

# The DSP-10: An All-Mode 2-Meter Transceiver Using a DSP IF and PC-Controlled Front Panel

*Part 2*—This versatile 2-meter transceiver uses a PC as its front panel. With most of the radio in software, the mechanical construction of the radio is much easier to handle.

**B**efore you get started with this installment, be sure you have your copy of Part 1 nearby.<sup>11</sup> I'll begin by covering the transceiver's control functions, briefly discuss the software, then move on to assembly and testing of the transceiver.

## Control Functions

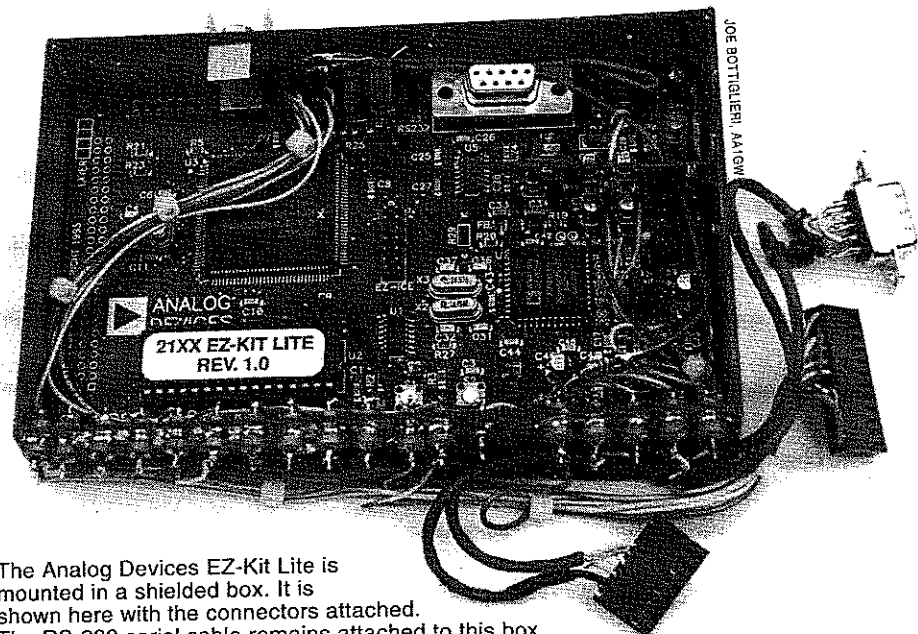
Other transmit functions on the board (see Figure 9) include a microphone amplifier (U109A), logic-level converters for the CW key (U110E and U110F) and the PTT line from the microphone (U110C).

Except for the voltage-tolerant audio amplifier, U14, the main circuit board is powered through a 10-V regulator, U101, as shown in Figure 10. This low-dropout regulator makes operation independent of input supply voltages ranging from 11 to 16 V. A noise filter consisting of C101, L101 and C102, along with reverse-voltage protection from a 1-A fuse (F1) and diode (D101) provide power conditioning.

MOSFETs Q105 and Q106 are used to switch the +10 V line between transmit and receive. Typically, there is a drop of about 0.25 V in these switches.

Two serial data streams coming from the DSP control the various functions on the main board. These DSP interconnects are three-line systems having one common line for *data*, one common line for *clocking* the data and two separate *enable* lines that indicate when all data has been clocked to the board. One of these serial streams goes to the second-conversion synthesizer, U7 (see Figure 8). The other goes first to a pair of eight-bit serial-to-parallel shift registers, U108 and U107, and then to the first-conversion synthesizer, U104.

Shift registers U107 and U108 have 16 outputs for control functions such as trans-



The Analog Devices EZ-Kit Lite is mounted in a shielded box. It is shown here with the connectors attached. The RS-232 serial cable remains attached to this box.

mit, receive, external-amplifier relay and external-antenna relay. The latter two functions are for relay sequencing that is controlled by the PC, eliminating the need for an external sequencer. There are three spare external control leads, E1, E2 and E3 at P108. The shift register also controls the receiver RF-stage gain by changing the current through the PIN diodes used for TR control.

Once full voltage has been applied to all circuits, U110A and its associated components reset the shift registers to a known condition. This reset status is also an input to the DSP so that hardware programming does not occur when the shift registers are not ready.

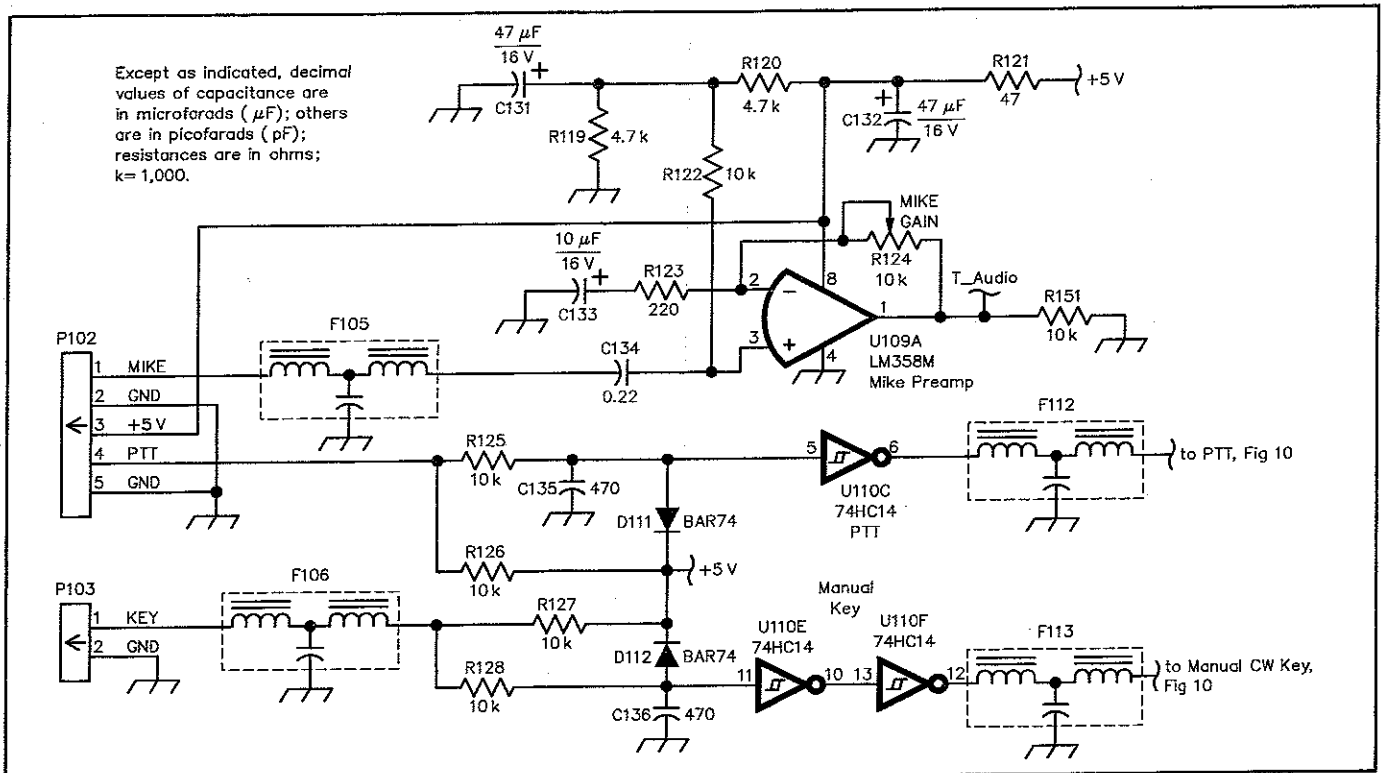
## DSP Software

The DSP program is roughly 2,000 words long and written in assembly lan-

guage. No attempt will be made here to show program details. A number of articles and books are available that provide details on the algorithms used for signal processing.<sup>12</sup> The source code for the transceiver programs is quite well commented and is available for study and change.<sup>13</sup> A code sample is shown in the sidebar "What Does a DSP Radio Look Like?"

The DSP program is synchronized by an AD1847 CODEC that performs the analog-to-digital conversion. To accomplish this, interrupts are generated by the CODEC 48,000 times each second. All internal timing is derived from these interrupts for functions such as frequency conversion, IF and AF filtering, SSB generation and serial communications with the PC. Some of these functions operate directly at the 48-kHz rate, while others run every fifth cycle at a rate of 9.6 kHz.

<sup>11</sup>Notes appear on page 40.



Except as indicated, decimal values of capacitance are in microfarads ( $\mu\text{F}$ ); others are in picofarads (pF); resistances are in ohms; k=1,000.

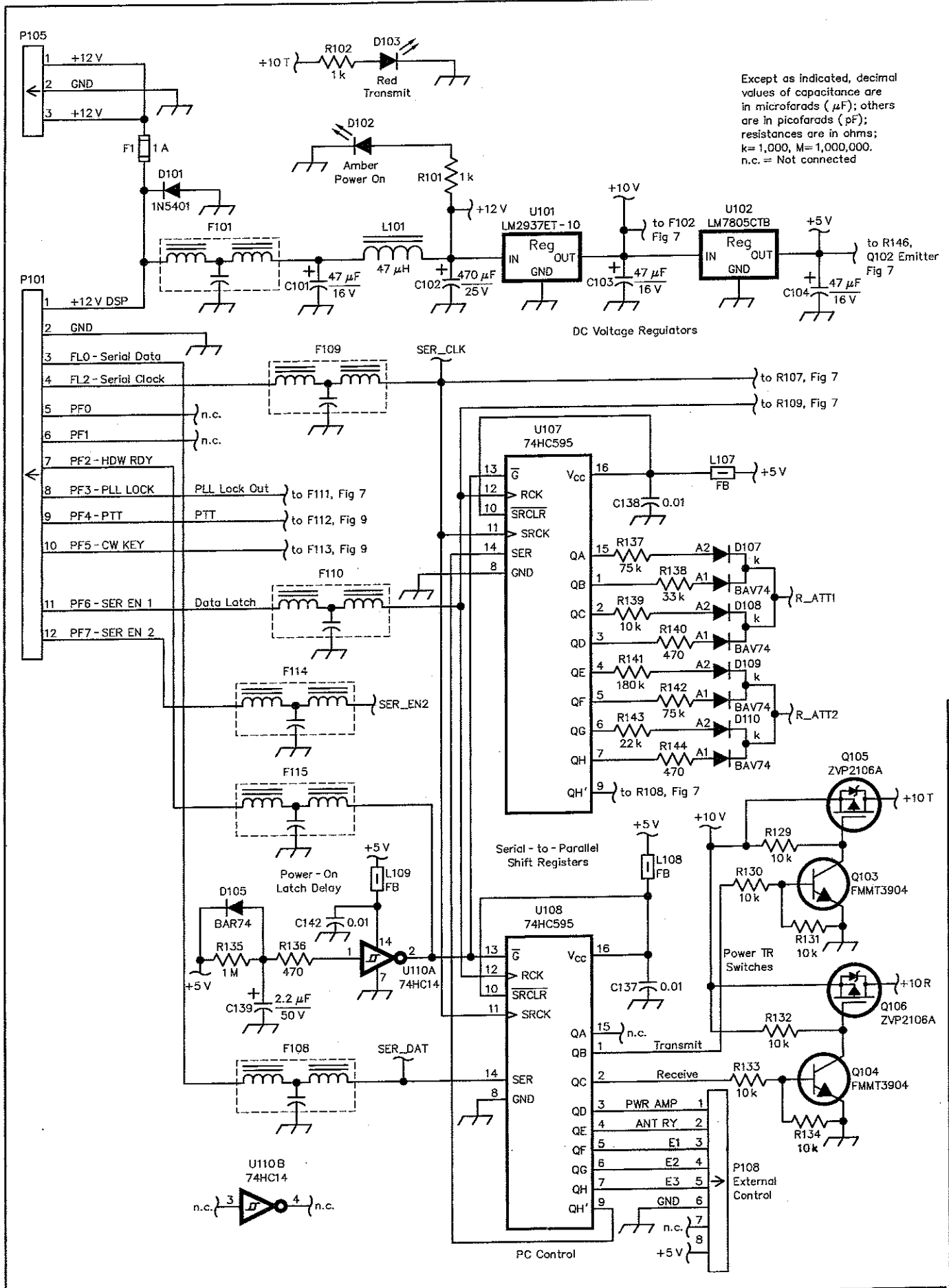
Figure 9—Microphone preamp, PTT and keying logic for the 2-meter transceiver. The microphone amplifier is adjustable to bring the voltage up to that required for the ADC. Protection circuitry is added to the keying and PTT circuits to protect against excessive external voltages. (See the sidebar "Parts Sources" in Part 1 for an explanation of the part-source abbreviations.)

- |   |   |  |
|---|---|--|
| C131, C132—47- $\mu\text{F}$ , 16-V surface-mount electrolytic (DK PCE3033CT) | FIL105, FIL106, FIL112, FIL113—470-pF filter (DK P9806CT) | R124—10 k $\Omega$ variable resistor, Bourns 3329H (DK3329H-103) |
| C133—10- $\mu\text{F}$ , 16-V surface-mount electrolytic (DK PCE3031CT)       | P102—5-pin 0.1-inch in-line header (DK WM4203)            | U109—LM358M dual op amp (DK LM358M)                              |
| D111, D112—BAR74 diode (DK BAR74ZXC7)   | P103—2-pin 0.1-inch in-line header (DK WM4200)            | U110—MM74HC14M (DK MMHC14M)                                      |

### What Does a DSP Radio Look Like?

Many people find writing computer programs to be a bit challenging. But it is interesting to see what a common circuit looks like when built in assembly language. What follows is a short clip from the DSP-10 image-reject mixer program used in SSB and CW to convert from 15 kHz to audio. The comments along with the computer instructions are enclosed in curly brackets, {}, and explain the operations.

```
{ The program starts here with the signal in the register my0 }
{ First we generate the DDS conversion oscillator using if_dphase that determines the frequency }
ax1 = dm(if_dphase);    { Phase increment for conversion osc, from memory }
ay1 = dm(if_phase);    { Phase, as computed for last data point, also from memory }
ar = ax1 + ay1;        { New phase is old phase + phase increment }
dm(if_phase) = ar;     { Save it for the next data point }
{ The routine named sin converts from phase to amplitude of a sin wave }
call sin;              { Phase in ar, Sin returned in ar }
{The following operation is a double balanced mixer (DBM)! }
mr=ar*my0(SS);        { Multiply the conversion oscillator and the signal }
dm(i_audio) = mr1;    { Store 0 degree (in-phase) output }
{ We now have 0 degree audio and to do image reject mixing we need the 90 degree audio: }
ax0 = dm(if_phase);  { Get current phase, as just computed }
ay0 = 16384;          { 90 degrees for quadrature osc. 16384 represents 0.25 (of 360) }
ar = ax0 + ay0;      { This is the phase of the 90 degree osc. }
call sin;            { Convert phase to 90 degree osc signal }
mr=ar*my0(SS);        { Signal is still in my0; This is the 90 degree DBM }
dm(q_audio)= mr1;    { Store sample in fir1q delay line }
{This leaves the two audio signals i_audio and q_audio in memory, ready to be low-pass filtered and then added or subtracted to form USB or LSB }
```



Except as indicated, decimal values of capacitance are in microfarads ( $\mu\text{F}$ ); others are in picofarads (pF); resistances are in ohms; k= 1,000, M=1,000,000. n.c. = Not connected

DC Voltage Regulators

Serial - to - Parallel Shift Registers

PC Control

P108 External Control

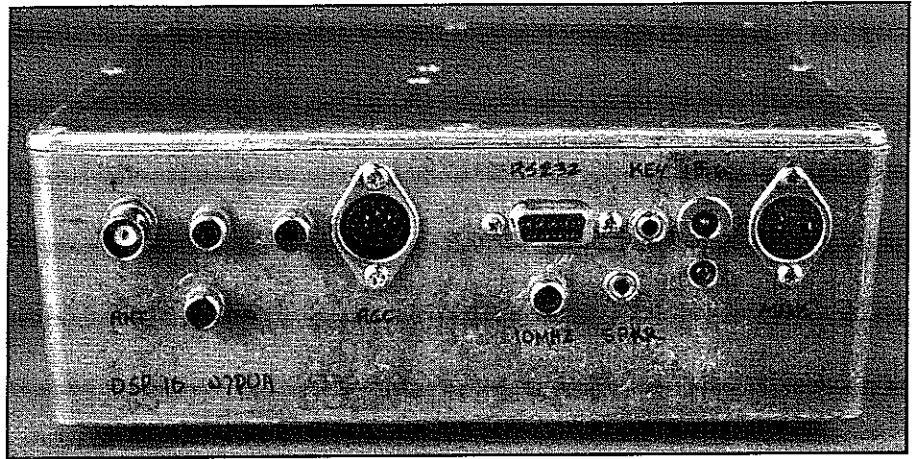
Figure 10—Power regulator and control circuitry. The shift registers, U107 and U108 are used to obtain digital outputs from the DSP used to control the RF gain and other parameters. R137 to R144 control the current through PIN diodes for the RF gain.

C101, C103, C104—47- $\mu$ F, 16-V surface-mount electrolytic (DK PCE3033CT)  
 C102—470- $\mu$ F, 25-V axial-lead electrolytic (DK P1329)  
 D105—BAR74 diode (DK BAR74ZXCT)  
 D101—1N5401 diode (DK 1N5401CT)  
 D102—Amber LED (RS 276-066)  
 D103—Red LED (RS 276-021)  
 D107, D108, D109, D110—BAV74 dual diode (DK BAV74ZXCT)  
 F1—1-A fuse, 5 mm (DK F948) with two fuse clips (DK F058)  
 FIL108-FIL110, FIL114, FIL115—470-pF filter (DK P9806CT)  
 L107-L109—Ferrite SMT bead 1206 (DK 240-1019-1)  
 L101—47- $\mu$ H iron-core inductor (DK TK4444)  
 P101—12-pin, 0.1-inch in-line header (DK WM4210)  
 P105—3-pin 0.1-inch header (DK WM4201)  
 P108—8-pin, 0.1-inch in-line header (DK WM4206)  
 Q103, Q104—FM3T3904 NPN transistor, SOT23 (DK FM3T3904CT)  
 Q3, Q6, Q102—FM3T3906 PNP transistor, SOT23 (DK FM3T3906CT)  
 Q105, Q106—ZVP2106A N-channel MOSFET (DK ZVP2106A)  
 U101—LM2937ET-10, low-dropout voltage regulator, TO-220 case (DK LM2937ET-10)  
 U102—LM7805CTB voltage regulator, TO-220 (DK LM7805CTB)  
 U107, U108—MM74HC595 (DK MM74HC595M)

Figure 1 in Part I includes a functional block diagram of the DSP programs used for reception. The input signal is an IF centered at 15 kHz. SSB and CW reception require mixing down to audio frequencies. The conversion oscillator (BFO) is a DSP-calculated sine wave in the 12.5- to 17.5-kHz range, with a resolution better than 1 Hz. This provides the fine-tuning needed because the first-conversion synthesizer changes in 5-kHz steps. To discriminate between LSB and USB, there are two software mixers, one driven by a sine wave and the other driven 90° out-of-phase by a cosine wave. The two audio signals, called in-phase (I) and quadrature (Q), are low-pass filtered at 2.8 kHz to remove the high-frequency conversion products and other possible interfering signals. Up to this point, all processing is at a 48-kHz rate.

Because the audio bandwidth has been limited at this point, it is possible to drop to a 9.6-kHz rate. The two audio signals must have a 90° phase difference to allow sideband selection. A DSP routine called a Hilbert transform accomplishes this. The desired sideband, upper or lower, is selected by respectively adding or subtracting the two audio signals.

Following the sideband selection are optional narrowband audio finite-duration



A front-panel view of the transceiver. The two phono jacks adjacent the BNC ANT jack are used for interconnection to an amplifier or transverter. The two jacks can be connected together with a short jumper cable for QRP operation.

impulse-response (FIR) filters and an LMS adaptive noise-reduction routine.<sup>14</sup> Presently, two CW filters having bandwidths of 200 and 450 Hz centered at 600 Hz are available. These filters can be changed easily by reassembling the DSP program with new files for the FIR-filter coefficients.

#### NBFM Reception

Narrowband FM is received in a manner that starts much like SSB reception. The I and Q audio signals generated by mixing are used to calculate a phase angle relative to a center frequency, using an arctangent function. The phase angle is subtracted from the previous measurement taken 1/48000 second earlier. This phase-angle difference, after low-pass filtering, is the desired detected FM signal.

During reception, spectral analysis is being done with a 1024-point FFT using the audio data sampled at a 9.6-kHz rate. The spectral data from 12 overlapping data sets are averaged and converted to decibels. These are transmitted serially to the PC at 9600 baud. The decibel conversion allows the spectral data to be transmitted using only eight bits per frequency point.

#### SSB Transmit

The SSB transmit process is essentially the same as that used for reception, but in reverse order. The microphone's audio signal is converted to a 16-bit word by the ADC. Next, a low-pass FIR filter limits the bandwidth of the audio signal. A Hilbert transform then generates a pair of signals with a 90° phase difference. These two signals are run through a pair of mixers having 90° out-of-phase conversion oscillators. Finally, the resulting signals in the 15-kHz region are either added or subtracted to form an USB or LSB signal, respectively, which is sent to the same DAC used for audio output during reception.

#### CW Transmit

For CW, the process is simpler. The keying signal comes from the PC or a key con-

nected to the RF board. This signal is fed through a 500-Hz low-pass filter to limit key clicks, producing a signal that amplitude modulates a sine wave in the 15-kHz region. In the DSP, this modulation is simply a multiplication routine. The resulting modulated output is ready for the DAC.

#### FM Transmit

FM transmission starts by limiting and filtering the microphone input as is done for SSB. This signal is then used to determine the frequency of a software oscillator in the 10- to 20-kHz range, which is sent to the DAC.

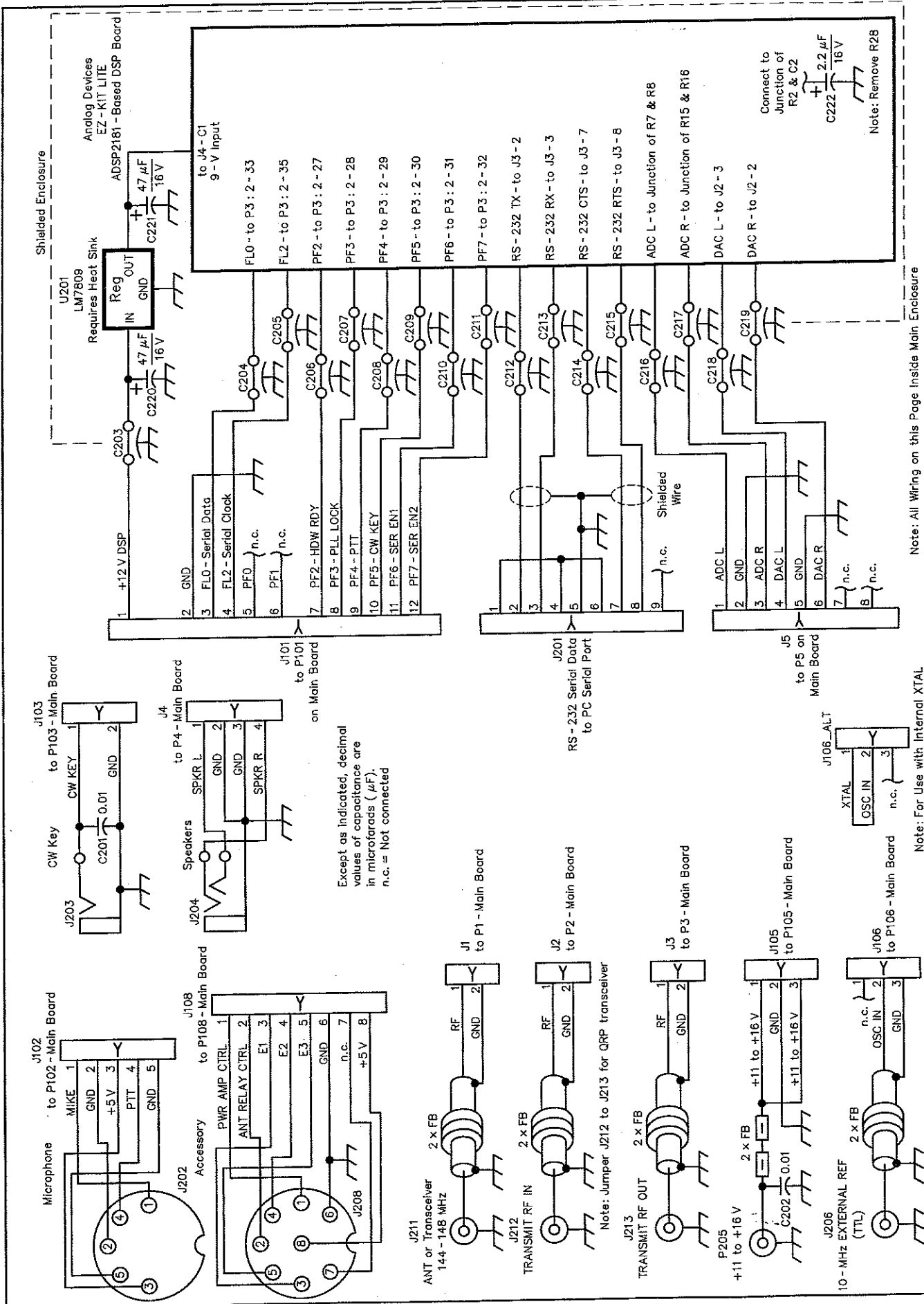
Serial communication with the DSP is at 9600 baud, and all UART functions are in software. All commands from the PC to the DSP consist of six bytes. This allows us to send commands for controls such as audio gain. About 15 different commands are available. These commands are kept as simple as possible and decision making is concentrated in the PC.

#### PC Software

To keep things simple, the PC software runs under DOS. It is written in C (not C++) and uses the Borland DOS Graphics Interface routines. The programs were compiled using *Borland C++* version 4.0.

All transceiver control is done via the PC keyboard. Alphanumeric keys and standard punctuation marks are reserved for sending CW; thus, most control operations involve the use of function keys, the ALT key and the CTRL key. A mouse is not used.

Basic display updating is controlled by the reception of the spectrum and status data from the DSP. This is about 535 bytes of data and takes approximately 0.6 seconds to receive. Once a full data set is received, and after the desired averaging, the display is updated. The received data is buffered up to 8 kB by the interrupt routine, so the display data updates can be delayed for up to eight seconds before data is lost. This provides some program-operation flexibility.



Note: All Wiring on this Page Inside Main Enclosure

Note: For Use with Internal XTAL

Figure 11—Interconnection diagram. The DSP board is treated as a component and mounted in a separate box with feed-through filters as shown here. The other connectors are a convenience to allow the boards to be separated for construction, changes and repair.

- C201, C202—0.01- $\mu$ F disc-ceramic capacitors. These are added as RF bypasses at the connectors of the CW key line and at the power connector.
  - C203-C219—Feed-through capacitor, 1500 pF min, Spectrum Control 1214-001 (NE 19F687) or similar are ideal. Other surplus feed-through capacitors or filters would also be suitable.
  - C220, C221—47- $\mu$ F, 16-V surface-mount electrolytic (DK PCE3033CT). These are mounted on the 9-V regulator U201.
  - C222—2.2- $\mu$ F, 16-V radial-lead electrolytic. This capacitor is added on the EZ-Kit Lite board at the junction of R2 and C2.
  - J1, J2, J3, J103—2-pin 0.1-inch in-line socket (DK WM2011) and two crimp terminals for each (DK WM2200). In general, this connector and the others that connect to the headers on the PC board are from the Molex 22-01-20x7, where x is the number of connections.
  - J4—4-pin, 0.1-inch in-line socket (DK WM2013) and four crimp terminals for each (DK WM2200)
  - J5, J108—8-pin, 0.1-inch in-line socket (DK WM2017) and eight crimp terminals for each (DK WM2200)
  - J101—12-pin 0.1-inch in-line socket (DK WM2021) and 12 crimp terminals for each (DK WM2200)
  - J102—5-pin 0.1-inch in-line socket (DK WM2014) and five crimp terminals for each (DK WM2200)
  - J105, J106—3-pin 0.1-inch in-line socket (DK WM2012) and three crimp terminals for each (DK WM2200)
  - J201—9-in female D connector (RS 276-1538)
  - J202—5-pin circular DIN connector (RS 274-005)
  - J203—Two-circuit, 1/8-inch phono jack (RS 274-251)
  - J204—Stereo 1/8-inch phono jack (RS 274-249)
  - J206, J212, J213—Phono jacks (RS 274-346)
  - J208—8-pin circular DIN connector
  - J211—BNC jack (RS 278-105)
  - P205—Power connector, 5.5 mm OD, 2.1 mm ID (RS 274-1563)
  - U201—LM7809CTB voltage regulator, TO-220 case (DK LM7809CTB) requires small heat sink and mounting hardware to fasten it to the inside of the EZ-Kit box.
- Misc: 10 ferrite toroids to isolate coax cables (Amidon FT-23-43). These are placed over the cables as shown on this schematic. Also needed are: EZ-KIT Lite PC board and box (see text); outer box Hammond 1590F (DK HM156); four 1/4-inch OD, 1/4-inch long brass standoffs, used to mount the main board to the box; four 1/4-inch OD, 1-inch long threaded #4-40 spacers, used to mount the DSP box to the main board. Microphone—Connections shown are compatible with RadioShack 21-1172.

Parameters that define the transceiver operation—such as audio gain—can be derived from an ASCII configuration file that is read when the PC program starts. These parameters override the default parameters, and in many cases serve to customize the transceiver. When a shutdown command is given, a new file is written that allows the transceiver to start up with the configuration last used.

### Building the Transceiver

Circuit immunity to noise and spurious response benefits greatly from use of a solid ground plane on the PC board. For this reason, a double-sided board is employed. The main drawback to this approach is the need for jumper wires on the backside, but the advantages far outweigh this minor inconvenience.

Surface-mount components are used for several reasons. The board ends up being smaller and costs less, the RF and ground paths are often shorter and troubleshooting is easier. That's because traces are not hidden on the back of the board and are easier to follow. After building many boards with both through-hole and surface-mount approaches, I am convinced that surface-mount boards are easier to assemble,<sup>15</sup> the main reason being that all work can be done on one side of the board.

A Hammond 1590F die-cast box holds the main board and the EZ-Kit DSP board. The latter is mounted in a separate box to provide shielding. I built the box from 1/16-inch-thick double-sided PC-board stock, but it can be fabricated from hobby store brass just as well. The mounting holes for the main board line up with the holes for the EZ-Kit, so it is easy to stack the entire sandwich of boards, boxes and standoffs. The two voltage regulators, U101 and U102, are mounted on the bottom side of the PC board. The ICs are fastened directly to the box with #6-32 hardware for heat sinking. The main board is secured to the die-cast box using four 1/2-inch-long spacers. Above the board are 1-inch-long threaded spacers that hold the DSP box.

All leads from the EZ-Kit pass through feed-through LC filters as they leave the inner box. This greatly reduces "birdies" and noise caused by coupling between the DSP and RF circuits. A cover on the DSP EZ-Kit box completes the shielding. Good shielding requires a connection between the cover and the box every two inches or so. I use small pieces of finger stock for this. Alternatively, #6-32 brass screws and nuts soldered to the box can be used.

All external transceiver connectors are fastened to the die-cast box. In some cases, there are bypasses right where a connector is mounted and ferrite beads are placed over the connecting wires. These beads are shown in Figure 11, the interconnection schematic. It is best to err on the side of extra shielding and filtering than having to add parts later on.

Another voltage regulator (U201) is shown in Figure 11. This device is needed

because the 5-V regulator furnished with the EZ-Kit cannot dissipate the power associated with operating voltages above 9 V. I tried various schemes to add heat sinking to the EZ-Kit, but they were not successful for operation at 16 V. U201 is bolted to the inside of the DSP box with a small heat sink on the outside.

Transceiver main PC boards are available.<sup>16</sup> The EZ-Kit Lite boards are available from most electronic distributors that carry Analog Devices products. You need to drill out the die-cast box and construct the enclosure for the EZ-Kit board. A number of plugs need to be made up and wired into the main box.

Some minor modifications are made to the EZ-Kit board as shown in Figure 11. Before making these changes, it's best to operate and test the DSP unit itself. Run the programs supplied with the EZ-Kit. Then load the transceiver program, *UHF3.EXE*.<sup>17</sup> This portion of the DSP and PC operation can be tested by operating the transceiver program as an audio processor. This requires running the PC program *UHFA.EXE* after loading the DSP and executing the **ALT-1** command to toggle between RF and audio processing.<sup>18</sup> The input can come from any transceiver phone jack and goes to the DSP left channel (phone-jack tip.)

After testing the EZ-Kit, mount it in its enclosure and wire the feed-through capacitors according to Figure 11. When making the connections to the main board and the RS-232 connector on the main enclosure, solder the wires of the three interconnecting cables to the feed-through capacitors. Leave an inch or two of slack in the cables so that the DSP box can be lifted above the main board with everything operating.

Main-board assembly requires some care, but there is a reasonable amount of room between components. There are no components on the back of the board, so it can be placed in the enclosure for testing.

### Testing

For transceiver main-board alignment and basic troubleshooting, you need a voltmeter. A signal generator covering 144-148 MHz is helpful, but on-the-air signals are an adequate substitute and their use is assumed in the following steps. First, apply +11 V to the main board *without* using the DSP board. At 11 V, it is not necessary to heat sink the voltage regulators, so the board can be tested outside the box. At this point, current consumption should be around 350 mA. If everything is operating properly, your checks should show the nominal voltages given in Table 1.

All dc voltages must be proper before further testing is possible. If they're not right, find out why. Next, mount the main board in the die-cast box and fasten the two regulator heat sinks to the box. Connect the EZ-Kit box wiring, but leave the EZ-Kit box separate from the main box so that it can be moved out of the way of the main board. Connect the transceiver serial con-

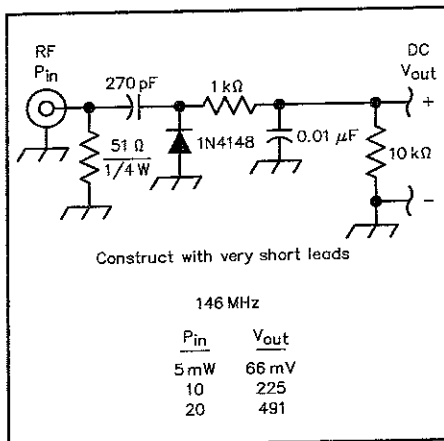


Figure 12—A simple power meter suitable for test and alignment of the transmitter. The dc levels shown in the chart can be measured with a dc voltmeter. Construct this circuit using very short leads.

nection to the PC's serial port using the 9-pin cable supplied with the EZ-Kit. Now both the main board and the EZ-Kit can be powered via the power connector. With power applied, load and run the EZ-Kit program *UHF3.EXE* as was done earlier. Next, execute the PC program *UHFA.EXE* that initializes all the parameters for the DSP program, including programming the synthesizers.

The amber **POWER LED**, D102, should be lit, but the red **TRANSMIT LED**, D103, should be off. Confirm the voltage readings at the following points:

Q106 pin 1	10 V receive	9.7 V
U10A pin 3	IF amplifier	6.0 V
U109B pin 6	Transmit IF driver	2.4 V

Be sure that the RF gain is at 100 (press **Ctrl-F8** on the PC keyboard) and confirm the following voltages:

D2-A1	Antenna TR diode	0.73 V
D1-A1	RF Filter TR diode	0.73 V

Measure the 19.68-MHz synthesizer tuning voltage at the U6 pin 6 side of R54 (Figure 8). Set this to about 4 V using C69. If it is not possible to set the voltage to that level, adjust the turns on the VCO coil, L21. Pushing the turns together raises the tuning voltage. After you are sure that L21 is at its proper setting, use a small dab of RTV sealant to hold the windings in place and secure the coil to the board.

Set the **MODE to CW** and set the **Operating Frequency** to 147.000 MHz. Adjust the 126- to 128-MHz VCO coil, L102, until the tuning voltage measured at the junction of R104 and R105 is about 3.5 V.

Ensure that a jumper is in place between pins 1 and 2 of P106, or that an external reference signal is being fed to P106 pins 2 and 3. Attach an antenna and see if you can receive a local repeater signal, with the transceiver in CW mode. If so, adjust the reference-oscillator frequency with C110 until the carrier pitch is about 600 Hz with

Table 1  
Nominal Voltages

Component ID and Pin Number	Function	V <sub>age</sub> (V)
U101 pin 1	10-V regulator input	11.0
U101 pin 3	10-V regulator output	10.0
U102 pin 3	Main 5 V regulator	5.0
U103 pin 3	First synthesizer regulator	5.0
U14 pins 2 and 13	Audio outputs	5.5
U1 pin 3	First RF amp	3.5
U2 pin 3	Second RF amp	4.7
R110	Source of Q101 VCO	0.23
U105 pin 3	VCO buffer	3.5
U106 pin 3	VCO buffer	4.6
R59	Source of Q4 VCO	0.91
U8 pin 3	VCO buffer	2.8
U9 pin 3	VCO buffer	3.6

the repeater frequency on the display. If it is not possible to get on frequency adjusting C110, change the value of C109. As you obtain more-accurate frequency references than a local repeater, it will be necessary to repeat this adjustment.

Next, peak crystal-filter coils L12 and L13 for maximum signal. The signal-level indication can be helpful for these adjustments. Select a repeater frequency as close as possible to 147 MHz and peak the RF-filter coils L1, L2, L8, L9, L10 and L11 at that frequency. Now, center the **MIKE GAIN**. That completes all adjustments.

Connect a dummy load to the antenna connector (a 51- $\Omega$ , 1/4-W resistor is adequate) and press the **Home** key to put the transceiver into transmit. With the key up, you should measure the following voltages:

D1-A2	RF Filter TR diode	0.73 V
U4 pin 3	1st transmit amplifier	3.6 V
U5 pin 3	2nd transmit amplifier	4.6 V
Q2 emitter	Power-amplifier emitter	1.2 V
Q2 base	Power-amplifier base	1.9 V

While holding down the CW key (right-hand **ALT** key), measure the transceiver's output power. It should be at least 20 mW at full-power setting. Figure 12 shows a circuit that can be used to measure the power output if a power meter is not available.

### Next Month

In the last installment of this series, I'll cover the operational aspects of the transceiver, its performance and future direction.

### Notes

<sup>11</sup>Part 1 of this article appears in the September 1999 issue of *QST* on pages 33-41.

<sup>12</sup>Bob Larkin, W7PUA, "A DSP Based Transceiver for UHF and Microwaves," *Proceedings of Microwave Update '96*, pp 15-31; available from ARRL. This paper covers an early version of the transceiver. The single-conversion transmitter approach shown was not able to achieve adequate spurious levels and was modified to the double-conversion approach used here; Rob Frohne, KL7NA, "A High Performance, Single Signal, Direct-Conversion Receiver with DSP Filtering," *QST*, Apr 1998, pp 40-45.

Analog Devices, *Digital Signal Processing Applications Using the ADSP-2100 Family*, Vol

1 and 2. These are available at some bookstores and directly from Analog Devices, (One Technology Way, PO Box 9106, Norwood, MA 02062-9106; tel 781-329-4700, 800-262-5643; [www.analog.com](http://www.analog.com)). Vol 1 has most of the basic routines needed for DSP work and Vol 2 has more specific applications, most of which are not involved in this project.

<sup>13</sup>Program source code is available from the author at [boblark@proaxis.com](mailto:boblark@proaxis.com). There is no charge for the software, but licensing is required. Notes on the program design and usage are available at <http://www.ao.com/~gnome>. These notes will be occasionally updated to reflect the current status of this on-going project.

<sup>14</sup>A. Bateman and W. Yates, *Digital Signal Processing Design*, Computer Science Press, Rockville, MD, 1989, pp 197-202 has a good discussion of the Hilbert transform 90° phase shifter. This engineering book also has a variety of topics related to DSP transceiver design. Also, see Doug Smith, KF6DX/7, "Signals, Samples and Stuff: ADSP Tutorial," *QEX*, Mar/Apr 1998, pp 3-16; May/June 1998, pp 22-37; July/Aug 1998, pp 13-27 and Sept/Oct 1998, pp 19-29. Many of the standard DSP routines are discussed in this four-part article.

<sup>15</sup>See Sam Ulbing, N4UUA, "Surface Mount Technology—You Can Work with It!," *QST*, —Part 1, Apr 1999, pp 33-39; —Part 2, May 1999, pp 48-50; —Part 3, Jun 1999, pp 34-36; —Part 4, Jul 1999, pp 38-41.—Ed.

<sup>16</sup>Unpopulated PC boards with top-side solder mask and full silkscreen legends on both sides, along with a full drawing package and assembly notes, are available from Mashell Electric, PO Box 5, Eatonville, WA 98328, for \$50 post-paid in the US. Alternatively, Gerber files for noncommercial fabrication of the main PC board are available by e-mail from the author. A free license is required to use these files.

<sup>17</sup>Analog Devices uses the .EXE extension for their DSP program files. These files cannot be run as standard PC .EXE files; they require a separate loader such as the *Windows loader* that comes with the EZ-Kit. An alternative shareware loader, *EZFAST.COM*, written by Dwight Elvey, speeds up the loading process and adds several diagnostic features. The program is available at <http://www.analog.com/techsupt/software/dsp/ezkitit/ezkitit.html>.

<sup>18</sup>All the transceiver functions that make sense for an audio processor are available. For instance, there is no RF gain control, but you can still tune the audio signal, thus shifting all frequencies up or down by some offset value. Additional information on audio-processor operation is available at <http://www.ao.com/~gnome>.

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