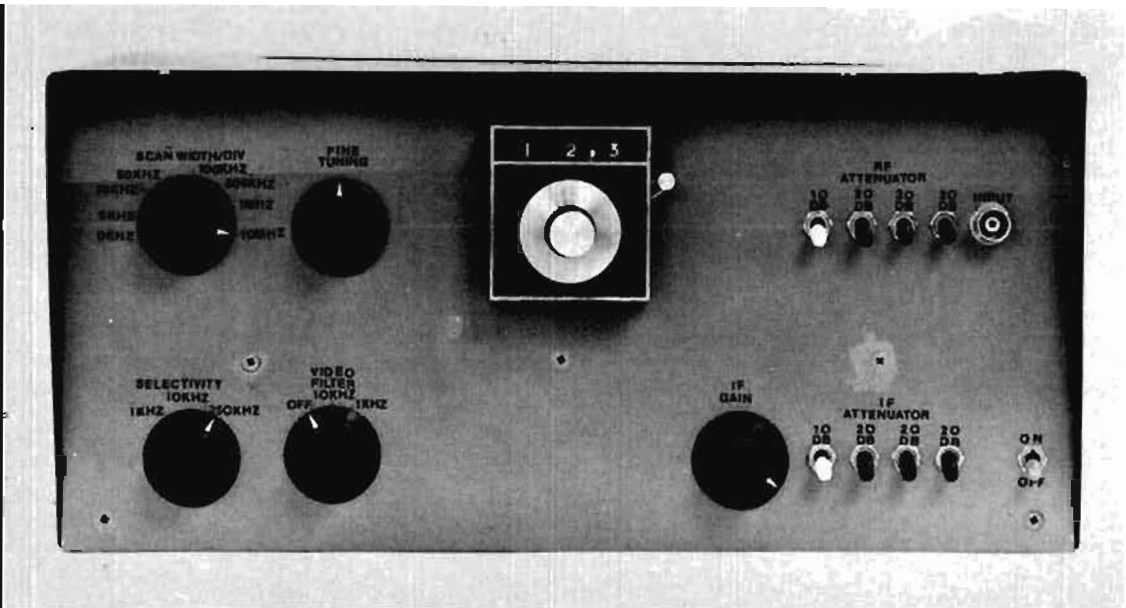

high-performance spectrum analyzer

These instruments have been limited mainly to professional labs — now you can build your own spectrum analyzer from the information furnished here

A spectrum analyzer is a radio receiver with a swept local oscillator that allows continuous tuning over a specified frequency range. The received signals are displayed on a conventional oscilloscope as pips. Fig. 1 shows the radio spectrum between 100 kHz and 100 MHz in the San Francisco area as displayed on the spectrum analyzer described in this article.

Because of their cost and complexity, good spectrum analyzers have been limited primarily to research and development activity. Some military instruments have shown up on the surplus market, but poor sensitivity and selectivity, images, spurious responses, and poor dynamic range have limited their usefulness.

Considerable time was spent in the design of the spectrum analyzer described here. Even more time was required to assure circuit reproducibility, minimize the variety of parts, and select the least-expensive components. No PC boards are used in the design nor are any planned. PC boards in the rf and i-f strips, unless very carefully made, would probably degrade the performance of the instrument. Complete design, construction, and testing details are included for those wishing to build the spectrum analyzer.

applications

The spectrum analyzer can be used to observe harmonics, parasitic oscillations, and sidebands of CW, a-m, fm or ssb signals. Propagation conditions in terms

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of station activity can be observed by looking at the number of signals on an amateur band. This suggests another use for DX and contest operating: You can immediately see where the pileups are without cranking the receiver tuning dial back and forth. The spectrum analyzer described in these pages was built to look for the source of birdies in an experimental general-coverage radio receiver.

The conventional way to observe radio signals is in the time domain on an oscilloscope. This is a good method when no harmonics, parasitic oscillations, or other signals are present. However, amplifiers can oscillate, modulators or mixers might not reject signals being modulated, oscillators may be oscillating on more than one frequency, or detectors may be passing the signal being detected. These signals might appear on an oscilloscope in the time domain as confusing pictures, as shown in fig. 2A. Fig. 2B shows a signal and behind it the second harmonic. This is the frequency domain. If a signal fundamental is on 5 MHz and the second harmonic in on 10 MHz, these appear on a spectrum analyzer as pips at 5 and 10 MHz. Instead of seeing a complex waveform in the time domain as on an oscilloscope, the signal is viewed in the frequency domain. The amplitude and frequency of each component can be seen (fig. 2C).

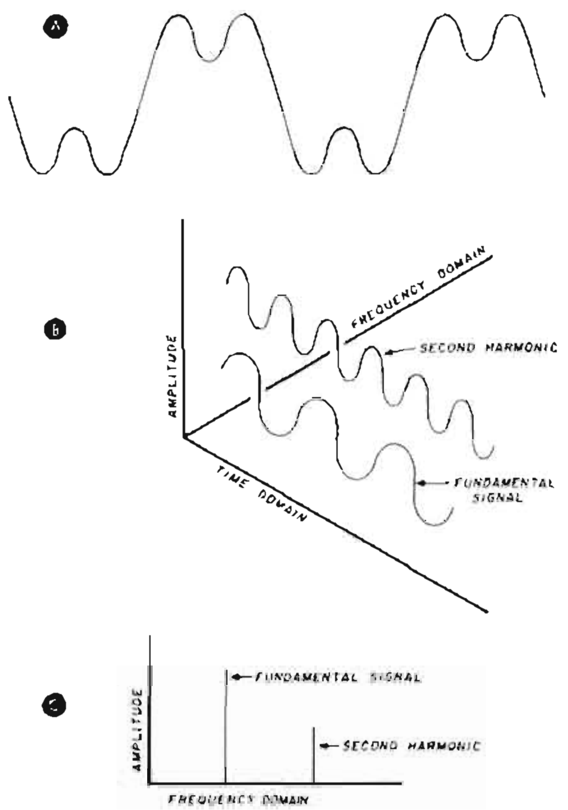


fig. 2. A fundamental-frequency signal and its second harmonic as shown on an oscilloscope in the time domain, A. The same signal and its second harmonic are shown in B in the frequency domain to illustrate their relationships. The spectrum analyzer displays a fundamental signal and its second harmonic in the frequency domain as shown in C. Amplitude and frequency of each can be seen.

three kinds of spectrum analyzers

Fig. 3 shows a real-time analyzer. The incoming signal is connected to a series of filters followed by detectors. A scan or sweep generator drives the horizontal plates of an oscilloscope and controls an electronic switch, which selects the proper detector output. The frequency range is limited by the number of filters and their bandwidth. This type of analyzer is quite expensive because of the large number of filters required to cover a spectrum. Its main application is in the audible or subaudible range.

Another type is the tuned radio-frequency analyzer shown in fig. 4. The input filter is a tunable bandpass filter, which is tuned by the scan generator. The TRF analyzer lacks resolution and sensitivity. Also, tunable filters usually don't have constant bandwidth. The TRF analyzer is used mainly for microwave analysis. There are other types of analyzers, such as a digital processor that performs Fourier analysis, but these are very complex.

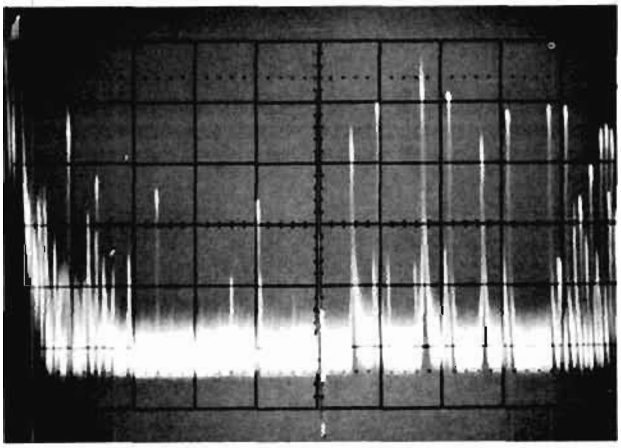


fig. 1. Display showing the San Francisco-area radio spectrum on the spectrum analyzer. A TV antenna was used to receive the signals on the right half of the display, and the TV antenna lead was used as a long-wire antenna to receive signals on the left half.

The most common type of spectrum analyzer is the superheterodyne, as shown in fig. 5. It is similar to a standard superheterodyne receiver with the following exceptions: There is no tuned circuit in the front end, because it would be difficult to make one continuously tunable from 100 kHz to 100 MHz, and the local oscillator is electronically tuned by the scan generator from the oscilloscope. The superheterodyne analyzer has the advantage of a wide tuning range and controlled bandwidth. Also the sensitivity can be made uniform. Image problems are minimized by triple conversion.

Fig. 6 shows the spectrum analyzer described here. No more than 1 volt rms should be applied to the input attenuator. The output from the attenuator should be limited to about 10 mV rms maximum. The function of each assembly is discussed with reference to the block diagram. Later, theory of operation, circuit design, construction, and checkout are described for each assembly.

The input attenuator is followed by an LC 130 MHz lowpass filter. Its purpose is to prevent incoming signal harmonics from mixing with the first local oscillator and producing spurious responses. The incoming signal, 0.1 - 100 MHz, is mixed with the vco to produce a 200-MHz first i-f. The vco is driven by a sweep shaper that predistorts the sawtooth wave from the oscilloscope to compensate for tuning nonlinearities of the varactor tuning diode in the vco.

The 200-MHz i-f output from the first mixer (all mixers are double balanced) goes to an amplifier, which compensates for the mixer loss. Next is a 200-MHz bandpass filter followed by the second mixer. The 200-MHz i-f signal mixes with the second local oscillator output to provide a 50-MHz i-f signal. This signal is amplified and applied to a 50-MHz bandpass filter. The output of this bandpass filter is mixed with 39.3 MHz to produce a third i-f of 10.7 MHz. The 10.7 MHz output from the third mixer is then amplified and fed through a 250-kHz bandpass ceramic filter. This stage is followed by an i-f attenuator.

Next are two identical crystal filters to provide 1- and 10-kHz bandwidths. These feed a gain equalizer, which compensates for the differences in gain between the various bandwidths. Completing the i-f section is an amplifier that drives a second 250-kHz bandpass ceramic filter.

The logarithmic amplifier compresses the output signal so that a large-amplitude signal can be displayed on an oscilloscope. Two divisions on the scope correspond to a change of 10:1, or 20 dB. Six divisions represent a change of 1000:1, or 60 dB. Without the log amp, a CRT about 30 inches (76cm) tall would be required to display the same information with the sensitivity available at the top of the display. A video filter is included to remove high-frequency noise in narrow-bandwidth operation. The performance specifications for the spectrum analyzer are listed in **table 1.**

table 1. Performance specifications of the W6URH spectrum analyzer.

frequency range:	0.1 MHz - 100 MHz.
sensitivity:	10 μV or less in the 1-kHz position.
selectivity:	Approximately 1, 10, or 250 kHz (switchable).
sweep width:	0, 5, 10, 100, 500, 1000, and 10,000 division. In the 10,000 kHz or 10 MHz/division position, the center frequency is set to 50 MHz. Otherwise, frequency is controlled by the center control on the front panel.
first LO frequency jitter:	≈ 5 kHz
signal separation:	10 kHz for 40-dB resolution in 1-kHz position.
input impedance:	50 ohms
response 100 kHz - 100 MHz:	±2 dB
frequency accuracy:	±3 MHz.
video filter:	10 and 1 kHz.
shape factor 3 - 60 dB:	250 kHz 2.5:1 10 kHz 50:1 1 kHz 30:1

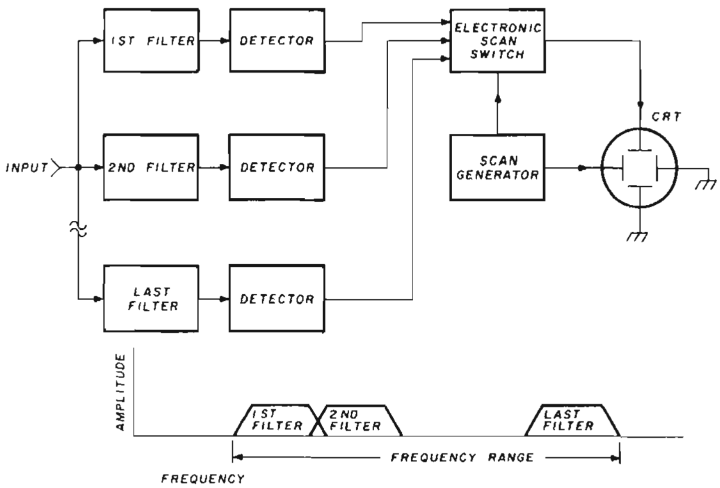


fig. 3. A real-time spectrum analyzer. Filters are spaced to provide continuous coverage of the frequency spectrum.

The display scope for the spectrum analyzer should be dc coupled, have 0.1 V/division vertical sensitivity, and have six divisions of vertical calibration by ten divisions of horizontal calibration. Also approximately 6V of horizontal sawtooth voltage should be available to drive the spectrum analyzer from the scope. Scope input impedance should be 1 megohm and input capacitance 10 - 40 pF.

circuit description

This section presents the theory of operation and design details of each of the major circuits in the spectrum analyzer. It is recommended that the following text be read before attempting to build the circuit modules as much information is provided that will be helpful when construction is started. Especially important are the suggestions on decoupling, shielding, and bypassing.

Sweep shaper. The sweep-shaper schematic is shown in **fig. 7.** The resistors in the input circuit, which are switched by S601A, determine the sweep width. In the 10-MHz/division position, the sweep center frequency is set to 50 MHz by R101. In all other positions the sweep center frequency is set by R601. R104 sets the low-frequency limit, 0.1 MHz, and R102 sets the high-frequency limit, 100 MHz. R103 is a fine frequency adjustment with about 500 kHz of range. U101 provides isolation for the input attenuator and some gain. U102 provides isolation for the frequency control. The outputs of U101 and U102 are resistively combined and drive U103, which is a nonlinear amplifier that complements the nonlinearities of the tuning diode, CR203, in the vco.

As the frequency is increased, more voltage is required. If a change of 1 volt is required to go from 260 to 270 MHz, a change of 1.3 volts may be required to go from 270 to 280 MHz. **Fig. 8** gives an idea of the distorted waveform available from U103 and the actual waveform required to compensate for nonlinearities of the tuning diode in the vco. Compensation is usually required between 270 and 300 MHz. When the voltage

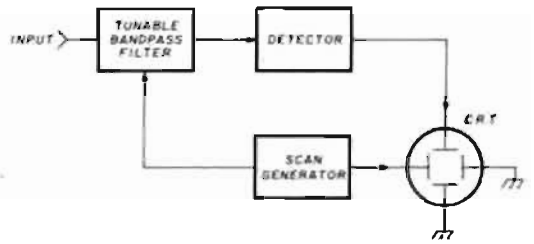


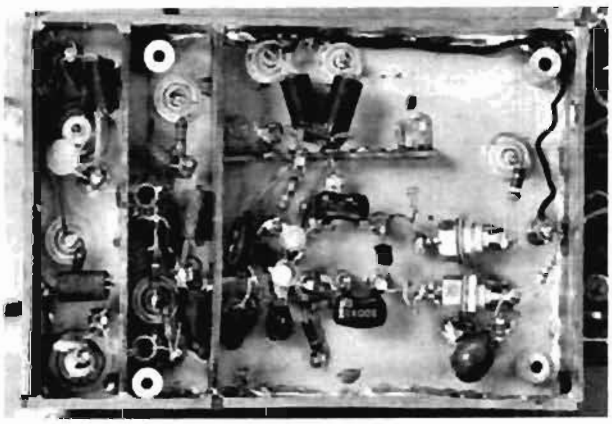
fig. 4. Tuned radio frequency (TRF) spectrum analyzer. Tuning is accomplished by adjusting the bandpass-filter frequency.

on pin 3 of U103 reaches the voltage on the right side of R115, gain will be increased by the setting of R115, and so on up the line, to R106. R115 sets the nonlinearity at 10 MHz and R106 at 100 MHz. The tuning diode used in the vco I built was linear up to about 280 MHz.

Care must be taken so that no low-frequency components, including power-supply hum, are added to the incoming sawtooth wave by the sweep shaper. Added low-frequency components will result in first local-oscillator instability. This shows up as jitter in the display when looking at narrow scan widths.

Voltage-controlled oscillator. Q201 and Q202 together with L201, L202, and CR203 form a 200-300 MHz voltage-controlled oscillator (vco — **fig. 9**). Q203 is a buffer amplifier. Q204 and Q205 provide outputs to the first mixer and a second output.

Several compromises were made in the design of the vco. To achieve high frequency stability, the oscillator should have a high C/L ratio; however, to tune it with a varactor, a low C/L ratio is required. Varactor circuits with reasonably high Q at these frequencies have a relatively small tuning range. When considering tuning range, linearity, and Q the Motorola Epicap tuning diodes seem to be about the best. Careful design of the oscillator and amplifiers was necessary to provide a constant output level to the first mixer. The 2N2369A did not have sufficient gain-bandwidth product to provide constant output when used as an oscillator transistor, but because of the low gain requirements of the amplifiers, the 2N2369A is satisfactory in these circuits.



Closeup view of the voltage-controlled oscillator. Main circuit is in the compartment to the right; connectors for output to the first mixer and tracking generator are in compartment on left.

Rf section. The rf section (**fig. 10**) contains the first two i-f stages operating at 200 and 50 MHz. The third i-f, operating at 10.7 MHz, is contained in the i-f section.

The input signal is applied to the first mixer, MX301, through an rf attenuator and a lowpass filter. The attenuator is required to keep the input to the first mixer below approximately 10 mV. MX301 combines the 0.1 - 100 MHz input with the 200 - 300 MHz signal from the vco to produce the first i-f of 200 MHz. Q301 provides gain to compensate for the loss through MX301. L305 through L307 form a 200-MHz bandpass filter. Output from the 150-MHz local oscillator, Q305, mixes with the 200-MHz signal in MX302 to produce a 50-MHz i-f. The 50-MHz signal is amplified by Q302 and Q304 then applied to the third mixer, MX303, through a four-section bandpass filter. The signal is then mixed with the 39.3-MHz output from Q306 to produce 10.7 MHz.

Several steps were taken to minimize spurious and image responses. The input to the pass filter attenuates harmonics that would otherwise mix with the first local oscillator signal, producing spurious signals. Using a first i-f twice, the highest input frequency minimizes basic image problems. Intermediate frequencies separated 5:1

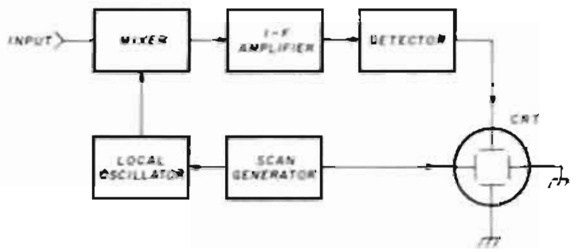


fig. 5. Simplified block diagram of a superheterodyne spectrum analyzer. Local oscillator is tuned by the scan generator.

or less from the next i-f further reduce any images. Double-balanced, four-diode mixers produce the fewest unwanted products and have relatively high local-oscillator isolation. Shielding and bypassing prevent the three local oscillators and their harmonics from mixing and producing spurious signals. For example, with inadequate shielding, the 39.3-MHz local oscillator signal would leak back through the front end. A local signal on 6 meters would be picked up by the second i-f (50 MHz). Ideally each section should be in a die-cast box with an rf gasket, but the construction with copper-clad board, described later, is adequate if care is taken to ensure an rf-tight enclosure.

A ferrite bead is used on all dc leads on each side of the feedthrough. Piston trimmers are required for the 200-MHz bandpass filter for mechanical rigidity. Links L309 and L311 should be constructed so they can be moved from 0 to ½ inch (0 to 12.5mm) away from their respective coils.

I-f section. The third-mixer output, 10.7 MHz, is amplified by Q401 (**fig. 11**). Q402 provides drive at 300 ohms to FL401. Next, an emitter-follower, Q403, provides drive at 50 ohms to the i-f attenuator. The two crystal filters are identical, and the first, Y401, is described.

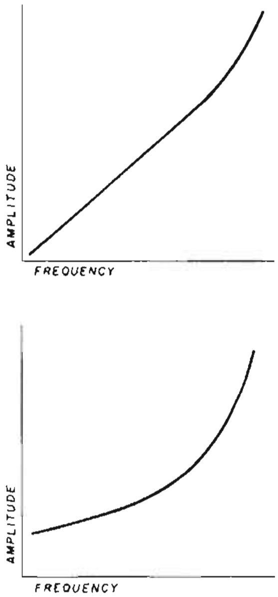


fig. 8. Top curve shows wave shape available from U103 in the sweep shaper; bottom curve shows actual wave shape required to compensate for the nonlinearity of the tuning diode, CR103, in the vco.

Q404 provides a paraphase output, which drives Y401 and neutralizes its capacitance. Q405 provides a high input impedance to the crystal-filter output. CR401 provides a bypass around Y401 for 250-kHz bandwidth. CR402 switches in R401 to broaden the crystal filter for 10-kHz bandwidth. R402 adjusts the gain in the 1-kHz bandwidth position, and R403 adjusts gain in the 10-kHz bandwidth position to the same as in the 250-kHz bandwidth positions. CR403 switches in R403 in the 10-kHz bandwidth position. Q408 and Q409 provide a gain of about 40. Q409 provides 300-ohm drive to FL501 in the log-amp section.

FL401 and FL501 provide 250-kHz bandwidth. After manufacture, these filters are separated into groups and are color coded as to their actual center frequency, which are around 10.7 MHz. Because of spurious resonances above the crystal-filter frequencies, *orange and only orange* color-coded filters maybe used. With the orange-colored ceramic filters, crystal-filter spurious responses are down −50 to −60 dB. With opposite-end ceramic filters, they may be down only 15 dB.

One of the more challenging aspects of designing a spectrum analyzer is selectivity. In its widest position, the spectrum analyzer should have a bandwidth to observe signals using a sweep width of 100 MHz. In its narrowest position, it should be able to resolve signals close together, such as a carrier and its sidebands. Spectrum analyzers with elaborate sets of carefully matched crystal filters can achieve bandwidths as low as 10 Hz at the 3-dB points. These crystals are especially ground to

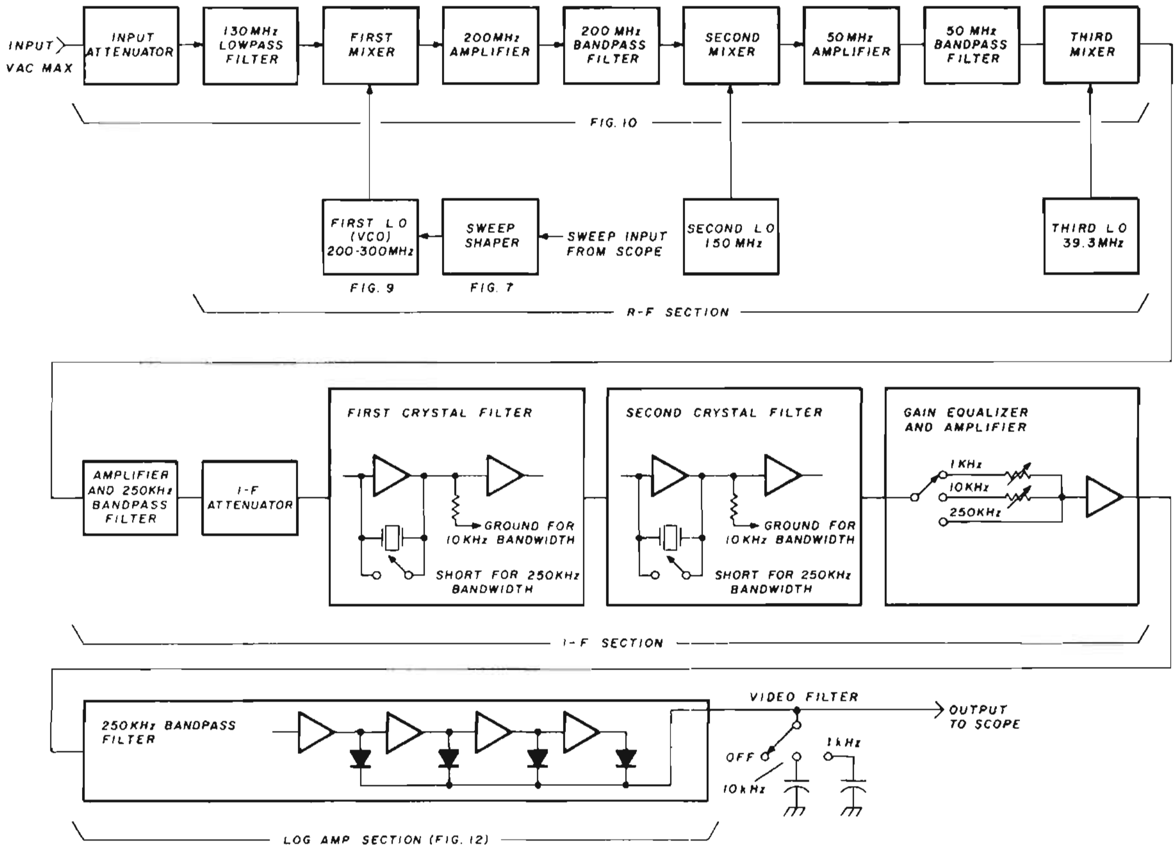


fig. 6. Complete superheterodyne spectrum analyzer described here. Each block represents an individually shielded section or assembly.

minimize resonances other than those desired for crystal filters.

Another important consideration is shape factor and ringing. Communications receivers often have a 3-60 dB shape factor of 2:1. Unfortunately, these filters with steep skirts have phase discontinuities at their band edges, and therefore ringing occurs when signals are rapidly swept through them. This phenomenon was demonstrated using a crystal filter from an fm transceiver in the spectrum analyzer. Shape factor of narrowband filters used in spectrum analyzers cannot be as low as that found in communications receivers.

The ceramic filter used in the 250-kHz bandwidth position has a shape factor of about 2.5:1. These filters are used mainly in fm automobile radios.

The crystal filters were made using off-the-shelf crystals from the local Heathkit store. The filters exhibit some resonance, −50 to −60 dB, slightly above the filter frequency. With a shape factor of about 30:1 two signals about 10-kHz apart have about 40 dB of resolution. The filters are not sufficiently narrow to look at 1- or 2-kHz sidebands of a transmitter. To observe signals which are separated by only 1 kHz would require a 500-Hz filter with a shape factor of 2:1, a sweep speed of 5 sec/cm, a

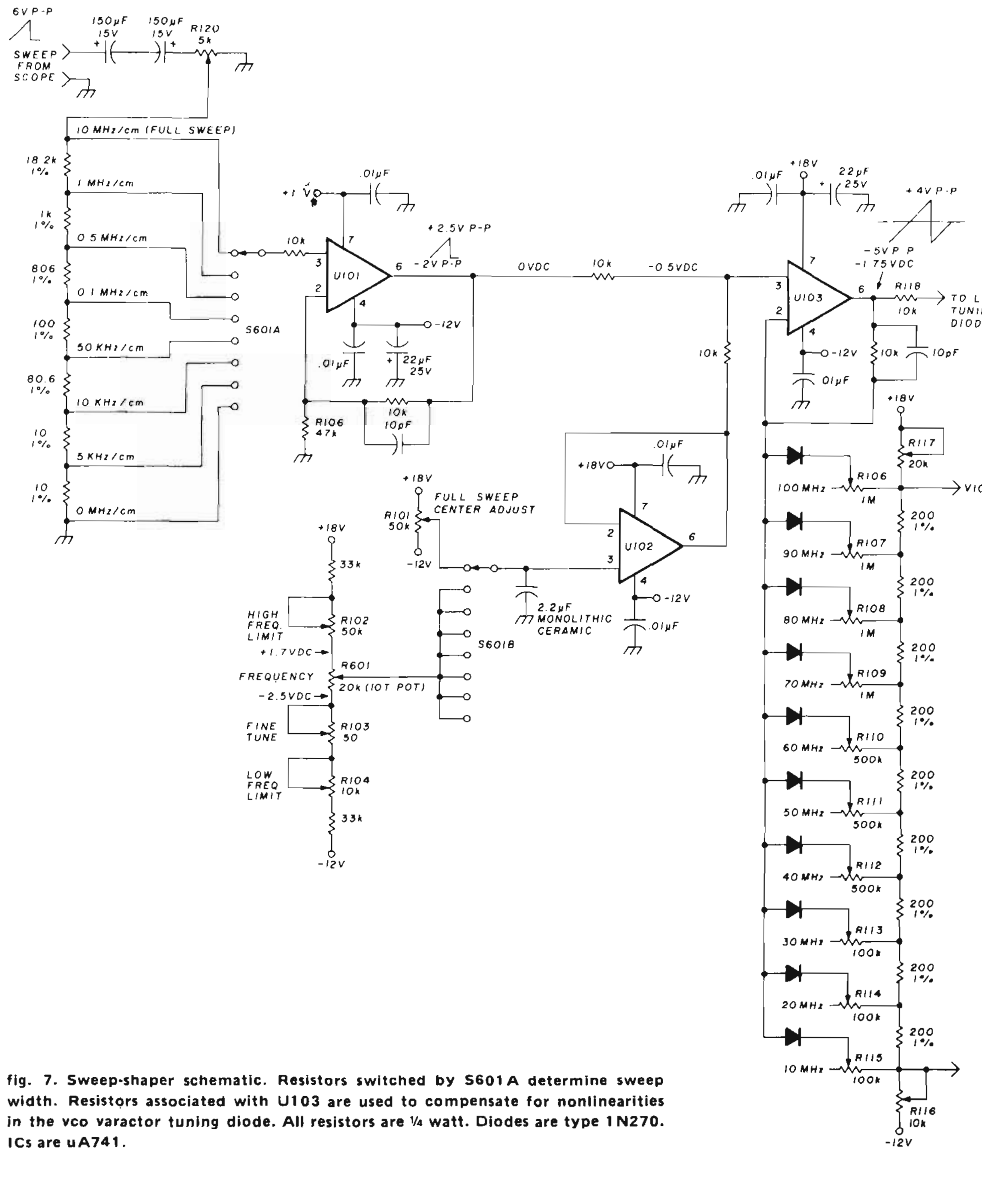


fig. 7. Sweep-shaper schematic. Resistors switched by S601A determine sweep width. Resistors associated with U103 are used to compensate for nonlinearities in the vco varactor tuning diode. All resistors are ¼ watt. Diodes are type 1N270. ICs are uA741.

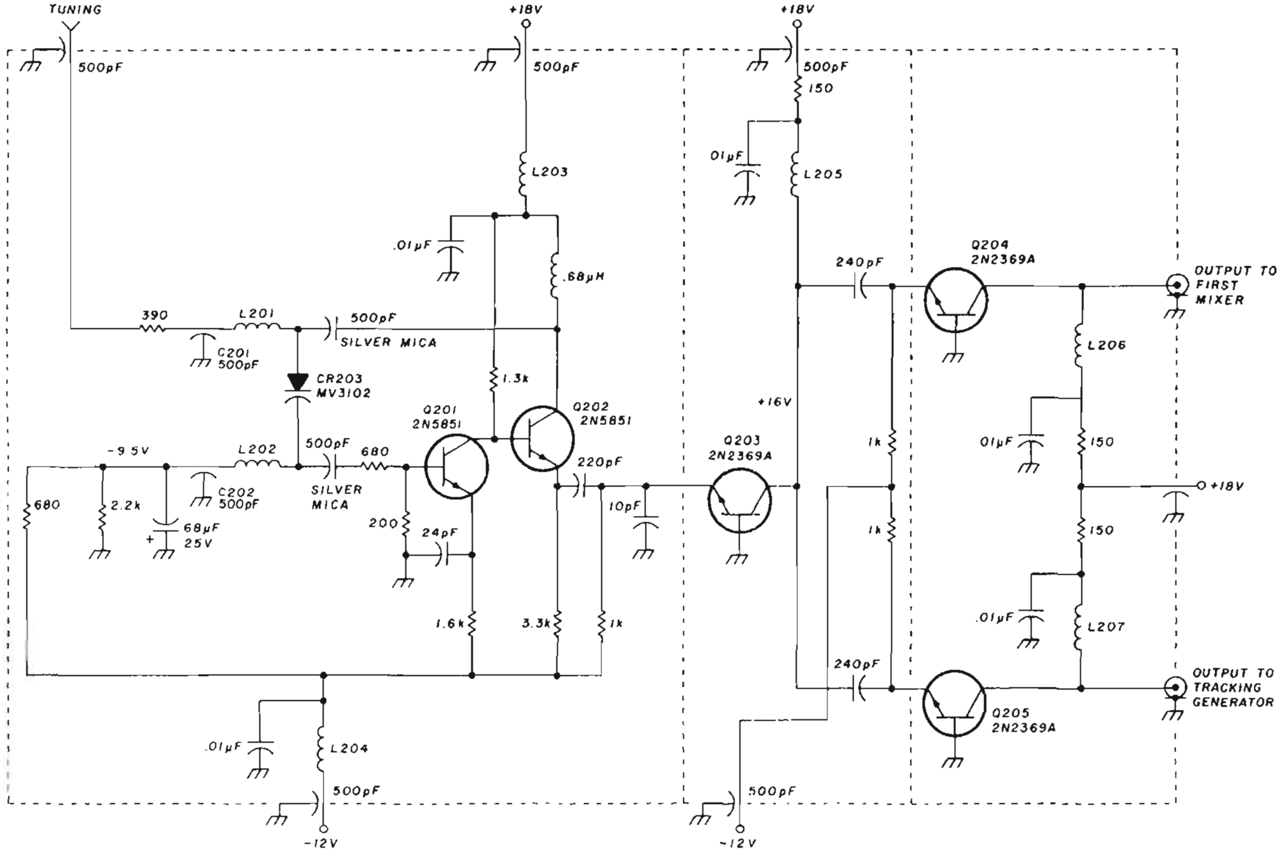


fig. 9. VCO schematic. Range is 200-300 MHz. CR203 is a Motorola MV3102. C201 and C202 are 500-pF feedthrough bypass capacitors. L201, L202: 1 turn no. 18 AWG (1mm) wire. L203-L207: 5½-turn chokes.

phase-locked vco to remove vco fitter, and a storage scope because of the very slow sweep speed.

Log amplifier. The log amp schematic is shown in **fig. 12.** FL501 provides selectivity in the 250-kHz position. Emitter-follower Q501 provides a low-impedance input for Q502. Q502 through Q505 are a series of four wideband resistance-coupled amplifiers. Each stage has a gain of 6 for a total gain of 1296, or slightly over 60 dB.

The detected output of each stage is summed through each diode at the output. As the signal level at the output of Q505 increases, CR505 conducts with a logarithmic-shaped curve. Q505 then saturates and CR504 starts conducting, and so on down the line. CR502 and CR503 are in series to provide a voltage greater than that of CR503 and CR504. R501 through R503 set the output level from each stage, and R504 sets the total output level. The video filter reduces high-frequency noise. It can be used only for narrow sweep widths. The video filter is described in detail in the section on operation.

construction

All assemblies except the sweep shaper are built in boxes made of 1/16-inch thick (1.5mm) single-sided copper-clad board. The rf assembly has double walls, as explained later, and individual covers. All other assemblies have single-wall separators and one cover for the entire assembly. All boxes are 3/4 inch (19mm) high (inside measurement), and the covers are secured with 3/4-inch long (19mm) 4.40 (M3) metal spacers. The following parts had to be obtained from the sources shown. All other parts came from the junk box and the sources are unknown.

component	source
ceramic filters (FL401, FL501) Vernitron FM-4	Vernitron, 232 Forbes Road, Bedford, Ohio 44146
crystals (Y401, Y402) Heathkit 404-39	local Heathkit store
2N2369A, J309 Siliconix	James Electronics, P.O. Box 882, Belmont, CA 94002
one-hole beads (Amidon FB-43-101) six-hole bead (Amidon FB-64-5111)	Order from Amidon Assoc., 12203 Otsego St., North Hollywood, CA 91607

Sweep shaper. This assembly is built on copper-clad boards without shielding or feedthrough bypassing.

vco. The vco is built in a copper-clad box measuring 4½x3x¾ inches (114x76x19mm). The buffer section and output amplifiers are shielded from the oscillator. Paper-thin copper is wrapped over the outside edges where the cover attaches.

rf section. The rf section has double walls between compartments, which ensures good shielding. The walls are spaced 1/16 inch (1.5mm) apart, and paper-thin copper (available from hobby shops) is laid over the walls. The covers for the two bandpass filters are cut as shown in **fig. 13** (a continuous shield will create a shorted turn, which will seriously detune the filters). All assemblies have 500-pF feedthrough capacitors for dc voltages and 0.01-μF capacitors across the feedthrough caps inside the compartments. Dimensions of the rf section are shown in **fig. 14**.

The construction of the three mixers is identical. The *transformers for each unit use four trifilar-wound turns.* All windings are wound at the same time for a total of 12 turns. **Fig. 15** shows four turns through a ferrite bead. The four turns are counted from the inside – *not* the outside. Also shown in **fig. 15** are the transformer connections and how they are installed in the mixer. All *ports have* baluns *consisting of two bifilar-wound turns* on ferrite beads. The same type bead is used for the transformers and baluns.

I-f section. Dimensions for this assembly are shown in **fig. 16**. It has one large cover rather than individual covers as used in the rf section.

power supply. The power supply is located beneath the chassis at the rear. Two separate supplies are required (**fig. 17**). Transformer T701 should provide 23-29 Vdc at approximately 200 mA and T702 should provide 18-24 Vdc at 100 mA. Both regulators are commonly available three-terminal ICs. The supplies must not go out of regulation above about 100 Vac line voltage.

checkout

Before any tests are made, all dc voltages should be checked against those shown in the schematics. In many instances, each stage of an assembly is checked. In each case, the generator should be terminated and coupled through a 0.01-μF capacitor. The existing input to the stage should be removed during these checks. The generator should then be carefully tuned to the frequency that produces maximum deflection on the display scope. Stage-by-stage checkout is important because it is otherwise difficult to determine which stage is at fault if *performance is not satisfactory.* Assembly checkout is followed by a final alignment.

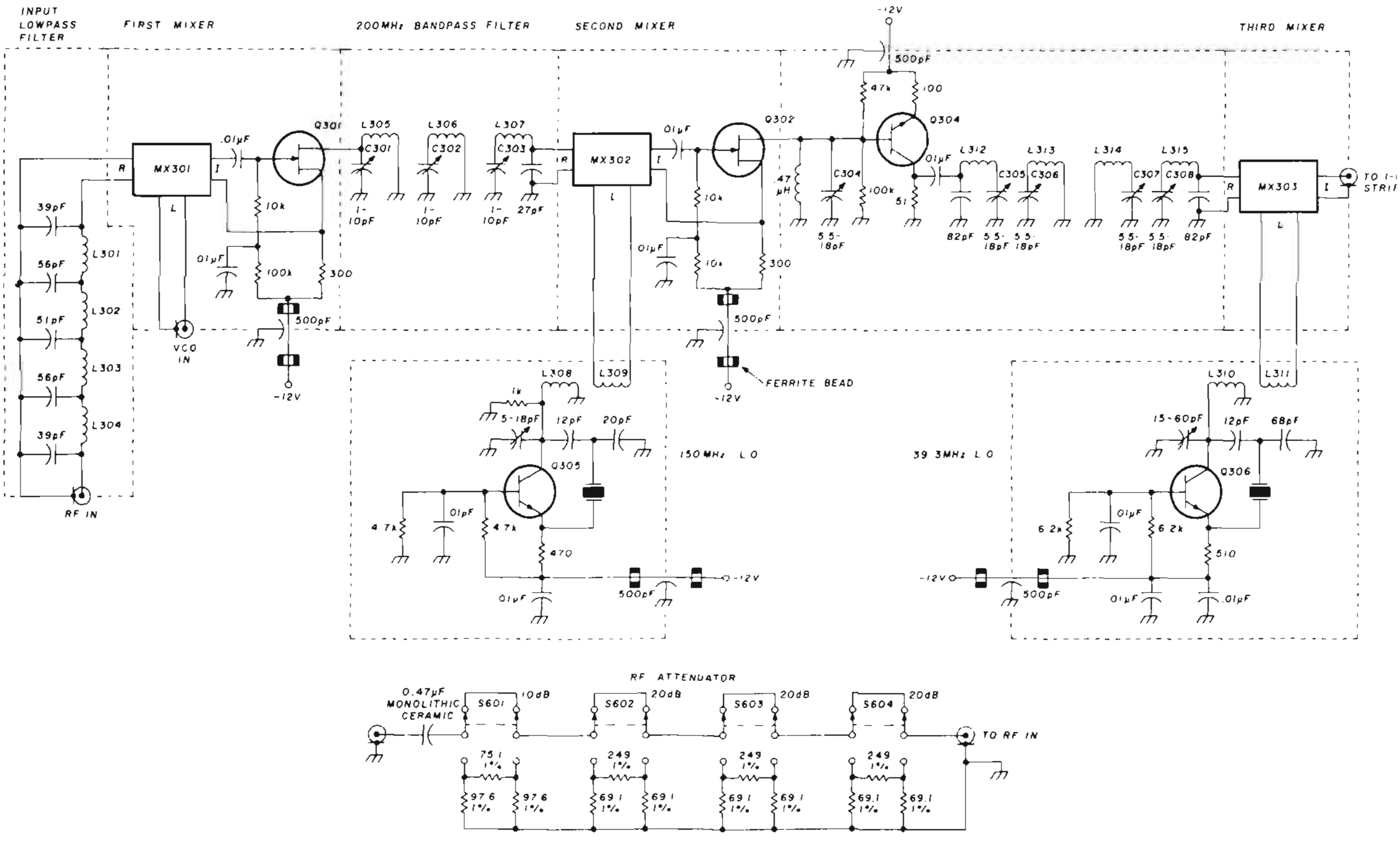


fig. 10. Rf-section schematic. All bipolar transistors are 2N2369As; fets are J309 or J310. Feedthrough caps are 500 pF.

L301-L304	*4 turns no. 18 AWG (1.0mm), 3/16" (5.0mm)* diameter, ¼" (6.5mm) long
L305-L307	4 turns no. 22 AWG (0.6mm), ¼" (6.5mm) diameter, 3/16" (5.0mm) long. Spacing between coils ¼" (6.5mm). All wound on one ¼" (6.5mm) diameter plastic form.
L308	3 turns no. 18 AWG (1.0mm), ¼" (6.5mm) diameter, ¼" (6.5mm) long
L309	2 turns no. 22 AWG (0.6mm), ¼" (6.5mm) diameter, close wound
L310	10 turns no. 18 AWG (1.0mm), 5/16" (8.0mm) diameter, close wound
L311	2 turns no. 22 AWG (0.6mm), ¼" (6.5mm) diameter, close wound
L312-L315	7 turns no. 26 AWG (0.3mm), ¼" (6.5mm) diameter, close wound. Spacing between coils is ½" (12.5mm)

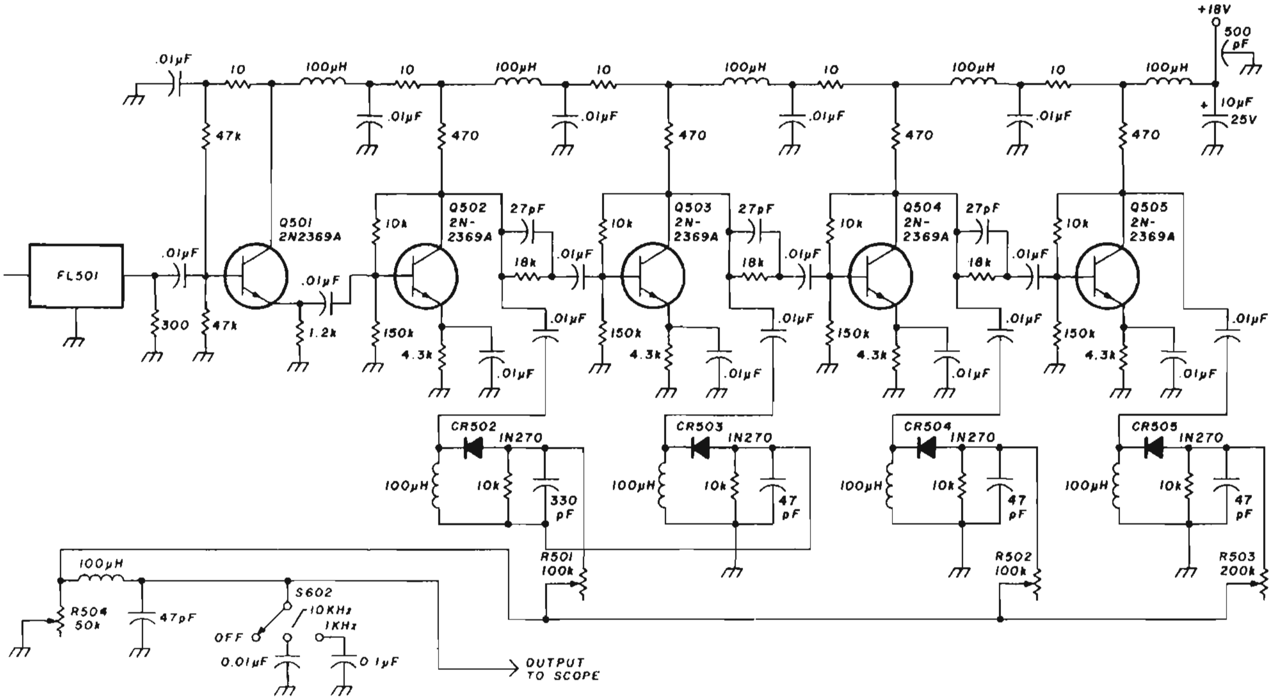


fig. 12. Log amplifier schematic.

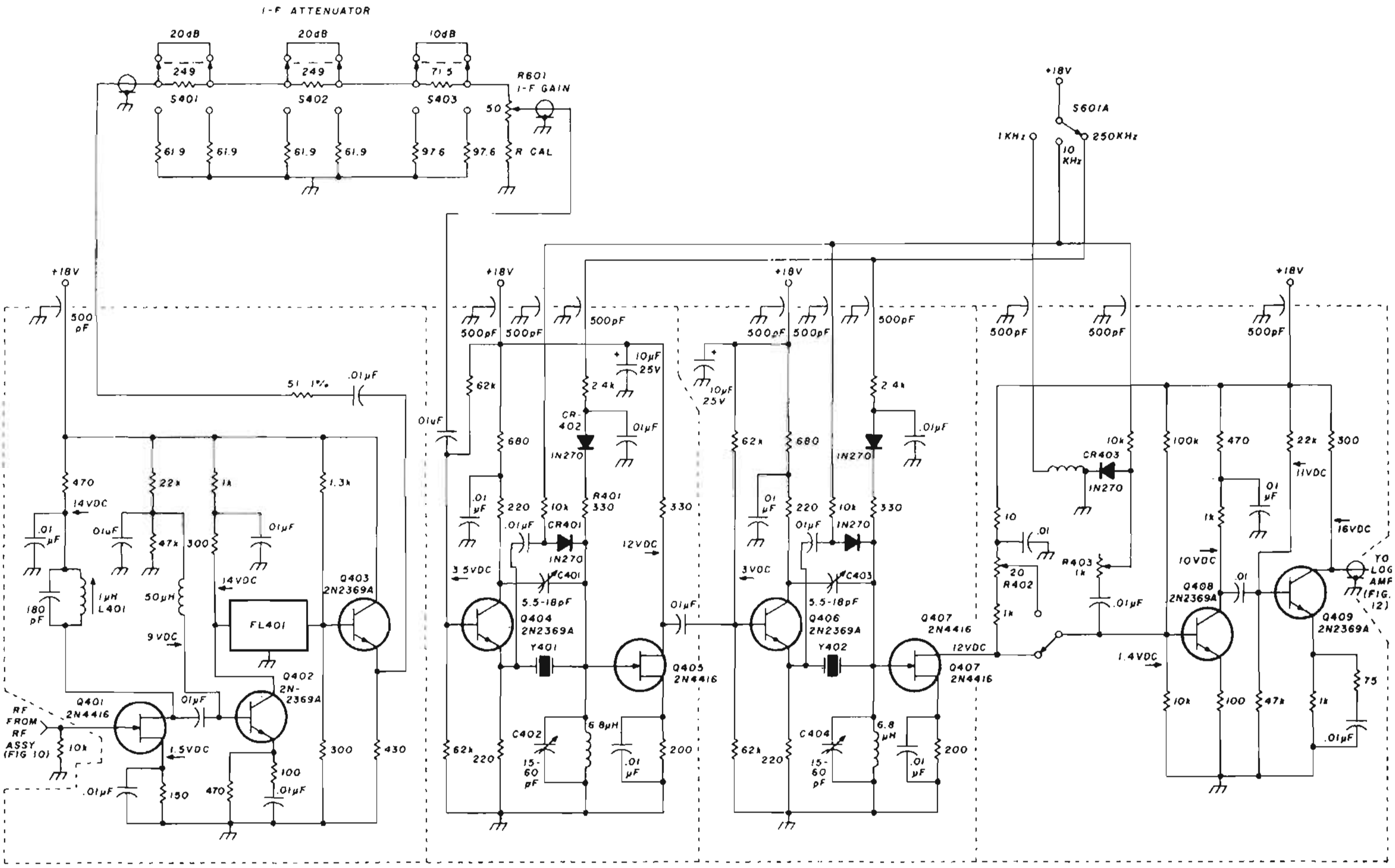


fig. 11. I-f section schematic. All resistors in the attenuator must be 1% tolerance. Resistors must be added in series or parallel to obtain 51 ohms ±1% with R601. Feedthrough caps are 500 pF.

test equipment required

1. Rf signal generator, 10-300 MHz, with calibrated attenuator 1 μV to 0.1V rms (Measurement model 80 or HP 608 or equivalent).

2. Grid-dip oscillator, 10 MHz - 200 MHz (Heath GD1 or equivalent).

3. Rf signal generator, 100 kHz - 10 MHz. Calibrated attenuator 1 μV - 0.1 V desirable (General Radio 605 or equivalent).

4. Volt-ohmmeter (Triplet 630 or equivalent).

5. Comb generator. (Prescalar described in June, 1975, *ham radio*[1] not absolutely necessary but convenient for adjusting vco linearity).

6. Frequency counter capable of counting to 300 MHz.

Sweep shaper and vco. Verify the voltages at the output of U101 and U103 against those shown in the schematic, fig. 7. Using a 300-MHz counter, determine what tuning voltages in the vco produce 200, 250, and 300 MHz. (Further checkout of the vco and sweep shaper is described in the section on final alignment).

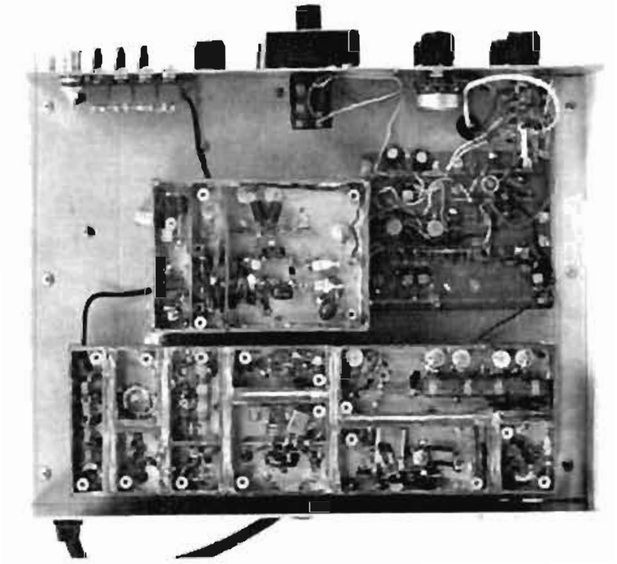
Log amplifier. Check dc voltages as shown in fig. 12. Ensure that 2-3 volts are between collector and emitter of Q502-Q505.

1. Set all pots to center range.

2. Connect generator to log-amp input.

3. Set display scope to 0.1 V per division.

4. Set generator for 300 μV output and tune generator for peak on display. Verify according to the chart shown in the next column.



Top view of spectrum analyzer chassis showing the rf assembly (along rear of chassis, bottom), voltage-controlled oscillator (center), and sweep shaper (top right).

300 μV	≈ 1 division
1,000 μV	≈ 2 divisions
3,000 μV	≈ 3 divisions
10,000 μV	≈ 4 divisions
30,000 μV	≈ 5 divisions
100,000 μV	≈ 6 divisions

5. Set R504 so that 100,000 μV equals six divisions.

Log amplifier tracking is described under final alignment.

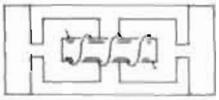


fig. 13. Foil cutout for the 200- and 50-MHz bandpass-filter covers used in the rf section.

I-f section. When checking dc voltages, verify voltages from S601 to the i-f section in all bandwidth positions.

1. Set bandwidth to 250 kHz.

2. Turn off i-f attenuator and turn i-f gain to maximum.

Because of noise or interfering signals, the baseline during some tests of the i-f and rf sections will shift up one or two divisions. If checkout shows that 100 μV should provide one division of deflection and the baseline is already up 1.8 divisions due to noise or external signals, this 100 μV should move the baseline up one to 2.8 divisions. Fifteen microvolts to the base of Q408 and Q404 should provide one division of deflection.

3. Connect generator to Q401 base.

4. Peak L401. Two microvolts should provide one division of deflection.

The crystal filter alignment is described in the section on final alignment.

Rf section. Using a grid-dip meter verify that the 39- and 150-MHz oscillators are oscillating and are crystal controlled. If the oscillators are free running, some adjustment of the two capacitors on the collector side of the crystal can be made. Turn power off and on several times to ensure that oscillators continue to run.

Perform the following steps:

1. Set bandwidth to 250 kHz and video filter to off.

2. Connect generator to input of MX303 (at lead that goes to L315).

3. Tune generator to a peak at 50 MHz and adjust L311 for maximum signal consistent with minimum coupling to L310. Ten microvolts should provide one division of deflection.

The 50-MHz bandpass filter is tuned next. The windings are critically coupled and require careful step-by-step tuning.

1. Connect generator to Q304 base and set display for about four divisions.

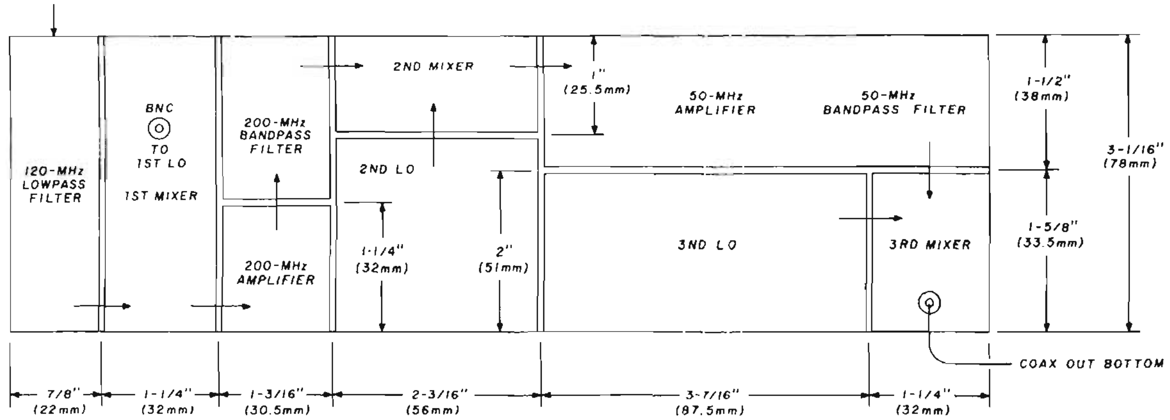


fig. 14. Rf-section dimensions.

2. Short L314 and adjust C306 and C308 for maximum deflection.

3. Short L313 and adjust C305 and C307 for maximum deflection.

4. Make slight adjustment of C305 through C308. Some interaction exists and several attempts will be required, but only a small adjustment will be necessary. Later, when the cover is installed, a slight readjustment will be required. Fifteen microvolts here should provide one division of deflection.

5. Connect generator to MX202 input and tune to a peak around 200 MHz. (At this frequency, signal generators sometimes drift and some readjustment may be necessary).

6. Adjust C304 for maximum deflection.

7. Set generator for exactly three divisions.

8. Install cover on 50-MHz bandpass filter and make slight adjustments of C304-C308. Twenty microvolts should produce one division of deflection.

As with the 50-MHz bandpass filter, the 200-MHz bandpass filter is critically coupled and needs careful adjustment. Proceed as follows:

1. Set all three piston trimmers to the center of their range.

2. Connect generator to Q301 gate.

3. Short L306 and peak C301 and C303.

4. Peak C302.

5. Make slight adjustments of C301-C303 for maximum deflection. Twenty microvolts here should provide one division of deflection.

6. Install covers. (Fine adjustment of the 200-MHz bandpass filter is covered under the section of final alignment).

final alignment

This section provides final alignment information on the sweep shaper and vco, crystal filter, gain equalizer, tuned circuits, and the log amplifier. Since the sweep shaper and vco may not be familiar, some background information is given on how these circuits work together.

Sweep shaper and vco. The first step is to provide a sweep signal between 0.1-100 MHz. Two conditions must be met to accomplish this: The sawtooth amplitude must be adjusted so that the varactor tuning diode can tune the vco from 200 to 300 MHz. Also, the dc level must be set so that the voltage *one-half way up the sawtooth* tunes the vco to 250 MHz.

The bottom of the varactor diode, CR203, is returned to about −9 volts. The sawtooth amplitude required to tune the vco from 200 to 300 MHz is about 8 volts p-p. The voltage level required to tune the vco to 250 MHz is about −2 volts. Therefore, the sawtooth should start at −6 volts, the half-way point should be at −2 volts, and the peak should end at +2 volts. R101 sets the dc level and R120 sets the sawtooth amplitude (see **fig. 7**).

When the vco was first built, a relatively nonlinear tuning diode (1N5140) was used. It required frequency correction at most frequencies between 240 and 300 MHz to provide linear change in frequency with linear change in dc voltage. However, the MV3102 required

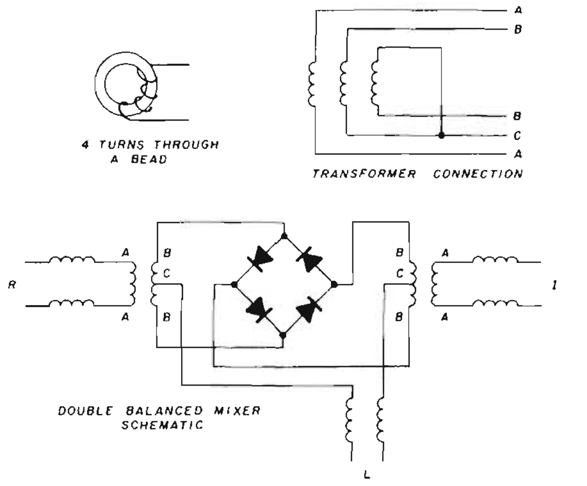


fig. 15. Construction details for winding transformers and baluns used in the r-f section.

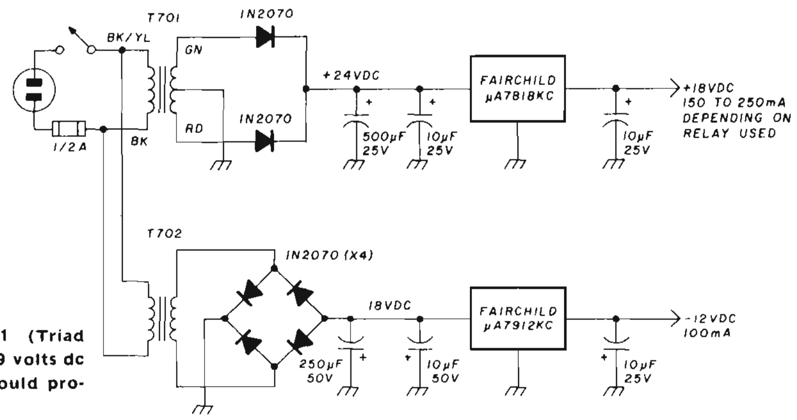


fig. 17. Power-supply schematic. T701 (Triad F90X or equivalent) should provide 23-29 volts dc at approximately 200 mA, and T702 should provide 18-24 volts dc at 100 mA.

correction only at 290 and 300 MHz, therefore R108 through R115 (fig. 7) were removed. Several MV3102s were tried with the same results; however, the entire correction circuit is included in the vco schematic.

The settings of R116 and R117 determine at what voltage, or frequency, the correction is made. If R107 is shorted, R117 can be adjusted by setting it so that a 90-MHz signal on the display is moved to the left. R106 through R115 determine the amount of correction, and R116 and R117 determine the position of correction.

A signal source that simultaneously puts out 10-100 MHz in 10-MHz steps makes vco alignment easier. The comb generator in the test equipment list fulfills this requirement. A comb generator can be made by feeding 100 MHz into the prescalar described in reference 1. The ECL logic has fast switching times and generates many harmonics, which provide the comb signal. Possibly other ECL prescalers would provide the comb signal. The frequencies generated will not be of equal amplitude.

In all scan widths other than 10 MHz/division, the center frequency is controlled by R601. R102 and R103 adjust the voltage to R601, so the oscillator is at 200 MHz when the dial reads 0 MHz and at 300 MHz when the dial reads 100 MHz. Errors of at least ±3 MHz are normal for the dial calibration.

Super heterodyne spectrum analyzers produce a signal when the local oscillator is at the i-f or 0 MHz. At 0 MHz, the local oscillator is at 200 MHz, the i-f, and energy from the local oscillator leaks through the first mixer, producing a 0-MHz marker. This is both normal and handy for calibration.

Sweep shaper and vco alignment. Set controls and test equipment as follows:

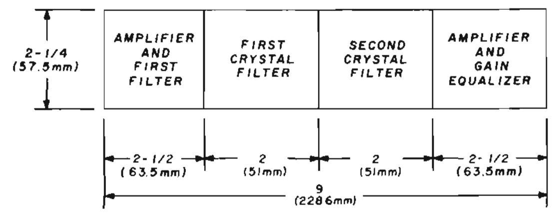


fig. 16. I-f section dimensions.

Bandwidth: 250 kHz.

Scan: 10 MHz/division.

Generator frequency: 50 MHz.

Generator output: ≈ 5 divisions.

Video filter: off.

1. Turn R106 through R115 to maximum resistance.

2. Adjust R101 so the 50 MHz signal appears at the center, fifth division, of the display.

3. Adjust R120 so the 0-MHz marker is at the first division. Some interaction occurs between R101 and R120. Readjust them so that the 0-MHz marker is at the first division and the 50 MHz signal is at the fifth division.

4. Look at the sawtooth with a scope and determine the dc value of the sawtooth at 0 MHz. Set R116 so this dc voltage is present on R115.

5. Look again at the sawtooth at 100 MHz and similarly set R117. Because of interaction, R116 and R117 must be adjusted several times. Final adjustment of R116 and R117 is as follows.

6. Connect comb generator.

7. Turn R108 and check that the 80-, 90-, and 100-MHz signals move to the left. Readjust R117 so only these signals move to the left.

8. Turn R108 to maximum resistance and adjust R114. All signals 20 to 100 MHz should move to the left. Adjust R116 so this condition can be met.

9. Alternately adjust R116 and R117 so that amplitude corrections are made at the proper frequencies.

10. Turn R106 through R115 to maximum resistance.

11. Determine the lowest frequency needing correction and adjust the appropriately labeled pot. Always start adjustment at the lowest frequency because all frequencies above are affected.

Fig. 18 shows final alignment. The camera lens did not have a wide enough angle to display 100 MHz. Note that 10 through 40 MHz are slightly high and 60 through

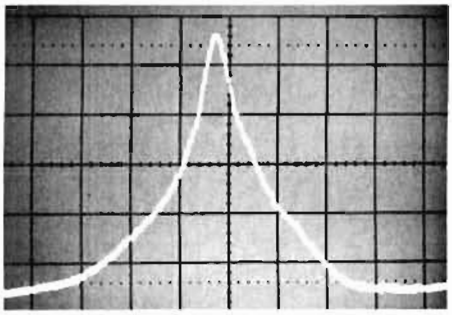


fig. 18. 10-kHz bandwidth position after alignment. Horizontal scale: 10 kHz per division.

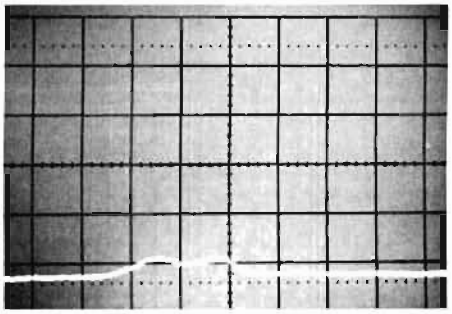


fig. 19. Setup as shown in fig. 24. Turn on video filter and note reduction of noise.

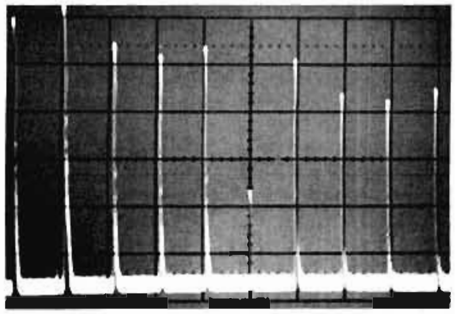


fig. 20. Output from comb generator, 10-100 MHz. Scope camera did not have enough width to display 100 MHz. Maximum errors are about 2 MHz.

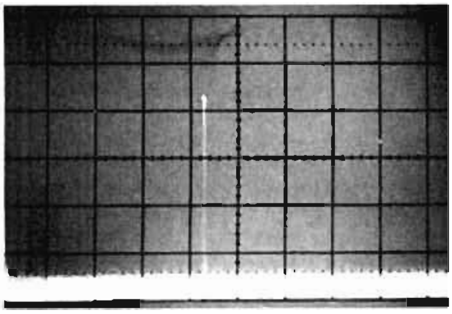


fig 21. Setup is as shown in fig. 27. I-f gain has been reduced to take advantage of the full dynamic range.

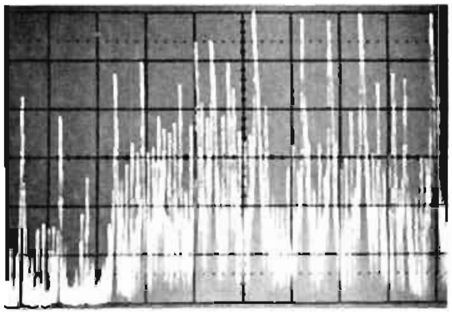


fig. 22. After connecting antenna to inputs, turn BW to 1 kHz and note how stations in the broadcast band can be resolved.

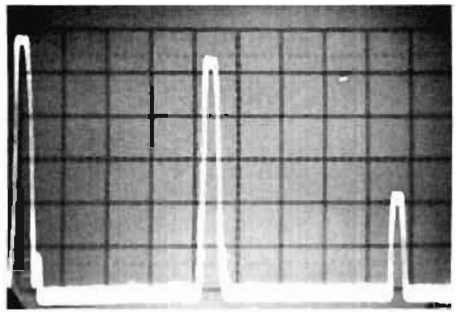


fig. 23. Second harmonic of transmitter operating at about 4 MHz. Second harmonic is down only about 32 dB.

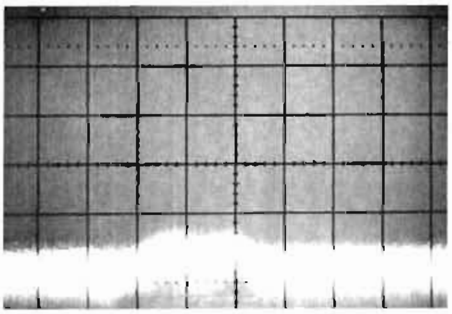


fig. 24. BW 250 kHz. Scan 100 kHz/division and generator frequency about 40 MHz. Increase generator output to see a signal in the noise with the video filter off.

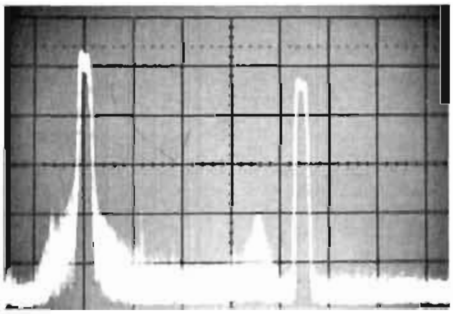


fig. 25. Setup as shown in fig. 27. Set scan to 1 MHz/division. Note video carrier, color information about 3.6 MHz above video carrier, and sound carrier 4.5 MHz above video carrier.

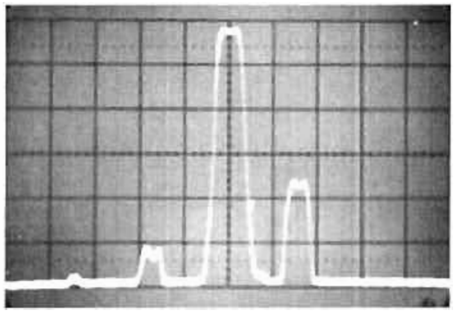


fig. 26. Output of a commercially made ssb transmitter into a 50-ohm load with carrier inserted at about 3.8 MHz. Scan 500 kHz/division. Note spurious signals at about 3050 kHz and 4550 kHz.

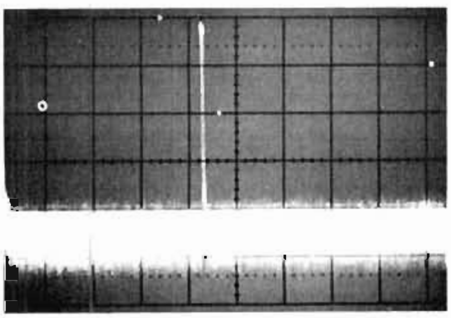


fig. 27. I-f gain adjustment. BW 250 kHz. Scan 10 MHz/division. Generator frequency 40 MHz; generator output about 4 divisions. The i-f gain is set too high, which shifts the baseline up two divisions. This results in a loss of about 20 dB of dynamic range.

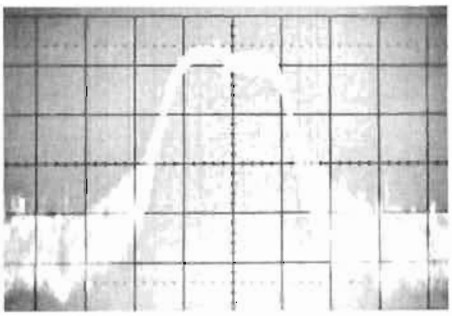


fig. 28. TV station. BW 250 kHz. Scan 100 kHz/division. Adjust frequency control to the video carrier of any TV station between channel 2 and channel 6. Connect 50- or 75-ohm TV antenna to input. Line lock the scope and note video sidebands and vertical sync pulse, which will drift through the top of the signal.

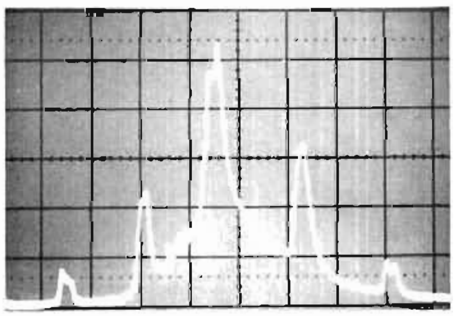


fig. 29. Nonlinear modulation. BW 1 kHz. Scan 10 kHz/division, generator frequency about 40 MHz, and about 50% modulation with a 15 kHz signal. The generator used here was not designed to be modulated at a 15-kHz rate. Note unsymmetrical sidebands and harmonics of the modulated frequency. The harmonics were generated in the modulation process.

90 MHz are slightly low. Maximum error shown here is about 2 MHz.

Crystal-filter alignment. Set controls and test equipment as follows:

Bandwidth: 1 kHz.

Scan: 50 kHz/division

Generator frequency: 20 MHz (not critical).

Generator output: 5½ divisions on display.

Sweep speed: 20 ms/divisions.

Video filter: 10 kHz.

Video gain: maximum.

The crystal filters are aligned one at a time. The filter not being aligned should have a 0.01-μF disc capacitor soldered across the crystal. Always maintain about 5½ divisions on the display but never more than six divisions.

1. Adjust C402 for a narrow peak at the crystal-filter frequency.

2. Go between 1 kHz and 10 kHz bandwidth, adjusting C401 for narrowest bandwidth without regard to amplitude. Do not adjust C402 in the 10-kHz position.

3. Adjust the second crystal filter as you did the first one.

4. Increase input level to 10,000 μV.

5. Turn i-f gain down to 5½ divisions and remove both .01-μF capacitors.

6. Alternately adjust C401 and C403 for minimum width and symmetrical skirts at the base of the signal in both the 1-kHz and 10-kHz positions. Possibly there will be some spurious resonances slightly above the filter frequency after alignment in the 10 kHz position.

Gain compensation. Set controls and test equipment as follows:

Bandwidth: 250 kHz.

Scan: 50 kHz/division.

Generator frequency ≈ 20 MHz.

Generator output: 5 divisions on display.

Sweep speed: 50 ms/division.

1. Go to 10 kHz bandwidth and adjust R403 for 5 divisions.

2. Go to 1 kHz bandwidth and adjust R402 for 5 divisions.

3. Drill access hole for L401 in i-f amplifier cover and install cover.

Tuned-circuit alignment. All tuned circuits are peaked during this procedure. Even though most have been adjusted, this is a good check to see if all are peaked at full operation. Again, only slight adjustments of the 50- and 200-MHz bandpass filters should be needed. If major adjustment is required, or if one coil won't tune, go back to the procedure in the rf section that describes initial alignment. Set controls and test equipment as follows:

Bandwidth: 250 kHz.

Scan: ≈ 500 kHz/division

Generator frequency: ≈ 20 MHz.

Generator output: ≈ 4 divisions on display.

1. Peak C301, C302, and C303 for maximum signal.

2. Peak C304 through C308 for maximum signal consistent with a flat top across signal.

3. Peak L401 for maximum signal consistent with a flat top across signal. There may be about a 1-dB dip in the center of the signal.

Log amplifier. Set controls and test equipment as follows:

Bandwidth: 10 kHz.

Scan width: 10 kHz/division.

Generator freuqency: ≈ 20 MHz.

Sweep speed: 10 ms/division.

Video filter: 10 kHz.

1. Set the generator output to 30 μV.

2. Set i-f gain for one division. Note that each pot adjusts the level for two divisions and the best compromise should be achieved. The tolerance is ±0.2 division. Always start from one division when performing this alignment.

divisions	output from generator (microvolts)	alignment pot
1	30	R503
2	100	R503
3	300	R502
4	1000	R502
5	3000	R501
6	10,000	R501

operation

This section provides an explanation of the function of the controls and concludes with some experiments to demonstrate operation.

Rf attenuator. The purpose of this circuit is to reduce the amplitude of the incoming signal to a convenient level for display on the spectrum analyzer. The maximum level to the attenuator should be no greater than 1 volt rms, and the maximum level to the first mixer should be no greater than 10 mV rms. One of the most common errors in the operation of a spectrum analyzer is to use too much i-f attenuation and feed an excessively high level to its input. This results in overloading the rf section, which generates spurious signals and causes possible damage to the first mixer. Never overload the front end.

Frequency control and fine tuning. The frequency control tunes the spectrum analyzer to the desired operating frequency. In the 10 MHz/division position, the center frequency is set to 50 MHz and the frequency control is inoperative. The fine tuning control has a range of about 500 kHz.

Scan width. After setting the center frequency with the frequency control, the scan width determines the frequency width that will be displayed. For example, if the frequency control is set to 20 MHz and the scan width to 100 kHz/division, the spectrum analyzer will sweep from 19.5 to 20.5 MHz.

Bandwidth. As in a conventional radio receiver, this control determines the selectivity of the analyzer. Narrow bandwidth is required to separate signals relatively close together and wide bandwidth is required for high sweep speeds.

I-f attenuator and i-f gain. The i-f attenuator is used for limited tests where discrete steps of attenuation are required. The i-f gain is used to provide sufficient gain with minimum noise at the baseline. The noise at the baseline rises as the bandwidth is increased and should be maintained at between one-half and one division to avoid degrading the dynamic range. See **figs. 22** and **23.**

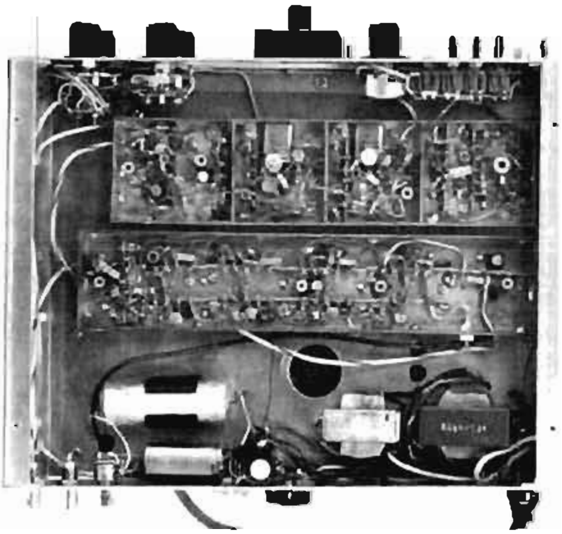
Video filter. The video filter is used to remove high-frequency noise from the signal when looking at small scan widths with slow sweep speeds. See table 2 for video filter operation. **Figs. 24** and **25** are examples of its effect in the 250-kHz bandwidth position.

Resolution. If the sweep speed is too high, the scan (or sweep) width too great, or the bandwidth too narrow, the display will lose amplitude or smear. **Figs. 26** and **27** show displays of a broadcast signal at the 250-kHz bandwidth setting. Further examples are shown in **figs. 28** and **29**, which are displays of a local television station.

A quick check on resolution is to decrease sweep speed and look for narrowing or increased amplitude of the displayed signal. The sweep speed should never exceed 2 ms/division. A P2 and P7 scope tube would be advantageous but is not absolutely required. **Table 2** gives maximum sweep speeds for some scan widths, bandwidths, and settings of the video filter.

table 2. Maximum sweep speeds for resolution at spectrum-analyzer bandwidth settings.

bandwidth (kHz)	scan width (MHz/division)	maximum sweep width (per division)	video filter (kHz)
250	10	10 ms	Off
250	1	5 ms	10
250	0.1	2 ms	10
250	0.01	not usable	—
10	10	not usable	—
10	1	0.2 sec	10
10	0.1	50 ms	10
10	0.01	20 ms	1
1	10	not usable	—
1	1	not usable	—
1	0.1	0.2 sec	10
1	0.01	50 ms	1



Bottom view of spectrum analyzer chassis showing the i-f assembly (along front of chassis, top) and logarithmic amplifier (center). Power supply components are located along the rear of the chassis, bottom.

400-500 MHz operation. If the input lowpass filter is disconnected, the 200- to 300-MHz first local oscillator will mix with 500 to 400 MHz, producing the required 200 MHz first i-f. This was tried and some strong local low-frequency signals leaked through. Sensitivity seemed similar to normal operation, but signals were displayed in reverse.

Use as a radio receiver. The output can be connected to an audio amplifier with 1-megohm input impedance and used to monitor radio signals. However, because it is a spectrum analyzer, the instrument has several limitations when used as a radio receiver. Dial calibration is accurate to only ±3 MHz. Because of its high frequency, the local oscillator drifts and some fine tuning might be required. There is no tuned circuit at the front end, therefore a strong signal can cross-modulate the analyzer. Despite these shortcomings, WWV, BBC, Australian Broadcasting, Radio Netherlands, Radio Moscow and many other stations have been received using a TV feedline as an antenna.

As with most anything else, there is more than one way to design a spectrum analyzer. If you find an easier or better way to improve this spectrum analyzer, without degrading its performance, or find any obvious errors, I'd appreciate hearing from you.

reference

1. Wayne C. Ryder, W6URH, "500-MHz Decode Prescaler," *ham radio*, June, 1975, page 32.

bibliography

1. *Spectrum Analyzer Basics*, Hewlett-Packard Applications note 150, Hewlett-Packard, 1501 Page Mill Road, Palo Alto, California 94304.
2. *Spectrum Analyzer Measurements*, (Tektronix part no. 062-1070-00), Tektronix, Inc., P.O. Box 500, Beaverton, Oregon 97077.
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ham radio