saturate.

Each interim amplifier stage drives two loads. One load is the next amplifier stage. The other load is a 100,000-ohm resistor connected to a summing

(Continued on page 80)

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SPECTRUM ANALYZER

(Continued from page 39)

bus with other 100,000-ohm resistors (R7, R10, R13, R16, R19, and R23). Because each stage is an inverter, there are two summing buses; with one for the "evens" and one for the "odds" of the seven stages. Those buses sum signal samples from each of the series-strung stages described above. Once a stage saturates, its output is limited, and it contributes no more to the summation. Thus, as the stages progressively saturate with increasing signal input, the summing buses appear to have less and less gain in front of them.

Each stage within the chain comes into saturation (limiting) very smoothly; there is no sudden "corner" in the individual stage transfer functions. This smoothness is due to the way the CMOS inverters behave. The overall effect is a smooth logarithmic amplifier performance.

Because of the "even-odd" signal collection on the two buses, it is necessary to invert the signal on one so that both are in phase and ready to be totaled. This is done with IC2-d and emitter follower Q1. The signal at the emitter is now in phase with the signal on the other summing bus. The two bus contributions are finally summed in IC2-e and Q2, which form the final output stage of the log amplifier. The transfer function slope (mV/dB) constant is set with resistor R28.

The signal input to the log amplifier is a symmetrical heterodyne "bubble" of sinusoidal signal that consists of positive and negative swings around a baseline. Because spectrum analyzer displays are unipolar (one signal polarity), output stage IC2-e is bias-offset with resistors R26 and R27. This clips the negative going spectral line spikes and so only positive going ones are displayed on the oscilloscope. Finally, input gain trimmer R2 sets the smallest signal at which logging begins, so that logging does not occur on baseline noise but rather just above it.

This completes the theory discussion for the HSA and pretty much all the space we have for this month. Next time, we will get right to work on showing you how you can build your own under-\$100 spectrum analyzer. Ω

DECISION MAKER

(Continued from page 42)

neath the LED cap, and about $\frac{3}{16}$ -inch from the bend to the end of the leads. Don't trim the LED leads until after you have soldered them in place.

First, mount all components except the LEDs. Use a socket for the microcontroller, but don't install that IC yet. Next drill the holes for the LEDs and the start switch in the enclosure's cover, using the template in Fig. 5 as a guide.

Now place the PCB in a pair of slots along the side of the enclosure and bend the leads of a single LED. Insert the LED into the board and tack-solder one lead. Temporarily place the cover on the enclosure to check lead length. If the cover fits properly, finish soldering the LED, then bend the remaining LEDs to fit, and solder them in. Otherwise, adjust the bend in the first LED and try again.

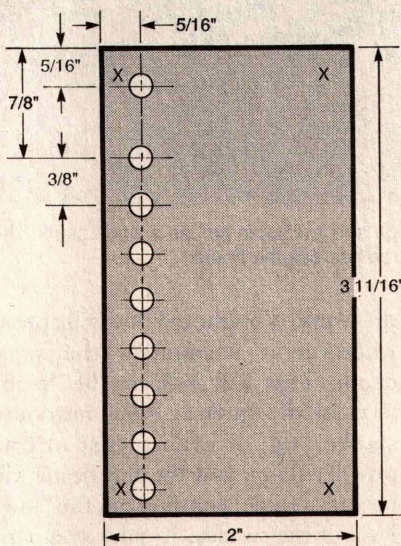


Fig. 5. Here's the hole template for the cover. Nine holes are required, eight for LEDs and one for the start switch. The power switch mounts on the upper end of the case.

To keep the front panel as clear as possible, we mounted power switch S2 in the side wall of the narrow end of the enclosure. We used a low-cost, low-profile slider for S2.

Test and final assembly. After completing construction, but before installing the microcontroller, let's do a few simple tests to ensure that everything is working properly.

Apply power to the circuit by closing S2. The battery voltage should now appear at the input of regulator IC2, and a constant 5-volts should appear at its output. The same voltage should appear at pin 13 of IC1's socket (remember, we have not installed that IC as of yet), at the anode of each LED, and at the buzzer.

Next, with power still applied, use a short jumper wire to short pin 3 of IC1 to ground (pin 14). That should cause the buzzer to sound. Also try grounding pins 5-12 of IC1. Each LED should light in turn. If LED4 does not light, put JU2 in the other position.

The last test verifies operation of S1. Connect your voltmeter between pin of IC1 and ground. When the switch is open, the meter should read +5-volts DC, but when closed it should read zero.

After verifying operation of all components, remove power and install the 68HC705K1 into its socket. Then reapply power. You should see and hear the initialization sequence, after which the unit is ready for use.

The label. The most difficult (and the most fun) part of this project is creating the front panel label. Self-stick labels work well in this application; you can also use heavy stock and rubber cement.

The author created a template file in Word for Windows that allows you to format labels precisely. One is shown in Fig. 1, and another in the lead photo for this article.

Customization is the key to transforming this project from simple blinking lights into a memorable gift. When creating the label, it's best to focus on either the personality quirks of the recipient or on the general humor of the situation. Ask yourself questions like: What things does this person like and dislike? When is he or she the least decisive? Are there any stereotypes concerning the new situation he will soon be in? As soon as you start letting the creative juices flow, you can have a lot of fun. Ω

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BUILD THIS Hobby Spectrum Analyzer

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this spectrum analyzer is
a must for every hobbyist!*

BOB KOPSKI

Last month we looked at the Hobby Spectrum Analyzer's theory of operation. Now, let's turn our attention to its construction.

The Hobby Spectrum Analyzer circuits are built in two basic ways. The RF circuits are built on double sided printed circuit board material used as chassis material. The non-RF circuits are built on RadioShack universal prototyping boards.

Four universal prototyping boards are needed. Three are used full size and stacked together, and the fourth one is cut into smaller pieces and used on the RF circuit module. All the circuit assembly drawings for the modules (Figs. 6 through 11) are top views, *i.e.*, component side up. The printed lands are shown dotted, *i.e.*, X-ray style. On most of the circuit assembly drawings, large "X"s indicate that existing copper-foil runs on the boards are cut. Do the cutting before you begin assembly of the boards.

DC/DC converter and regulators.

While all universal prototyping board circuits are built similarly, the DC/DC converter and regulators board does have a unique modification in the form of added copper foil lands on the conductor side. The board drawing (Fig. 6) includes shaded markings where the copper foils are added.

This foil encompasses the board mounting holes and is pressed against the four "stack screw" double-nuts during case installation, assuring good ground contact to the cabinet floor. The board has a formed, thin aluminum shield cover over it to contain the switching emissions associated with the voltage multiplier.

Install the IC sockets first, then the parts and jumpers as indicated in Fig. 6. Finish up by adding twisted wire cables with connectors, switches, and the POWER LED2 where shown. Stake the cables to the board with insulated wire, upside-down "U"s as shown. The technique used to do this is not critical, so if you have a better technique, use it. Clean the copper side with flux solvent, and inspect your solder connections with a hand lens or eye loop for any of the usual problems.

Initial board testing of the DC/DC converter and regulators and subsequent adjustment requires an adjustable (variable) power supply and current meter. Make temporary test leads with the same pins and sockets as used on the assemblies. Begin testing the board by first setting trimmers R4 and R7 to mid-range, turn the power switch on and the comb generator switch off. Connect the power supply to the board's battery snap connector—be sure the polarity is

correct! Slowly bring up the voltage from zero to the +12-volt level with an eye on the current meter. Normal current drain at 12.0-volts DC input is about 7 to 8 mA. Verify LED1 is dimly lit, and LED2 is brightly lit. If any of those indications aren't correct, re-examine the board to determine the fault(s)' location.

Use a DMM to measure the +5-volt and V+ DC regulator outputs. Varying

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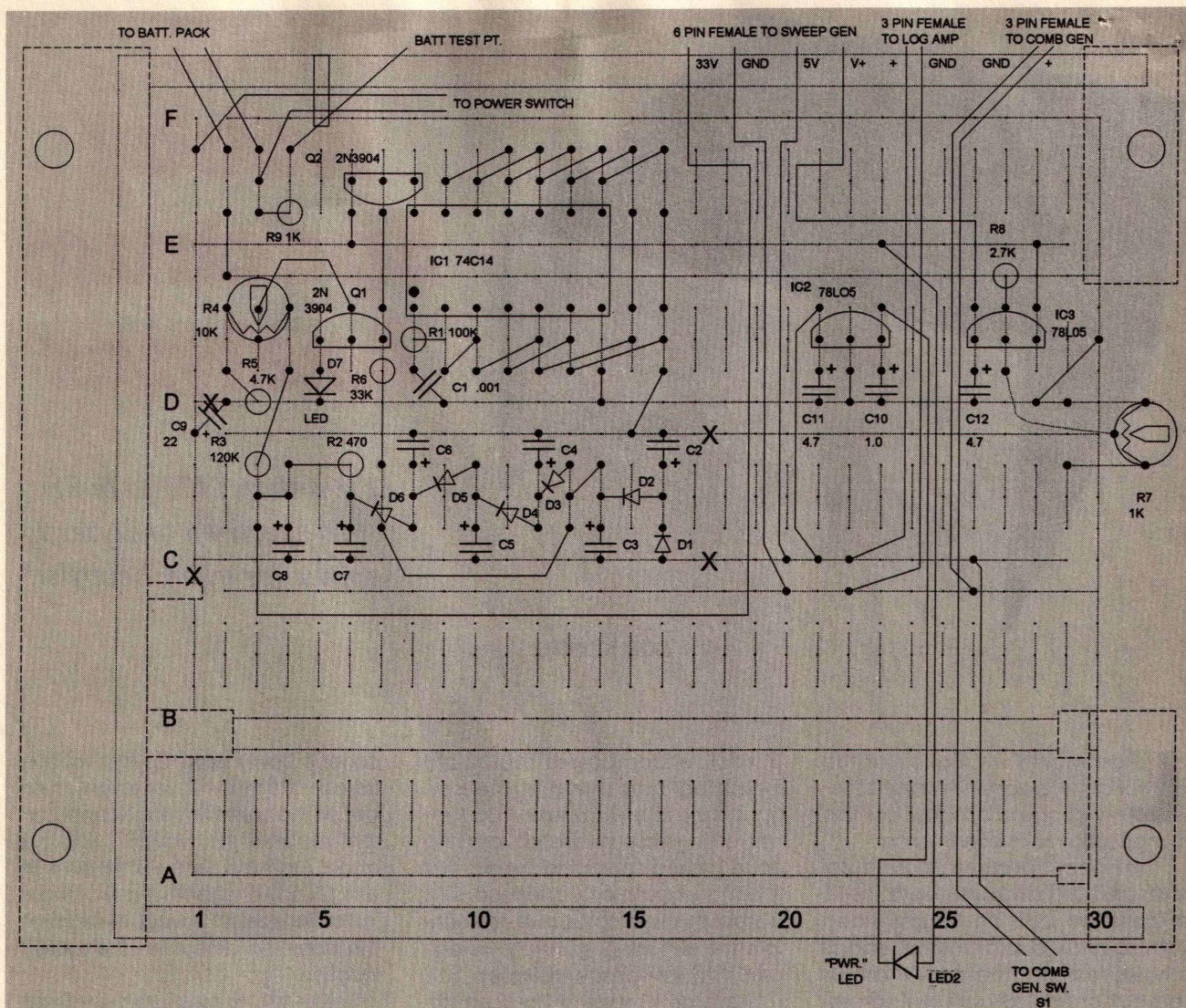


FIG. 6—DC/DC CONVERTER AND REGULATORS MODULE is diagrammed here using the author's original illustration (as are the following figures). Parts are mounted on a PC universal prototyping board (RadioShack 276-168). Original copper-foil runs are used but broken at selected points as indicated by bold "X"s in the diagram.

the setting of R7 should vary the V+ range from five to about seven volts or more. Move the DMM connection to the high-voltage terminal. The +33-volt potentiometer, R4, should vary the voltage from about 25 to 40-volts DC. Reset R4 so the DMM reads +33-volts DC. Now adjust the bench supply over the 10- to 13-volt range. The 33-volt DC output should stay within 0.5 volt of the set level. Connect the DMM to the comb generator connector set and verify the operation of the COMB switch (see Figs. 2 and 3). You should read five volts when the switch is on. Turn off both power switches. This completes the initial DC/DC converter and regulators board tests.

the log amplifier board (Fig. 7) uses 14-pin IC sockets so that all assembly work can be done and then the ICs plugged in. Assemble the board carefully as done previously, clean it, and inspect it. Temporarily short together the input signal leads. Cut the top lead of the vertically-mounted resistor R27 (located between potentiometers R26 and R28). This cut in the lead of R27 will be tack-soldered together later, so do not cut too close to the resistor body. Adjust R2, R26, and R28 to about mid-range. Now install the ICs, carefully noting pin orientation.

Set the adjustable DC power supply to zero, hook it and the current meter up to the onboard power-input connector pins, and slowly bring the volt-

age up, keeping an eye on the current meter. The log amplifier current drain is a very sensitive function of applied DC voltage. Prototypes drew 2.7 mA at +4.0 volts, 7 mA at +5 volts, and 14 mA at +6 volts. Expect similar behavior although the currents you measure could shift up or down as much as 50%. Set the input DC voltage to +5.0 volts for the following tests.

Using a DMM, measure the voltages at IC1, pin 8, and IC2, pin 10. Those should read $+2.5 \pm 0.2$ volts. Now measure the voltage at IC1 pins 12, 2, 4 and 6; IC2 pins 2, 4, and 6; and Q1 and Q2 emitters. Again, $+2.5 \pm 0.2$ volts is the target, but it's possible to exceed this target value a little at one or two test points.

Connect your oscilloscope to the signal output. There should be no indication of board instability or oscillation, but there should be a 25-30 millivolts peak-to-peak broadband noise present. Vary trimmers R2 and R28 individually, and confirm that both vary to output noise level, with R28 producing the greatest effect. Reset all trimmers to mid-range position. A special note: Because of the very high gain of the log amplifier, you may experience enough hum pickup to preclude a successful noise test. If that is so, power the board from the DC/DC converter and regulators board, operating the latter from the HSA battery pack. The hum level should drop considerably allowing the broadband noise to be measured.

Connect a 10,000-Hz sinewave signal source to the log amplifier input. Set the input signal level to 1.0 mV peak-to-peak and observe the signal at IC2, pin 6. The signal should be

about three volts peak-to-peak, representing about a 70-dB gain. Vary R2 from limit to limit and verify a little under 2:1 output change. Restore R2 to mid-range.

Connect the oscilloscope to the log amplifier output, and verify a signal level of about 250 mV peak-to-peak. (The input-output gain should be about 250.) Vary the setting of R28 from limit to limit, and verify an output level change of about 3:1. Reset R28 to mid-range. Gradually increase the input signal swing up to about one volt peak-to-peak, and verify that the output waveform transitions from that of a sinewave shape to a compressed appearance on both positive and negative peaks. (Waveform symmetry may vary about 5% over the range.) With a 1.0-volt peak-to-peak input, the output should be about 1.6 volts peak-to-peak. This result means the input-output gain is now only 1.6. If you vary R28's setting from limit to limit, the out-

put will vary about 3:1. Reset all trimmers to their mid-range settings.

Solder together the cut lead at the top of R27. Set the input signal level to 10 mV peak-to-peak, and observe the output wave shape while adjusting R26. Observe that at some point the output negative-going swings get cut off. This occurrence verifies operation of the base-line clipper circuit. Reset R26 fully clockwise to complete the initial board test. Remove signal and power connections and set the board aside.

Sweep circuit. The sweep circuit board is assembled like the previous boards, but it does have more land cuts, as indicated by the "X"s in Fig. 8. Because of the complex wave-shapes involved and the numerous associated adjustments, this board is a bit more complicated to test and tune. In the initial checkout, the waveforms will only be roughly set to shape;

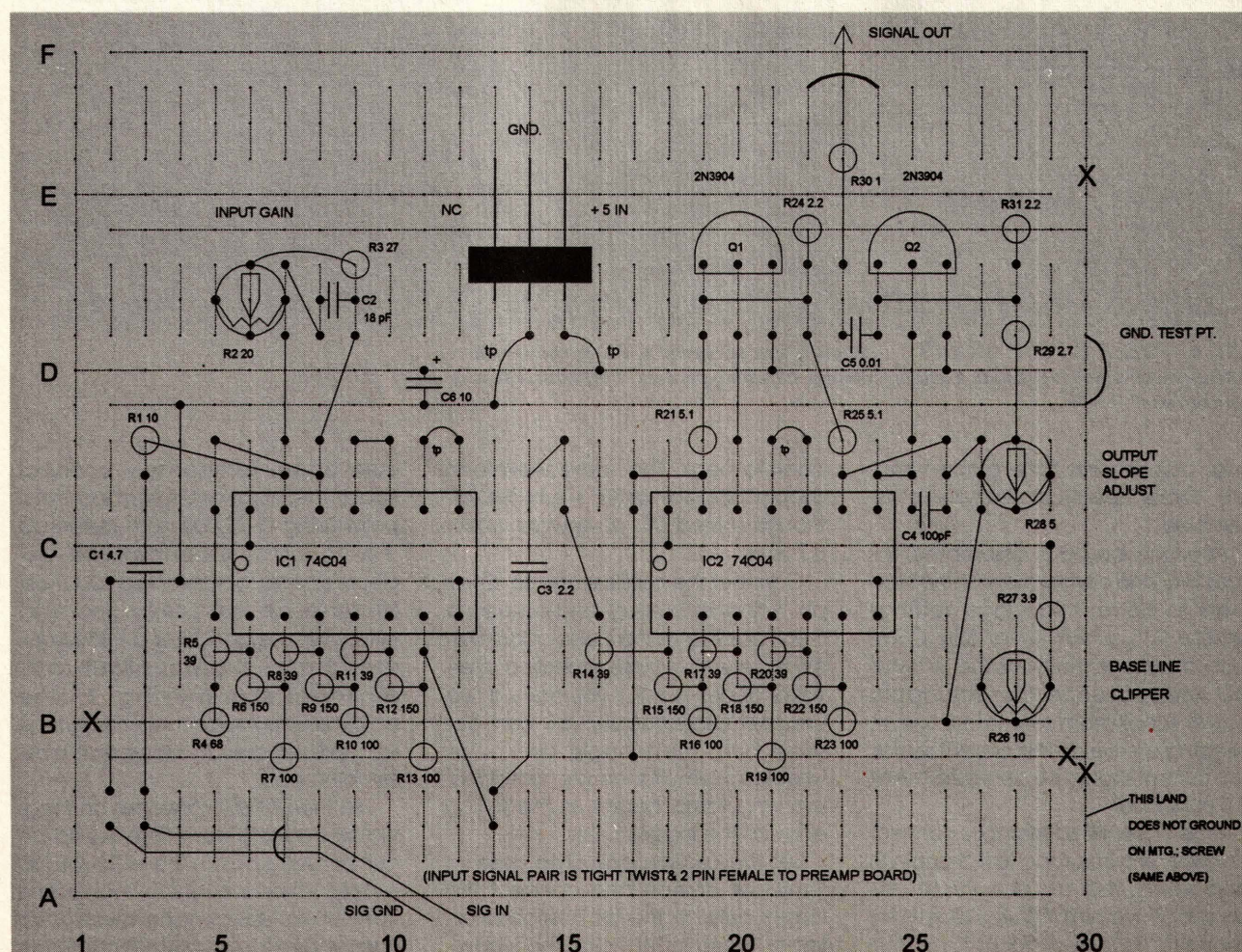


FIG. 7—LOG AMPLIFIER MODULE has its parts assembled on a PC universal prototyping board (RadioShack 276-168) in a similar style used in Fig. 6. "X"s indicate deliberate foil breaks to isolate selected circuit portions.

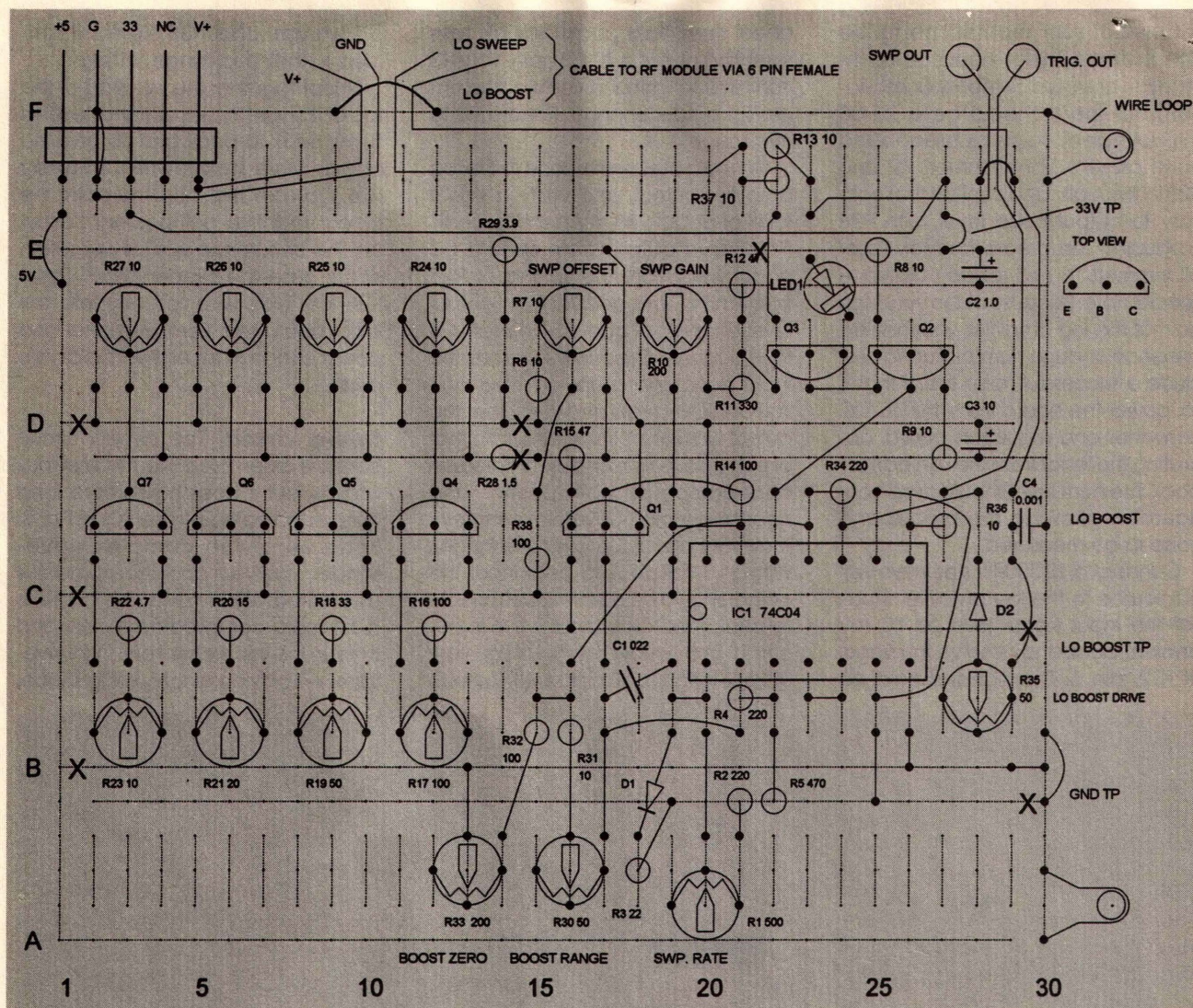


FIG. 8—SWEEP CIRCUIT MODULE contains a host of one-turn, PC-mount trimmer potentiometers that suggest an eventual complex adjusting process. Fortunately that is not the case!

final adjustments take place when the Hobby Spectrum Analyzer is assembled.

After the board is assembled, inspected, and cleaned, set all the trimmers to about mid-range settings except R35, which is set fully CCW. With a current meter in the +5-volt DC line, advance the adjustable power supply from zero to +5.0 volts, keeping an eye on the current meter. The current should be about 2.5 mA at 5.0 volts input.

If the current is satisfactory, connect an oscilloscope probe to IC1-a, pin 2, and verify the asymmetrical triangular waveform (Fig. 4). Adjust R1 for a long ramp time of about 11 mS. The short ramp time should be about 0.6 mS. The waveform should swing from about 1.3 volts to 3.7 volts, or 2.4 volts

peak-to-peak. This same waveform should appear at Q1's emitter, although shifted DC downward about 0.7 volts.

Connect the oscilloscope to IC1-d, pin 8 (trigger output), and observe a 5-volt positive-going pulse about 0.6-mS wide with a pulse repetition interval of about 11 mS. If you have a two channel oscilloscope, you can observe both the triangle and pulse waveforms simultaneously, noting that the long ramp begins at the falling edge of the trigger pulse.

Set the oscilloscope time base to 1-mS per division and connect the trigger pulse to the oscilloscope's external trigger input. Adjust the triggering controls for the long ramp to begin at the left screen graticule and extend somewhat past the right grati-

cule edge. Temporarily connect (load) the local-oscillator-boost test point using a 22,000-ohm resistor to +5-volt DC. Connect the oscilloscope to observe the local-oscillator-boost test point signal and alternately adjust R30 and R33 to approximate the waveform appearance shown in Fig. 4. (The amplitude is lower than depicted.) Final adjustments are done on the assembled HSA.

Use the DC/DC converter and regulators board to power the sweep circuit board to obtain the +33-volt DC supply. When powering that board from the adjustable supply, watch the current as you advance the voltage from zero to +12.0 volts. Current should be between 11 and 12 mA. Verify that the 33-volt level is correctly set.

Connect the oscilloscope to the sweep output at its connector pin. You should get some resemblance to the varactor sweep waveform shown in Fig. 4. Adjust all the influential trimmers one at a time (R17 through R27 and R10). Each one should affect the waveform in some manner verifying basic operation. Return them to mid-range position.

Now the sweep waveform can be trimmed closely to the estimated final shape. With the oscilloscope still connected, set the oscilloscope's vertical coupling to DC, the vertical position near the bottom of the screen, the vertical sensitivity to 5-volts per division, and the time base to 1-mS per division. Display the sweep waveform. Adjust the sweep offset trimmer, R7, so that the start of the sweep is about +4 volts above ground. Then adjust sweep gain trimmer (R10), so the ramp hits about 9 volts at 5 mS. Adjust R24, so the waveform slope just begins to increase about that same point. Adjust R26, so the new slope begins to increase at 7 mS.

Finally, adjust R27 for the last slope increase beginning about 9 mS. At that point, you should have a rapidly and smoothly rising voltage curve filling the oscilloscope screen. Final fine adjustment can only be made with the Hobby Spectrum Analyzer operational. Remove power and test leads, and set the sweep generator board aside.

RF circuit module. Begin the RF circuit module assembly by cutting the PC board chassis and shield partitions to size and accurately drilling the various mounting and parts holes as shown in Fig. 9. The overall size of the main board is 1 7/8-inch by 5.0-inch. The four shield partitions are cut to fit on the locations indicated on the board with a height of 0.5-inch.

Carefully drill #50 holes through the plastic knobs of both slide switches as shown. Trial mount the two switches and confirm smooth operation. Test fit the ICs and six-pin connector, the latter with its piece of Universal prototyping board underneath. Note that the connector and IC pins go through the chassis. Use #60 drilled holes. The copper around those holes must be coned away on both sides of the board by countersinking, using a finger-driven sharp, 1/8-inch bit. That pre-

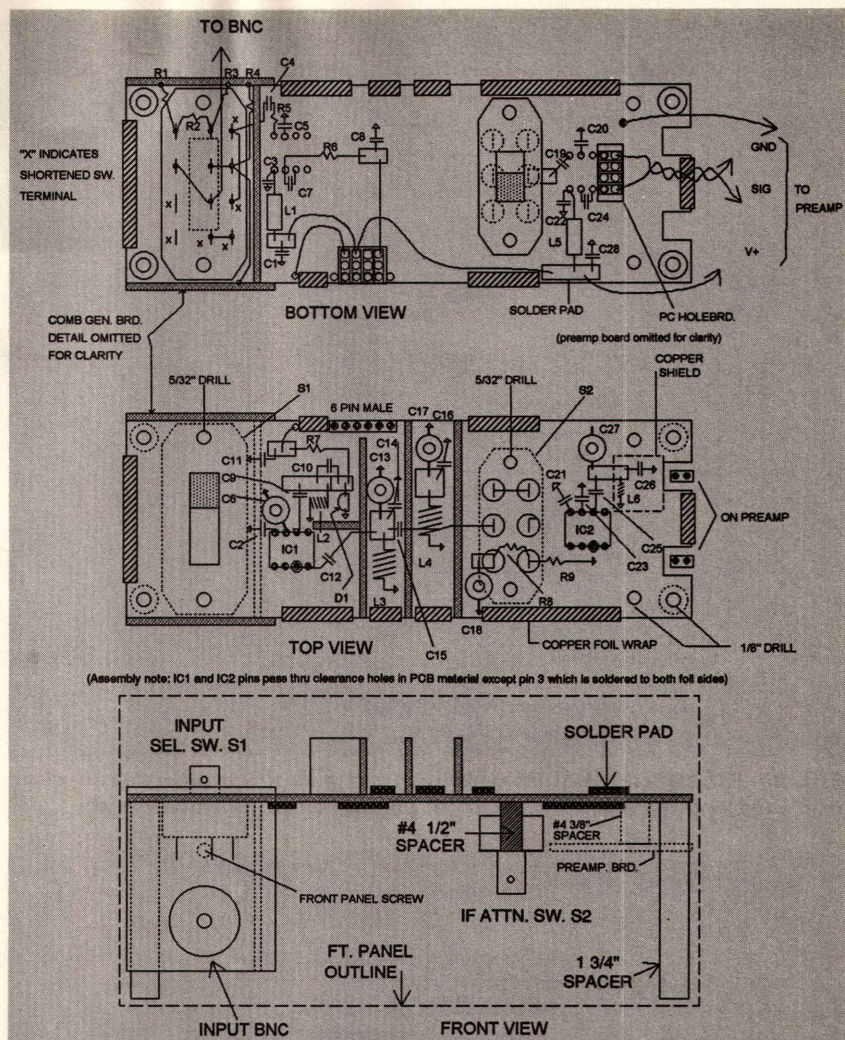


FIG. 9—RF CIRCUIT MODULE differs from other assemblies in that unetched, double-sided PC board material is used to mount components, RF (Faraday) shields, and subassemblies. Point-to-point wiring technique is used here. Soldering pads are used for common tie points.

vents accidental shorting between the copper and leads passing through the holes. Do not countersink the ground pins on the 6-pin connector and pin 3 on the ICs.

Form and sweat solder the copper foil edge wrap-arounds (Fig. 9). Install the IC's soldering pin 3 on both sides of the board. Note that all other IC connections are made directly to the device leads on either or both sides of the chassis. Install the six-pin connector.

Solder pads are used wherever wiring interconnections are needed. The solder pads are small pieces of double-sided PC board sweat soldered to the chassis at the locations shown. The top surfaces of those pads then become the soldering sites for the various interconnecting parts and wiring.

Install the solder pads and then all

the small components as shown in the drawings and photos. Keep the leads short and wiring neat. Keep all capacitor leads trimmed to the minimum length. The ground end of the various components is simply a solder attachment to the copper-clad chassis. When installing the trimmer capacitors, be sure to solder the "cold" ends to ground. (The cold ends electrically connect to the adjustment screw and indicate zero ohms when measured.)

Trial place the shield partitions (see Fig. 9) as you go along, but do not solder them in place just yet. Install the slide switches noting that the switch lugs are cut short whenever possible. The center lug on switch S2 (IF attenuator switch) is bent at right angles toward IC2. Install all the components associated with the switches except

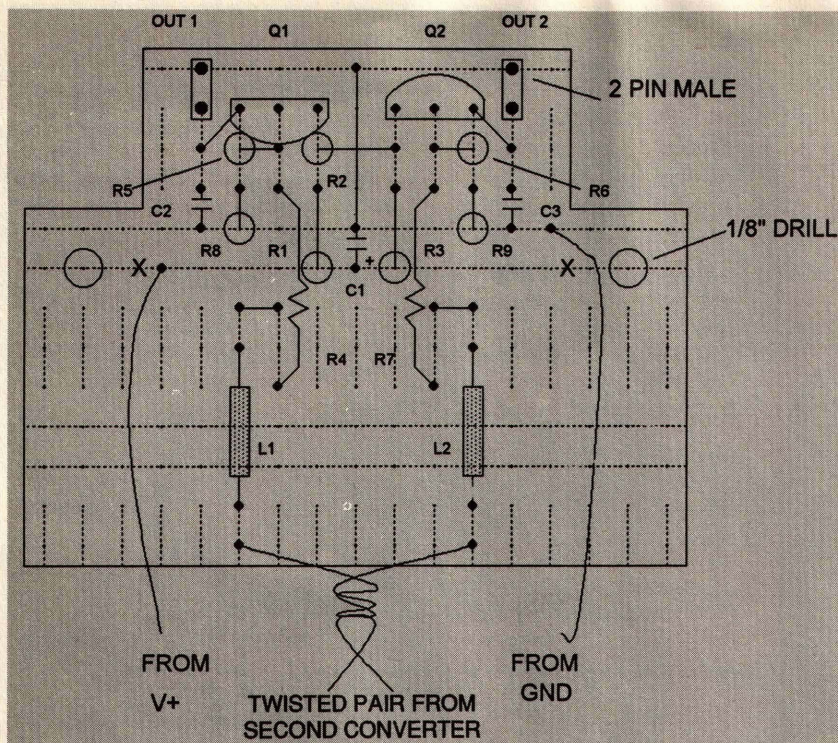


FIG. 10—PREAMPLIFIER SUBASSEMBLY, a part of the RF circuit module, is wired on a scrap piece of PC universal prototyping board with 0.1-inch hole spacing.

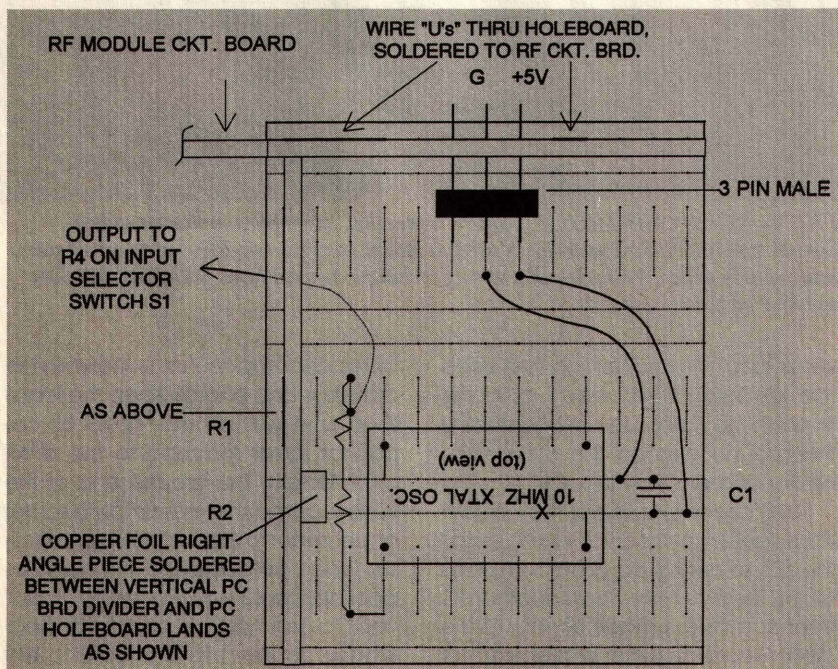


FIG. 11—COMB GENERATOR SUBASSEMBLY, a part of the RF circuit module, is constructed like the preamplifier subassembly.

the resistors that return to the BNC mounting plate.

At that point, perform a visual inspection and clean off flux as you proceed. Be sure the tricky solder attachments to the IC leads are not shorting. Following that, you can hook up the bench supply/current meter

combo to the V+ connector pin. Advance the power supply voltage to +5.0 volts, watching the current. It should level out around 4 to 5 mA. Carefully check the voltage at pins 1 and 2 of each IC. They should be closely matched within each individual IC at about 1.4-volts DC. Pins 4 and 5

should be about 3.75-volts DC.

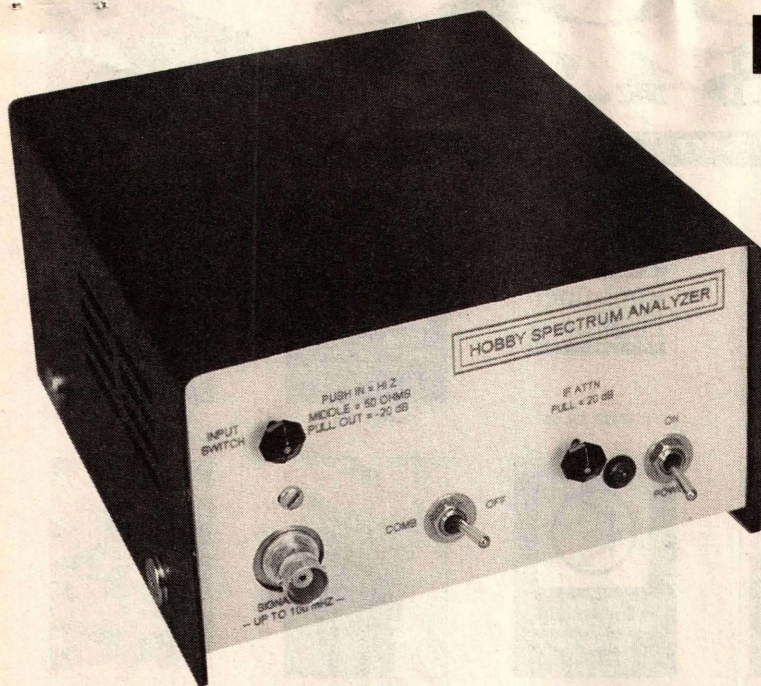
If the above is okay, remove power and proceed to tack solder the vertical partitions in place on each side of the main chassis. Install the BNC panel, and mount the BNC connector and the resistors from the input switch to the panel.

The comb generator and pre-amplifier boards (Figs. 10 and 11) are cut from the Universal prototyping board with a model hobby saw and then assembled as before. The comb generator can be powered up with +5.0 volts and checked for a 5-volt, 10-MHz squarewave prior to installation. The preamplifier board is best tested when interconnected to the RF chassis assembly.

Install the comb generator board by tack soldering its PC lands to the main chassis and front bottom vertical shield. Reinforce the attachment with #22 gauge wire "U"s soldered through lands in the universal prototyping board and then to the PC chassis material. Be sure the comb generator ground conductors are soldered to the main chassis underside vertical shield with the copper foil "L" as shown. Wire the generator output to the INPUT SWITCH.

Set the INPUT SWITCH to mid-position and directly connect the HSA input BNC to an oscilloscope. Power the comb generator with 5.0 volts. The 10-MHz waveform should read about 17 mV peak-to-peak. This level square-wave is about equivalent to a -30 dBm level at 10 MHz and is used in the amplitude calibration of the HSA.

Connect the four preamplifier leads to the appropriate locations, but do not mount the board yet. Again, connect the power supply to the RF circuit module V+. At 5.0 volts input, the current should now be 8-9 mA. Preamplifier Q1 and Q2 collectors should measure about 2.25-volts DC above ground. Power down and mount the preamplifier in position on the RF chassis. Form a half-round cover from copper foil and tack solder it. The copper foil serves as a RF cover over the L6 area. This prevents a flopping cable to the log amplifier from detuning the second local oscillator. That completes the assembly and initial test of the RF circuit module and all the room we have for now. Next time, we'll finish up the Hobby Spectrum Analyzer. Ω



BOB KOPSKI

BUILD THIS Hobby Spectrum Analyzer

*At less than \$100 to build,
this spectrum analyzer is
a must for every hobbyist!*

Over the last two months we have discussed the theory behind the \$100 *Hobby Spectrum Analyzer* and built and tested its various boards and subassemblies. Now it's time to put everything together and finish up the project.

Functional Interconnection and Test. Connect all four functional modules together on the bench top for a final check. This is not the *cleanest* RF arrangement, but it is workable for initial inter-module checkout.

Hook up the bench supply and current meter to the DC/DC converter and regulators battery lead. Turn on the HSA power switch but not the comb generator switch, and slowly run up the variable supply from zero, watching the current drain behavior as you advance to 12-volts DC. Look for a current draw of 26-31 mA. Turn on the comb generator; the current draw should increase 5-8 mA. Turn the comb generator off.

Connect the log amplifier output temporarily to the oscilloscope input, and the trigger output to the oscilloscope's trigger input. Set the vertical coupling to AC, and the range to 0.1 volts/division. Set the sweep to 1-mS per division. Set the IF ATTN to normal, and the INPUT SWITCH to mid-position (50

ohms). You should see a noisy baseline trace having about 0.1 volt peak-to-peak of noise. Be sure the oscilloscope is triggered for a stable display. Turn on the comb generator. You can expect a mess of vertical lines to appear on the oscilloscope. If so, you're now ready to do final assembly and alignment.

Cabinet Assembly. All modules and related parts easily fit in the specified cabinet; nevertheless, care is required in marking, drilling, and installing everything.

Start by flattening the dimples in the cabinet bottom where the feet screws were intended to go. The rubber feet can be glued on later. Hold a Universal prototyping board on the cabinet floor and mark four hole locations for the stack bolts. The rear board edge should be located 0.5-inch inside the rear panel, and as far to the right side of the cabinet as possible. Drill the holes. The stack screws are #6 machine screws. It is easier to slip the Universal prototyping boards over the #6 screws if the holes in the boards are drilled out to 5/32-inch diameter.

Next, drill the holes for the four phono jacks on the rear panel located on a line 1 1/8-inch up from the cabinet floor to clear the stacked boards inside. Jack-to-jack spacing and elec-

trical assignment are not critical. Glue or double stick tape a 1/4-inch thick, 3/4-inch wide, 2 1/2-inch wood or foam spacer block on the rear cabinet wall right behind the battery box location. Attach a strip of self-adhesive-backed Velcro tape to the battery box bottom and the cabinet inside floor, and trial mount the battery box.

The front panel is the most difficult mechanical task. With the RF circuit

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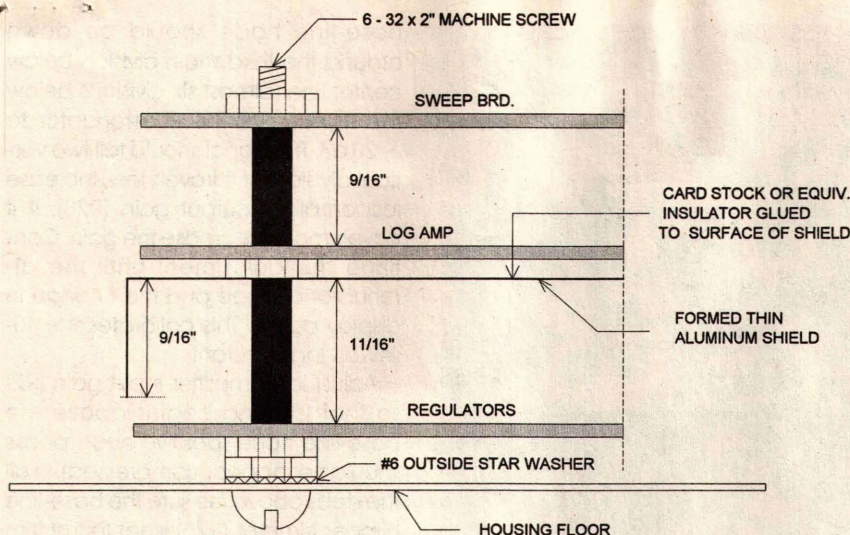
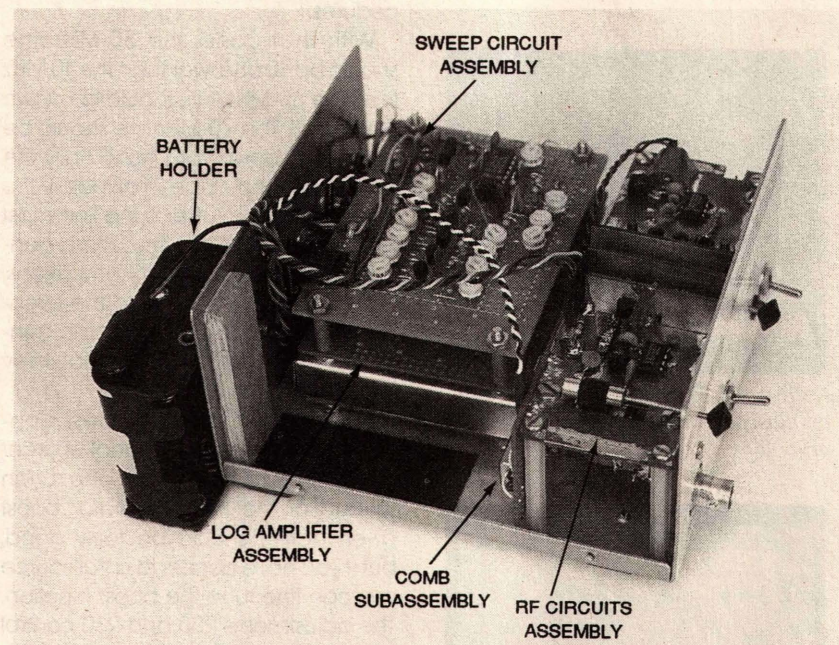


FIG. 12—MODULE STACK ASSEMBLY details are illustrated here (not to scale). Aluminum shields between the log amplifier module and DC/DC converter and regulators module provides RF shielding from stray radiation generated in the DC/DC converter circuitry.



FRONT PANEL OF THE HSA mounts four switches and a BNC connector for the input signal. The rear panel (not shown) has four RCA phono jacks that provide three output signals and a battery test point.

module in hand, mark off the various hole centers in the front panel. There are two critical hole locations: the $\frac{5}{64}$ -inch holes for the switch push rods (discussed in a moment). Make sure the alignment is correct before you drill. Use a $\frac{5}{16}$ -inch chassis punch to make the clearance opening for the BNC connector. Finally, the panel screw just above the BNC connector is a 4-40- $\frac{1}{4}$ -inch screw. It screws into a tapped hole in the BNC mounting plate to draw the latter snug against

the rear surface of the cabinet front panel.

Locate and drill the four mounting holes in the cabinet floor for the RF circuit module spacers ("legs"). The mounting holes for the toggle switches and POWER LED2 are not critical. Make push rods for the switches using $\frac{1}{16}$ -inch brass rod, a decorative bead glued on for a knob, and model-plane wheel collars to capture the sliding switch knobs themselves. Install all the electronics/interconnections in

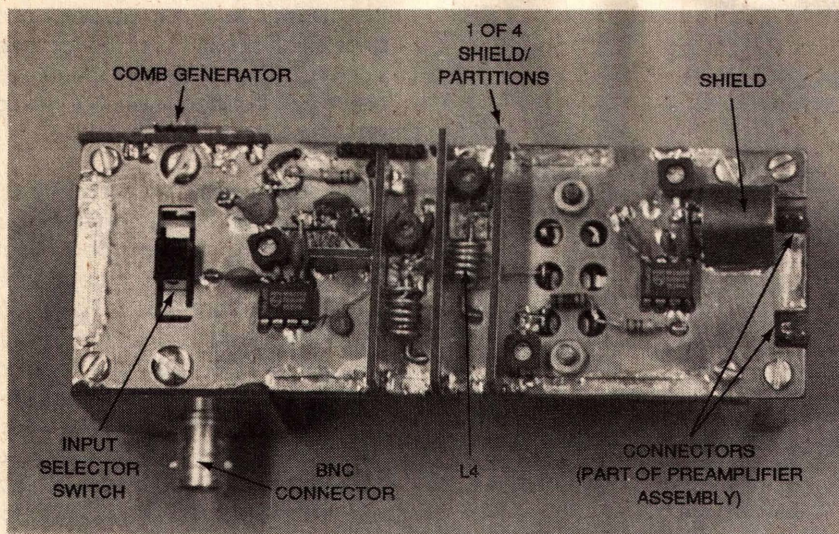
the cabinet as in the drawings and photos. Temporarily omit the topmost stack nuts (Fig. 12), so that the sweep board can be lifted to access the log amplifier.

Final Alignment. Temporarily connect the unused preamplifier output test point to the oscilloscope vertical, and connect the trigger output to the oscilloscope trigger input. Power up. Connect a lead to a source of 145-MHz signal and allow the lead to radiate near the double-tuned 145-MHz filter. Tune the second local oscillator trimmer capacitor C27 and the filter capacitor trimmers C13 and C17 iteratively (again and again) for both a visible audio frequency heterodyne and maximum signal as well. Remove the 145-MHz signal.

Position the start of the baseline sweep precisely at the left most graticule line on the oscilloscope. Turn on the comb generator. Readjust the sweep circuit board adjustments (in the same sequence as before) to progressively locate the spectral lines on subsequent graticule divisions. The sweep offset (R7) and sweep gain (R10) board-mounted controls are used to set the lines from zero to mid-screen (50-MHz) beginning with the 10-MHz component on the first graticule line. The remaining adjustments cover the last 50 MHz. Unlike the earlier rough tuneup, you can now use the segment gain adjustments (R17, R19, R21, and R23) for fine-fitting the entire sweep shape. Work with all the screw adjustments; you can't hurt anything, and you'll observe that sweep alignment goes easily.

If you find that you can't quite hit the highest and/or one or two of the lowest frequencies, note that the HSA will likely not tune below 1-2 MHz. As for the high-end difficulties, try adjusting RF circuit module capacitor C6 in conjunction with re-spacing the loops in inductor L2. The trick is to have a suitable ratio of L and C and enough motion in C (via varactor D1) to cover the band.

Fine tune the HSA using one of the comb generator's spectral lines. The 30-MHz line is good, or an external source can be used. Connect the unused preamplifier output to the oscilloscope vertical input and the trigger output to the oscilloscope trigger input. Power up. Center up the



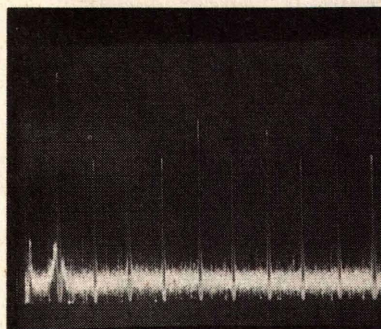
THE RF CIRCUITS MODULE has two subassemblies—preamplifier and comb generator. Note the partition/shield area in the center that isolates the two sections of 145-MHz bandpass filter. Inductor L4 has a tap on the first turn (bottom in photo) that is difficult to see in this view.

desired spectral line on the oscilloscope display, and then use the scope magnifier if it has one. You should see a symmetrical heterodyne bubble including a "suck out" at zero beat. Fine tune the IF trimmer capacitors C13 and C17 iteratively for a smooth sharp passband peak with the heterodyne dead center.

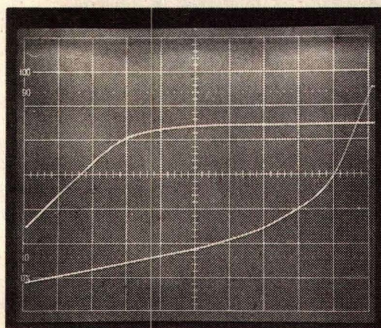
Switch in the IF attenuator and increase signal or oscilloscope gain as necessary to re-display the bubble. It will likely be detuned. Adjust attenuator-compensation capacitor C18 to reshape the display. Note that the bubble should have $\frac{1}{10}$ the amplitude of the original signal (it is 20 dB down).

The adjustment of the V+ level is somewhat subjective and somewhat quantitative. Lower voltages reduce the overall HSA gain; the highest values increase it significantly. However, along with higher gains comes more noise, jitter and trash near the base-line. The baseline may also take on an undulating or curvy appearance. Another indication is an unaccounted baseline spike located at about 72 MHz. Setting V+ to a compromise level eliminates all the above unpleasantness and provides for very good operation as well. The prototype's V+ setting is about 5.7 volts.

The spectral line at the 10-MHz position can be used to help adjust HSA amplitude performance. Locate the top of that line on an upper oscilloscope's graticule line at three



A VIEW OF THE HSA comb generator oscilloscope display after the alignment procedure is completed.



THE SWEEP-CIRCUIT OUTPUTS as viewed on an oscilloscope. The lower-most curve is the varactor (sweep) drive waveform—the bottom grid line is 0.0 volts, 5-volts per division. The upper-most waveform is the local-oscillator boost waveform—1-volt/division, top of trace is 4.5 volts. Both curves are displayed on a 1- μ s/division time base.

main graticule divisions up from center face. This is the -30 -dBm level. The

base-line noise should be down around the third main division below center line (almost six divisions below the signal). Set the IF attenuator to -20 dB. The signal should fall two vertical divisions. If it travels less, increase log amplifier output gain (R28); if it travels more, decrease the gain. Continue the adjustment until the attenuator change and the change in display agree. This calibrates the 10-mV/dB log constant.

Adjust log amplifier input gain (R2) so that logging begins above the base-line noise (positive noise peaks should not appear compressed). In all the steps above, be sure the base-line clipper trimmer (R26) is set to just trim off negative going spectral lines and not infringe on the magnitude of the base-line noise. Trimmer R26 will require resetting during the above procedures.

With that done, the 30-MHz line should be 10 dB lower than the 10 MHz line. The 50-MHz line should be down 5 more dB. The 70-MHz line should be about 3 dB down from that. Finally, the 90-MHz line should be 21 dB below the 10-MHz line. The latter is the line most likely to be off due to the comb-generator-waveform quality limitations. Finally, pay no attention to the even-order spectral lines; if the comb generator waveform were ideal they would not be present at all.

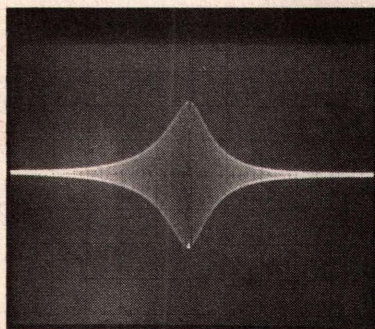
Frequency flatness is best confirmed with a quality signal source/power meter combination. The rough tuneup of the local oscillator boost given earlier should be fairly good, but if you have access to a flat source you can fine tune the boost function. The adjustments R33 and R30 control boost waveform "zero" and ramp rate respectively. The setting of R35 controls the waveform effect on local oscillator power.

Hints. The Hobby Spectrum Analyzer just begins to overload for signals exceeding -30 dBm. This is about 20 mV peak-to-peak on 50-ohm lines. Distortion manifests itself in several ways including baseline "buckling" at the base of such a spectral line, and "splatter" across the display. This situation can often be controlled with the input and/or IF attenuators.

It is sometimes convenient to transformer couple RF energy into the HSA. (Continued on page 118)

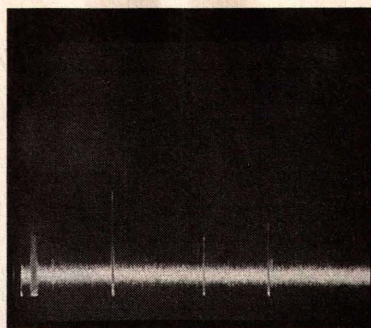
SPECTRUM ANALYZER

(Continued from page 52)



THE OSCILLOSCOPE'S VIEW of the bubble sampled from the preamplifier assembly's test point after the 145-MHz IF filter alignment. The oscilloscope's 10× time-base magnifier is switched on. You should be able to see the zero beat at the center of the bubble.

For example, EMI on cables might be best observed by passing the cable through a toroid ferrite. Wrap a few turns of finer wire as a secondary and



THE OSCILLOSCOPE'S DISPLAY of the HSA output when a short-wire antenna is connected to the BNC connector. The extreme left burst is an unknown signal. Local radio-control signals from left to right are at 27.995 MHz, 53.4 MHz, and 72.280 MHz.

connect to the HSA. This allows examination of what is on a suspect cable but avoids electrostatic pickup.

It is also possible to extend the reach of the HSA with a length of coax cable with a one or two turn sniffer loop on the pickup end. In all cases, be careful when working around

power lines or line-powered equipment.

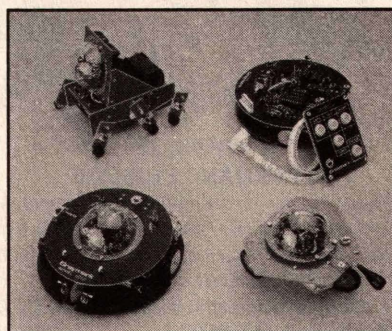
Parts and Supplies Hints. All parts and supplies for the Hobby Spectrum Analyzer came from electronics parts mail-order suppliers listed in the sidebar and from local hardware, model hobby, craft, and RadioShack stores. No single parts source can supply everything needed. A very few parts such as slide switches and beads came only from Digi-Key. The NE602 IC came from Ocean State Electronics and DC Electronics. The MV209 varactor comes from DC Electronics or Hosfelt. Many catalogs list ceramic disc capacitors; however, the RadioShack capacitor assortment #272-806 has all the smaller picofarad values on the RF circuit module. Consider using cut-to-length plastic ball pen handles for spacers. Metal and plastic tubing of many sizes as well as brass, aluminum, tin plate, and copper sheet is available at model hobby shops. Ω

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