Poor Man's Spectrum Analyzer

—another 73 breakthrough

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Hams enjoy making all types of electrical measurements. In fact, it's one of our favorite pastimes and topics of conversation. Fortunately, good, low-cost oscilloscopes, DVMs, and other instruments are available to us for measuring voltage, current, power, swr, frequency, and so on.

There is one instrument, however, that has been beyond the reach of most of our budgets—the spectrum analyzer. Commercial versions of this useful rf instrument start at $2500, which is a little steep for most of us. It is possible for you to build a simple spectrum analyzer for about $150 that works with a low-cost oscilloscope. The analyzer can be used to check HF transmitting equipment, among other applications. Its use, theory of operation, and construction are discussed in this article.

Spectrum Analyzer Operation

A spectrum analyzer is a special receiver that allows you to view the frequency components of its input signal on an oscilloscope CRT. The spectrum analyzer repeatedly tunes across the frequency band you have chosen with its center-frequency and frequency-span controls. For example, if you set the center-frequency control for 20 MHz and adjust the frequency-span control for a tuning range from 10 MHz below to 10 MHz above the center frequency, the analyzer will repeatedly tune the 10-MHz-to-30-MHz band.

Photo A. High frequency spectrum analyzer covers 0 to 60 MHz.

As the analyzer tunes from the low end to the high end of the band, it moves the CRT trace from left to right. The S-meter output from the analyzer moves the CRT trace upward from the bottom of the CRT screen according to signal strength. A spectrum analyzer display usually looks like a number of spikes. The farther to the right a signal (spike) appears on the CRT, the higher its frequency; the strength of the signal is indicated by its height. There usually appears to be some "grass" along the bottom of the CRT display. This is due to noise. You probably have seen spectrum analyzer displays in ham gear sales literature and some magazine articles.

To appreciate how useful a spectrum analyzer can be, let's first look at Photo B, an rf signal on a normal oscilloscope. To me it looks like a clean sine wave. What do you think?

Now let's look at Photo C, the same rf signal on our spectrum analyzer. The half-spike on the left is our zero-frequency reference. The next signal to the right, which is the tallest, is the fundamental component of our rf signal. The three signals to the right of the fundamental are the 2nd, 3rd, and 4th harmonics.

If the spectrum of our transceiver or linear amplifier output looked the same as this photo, we would not be complying with FCC Regulation 97.73, even though our fundamental signal was properly within an HF amateur band.

To understand what's wrong, compare the height of the 2nd harmonic signal to the fundamental. The second harmonic is about 2.6 CRT divisions shorter than the fundamental. With a 10-dB-per-division vertical calibration, the second harmonic is 26 dB below the fundamental.

FCC Regulation 97.73 re-

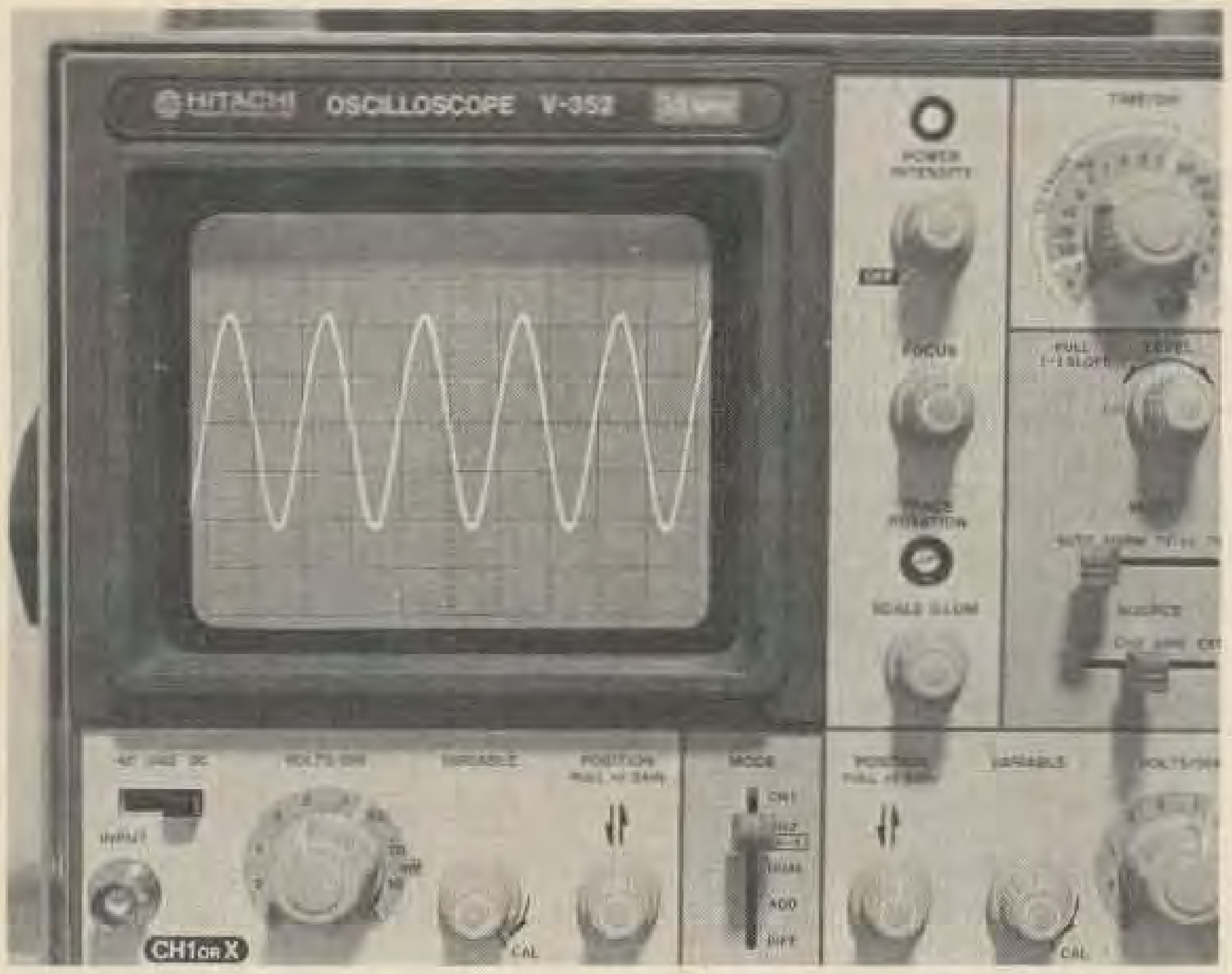


Photo B. Rf signal as viewed on an ordinary oscilloscope. Is this a clean signal?

Photo C. Same rf signal on the spectrum analyzer. Second harmonic is only 26 dB below the fundamental. Don't put this signal on the air!

quires low-power transmitters up to 5 Watts to suppress all signal frequency components (spurs) outside the HF band of operation at least 30 dB below the fundamental. For a transmitter from 5 to 500 Watts, this figure is 40 dB. For a 1000-Watt transmitter or linear amplifier, the figure is 43 dB. Checking our photo again, we notice that the 3rd harmonic signal is about 39 dB below the fundamental. We're also going to have a problem with the 3rd harmonic if we are running 5 Watts or more power. The 4th harmonic is no problem since it's about 55 dB below the fundamental.

We can correct the problem by adding a filter between our transceiver or linear and the antenna. However, unless we are able to check the output spectrum of our transmitting equipment, we may never know we have a problem—until our neighbors start complaining or we get a "friendly advisory" from the local FCC monitoring station.

There are many uses for a spectrum analyzer besides monitoring transmitter outputs, but this use alone can make an HF spectrum analyzer construction project worthwhile. If you build one, you'll probably be the first on your block (or in your favorite net or club) to have one of your own!

Spectrum Analyzer Hookup

Fig. 1 shows how to hook up the high frequency spectrum analyzer for monitoring the output spectrum of a transmitter or linear amplifier. Remember, the analyzer is a receiver. It requires a very small sample of power for operation. This is done with an L-pad sampler. The sampler will not interfere with normal transmitting or transceiving operation. The output from the L-pad is further reduced with a step attenuator to match the full-scale input-power requirements of the analyzer (1/4 to 1/10 of a milliwatt). The spectrum is displayed on the oscilloscope being used with the spectrum analyzer.

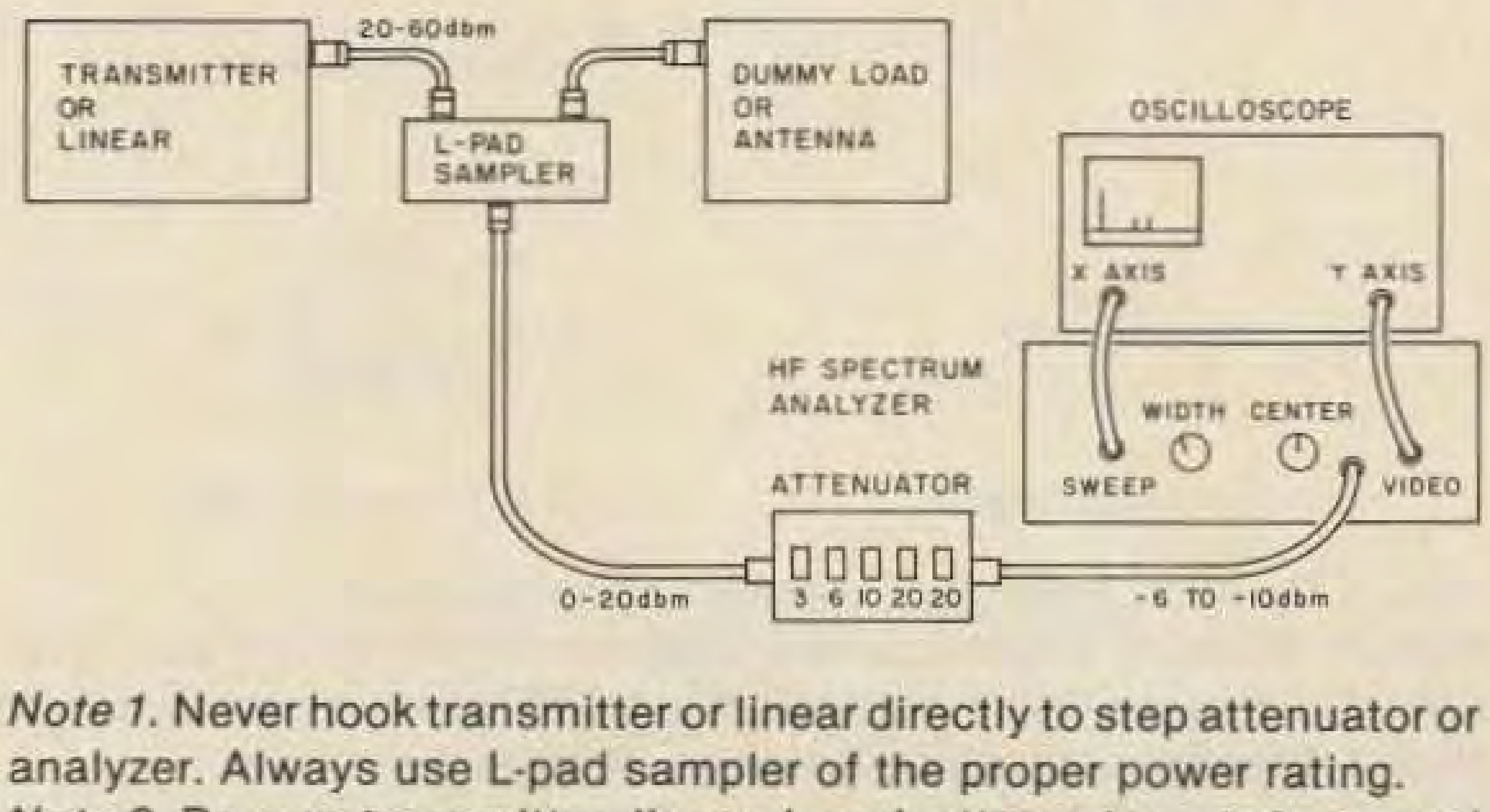
It is important to observe good safety practices when using the L-pad, attenuator, and spectrum analyzer. Be sure all station equipment, the L-pad, attenuator, analyzer, and oscilloscope cases are properly grounded. Use the proper L-pad for your power range. Double-check your hookup before applying power. If the output of a transmitter was directly connected to the analyzer by accident, it would instantly be damaged when the transmitter was keyed.

Overall Circuit Operation

Let's first discuss Fig. 2, the spectrum analyzer block diagram. We will then look at the circuits in each block in detail. Notice that the analyzer block diagram looks similar to that of a single-conversion superheterodyne receiver. The i-f frequency of the spectrum analyzer is 90 MHz.

The sampled input signal from the L-pad is adjusted to the proper power level with the step attenuator, as we discussed before. The signal is then taken through a low-pass filter with a 60-MHz cutoff frequency. The low-pass filter prevents 90-MHz signals from leaking into the analyzer and "confusing" it. The input is next mixed with the 90-MHz to 150-MHz voltage-controlled oscillator (vco) in the double-balanced mixer. The difference output from the mixer, which is the desired i-f signal, is then filtered by the 90-MHz bandpass filter. The bandpass filter provides the necessary selectivity for the spectrum analyzer. The 90-MHz signal from the bandpass filter is preamplified and applied to the log amplifier. The output of the log amplifier is logarithmic signal strength video for the oscilloscope vertical (Y) axis.

The voltage-controlled oscillator frequency is controlled by the sweep generator, which simultaneously controls the horizontal (or X axis) of the oscilloscope. Note that when the vco is



Note 1. Never hook transmitter or linear directly to step attenuator or analyzer. Always use L-pad sampler of the proper power rating.
Note 2. Be sure transmitter, linear, L-pad, attenuator, analyzer, and scope are grounded.

Fig. 1. Typical HF spectrum analyzer hookup.

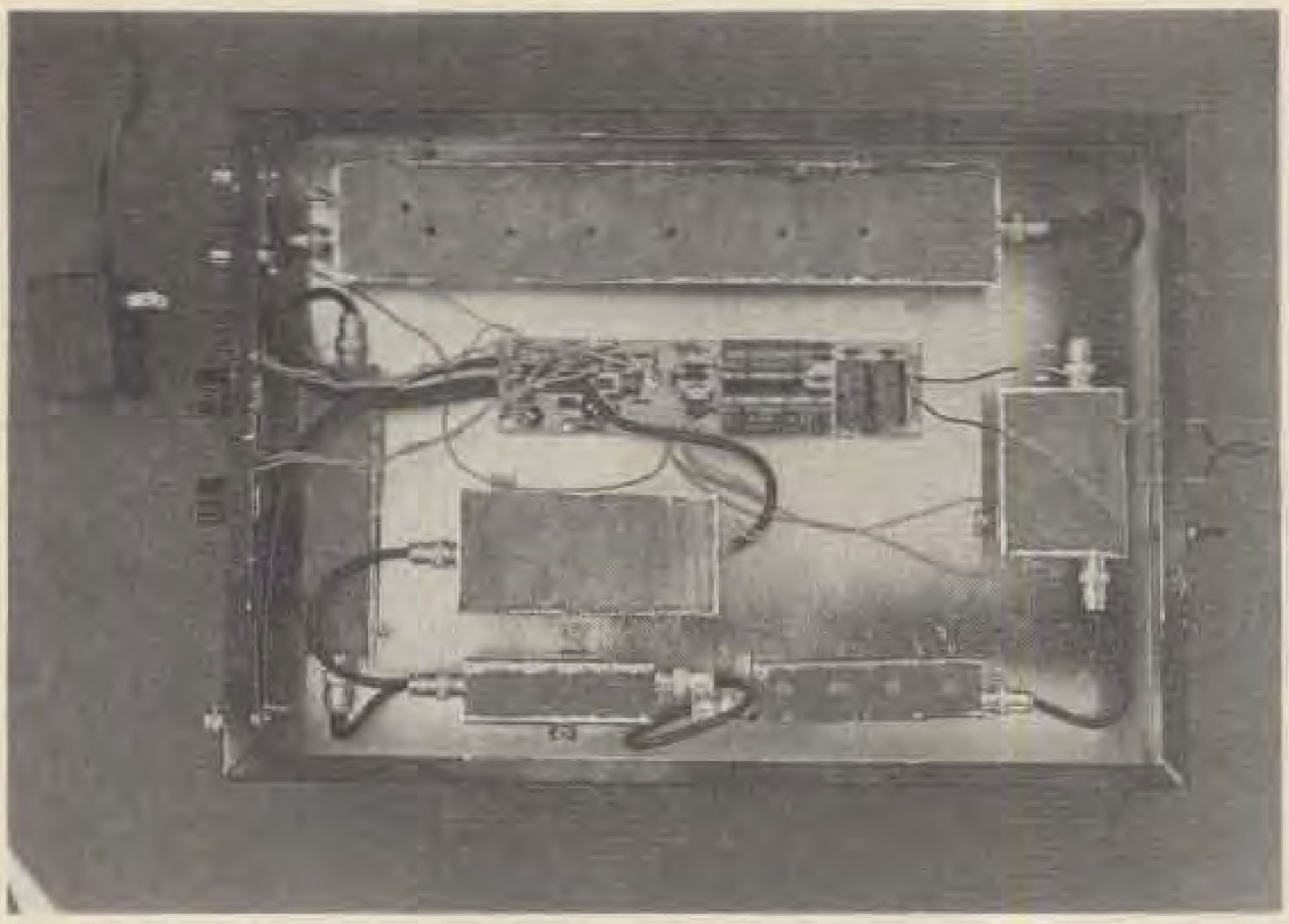


Photo D. Bottom view of spectrum analyzer chassis. Log amplifier is at the top. Power supply and sweep generator board is directly below the log amplifier. Vco is next. The mixer is directly below the vco. The mixer connects to the low-pass filter at the left. The bandpass filter is at the lower right. Preamplifier is on the middle right.

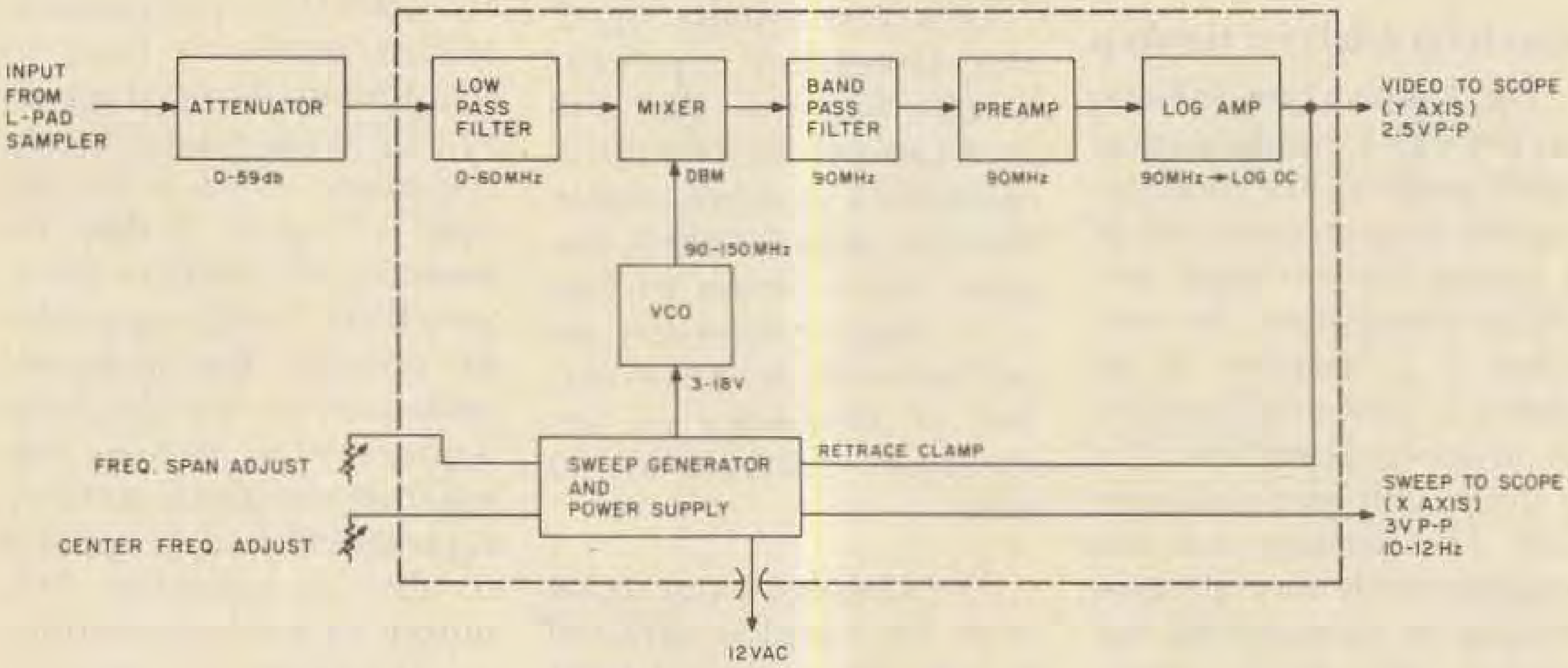
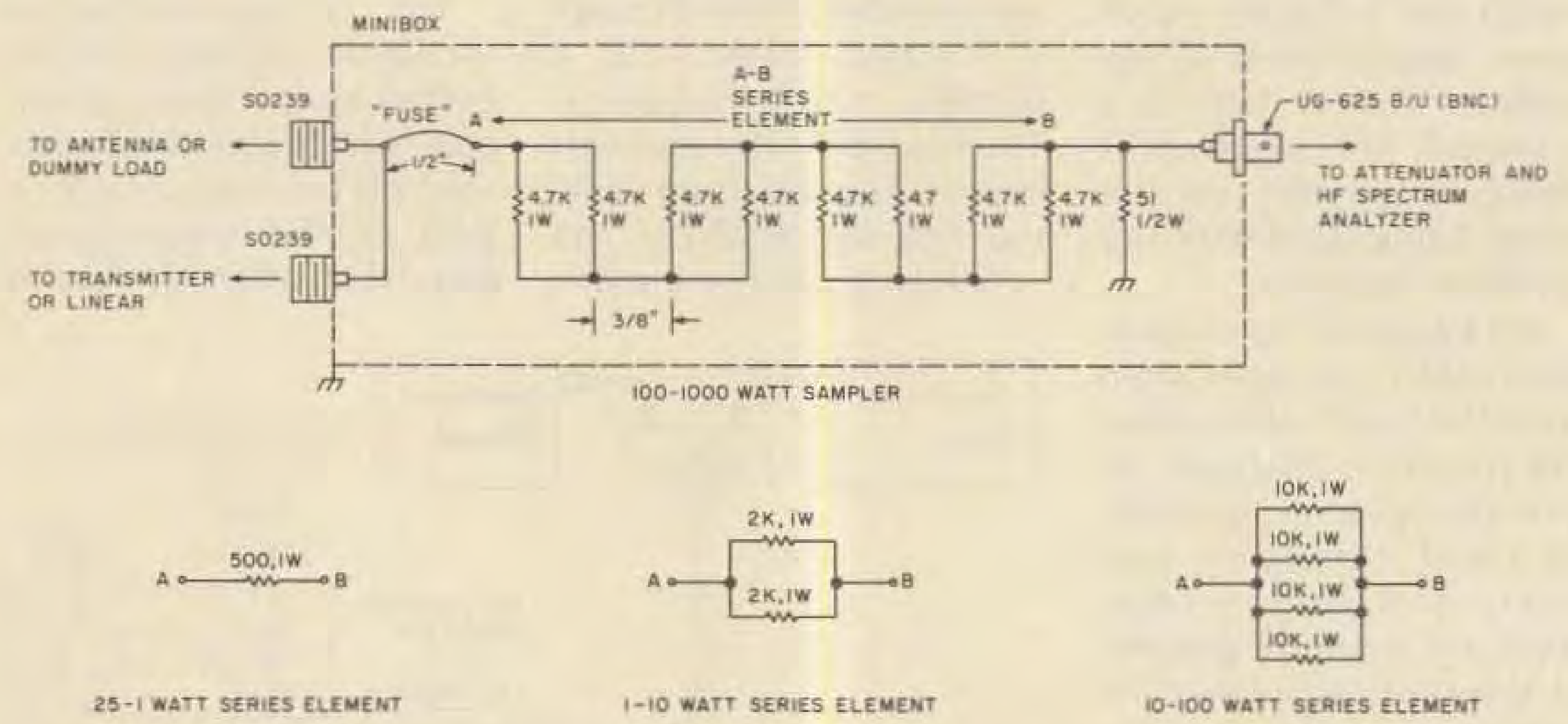


Fig. 2. Block diagram.



Note 1. Carbon composition (noninductive) resistors.
Note 2. "Fuse" is single, hair-thin copper strand from ac "zip" cord.
Note 3. Connect SO-239 connectors with RG-8 center conductor wire.
Note 4. Test-run sampler before connecting to attenuator.
Note 5. Keep BNC connector 3" away from SO-239s; space resistor sets 3/8" minimum; "fuse" is 1/2" to 3/4" long.

Fig. 3. L-pad power samplers.

tuned to 90 MHz, the analyzer is tuned to zero MHz. When the vco is tuned to 120 MHz, the analyzer is tuned to 30 MHz. With the vco at 150 MHz, the analyzer is tuned to 60 MHz.

The tuning range of the analyzer is adjusted with the center-frequency and frequency-span controls on the sweep generator. The sweep generator automatically tunes the analyzer across its tuning range about 10 times each second. The sweep generator clamps or "shorts out" the video during the retrace between each sweep to avoid a confusing oscilloscope display. This eliminates the need for an oscilloscope with a Z-axis (blanking) input. The power supply provides +24 V dc, +12 V dc, and −6 V dc for the spectrum analyzer circuitry. The power supply operates from 12 V ac supplied by a wallplug transformer.

L-Pad

Fig. 3 shows the schematic of a 100-to-1000-Watt L-pad sampler, with alternate circuitry for a 10-to-100-Watt sampler, a 1-to-10-Watt sampler, and a 0.25-to-1-Watt sampler. Four pairs of 4.7k, 1-Watt resistors form the series element of the 100-to-1000-Watt sampler. A 51-Ohm, 1/2-Watt resistor forms the shunt element. The L-pad resistors are rated for continuous operation. A single hair-thin strand from an old "zip" cord provides some fusing protection in the event of a component failure or circuit fault. The series elements for the other power ratings are shown in Fig. 3.

0-to-59-dB Step Attenuator

Fig. 4 shows the step attenuator schematic. Five pi-style resistive attenuators are switched in or out as necessary to achieve the proper attenuation. Switches are double-pole, double-throw. Resistors may be 1/2 Watt or 1/4 Watt, although 1/4-Watt resistors are easier to work with. Note the shielding between sections. Resistors must be 5% tolerance. (The resistor values for each attenuator came from Reference 1.)

Low-Pass Filter, Mixer, and Vco

Fig. 5 shows the details of these circuits. The low-pass filter consists of three pi-sections, separated by shielding. The cutoff frequency of the filter is about 60 MHz. Three sections are used to give a high attenuation at the 90-MHz i-f frequency and above.

Each port of the double-balanced mixer is padded with 50-Ohm attenuators to encourage good mixer performance (low mixer spurs) at the expense of extra conversion loss. Mini-Circuits SRA-1 and SBL-1 are good commercial mixers. It is quite possible to build a suitable double-balanced mixer from small ferrite toroids and hot carrier diodes, if you have trouble finding these commercial units. (Consult Reference 1 for details.)

The vco consists of an MRF901 Colpitts oscillator coupled to a wideband 2N5179 amplifier. The MRF901 was eventually chosen for the oscillator transistor because of its well-behaved phase-shift characteristics between 90 MHz and 150 MHz. The two MV109 hyper-abrupt Epicap diodes act as tuning capacitors and account for the oscillator's wide tuning range. A small pick-up loop near the oscillator coil provides an output for checking frequency and doing other tests. The oscillator is also lightly coupled to the 2N5179 vco amplifier. The output of this amplifier drives the local oscillator port of the mixer. A diode-capacitor rf detector provides a dc output for checking amplifier output power. The wideband amplifier design is based on data from Reference 1. The oscillator design is based on third-attempt desperation! Note the use of the feedthrough capacitors and shielding. These are as much a part of the circuit as the MRF901.

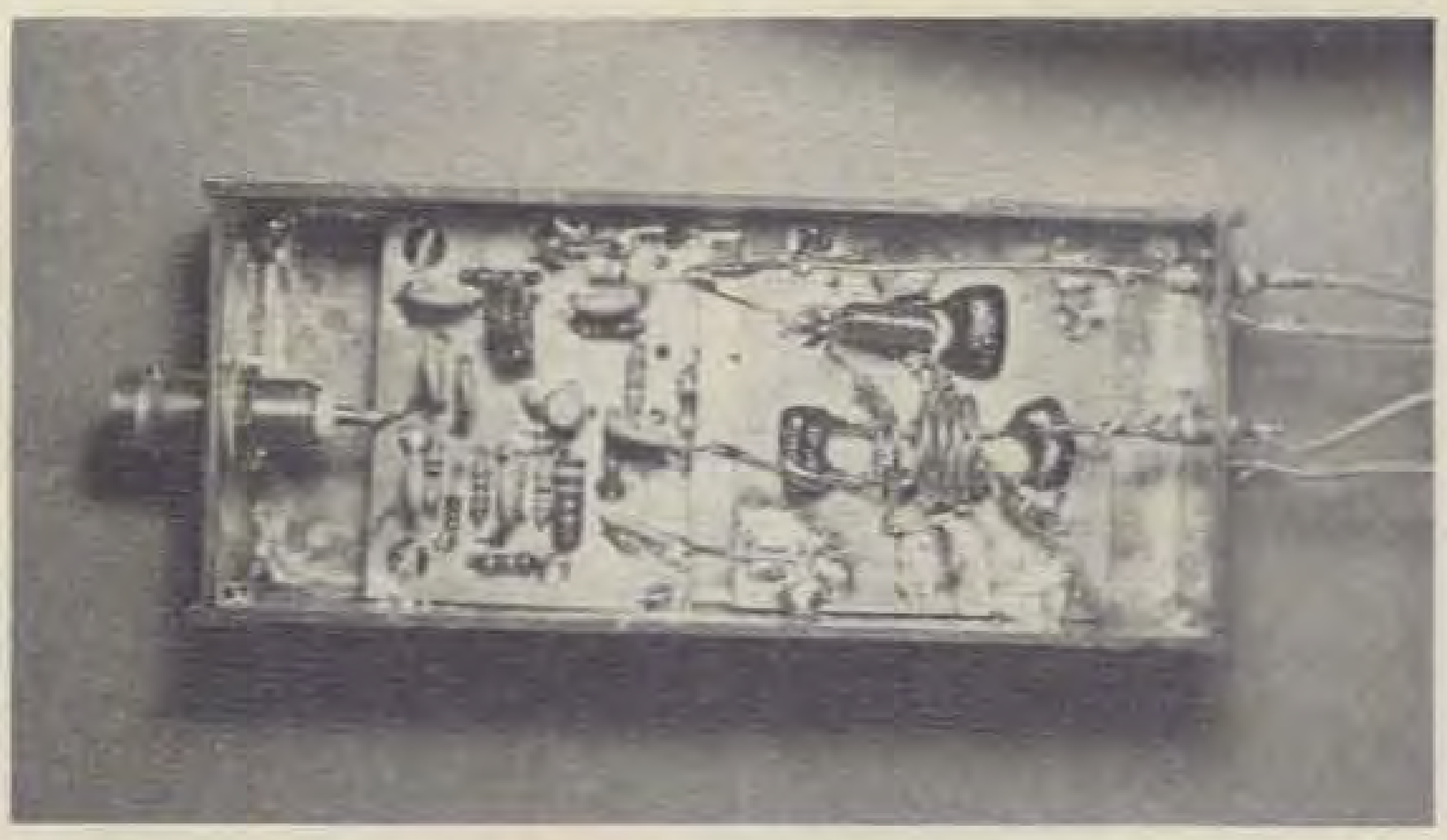
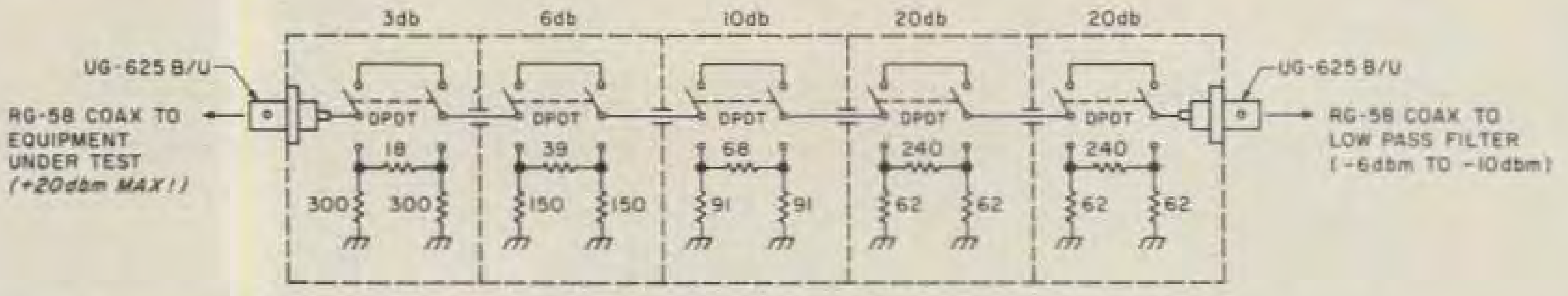


Photo E. Vco layout. Oscillator is near the feedthroughs.

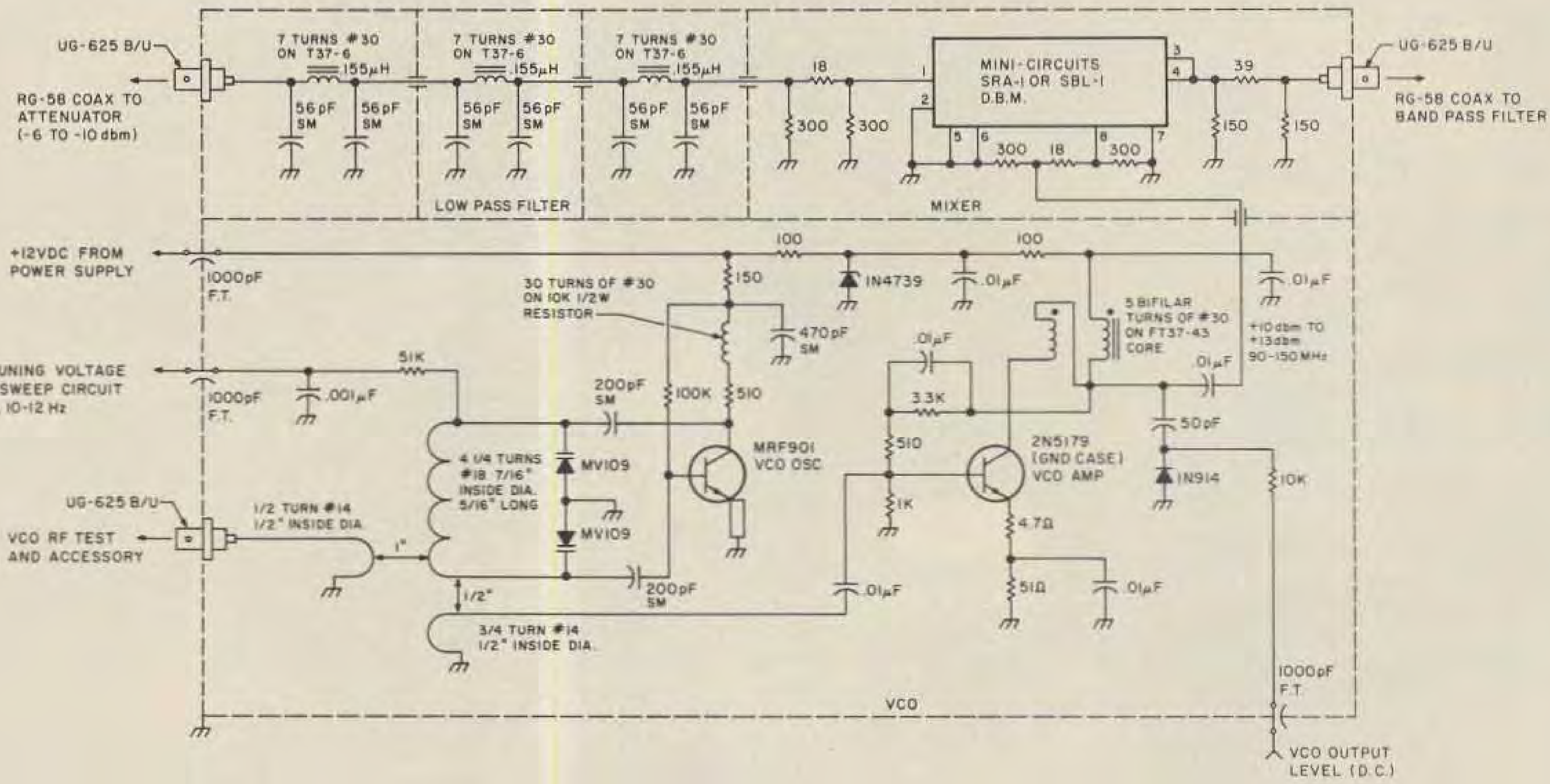
Bandpass Filter

The bandpass filter is detailed in Fig. 6. It consists of four relatively small helical resonators. The input and output resonators are tap-coupled to the input and output connectors. The four resonators are aperture-coupled to each other. The two center resonators are slightly stagger-tuned to give the filter bandpass a sharp "nose." The 3-dB



Note 1. DPDT toggle switch—Radio Shack 275-1546 or equivalent.
Note 2. BNC receptacle—Radio Shack 278-105 or Amphenol 31-236.
Note 3. Resistors 1/2 or 1/4 W, 5% noninductive.
Note 4. Attenuator box made from single- and double-sided G-10 circuit board plus copper shim stock.

Fig. 4. 0-59-dB step attenuator.



Note 1. Resistors are 1/4 W, 5%; unspecified capacitors are 50-V ceramic.
Note 2. Capacitors marked "SM" are ±5% silver mica.
Note 3. 1000-pF feedthrough capacitors available from Alaska Microwave.
Note 4. MV-209s or MV-309s may be substituted for MV-109s (contact Motorola distributor).
Note 5. Box built from single- and double-sided G-10 circuit board plus copper shim stock.

Fig. 5. Low-pass filter, mixer, and vco.

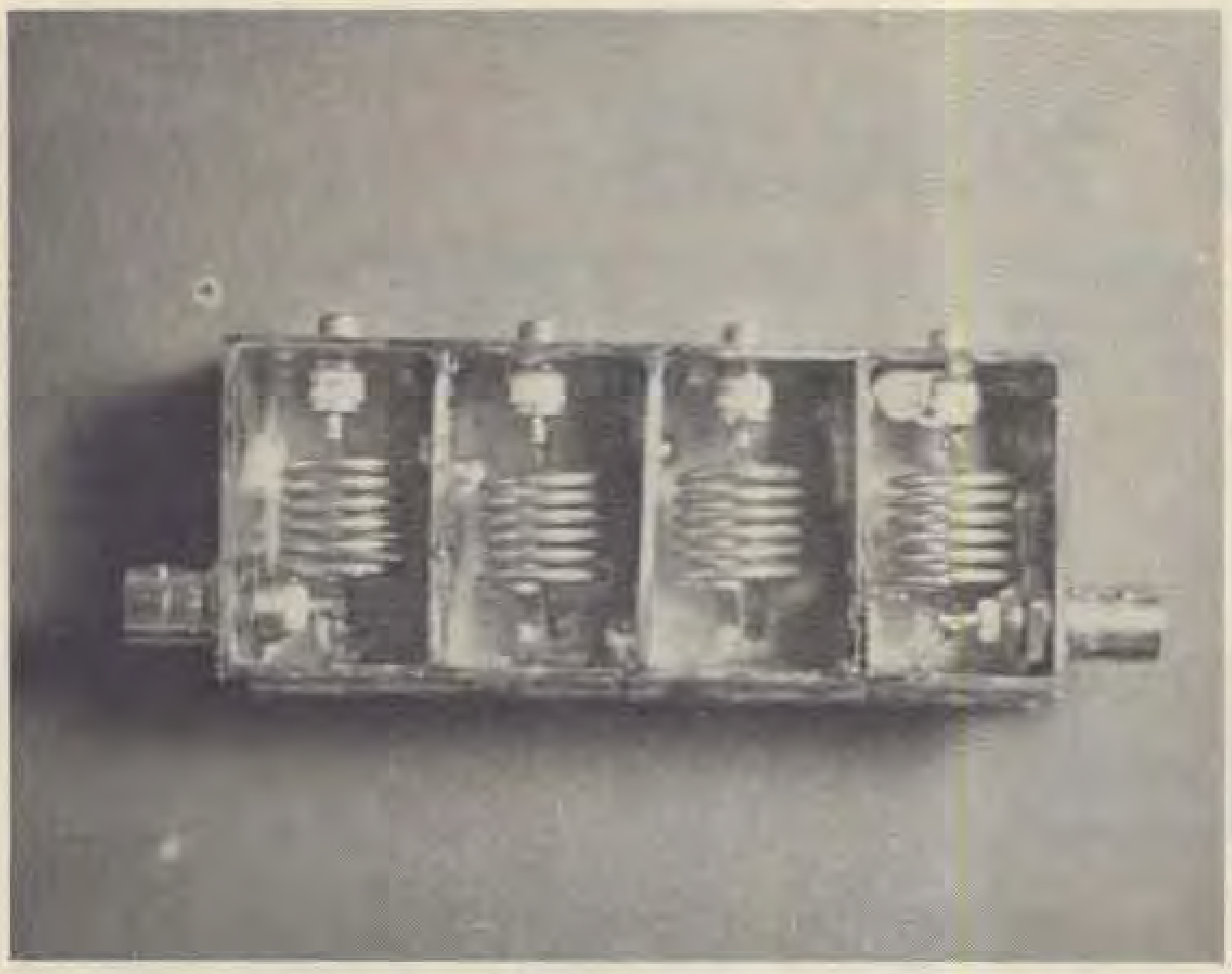


Photo F. Bandpass filter layout.

bandwidth of the filter is about 220 kHz. Insertion loss is somewhat high, but is acceptable for this application.

Preamplifier and Log Amplifier

The schematics of the preamplifier and log amplifier are shown in Fig. 7. The preamplifier consists of two wideband 2N5179 amplifiers. The log amplifier consists of six tuned 90-MHz i-f stages. Each stage uses the friendly 40673 dual-gate FET. The input stage acts as a buffer amplifier. The next five stages form the logarithmic signal-strength video detector. The log amplifier may remind you of an i-f strip in an FM receiver. In fact, it uses the limiter principle in its operation.

Notice that each stage in the log amplifier has an rf detector across its output consisting of a 50-pF capacitor, a 1N914 diode, and a 10k resistor. The rf detector on the buffer stage is just a tuning aid. The outputs of the rf detectors on the 1st through 5th log amp stages are tied to a common 1k resistor (in parallel with a 150-pF capacitor). Because of its relatively low value, the detector outputs are more or less summed across the 1k resistor.

A small input signal is amplified by all five log amp stages. Only the 5th stage will develop enough signal to provide an output from its detector. As the input signal is made larger, the 4th stage detector also will begin contributing to the output. As the output is made still larger, the 5th stage will saturate or limit. From this point it will contribute no additional voltage across the 1k output resistor. At about this same signal level, the 3rd log amp stage will begin to contribute some output, and so on. Each log amp stage provides a gain of about 12 dB until it saturates. The gain of the i-f strip, from the 1k resistor's point of view, then drops 12 dB. It is this successive limiting and dropping off of i-f stages that creates the logarithmic video output characteristic. Note that when the 1st log amp stage saturates, the log amplifier reaches its full-scale output.

I was surprised how accurately the logarithmic amplifier does track a logarithmic curve. Using my commercial step attenuator as a reference, the calibration of my logarithmic amplifier was within 1 dB. The sensitive i-f system must be shielded to prevent interference from commercial FM stations.

Power Supply and Sweep Generator Circuits

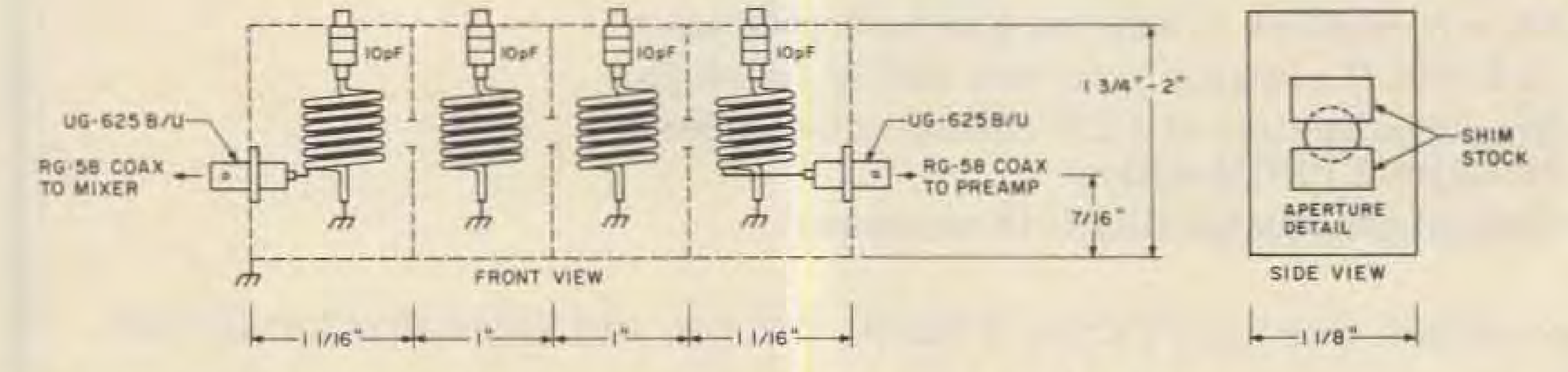
These circuits are shown in Fig. 8. The power supply is straightforward, providing +12 V dc, +24 V dc, and −6 V dc. Note the feedthrough capacitors used to filter out any rf picked up by the 12-V-ac power leads.

The heart of the sweep generator is the 555 IC timer. The two 2N2907s act as current sources. Each generates linear ramp voltages across 10-uF tantalum capacitors. The 555 synchronizes the ramps. The ramps are set at a 10-Hz-to-12-Hz repetition rate. One ramp is fed through a dc-restoring capacitor-diode clamp to the output connector for the oscilloscope horizontal (X) axis. The second ramp is fed to the 5k frequency-span potentiometer through an inverting operational amplifier buffer. The output from the frequency-span pot is summed with the output of the 5k center-frequency pot in the vco-tuning voltage amplifier. The output of this amplifier is fed to the vco-tuning voltage input.

When the ramps are reset by the 555, pin 3 of the 555 also trips the retrace VMOS clamp transistor through the retrace comparator amplifier. This shorts the logarithmic amplifier video output to ground during retrace. Otherwise, the video is fed to the output connector for the oscilloscope vertical (Y) axis. The 4th amplifier in the TL084C quad-operational-amplifier IC is used simply as a 6-V-dc reference by the other three amplifiers.

Shielded Enclosure Construction

All circuits in the high frequency spectrum analyzer except the sweep generator and the power supply must be installed in shielded enclosures. I built each enclosure for my analyzer using 1/16-inch, G-10 epoxy circuit board stock. Enclosure base plates are made from single-sided or double-sided stock. Double-sided stock must be used for the enclosure sides, ends, and partitions. (See Fig. 9 for construction details.)



Note 1. Coils are 6 turns of #12, 1/2" inside diameter, 5/8" long, taps at 1/4 turn.
Note 2. 10-pF piston trimmer, Sprague-Goodman GGP8R500 or equivalent; alternate, air-variable, Johnson 189-564-1.
Note 3. Filter box made from single- and double-sided G-10 circuit board plus copper shim stock.
Note 4. Filter box is 1-1/8" deep.
Note 5. Mount BNC connectors near front side.
Note 6. Coupling apertures are 3/8" × 3/16". Drill 3/8"-diameter holes in compartment wall pieces and then solder copper shim strips across tops and bottoms to narrow apertures.

Fig. 6. Bandpass filter.

Note the brass "cap strips." These provide a base for soldering on the thin copper (shim stock) enclosure tops. I use this method for mounting the tops so that they can be peeled back easily when I need to modify or repair circuitry. Use a 40-Watt soldering iron for soldering the enclosures together. Solder the tops on with a 25-Watt iron. Be sure the solder seams have no gaps.

Don't let the need for shielded enclosures discourage you. There are several easy, accurate ways to cut circuit board material. Beg, borrow, or buy a copy of *Printed Circuits Handbook* (Reference 4). This book does a good job of showing how to cut circuit board stock. Alternatively, make friends with a ham who owns or works at a commercial circuit board shop! Anyway, making shielded enclosures is easier than it first appears.

My original analyzer used quite a few BNC connectors. The number of connectors can be reduced by building the low-pass filter, mixer, and vco enclosures together on one base plate. Look at the schematic, Fig. 5, for shield partitioning details. Likewise, the preamplifier and log amplifier enclosures can be built together (Fig. 7). The bandpass filter should be built by itself, as should the attenuator. This arrangement allows the analyzer to be tuned up with very little test equipment.

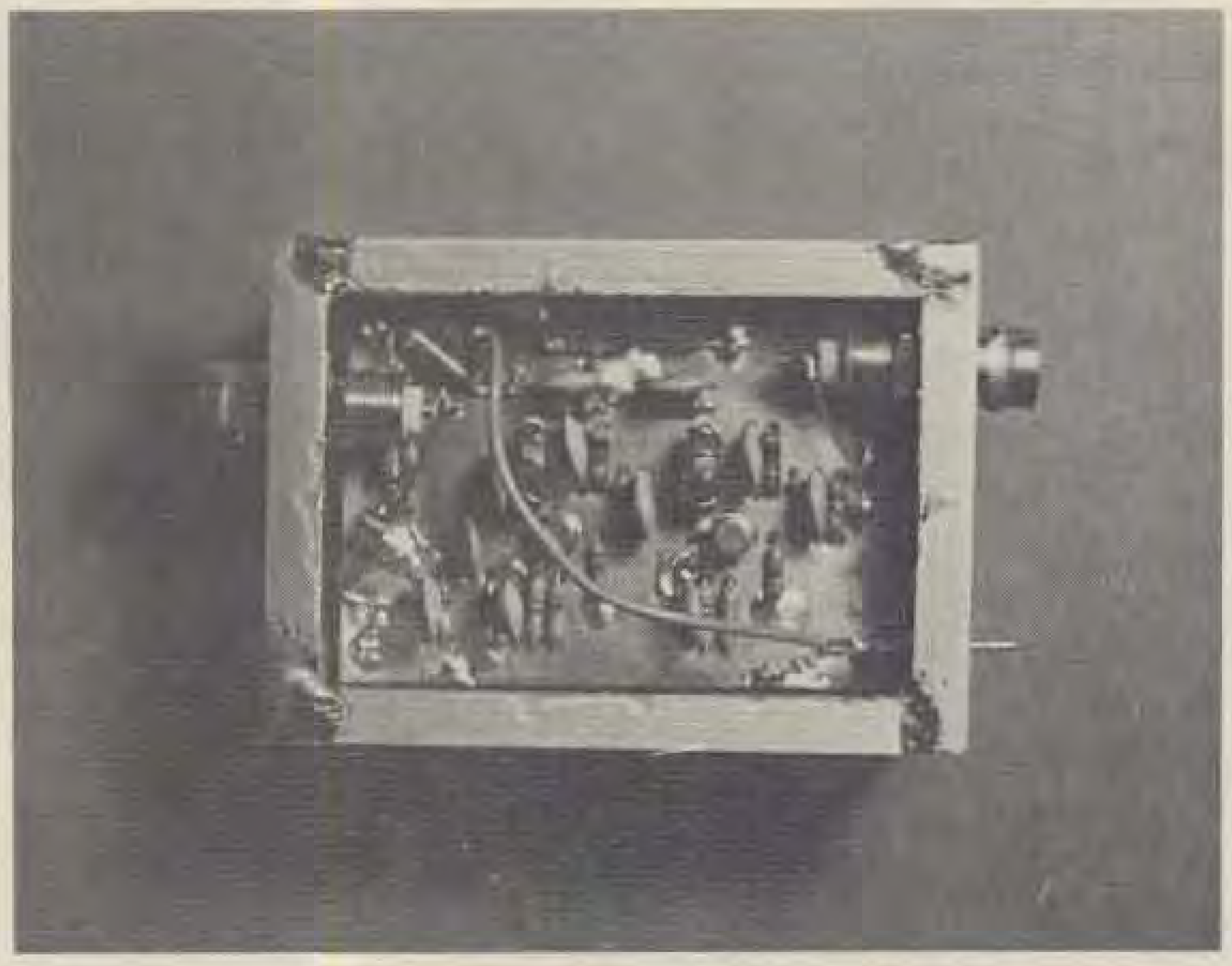


Photo G. Preamplifier layout. Note that the brass "cap strips" have been installed.

Circuit Board Layout and Construction

There are a lot of possible component substitutions for the spectrum analyzer. Some of the components you use in your analyzer will no doubt be different from the ones I used—at least in physical size. This makes standard circuit boards impractical. It is easy to lay out your circuitry for construction on single-sided circuit board stock. The copper is on the top side. It acts as a ground plane and helps stabilize the circuitry. All analyzer circuitry built in this manner was built on 1.8-inch-wide circuit board strips—lengths as needed. The low-pass filter, bandpass filter, and attenuator are built "in the air" inside their shielded enclosures. They don't need a circuit board.

Get some drafting vellum with a light blue, 1/10-inch grid on it. After you have all the parts for a circuit, you can begin developing its circuit board layout. After mulling over the schematic, lay the actual components on the grid paper and think through their interconnections. Juggle them as needed into a neat arrangement. Remember that all ground connections are going to be made on the top.

After you have the layout and interconnections visualized in an area, pick up each component and sketch in its outline on the vellum. Show its connection to other components (under the board) with dotted lines. You will be surprised how fast this goes. Remember to keep the input and output components of each rf stage separated. This is aided by using circuit board strips. Check the photos of my layout for ideas (minor circuit changes were made after some of the photos).

Once the layout is complete, tape it to your circuit board blank. Drill through the layout into the circuit board each place where a component or wire lead goes through the board. Use a #55 drill bit. After all holes are drilled, lightly countersink with a 1/8-inch drill bit all holes that are not going to be a ground connection. This keeps the leads going through these holes from shorting to the ground plane. Drill 1/8-inch holes in each corner of the board. 4-40 × 1/2-inch screws are put in these holes to act as legs for the board. Begin installing components. They are interconnected under the board by their leads and/or bus wire. Remember to keep connections as short as possible.

The vco oscillator circuit is built totally on top of the circuit board ground plane so that leads can be very short. Follow the layout in the photo carefully. The vco amplifier is built in the normal way.

I used brass tubes (bought at a hobby shop) for coil-winding mandrels. Where wiring goes through a partition on the schematics, use a 1/8-inch hole drilled in the partition wall.

After you double-check your wiring, install the circuit boards in their shielded enclosures. Tack-solder the ground plane of the circuit to one side of the enclosure. Do not install the tops of the enclosures yet—we have testing to do!

Because of the power involved, build the L-pad sampler carefully. The circuit board used to mount the resistors has no copper on either side except at the corner on the far side of the SO-239 connectors. This small piece of ground plane is covered with masking tape before the copper is etched with ferric chloride. The 51-Ohm resistor is grounded here. A ground wire is then taken from here to a lug at the BNC connector (make the lug from copper shim stock).

Mount the board using 4-40 × 3/4-inch screws. Use 5/16-inch-diameter × 1/2-inch-long aluminum tubing slipped over each 4-40 screw to stand the circuit board off. Be sure the resistor pairs are separated from each other by 3/8 of an inch. The physical layout of the resistors should look like the schematic in Fig. 3. The "fuse" wire, which is a single, hair-thin strand of copper wire from an old "zip" cord, must be at least 1/2 inch long. The L-pad is built in a medium-size minibox.

I mounted the shielded enclosures and the sweep generator/power-supply board in a 3-inch-high × 12-inch-wide × 18-inch-deep aluminum chassis. (Refer to Photo D for typical mounting.) Individual circuits are tested before final mounting and installation of the enclosure tops.

Testing and Alignment

The minimum test equipment needed to align and test the HF spectrum ana-

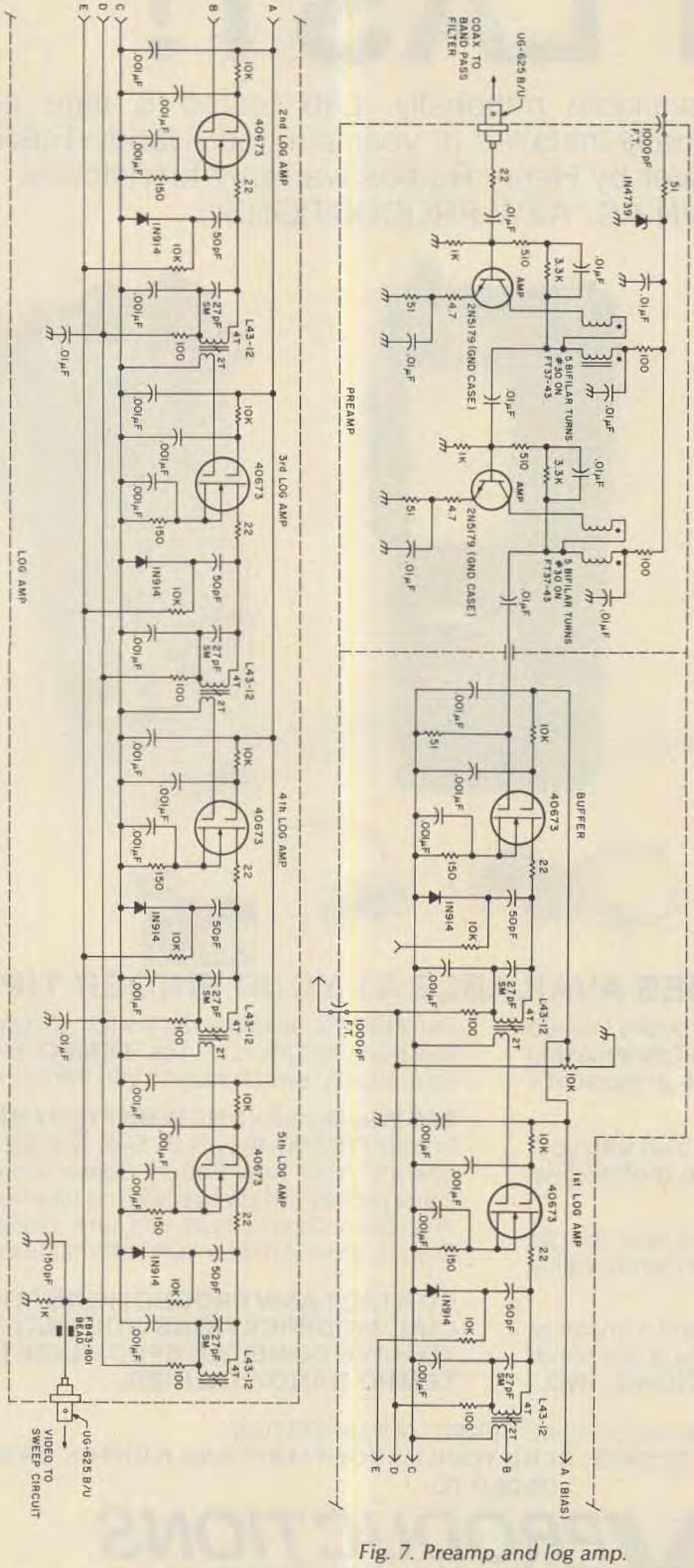


Fig. 7. Preamp and log amp.

Note 1. Resistors are 1/4 W, 5%; unspecified capacitors are 50-V ceramic.
Note 2. Capacitors marked "SM" are ± 5% silver mica.
Note 3. L43-12 rf transformers and FT37-43 toroids are available from Amidon.
Note 4. Shielded box made from single- and double-sided G-10 circuit board plus copper shim stock.

lyzer includes a high-impedance volt ohmmeter, a 350-MHz frequency counter, and a 5-MHz bandwidth, single-channel, dc-coupled oscilloscope with a triggered sweep. A grid-dip oscillator also is useful. You should make up several 2-foot RG-58 cables with BNC connectors. These will be used during testing. For best results, testing and alignment should be done in the order listed below.

Power Supply Testing. Check the resistance between the primary and secondary of the wallplug transformer before use. It should show an open circuit. Check the secondary ac voltage. It should be 12 V ac to 15 V ac with no load. Hook the 12 V ac to the power supply and check the 12 V dc, 24 V dc, and −6 V dc outputs. They should be within 1/2 volt.

Sweep Generator Testing. Connect the power supply to the sweep generator and turn the power supply on. Check pin 2 of the 555 IC with your oscilloscope. You should find a 10-Hz-to-12-Hz ramp waveform. The bottom of the waveform should be at 4 volts and the top of the waveform at 8 volts. The front of the ramp (long slope) should appear straight. You should find a similar ramp at the X-axis output connector. This ramp will be between −0.6 volts and 3.4 volts.

Check pin 8 of the TL084C op amp. You should find a pulse train with a 10-Hz-to-12-Hz repetition rate. The pulse train should be high (20 volts) about 20% of the time and low (−3 volts) about 80% of the time.

Turn the frequency-span pot fully clockwise (no ramp) and set the center-frequency pot mid-range. You should find 6 V dc to 12 V dc on pin seven of the TL084C op amp (vco-tuning voltage). Vary the setting of the center-frequency pot. The vco-tuning voltage should vary from −3 volts to 21 volts. Set the center-frequency pot for a 10-volt output. Turn the frequency-span pot counterclockwise until you have a ramp waveform from 2 volts to 20 volts (readjust the center-frequency pot as needed). This completes preliminary sweep generator testing.

If your sweep generator fails to act as above, recheck component values and circuit hookup for problems. Refer to the theory of operation for additional hints.

Vco Testing. Connect the vco-tuning voltage from the sweep generator to the vco. Ground the RG-58 shield at the vco enclosure. Connect 12 V dc from the power supply to the vco power input. Disconnect one side of the oscillator coil for a moment. Power up and check the MRF901 collector voltage. It should be about 6 V dc to 8 V dc. If it is too high, reduce the value of the 100k bias resistor. If it is too low, increase the value of the bias resistor. You can't use a pot here! Once the collector voltage is verified, power down and reconnect the coil.

Power up and connect your counter to the vco rf test jack. Turn the frequency-span pot fully clockwise (no ramp) and adjust the center-frequency pot for a 3-volt output. Your counter should read about 90 MHz. Adjust the vco coil spacing to get the vco in the 89.5-MHz-to-90.5-MHz range. Check the dc output from the rf detector of the vco amplifier output for a 0.8-V-dc-to-1.3-V-dc level. Adjust the spacing between the vco coil and the amplifier pick-up loop, if necessary, to obtain the proper detector output.

Photo H. Log amplifier layout. Note strip design.

Set the center-frequency pot for a 150-MHz oscillator output. You should have a tuning voltage of about 18 V dc. Check the rf-detector output voltage again to be sure it's still between 0.8 V dc and 1.3 V dc. Monitoring the dc voltage from the rf detector with your scope, tune the center-frequency pot back and forth between 3 volts and 18 volts. The detector output voltage may smoothly vary some but should not "jump." An abrupt voltage change indicates a parasitic oscillation. If this should occur, work with your oscillator layout (very short leads) to get rid of it.

A tuning voltage of less than 1 V dc may cause the oscillator output to be erratic in frequency and amplitude. This is not a problem. Once the vco oscillator and amplifier are operating properly, install the vco enclosure top.

Preamplifier and Log Amplifier Testing. Connect 12 V dc to the preamplifier and log amplifier circuits and power up. Turn the frequency-span pot fully clockwise (ramp off) and adjust the center-frequency pot for 90 MHz at the vco rf test jack. Disconnect the frequency counter. Hook the attenuator box to the vco rf test jack with a two-foot RG-58 cable. Hook the output of the attenuator to the input of the preamplifier with another two-foot cable.

Set the bias pot on the log amplifier about mid-range. Monitor the dc output of the rf detector on the log amplifier buffer. Tune the buffer transformer slug for peak output. Use the attenuator to set the detector output to 0.2 V dc. Now adjust the bias pot of the log amplifier for peak output. Adjust the attenuator for a just-detectable output at the log amplifier buffer. If all seems well with the preamplifier, install the top on its enclosure. Prepare the top for the log amplifier section. Drill 1/8-inch-diameter holes in the top over each i-f transformer location and over the bias pot. (Use drafting vellum as a template.)

Hook the oscilloscope to the video output of the log amplifier. Adjust the slugs in each log amplifier stage for peak video output. The tuning of each stage should be smooth, and the tuning of the bias pot should also be smooth. If the video output from the log amplifier jumps suddenly while tuning, you may have a self-oscillation in the log amplifier. If this happens, carefully work with your layout. Ferrite beads, extra bypass capacitors, and small copper shim stock shields can be used to eliminate the problem. My i-f strip was quite stable, so I do not think you will have a problem.

If you live near a commercial FM station, it may interfere with your tuning efforts. Tape the shield top on the log amplifier during initial tuning to help eliminate this problem. As soon as it appears that the log amplifier is working, solder on the top. Once the top is soldered on, it will totally eliminate the interference.

Bandpass Filter Tuning

Set the vco to 90 MHz. Hook the attenuator between the vco rf test jack and the bandpass filter input. Hook the bandpass filter output to the preamplifier and log amplifier. Monitor the video output of the log amplifier on your oscilloscope. With the tops off the bandpass sections, you should get some signal. If not, temporarily bridge the input and output sections with a 1-pF capacitor tack-soldered at the input and output tap points. Tune the input and output stages for peak response. Remove the 1-pF capacitor if used. Now peak the two middle stages. You probably will get an overcoupled response (double-hump). Just center the tuning between the humps.

Now install the shield tops, one at a time. Tune all bandpass stages after each top is installed. Tuning will become very sharp, especially if you are using air-variable tuning capacitors instead of piston trimmers. When the last top is installed, carefully peak all stages.

Set up your oscilloscope for X-Y operation, using the X-axis output of the sweep generator for the oscilloscope horizontal input and the log amplifier video output for the vertical input. Gradually turn the frequency-span control counterclockwise until you get a sweep display of the filter

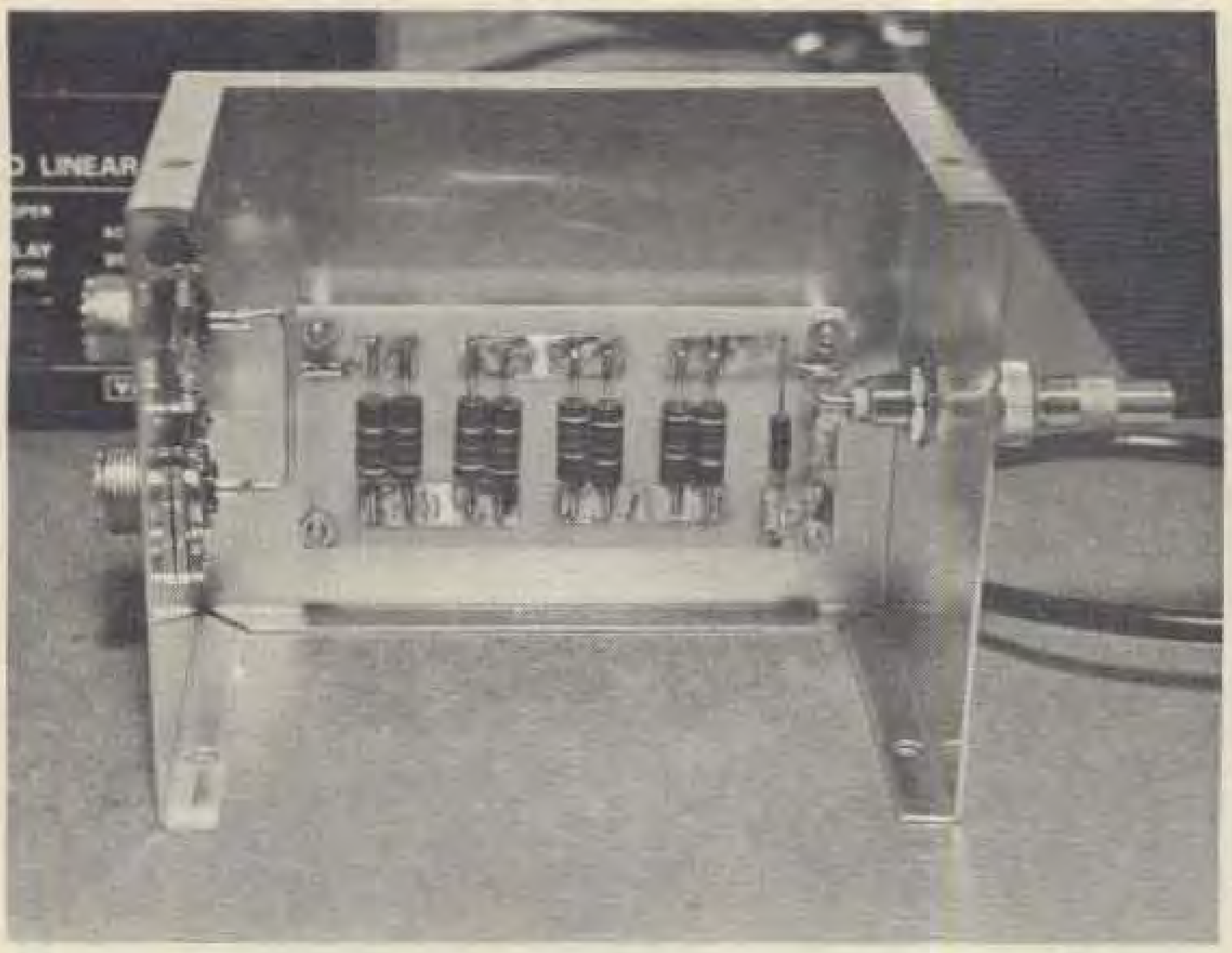


Photo I. L-pad sampler.

bandpass. Make fine adjustments for a smooth bandpass shape. Stagger-tune the two middle bandpass filter sections just a bit to sharpen the nose of the filter. Be sure to put in enough attenuation to keep the video output from the log amplifier under two volts during the bandpass filter tuning procedure.

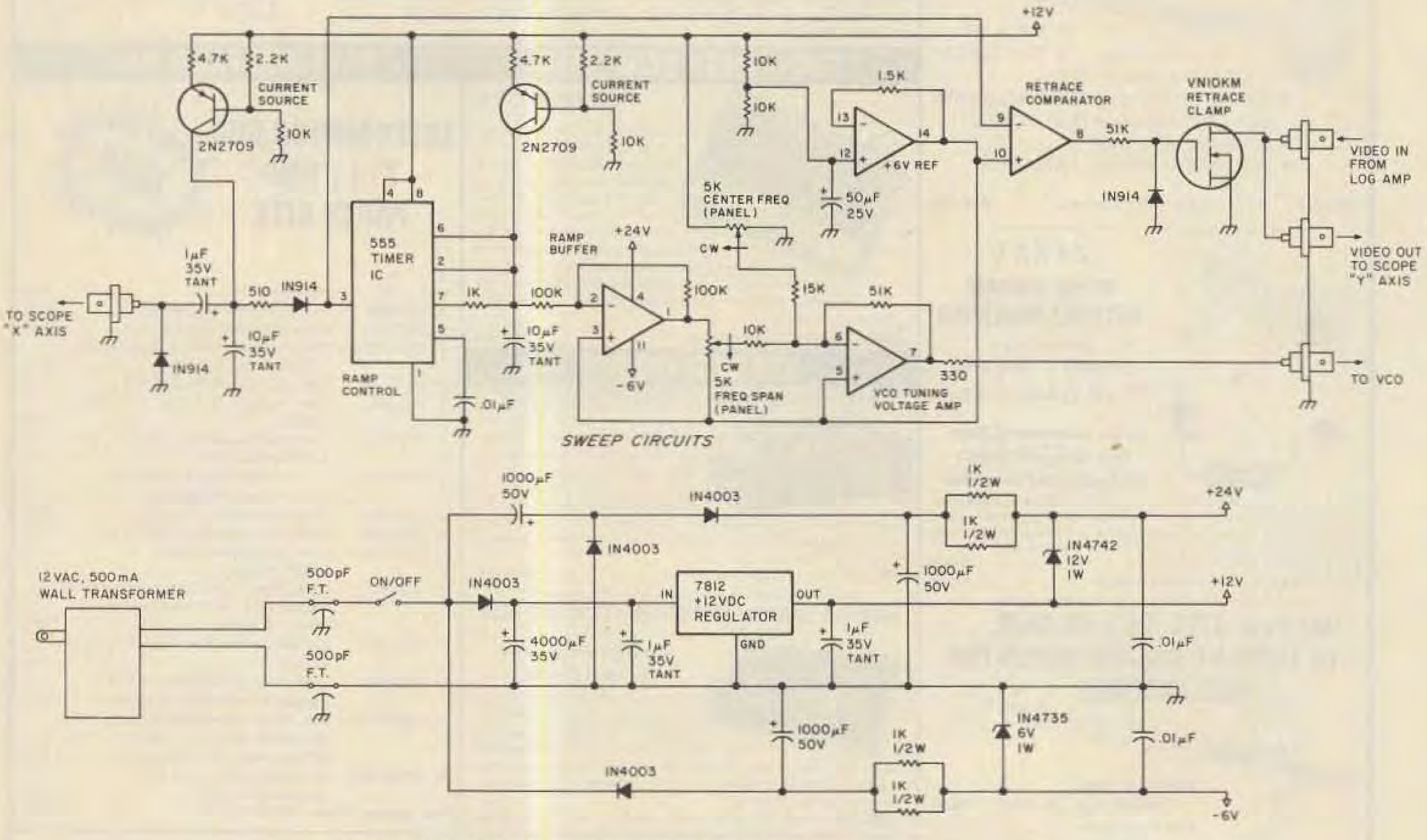
If it seems that you have an over-coupled response in your filter, narrow the aperture between the two middle bandpass filter sections. If the filter tunes sharply but exhibits high loss, then widen the aperture between the two middle sections.

Final Setup

Install all circuitry in your chassis and complete all wiring and coaxial cable hookup. Set the analyzer upside down in front of your scope. Connect your oscilloscope to the analyzer X- and Y-axis outputs. Set up the oscilloscope again for X-Y operation. Turn the analyzer on (no signal). Turn the frequency-span pot fully clockwise (no ramp). Using your frequency counter at the vco rf test jack, set the vco for 90 MHz operation with the center-frequency pot. You should see two horizontal lines about 2 volts apart. Rotate the frequency-span pot counterclockwise a little. You should see the bandpass-filter response again. This is due to mixer leak-through and is normal.

Set the retrace line (lower straight line) under the bandpass response curve at the bottom of the CRT screen. Widen the trace with the oscilloscope controls to reach across the screen. Turn the frequency-span pot fully clockwise again. Set the vco frequency to 120 MHz. Now turn the span pot counterclockwise until the zero-frequency half-spike appears on the left side of the screen. There should also be some grass above the retrace line along the bottom on the screen. The analyzer should now be scanning 0 to 60 MHz.

Feed a small 30-MHz signal from a grid-dip oscillator (use a pick-up loop as shown in Photo J) or a low-power-signal generator to the analyzer through the attenuator. You should now see the 30-MHz signal spike about mid-screen. You may also see the 2nd harmonic of the 30-MHz signal on the right edge of the screen. Adjust the attenuator so that the 30-MHz signal is about



Note 1. Wall transformer available from Jameco.
Note 2. Other devices available from Radio Shack.
Note 3. TL084C is quad op amp.
Note 4. 500-pF threaded feedthroughs available from Alaska Microwave.

Fig. 8. Power supply and sweep circuits.

the same height as the zero-frequency half-spike. If things have gone well so far, you are getting a signal through the low-pass filter and mixer, so you can now install their enclosure tops.

Set the frequency-span control so that the 30-MHz signal spike is about two scope divisions wide. Now fine-tune the bandpass filter again and re-peak the log amplifier. Switch the 10-dB attenuator section in and out while adjusting the vertical gain of the oscilloscope so that the signal height changes one CRT division. Now switch a 20-dB section in and out. Signal height should change two CRT divisions. Readjust the frequency span control for a 0-to-60-MHz analyzer tuning range.

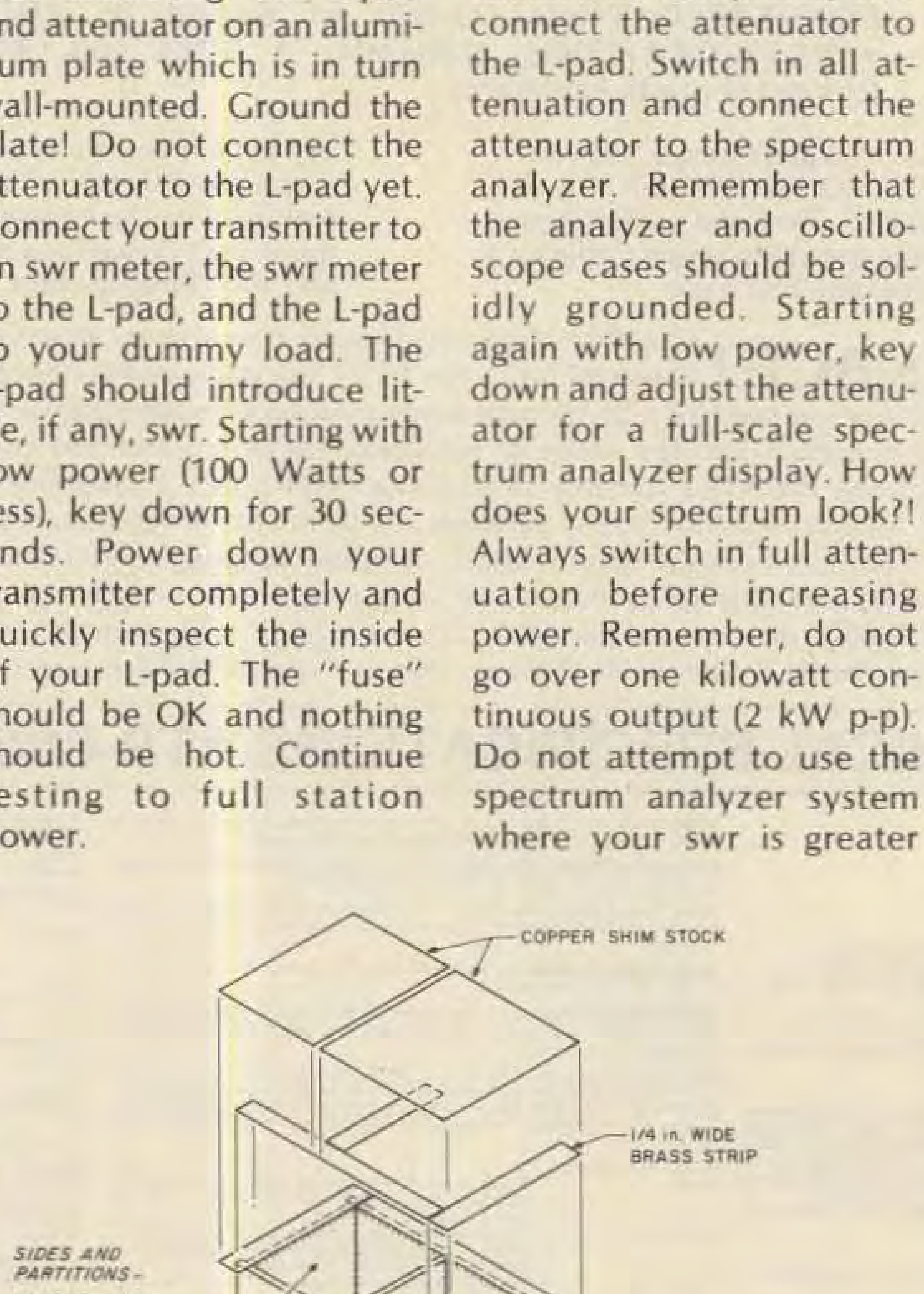
Increase signal strength until the first small spike pops out of the grass between the 0- and 30-MHz signals. This is slightly above the overload point of the analyzer. The 30-MHz signal spike should be near the top of the CRT screen (8th vertical division). Full-scale inputs should be the next (7th) CRT division down. Touch up the oscilloscope controls if necessary. The zero-frequency half-spike will be about six divisions tall. Switch all attenuation out and reduce the signal generator output so that the 30-MHz test signal is seven divisions tall. Check the vertical calibration of the analyzer over the attenuator's 59-dB range.

Using your signal generator and frequency counter, take notes on the horizontal calibration of your analyzer. This is done by centering a signal from your signal generator on each CRT horizontal division (vertical line) and recording its frequency. Your analyzer is now ready for use. But first, test the L-pad carefully!

Hook up your L-pad to your transmitting equipment. Be sure everything is grounded properly. I suggest mounting the L-pad and attenuator on an aluminum plate which is in turn wall-mounted. Ground the plate! Do not connect the attenuator to the L-pad yet. Connect your transmitter to an swr meter, the swr meter to the L-pad, and the L-pad to your dummy load. The L-pad should introduce little, if any, swr. Starting with low power (100 Watts or less), key down for 30 seconds. Power down your transmitter completely and quickly inspect the inside of your L-pad. The "fuse" should be OK and nothing should be hot. Continue testing to full station power.

Photo J. The spectrum analyzer can easily be tuned up with simple test equipment.

If everything has gone well, then power down your transmitter completely and connect the attenuator to the L-pad. Switch in all attenuation and connect the attenuator to the spectrum analyzer. Remember that the analyzer and oscilloscope cases should be solidly grounded. Starting again with low power, key down and adjust the attenuator for a full-scale spectrum analyzer display. How does your spectrum look?! Always switch in full attenuation before increasing power. Remember, do not go over one kilowatt continuous output (2 kW p-p). Do not attempt to use the spectrum analyzer system where your swr is greater than 2:1. Always be sure you are using an L-sampler with a high enough power rating!



Note 1. Solder G-10 circuit board and brass strips with 40-W iron.
Note 2. Solder copper shim stock with 25-W iron.

Fig. 9. Shielded box construction detail.

Component Sources and Substitutions

It often is lamented that home-brewing projects is difficult these days because of poor component availability. I started seriously experimenting with electronics 20 years ago in the good old days of component availability. The difference between now and then is that we have about a thousand times more components to experiment with!

It's simply a matter of motivation and tenacity. You can get any component that you need. True, Mom and Pop's local TV component place doesn't carry everything, but they may be able to order it for you. Don't be afraid to contact a manufacturer or a big distributor like Hall-Mark, Arrow, Allied, etc. They are usually glad to work with you (although order minimums can be an occasional problem). Best of all, look at the ads in this magazine. There are several dozen mail-order distributors which market primarily to the experimenter.

On specifics: You can get circuit board stock, chemicals, drill and router bits, etc., from Kepro in Fenton, Missouri. You can get MRF901s, 40673s, 500-pF and 1000-pF feedthrough capacitors from Alaska Microwave Labs in Anchorage, Alaska. You can get ferrite beads, toroids, and i-f transformers from Amidon Associates in N. Hollywood, California. Small air-variable capacitors for the bandpass filter are available from Radiokit in Greenville, New Hampshire. You can get resistors, capacitors, 555 ICs, TL084C quad op amps, VMOS transistors, and many of the parts discussed above from Radio Shack. You can get

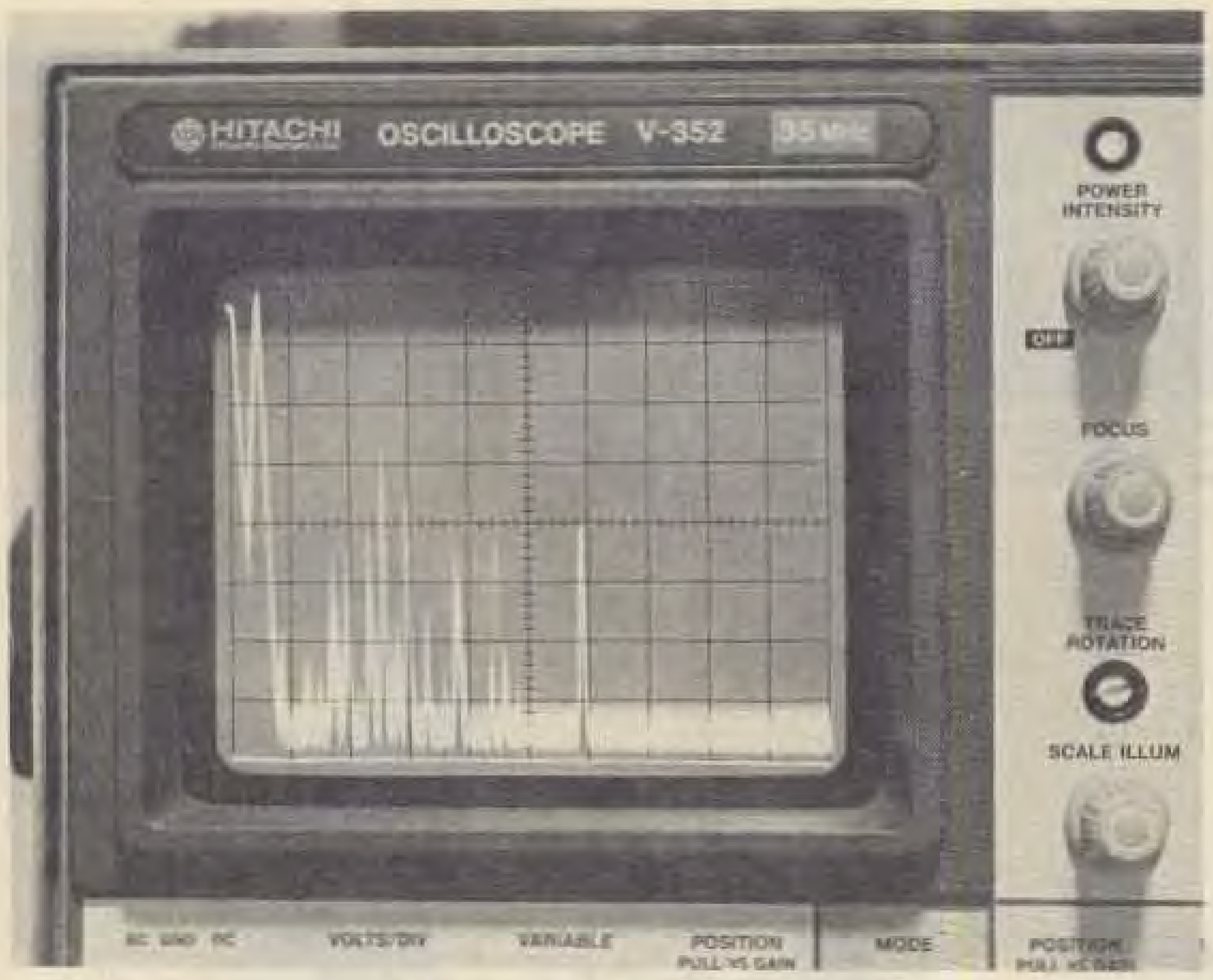


Photo K. 0-to-60-MHz spectrum on longwire antenna, using accessory preamplifier.

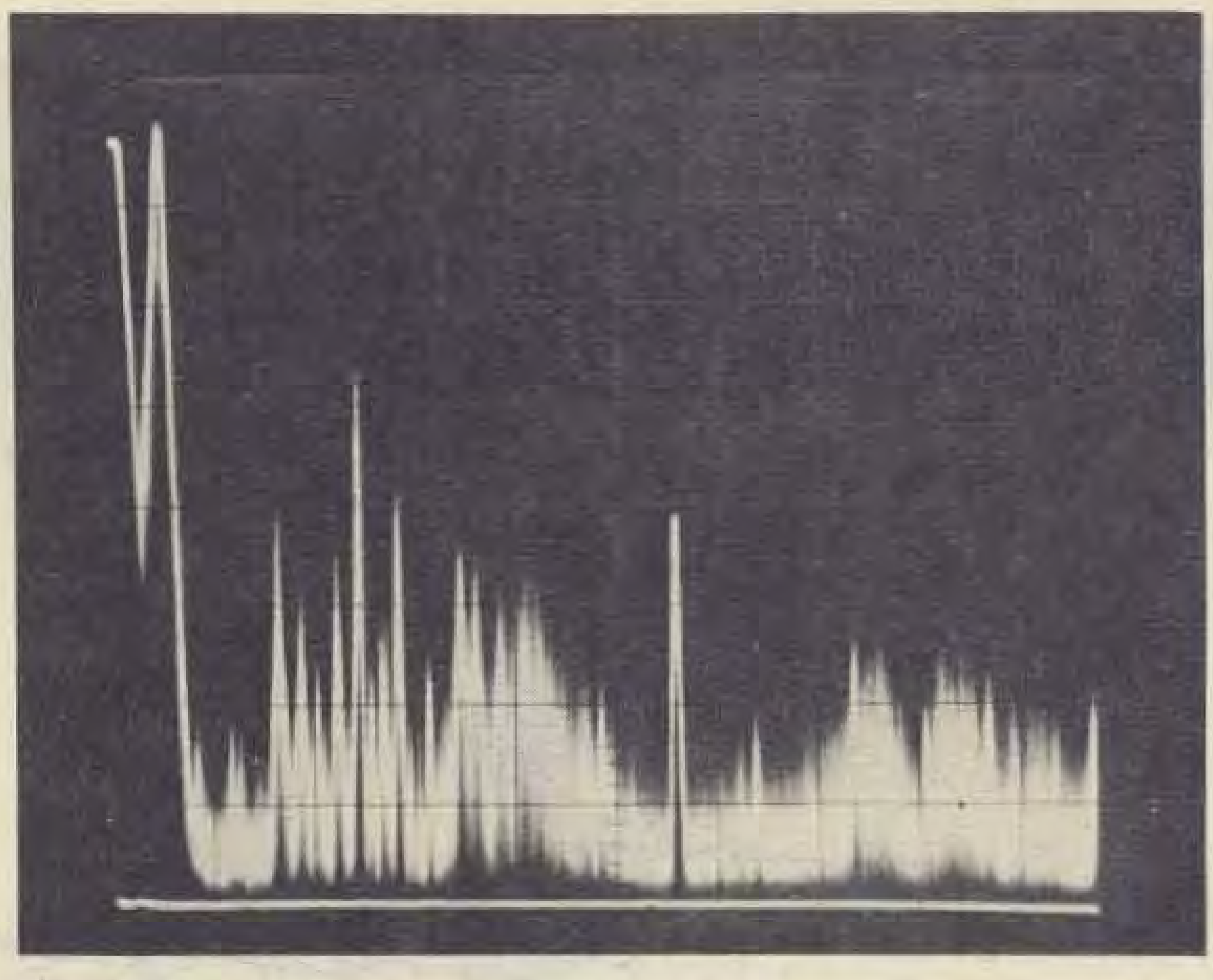


Photo L. 0-to-60-MHz spectrum on longwire antenna with my trusty but noisy computer on.

wall transformers and tantalum capacitors from Jameco in Belmont, California. 2N5179s are carried by most TV parts houses. The double-balanced mixers can be ordered directly from Mini-Circuits in Brooklyn, New York. See, you have no excuse!

OK, the MV109s might be a slight problem. An MV209 or MV309 should also work. I got my stock from Hall-Mark. If you run into a problem getting these diodes, pick up the phone and call Motorola Semiconductor in Phoenix, Arizona, for help.

The high frequency spectrum analyzer should be fairly tolerant of component substitutions except in the vco oscillator circuit and the L-pad. For example, the "hotter" 3N211 could substitute for the 40673 if you crank its gain down a bit with the log amplifier bias pot. You could use MRF901s in place of the 2N5179s (don't try to go the other way!). Solid copper conductors (#12) stripped from house wiring can be used for coil stock in the vco and bandpass filter. Any decent electrolytics of the proper capacitance and voltage rating can be used in the power supply and sweep generator circuits. Electrolytics could also be used in place of the tantalum capacitors in a pinch. Try to get close-tolerance parts in this case.

Useful Accessories

You can duplicate the 2-stage wideband-preamplifier circuit to use as an accessory ahead of the attenuator. This will allow you to view the 0-to-60-MHz radio spectrum on a longwire antenna and quickly judge the band conditions through six meters. Vco frequency-tuning is somewhat nonlinear, which is typical of simple wideband oscillators. A 6-MHz crystal oscillator driving a TTL Schmitt trigger makes a useful calibrator. The output of the TTL gate contains every harmonic through 60 MHz. Lightly couple the TTL gate to the spectrum analyzer input with an insulated wire antenna placed near the analyzer input connector. A momentary-on push-button can be used to activate the calibrator.

Specifications for HF Spectrum Analyzer

Frequency range	0 to 60 MHz
3-dB bandwidth	220 kHz
30-dB bandwidth	1,100 kHz
3:30-dB shape factor	1:5
Dynamic range	60 dB
Spurious responses	60 dB below full-scale
Noise floor	65 dB below full-scale
Full-scale input	−8 dBm ±2 dBm
Y-axis output	0 to 2.5 volts
X-axis output	−0.5 to +3.5 volts
Y-axis calibration	10 dB/division
X-axis calibration	6 MHz/division (approximate)
0 to 8 MHz	4 MHz ± 0.75 MHz/division
8 to 24 MHz	8 MHz ± 1 MHz/division
24 to 60 MHz	6 MHz ± 1 MHz/division

Analyzer Applications

We have talked about using the HF spectrum analyzer to monitor transmitting equipment. This was the primary application I had in mind when I designed the analyzer. It is especially useful to hams who are home-brewing their own HF transmitters or linears. It is also useful for checking low-pass filter performance and band conditions. I'm sure you will find other applications.

The analyzer has a 50-Ohm input impedance and is dc-coupled. Be sure to add a blocking capacitor ahead of the attenuator if you are going to look at an rf signal that is riding on a dc level. Stay away from high-voltage dc circuits. The bandpass of this analyzer is too wide for looking at SSB modulation linearity. However, this can be judged adequately from a two-tone pattern on a normal oscilloscope.

From Here

This project demonstrates that a useful spectrum analyzer can easily be built from relatively common and inexpensive components. Avid experimenters should treat this design as a starting-off point. Meanwhile, let's get those transmitter spectrums cleaned up! If you would like to ask me a question about the analyzer project, please send an SASE. 73! ■

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3. "High Performance Spectrum Analyzer," Wayne Ryder, *Ham Radio*, June, 1977.

4. *Printed Circuits Handbook*, 2nd Edition, by Clyde F. Coombs, McGraw-Hill.