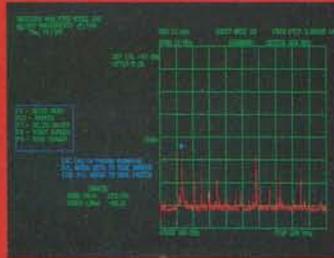48783

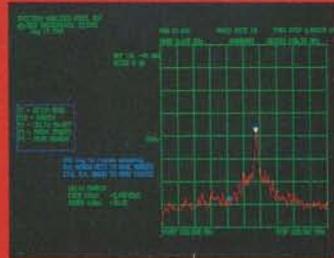# BUILD VOLTAGE DOUBLERS FOR HIGH-VOLTAGE PROJECTS

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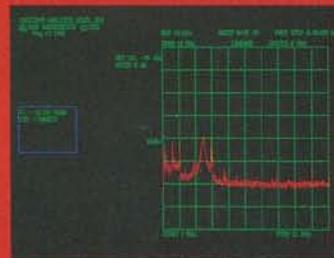## TECHNOLOGY - VIDEO - STEREO - COMPUTERS - SERVICE

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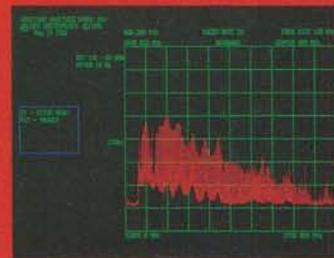for a fraction of the cost of
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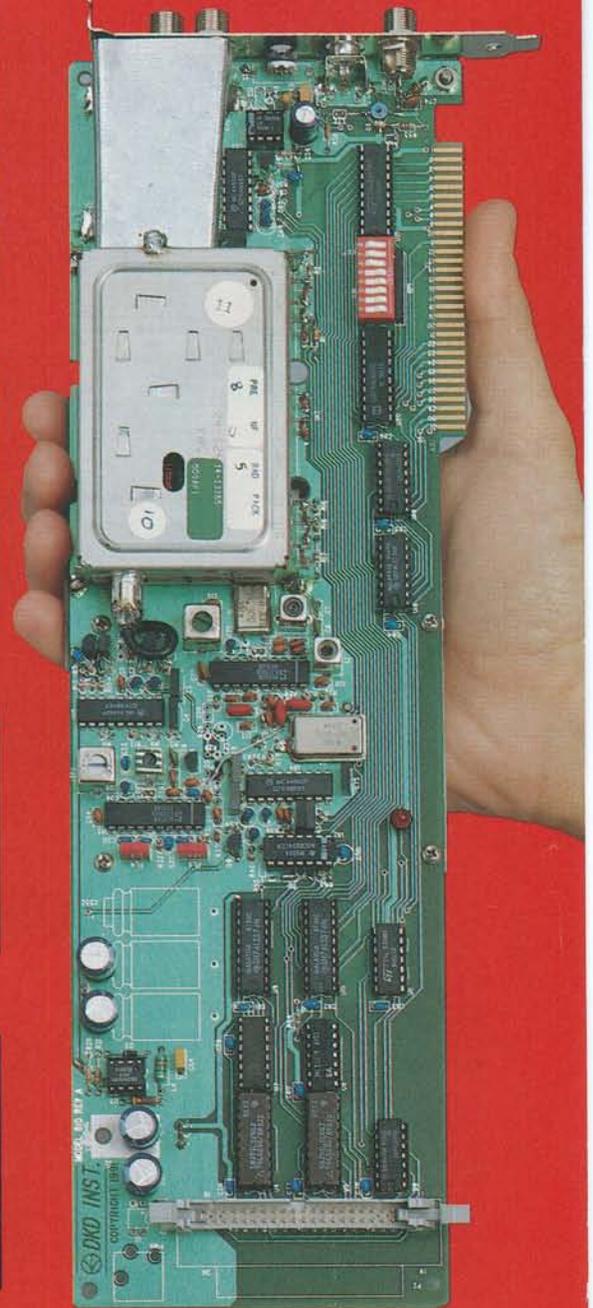to keep tabs on your heart

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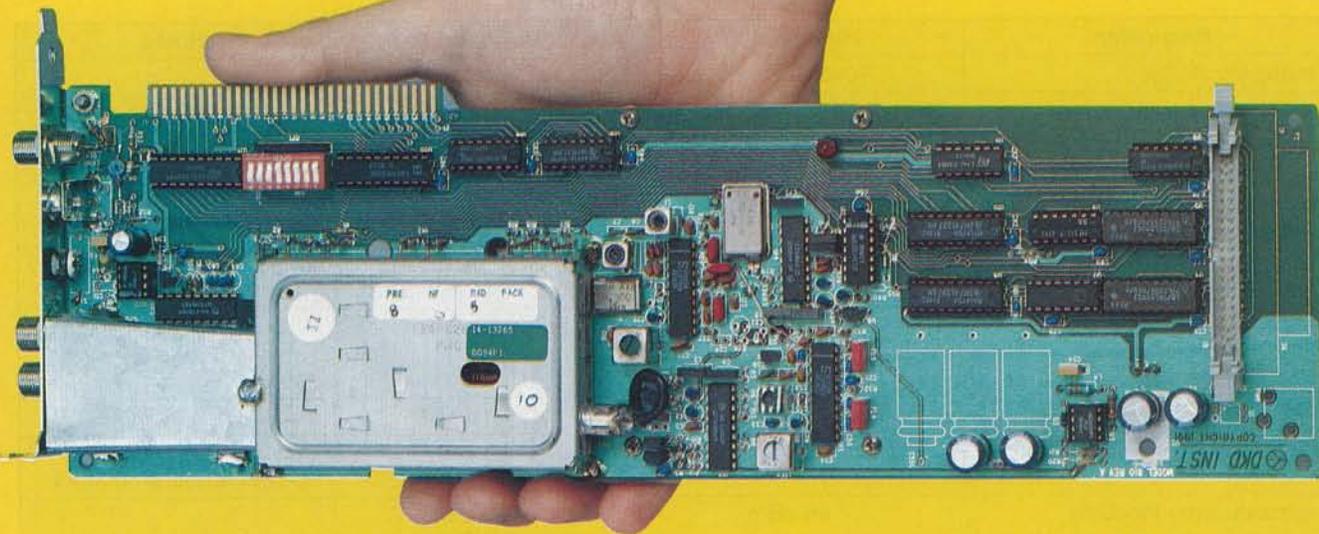
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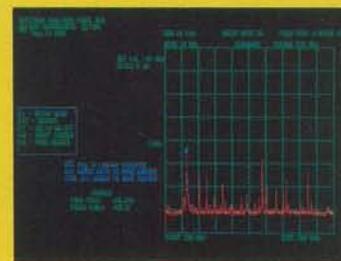**VOLTAGE DOUBLERS**
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Spectrum Analyzer

DAN DOBERSTEIN AND JOHN CARDONE

A SPECTRUM ANALYZER IS AN INVALUable tool for examining the components of a signal spectrum. It provides a way to measure such parameters as power, harmonic distortion, frequency response, and the amplitudes of complex components. With our calibrated 0.1 to 810-MHz spectrum analyzer, repeatable, accurate measurements of power and frequency are possible. The PC-based spectrum analyzer we present in this article offers features normally found only in instruments costing many times more.

Although the "guts" of the analyzer resides on a single PC board, an IBM XT or compatible computer is required to act as a display, as well as to precisely position phase-locked loops (PLL's) for frequency control and to provide look-up tables for power calibration. Using a PC allows us to include such features as marker and delta-marker readout of frequency and power, hardcopy printer output, instrument-setting memory so that "front-panel" settings can be saved and recalled, and tunable FM demod-

ulation. Refer to Table 1 for complete instrument specifications.

A modestly configured PC is required to work with the spectrum analyzer: A single 360K floppy drive, CGA or EGA video adapters, and 512K RAM are all that's required. The card either plugs directly into an 8-bit slot or, with an external power supply, runs off the parallel printer port. That dual interface allows the user a wide choice of host machines—from basic laptops to high-end machines. So if you already have a PC, for about $300 you can have a very capable instrument that allows spectrum analysis from 0.1 MHz to over 800 MHz.

Before we go into the theory behind our spectrum analyzer, let's briefly discuss what this instrument actually does, and how it operates.

Spectrum analyzer displays

Electronic signals, whether they are periodic, aperiodic, or transient, can be shown in a time-domain plot where the amplitude is a function of time (left

side of Fig. 1). All time-domain plots have an associated spectrum that can be graphically described in a frequency-domain plot where the amplitude of the signal is a function of frequency. (Mathematically, that's done using the Fourier transform.) It is in the frequency-domain where the spectrum analyzer draws a picture, so that you can analyze the signal spectra in question.

A spectrum analyzer is used to display the power distribution of a signal as a function of frequency, as shown in the right side of Fig. 1. It is basically a tuned receiver with selectable frequency ranges and intermediate-frequency (IF) bandwidths. A spectrum analyzer separates an input signal into its various frequency components and displays each component as a vertical line on a CRT. The height of each vertical line on the display represents the amplitude of each frequency component, the horizontal position of each line indicates the frequency location.

Figure 1 shows three examples of input signals represented in

TABLE 1—SPECIFICATIONS

Parameter	Highband	Lowband	Notes
Frequency Range	50-810 MHz	0.1-100 MHz	
Available Spans	0.625, 1.25, 2.5, 5, 10, 25, 50, 100, 200, 300, 400, 500, 600, 800 MHz	0.625, 1.25, 2.5, 5, 10, 25, 50, 100 MHz	0.625 MHz to 800 MHz
Resolution Bandwidths (RBW)	10 KHz, 280 kHz	10 kHz, 280 KHz	Maximum frequency resolution is 10 kHz
Power Accuracy*	±3 dB	±3 dB from 4–100 MHz (Below 4 MHz, ±5-6 dB)	With min. 6-dB (50-ohm) pad on input.
Sensitivity	>−98 dBm	>−92 dBm	With internal attenuation set to 0 dB and 50-ohm source.
VSWR Input (50 ohms)	<1.2 (6 dB)	<1.3 (10 dB)	50-ohm pad on input.
Spurious Response (Birdies)	<−95 dBm	<−92 dBm	Unit outside of PC case, 50-ohm terminal on input.
Intermodulation Products	<−95 dBm	<−90 dBm (280-kHz RBW)	
Dynamic Range	>58 dB (all bands and RBW's)		
Internal Attenuation	0, 10, and 20 dB		
Maximum Input Power	+10 dBm		
Frequency Accuracy	<10 kHz		Limited by 10-kHz RBW.
Reference Oscillator	4.000 MHz crystal, ± 100ppm		All VCO's phase-locked to this reference.
FM Demodulator	280-kHz bandwidth, quadrature detection, manual volume control. Tuning stepsizes 125 kHz at 280 kHz RBW; 62.5 kHz at 10 kHz RBW.		FM demodulator is for wideband FM. Narrowband FM is demodulated, but because of the 10-kHz RBW, it cannot be seen on the display.
Power Requirements	+5VDC at 0.45A, +12VDC at 0.12A		
Interfaces	PC bus or parallel interface (Centronics)		
System Requirements	360K disk drive, EGA or CGA graphics adapter, 512K Ram, DOS 3.0 or higher.		

*The power accuracy noted above is for factory calibrated units. Kit builders who use the generic calibration tables will degrade by about 3 dB from the above numbers, assuming proper adjustment. Relative power accuracy within a narrow band (less than 25 MHz) is usually better than ±2 dB over a 45 to 50 dB range of power for kit builders and factory calibrated units.

time and frequency domains. When two different signals, f_a and f_b, are simultaneously applied to the input of the spectrum analyzer (Fig.1-a), two frequency components would appear as vertical lines at 200 kHz (f_a) and 300 kHz (f_b). The amplitude of f_a would be twice that of f_b. With an amplitude modulated (AM) signal applied to the input (Fig. 1-b), the waveform is separated into its carrier frequency, f_c, and two sidebands. An apparently perfect sine wave, f_s (Fig. 1-c), might show harmonic distortion as multiple frequency components of the input signal.

Now that we have an idea of what a spectrum analyzer displays, let's take a look at some of the techniques used in the operation of these instruments.

Techniques

There are three types of spectrum analyzers: the swept filter, heterodyne, or heterodyne with tracking filter type. Although the swept-filter method (Fig. 2-a) is seldom used, we will discuss it first because it's easy to understand. The swept-filter analyzer sweeps, or tunes, a bandpass filter over the frequency band of interest. The voltage output of the filter is plotted against frequency, resulting in the spectrum display. The problem is that narrowband, wide-tuning range filters just don't exist.

The most common type of spectrum analyzer, however, is the heterodyne type (Fig. 2-b). With that technique, the bandpass filter is fixed at some frequency and a swept oscillator, in combination with a mixer, performs the same function as the swept filter. The fixed filter determines the resolution of the analyzer. The 3-dB bandwidth of that filter is referred to as the resolution bandwidth (RBW). The advantage of mixing, or heterodyning, which converts energy at one frequency to energy at another frequency, is that the filter is cut to a particular frequency and, therefore, its characteristics are fixed. It's also much easier to build a sweepable oscillator than a narrow-band swept filter. Voltage controlled os-
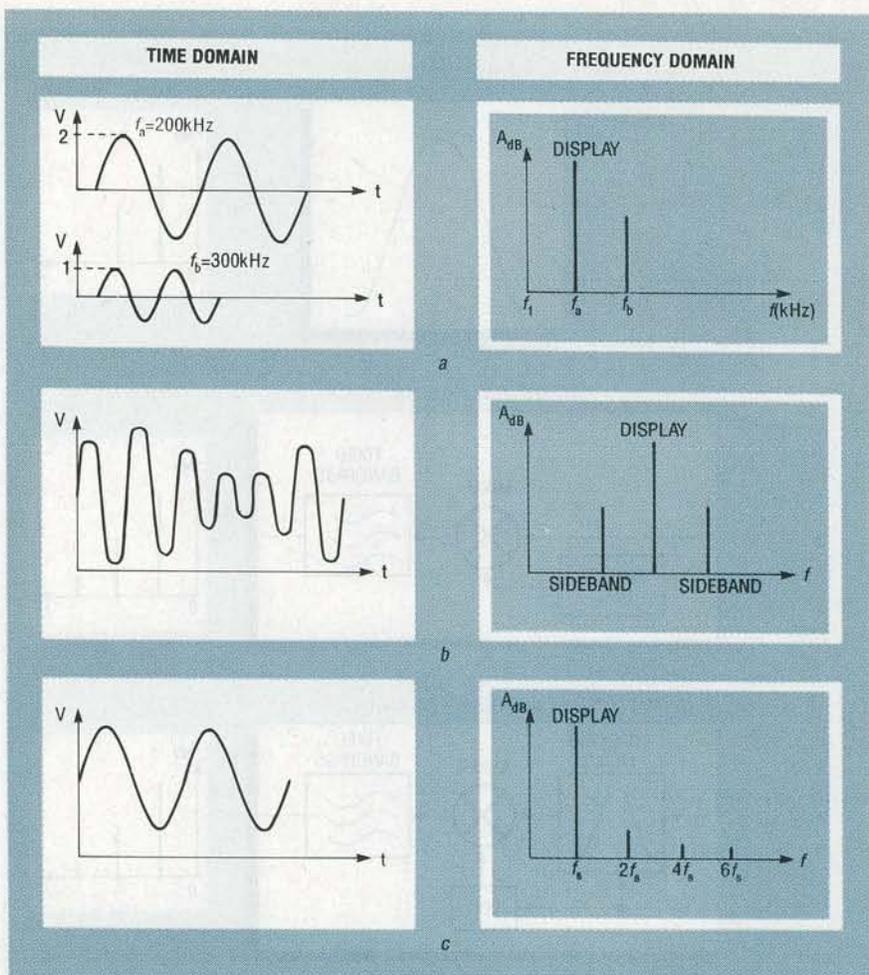
TIME DOMAIN

FREQUENCY DOMAIN

FIG. 1—TIME AND FREQUENCY DOMAINS of input signals. Two different signals applied at the same time results in two separate frequency components (a). An AM signal is displayed with its carrier and two sideband frequencies (b). A sine wave that appears perfect on an oscilloscope may show harmonic distortion on a spectrum analyzer (c).

cillators (VCO's) are used for that purpose.

There are problems, however, with the heterodyne type. In the mixing process, unwanted frequencies can appear in the fixed-filter bandwidth—additional noise is added and there is a reduction in dynamic range (the difference between the smallest signal detectable and the largest signal allowed).

One way to help eliminate the unwanted heterodyne frequencies is to use tracking filters (Fig. 2-c). A tracking filter is a filter that is tuned by voltage. In practice, tracking filters are used ahead of the mixer stage to reduce the number of frequencies that are mixed with the oscillator. A tracking filter is just a swept filter used in different way. It is designed to follow the oscillator (usually a VCO) so that some protection from the unwanted frequencies is provided.

Our analyzer uses the heterodyne principle in combination with tracking filters. Fixed ceramic 10-kHz and 280-kHz bandpass filters provide the two resolution bandwidths.

Phase locking

Phase locking a VCO takes an otherwise unpredictable beast and nails down its frequency. VCO's, if left on there own, wander in frequency due to temperature, vibration, and a host of other causes. Frequency calibration is impossible with such variations. Frequency wandering can be greatly reduced by phase-locking the VCO with a highly stable source, such as a quartz-crystal oscillator. The VCO's in our analyzer can wander as much as 1 to 5 MHz. When phase-locked to the 4.000-MHz reference, the frequency drift is only a

few hundred hertz.

That accuracy does not come without a price. Phase locking to a given frequency takes a significant amount of time. That results in longer sweep times when compared to sweeping an unlocked VCO. Also, phase-locking forces frequency steps on the VCO, whereas the unlocked VCO can be put at any frequency, at least in theory. For our design, the advantages of PLL's far outweigh the disadvantages.

The big picture

Figure 3 shows the overall block diagram of the spectrum analyzer. At the heart of the unit is a Zenith tuner module (IC17). The tuner takes highband inputs from 50 to 810 MHz and converts them to a 45-MHz IF, which is the first IF stage. After that conversion, the first of two Signetics NE615 receiver IC's (IC16) downconverts the 45-MHz IF to a 10.7-MHz IF, which is the second IF stage. The 10.7-MHz IF is tapped off and sent to another NE615 (IC13) where the 10.7-MHz is downconverted to the standard 455-kHz IF, which is the third IF stage.

Figure 4 shows the circuit of the first 45-MHz IF stage. Of the four local oscillator's (LO's) used, three are phased-locked using Motorola's MC44802 IC (IC14, IC15, and IC23). The LO for the 10.7-MHz IF is crystal-controlled by XTAL1. The PLL's used for the tuner IC also perform band switching, which will be discussed in more detail below. Those PLL's are self contained and have a serial interface. A 4-MHz crystal oscillator (XTAL2, Fig. 5) is used as a common reference for all the PLL's, as indicated in the block diagram (Fig. 3).

The circuit of the second and third IF is shown in Fig. 5. FM demodulation is provided by IC13 and IC16. The output of the 10.7-MHz IF is suitable for wide-band FM such as standard FM radio broadcast. The FM output of the 455-kHz IF is not very clean but can be used for narrow-band FM signals such as voice-only broadcasts. However, only the FM from the 10.7-MHz IF is sent to the audio amp (IC22).

The NE615 receiver IC's (IC13 and IC16) have a received-signal strength indicator (RSSI) out-

put. When the RSSI output is read by the computer using an 8-bit analog to digital converter (ADC) (IC12, an ADC0834), raw data is provided for the spectrum display. Extensive use was made of serial interfaces in our analyzer to cut down on computer interface requirements.

The analyzer has two resolution bandwidths that are provided by a combination of ceramic filters. The 10.7-MHz filters (FL1 and FL2) are used for the 280-kHz RBW. Pretuned filters (FL3 and FL4) are used to provide the 10-kHz RBW.

In order to see frequencies below 50 MHz (the tuner's lower limit), an additional mixer and local oscillator (LO), IC24, are used to upconvert the 0.1–100-MHz band to an IF of 145 MHz. The analyzer's lower limit has its own separate input jack, LOWBAND INPUT. The 145-MHz IF is fed to the tuner where it is down converted, as before, to the 45-MHz IF. From here on, the signal is processed as in the highband case (50–810 MHz).

As shown in the block diagram (Fig. 3), an 8-bit DAC (IC7) controls the automatic gain control (AGC) input of the tuner. AGC cancels out gain variations and provides signal attenuation. An 8-bit shift register (IC8) is used to provide IC7 with a serial interface to the host PC.

The signal analyzer supports two interfaces; PC bus and the parallel printer port. Either interface may be used, but not simultaneously. There is no difference in operation between the two interfaces. All frequency, AGC, and RSSI information are communicated over those interfaces to or from the host PC.

Signal processing

Figure 6 shows a block diagram of the RF signal processing. Starting with the 0.1–100-MHz front end shown in Fig. 7, IC24, a Signetics NE602 oscillator/mixer, is used to provide the up-conversion to the 145-MHz IF. The oscillator of the NE602 is buffered by Q5 and sent to PLL2 (IC23) for frequency locking. A varactor diode (D4) in the oscillator of the NE602 allows for voltage control of its frequency. That oscillator is swept from 145 MHz to 245 MHz in order to cover
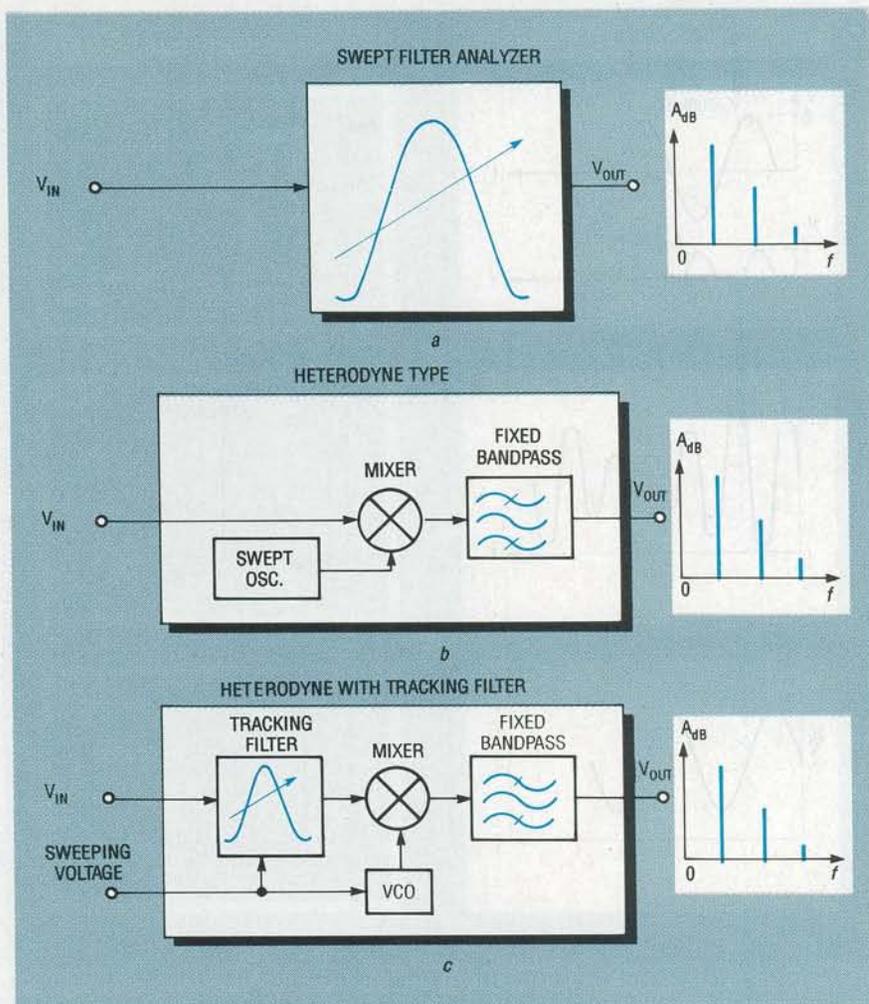

FIG. 2—SPECTRUM ANALYZER TECHNIQUES. The swept-filter analyzer sweeps, or tunes, a bandpass filter over a specific frequency range (a). The heterodyne type uses a swept oscillator in combination with a mixer to sweep over a frequency range; a fixed filter determines the resolution of the analyzer (b). A heterodyne type with tracking filter eliminates undesired heterodyne frequencies (c).
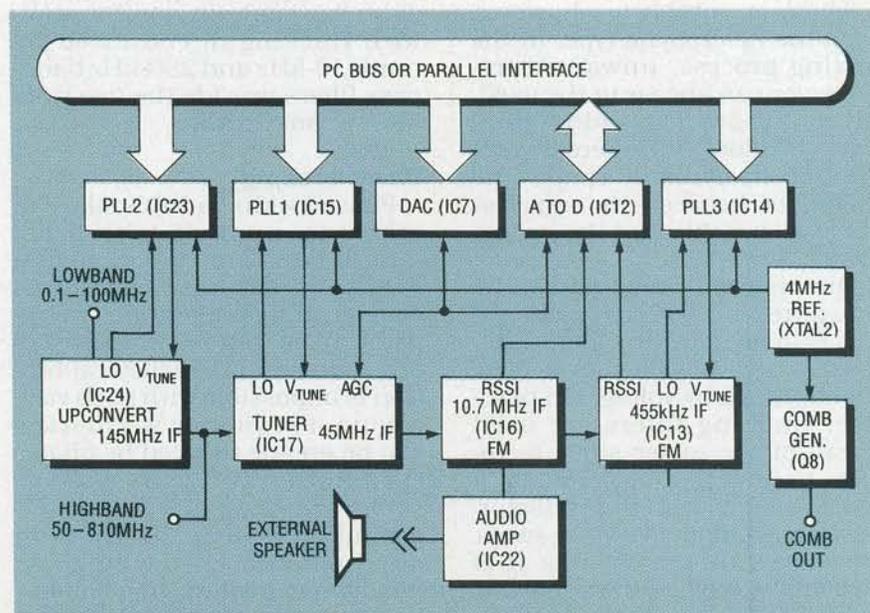

FIG. 3—A BLOCK DIAGRAM OF THE SPECTRUM ANALYZER shows the tuner module, phase-locked loops, receiver blocks, DAC, ADC, and the PC bus connection.
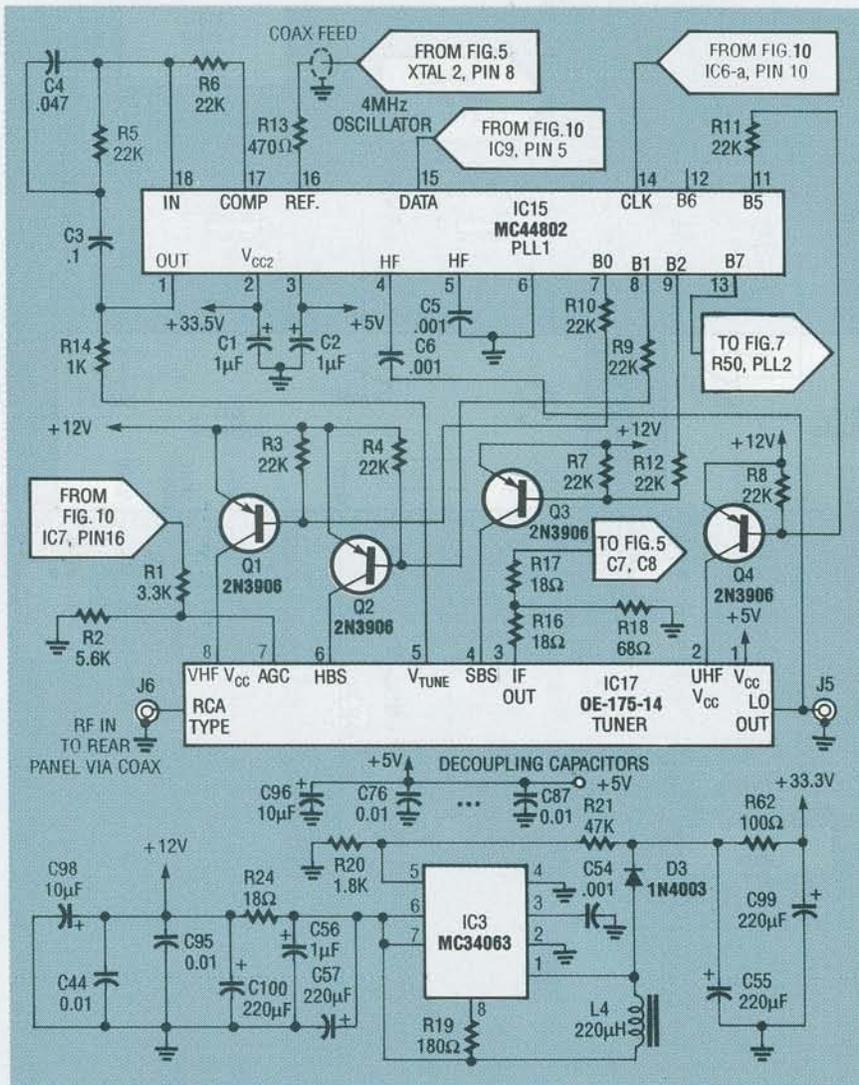
RADIO-ELECTRONICS

FIG. 4—THE FIRST 45-MHz IF STAGE. The tuner takes highband inputs from 50–810 MHz and converts them to 45 Mhz.

the instrument.

The 10.7-MHz IF is produced by mixing the 45-MHz IF with a 34.3-MHz third overtone crystal-controlled oscillator, which is tuned by L2. The 10.7-MHz output of the mixing process is bandpass filtered by two 10.7-MHz ceramic filters (FL1 and FL2) with a buffer amp between them. The 10.7-MHz IF is fed to a limiting amp and a quadrature tank (T1) to perform FM demodulation. The functions of LO, mixing, amplification, and FM demodulation are performed by IC16. The bandwidth of the 10.7-MHz ceramic filters is 280 kHz.

With the tuner or lowband LO set to a step size of 125 kHz and swept over the frequency span, those filters provide the 280-kHz resolution bandwidth (RBW) using the received signal strength indicator (RSSI) from IC16 (Fig. 5). The RSSI is lowpass filtered by R41 and C43 to smooth the voltage. The lowpass filter forms what is commonly called the video bandwidth. The audio from the 10.7-MHz IF is lowpass filtered by C52 and R43 and sent to the audio amp (IC22).

A sample of the 10.7-MHz IF is taken just after the first 10.7-MHz ceramic filter, passed through FL5 and sent to IC13 for downconversion to 455 kHz. The additional ceramic filter is used to further reduce unwanted mixer products and to provide isolation between the 10.7-MHz IF and the 455-kHz IF.

To produce the 455-kHz IF, a 10.245-MHz LO is needed. That LO is provided by phase-locking the oscillator of IC13 using PLL3 (IC14, Fig. 5). The oscillator of IC13 in our analyzer has been set up as a VCO using a varactor diode (D1). A sample of the LO is buffered by Q6 and sent to PLL3 (IC14) for error generation and locking. The LO is swept from 10.21375 MHz to 10.27625 MHz in step sizes of 3.90625 kHz. That is a total span of 62.5 kHz; the step size of the tuner LO, or the lowband LO when the RBW is set to 10 kHz.

It is necessary to sweep the 10.245-MHz LO because a step size of 3.90625 kHz is not possible with the tuner LO or the lowband LO phase-locked loops. Those step sizes must fall within the 10-kHz bandwidth of the 455-

the 0.1 to 100-MHz band. A lowpass filter, consisting of L5, C68, and C69, with a 100-MHz bandwidth is used on the input to the mixer to reduce unwanted frequency products at the output. The tuner is set up to receive the 145-MHz IF from the NE602 mixer. The NE602 is turned off for the highband mode using Q7 as an on/off switch, which is controlled from a PLL1 band-switching output.

The input is fed directly into the tuner module (IC17) in the highband case. The tracking filters are Internal to the tuner, as previously described. Two bandpass trackers are used with a buffer amp between them. The output of the second filter is fed to the mixer for downconversion to the 45-MHz IF. A 45-MHz bandpass filter, with a 6-MHz band-

width, follows the mixer. The local oscillator (LO) must be 45 MHz above the input signal to mix to the 45-MHz IF. For the 50 to 810-MHz bandwidth, the tuner VCO must have a range of 95 to 855 MHz. The LO from the tuner is internally buffered and is sent to PLL1 (IC15, Fig. 4) for frequency locking.

The 45-MHz IF is fed through a 6-dB attenuation pad (R16–R18, Fig. 4) and a tuned circuit to the mixer for the 10.7-MHz IF. The attenuation pad is used to reduce signal gain from the tuner and to provide a wide-band termination for the output of the tuner mixer. The tuned circuit, consisting of L1, C8, and C7 (as seen in Fig. 5), acts to match impedance, filter, and to adjust the voltage gain. The tuning of L1 (Fig. 5) affects the overall gain and noise floor of
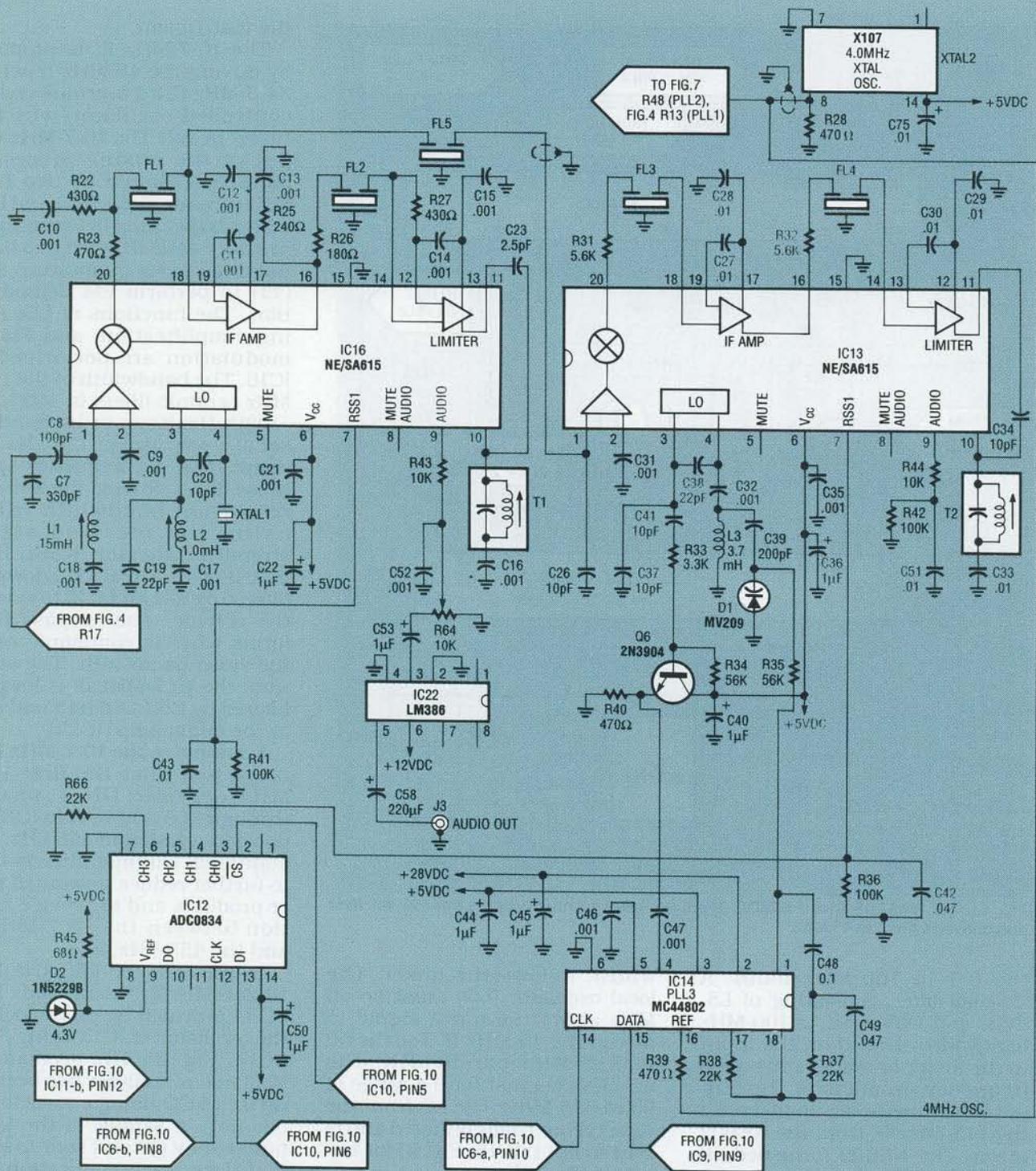
FIG. 5—SECOND AND THIRD IF STAGE. IC16 downconverts the 45-MHz IF to a 10.7-MHz IF, which is tapped off and sent to IC13 where the second IF is again downconverted to the standard 455-kHz IF. Pretuned ceramic filters FL3 and FL4 provide the 10-kHz resolution bandwidth (RBW).

kHz ceramic filters. That combination of dual LO sweeping with the 455 kHz ceramic filters provides the 10-kHz RBW. As with the 280-kHz RBW, the 10-kHz RSSI is lowpass filtered using R36 and C42. That forms the video bandwidth for the 10-kHz RBW. The 10.245-MHz LO is not swept in the 280-kHz RBW.

As with the 10.7-MHz IF, the 455-kHz IF is FM demodulated using quadrature detection (T2). The comb generator, shown in Fig. 8, provides a wide-band test signal. Transistor Q8 is biased to produce the harmonics of the 4.0-MHz reference, XTAL2. That signal has detectable harmonics past 500 MHz.

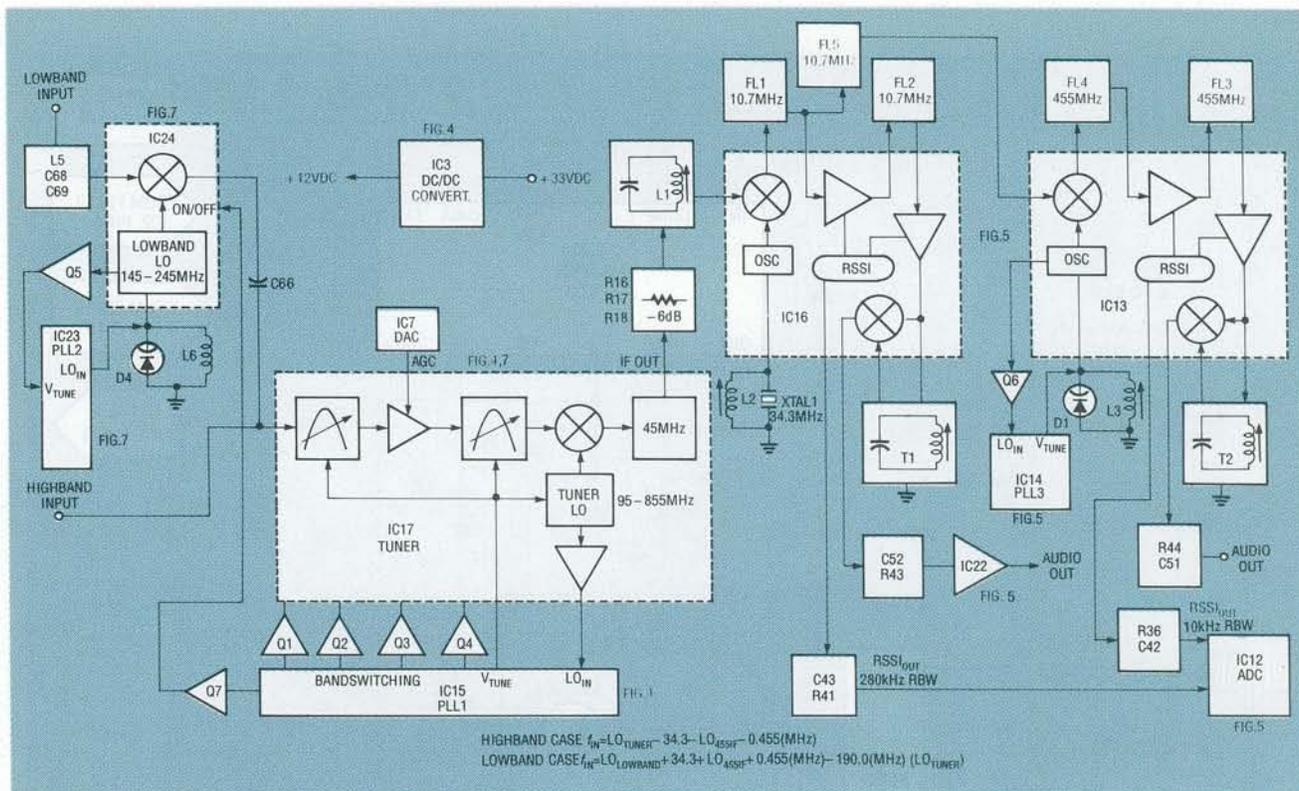Now that we've gone over the operating theory in some detail,

HIGHBAND CASE $f_{IN} = LO_{TUNER} - 34.3 - LO_{455IF} - 0.455 (MHz)$
LOWBAND CASE $f_{IN} = LO_{LOWBAND} + 34.3 + LO_{455IF} + 0.455 (MHz) - 190.0 (MHz) (LO_{TUNER})$

FIG. 6—RF SIGNAL PROCESSING block diagram.

we will discuss some of the more important IC's in this design, and the reason why each of them were chosen.

Tuner module

The tuner is a CATV type made by Zenith. No modifications to the tuner are needed to use it in our analyzer. Along the bottom is a row of pins for the AGC input, +5 VDC, VCO tuning input, IF out and band-switching inputs. Band-switching inputs are used because LO's cannot sweep from 95 to 855 MHz. Instead of one LO, there are four that are switched in one at a time to provide the complete span. Table 2 shows the points where the LO is switched at various frequencies.

The frequencies shown in the table are with respect to the *input*

frequency; to get the LO frequency, just add 45 MHz. Not only is the LO switched, so is the mixer! Two mixers are used: one for the VHF band and one for the UHF band. The mixers are switched by the same inputs as the LO so no additional switching logic is needed. The band switching results in two effects: a momentary delay in the sweep at the band switching points, and a slight step up or down in the noise floor at the switching points. The switching also affects the operation of the tracking filters. The tracking filters are internally tied to the VCO control voltage so that the input signal is always kept in the center of the bandpass filters.

PLL IC MC44802

The Motorola MC44802 IC,

used in IC14, IC15, and IC23, is tailor made to interface to a band-switching tuner. Figure 9 shows a block diagram of that IC. All the switching logic is provided in the IC for band switching. An on-board prescaler with associated divide counters enables the MC44802 to directly sense and control VCO's up to 1.3 GHz. An error/driver amp is also included that is used to provide VCO tuning voltages from 0 to 35 volts. Programmable reference dividers are also present in the IC. All of the internal settings of the MC44802 are controlled via a three-wire interface.

You can continually change the contents of the VCO divide counter by sweeping the VCO being controlled by the step size selected. You can control tuner band-switching by writing to the band-switching register of PLL1 (IC15). Transistors Q1–Q4 are used as drivers for the tuner band-switching inputs.

To set the PLL to a particular frequency, divide the frequency by the step size, truncate, and insert the resulting number into the divide counter. For example, if you want to set the tuner VCO frequency to 400 MHz using a step size of 125 kHz, the divide

TABLE 2—BAND SWITCHING

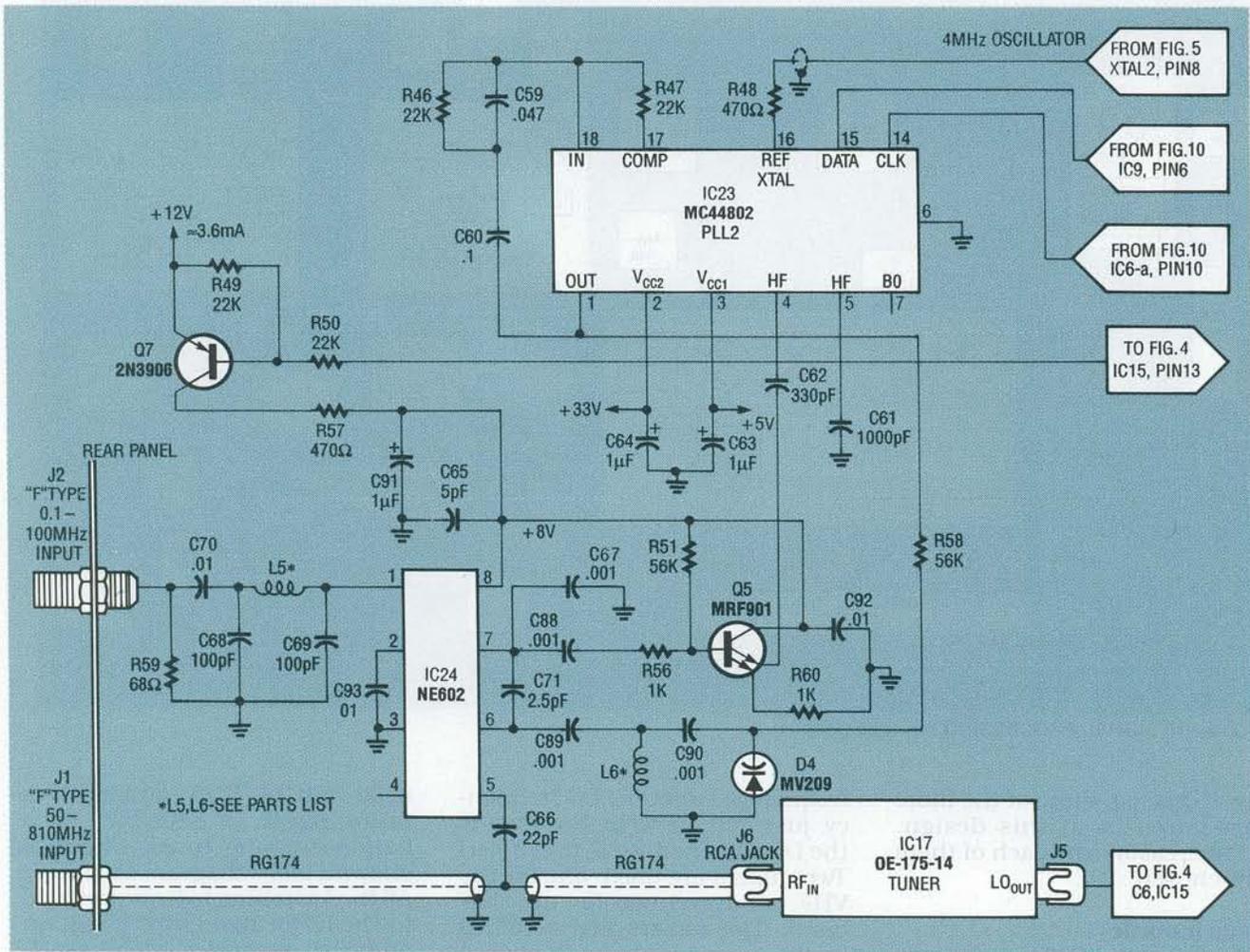| BANDS	SWITCH SETTINGS				
	VHF B+	Highband	Superband	UHF B+	Lowband
VHF Low (50 to 100 MHz)	+12	Open	Open	Open	Open
VHF High (100 to 200 MHz)	+12	+12	Open	Open	Open
Super Band (200 to 372 MHz)	+12	+12	+12	Open	Open
UHF Band (372 to 810 MHz)	Open	Open	Open	+12	Open
Lowband (0.1 to 100 MHz)	+12	+12	Open	Open	+12

FIG. 7—0.1 TO 100 MHz FRONT END. An oscillator/mixer, IC24, provides the up conversion to the 145-MHz IF. The oscillator in IC24 is swept from 145 MHz to 245 MHz to cover the 0.1 to 100-MHz band.
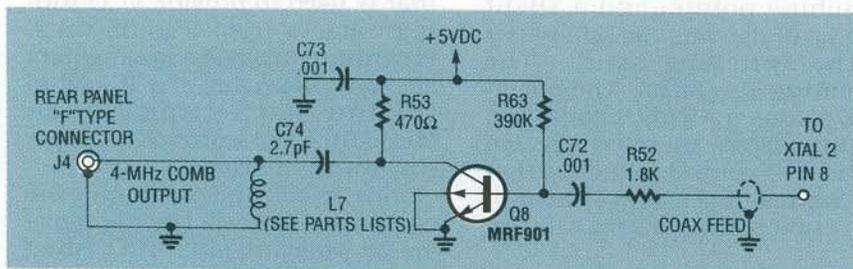

FIG. 8—THE COMB GENERATOR provides a wide-band, 4-MHz test signal.

counter should be loaded with 400/0.125 = 3200 counts, of course you would also have to set the band switches accordingly. All of that programming is done by the host PC. A complete discussion of the details of programming this IC is too long to be presented here. You can refer to the *Motorola Linear and Interface Data Book* if you would like more information on programming the MC44802. Because of the high frequencies involved, the use of sockets is not recommended for these IC's.

Receiver IC NE615

The Signetics NE615 IC contains all the necessary components to do frequency conversion. The RSSI output has a 90-dB dynamic range, although our analyzer only has a 60–70-dB dynamic range due to compression in the tuner. The oscillator can be either crystal controlled or LC-tank controlled. If a varactor diode is added to the LC tank, you have a VCO.

One feature of the NE615 that is not used in our unit is the audio mute. That input allows for killing the audio output when no signal is present. The IF section has a total gain of 90 dB. The high gain can cause stability problems and consequently performance of this IC is greatly effected by circuit board layout. If you build a kit, do not put a normal socket on this chip! Individual, high-frequency, pin-type sockets can be used, but those are hard to come by.

ADC0834

The only thing that is unique about this ADC used for IC12 is its serial interface. Just four wires are needed to interface this IC to a processor. The ADC is used to convert the analog RSSI voltages to 8-bit digital information which is read by the PC. Diode D2 provides the reference voltage of 4.3 volts. This ADC has
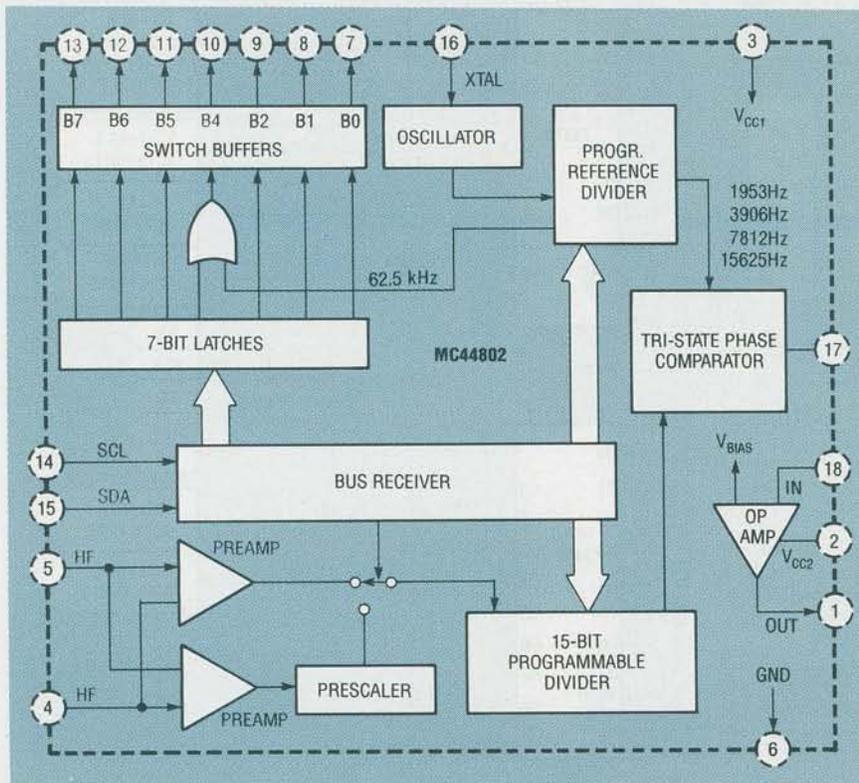
FIG. 9—BLOCK DIAGRAM OF THE MOTOROLA MC44802 IC. All switching logic is provided in this PLL IC. An on-board prescaler with associated divide counters allow the MC44802 to control VCO's up to 1.3 GHz.

four channels, all of which are programmable. Channels 0 and 1 are used for the two RSSI voltages from the NE615's. Channel 2 is unused. Channel 3 is connected to the DAC and is used for self testing. As with the MC44802, the details of programming this IC are too lengthy to be presented here and the reader is referred to National Semiconductor's Databook.

8-bit DAC AD558

This Analog Device's DAC was chosen for IC7 primarily because of its self contained reference and voltage output. It also needs only one supply voltage, +12 VDC. In keeping with the serial interface approach, a 74164 8-bit shift register (IC8) is tied to the input data of the DAC. Three lines, a clock, data, and strobe, are use to insert the shift register and load it into the DAC.

DC to DC converter

The PLL's used need +33 VDC to control the VCO's over the spans used. Motorola's MC34063 (IC3) can be configured as a step-up or -down DC-to-DC converter. In our case it is used to convert

+12 VDC to +33 VDC. Only 3 mA are needed to drive the three PLL's. The input and output voltages are heavily filtered by C57, C100, R24, C55, C99, and R62, as any ripple on the supply will show up as unwanted FM on the LO's.

Interfaces

As already stated, the analyzer can communicate via the PC bus or the parallel port LPT1 through LPT4. A header is provided on the board for a ribbon cable to connect to a Centronics-type adapter cable. If the card is operated external to the PC, an external power supply must be provided. The supply plugs into a 3-pin, Molex-type connector toward the back of the board.

A good quality DC supply with +5 volts at 1.0 amp and +12 volts at 0.4 amps is adequate. None of the DIP switches need to be set to select PC or LPT interface. When the Centronics cable is attached to the computer, it pulls pin 30 of the connector low which selects the LPT interface. The software, however, must be instructed by the user which interface is going to be used. That

is done using the SETUP program, which will be discussed in our next issue. You can actually operate the card plugged into the PC bus using the LPT interface. In that configuration, the PC interface is used just for power.

Figure 10 shows the PC bus interface circuitry. The entire LPT interface is accomplished by using two 74LS244's (IC4 and IC5) and one 74LS04 (IC6). The 74LS244's are three-state octal drivers, which are used to buffer the signals to and from the LPT interface. The PC bus interface is considerably more complex. It consists of one 74LS688 comparator (IC20), two 74LS138's 3-to-8 decoders (IC18 and IC19), two 74LS374 8-bit latches (IC9 and IC10), one 74LS245 bidirectional buffer (IC21), and one DIP switch (S1). The DIP switch is used to select the PC bus address. The default address is 768 decimal. The default DIP-switch setting for S1 is: positions 1–5 on, positions 6 and 7 off.

If another address is desired you will have to use SETUP to change the address used by the software and of course set the DIP switches to the new address. Details of setting the address switches are included in the README.DOC file contained in the SPECAN.ARC file. SPECAN.ARC can be copied from the **Radio-Electronics** BBS (516-293-2283, modem settings: 1200/2400, 8N1). If you never intend to operate the analyzer from the PC bus IC9, IC10, IC18, IC19, IC20, IC21, and IC11 can be removed from the circuit.

The PC interface does a comparison of the address bits A3 through A8 to determine where a block of eight decoded addresses will fall. Although eight READ/WRITE addresses are decoded, only two of the eight WRITE addresses are used, and one of the read addresses. That is modeled after the LPT interface, which has two WRITE registers and one READ register.

Operation

The PC host controls all aspects of the spectrum analyzer's control and data collection. After the user selects a start or center frequency and a span frequency, computations are performed to set up the various LO's that need

FIG. 10—PC BUS INTERFACE CIRCUITRY. The entire LPT interface is performed by IC4 and IC5. Those two 74LS244's buffer the signals to and from the LPT interface.

PARTS LIST

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to be swept using the PLL's. Once everything is properly set up, the computer starts sweeping the appropriate LO's and collecting data via the ADC data from the RSSI outputs.

If the RBW is 280 kHz, the 10.7-MHz RSSI output is read. If the RBW is 10 kHz, the 455-kHz RSSI is read. The LO's are not swept continuously, but rather in steps. The steps are determined by the internal settings of the PLL's. The steps used for the tuner are 125 kHz and 62.5 kHz. Steps for the 455-kHz IF are 3.90625 kHz. Those different step sizes are needed to accommodate the two filter bandwidths of 280 kHz and 10 kHz. As the computer is sweeping the LO's, it is also controlling the AGC via the DAC, which is there to keep the gain flat.

The overall basic sequence is
● Command LO's to the next frequency.
● Set AGC level from the look-up table.
● Allow adequate time for settling of PLL's.
● Read RSSI voltage.
● Calibrate RSSI data to Power in dBm.
● Display the power/frequency pair on the screen.
● Repeat.

Those operations are performed continuously by the computer until interrupted by the user.

In our next edition, we'll go over the software, kit construction, tuning, power calibration, and troubleshooting of the spectrum analyzer.   **R-E**
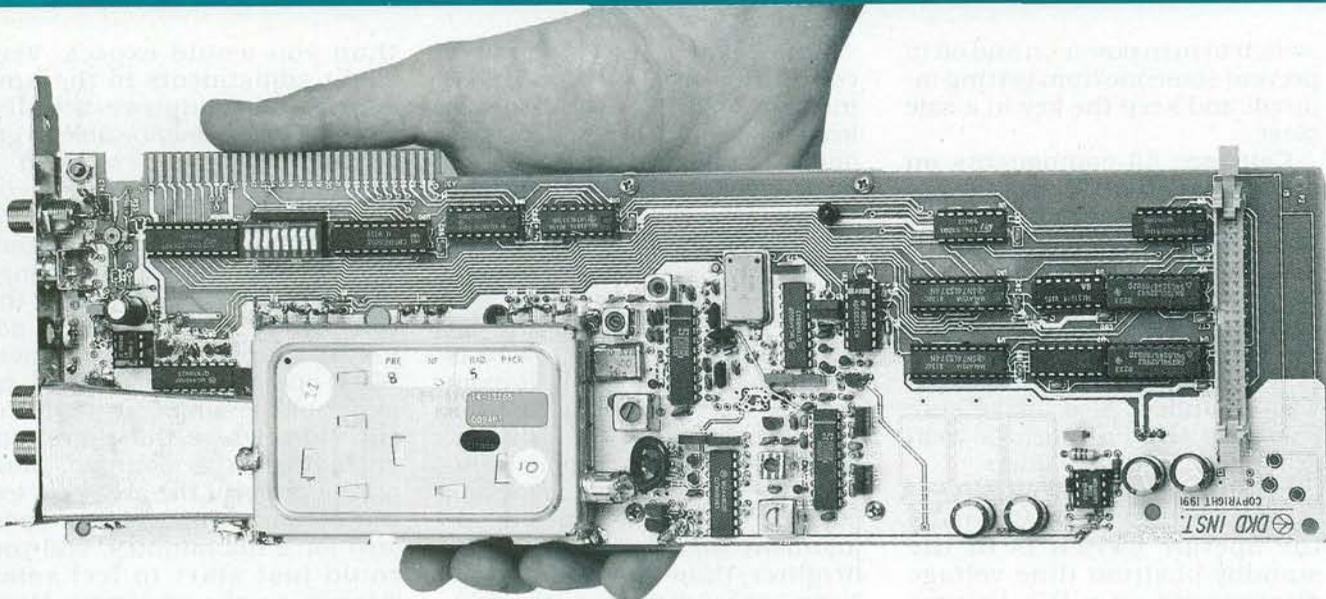
Spectrum Analyzer

DAN DOBERSTEIN AND JOHN CARDONE

LAST MONTH WE DISCUSSED THE theory behind our PC-based 810-MHz spectrum analyzer. This month, we'll show you how to build it and discuss the software used to operate the instrument. Before we get into the construction, let's start off with a description of the setup and operating software. All executable files we mention here can be downloaded from the **Radio-Electronics** BBS (516-293-2283, 1200/2400, 8N1, file SPEC-AN.ZIP). Even before you build the analyzer, we would recommend that you download and run the software. (It will run even without the board installed.) Even though you won't get any meaningful data, it will help you to understand exactly how the software operates.

Software and operation

Before you can use the spectrum analyzer, some software settings must be initialized so that the host computer will know at what address the analyzer resides, which printer port will be used, and the type of printer that will be used. The initialization is

performed with SETUP.EXE, which is a stand alone program that must be executed outside of the main program menu. The details of using SETUP are covered in the README.DOC file. SETUP stores your system configuration and needs to be re-executed only if something changes.

The two main programs are 810EGA.EXE and 810CGA.EXE. One is used for EGA systems, the other for CGA. Both programs operate the same way. The EGA version supports VGA/EGA monitors and has color capabilities if your monitor supports color. The CGA version has reduced graphics resolution and the sweep display will be monochrome. All the photos presented here are from the EGA version. The CGA version was included primarily to support low-end laptop computers using the parallel-printer interface.

When the software is executed, a copyright message will be displayed while it is loading the calibration files. After a few moments the sweep display will come up. Figure 11 shows a typical sweep display. The display is

continually updated as the local oscillators's (LO's) are swept and new data is gathered. The box on the left side of the screen contains the list of function keys that are currently active. All user interactions from the sweep display are initiated by function keys, arrow keys, or the ESC key. Function key F1 is always used to bring up the Instrument Setup menu. The user can change all the settings of the spectrum analyzer from the menu. That will be covered in more detail later.

Function key F10 activates the marker function. When the marker is on, the sweep is interrupted until a return to sweep mode is commanded (ESC key). Once the Marker is up, the user can do a peak search, or by using function key F7 toggle the delta marker on and off. The marker is moved using the arrow keys with the power and frequency (or delta power and delta frequency) displayed in the lower left corner of the screen. Another feature of the marker is to tune the spectrum analyzer as you move it, enabling the marker to act as a station indicator for the FM demodulator.
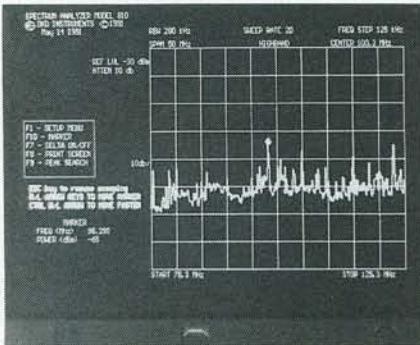
FIG. 11—THIS IS WHAT YOU might see on a typical sweep display.

Using an external speaker and an antenna on the input you can "scan" the bandwidth of the analyzer, listening for different FM broadcasts.

Function key F8 activates a screen dump. Your printer must be selected using SETUP for this to work. A large number of printers are supported, ranging from Laserjets to low-end dot matrix types. When you return to active sweeping the marker turns off and the functions associated with it (FM tuning, screen dump, and so on) are not accessible to you.

When you're in the sweep mode, you can save and recall all the settings of the analyzer using the function keys preceded by the ALT key for saving states, and the CNTRL key for recalling states. Ten states are available: one for each ALT/CNTRL function key pair. The states are numbered 0 through 9 and are stored on the disk as STATEx.DAT. STATE0 is special because it is used as the wake up state of the machine. You can modify the wake up state of the analyzer by just saving a new STATE0 using the ALT F1 keys.

Instrument setup menu

By using the up/down arrow keys of the setup menu you can move to the item you wish to change or execute by hitting return. Start frequency, center frequency, and span determine the portion of the spectrum analyzer's bandwidth you wish to examine. Center and start frequencies cannot be independently chosen. In other words, you can only specify start and span or center and span frequencies. That's due to the fixed-span table approach used in the analyzer. The fixed spans are: 800, 600, 500, 400, 300, 200, 100, 50, 25, 12.5, 10,5, 2.5, 1.25, and 0.625 MHz. When the span is less than 12.5 MHz, the resolution bandwidth (RBW) is automatically switched from 280 kHz to 10 kHz. No direct user control is provided for the RBW setting.
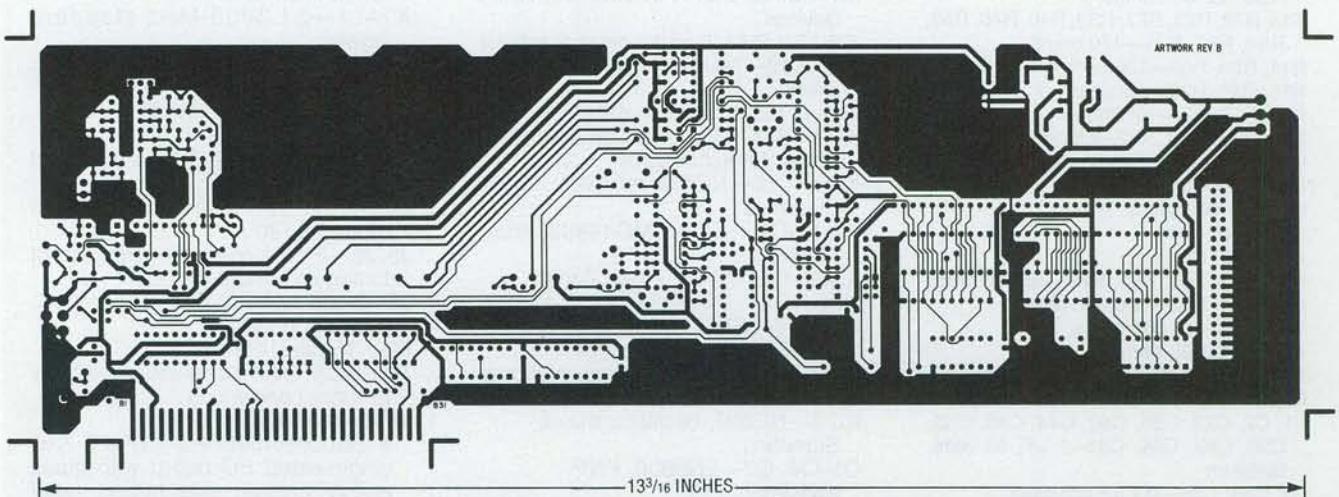
THE SOLDER SIDE of the foil pattern is shown here.
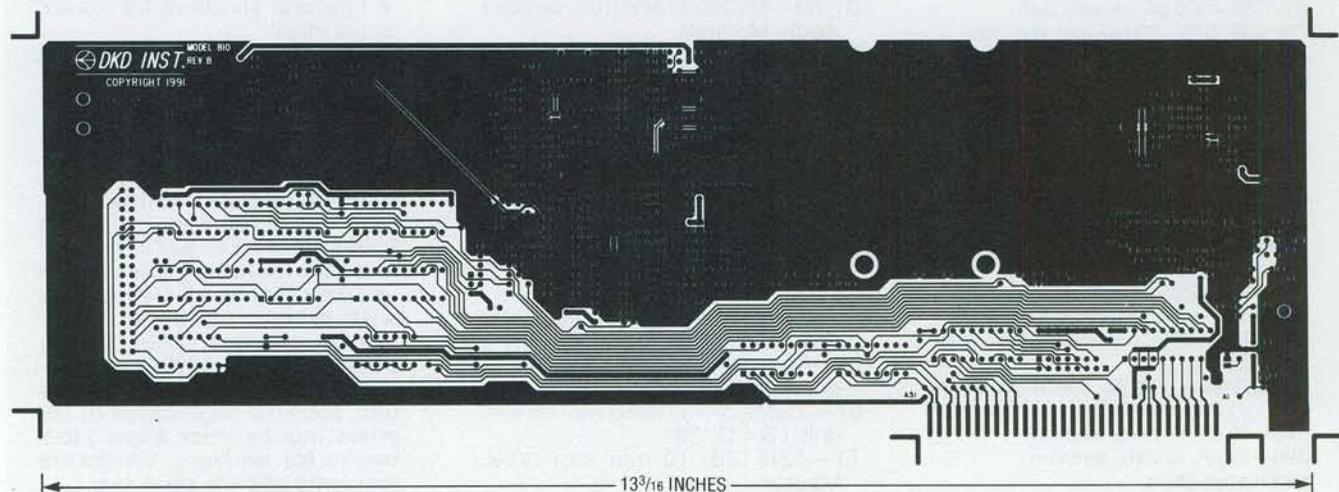
THIS IS THE COMPONENT side of the foil pattern.
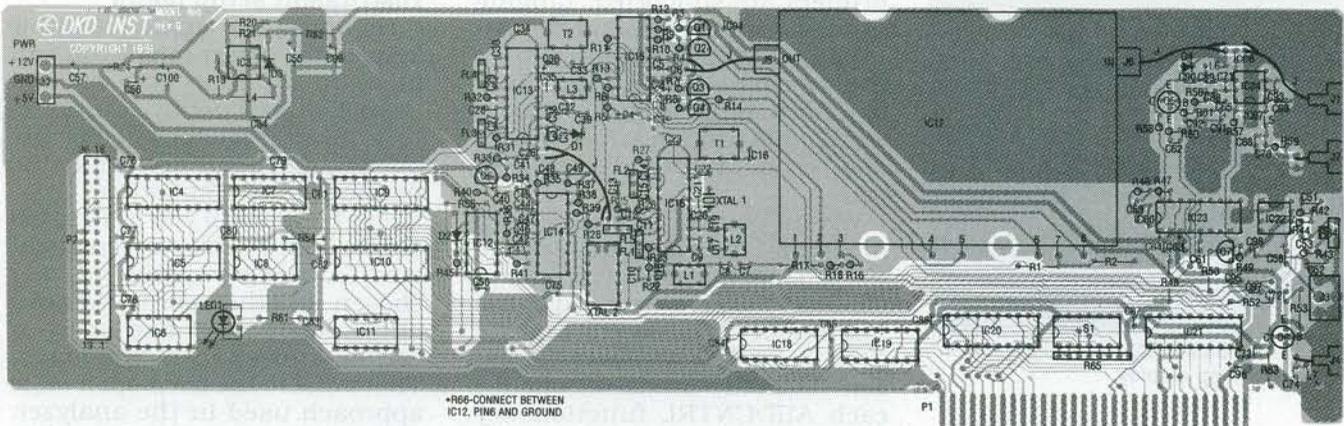
FIG. 12—PARTS PLACEMENT DIAGRAM. Note the location of the four coax runs. Make sure you install all chip capacitors first because of their small size.

PARTS LIST

All resistors are ⅛-watt, 5%, unless otherwise noted.
R1, R33—3300 ohms
R2, R31, R32, R43—5600 ohms
R3–R12, R37, R38, R46, R47, R49, R50, R66—22,000 ohms
R13, R22, R23, R27, R39, R40, R48, R53, R54, R57, R61—470 ohms
R14, R56, R60—1000 ohms
R15, R28–R30—not used
R16, R17, R24—18 ohms
R18, R45, R59, R62—68 ohms
R19—180 ohms, ¼-watt
R20, R52—1800 ohms
R21—47,000 ohms
R25—240 ohms
R26—180 ohms
R34, R35, R51, R55, R58—56,000 ohms
R36, R41, R42—100,000 ohms
R44, R64—10,000 ohms
R63—390,000 ohms
R65—10,000 ohms × 7 SIP resistor
Capacitors
C1, C2, C22, C36, C40, C44, C45, C53, C56, C63, C64, C91—1 μF, 50 volts, tantalum
C3, C48, C60—0.1 μF polyester
C4, C42, C49, C59—47,000 pF, polyester
C5, C6, C9–C18, C32, C46, C47, C61, C88–C90—0.001 μF, ceramic disc
C7, C62—330 pF, ceramic disc
C8, C68, C69—100 pF, ceramic disc
C19, C38, C66—22pF, ceramic disc
C20, C26, C34, C37, C41—10 pF, ceramic disc
C21, C35, C67, C73—1000 pF, chip
C23, C71, C74—2.7 pF, ceramic disc
C24, C25, C97—not used
C27–C31, C33, C50, C70, C72, C75–C87, C92–C95—0.01 μF, ceramic disc
C39—200 pF, ceramic disc
C43, C51—0.01 μF, polyester
C52, C54—1000 pF, polyester
C55, C57, C99, C100—220 μF, 35 volts, electrolytic
C58—220 μF, 16 volts, electrolytic
C65—5 pF, ceramic disc
C96—10 μF, 16 volts, tantalum
C98—10 μF, 16 volts, tantalum
Semiconductors
IC1, IC2—Not used

IC3—MC34063, step-up voltage regulator, Motorola
IC4, IC5—74LS244, three-state octal driver
IC6—74LS04, hex inverter
IC7—AD558, 8-bit A/D converter, Analog Devices
IC8—74LS164, 8-bit par out shift register
IC9, IC10—74LS374, three-state octal driver
IC11—74LS32, quad OR gate
IC12—ADC0834, A/D converter, National Semiconductor
IC13, IC16—NE615, receiver, Signetics
IC14, IC15, IC23—MC44802, PLL, Motorola
IC17—OE-175-14, tuner, Zenith
IC18—74LS138, decoder
IC19—74LS138, decoder
IC20—74LS688, address decoder
IC21—74LS245, bus transfer
IC22—LM386, audio amp, National Semiconductor
IC24—NE602, oscillator/mixer, Signetics
Q1–Q4, Q7—2N3906, PNP transistor
Q5, Q8—MRF901, double emitter NPN transistor, Motorola
Q6—2N3904, NPN transistor
D1, D4—MV209 or MV2105, varactor diode, Motorola
D2—IN5229B, 4.3 volts, Zener
D3—1N4003, diode
LED1—Any red light emitting diode
Other components
L1—T10307, 0.15 mH, 7-mm can type, Toko
L2—T10407, 1.0 mH, 7-mm can type Toko
L3—421F224, 5.8 to 3.7 mH, 7-mm can type, Mouser
L4—220 mH coil, Mouser
L5—3 turns of #30 AWG wire on #23 drill, LS = O.138"
L6—5 turns of #30 AWG wire on #42 drill, LS = O.2"
L7—3 turns of #30 AWG wire on #42 drill, LS = O.138"
T1—42IF128, 10-mm can type, Mouser

T2—42IF102, 10-mm can type, Mouser
FL1, FL2, FL5—SK M1, 10.7-MHz ceramic filter, Toko or Murata Erie
FL3, FL4—CFM2-455E, 455-kHz ceramic filter, Toko
XTAL1—34.3000-MHz standard crystal
XTAL2—XTAL107, 4.00-MHZ TTL oscillator
S1—7-position DIP switch
Connectors
J1, J2, J4—Female F-type bulkhead connector
J3—RCA audio jack, PC board mounted (90°)
J5, J6—F-type connectors are part of tuning assemble (IC17)
J7—3-pin type, Molex, 0.156" O.C. power connector
P2—36-pin DIP header
Two RCA male connectors for coax to tuner connection
Miscellaneous
● Bottom shield—3-7/8" × 3-7/8" single-sided PC board with glass epoxy, copper side facing away from board. Four ½-long screws, four 4-40 nuts and bolts, four lock washers and insulating washers.
● Lowband shield—2-1/4" × 2-1/2" sheet metal.
● Rear panel with mounting screws.
● 3 inches of 0.047 miniture coax.
● 16 inches of RG174 coax.

The reference level and attenuation settings determine the power level of the top line of the sweep grid. That is a user-entered number that can take on any floating-point value. The user has a choice of three settings for internal attenuation: 0, 10, and 20 dB. The attenuation is implemented by reducing the gain, not by the use of attenuation pads. That's a subtle yet significant difference from high-end analyzers that use switched attenuators for gain reduction. User attenuation is located in the input path, which is convenient for automatically calculating in the effects of inline attenuations. Since that's a floating point entry, negative attenuations (or gains) can also be entered in the signal path. There are three choices for the vertical power scale units using the dB/div entry: 2, 5, and 10 dB. Reference level, attenuation, and dB/div affect the placement of the power data on the sweep grid. It's best to experiment with different settings to get a feel for how they interact.

Sweep rate

The sweep rate determines how fast the display is updated and how long it takes to go through one sweep. It is directly affected by the CPU clock speed. For a given sweep rate, a faster PC will finish the sweep in less time than a slower PC. Sweep speed increases with higher values of sweep rate. The sweep rate and power accuracy are interrelated; longer sweep times usually result in more accurate power measurements. That has to do with the video bandwidth and PLL settling time. A fixed number of sweep rates are provided in the analyzer: 1, 3, 5, 10, 15, 20, and 30. A more complete discussion of the sweep rate and power accuracy relationship is given in the README.DOC file.

Band select

The band select menu item allows the user to select which input is going to be used: highband or lowband. The user must select the band of operation and connect to the appropriate input because autoswitching is not provided. The highband input should not be terminated when using the lowband input. That
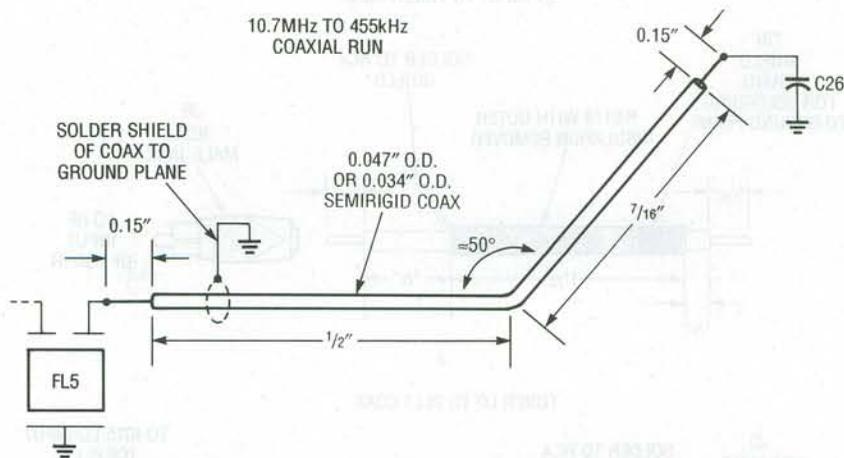
FIG. 13—THE 10.7 MHz TO 455 kHz COAXIAL RUN reduces spurious pickup from the 455-kHz IF.

would result in erroneous power measurements.

The exit to sweep menu item returns the user to the sweep display. Hitting the ESC key while on the menu bar does the same thing. Exit to Dos returns control of PC to DOS.

Calibration

Three power related calibration files are used by the spectrum analyzer: one for the automatic gain control (AGC), one for the received-signal strength indicator (RSSI), and a user-generated error table. The AGC calibration tables correct any variations in gain using the DAC input to the AGC pin of the tuner. Most of the variations are in the tuner. One table for each value of internal attenuation is provided.

A set of six data files are also used for the lowband and highband modes; namely the AGC*.DAT files. The RSSICAL*.DAT calibration files are used to "linearize" and map the RSSI voltages to an absolute power level. Two RSSI files are used; one for each RBW. Two user-generated files, POWERRH.DAT and POWERRL.DAT, can be used by kit builders to improve the accuracy of their power readings if they can get their hands on the equipment needed. The details of using the program USERCAL.EXE are covered in README.DOC. That error table is optional, and for factory calibrated units it is zeroed out.

If you build a kit, you'll have to live with the generic calibration files which, as mentioned above, result in degraded power ac-
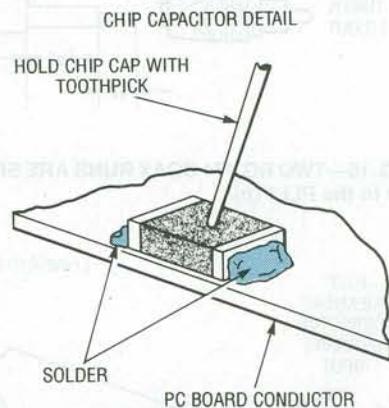
FIG. 14—USE THIS DIAGRAM as a guide to installing the chip capacitors.

curacy. Most of the power errors come from variations in the gain of individual tuner modules, which are approximately ± 2 to 3 dB over the entire bandwidth. The RSSI data tends to change very little. Because of that, the largest errors will be at the band-switching points. The averaged generic calibration files are provided with the kit, and are posted on the **Radio-Electronics** bulletin board.

Construction

The entire circuit of the spectrum analyzer is mounted on one double-sided PC board. We have provided foil patterns of the component side and the solder side of the PC board if you wish to make it yourself. Before mounting any components, you should visually inspect the board for shorts and solder bridges, especially around the pads that are surrounded by the ground plane. That can be done by putting a bright light behind the board, which really

RF INPUT TO TUNER COAX
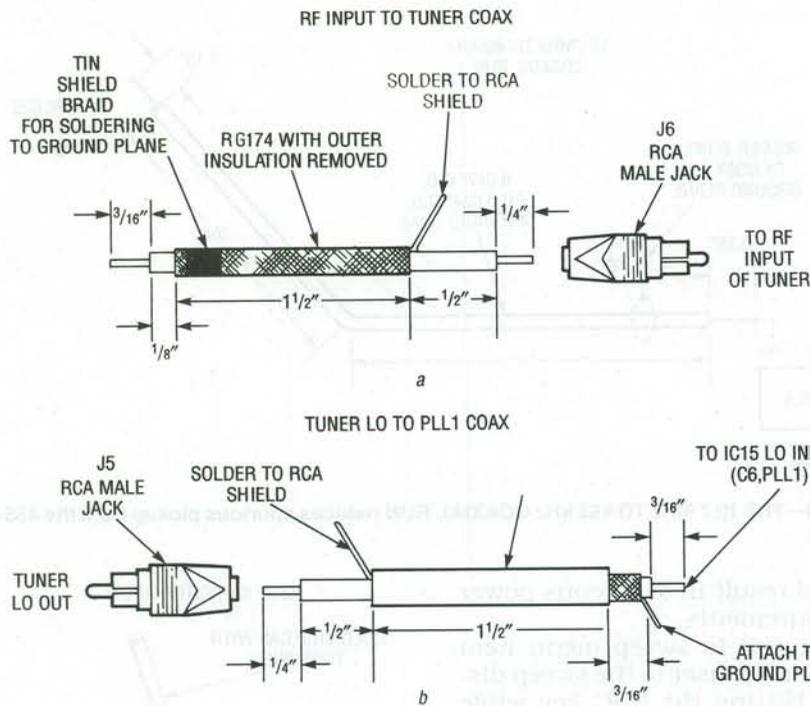
FIG. 15—TWO RG-174 COAX RUNS ARE SHOWN for the RF input to tuner (a) and the tuner LO to the PLL1 (b).
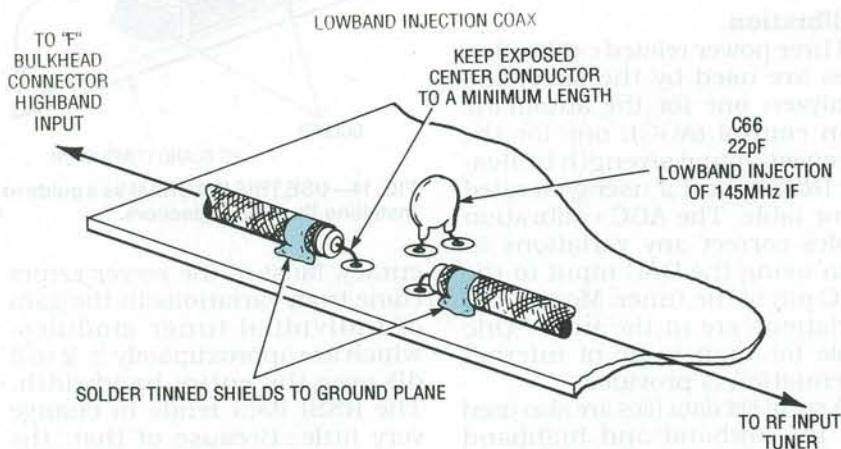
FIG. 16—THE RF FEED FOR the lowband injection coax. Make sure your center conductor is as short as possible.

makes the pads standout. After careful visual inspection, check the +5-, +12-, and +33.3-volt power buses for shorts to ground.

Figure 12 shows the component placement, as well as the locations for all coax runs. Before mounting any components, a short coax run must be installed on the top side of the board. A small piece of semirigid coax is used to connect the 10.7-MHz IF from FL5 to the input from the 455-kHz IF mixer (IC13, pin 1). The coax reduces the spurious pickup for the 455-kHz IF. Cut, strip, and bend the coax as

shown in Fig. 13. Using an ohm-meter, check to make sure the inner conductor is not shorted to ground. RG174 type coax, with the external insulation removed, can be used but it's a tight fit.

You're now ready to start soldering in the components. Install chip capacitors C21, C35, C67, C72, and C73 first, using Fig. 14 as a guide. Because of their small size they can be very difficult to install with the board fully stuffed. Solder in all remaining capacitors. Check them off on the parts list as you install them, then re-check the power buses with an ohmmeter. You should read infi-

nite resistance, as before. If you read a short or very low resistance, look for solder bridges.

Now solder in the resistors according to the component layout. Again, check the power buses for shorts using the ohmmeter. Install the inductors and coils next. If you buy a kit, L5, L6, and L7 are already made. Install all filters and crystals. Their leads can go in either direction. Lay XTAL1 down flat and solder its case to ground. The case of XTAL2 should also be tied to ground using a small piece of wire. Solder in the diodes, being careful to observe the correct polarity. Do the same for transistors Q1–Q8. Q5 and Q8 are surface-mount types from Motorola; "M" marked on the top indicates the collector. Using the ohmmeter again check for shorts on the power buses.

When installing the IC's, use sockets for all the chips except the NE615's, MC44802's, and the NE602. Those chips need a close connection to the ground plane to ensure proper operation. Check for shorts again. After you install IC3 (the MC34063 step-up voltage regulator), make sure you have 33.3 volts DC between R62 and ground. That is where the 33.3-volt power line comes from. If you really want to be thorough, use an ohmmeter to check every IC pin for shorts to ground and verify that the pins that should be grounded are grounded. Now install the mechanical parts: the RCA jack, 3-pin Molex connector, 36-pin dual header (for the parallel interface), DIP switch S1, and R64.

Tuner installation

Before the tuner can be installed, two RG-174 coax runs to the RF input and the LO output must be connected, as shown in Figs. 15-a and -b. If you don't get the lowband option, the RF input is just a direct feed using RG59 cable to a female/female F-type connector on the rear panel plate. After the cables are made, connect the LO cable to the board and solder the coax shield to the ground plane. Now make the RF feed. (If you have the lowband option, Fig. 16 shows you how to connect the coaxial cable to the board.)

Using the outer shield of the

lowband coax as a gauge, put the tuner on the board, top side up, by tacking the corners down with solder. Don't solder the lowband shield on yet, that goes on after tuning L6. Two holes are provided for using tie wraps to hold down the tuner if you desire. Cut small pieces of wire to connect tuner pins 1–8 on the bottom edge to the appropriate holes on the board. Make sure the IF OUT jumper is as short as possible. Now connect the two RCA jacks for the LO OUT and the RF IN coax runs.

Terminal panel and shield

Before you mount the terminal panel to the board, connect the highband coax run as shown in Fig. 17. Connect the coax to the board first, then connect the lowband and comb F connectors to the terminal panel. Now connect the highband F connector to the terminal panel and secure the panel to the board using two 4-40 screws and nuts. Solder jumpers from the plated holes in the printed-circuit board to the center conductor lowband and comb F connectors.

Figure 18 shows the mounting details of the bottom shield, which is made of a single-sided PC board and is mounted, with the copper side facing away from the main board, using four 4-40 bolts. This shield should be in place before you perform any final tuning as it effects signal levels.

Coil pretune

We're almost ready to power the unit up, but first we need to pretune the coils. Most of coil adjustments are noncritical. Use the following initial settings just to get you started:

● L1—Slug is 1½ turns from the bottom (fine adjust later).
● L2—Slug is 1½ turns from the top (±1 turn).
● L3—Slug is all the way to the bottom.
● L5—Close wound.
● L6—Close wound.
● L7—Close wound.
● T1—Slug is 1½ turns from the top.
● T2—Slug is 1½ turns from the top.

The spectrum analyzer should work with those settings. All adjustments from here on for fine tuning.
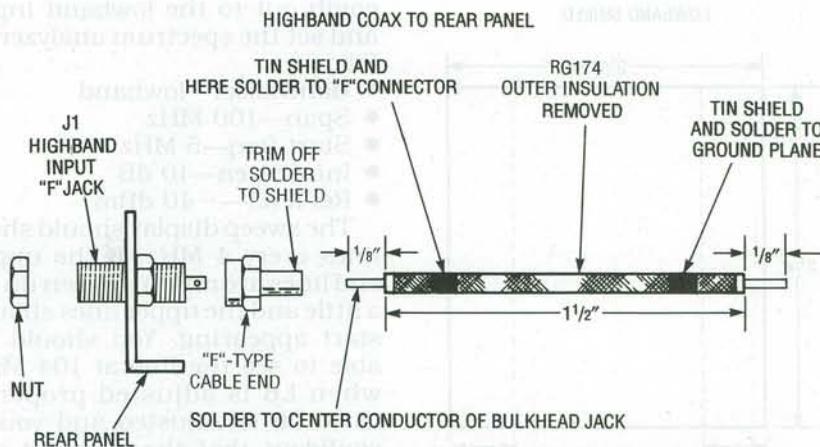
FIG. 17—THE HIGHBAND COAX RUN is shown here. This coax connection must be made before the terminal panel is installed on the PC board.
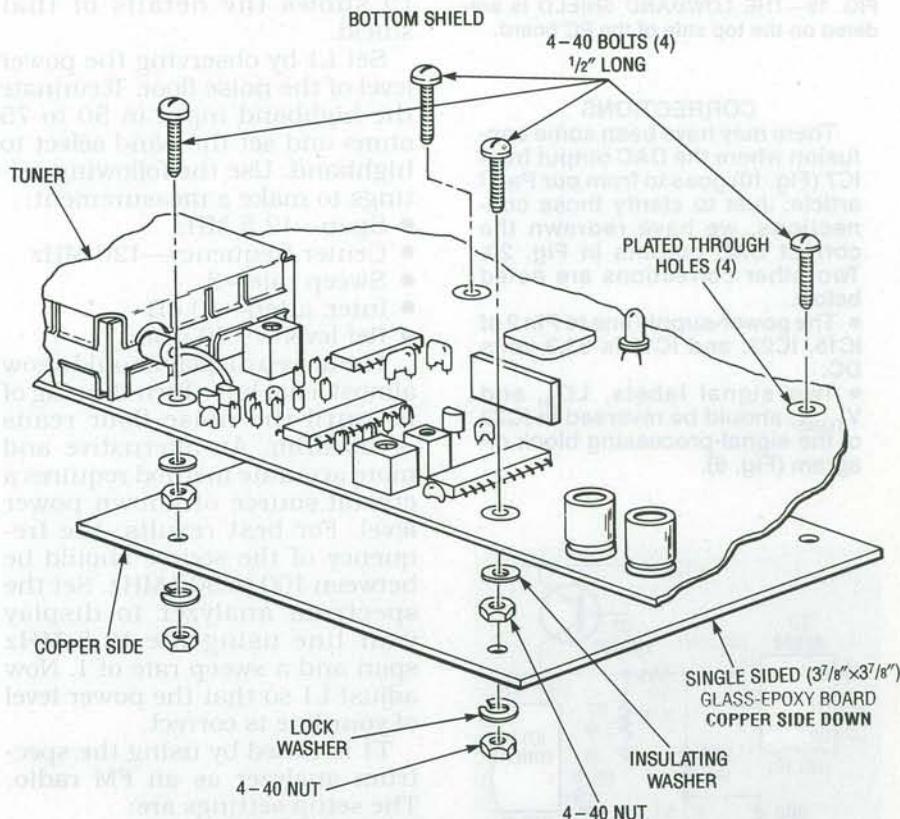
FIG. 18—THE BOTTOM SHIELD ASSEMBLY is shown here. Make sure the copper side of the shield is installed away from the PC board.

First power up

Put the card in the computer or, for external use, connect it to a parallel port and external power supply. Connect the comb output to the highband input and turn it on. Check the +5-, +12-, and +33-volt levels to make sure they are correct. Run either 810EGA or 810CGA program, depending on your video adapter. The supplied wake-up state is a span of 400 MHz with a start frequency of 100 MHz. Assuming every-

thing goes well, you should see a series of lines 4 MHz apart slowly rolling off in amplitude. If you don't, go to the "Troubleshooting" section.

Tuning the unit

The spectrum analyzer can be used to fine tune L1, L6, T1, and T2; L2, L3, L5, and L7 should need no further adjustment. Adjusting the coils is easier with the card outside of the PC case, for instance if you use the parallel

LOWBAND SHIELD

FIG. 19—THE LOWBAND SHIELD is soldered on the top side of the PC board.

CORRECTIONS

There may have been some confusion where the DAC output from IC7 (Fig. 10) goes to from our Part I article. Just to clarify those connections, we have redrawn the correct DAC outputs in Fig. 20. Two other corrections are noted below.

● The power-supply line to Pin 2 of IC15, IC23, and IC14 is 33.3 volts DC.

● Two signal labels, LO_{IN} and V_{TUNE}, should be reversed in IC23 of the signal-processing block diagram (Fig. 6).

FIG. 20—THE DAC OUTPUT from IC7 goes to IC17 and IC12 as shown here.

interface. Allow about 5 minutes for warm up and then tune the coils in the following sequence.

The maximum span available from the lowband is affected by L6. It is tuned by spreading, or closing, its turns. Connect the comb out to the lowband input and set the spectrum analyzer as follows:

● Bandselect—lowband
● Span—100 MHz
● Start freq—5 MHz
● Inter atten—10 dB
● Ref level—– 40 dBm

The sweep display should show lines every 4 MHz. If the upper end lines are missing, open up L6 a little and the upper lines should start appearing. You should be able to see the line at 104 MHz when L6 is adjusted properly. Once L6 is adjusted and you're confident that the lowband circuit is working properly, install the shield over the circuit. Figure 19 shows the details of that shield.

Set L1 by observing the power level of the noise floor. Terminate the highband input in 50 to 75 ohms and set the band select to highband. Use the following settings to make a measurement:

● Span—12.5 MHz
● Center frequency—120 MHz
● Sweep rate—3
● Inter. atten—10 dB
● Ref level—– 40 dBm

The sweep display should show almost a flat line. Turn the slug of L1 until the noise floor reads – 100 dBm. An alternative and more accurate method requires a crystal source of known power level. For best results, the frequency of the source should be between 100 to 500 MHz. Set the spectrum analyzer to display your line using the 12.5-MHz span and a sweep rate of 1. Now adjust L1 so that the power level of your line is correct.

T1 is tuned by using the spectrum analyzer as an FM radio. The setup settings are:

● Span—25 MHz
● Start freq—85 MHz
● Band select—highband
● Volume potentiometer (R64)—centered

Connect an antenna up to the highband input. You may have to use an outside antenna. You can make a simple antenna by attaching a 2- to 3-foot piece of wire to the center conductor of the input. Connect a speaker to the audio out RCA jack. Now let the analyzer make a few sweeps. You should be able to hear FM broadcasts as the analyzer sweeps by them. Now activate the marker and find a strong station. Put the marker at the peak of the signal, even if the audio drops out. Adjust T1 now for the best sound. T2 can be adjusted the same way, but you'll have to pick off the audio and amplify it as it is not connected to an amplifier. You will also need a narrowband FM broadcast for proper adjustment. With a little hunting you should be able to find one. (Try your local National Weather Service broadcast station in the 162.4–162.6 MHz band.) The adjustments of T1 and T2 only effect the FM demodulation and do not effect the accuracy of the instrument.

Troubleshooting

Typical symptoms indicating a problem are a flat or "pegged" sweep display and no response to inputs. Two programs are available to help in the troubleshooting process; BLINK.EXE and ADCDAC.EXE. BLINK is used to give a simple visual indication that the host PC has some communication with the card. With the card plugged into the PC or parallel cable, run BLINK. The LED on the card should blink at approximately 1-second intervals. If no blinking at all occurs, you have a communication problem with the PC. Double check the interface settings using SETUP; if those are wrong the card won't respond. If wiggling cables, checking power-supply voltages, and every permutation of interface selections does not result in a successful BLINK, you most likely have a hardware problem.

ADCDAC.EXE is a more extensive test in that both reading and writing to the card are involved. There is little chance that this test will be successful if BLINK fails. ADCDAC sends a voltage level to the DAC, then reads that voltage using the ADC. If the read voltages are within the tolerances, the test is declared a success. ADCDAC returns a pass/fail verdict upon completion. If you fail, it could be an interface problem or a problem with the ADC or DAC. Passing does not guarantee that all systems are go, just that the interface and ADC/DAC seem to be working.

If you still can't find the problem, see README.DOC for more things to try, or call DKD Instruments at (805) 581-5771. They'll be happy to help you. **R-E**