

# The LP-100 Wattmeter



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*A high-performance, microprocessor-controlled digital SWR/wattmeter with wide dynamic range*

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By Larry Phipps, N8LP

The LP-100 project is really an ongoing design exercise. The main meter chassis has remained fairly unchanged through several iterations of the project, but the directional coupler has undergone some radical changes, with several new designs still undergoing testing and modification. I will describe the first iteration of the project fully in this article. At the conclusion of the article, I will discuss some of the changes to the coupler, and will refer the reader

to my Web site ([www.telepostinc.com](http://www.telepostinc.com)) for the latest details.

Here are the basic specifications/features of the meter...

- Coverage from 0.5 to 54 MHz for rated specs with the specified coupler designs
- Auto-ranging scales covering 0-2, 20, 200 and 2000 W
- Modular design to allow for different couplers
- Scale for dBm measurements, ~ -15.0 dBm to +63.0 dBm in 0.1 dB steps
- Power display resolution of 0.01, 0.1 or 1 W depending on scale.
- Power accuracy better than  $\pm 5$  dB to <10 mW, typically 5% after calibration
- Displays actual power delivered to the load (Fwd minus Ref)
- SWR display resolution of 0.01
- Overall SWR accuracy typically within  $\pm 0.1$  of actual down to 100 mW
- Return Loss (RL) display of 0 to 49.9 dB
- State-of-the-art PLED display with screen saver
- Fast responding logarithmic bargraphs for power, SWR and RL
- Peak-hold numerical power readout with fast and slow time constants
- SWR Alarm system with set points for 1.5, 2.0, 2.5 and 3.0
- Separate calibration screen
- Serial port for external software control

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- Virtual Control Panel (VCP) software for *Windows*
- Remote control supported directly or through *TRX-Manager*

Among the most interesting aspects of the design of the LP-100 are the coupler, the logarithmic detectors, the microcontroller and the *Windows* VCP software. The area that received the most attention (and created the most frustration) was the directional coupler. Over 50 designs were built and tested. Each had its good points and bad, but I settled on two for the final versions.

## Coupler

Before discussing coupler design, let's define a few terms.

**Directivity**—the difference (in dB) between forward (Fwd) and reflected (Ref) power when the output port is terminated in the design impedance... 50  $\Omega$  in this case.

**Insertion Loss**—the loss (in dB) between the input and output ports

**Coupling Factor**—the loss (in dB) between the input port and the forward sample port, or between the output port and the reflected sample port.

**Input Return Loss (RL)**—the amount of power reflected back into the source (in dB) when all other ports are terminated with accurate 50- $\Omega$  terminations.

I used eight criteria to evaluate my coupler designs.

1. 50  $\Omega$  Z on all ports
2. cover 160 to 6 m in one design.
3. >30 dB directivity over the entire frequency range
4. Level passband response over the entire range
5. >25 dB input RL presented to the transmitter over the entire range
6. Insertion loss < 0.2 dB
7. 1500 W continuous power handling capability
8. Easy to duplicate

First, let's review how a coupler operates. Probably the grandfather of broadband frequency-independent directional couplers is the design developed by Warren Bruene, W5OLY, of Collins Radio. The best coupler article I've read is his "An Inside Picture of Directional Wattmeters," published in April 1959 *QST*.<sup>1</sup> It is must reading for anyone interested in the subject because it analyzes the Bruene Bridge as well as other coupler designs.

Underlying Bruene's design, as well as that of many other couplers, is a current sampling transformer in series with the transmission line combined with a circuit to sample voltage

across the load. The voltage sampler may be a capacitive or resistive divider, or a transformer. The current and voltage samples are combined so as to isolate the forward and reflected components. This is possible because the voltage and current of the forward wave are in-phase, while the voltage and current of the reflected wave are out-of-phase.

Another type of coupler, which at first would seem to be radically different from these, is also related. It is the line-section or loop coupler as pioneered by Bird. In this design, a terminated loop is brought into proximity to the center conductor of a transmission line, and provides a Fwd or Ref sample, depending on which end of the loop is terminated. This is possible because the loop provides two kinds of coupling at the same time. Inductive coupling to the line produces a current sample, and capacitive coupling provides a voltage sample.

My first criterion—50- $\Omega$  impedance at all ports—eliminated many published coupler designs, including the Bruene bridge, which must be terminated in high Z loads for the forward and reflected ports. After reviewing the available 50- $\Omega$  designs, I settled on a couple to try. One was the Tandem Match,<sup>2</sup> covered in depth in a *QST* article and recent issues of the *ARRL Antenna Book*. Another version uses a binocular ferrite core and is described in a comprehensive article by Michael G. Ellis.<sup>3</sup> These designs, and others such as the Stockton coupler, are descendants of a design using two toroidal transformers patented by Sontheimer and Fredrick in 1969. See Fig 1.

By using identical transformers, wired as shown, all four ports will have the same impedance. The current transformer, T1, has a one-turn primary in series with the main transmission line, while the voltage transformer, T2, has its secondary connected across the transmission line. If the two transformers have the same turns ratio, and the current sample is terminated in a 50  $\Omega$  load, then the

voltage across the termination will be the same as the voltage from the voltage sampler. If the two voltages are combined, then the phase relationship mentioned above will cause the Fwd components to add and the Ref components to subtract.

The correct transformer turns ratio, N, is determined by balancing a number of factors, including keeping T2's reactance high to prevent loading of the line, and keeping T1's winding length short to minimize stray capacitance which reduces high frequency response. N also determines the coupling loss, and hence the required Fwd port termination power rating, since the power at this port is proportional to  $1/N^2$ .

The first version of this design that I tried used a ferrite binocular core, which allowed very simple construction techniques. I discovered that in order to meet my bandwidth objective with available cores, T1 and T2's secondary windings had to be kept under 10 turns. Since the only commercially available binocular core that could possibly handle 1500 W is about 1-inch long, each turn takes nearly three inches of wire. Since the upper frequency response is largely related to the length of the wire in the secondary windings, keeping the coupler functioning at even 28 MHz limited my design to fewer than 10 turns.

But if T1's secondary is only 8 turns, for example, with an input power of 1500 W, the forward coupling port termination must dissipate nearly 25 W. Dissipating 25 W in a small box, while keeping the temperature rise to acceptable levels is not easy.

My second attempt was the Tandem Match coupler. One problem I noted with this design duplicated the experience related in an article by N2PK.<sup>4</sup> He discovered a problem with the input RL of the Tandem Match at 1.8 MHz. He indicated that this was a factor of inadequate  $X_L$  at 1.8 MHz, thereby shunting the line at that frequency with a relatively low value inductance.

By replacing the powdered iron cores of the Tandem Match design with higher permeability ferrite cores, this problem is eliminated. I used Fair-Rite # 596100501 cores (Amidon part # FT-114-61), with an initial permeability ( $\mu_i$ ) of 125, compared with 8 or 10 for the powdered iron cores used in the two Handbook designs. Although the ferrite cores provide excellent RL performance at 1.8 MHz, because ferrite is more easily saturated at high flux levels than is powdered iron material, I had to increase the size of the cores

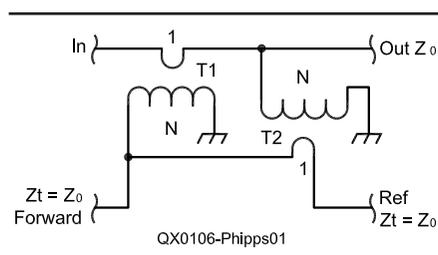


Fig 1—Tandem Match Schematic.

<sup>1</sup>Notes appear on page 13.

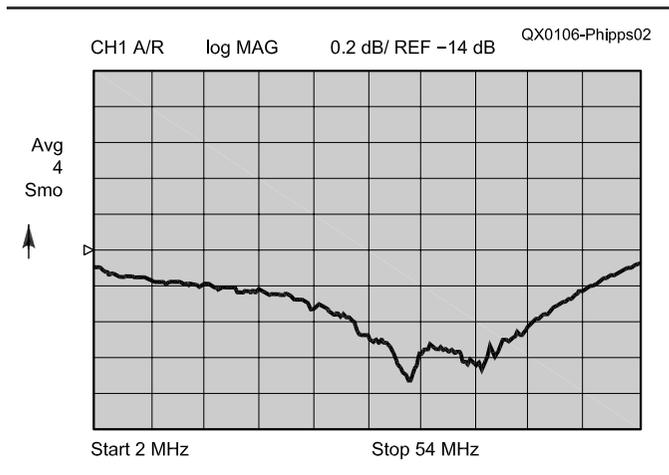


Fig 2—Coupler directivity with a 50  $\Omega$  load. Vertical scale is 5 dB/div; mid-scale is -30 dB.

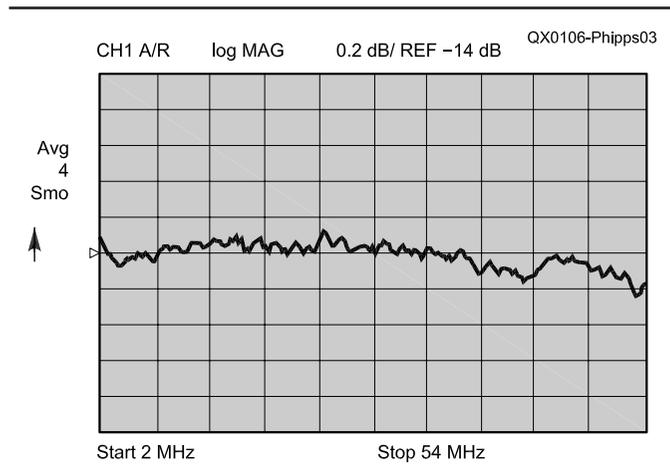


Fig 3—Coupler directivity with a 75  $\Omega$  load. Vertical scale is 0.2 dB/div; mid-scale is -14 dB.

considerably. I determined experimentally that the chosen cores were the smallest available cores that would safely handle 1500 W.

The larger cores necessitated the use of longer windings, so I reduced the number of turns from the 31-40 used in the Tandem Match article to maintain good response at 54 MHz. As a compromise between Fwd port termination dissipation, flux density and 54 MHz response, I settled on 26 turns.

Even with fewer turns than the original design, I had to spend time to achieve an acceptable input RL at 54 MHz. Stray capacitance and inductance from mechanical layout was the culprit here. By making the length of the primary windings as short as possible, I was able to achieve close to 30 dB RL at 54 MHz.

To measure SWR accurately, directivity must exceed 25 dB. I found that it is difficult to achieve reliable measurements when testing a 50  $\Omega$  load. This has to do with the vector addition of the Fwd and Ref samples. It is possible to get wildly optimistic readings of directivity at 50  $\Omega$ , because while the Fwd power can have a 6 dB maximum range of addition, the reflected power can theoretically be zero under certain conditions. I found it was much better to use a load with an accurately known error. I chose 75  $\Omega$  for my tests, and computed directivity from the measured SWR. Table 1 shows the range of SWR accuracy available with various values of coupler directivity, for a 75- $\Omega$  load.

With even 20 dB directivity, the SWR error is sizeable. An indicated SWR of 1.5 could actually be anywhere between 1.2 and 1.9. Unfortunately, 20 dB is probably typical for many ham-grade SWR bridges across the HF

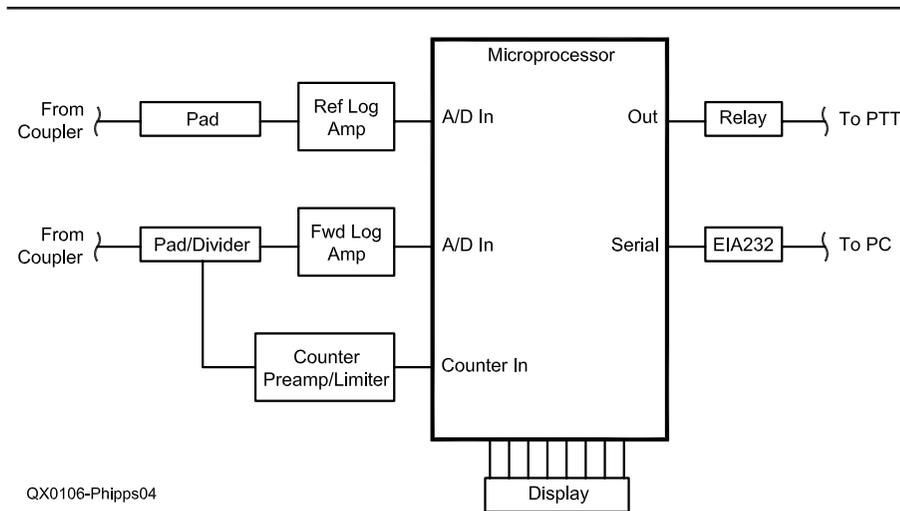


Fig 4—LP-100 block diagram.

Table 1—SWR Measurement Range versus Coupler Directivity for a 75  $\Omega$  Load

Directivity	Minimum SWR	Actual SWR	Maximum SWR
10 dB	1.00	1.50	4.22
15 dB	1.04	1.50	2.36
20 dB	1.22	1.50	1.90
25 dB	1.33	1.50	1.70
30 dB	1.40	1.50	1.61
35 dB	1.44	1.50	1.56
40 dB	1.47	1.50	1.53

spectrum, and they're probably much worse at 50 MHz.

The measured directivity of this coupler with 50 and 75  $\Omega$  terminations is shown in Figs 2 and 3. These graphs were output from my HP-87510A Vector Network Analyzer (VNA). Especially noteworthy is the 75  $\Omega$  directivity, which is within 0.2 dB of

the ideal value of 13.98 dB, verifying a directivity of >30 dB.

To obtain the best high-frequency directivity, the toroids needed to be rotated carefully. I am convinced that this was a result of stray coupling: both inductive and capacitive. For this reason, I took care to make the design symmetrical to balance out the effects

of this parasitic coupling.

The coupler is built in a separate shielded box, and connected to the LP-100 through a pair of short coaxial cables. Employing a separate coupler eliminates the problems associated with having a small box on the operating table connected to heavy, stiff feedlines. Furthermore, it removes high power levels from the vicinity of the microprocessor and other sensitive

circuitry, as well as reducing the possibility of RF noise from the microprocessor being radiated into the station receiver.

### Logarithmic Detectors

The genesis for the LP-100 detectors came from the auto-tuner section of a mini-beam project. I sought a fast, efficient tuning algorithm permitting near instantaneous tuning of the mini-

beam elements. To make this work, it was especially important to resolve accurately slight differences in SWR at very low power levels, because very little power is available when the antenna is far from resonance.

To compound the problem, a high-directivity coupler—like the one I'm using—can place high demands on the detector when measuring a high-quality load. This is so because the signal

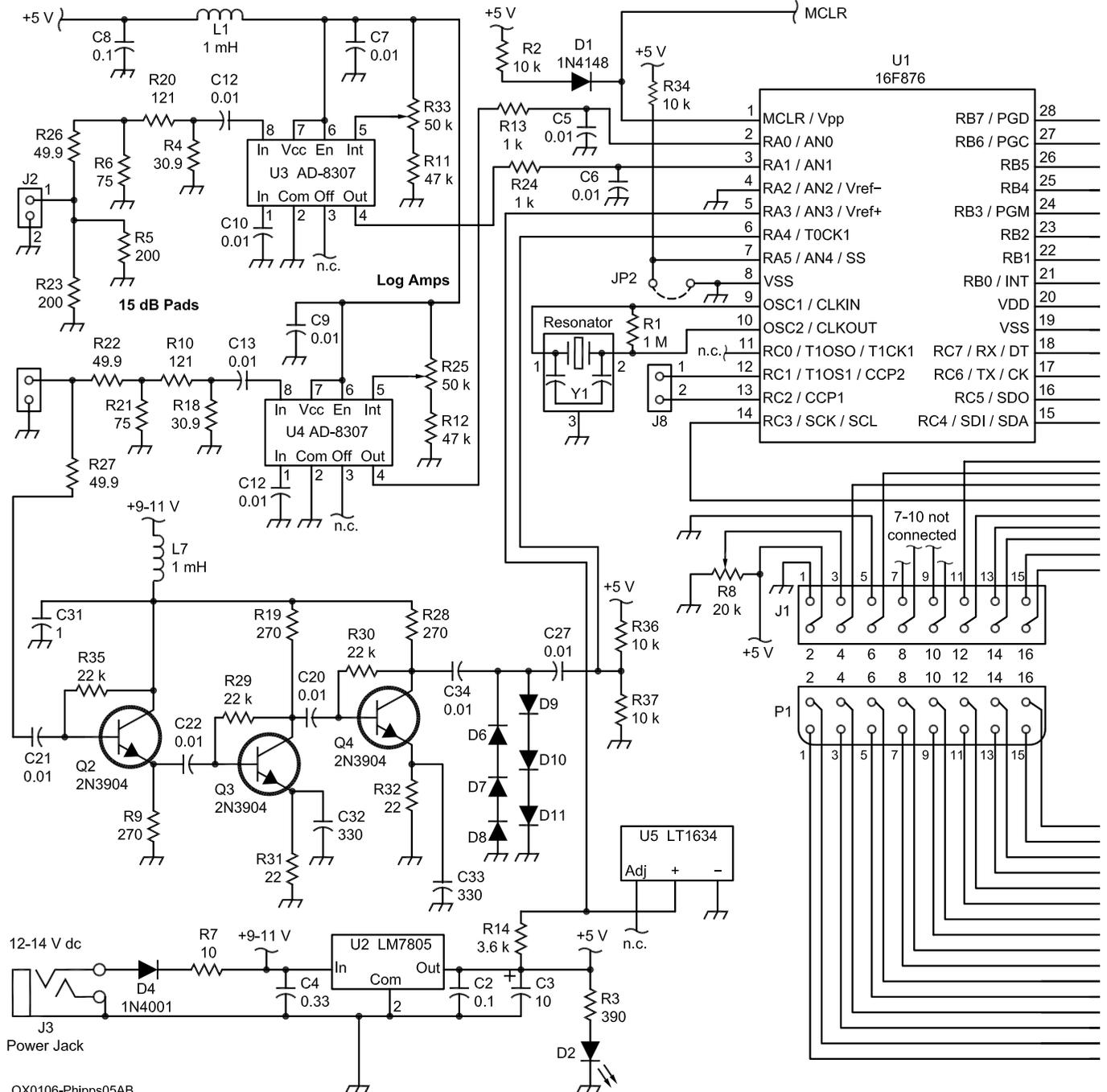


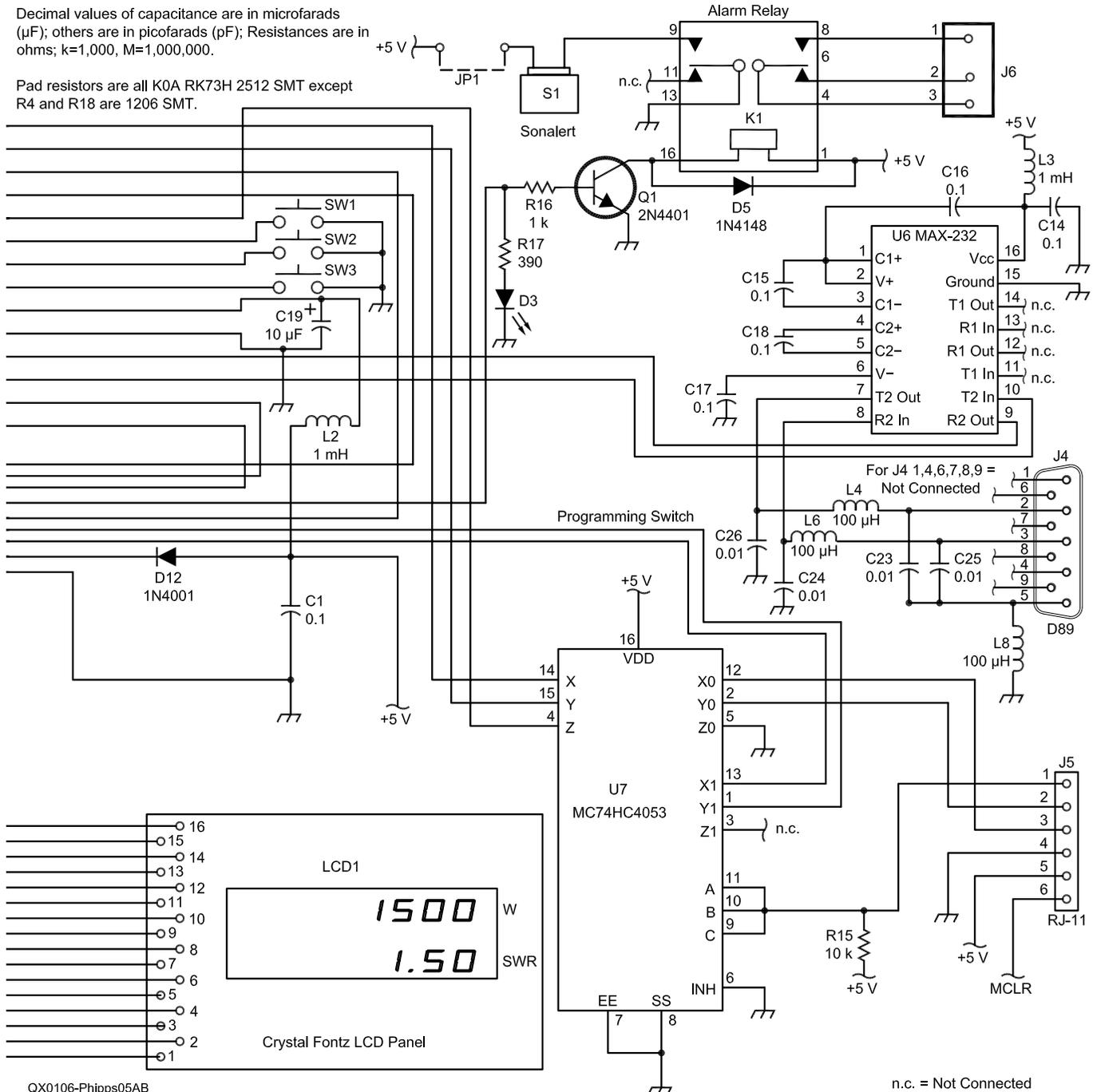
Fig 5—LP-100 schematic diagram.

at the reflected port is very small. For 100 W input, the reflected power detector must provide accurate level data for an input signal of 1 mW or less. I ruled out op-amp corrected diode detectors, even though they have been used effectively in circuits such as the Tandem Match and Lewallen's QRP Wattmeter.<sup>5</sup> To handle a wide range of power with these circuits requires an array of precision resistive dividers to

set the ranges. I wanted a meter that would continuously display power over a very wide power range with consistent accuracy at any level in the range. So how might we detect these very small signals while still handling the larger signals generated by 1500 W without overloading?

Enter the logarithmic detector. Based on work I had done in another project, I knew that a log-detector

would handle the dynamic range needed for these projects. I chose the AD-8307 logarithmic detector from Analog Devices.<sup>6</sup> This chip was designed for use in the cellular telephone market and is used to convert RF levels into a dc Received Signal Strength Indicator (RSSI) output. The chip can accurately translate an RF input with about 80 dB dynamic range into a dc output corresponding to the



log of the input signal. When connected to a high quality directional coupler, a pair of these chips is capable of providing accurate forward and reflected power detection over a dynamic range of almost 50dB at an SWR of 1.1. In terms of the LP-100, this corresponds to a range of ~20 mW to 2000 W for full SWR accuracy, or less than 1 mW if only forward power accuracy is needed. The chip is capable of operation from dc to over 500 MHz, and provides a linear RSSI output of 0 to 2.5 V, with a conversion factor of 25 mV/dB and a typical accuracy of  $\pm 0.25$  dB.

For an input power of 5 W, the power available at the Fwd power port, expressed in dBm, is roughly +7 dBm (coupling factor is approximately 30 dB). The signal at the reflected power port, for an SWR of 1.1:1, is ~26 dB lower, or -19 dBm. The AD-8307's rated linear input range is -65 to +10 dBm, so this is no problem.

But since we want to measure power up to about 2000 W (+63 dBm) we see that 30 dB coupling loss results in +33 dBm (2 W) of power at the input of the forward detector, grossly exceeding the AD-8307's maximum permitted input signal level of +20 dBm. To keep the AD-8307's input level within its recommended linear operating range, therefore, we will need a pad between the coupler ports and the log-detectors. My design uses 25-dB total attenuation, split 10 dB at the coupler outputs and 15 dB at the LP-100 inputs. The pads also help isolate the coupler and log-detectors from variances in the connecting lines.

In round numbers, the maximum signal that the AD-8307 would normally see for approximately 1500 W input is:

$$\begin{aligned} &+62 \text{ dBm (1585 W)} - 30 \text{ dB (the} \\ &\text{coupler loss)} - 25 \text{ dB (the pad)} \\ &= +7 \text{ dBm} \end{aligned}$$

With this input power and an SWR of 1.1, the signal at the reflected power port will be -19 dBm. Now, what happens with only 5 W input? Since 5 W is ~25 dB below 1500 W, all the values must be reduced by this amount. The critical port is the reflected port, so let's look at that. The signal available there would be -44 dBm (19 + 25). This is still no problem since the AD-8307 will accurately handle signals as low as -65 dBm. The AD-8307 still has ~20 dB of range left, indicating that power as low as ~50 mW (20 dB below 5 W) can provide accurate results at an SWR of 1.1 or higher. I used an SWR of 1.1 for this illustration since it represents a challenge in terms of testing the limits of the noise floor on

the Ref port detector.

### LP-100 Microcontroller

The "brain" of the LP-100 is the microcontroller. This circuit is based on the 16F876 PIC chip from MicroChip.<sup>7</sup> It is an 8-bit controller with 8kB of EEPROM program memory (14-bit width), 368 bytes of RAM and 256 bytes of EEPROM working memory. The chip has an internal A/D converter that can accept up to 5 analog inputs, and provides up to 22 I/O pins, which can act as TTL/CMOS compatible inputs or outputs. The LP-100 uses these ports for interfacing the log-detectors, implementing a frequency counter, PLED screen, switches, LEDs and an SWR alarm relay. See Fig 4.

Operationally, the PIC sequentially samples the RSSI outputs of the forward and reflected power log-detectors using two of its A/D inputs. The inputs have 10-bit resolution and use a precision 2.56-V reference. The AD-8307 output is set so that the maximum input power of 2000 W produces a dc output of 2.56 V, corresponding to an A/D output of 1023. Each sample of the A/D converter is therefore 2.56/1024, or 2.5 mV. Since the AD-8307 has an output slope of 25 mV/dB, the A/D readings equal 0.1 dB per step. (The inter-sample interval is sufficiently short that the transmitter output power does not materially change between the forward and reverse samples even when operating SSB.)

The firmware calculates the "true" power in dBm and W then calculates RL and SWR using the forward and reflected power samples. I define "true" power as the net power delivered by the source to the load, or forward power minus reflected power. Thus, the meter always displays the actual power delivered to the load, regardless of SWR. The values are displayed on a 2x20 character PLED panel. I originally used an LCD display, but found the PLED was better looking and has faster response. It is plug-in compatible with the LCD. The various displayed screens are shown in Fig 6.

The first range, labeled "A," is not shown. It is an auto-ranging screen that displays power at any level. The next four screens display power in ranges of 2, 20, 200 and 2000 W, along with SWR. The fifth screen shown in the figure is the overload indication that will appear if one of the fixed-power screens is selected and the power exceeds the limit of that screen. The next screen shown displays power in dBm along with RL in dB, followed by the Alarm Set

screen, described later.

The final screen is the calibration screen. The CAL screen shows the raw Fwd and Ref power sample values simultaneously, making it easy to calibrate and match the two log-detectors. It also allows for matching the power readout to a reference meter at 1 MHz intervals from 1-54 MHz. The current frequency and A/D counts are displayed, along with the "trim" value, which is adjusted with the UP and DN buttons. This value is stored in non-volatile memory, indexed to frequency.

The power scales use a logarithmic bar-graph display, which is comprised of custom characters to allow the display of 36 vertical bars. These bars respond instantaneously to changes in power. This was done in part to make it easy to adjust things like an antenna tuner or linear amplifier. Although the response is quick enough to follow SSB voice peaks, the display is smooth due to a combination of the logarithmic scale and over-sampling of the A/D inputs.

The maximum power scale is changed by pressing the SCALE button, which increments the scale once for each button press. After seven presses, you return to the original scale. The current scale selection is stored in the PIC's non-volatile memory, so that if you lose power, the LP-100 will remember your last selection. The first position is an auto-ranging screen, which allows continuous display from 0.01 W to 2000 W. If one of the fixed power screens is used, and the power level exceeds full scale on the bar-graph, the over-limit message is displayed, indicating the operator should increment to a higher scale.

Next to the bar-graph display is a numerical power value. Unlike the bar-graph, the numerical readout is peak reading, so that it is easy to monitor power while operating SSB or CW. The peak-hold algorithm freezes the reading unless a higher value is encountered during the hold period, in which case the higher value is displayed and the hold timer reset. The FAST/SLOW button disables the hold function to allow the numerical readout to follow changes during adjustment of antenna tuners if desired.

The display resolution of the numerical readout varies with the maximum value of the scale, from 0.01-W resolution on the 2-W scale to 1-W resolution on the 200 and 2000-W scales.

Below the power bar-graph is the SWR bar-graph. Next to the SWR bar-graph is the numerical SWR readout, with a display resolution of 0.01. The

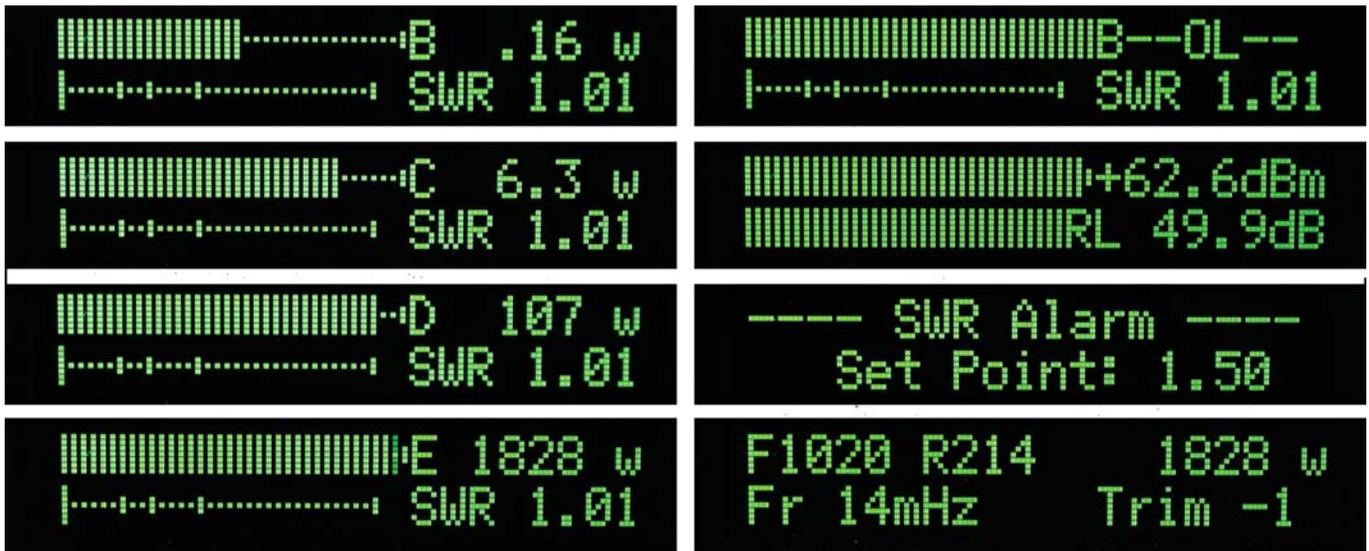


Fig 6—LP-100 Display Screens. (N8LP).

SWR display is the same for all four “W” scales. An interesting idea I borrowed from the on-screen display of one of my TVs, is the use of markers to show the limits of the bar-graph. This makes it easy to see what portion of the full range is being displayed. Additional larger markers are provided on the SWR scale for SWRs of 1.5, 2.0 and 3.0.

The dBm scale displays power in 0.1 dB steps from about -15 dBm (the noise limit of the instrument in a typical ham shack environment) to +63 dBm (2000 W). For this screen, the SWR display is replaced with a RL scale. The RL scale is limited to 49.9 dB maximum, even if RL is higher, to prevent overflow in some of the internal calculations.

The LP-100 also includes an SWR Alarm function. The “Alarm Set” button controls this function. When pressed, the button changes the display to an Alarm Set screen, as seen earlier in Fig 6. Repeatedly pressing the button cycles through the set-point choices... Off, 1.5, 2.0, 2.5 and 3.0. When you have reached the choice you want, stop pressing the button and the screen will return after about one second to the power screen displayed before entering the Alarm Set mode. The set-point choice is stored in EEPROM. If the SWR reading reaches your set point in any mode, the front panel “Alarm” LED will light, the Sonalert will beep and the relay will close.

The Alarm is deactivated by correcting the over-limit condition. There is a delay of about five seconds built into this action, to allow for antenna tuning without constant interruption by the relay. Setting the Alarm Set mode

to OFF at any time will also deactivate the alarm, and cancel any current alarm. I included a jumper in the circuit to permanently disable the Sonalert if desired.

The relay contacts are brought out to the rear panel to allow disabling the PTT connection to a linear amplifier or transmitter. The relay terminates in a pair of RCA type PTT connections, which should make for easy interfacing to most amplifiers. This is a great way to protect those expensive finals from a catastrophic antenna failure!

I have included a serial port for software control of the LP-100, which terminates on the rear panel with a standard DB9 connector. I have also included a programming port to allow the PIC to be reprogrammed in-circuit. The programming port connects through an RJ-11 jack on the PCB to a Basic Micro<sup>s</sup> programmer. Anyone who doesn't need either of these last two capabilities can simply delete the

associated parts from the project.

### Software Virtual Control Panel

I have developed Virtual Control Panel (VCP) software to provide computer control of the LP-100, as well as offering extended functionality. The Windows-based VCP mirrors the controls and display of the micro-controller box, but adds calibrated scales below the bar graphs (see Fig 7). Further information can be found in the SteppIR VCP Help. A copy of the help file is also available on my Web site. The VCP program is available as a free download.

In addition, I am working on a charting program to automatically create an SWR-versus-frequency graph for a selected frequency range. The chart could be printed and saved for future reference. In order to use this feature, the LP-100-Chart software must be used in conjunction with TRX-Manager<sup>9</sup> to control the transmitter.

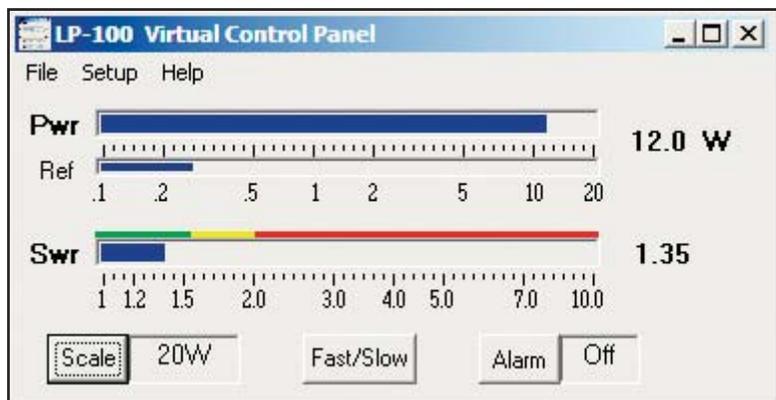


Fig 7—LP-100 Virtual Control Panel.

The LP-100 is also supported directly in *TRX-Manager* allowing remote monitoring of LP-100 basic parameters using *TRX-Manager's* Remote telnet mode. Details of all of the LP-100 software are available on my Web site ([www.telepostinc.com](http://www.telepostinc.com)). The LP-100 can also be controlled and monitored over any network connection, including the Internet. For details of doing this, see my article in the Oct 2005 *QST* entitled, "Using Networked Equipment for Remote Station Control."<sup>10</sup>

### Construction

Most of the parts for the LP-100 are mounted on a single, double-sided PC board, except for those associated with the PLED display and coupler. Fig 8 shows the completed board, with the PLED board mounted in front of it on the front panel. The PLED board is connected to the main board with a 16-pin header and ribbon cable.

A version of the main board with silk-screened component placement, and a solder mask, will be available on my Web site for those wishing to replicate this project. A pre-programmed PIC chip will also be available. Since I have already had numerous requests for a kit of parts for this project, I plan to offer that as well.

The main PC board mounts on four standoffs in a Pac Tec CM6-225 black ABS plastic case. This case is available in plain ABS or with an RF shield coating. The rear-panel PC board-mounted BNCs are secured to the rear panel. All connectors and switches are PC board mounted for ease of assembly and reliability. All parts are through-hole except the resistors in the input pads and dividers. This was necessary from a performance standpoint, but the parts are easier to handle than you might imagine.

KSZOA did the drilling and milling of the front and rear panels for my prototype. The panels are brushed aluminum, and the labeling is an overlay I produced in Microsoft *Word*, which is printed on adhesive vinyl transparency material.

The prototype coupler is mounted in an aluminum clamshell box with SO-239 connectors for the XMTR and ANT ports, and BNC connectors for the FWD and REF ports. The main connectors could be replaced with N connectors if desired. Figs 9 and 10 show the prototype coupler in detail. I used external 10 dB BNC inline coaxial pads from Mini-Circuits<sup>11</sup> in my prototype. It is important that these two ports always have a load to prevent high voltages from developing on the transformer windings when transmitting. I

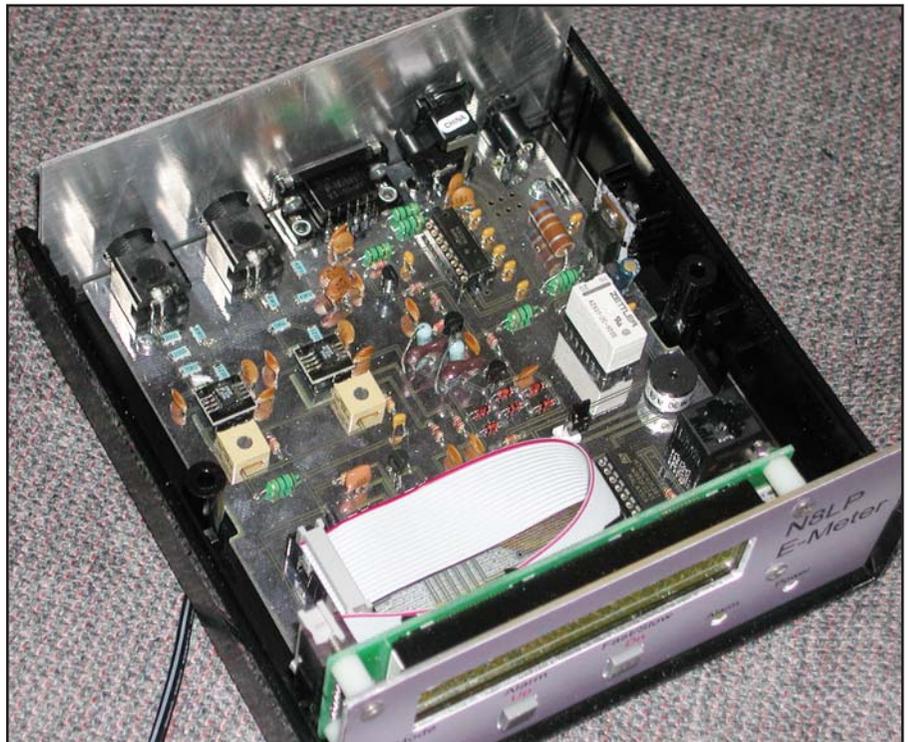


Fig 8—Main Board. (N8LP).

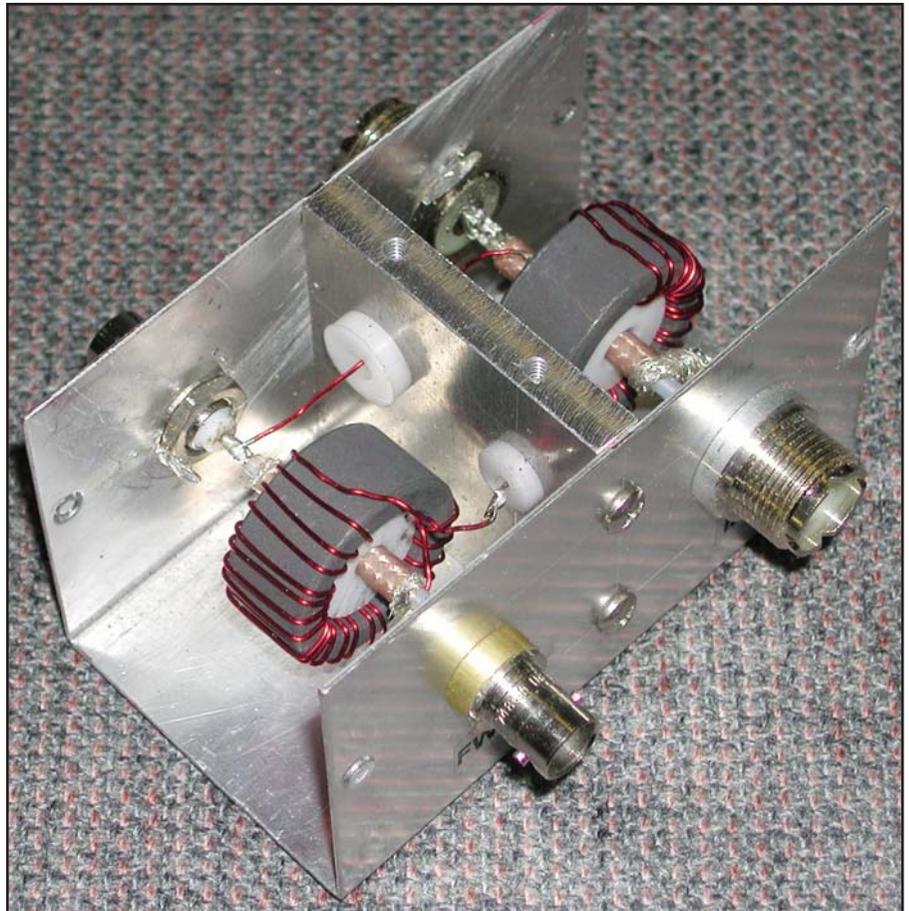


Fig 9—LP-100 Coupler photo. (N8LP)

plan to integrate the pads into the case in the future.

The coupler box dimensions are important. Don't use one that's much smaller than mine, which might result in stray coupling degrading high-frequency directivity. Also, be sure to include the shield partition between sections to improve isolation of the transformers. I used grommets in the shield to connect the transformer secondaries between sections.

The primary of T1, which goes between the XMTR and ANT connectors, is a short piece of RG-142 Teflon coax. The shield is grounded on one end, and left open at the other. This provides electrostatic shielding, and reduces the effects of capacitive coupling. (If you ground the shields at both ends, it will create a shorted turn and render the coupler useless.) The primary of T2 is connected between the FWD and REF connectors.

Both secondaries are 26 turns of #26 (AWG) enameled copper wire, spaced evenly over about  $\frac{2}{3}$  of the cores. The cores are supported by short lengths of plastic rod, drilled down the center. I used Teflon, but any decent low-loss plastic should work. I have seen small sink plungers with plastic handles of the right diameter, which could be cut and would probably work okay.

A support package with complete assembly details, schematics, parts list, mechanical drawings, panel templates and graphics files for the front and rear panels, is available on my Web site if you want to duplicate this project.

The package should be downloaded by anyone interested in replicating the project. The package contains a wealth of information that will make the project easier to build.

### Performance

Tables 2 and 3 show the measured performance of the LP-100 prototype at various frequencies and loads. In general, power accuracy is dependent upon the reference against which the LP-100 is calibrated. (Calibration is necessary because of the manufacturing variation of the log amps.) After calibration, the meter will match the reference exactly at the calibration level and should be within  $\pm 0.25$  dB at any power level. Table 2 shows a comparison of the LP-100 to Bird 4410A and Alpha 4510 power meters. The source is my Elecraft K2.) These are exceptionally good meters, but even at this level, it is apparent that there are some differences. The LP-100

matches the Bird exactly because it was calibrated against it. A spot check of the meters at 100 W, without further calibration, showed a  $\pm 3\%$  variation between the three instruments.

SWR accuracy was calculated to be better than 5% based on device specs. The SWR readings in Table 3 are compared with those from my HP-87510A VNA. The table shows the displayed

SWR for nominal load values of 50, 75 and 25  $\Omega$ , using precision terminations. Readings were taken at +20 dBm (100 mW) for all load values, using my HP-8640B signal generator.

SWR results below 1.1:1 would require 0.5 W to reach full accuracy. This is due to the reflected power signal being below the noise floor of the log-detector as discussed in the coupler description above.

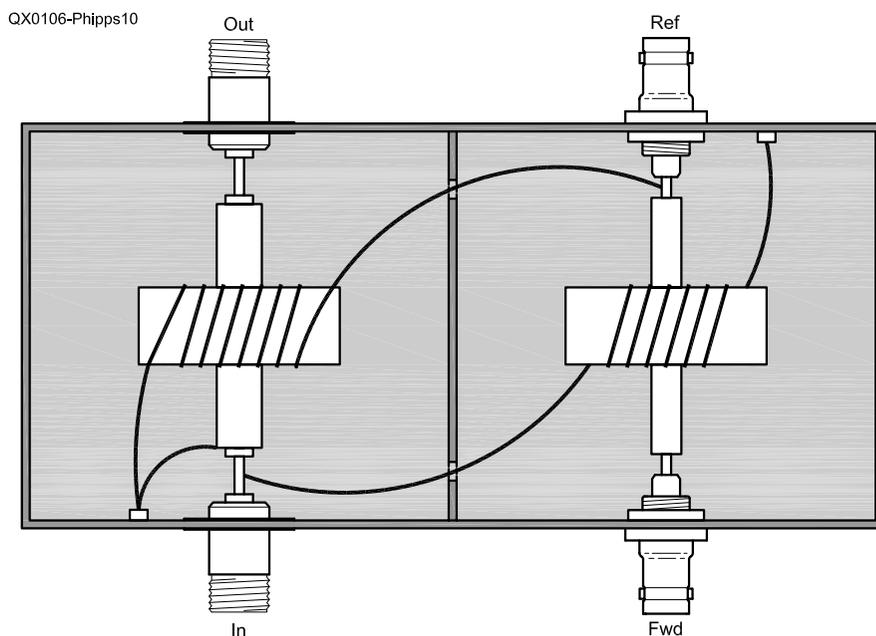


Fig 10—LP-100 Coupler drawing.

Table 2—Power measurements of the LP-100

LP-100 measurements (watts) compared with those of Alpha 4510 and Bird 4410A wattmeters

<i>f</i> (MHz)	LP-100	Alpha 4510	Bird 4410
1.80	7.10	7.20	7.10
3.50	9.50	9.45	9.50
7.00	9.60	9.45	9.60
14.00	8.40	8.45	8.40
21.00	7.80	7.70	7.80
28.00	6.70	7.00	6.70

Table 3—SWR Accuracy of the LP-100

LP-100 measurements (SWR) compared with those of an HP-87510A VNA

Frequency (MHz)	75 $\Omega$ LP-100	75 $\Omega$ VNA	25 $\Omega$ LP-100	25 $\Omega$ VNA	50 $\Omega$ LP-100	50 $\Omega$ 0.5 W + VNA	50 $\Omega$ VNA
1.80	1.55	1.55	1.95	2.02	1.06	1.03	1.02
3.50	1.55	1.55	1.97	1.98	1.06	1.03	1.02
7.00	1.56	1.53	1.99	1.94	1.06	1.02	1.02
14.00	1.56	1.48	1.99	1.90	1.07	1.02	1.02
28.00	1.57	1.47	2.03	1.95	1.08	1.05	1.04
56.00	1.54	1.48	2.14	2.20	1.10	—	1.09

Table 3 compares the LP-100 with my HP 87510A VNA. The table shows the displayed SWR for nominal load values of 50  $\Omega$ , 75  $\Omega$  and 25- $\Omega$ , using precision terminations. Readings were taken at +20 dBm (100 mW) for all load values, using my HP-8640B signal generator.

Remember, accurately measuring extremely low SWR levels at very low power requires an RF environment with low interference levels. The normal noise floor as indicated on the dBm scale should be between -20 and -10 dBm with no signal applied. This is dependent on a number of factors such as proximity of other gear, or a PC. If it is much higher than that, you may have a strong local broadcast station that is affecting the noise floor. Contact me for a suitable filter design in such a case.

### Continuing Development

In an effort to eliminate the parasitic coupling, and provide a repeatable design without the need for tweaking of the transformers, I decided to try a line-section coupler. Instead of the Bird approach of inserting a small loop into a transmission line, I chose to make the line a microstripline sampler using a PC board. The loop was a length of Teflon wire (from the center conductor of RG-142 coax), placed directly on top of a stripline trace. This loop design was settled on after dozens of different configurations were tried by both me and Jack, K8ZOA.

There is one major drawback to line-section couplers, however, and that is that the response varies with frequency at the rate of 6 dB/octave. This meant that I would have to find a method of flattening the response. To level the response, I added a small coil in series with the feed to the log amps. After testing dozens of coils, I settled on a SMD part from CoilCraft. This was necessary to keep the self-resonant frequency of the coil above 54 MHz. Small remaining variations can be easily compensated by calibration.

In an effort to minimize the effects of the connecting lines to the main chassis, I decided to move the log amps to the coupler chassis. I also added a 12-bit A/D converter to the coupler case to increase resolution, as well as a temperature sensor, precision reference chip and RF pickup for the frequency counter.

Fig 11 shows the stripline coupler. The stripline is on the underside for isolation. The cable is an 8-pin DIN cable, which carries power, ground, the SPI bus data to/from the A/D converter

**Table 5—Parts List**

<i>Part ID—Description</i>	<i>Vendor</i>	<i>Part #</i>
<b>Main Chassis</b>		
Caps—Keypcaps	Digi-Key	401-1221-ND
Case—CM6-225	Mouser	616-63075-510-000
C1—1 $\mu$ F	Digi-Key	P4675-ND
C3, 4, 19—10 $\mu$ F	Jameco	29891CX
C5-7, 9-13 —0.01 $\mu$ F	Jameco	15229CL
C4, 8, 14-18—0.1 $\mu$ F	Jameco	25523CL
D1, 5—1N4148	Digi-Key	1N4148FS-ND
D2—LED	Digi-Key	67-1236-ND
D3—LED	Digi-Key	67-1235-ND
D4—1N4001	Digi-Key	1N4001DICT-ND
JP1-2—Header 2 Pin Jumper	Digi-Key	A1911-ND
J1—16-pin ribbon connector	Digi-Key	A26242-ND
J3—dc Jack	Digi-Key	A26271-ND
J2, 7—BNC	Digi-Key	CP-202B-ND
J4—DB9 D-SUB	Digi-Key	A24495-ND
J5—RJ-11	Digi-Key	A2100-ND
J6—Dual RCA Jack	Digi-Key	A9073-ND
L1-3—1 mH choke	Jameco	CP-1433-ND
L4, 6, 8—100 $\mu$ H	Jameco	208240CA
PLED1—PLED Display	Jameco	208194CC
P1—16-pin ribbon cable assembly	CRYSTALFONTZ	CFAP-2002A-Y-ECS
Q1—2N4401	Digi-Key	M3AAA-1606J-ND
Q2, 3, 4—2N3904	Digi-Key	2N4401-ND
R1—1 M $\Omega$ , -1/8 W	Jameco	38359CC
R2, 4, 15—10 k 1/8 W	Digi-Key	P1.0MBACT-ND
R3, 17—390 1/2 W	Digi-Key	P10KBACT-ND
R6, 9—50 k $\Omega$ pot	Digi-Key	P330W-1BK-ND
R7—330 $\Omega$	Digi-Key	3386P-503-ND
R8—20 k $\Omega$ pot	Digi-Key	P330BACT-ND
R11, 12—47 k $\Omega$ 1/8 W	Digi-Key	3386P-203-ND
R13, 14, 16—1kW 1/8 W	Digi-Key	P47KBACT-ND
R24, 25—52.3 $\Omega$ $\pm$ 1% 1/4 W	Digi-Key	P1.0KBACT-ND
R10, 20—121 $\Omega$ $\pm$ 1% 1/4 W	Mouser	271-52.3
R22, 26, 27—49.9 $\Omega$ $\pm$ 1% 1/4 W	Mouser	271-121
RL1—Omron G5V-2-H1-5	Mouser	271-49.9
S1—CEM-1212C piezo transducer	Digi-Key	Z108-ND
SW1-3—Tactile Switches	Digi-Key	102-1123-ND
U1—16F876	Digi-Key	EG1822-ND
U2—LM7805T	Digi-Key	PIC16F876-20/SP-ND
U3-4—AD8307	Jameco	51262CX
U5—LT1634	Analog Devices	AD8307AN
U6—MAX232CPE		LT1634-CCZ-2.5
U7—74HC4053	Jameco	24811CX
Y1—20 MHz resonator	Jameco	272111CX
	Digi-Key	X909-ND
<b>Coupler</b>		
J8, 9—Chassis BNCs	Jameco	159484CL
J10, 11—Chassis SO-239s	Mouser	530-CP-AD206
FT1, 2—Ferrite Cores	Amidon	FT-114A-61
Case—Bud CU-3003A minibox	Digi-Key	377-1090-ND

and the RF sample for the counter. I am thinking of changing to a VGA video cable, which offers shielded coaxial wires.

This design improves on the already very good SWR accuracy, while eliminating the problems associated

with stray coupling in the toroidal design. By moving all RF circuitry to the remote coupler, it should be possible to allow for switching of multiple couplers to allow for VHF and UHF couplers, for instance. I have played a bit with such a design, in fact.

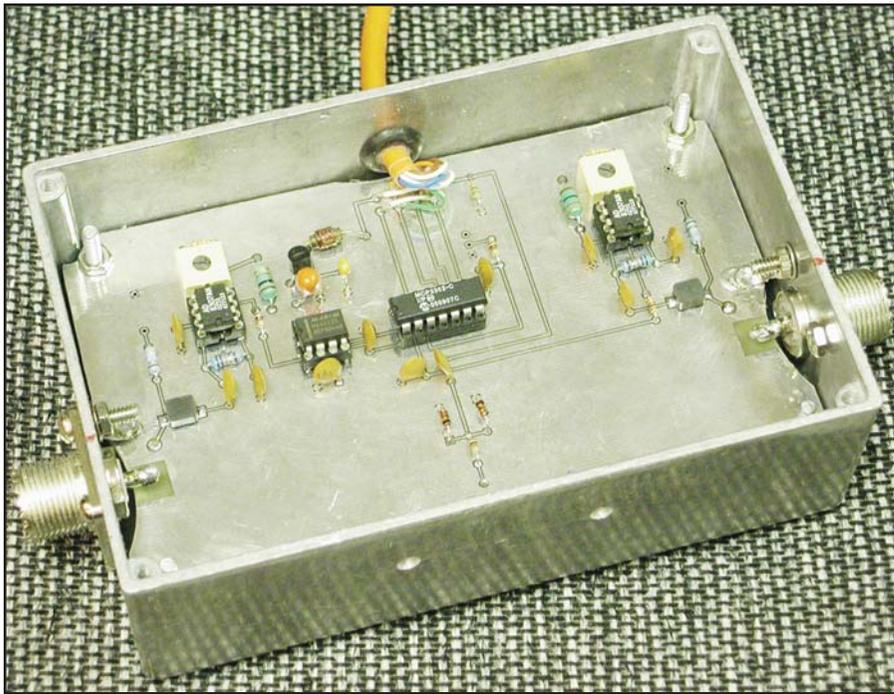


Fig 11—LP-100 stripline coupler. (N8LP)

Because of the need for accurate calibration of the LP-100 before use, I am working on a couple of inexpensive calibrator designs to support the project. For complete details on the stripline coupler design, and for the latest news on the project, check out my website under the LP-100 link. I am also interested in any feedback about feature enhancements that could be implemented in the LP-100.

In closing, I would like to thank my wife, Janet, for her patience and support with all my projects, and to

Jack, K8ZOA, for his help and expertise in making this project a success, including design help, machining and testing.

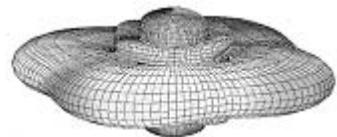
**Notes**

- <sup>1</sup><http://www.arrl.org/tis/info/pdf/5904024.pdf>
- <sup>2</sup><http://www.arrl.org/members-only/tis/info/pdf/99hb2236.pdf>.
- <sup>3</sup><http://members.tripod.com/michaelgellis/direct.html>.
- <sup>4</sup><http://users.adelphia.net/~n2pk/RLPmtr/RLPv1c.pdf>, also appeared in *QRP Quarterly*, Oct 2002.
- <sup>5</sup><http://www.arrl.org/members-only/tis/info/pdf/9002019.pdf>.

- <sup>6</sup>[www.analog.com/UploadedFiles/Data\\_Sheets/4833689284721AD-8307\\_b.pdf](http://www.analog.com/UploadedFiles/Data_Sheets/4833689284721AD-8307_b.pdf).
- <sup>7</sup><http://ww1.microchip.com/downloads/en/DeviceDoc/30292c.pdf>.
- <sup>8</sup><http://www.basicmicro.com>.
- <sup>9</sup>[www.trx-manager.com](http://www.trx-manager.com).
- <sup>10</sup>Oct 2005 *QST*, page 40.
- <sup>11</sup>[www.mini-circuits.com](http://www.mini-circuits.com).

*Larry Phipps, N8LP, has been licensed since 1965, first as WN8PSD, later as WA9PSD and finally as N8LP, when he upgraded to Amateur Extra. Larry also earned an FCC First Class Radiotelephone license in 1967. He is retired from TelePost Inc, a television post-production facility that he and his wife Janet founded and owned for 16 years. Larry worked for WJBK-TV, Detroit, while attending the University of Michigan College of Engineering. He left school in 1971 to work full-time at WJBK as a broadcast engineer. He then went to NET Television Inc (a subsidiary of WNET-TV, New York), where he was instrumental in launching one of the first computer controlled videotape-editing systems in the country. Larry now devotes time to his house, his wife and ham radio (not necessarily in that order!), all sorely ignored while he and his wife operated the company.* □□

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