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A Spectrum Analyzer for the Radio Amateur

Good tools are priceless when you need them. Here's a piece of test equipment you've always wanted for your workbench. Now you can have it—without spending a fortune.

A mong the many measurement tools sought by the amateur experimenter, the most desired—but generally considered the least accessible—is the *radio-frequency spectrum analyzer* or SA. This need not be. Simple and easily duplicated, this home-built analyzer is capable of useful measurements in the 50 kHz to 70 MHz region. The design can be extended easily into the VHF and UHF region with methods outlined later. The instrument is configured to be self-calibrating, or capable of calibration with simple home-built test gear.[1]

[1]Notes appear on page 43.

We often read and hear about "simple designs." Simplicity implies that something is eliminated to make the equipment easier to build, use or afford. Unlike designs that sacrifice performance for cost and simplicity, this one sacrifices only convenience, while retaining the capabilities needed for accurate measurements.
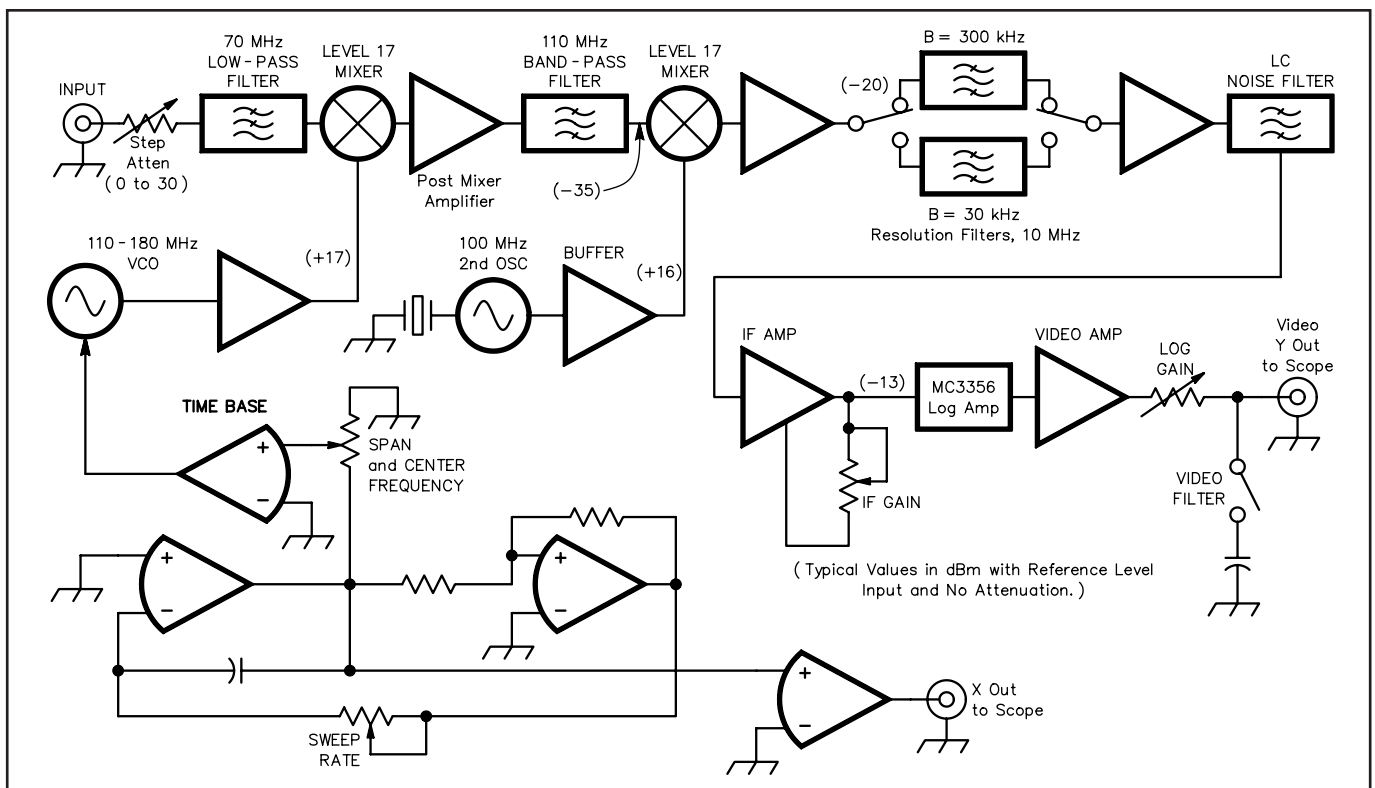

Figure 1—Block diagram of the spectrum analyzer. The circuit is a double-conversion superheterodyne design with intermediate frequencies of 110 and 10 MHz.
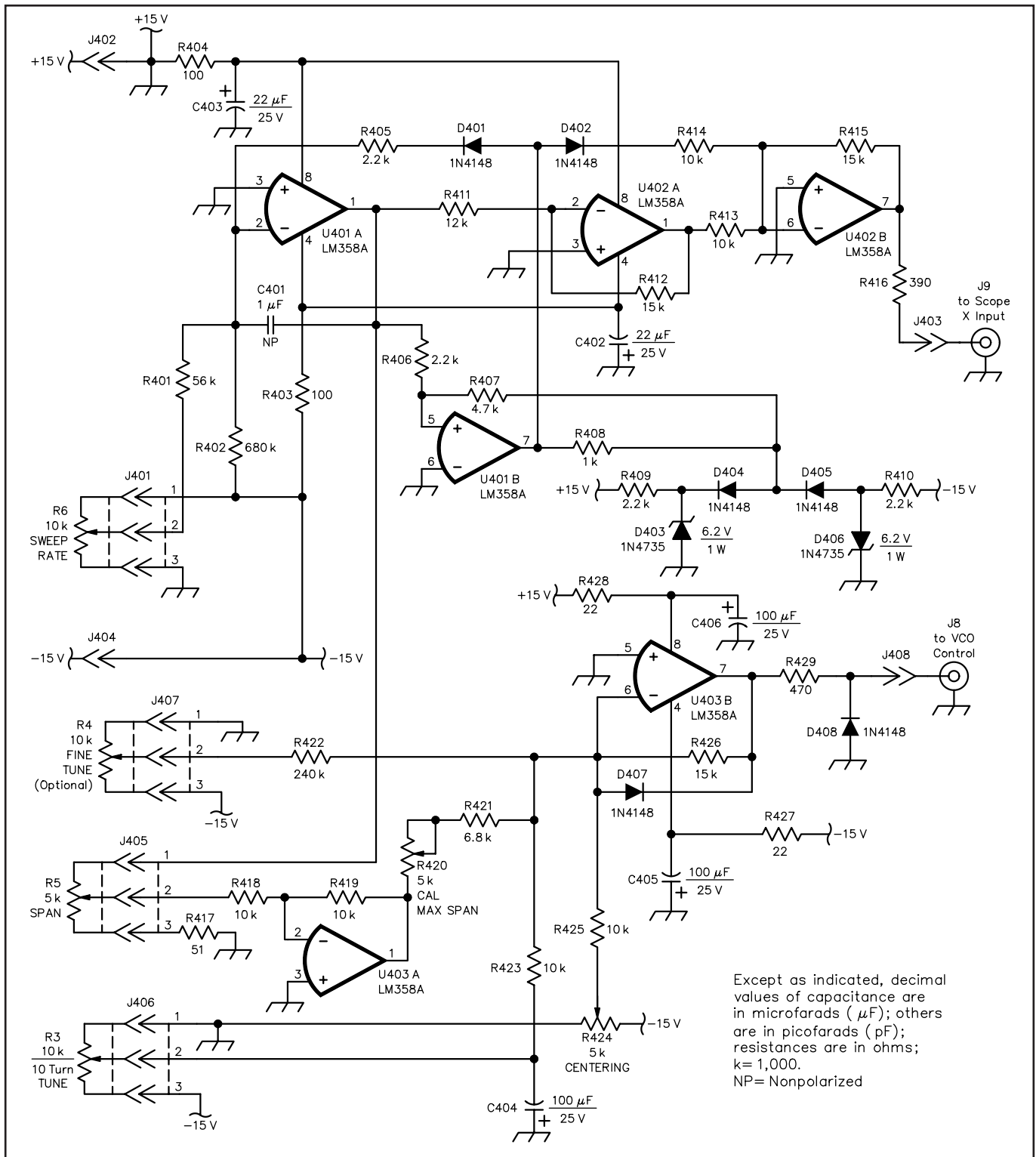
Figure 2—Time base for the spectrum analyzer. Refer to the text for a discussion of the various circuit functions. Front-panel controls include **SWEEP RATE, SPAN** and **TUNE**. Unless otherwise specified, resistors are ¹/₄ W, 5% tolerance carbon-composition or film units. Equivalent parts can be substituted.

U401, U402, U403—LM358 op amp
D403, D406—6.2 V Zener diodes, 1 W
C401—Metal film or Mylar, 1.0 µF
  capacitor

R420, R423—PC-mount trim pots, 5 kΩ or
  10 kΩ suitable
R3, R4, R5, R6—Panel-mounted linear

control, 5 kΩ or 10 kΩ suitable. If a 10
turn pot is used for R3, R4 is not
needed.

Modern technology eases the construction of this spectrum analyzer. The logarithmic amplifier uses an IF amplifier IC found in cellular telephones and includes a *received signal strength indicator* (RSSI) function. Hybrid and monolithic IC building blocks are employed extensively. These include mixers, amplifiers and VCOs—all vital elements in an analyzer. Finally, it is a rare devoted experimenter today who does not own an oscilloscope. With good basic 'scopes available for about the price of a hand-held FM transceiver, every experimenter should have one. Our spectrum analyzer uses a 'scope as the display. There

are no special requirements for 'scope performance other than an X-Y mode with dc coupling in the X and Y axes.

Some Spectrum-Analysis Basics

The RF spectrum analyzer is essentially a swept receiver with a visual display. The display shows the strength of all signals within a user-defined frequency span. Each signal is represented by a line or blip that rises out of a background noise, much like the action of an S meter. Commercial analyzers are calibrated for signal power, with all signals referred to a reference level at the top of the screen. Our analyzer is designed for a basic reference level of –30 dBm, a common value in commercial analyzers.[2]

Signal levels are read from the display by noting that power drops by 10 dB for each major division on the 'scope. You can change the reference level. Adding gain to the analyzer moves the reference to lower levels; introducing attenuation ahead of the instrument moves the reference to higher power levels.

Circuit Overview

Figure 1 is a block diagram of our spectrum analyzer. A double-conversion superheterodyne, it begins with a step attenuator, followed by a low-pass filter and the first mixer, where incoming signals are upconverted to a 110 MHz first IF. After some gain and band-pass filtering, a second conversion moves the signals to a 10 MHz IF. The resolution bandwidths available are 30 kHz and 300 kHz. A video filter smooths or averages noise. The available frequency spans range from a per-division maximum of 7 MHz to about 50 kHz. The center frequency can be adjusted over the entire 70 MHz range. An uncalibrated **SPAN** control allows expansion of the display about the screen center. An uncalibrated **SWEEP RATE** control allows the sweep to be controlled and matched to a given span while avoiding excessively fast scans that could introduce errors.

Ideally, a receiver's first IF should be greater than twice the highest input frequency, a design rule that we bend in this application. The input tuning range includes all HF amateur bands and 6 meters. (We'll discuss higher tuning ranges later.) We picked the 10 MHz second IF because surplus-crystal filters and LC filters for this frequency are easily built. You can easily adapt the design's IF to 10.7 MHz, or other close, convenient values.

The swept LO tunes from 110 to 180 MHz with a commercial VCO module. The VCO output is amplified to drive a high-level-input mixer. The commercial VCO is a recent modification to a design that started with a homebrew oscillator.[3]

Amplifiers are included at the 10 and 110 MHz IFs. These establish signal levels that properly match the log-amplifier win-

dow, while preserving system dynamic range. The proper distribution of gain, selectivity and signal-handling capability (intercepts) of the amplifiers and mixers is vital to achieving good performance in a spectrum analyzer, and indeed, any receiver. A proper design will have the same number of stages as a poor one, but will probably use different components and consume more current.

The analyzer uses a ±15 V power supply. The positive supply delivers about 0.5 A. The negative supply current drain is under 50 mA.

Following sections present the circuit blocks in greater detail, in the order that they should be built. The partial but growing system can then be used to test the other sections as they are built, turned on and integrated. We *strongly discourage* building the entire analyzer before testing specific sections. Such an approach may work for casual kits, but is *not suitable* when careful control of signal levels is required. That approach also robs you (the builder) of the excitement of the process: the learning that comes from detailed examination.

Before jumping into the circuit details, we reemphasize that this analyzer—although simple—is intended for *serious* measurements. This means that a normal maximum span display contains no spurious signals. When clean (well-filtered, harmonic-free) signals are applied to the analyzer, there should be *no* extra products as long as the signal level is kept on screen. This performance goal applies for a single tone, or for two equal signals at the top of the screen.

Time Base

Figure 2 shows the analyzer time base, designed for basic functionality without frills; the result is a circuit using only a handful of op amps.[4] U401A and U401B form a free-running sawtooth generator, a

circuit commonly found in function generators. U401A operates as an integrator; current is pulled from the inverting input through a 56-kΩ resistor connected to the **SWEEP RATE** control. This current must flow through the capacitor (C401), creating a linearly changing op-amp output voltage. This ramp is applied to U401B, a regenerative comparator, which provides a reset signal to the integrator. The sawtooth waveform (pin 1 of U401A) is asymmetrical: The positive-going ramp grows with a slope determined by the front-panel-mounted **SWEEP RATE** pot, while the negative-going, faster reset ramp is determined by fixed-value components.

The U401 ramp is used twice. U402A and B process the ramp to generate a signal that drives the 'scope's X axis. The signal has a 0 V-centered range with just over a 10 V total swing. Some of the "square wave" from the basic time base (U401B, pin 7) is added to the input of U402B to cause the sweep to reset quickly, even though the return sweep for the VCO occurs in a more stable, smooth way. A slight overscan is generated for the X axis, serving to hide an aberration occurring near the sweep beginning.

The sweep also generates the signal that controls the VCO. The sweep signal (U401A pin 1) is applied to a **SPAN** control. When the analyzer is set for maximum span, the VCO voltage (about 2 to 10 V) generates a sweep from 110 to 180 MHz. The VCO uses only positive sweep voltages, so the output of U403B is diode-clamped to prevent negative output. The center frequency **TUNE**, **FINE TUNE** and a **MAX SPAN** calibration pot set up the proper sweep for maximum span. As the span is reduced with the **SPAN** control, the sweep expands on (or zeroes in on) whatever appears at the center of the screen, determined by the tuning. The center frequency must be set for 35 MHz at maximum span, which coincides with having the zero signal, or
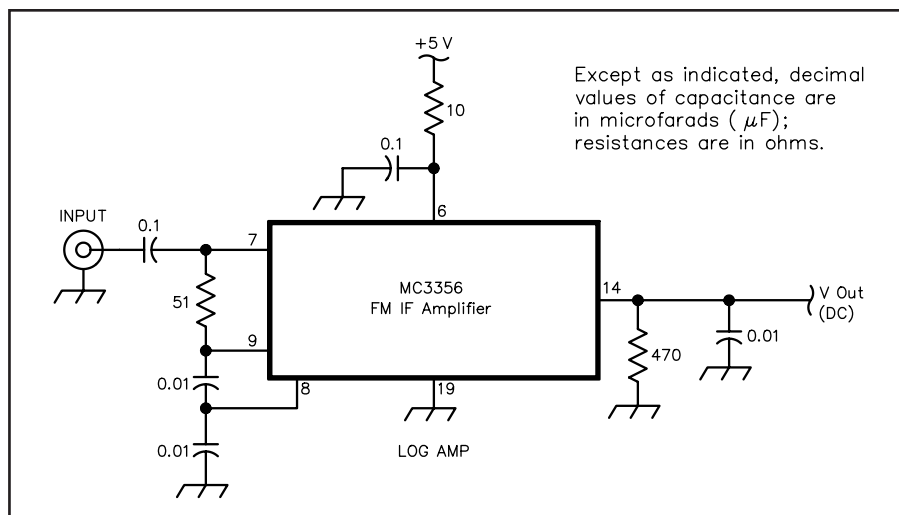

Figure 3—An experimental logarithmic amplifier breadboarded to evaluate performance prior to analyzer construction. You may want to duplicate this circuit and analyze its performance if you decide to use other log-amp ICs.
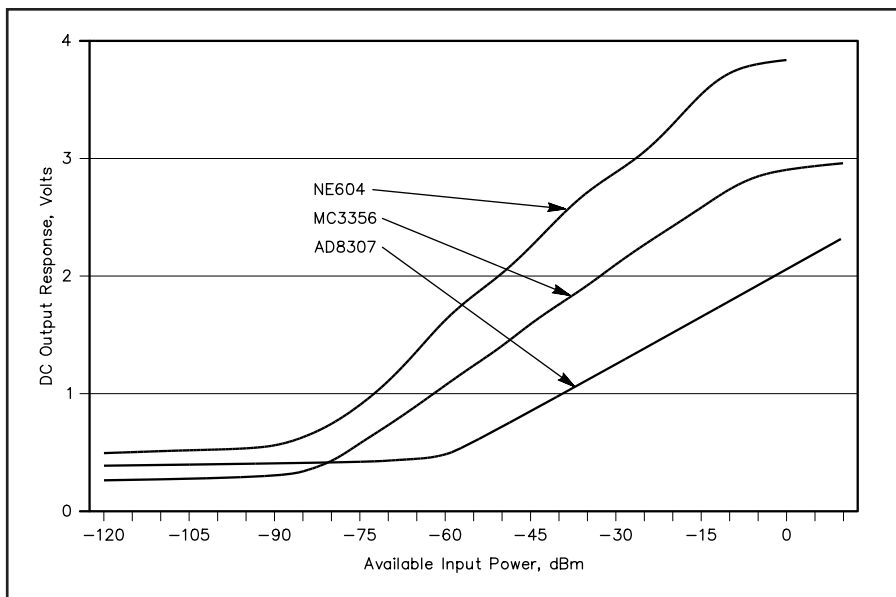
Figure 4—Transfer characteristics for three different logarithmic amplifier ICs. Although the MC3356 is used in our analyzers, use of the AD8307, shown in the lower curve, is recommended. Some curves have been linearly scaled to ease comparison.

"zero spur" at the left edge of the screen.

Setting up the time-base function is generally straightforward. The 'scope can be used to debug, check and study the circuits. The X-axis signal is a ramp ranging from –6 to +6 V with a reset to –15 V during the retrace. A similar ramp appears (without a reset pulse) at the VCO output, but with an amplitude dependent on the **SPAN** control setting.

Although the op amps are carefully bypassed, and the signal that tunes the VCO is shielded, most circuits are noncritical. Normal op-amp circuit precautions are taken with resistors injecting signals into inverting inputs positioned close to the op-amps.[5]

A 10-turn front-panel-mounted pot is used for the **TUNE** control (any value from 5 kΩ to 50 kΩ is suitable). A single-turn pot can be substituted if a 10-turn pot is not available. A fine-tuning function is included in this design, but may be omitted if a 10-turn pot is used for the main tuning.

Log Amplifier and Detector

Central to any spectrum analyzer is a *logarithmic amplifier*. The need for logarithmic processing becomes clear if we consider the range of signals we want to measure: At the low end, we may want to look at submicrovolt levels: under –107 dBm in a 50-Ω system. At the other extreme, we may want to measure the output of small transmitters, perhaps up to a power of 1 W, or +30 dBm. The difference between the two levels is 137 dB. The human ear is capable of handling linear ranges well over 60 dB.[6] This is a wide dynamic range world and linear displays, such as our screen, are inadequate unless some form of data compression or loga-

rithmic processing is used.

The circuit element we use for this processing is the log amplifier.[7] The term is a misnomer, for the usual log-amp IC is both a logarithmic processor (amplifier) and a detector. The chips provide a dc output voltage that increases in proportion to the logarithm of the input amplitude. The central sensitivity specification for a log amp is a voltage slope that is equal to the voltage change (per decade or per decibel) of input-voltage-amplitude change.

An experimental log amp is shown in Figure 3. We breadboarded and tested this circuit to evaluate the log IC. To produce the MC3356 curve shown in Figure 4, the 10 MHz output of an HP-8654 signal generator was applied through HP-355 step attenuators. Exact dc output levels are insignificant, for they can be adjusted with dc voltage gain in a following amplifier. The salient detail that we observe is the dynamic input window. The MC3356, with a 50-Ω input termination, produces a nearly straight-line output voltage versus input power for inputs in the –80 to –10 dBm range. Hence, the analyzer log amp should operate with an input signal of –10 dBm for signals at the top of the screen.

We evaluated two other ICs. One, the commonly available NE/SA604, shows considerable ripple. The best performance offered came from a recently introduced chip from Analog Devices: the AD8307. This IC is designed specifically for measurement applications and offers outstanding logarithmic accuracy, a dynamic range exceeding 90 dB and better temperature stability than found with the usual cellular-receiver chips. The AD8307 requires a high drive level, so it must be preceded with higher-power amplifiers or impedance-

transforming networks. The bandwidth of the AD8307 is about 500 MHz, so care is required in its use.

Our analyzer uses the inexpensive and readily available MC3356 log amp shown in Figure 5.[8] An op amp, U303, used to increase the signal output to 0.5 V per division, follows the log chip, U301. The 0 V level corresponds to the bottom of the screen; a signal of 4 V brings the response to the top of the screen. The op-amp output is slightly higher than this, but is then attenuated with a **LOG AMP CAL** control, R2. This pot should be accessible from the outside of the instrument.

The log amp is preceded by an IF amplifier, Q301 through Q303. These stages are biased for relatively high-current operation to preserve linearity. Gain is controlled through variable emitter degeneration in the form of a PIN diode, D301. Most common 1N4000-series power rectifiers work well for gain control. The **IF GAIN ADJ** control (R1) should be available from the exterior of the RF-tight amplifier box. We have placed it on the front panel of our analyzers.

Calibration of the IF and log amplifier is straightforward. First, set the 'scope's Y axis to 0.5 V/division and short it. Set the now-working time base to drive the X axis and adjust the 'scope's vertical position control to place the horizontal line at the bottom of the screen. Inject a –10 dBm signal from a signal generator into the log amplifier input, remove the short circuit and adjust R2, **LOG AMP CAL**, for a full-screen (reference level) response. The input level is next reduced in 10 dB steps. The horizontal sweep line should drop down one major division for each 10 dB reduction over a 60 dB range. If this does not happen, repeat the procedure with a slightly different drive level. In our analyzers, a typical drive level of –13 dBm produced good accuracy.

Now, attach the IF amplifier to the log amplifier and drive them with an input level of –23 dBm. Peak the IF output filter for maximum response and set R1, **IF GAIN ADJ**, for a full-screen response. A true filter peak can be confirmed by varying the generator frequency. There is considerable extra range in the **IF GAIN ADJ**, providing extra flexibility during use.

Resolution Filters

Continuing the backward progression through the system, we encounter the resolution-bandwidth-determining filters. Our analyzer uses bandwidths of 30 and 300 kHz, provided by crystal and LC filters, respectively. The 300 kHz LC filter, the crystal filter and the relay circuitry for bandwidth switching are shown in Figure 6. Although shown as individual modules, they can be incorporated into one. The PC board for the filter includes the LC filter and switching relays with room for a user-selected crystal filter. Builders may want to implement their own scheme here. We
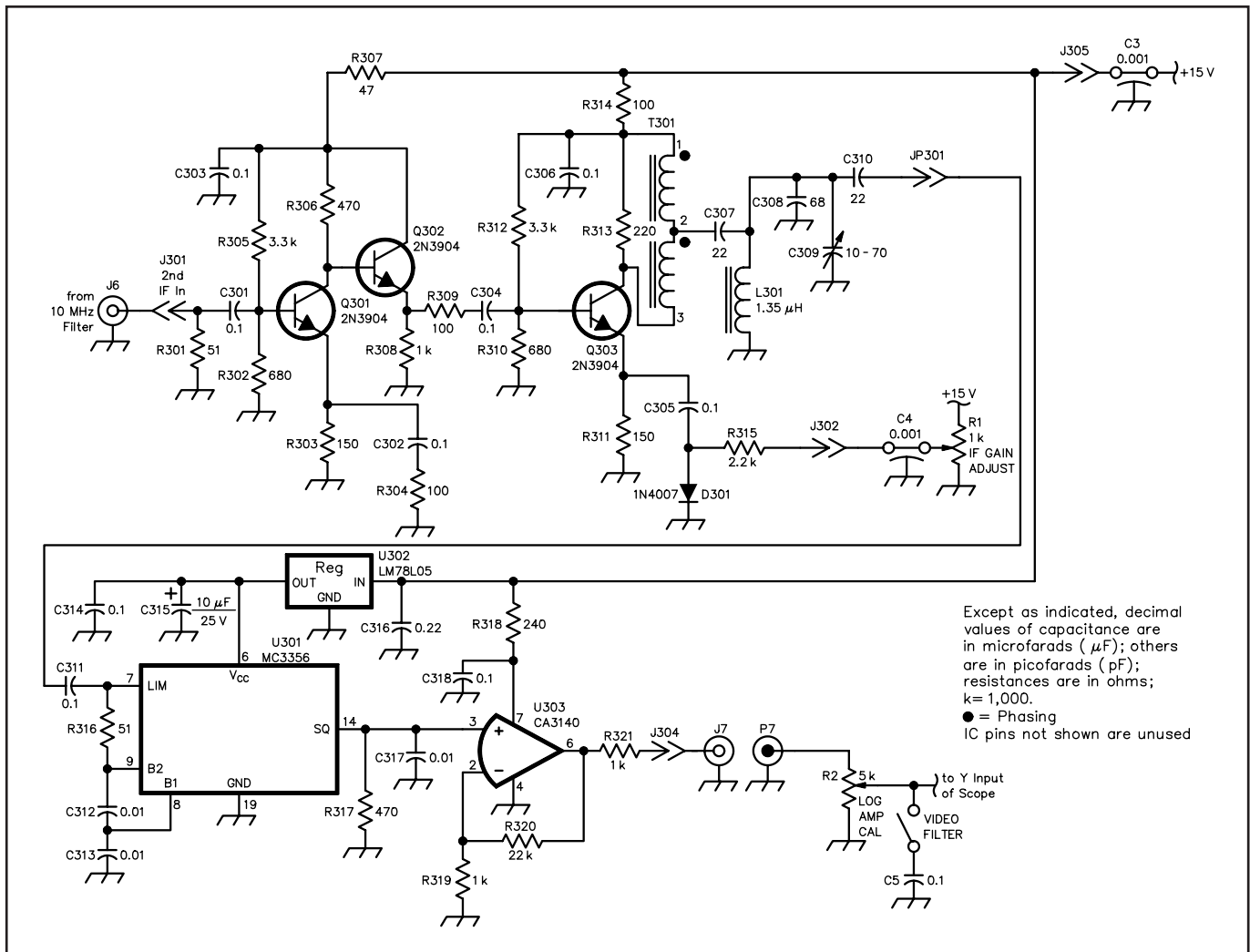
Figure 5—The 10 MHz IF amplifier and log amplifier used in the analyzer. Refer to the text for adjustment details. Unless otherwise specified, resistors are $1/4$ W, 5% tolerance carbon-composition or film units. Equivalent parts can be substituted.

C309—Plastic dielectric trim cap
  (Sprague-Goodman GYD65000)
C307, C308, C310—Silver mica or NP0
  ceramic capacitors, 10% tolerance
C316—0.22 µF ceramic

D301—PIN diode; 1N4007 used
L301—1.35 uH, 18 turns #24 enameled
  wire on T-44-6 core, Q >150
Q301, Q302, Q303—2N3904

R1—Panel-mount, 1 kΩ linear
R2—Panel-mount, 5 kΩ linear
U301—Motorola MC3356
U302—78L05 +5 V regulator
U303—CA3140 op amp

reasoned that builders would want to implement their own ideas. Maintain reasonable shielding for this part of the system. Additional attenuator pads can be inserted in line with one filter or the other to approximately equalize filter loss in the two paths.

You may want to build crystal filters for your analyzer.[9] The VCO stability in this analyzer will support resolution bandwidths as narrow as 3 to 5 kHz. For a simplified beginning, a very practical analyzer can be built with only one resolution bandwidth of 300 kHz.

Second Mixer and Second Local Oscillator

Figure 7 shows the second mixer and related LO. The heart of this module—and to some extent that of the entire analyzer—is U202, a high-level second mixer. This mixer is bombarded by large signals that are as strong or stronger than those at the front end. Accordingly, the second mixer should have an intercept similar to that of the first mixer. This is the usual weak point in all too many homebrew spectrum analyzers—as well as more than a few receivers! The second mixer, U202, uses a +17 dBm level Mini-Circuits TUF-1H. This is *not* the place for a current-starved telephone component! The second mixer is terminated in a high-pass/low-pass diplexer followed by an IF amplifier (Q202) biased at 50 mA. This is a critical stage for dynamic range: Don't replace it with a monolithic substitute of reduced gain or intercept.

The second LO begins with a 100 MHz, fifth-overtone crystal oscillator (Q201), followed by a pad and a power amplifier. The oscillator inductor, L201, in Q201's collector is made of five turns of #22 wire wound on a 6-32 machine screw. (Remove the screw before installing the coil.) Here's an excellent way to align the oscillator:

Temporarily replace the crystal, Y201, with a 51 Ω resistor. Adjust the tuned circuit until oscillation occurs at the desired 100 MHz frequency. Then, replace the 51 Ω resistor with the 100 MHz crystal; no further tuning is required. Measure the oscillator's output with a power meter before applying it to U202. Adjust the pad attenuation (R205, R206, R207) to realize the specified LO drive level.

After the second LO is operating, attach it to the second mixer and the rest of the analyzer. With a second mixer input of –35 dBm at 110 MHz, you should obtain a reference-level response.

Voltage-Controlled Local Oscillator and First Mixer

Figure 8 shows the analyzer's swept LO. The foundation for this module is a Mini-Circuits POS-200 VCO module, U101. Similar VCOs are available from many
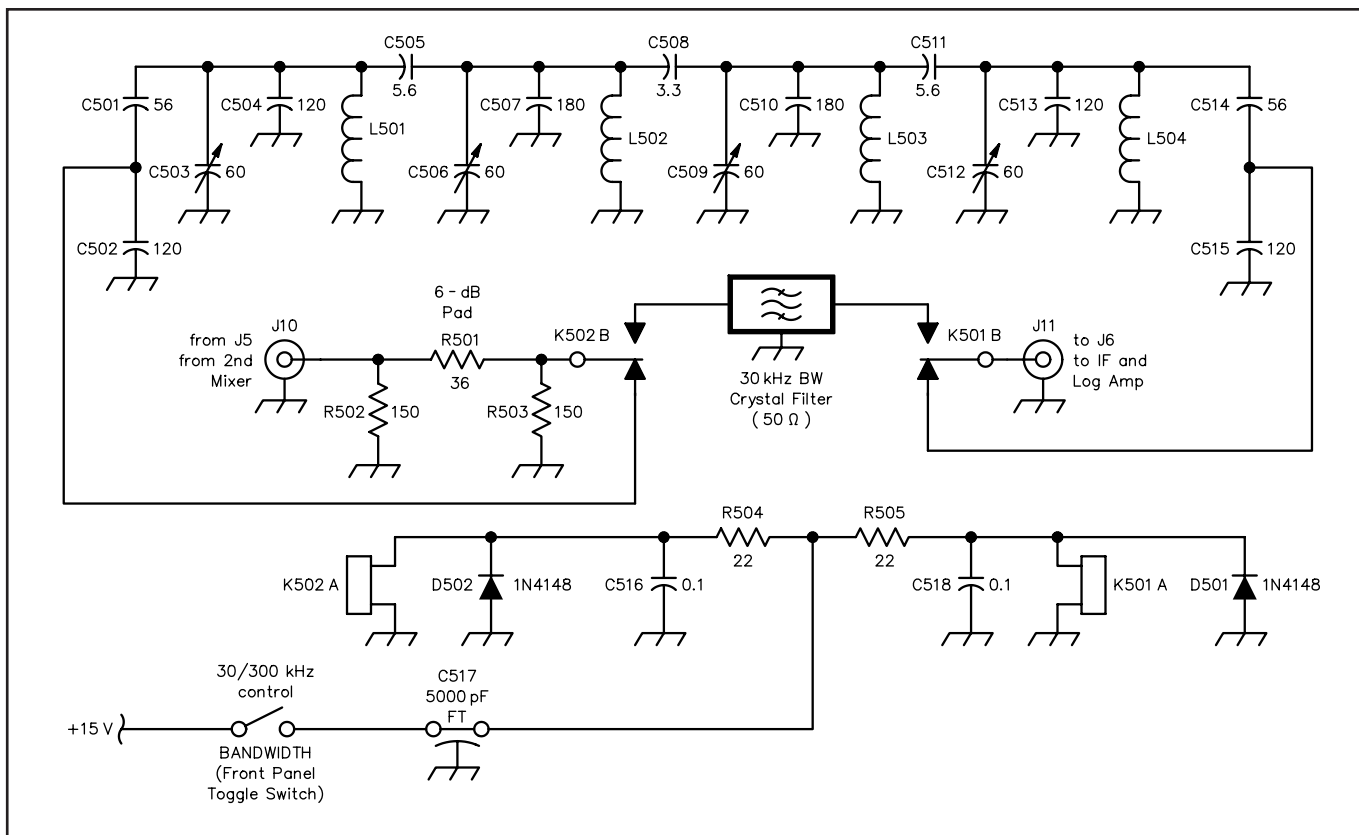
Figure 6—Resolution filters: The upper schematic shows the 300 kHz bandwidth 10 MHz LC filter. If desired, that circuit can be realigned at 10.7 MHz without other design changes. The LC filter is shown as a separate unit connected to the rest of the analyzer with coaxial cable. However, the filter can be constructed on the board with the crystal filter and relays. Unless otherwise specified, resistors are $^1/_4$ W, 5% tolerance carbon-composition or film units. Equivalent parts can be substituted.

C501, C502, C504, C505, C507, C508, C510, C511, C513, C514, C515—Silver mica or NP0 ceramic, 5%
C503, C506, C509, C512—65 pF plastic

dielectric trim cap (Sprague-Goodman GYD65000)
K501, K502—SPDT relay; Aromat TF2-12V used here (one contact set

unused); values of associated dropping resistors may need adjustment.
L501-L504—17 turns of #22 enameled wire on a T-50-6 toroid (1.15 µH), Q > 250

vendors.[10] The VCO output is about +10 dBm, too low a level for the high-level mixer. A MAV-11 amplifier, U102, preceded by a pad to provide level adjustment, increases the signal level. Confirm the output power level before applying it to the mixer, U103.

Once the VCO output level is adjusted and confirmed, calibrate its frequency against the VCO control voltage. If a VHF counter is not available, you can obtain a few points by tuning the VCO to hit local FM broadcast signals of known frequency. Calibrating the VCO is useful if the module is used later as a signal source for alignment of the 110 MHz band-pass filter.

Figure 8 also shows the input mixer, U103, another Mini-Circuits TUF-1H, terminated in a 6 dB pad. Although the pad degrades the noise figure, it presents a solid output termination for the mixer. This termination is reflected, helping to provide a good mixer-input impedance match, important in a measurement instrument. The pad is followed by a Mini-Circuits MAV-11 IF amplifier (U104) that restores the gain lost in the mixer and pad.

The mixer application differs from a

normal diode ring: The RF input is now attached to the dc-coupled port. This allows input frequencies as low as 50 kHz to be converted to the first IF. The low-frequency end is limited by mixer LO to RF isolation, which determines the LO energy that reaches the first IF. The related on-screen response is often termed the *zero spur*, a familiar "feature" in most RF spectrum analyzers.

This module (VCO and first mixer) is contained in a shielded enclosure with coaxial inputs and outputs, including coaxial routing of the VCO control voltage. The front end is susceptible to any VHF and UHF signals reaching it, making shielding and decoupling especially important.

The 110-MHz IF Band-Pass Filter

One of the more-critical blocks in the analyzer is the filter that establishes the bandwidth of the VHF IF. The bandwidth must be at least as wide as the widest 10 MHz filter, but must be narrow enough to reject the 90 MHz second-conversion images by 80 dB or more. This performance is only available with a three-pole or higher-order filter. The best double-tuned

circuits we built (or computer simulated) came close, but just didn't cut it.

We described double-tuned circuits in detail in a 1991 *QST* tutorial paper.[11] Those methods have recently been extended to three-resonator filters.[12] One of the methods presented in the later paper is a sequential approach that begins with a double-tuned circuit (DTC). First, a DTC is built for the desired 3 dB bandwidth and has its performance confirmed with a wideband sweep (a vital requirement!) Then, a third resonator is inserted between the original two. Coupling elements similar to the one that produced the required DTC bandwidth are repeated in the triple-tuned circuit, but end-section loading is not changed. The center frequency of the three resonators is aligned to complete the filter.

The schematic for the 110 MHz triple-tuned circuit is shown in Figure 9. The inductors,100 nH, are made by winding 5 turns of #18 wire on the shank of a $^1/_4$-inch drill bit. These inductors typically have an unloaded Q of just over 200 at 110 MHz. Larger-diameter inductors would have produced higher unloaded Q with the attendant lower insertion loss. However, the
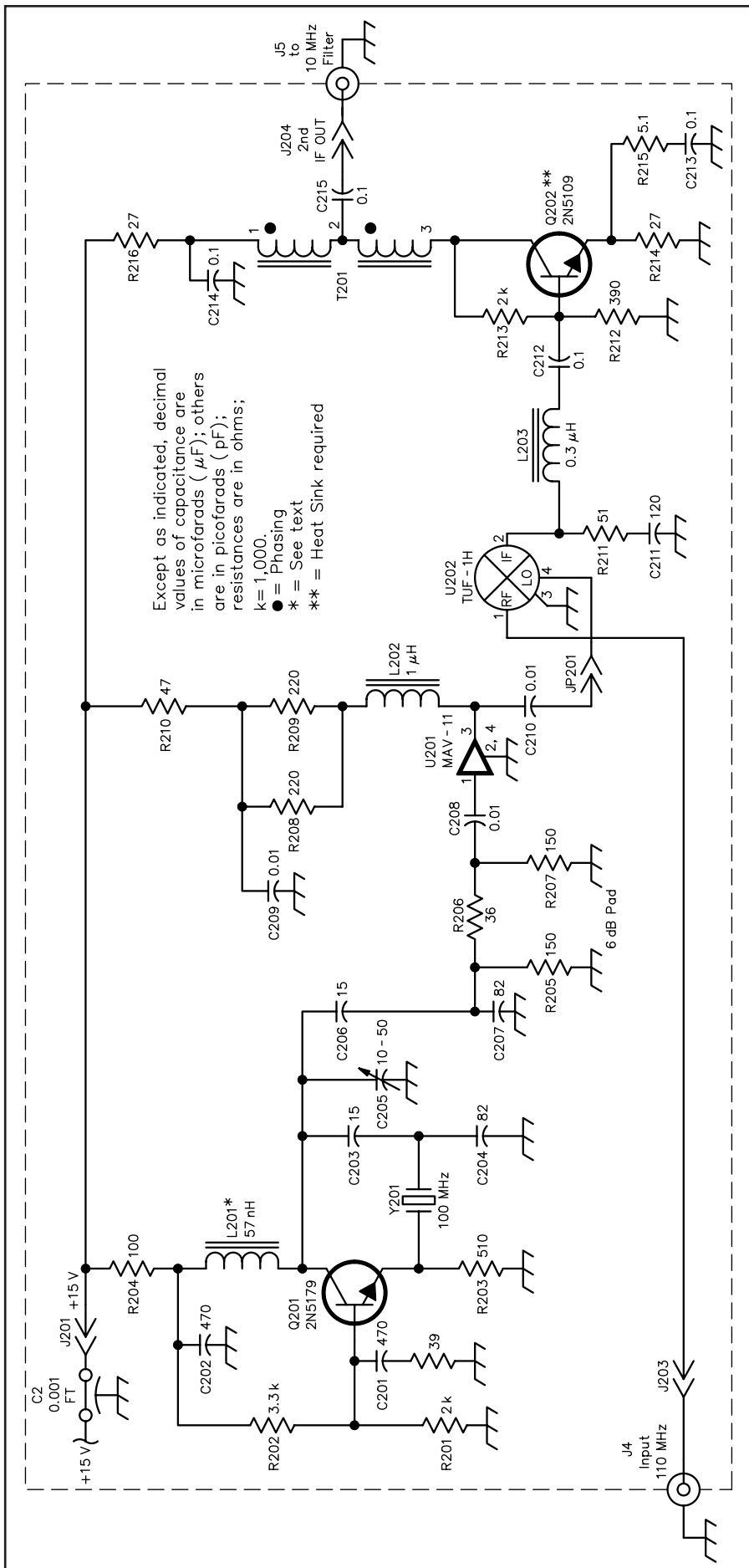
Figure 7—Second mixer and second LO. L203 in the output of U202 consists of 17 turns of #28 enameled wire on a T-30-6 toroid. The actual value is not critical and a molded RF choke can be used in place of the toroid. Unless otherwise specified, resistors are 1/4 W, 5% tolerance carbon-composition or film units. Equivalent parts can be substituted.
C201, C202—470 pF ceramic
C203, C206—15 pF NP0 ceramic or silver mica
C204, C207—82 pF NP0 ceramic or silver mica
C205—65 pF plastic dielectric trim cap (Sprague-Goodman GYD65000)
C211—120 pF, silver mica or NP0 ceramic
L201—57 nH; 5 turns of #22 wire wound on a 6-32 machine screw. Remove the screw before installing the coil.
L202—1 µH molded RFC; any value from 100 nH to 2.7 µH is okay
L203—0.3 µH; 9 turns #24 enameled wire on a T-30-6 core
Q201—2N5179
Q202—2N5109, 2N3866, 2SC1252, etc
U201—Mini-Circuits MAV-11
U202—Mini-Circuits TUF-1H mixer
T201—10 bifilar turns #28 on FT-37-43 ferrite toroid

stray coupling between coils would have increased, which would have necessitated shields between filter sections. The smaller (10 nH) end-matching inductors are one-inch lengths of #18 wire. The triple-tuned filter, and its parent DTC, have bandwidths of 2 to 3 MHz.

The filter alignment and experimentation is usually done with a sensitive power meter,[13] a step attenuator and a signal source. As mentioned earlier, the VCO can serve the role of signal generator, if one is not available.

The second-conversion image rejection is easily measured with a finished analyzer. Apply a 40 MHz signal to the analyzer and adjust it for a reference-level response. Don't touch the analyzer tuning, but move the signal generator to 60 MHz. An image signal may appear at the same point on screen as the original 40 MHz signal. The rejection was only 66 dB with a DTC used for some experiments. The triple-tuned filter produced 90-dB rejection. The slight extra effort of the triple-tuned circuit is easily justified. No PC board is available for the IF filter.

Input Low-Pass Filter

A 70 MHz low-pass filter is shown in Figure 10. This circuit and a step attenuator are housed in separate shielded enclosures in one of our analyzers. In the other, the filter and the attenuator remain outboard elements. Integral components are more convenient for routine analyzer applications, but incorporation removes them from the equipment pool available for other experiments. Also, operation without an outboard low-pass filter allows the instrument to be
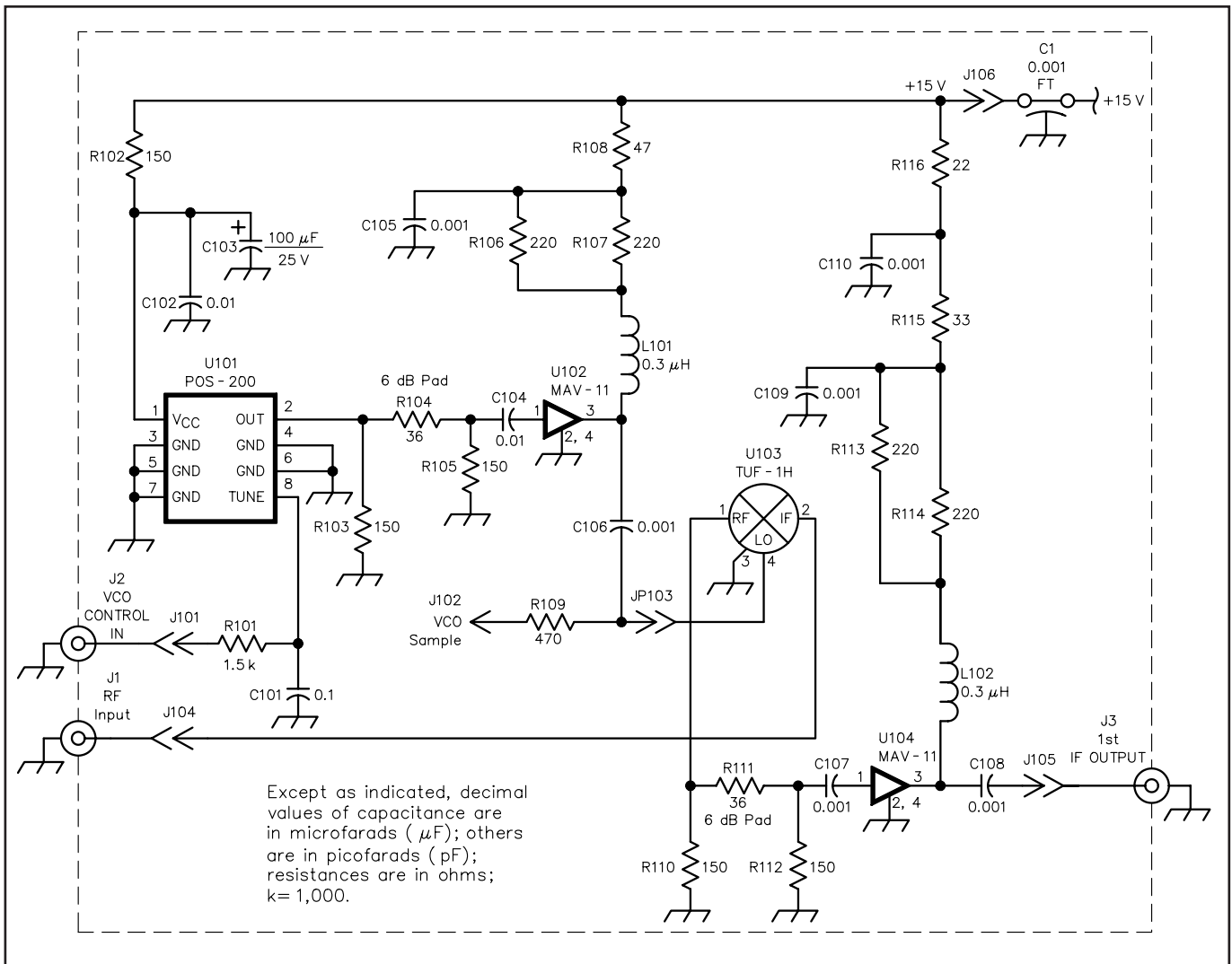
Figure 8—Front-end for the spectrum analyzer. The LO drive level is set to between +16 and +18 dBm by trimming the pad attenuation. The 1 µH inductors used in the MAV-11 outputs can be molded RF chokes or made of 17 turns of #28 enameled wire wound on T-30-6 toroids. Unless otherwise specified, resistors are 1/4 W, 5% tolerance carbon-composition or film units. Equivalent parts can be substituted.

L101, L102—1 µH molded RFC; any value between 100 nH to 2.7 µH suitable

U101—Mini-Circuits POS-200 VCO
U102, U104—Mini-Circuits MAV-11
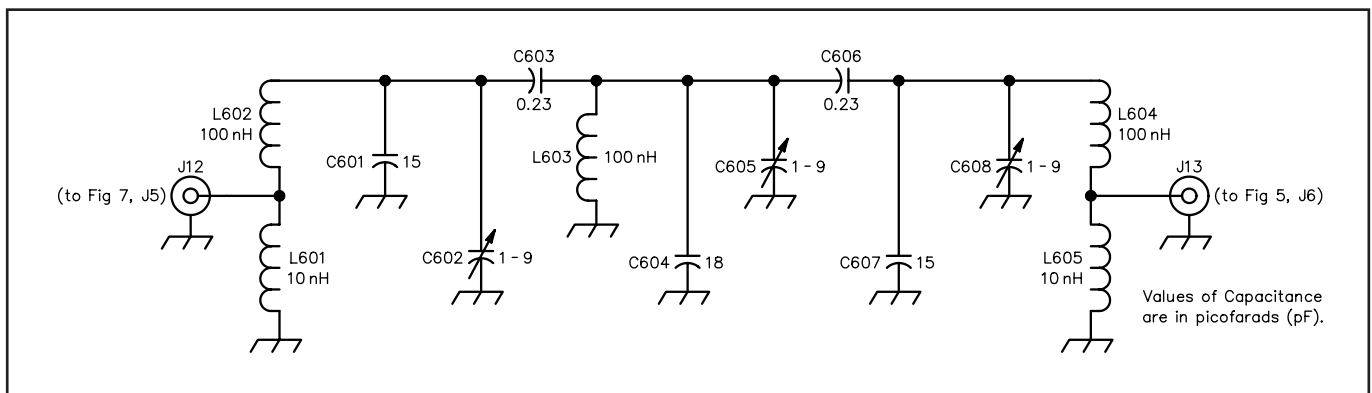
U103—Mini-Circuits TUF-1H

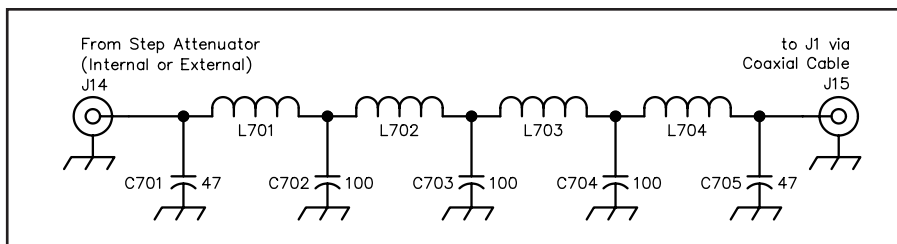Figure 9—VHF band-pass filter used in the 110 MHz IF.

Figure 10—Input 70 MHz low-pass filter. The filter started as a ninth-order Chebyshev design, but was modified through computer manipulation to use equal-value inductors and standard-value capacitors. The inductors each consist of 8 turns of #22 wire. The wire is wound on the threads a $\frac{1}{4}$-20 bolt as a form; remove the bolt after winding the inductor. See text.

C701-C705—NP0 ceramic, 5% tolerance.

L701-L704—8 turns #22 bare wire wound in 1/4-20 bolt threads; see text.

used well into the low UHF area by operating the mixer with VCO harmonics. (No circuit boards are available for this filter.)

Construction and Adjustment Hints

The spectrum analyzer can be built using a number of RF techniques. Our analyzers are collections of small boxes using coaxial-cable interconnections. Power supplies reach the interior of RF modules through feedthrough capacitors. The only open boards in the system are the time base and (in one instrument) the log amp, both constrained to low frequencies. The 110 MHz IF filter and all RF circuit boards are designed to fit in Hammond 1590B diecast aluminum alloy boxes.

The sensitivity of such RF measurement equipment justifies the extensive shielding. Spurious responses are readily seen on the display. While a few can be tolerated, they seriously detract from a measurement when, for example, spurious transmitter products are being examined.

Most of the adjustment has already been discussed. Indeed, by the time the analyzer is finished, there is little alignment left! The block diagram (Figure 1) has typical signal levels shown in parentheses.

The finished analyzer is set up with a –30 dBm signal from a stable-impedance source. Adjust the IF gain to establish the reference level. If the 10 dB per division tracking is not quite correct, change the log amp gain, followed by a readjustment of the IF gain until tracking is correct. IF gain is adjusted to the reference level whenever the analyzer is used.

Next month, we'll present methods to extend the analyzer to higher frequencies. We'll discuss simple test equipment that can be used in alignment and present some typical examples of spectrum-analyzer use.

Notes
[1] Homebrew analyzers described in amateur literature in recent years have often used TV tuners as the front end. See, for example, Al Helfrick, K2BLA, "An Inexpensive Spectrum Analyzer for the Radio Amateur," *QST*, Nov 1985, pp 23-29. A more recent example is Fred Brown, W6HPH, "Build a 5- to 850-MHz Spectrum Analyzer," *Communications Quarterly*, Winter, 1997, pp 91-96.

[2] The usual unit for power measurement with a spectrum analyzer is dBm. This is an absolute, impedance invariant unit, signifying power compared with 1 mW. Hence, –30 dBm is 30 dB below a milliwatt, or a microwatt. The dBm unit is especially useful in spectrum analysis where two levels are often compared. The difference between two powers in dBm is a power ratio in dB. (See Jay Craswell, WB0VNE, "Converting Between dBm, Milliwatts and Watts," Technical Correspondence, *QST*, Jul 1998, p 70.—*Ed.*)

[3] Excellent homebrew VCOs can be built using the work of Allan Victor, WA4MGX, "Wideband VCO Design," *Ham Radio Magazine*, Jul, 1984, pp 49-58. See also the recent work of Colin Horrabin, G3SBI, as reprinted in "Tech Notes," *Communications Quarterly*, Winter, 1996, pp 94-104.

[4] Many amateurs are uncomfortable with op-amp circuits, a situation easily remedied by a study of the excellent text by Horowitz and Hill, "The Art of Electronics," 2nd Edition, Cambridge University Press, 1989. See the golden rules presented on page 177. An op-amp integrator is presented on page 222. The information on sawtooth oscillators beginning on page 288 is also useful.

[5] PC boards for several of the analyzer circuits are available from Kanga USA. Details are available at the Kanga Web site, **http://www.bright.net/~kanga/kanga/**, or from Kanga USA, 3521 Spring Lake Dr, Findlay, OH 45840.

[6] The best digital audio recording and playback systems have a dynamic range around 90 dB.

[7] An outstanding fundamental treatment of log amps is given in applications data from Analog Devices. See, for example, the data sheet for the AD8307, Analog Devices, Norwood, MA, 1997, **http://www.analog.com/product/Product_Center.html**.

[8] The log/IF board available from Kanga (see Note 5) is configured for the MC3356. Most of the 20 pins allotted to the IC are not used and their locations can be employed to breadboard and retrofit the AD8307 (8 pin DIP) into the system, if desired.

[9] If crystal filters are built especially for this project, we recommend a peaked response shape (such as Gaussian-to-6 dB). We have investigated wider bandwidth crystal filters as presented in Wes Hayward, W7ZOI, "Refinements in Crystal Ladder Filter Design," *QEX*, Jun, 1995, pp 16-21. See also the careful work of Bill Carver, "High Performance Crystal Filter Design," *Communications Quarterly*, Winter, 1993, pp 11-18, and that of Jacob Makhinson, N6NWP, "Designing and Building High Performance Crystal Ladder Filters," *QEX*, Jan 1995, pp 3-17.

[10] See the Mini-Circuits catalogs and applications manuals. A family of viable VCOs are also available from Synergy Microwave. These units are more expensive, but offer lower phase noise, which would be significant for more-stringent applications.

[11] Wes Hayward, W7ZOI, "The Double Tuned Circuit: An Experimenter's Tutorial," *QST*, Dec 91, pp 29-34.

[12] Wes Hayward, W7ZOI, "Extending the Double-Tuned Circuit to Three Resonators," *QEX*, March-April, 1998, pp 41-46.

[13] Denton Bramwell, K7OWJ, "The Microwatter," *QST*, Jun 1997, pp 33-35. Also, see the sidebar in the referent of Note 11.

Wes Hayward, W7ZOI, and Terry White, K7TAU, are not strangers to QST. *This is also not the first* QST *project on which they've worked together. The first, "The Mountaineer—An Ultraportable CW Station," described a QRP transceiver and appeared in the August 1972 issue. At the time this spectrum-analyzer project evolved, the authors worked together in the Advanced Circuits section of the Receiver Group at TriQuint Semiconductor in Hillsboro, Oregon. Over the years, Wes has provided readers of* QST, The Handbook *and other ARRL publications with a wealth of projects and technological know-how. You can contact Wes at 7700 SW Danielle Ave, Beaverton, OR 97008; e-mail* **w7zoi@teleport.com**. *Terry can be reached at 9480 S Gribble Rd, Canby, OR 97013; e-mail* **twhite@tqs.com**. **QST**

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