A PIC-based HF/VHF Power Meter

Add an LCD display and a versatile pic-Programmed CPU to this popular log amp for 80 dB of calibrated resolution on your bench.

By Roger Hayward, KA7EXM

Introduction

A variety of articles has been presented recently on simple, accurate, power measurement using a logarithmic amplifier by Analog Devices. The article by Wes Hayward, W7ZOI, and Bob Larkin, W7PUA,[1] revealed the AD8307 log amp, capable of measurements from –80 dBm to +7 dBm and from 1 to 500 MHz. Measurements can be taken to levels up to nearly 100 W with the use of an easy-to-build 40 dB tap.

As is the case with most power meters, an accurate calibration step is

[1]Notes appear on page 10.

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required. This is performed by using either a signal of known level, or by comparing an unknown signal level against another calibrated measurement device.

Bob Kopski, K3NHI, presented an article describing a way to provide the home-experimenter with a method to calibrate the meter. He translated the output of the log amplifier into a 1 mV/dB range, such that the measurements could be displayed by a digital voltmeter (DVM) module without the need to convert measurement levels through a lookup chart.[2] In a later paper, he presented a simple RF signal source that can be calibrated with an oscilloscope or RMS voltmeter.[3]

This project begins with the same log amplifier, and adds a PIC processor, LCD display and user control. With a small on-board microprocessor,

significant additional features may be employed:

- Calibration points are stored within the FLASH memory of the PIC processor.
- Power measurement levels are displayed on the screen in dBm, and, optionally, in watts.
- When using a coupler, on-screen offset is included within the software.
- A high-accuracy differential measurement mode allows the operator to measure insertion loss with resolution better than 0.1 dB.
- Amplifier gain, return loss and even VSWR can also be measured and displayed with this differential mode.

There are two goals in the presentation of this article: First, if you haven't built a general-purpose RF

power meter for your bench yet, this may be of interest for you. Second, the PIC code is available in both pre-programmed format, as well as in source-code. With a relatively small investment, the amateur has the capability of developing new projects based upon the generic PIC and LCD module presented in this article.

For those interested in replicating either part of the design, parts are available from Kanga US.[4]

Theory of Operation

The heart of the entire system involves the Analog Devices AD8307 logarithmic amplifier. This part accepts RF input from 1 to 500 MHz, and converts the power level to a voltage. The conversion is on a logarithmic scale, such as 25 mV of output change per dB change in input power. The output voltage is then scaled by an op amp to roughly 50 mV/dB, such that the entire –80 to +7 dBm range spans from 0 to just under 5 V. This range may be easily captured by an A/D converter and converted from V to dBm through a lookup and interpolation step.

The Microchip-PIC chosen is the 18F452.[5] The built-in A/D converter has a resolution of 10 bits or 1024 unique values. Assume for a moment that the RF range of 87 dB spans 0.5 V to 4.5 V to the A/D converter. This uses 80% of the 1024 points in the A/D converter. With 80 dB relating to 800 points, the highest resolution available is roughly 0.1 dB per step from the converter. This limits measurements to a ±0.1 dB resolution.

For some applications, power measurements accurate to ±0.1 dB are probably sufficient. If you are measuring the output power of a transmitter, 0.1 dB variations in output level are minor. However, if you are checking insertion loss of a filter, or trying to measure the loss in a piece of coax, an error of 0.1 dB may be large. Faced with this deficiency, I was prompted to find a way to improve the resolution of the power measurement system, without moving to a higher-cost A/D converter.

One simple way of improving the resolution was to add even more gain after the log amp output. Additional dc gain (for example, another 5×) can be added after the log amp to generate greater sensitivity. This creates a system with 250 mV/dB of sensitivity. Although this exceeds the specified absolute accuracy of the AD8307, it is not significant for difference measurements.

From this, the concept of relative power measurement is introduced. For a given input power level, remember this value and establish a reference voltage. The power meter then measures the difference from this point, and places a high gain in the signal, allowing the A/D converter to see far more resolution than during the absolute power measurement mode. This is shown in Fig 2. The absolute gain curve depicts the expected output voltage for a given input level. The relative power gain curve depicts the output voltage, once a reference point has been established.

A D/A converter is required to set up a reference signal. The Analog Devices AD7391 is a low-cost 8-bit DAC that operates off a single +5 V supply and has a serial interface that is easily controlled via the PIC processor. With this and a differential op amp (with gain), a higher-resolution measurement may be performed.

The reference signal is set up to provide a 2.5 V output from the differential amplifier upon initial setup. With a feedback gain of approximately 5 in the op-amp circuit, changes in power level on the order of 0.02 dB relate to a

Fig 1—Exterior view of the PIC power meter.

single bit of resolution in the 10-bit A/D converter. Although a change of 0.02 dB is probably nonsense on the workbench, it does provide the assurance that measured values on the order of 0.1 dB are now indeed believable.

The bulk of this system is controlled through software inside the PIC processor. Since the PIC has multiple A/D converter inputs, both the absolute (RF_ABS) and relative (RF_DIFF) power measurements are captured separately. If the operator wishes to measure insertion loss, or antenna return loss, the software will automatically keep track of what measurement mode the meter should be running in. When relative measurements exceed the range of the higher-gain differential amplifier, the program will automatically shift to using the absolute power measurement value to determine the difference. The resolution of the measurement will change on the display, depending upon which internal measurement mode is being utilized.

Consider the example shown in Fig 2. If the input signal level is at –28 dBm, then the absolute power measurement A/D measures approximately 3.2 V (as seen on the left axis). If a relative measurement needs to be taken from this point, the circuitry will set up a reference value such that the relative power measurement A/D input is 2.5 V (as seen on the right axis). Any change in the power level from this point on will result in a greater change on the relative slope than on the absolute slope.

By setting the initial reference point at half of the supply voltage, the
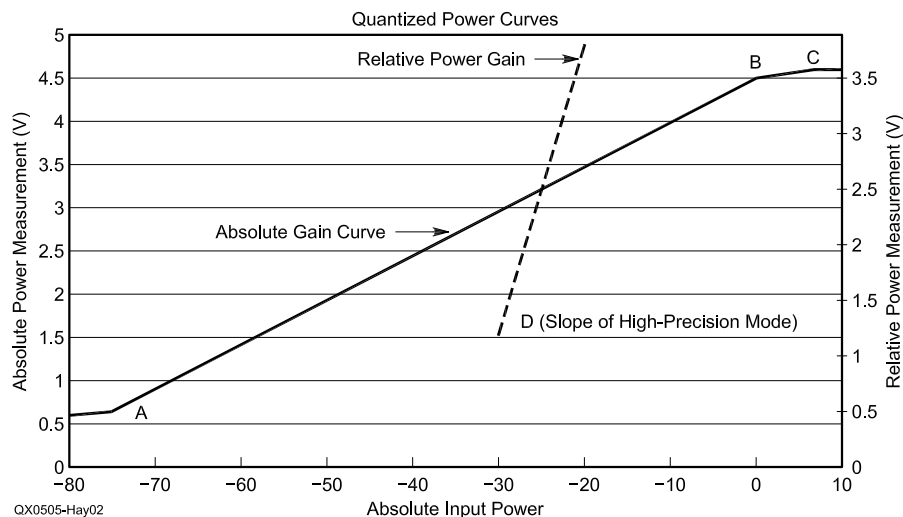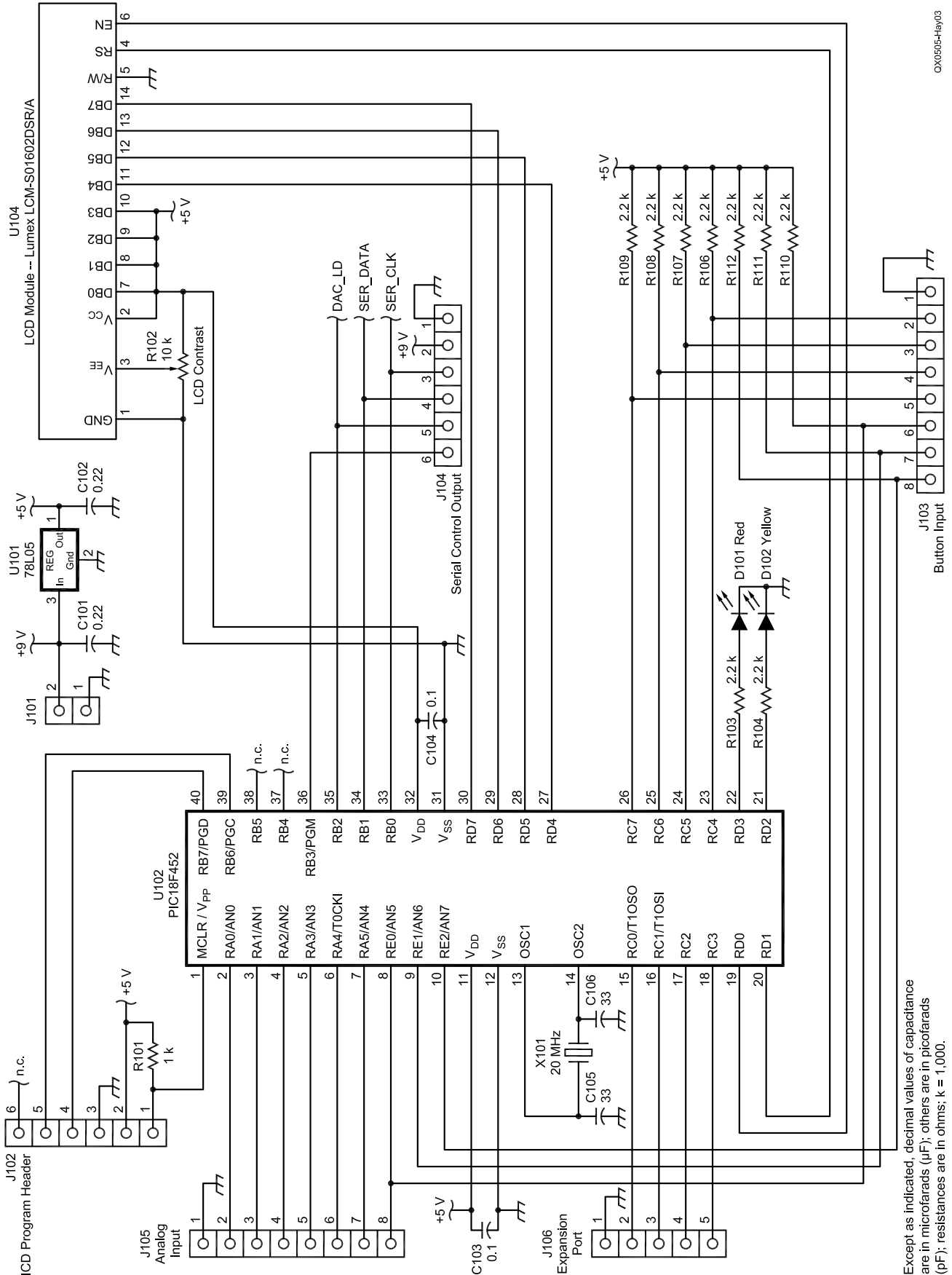

Fig 2—Log amplifier voltage output is interpreted between three calibration points, A, B and C. For relative measurements, an absolute reference is determined and a higher-gain slope output is used to determine the relative change.

Fig 3—PIC and display module—schematic diagram.

Fig 4—RF measurement module—schematic diagram.

Except as indicated, decimal values of capacitance
are in microfarads (µF); others are in picofarads
(pF); resistances are in ohms; k = 1,000.
T = Tantalum

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high-resolution system can measure gain as well as loss.

Because the PIC processor contains flash memory, three calibration points (A, B and C) may be stored within the meter. Any measurement between these three data points are interpolated automatically. In addition, the relative power measurement mode (D) may be calibrated with any 3 dB to 10 dB attenuator and any RF signal source as input. These will be illustrated in the examples below.

CPU Module

The CPU module utilizes the PIC 18F452. A crystal provides the CPU clock. An on-board voltage regulator allows the system to be run from a 9 V battery.

Various header pins are exposed on the top and bottom edges of the board. Analog input is on J105. J103 provides room for the four function buttons. J104 controls the D/A converter

Fig 5—Inside view of the meter. The CPU module is on the top, the RF measurement section is on the bottom. The LCD is mounted under the CPU module.

through a 3-wire serial interface. U104 is a Lumex 2×16 character LCD. It is mounted on the back side of the PCB with 4-40 standoffs.

There are two LEDs on the CPU module. Although these are for debug purposes, I would encourage you to include them. The CPU's most-common

event is watching the four user-interface buttons. Within this routine, the two diodes are toggled. Under normal operations, they should continually flicker. An occasional stall indicates that the CPU is doing something more important than watching the state of the buttons (such as performing an A/D conversion, or calculating the power or VSWR, updating the LCD display, etc). It is a great way to verify (even before getting the LCD connected) that the PIC is alive and well.

On one end of the CPU board is J102, a header that matches Microchip's ICD header. This allows the developer to program the PIC in place. Although the header is not required for normal power-meter operation, R101 must still be inserted on the board, in order to keep the part running the stored program.

A large bank of 2.2 KΩ pull-up resistors for the push buttons is present, along with a number of headers sur-

rounding the PIC, for off-board inter-action.

The board has an empty SO-16 footing, along with a few landings for electrolytic capacitors. These will accommodate an RS-232 interface for a future project.

RF Module

Because of the low-level signals to be measured, the RF module was designed from the start to be on its own RF-shielded board.

Fig 4 shows the RF module. The log amp is the Analog Devices AD8307 in an SO-8 package. The RF input stage is virtually identical to the previous design of Hayward and Larkin, including slight equalization to level the measurement accuracy at higher frequencies. The absolute RF output is sent to a quad op amp. An AD7391 DAC provides the reference voltage for the high-precision circuitry.

The RF module utilizes surface mount technology throughout. Although this was not an absolute requirement, some components (such as the AD8307) are readily available in SO-8 packaging, while the DIP-8 often has a longer lead time. With no pitches tighter than 0.05", it is still practical to hand-solder these parts to the printed circuit board.

While studying the schematic, you may encounter additional components in places where you might not expect them. I encountered some noise issues with the AD7391 DAC in an earlier prototype. In an effort to isolate the noise, I employed extra decoupling and bypass stages. Two separate voltage regulators provide a clean supply to each of the two 5 V devices. Series resistors, along with the 0.1 uF capacitors, in and out of the regulators act as a low pass filter, designed to stop stray noise from working its way through these stages. Series resistors near the inputs of op-amps also isolate noise. I switched to the LM324, a quad op-amp, so I could further isolate potential noise by adding two pass-thru stages between the DAC and the differential amplifier.

The RF module *must* be enclosed in its own RF-tight enclosure. A limited number of interface wires should all be fed to the board via 1000 pF feed-through capacitors, soldered on the wall of the RF enclosure.

Operating the Meter

With the advent of newer miniature "appliances" from the major vendors, most Amateur Radio operators have become accustomed to driving their radios by way of some menu-driven in-terface. Often, the bottom of the LCD display is lined with push buttons. The buttons perform different features, depending upon what the radio is doing. The operator can shift to another bank of features by pressing an F button, or perhaps scrolling an optical shaft encoder until the desired selection is found.

I've grown accustomed to scrolling around within the menu system to change power levels on my FT-817, alter CW speed, or rapidly pop between memories or bands. The '817 incorporates an F, or function key that wakes up the bottom line of the display into a menu-driven mode. Buttons A, B and C perform various features as indicated on the display. On the '817, pressing F turns the menu on and off, while advancing to the next bank of menu features is accomplished with the small optical shaft encoder.

I chose to integrate a similar approach on the power meter. Subsequent presses of the F button will advance the operator to the next set of features. Typically after choosing a setting, the menu line will return to blank until you need to set or change something again.

Calibrating Absolute Power Measurements

Upon first power-up, the meter will move *factory* settings from ROM to flash memory. You will want to calibrate your meter before taking any serious measurements. For our discussion, assume for a moment that you have a signal generator capable of output at –70 dBm to +7 dBm.

Three calibration points need to be stored within the meter. It is important to make sure that $P_a < P_b < P_c$, as the interpolation code assumes this. The strongest level, P_c, will be +7 dBm, as an overload warning will trigger when any level exceeding this value is detected.

You may set the calibration points in any order you choose. Let's begin with point A on the absolute power curve shown in Fig 2.

The push button under the power switch (see Fig 1), acts as the F or function key. Press F until the display reveals the prompt CALA. Press CALA. Apply a very weak signal to the meter, such as –70 dBm. To tell the meter that this is –70.0 dBm, select the SET_DB button. Use the UP and DOWN buttons to set the display to the exact value that you are applying to the meter, such as –70.0 dBm. The calibration point will move in 0.1 dB steps. If you press-and-*hold* the UP or DOWN button, the meter will scroll in 1.0 dB steps to speed up the process. Once the display matches the known signal level, press SAVE. This point has been calibrated and stored in to the flash memory of the PIC processor.

If you wish to back out of the calibration process, press the F key and the display will return to normal operation.

Repeat the procedure again for a +0 dBm signal (or so). This is CALB. After setting the B point, carefully apply a +7 dBm signal source and calibrate for point C.

Note that the CALC point of calibration should be set near the strongest acceptable power level for the log amp. Signal levels in excess of +10 dBm may harm or destroy the log amp. To alert the operator of an overload, the meter will flash the measured value on the display, an indication that the input signal level needs to be reduced to a safer level.

At this point, your meter is calibrated against your signal source. Vary the amplitude of the input signal level to see how well things track. The meter should reflect changes across the span over which it was calibrated.

When setting calibration points, note that a voltage is present on the display as well. This is the actual measured voltage presented to the A/D converter (RF_ABS). Write the dBm and voltage pair down for each of three calibration points into your notebook. If you ever need to re-calibrate the meter in the future without a wide-range signal generator, the meter allows you to enter the calibration points without a signal source. With no signal source required at the input, simply calibrate the dBm value first, then enter the voltage by selecting the ADJ_V button in the calibration menu.

Calibrating the Differential-Mode Measurement System

To calibrate the absolute power measurement points, we input a known power level to the system and ask it to remember the value. To calibrate the relative measurement system, we have to provide a known relative change in power. The easiest way to do this is with an RF carrier and an attenuator of known value.

Apply a signal source to the meter, somewhere in the 0 to –10 dBm range (it is not critical, as long as it is stable). Press F , then ZERO, and wait for the meter to converge on this signal. The second line should show +0.00 dB, or something very close to zero. Now insert an attenuator, such as 10dB, between the signal source and the meter. The relative measurement should show something near –10.00 dB. To calibrate this value, press F until you

see the CALD (short notation for Calibrate-Differential) button. Select it. The values you see reveal the gain of the op amp. As you did with the absolute power measurement system, all you have to do is press SET_ DB, and enter the amount of attenuation you have applied to the signal (such as 10.0 dB), then press SAVE. From this point on, differential power measurements are calibrated against your attenuator. Again, you may want to write this value down for future reference.

Calibrating the Tap Offset

I find it very handy to grab my 40 dB tap for higher power measurements. The power meter can be shifted into TAP mode, in which the signal level on the screen will reflect the fact that the tap is being used. To toggle this feature, press F, then TAP. The letter T will show up to the left of the absolute power level, to remind you that you are reading a shifted value on the display.

If you wish to read or set the tap calibration point, simply press F then press and hold the TAP button until the calibration is revealed on the display. To change this value, press SET_ DB. Use the UP and DOWN buttons to step in 0.1 dB steps (press and hold to step in 1 dB steps). When you have the value of your tap, press SAVE.

Although the TAP position is generally thought to correspond to the tap described in the earlier article by Hayward and Larkin, it could also be another circuit. This could be a power attenuator, a fixed-gain amplifier, or a directional coupler.

General Operation

Once the calibration points are set, the meter becomes quite simple to operate. Just turn the meter on and wait for the banner message to clear. The top line of the meter always reveals absolute power level measured.

If you wish to show the power level in watts, press the F button until the mW button is found. The power level will auto-scale from picowatts to watts, and be shown on the bottom line. If you are using a tap offset device, you will see power in watts at the tap input on the display. Remember to *never* exceed +7 dBm into the front end of the meter, or +47 dBm into the tap with the 40 dB tap being used.

For most toggle modes, such as displaying power in watts, the menu will show the > character next to the menu item, to indicate this mode is active.

To perform a differential power measurement, you must first present the signal to the meter and let it establish a baseline. Press F, then ZERO. A * will appear on the display while the program converges to the reference signal. The second line of the display will show the difference, in dB. Note that this line will provide a resolution of 0.01 dB when the high-precision mode is active. The resolution of the display will shift to 0.1 dB automatically (a digit will disappear), once the range of the high-precision mode has been exceeded. A slight jump in relative measurements may be noticed during the transition, as the CPU shifts from interpolating with the high-resolution mode and associated calibration points, and the lower resolution of the absolute power measurement. The high-resolution measurement mode typically falls out of range beyond roughly ±10 dB.

Upon completion of differential power measurement, simply press F ZERO again, and the meter will return back to normal operation.

Some operators may wish to use the meter with a directional coupler to measure antenna return loss. Connect the return loss bridge such that the meter is detecting reflected power. With the antenna disconnected, apply a test signal to the meter and press F ZERO. Then, connect the antenna. The return loss will be shown as a relative power measurement on the second line of the display. If you wish to display this as VSWR, select the VSWR mode through the menu.

Table 1—Parts list for the PIC and display module shown in Figure 3. Digi-Key part numbers (DK) are shown.

C101, 102—0.22 µF, 50 V, X7R 1206	DK-399-1251-1-ND
C103, 104—0.1 µF, X7R 1206	DK-399-1248-1-ND
C105, 106—33 pF, 50 V, NP0 1206	DK-399-1199-1-ND
D101—Red, LED (small)	DK-67-1069-ND or equiv.
D102—Yellow, LED (small)	DK-67-1078-ND or equiv.
R101—1 kΩ, 5%, SMT 1206	DK-P1.0KECT-ND
R102—10 kΩ, variable	DK-3329H-103-ND
R103, 104, 106—112—2.2 kΩ, 5%, SMT 1206	DK-P2.2KECT-ND
U101—78L05-SOT89	DK-NJM78L05UA-ND
U102—PIC18F452 (requires programming, see text)	DK-PIC18F452-I/P-ND
U104—LCM-S01602DSR/A	DK-67-1768-ND
X101—20 MHz, CA-301	DK-SE3438-ND

Table 2—Parts list for the RF measurement module shown in Figure 4. Digi-Key part numbers (DK) are shown.

C201, 202, 205 – 211, 213—0.1 µF X7R 1206	DK-399-1248-1-ND
C203—15 pF, 50 V, NP0 1206	DK-399-1194-1-ND
C204—0.01 µF, 50 V, X7R 1206	DK-399-1234-1-ND
C212—10 µF tantalum	DK-478-1762-1-ND
L201—10 nH, 10%, SMD 0805	DK-PCD1160CT-ND
R201—51 Ω, 5%, SMT 1206	DK-P51ECT-ND
R202—470 Ω, 5%, SMT 1206	DK-P470ECT-ND
R203, 204, 211, 212, 215—22 Ω, 5%, SMT 1206	DK-P22ECT-ND
R205—6.8 kΩ, 5%, SMT 1206	DK-P6.8KECT-ND
R206, 208, 214—4.7 kΩ, 5%, SMT 1206	DK-P4.7KECT-ND
R207—1 kΩ, 5%, SMT 1206	DK-P1.0KECT-ND
R209, 210, 216, 217—100 Ω, 5%, SMT 1206	DK-P100ECT-ND
R213—1 kΩ, 5%, SMT 1206	DK-P1.0KECT-ND
U201, 205—78L05-SOT89	DK-NJM78L05UA-ND
U202—AD8307AR, log amplifier, SO-8	DK-AD8307AR-ND (or direct from Analog Devices)
U203—AD7391AR 8-bit DAC, SO-8	DK-AD7391AR-ND (or direct from Analog Devices)
U204—LM324 quad op amp, SO-14	296-9540-5-ND

I found it extremely handy to monitor the values measured by the A/D converter during debug and test. This may be toggled by pressing the V button under the menu.

If for any reason you want to restore the meter back to its default settings, a back door has been provided. With the meter shut off, press and hold the B and C buttons together, and turn the meter on. You will see the display begin with RESETTING FACTORY SETTINGS. From there, you will want to re-calibrate, or enter your calibration points again.

Software

The source code is available for examination or augmentation, from the Web site listed at the end of the article. It could also serve as a good springboard for the development of other projects as well, since the LCD driver code, flash memory, and interactive menu have already been written. Since all of the RF measurement hardware is on its own sub-assembly, the CPU/LCD could be used for other creative ideas within the amateur community.

I chose to write the program in *C* (and purchase the *C-compiler*), rather than to write the application in assembly language. This was a direct tradeoff between my time and my financial resources. Although everything could have been performed in assembly, my family and I are happy I chose the route of purchasing the compiler. CCS[7] provides not only the compiler, but many useful tools to ease the development of any project. Test code, interrupt handlers, and functions for manipulating the flash memory are all available as part of the standard CCS compiler package. This allows the developer to concentrate more on the application at hand, and less on the inner workings of the PIC.

Programming the PIC processor was accomplished with the Microchip USB ICD-2 module. With the addition of the header J102, the PIC may be programmed and re-programmed countless times without the need to remove the part from the board. This was vital to the development of the project, as new ideas could be coded and tested within the shack, without the need for expensive programmers or JTAG emulators.

Assembly Notes

As is the case of many projects, this project is best constructed in stages. Depending upon the size of the chassis you have selected, it might be useful to perform some dry-fit mounting prior to assembly of the m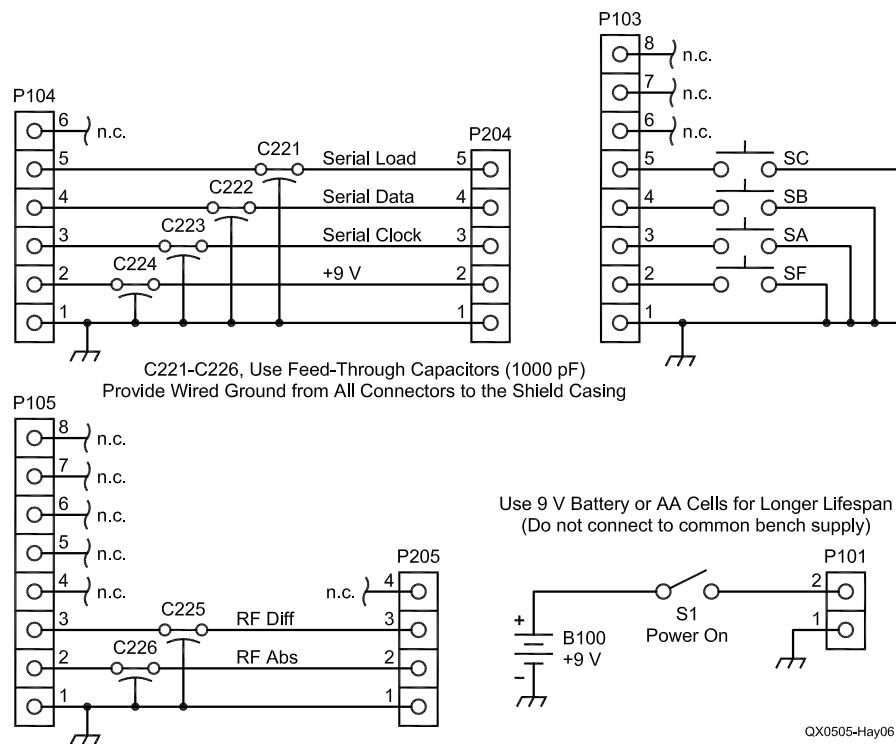odules. I found the Hammond 1590J case to be large enough to hold both the circuitry, as well as a 9 V battery. If you plan on using the meter more routinely, it may be better to choose a larger enclosure, such that six to eight AA batteries could be used instead.

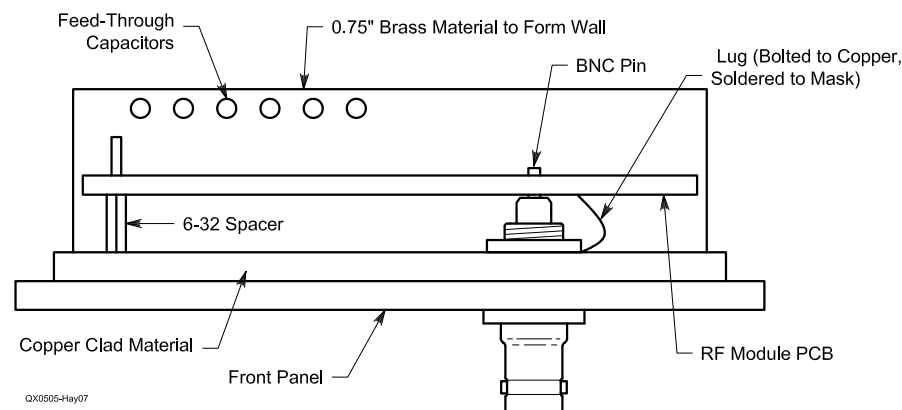Start by cutting a hole for the LCD display, then finding the right locations for the four mounting holes. Dry-fit the LCD bezel until it fits snugly on the front panel. After this, mount the bare PCB in place and locate positions for the four push buttons. Space the A, B, and C buttons equally across

Table 3—Interconnect parts list.

C221-226—1000 pF feed-thru capacitor   EMI-ZPC102D or equiv.
SW-A, B, C—N.O. push-button, black cap   DK EG2011-ND or equiv.
SW-F—N.O. push button, red cap   DK EG2015-ND or equiv.
EMI—EMI Filter Company (**www.emifilterco.com**)

Fig 6—Interconnection details.

Fig 7—Side cutout details of RF module and enclosure.

the bottom of the display. The F key can be located anywhere you choose.

The CPU module board can be booted without the need to connect the RF module. Start by soldering all resistors and capacitors on the back side of the board. Populate the front-side components on the board, including the crystal oscillator section (X101) and capacitors. Finally, solder in the socket for U102, the PIC processor. After verifying that the 5 V regulator is supplying voltage to the board, it is time to confirm that the pre-programmed PIC processor springs to life. Install the processor into the socket and verify the board is operational by applying power and viewing the LEDs D101 and D102 on the circuit board. (It may take up to 10 seconds after power is applied to see the LEDs begin to flash.) Once this is verified, mount the LCD on to the back of the board, and mount all 16 wires from the LCD to the CPU board. These pads line up with one-another such that only a 0.25 inch piece of bare wire is needed for each. I used the leads from 1/4 W resistors to bridge the two. Again, power up the meter and watch the display for the banner. Adjust the LCD contrast by varying R102—the display may appear blank until this has been adjusted. Next, wire in the push buttons to make sure the F, A, B, and C buttons behave as expected.

With the remaining space in the chassis, it is time to construct an RF-tight box for the measurement module. The RF PCB was designed to rest right onto the pin of a BNC connector. See Fig 7 for a detailed side-cutout diagram of the RF module.

Cut a piece of copper-clad material approximately 0.1 inch wider on all edges than the RF module circuit board. Plan on having it rest up against the back-side of the front panel. Drill a hole for the BNC connector, centered over J201 on the RF module. Include a ground lug while bolting on the BNC. Drill another hole at the opposite side of the board, such that the printed circuit board will have mechanical stability. Plan on using a short 6-32 spacer to hold the RF module away from the copper material.

Using soft 0.75 inch strips of brass,

cut a wall for the back side of the RF module. Pre-drill six holes for the feed-thru capacitors in this wall, add the capacitors, and solder the wall on to the copper-clad material. This needs to be done *before* mounting the RF module in-place, as it will be nearly impossible to get a hot soldering iron to it afterwards.

Verification of RF module operation should be completed prior to mounting it into the chassis. Apply +9 V to pins 2 and 1 of J204. Verify each of the two 5 V regulators, U201 and U205, are functioning properly. With a DVM, measure the DC voltage out of the log amplifier and from the output of the op amp U204. Remember that even with no RF input to the log amplifier, a small residual output will still be measured. Early prototypes, when shielded properly, measured approximately 0.65 V at RF_ABS.

To mount the RF module, slip the center pin of J201 directly onto the center pin of the BNC connector. To provide a solid RF ground to the board, bend the ground lug of the BNC until the end of the lug is pushing up against the back-side of the RF module's ground plane. You may need to scrape off additional solder mask in the location where the ground lug touches the ground plane. Using a HOT soldering iron, solder the lug directly to the backside of the PC board. (Do not omit this step. A solid ground-return is required for accurate measurements.)

Solder the center pin of J201 to the BNC connector. Mount a 6-32 screw to your spacer on the other end of the board.

Now that the board is in place, build and mount the other three sides of the RF box using brass material. Seal the container with a lid made of copper or brass. Although it is recommended that this box be as RF tight as possible, remember that you may want to get back in to the box at some point in time, so don't seal it so tight that you can't get the lid back off again!

After mechanical assembly, complete wiring the interface to the CPU. When running in ZERO mode, the DAC should present a 2.5 V output to the

A/D converter on the RF_DIFF net.

First licensed in 1979, Roger Hayward, KA7EXM, is active in portable VHF hilltopping adventures, as well as experiments in the shack. He is married, with three children in Beaverton, Oregon. Experiment notes, software source code and updates, and a chronicle of past adventures may be found on his Web site at **www.ka7exm.net**. *You may reach Roger at 13405 SW Juanita Pl, Beaverton, OR 97008 or at* **ka7exm@ arrl.net**.

Notes
[1]W. Hayward, W7ZOI, and R. Larkin, W7PUA, "Simple RF-Power Measurement,"*QST*, Jun 2001, pp 38-43.
[2]R. Kopski, K3NHI, "An Advanced VHF Wattmeter," *QEX*, May/June 2002, pp 3-8.
[3]R. Kopski, K3NHI, "A Simple RF Power Calibrator," *QEX* Jan/Feb 2004, pp 51-54.
[4]Parts are available from Kanga US in a variety of configurations. See **www.kangaus.com** for details. Pre-programmed CPUs will be available in addition to the full part kitting. See Web site for details.
[5]The Microchip PIC-18F452 is pin-compatible with the more popular 16F877. See **www.microchip.com**.
[6]See Note 1.
[7]Custom Computer Services offers a *C* compiler for most of the PIC processor families. See **www.ccsinfo.com** for more details. The PCH module was used to compile the code for the 18F452 target. □□