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The DWM-4: A Microprocessor Controlled Multichannel Wattmeter for HF, VHF and UHF

This handy station accessory saves desk space and centralizes all your RF power and SWR metering.

My radio desk was already cluttered, and I was thinking of adding a backup HF rig. Unfortunately, there was no desk space left! I started looking at items that could be removed or consolidated. I combined a couple of antenna switches into a larger one, but that merely cleared out a few square inches—not enough. Then I realized that each rig had at least one SWR or power meter on it! My HF rig, an IC-706, has two coaxial outputs, so it had one external SWR/power meter on each output. My dual-band VHF/UHF rig has separate antennas, so it had separate meters on it. On top of that, my VHF packet rig had an SWR meter on it! Combined, the lot took up more room than a backup rig!

The thought that I might be able to combine *all* the meters into one unit had me visualizing lots of saved table space. Looking through the catalogs, I found many dual and triple-band meters, but none with multiple inputs. Taking this as a challenge to clear the desktop, designing what I needed got under way. The result—presented here—is the DWM-4: a digital wattmeter with four inputs.

Research

Because nothing like this existed (at least, nothing that I could find), I had to do some research on wattmeters. I set about gathering information on the various wattmeters and SWR meters currently available. It was then that I realized there are *many* meter functions to take into consideration. Some units allow selection of peak or RMS power readings. Others have alarms

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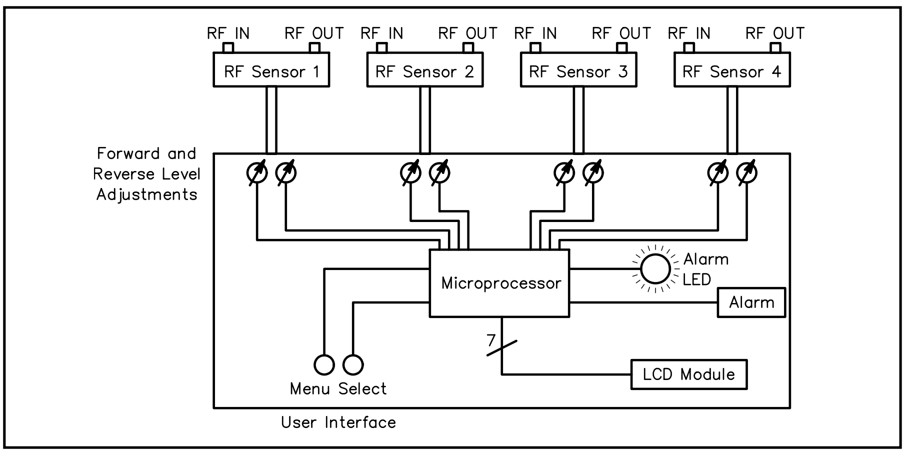


Figure 1—Block diagram of the multichannel wattmeter.

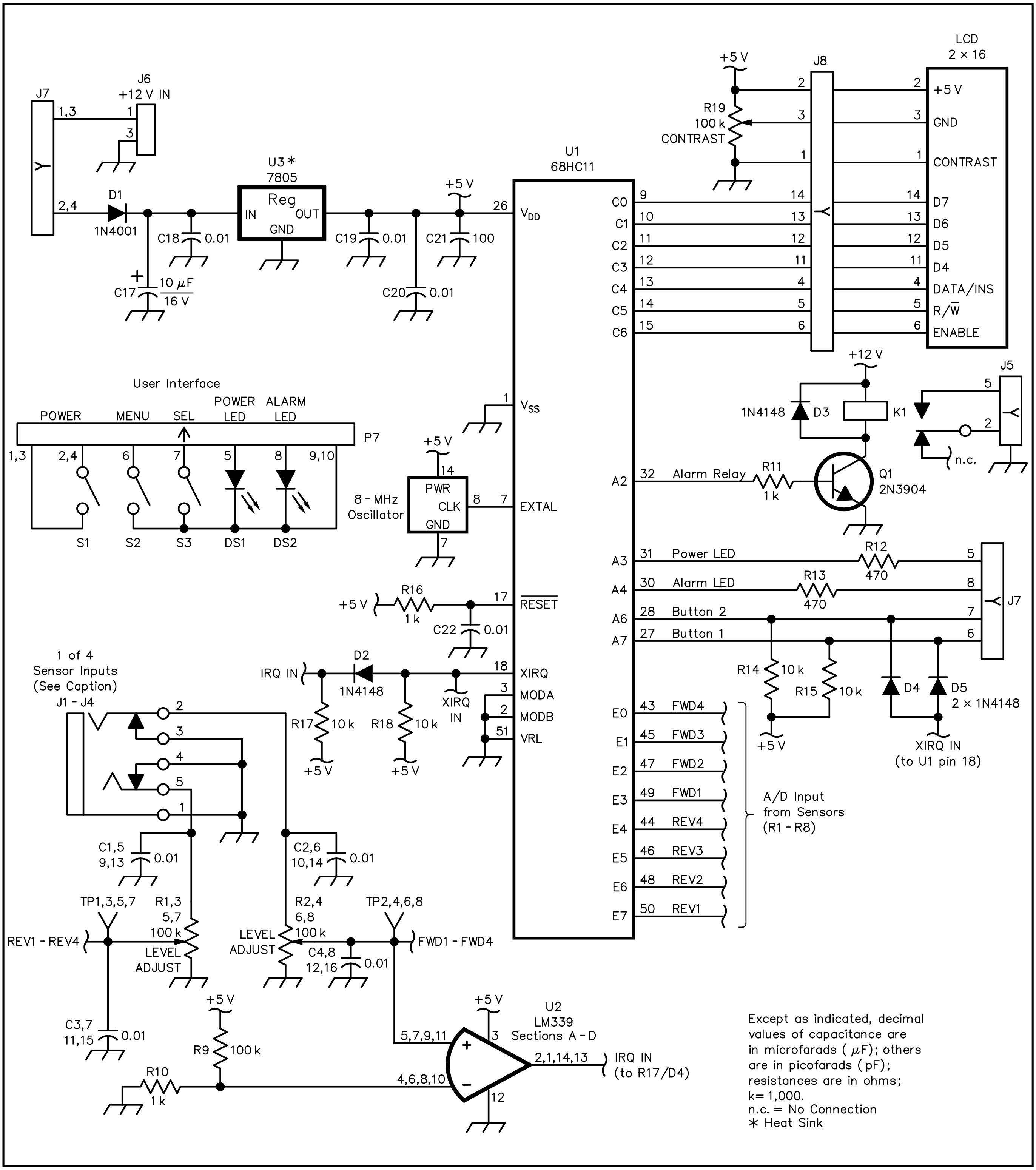


Figure 2—Schematic of the multichannel wattmeter. Unless otherwise specified, resistors and capacitors are standard leaded units. Equivalent parts can be substituted; n.c. indicates no connection. For compatibility with existing construction, some component identifiers deviate from standard *QST* style. A single sensor-input circuit is shown with part IDs for four such units.

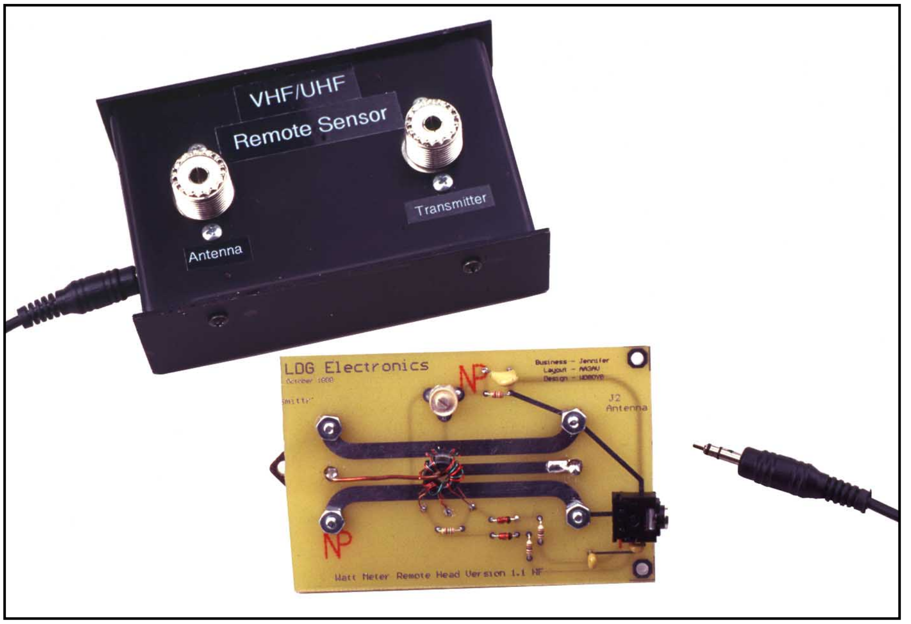
D1—1N4001 silicon diode
D2-D5—1N4148 silicon switching diode
DS1—Green LED
DS2—Yellow LED
J1-J5—PC-mount, three-circuit (stereo) 1/8-inch jack
J6— PC-mount, 2.0-mm male coaxial power jack
J7—Female header, 2 row, 7 conductor, 0.1 inch spacing.
J8—14-pin socket
K1—12-V, 10-A SPDT relay (Aromat JS1-12V)
LCD—Timeline 2-line, 16-character LCD
OSC—8.0-MHz oscillator module
P7—Male header, 2-row, 7-conductor, 0.1-inch spacing
Q1—2N3904
R1-R8, R19—100 kΩ PC-mount potentiometer
S1—SPST toggle switch
S2, S3—SPST momentary pushbutton
U1—68HC11 *programmed* microprocessor; see Note 1.
U2—LM339 quad comparator
U3—LM7805 three-terminal regulator
Misc: 10-pin header, 10-conductor IDC ribbon cable, 14-pin header, 14-conductor IDC ribbon cable, enclosure, hardware.

that notify the operator of a high SWR condition. A number of units have dual-reading meters to allow simultaneous viewing of forward and reverse power. There are meters with analog and digital displays. Some meters have microprocessors that calculate the power and SWR, but use an analog meter for display. Finally, I noted that most of the meters have an accuracy of 10 to 20%. There are some units with better accuracy, but they carry a high price tag.

The greatest difference among the meters appeared to be the SWR-sensing systems used. HF meters usually employ a toroidal bridge pickup. VHF and UHF meters generally use a stripline sensor. Some more-expensive hybrid meters use both sensor types.

For my DWM-4, most of the design choices were obvious. A 16-character, two-line LCD module provides the greatest flexibility and allows considerable information to be displayed at once. Because a microprocessor would control the LCD, all kinds of functional possibilities opened up. The processor's A/D converters could digitize the sensor readings, making it easy to display bar graphs, numbers and alarm messages. A menu system could be used to allow user selection of settings and display options. (More on the menus later.)

The most important choice I had to make was that of sensor type. Having a single sensor that operated from 1 to 500 MHz would be *really* nice, but it would add considerable cost to the unit, especially if four separate sensors were used. Instead, I opted to use two inexpensive sensors: a toroidal bridge for HF and 6 meters, and a stripline sensor for VHF/UHF. Both sensors are designed to handle power levels of up to 150 W.



A VHF/UHF sensor inside its enclosure and a rear view of an HF sensor's PC board.

Design

To see the layout of the major system functions, refer to the block diagram of Figure 1 and the schematic of Figure 2. Basically, there are three major subsystems: the sensors, the microprocessor and the user interface. Because this is a microcontroller project, some of the hardware is highly integrated with the software. The microprocessor and display have physical hardware, but are controlled by software.

The signal flow is straightforward. The sensors detect the power and send the information to the microprocessor, which changes the incoming analog voltage to a digital signal. Then, the microprocessor performs the calculations and displays the resulting information on the LCD.

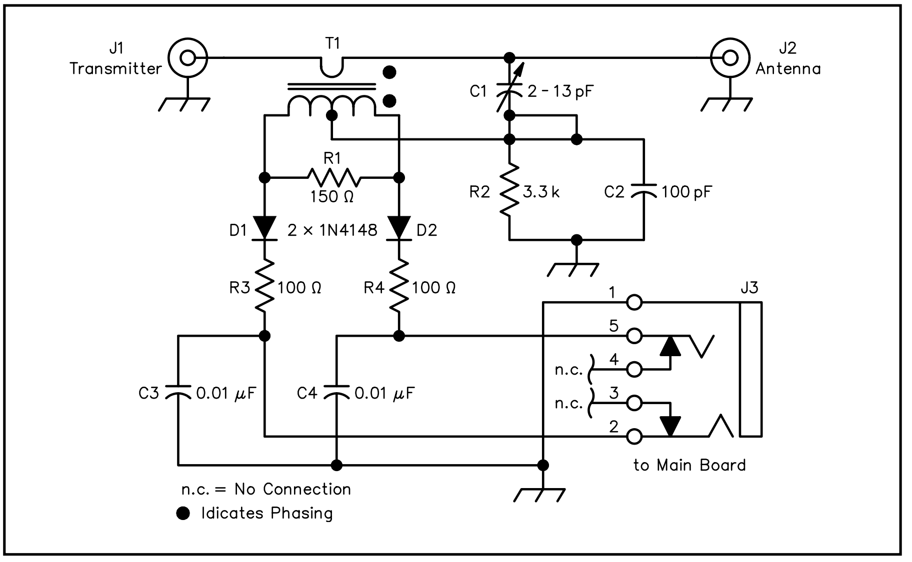


Figure 3—Schematic of the wattmeter's HF sensor.

C1—2-13 pF air-variable trimmer
D1, D2—1N4148 silicon switching diode
J1, J2— SO-239 chassis-mount connector
J3—PC-mount, three-circuit (stereo) 1/8-inch female jack
T1—14 bifilar turns #28 enameled wire wound on an FT-37-43 core
Misc: Shielded 1/8-inch stereo cable, 6 feet long, male plug ends, enclosure, hardware.

HF Sensor

The HF sensor (Figure 3) is a common toroidal bridge.[1] This SWR measuring technique is seen in most HF dual-meter and direct-reading SWR meters. Normally current is used to drive a meter movement. I made slight modifications to the circuit to provide voltages (instead of currents) that are proportional to the forward and reverse power.

The single-lead primary passing through the toroid center of T1 provides RF-current sampling to the secondary winding. Variable capacitor C1 allows adjustment of circuit balance. D1 and D2 rectify the forward and reverse current samples and provide the required dc voltages.[2] Bypass capacitors help filter out the RF to provide a smooth dc signal.

The two voltages are sent to variable resistors in the display unit (Figure 3) that are used in conjunction with the A/D converters of U1 to adjust the forward and reverse power sensitivity. Once in a digital format, the resulting forward and reverse values are used to calculate forward and reverse power and SWR. The sensor delivers about 4.5 V dc to indicate full-scale readings on the display. Using menus, the display scale can be set for 15 or 150 W on HF. For QRP operators, the 15-W scale may

[1]Notes appear on page 46.

be more useful. It provides rougly 10 times the resolution of the 150-W scale.

VHF/UHF Sensor

The VHF/UHF sensor is similar to others found in dual-meter and direct-reading meters for those bands. It is also modified to provide voltages instead of current. This sensor differs primarily from the HF sensor in its use of stripline sampling. The strip-lines above and below the main line provide the forward and reverse sampling. Germanium diodes (1N34As) are used for greatest sensitivity. The diodes, along with the bypass capacitors, rectify and smooth the sample to provide the dc voltages. Again, variable resistors on the display board and the A/D converters of U1 allow for adjustment of the full-scale reading on the LCD. For VHF/UHF, there is but one scale of 150 W.

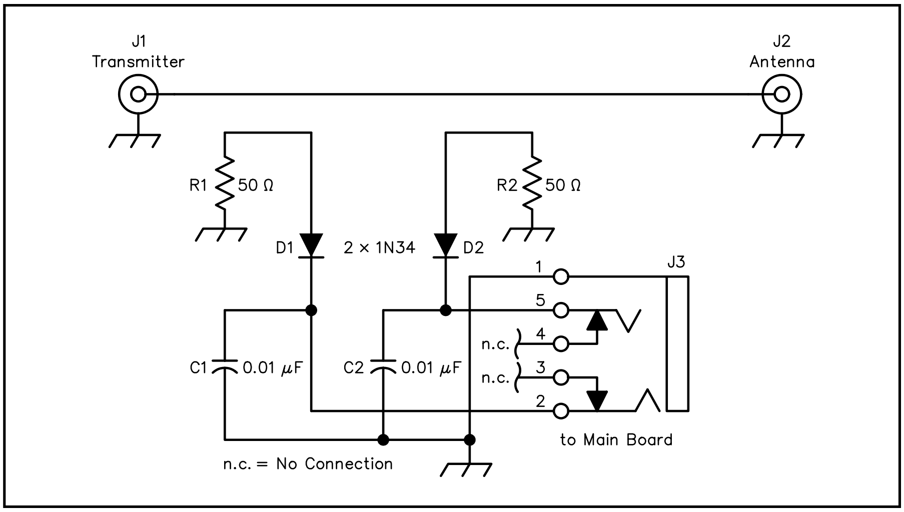


Figure 4—VHF/UHF sensor diagram.

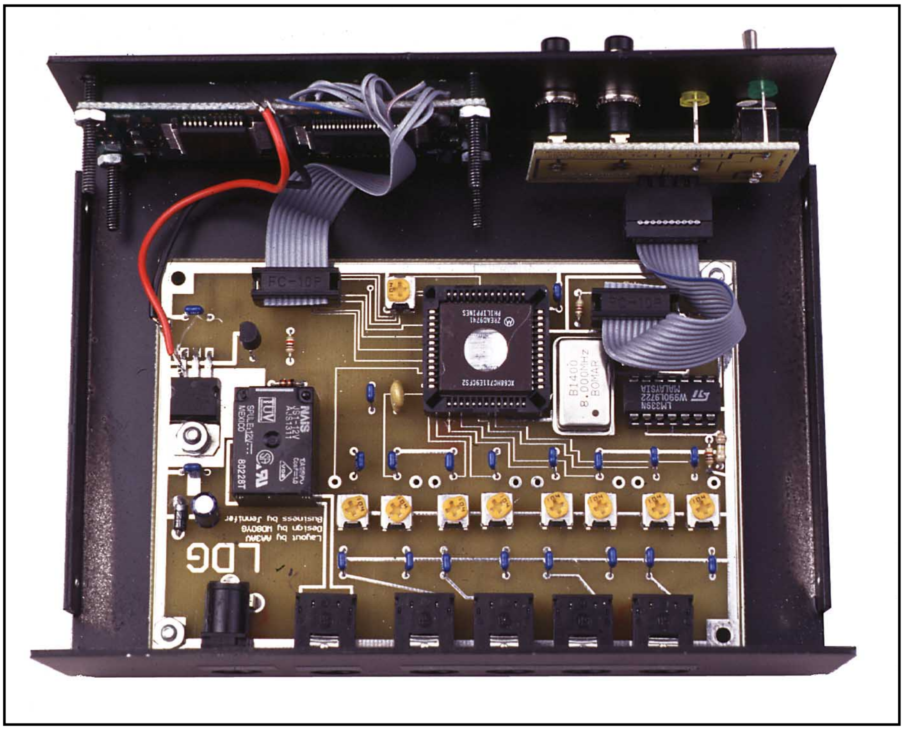
D1, D2—1N34A germanium diode
J1, J2—SO-239 chassis-mount connector
J3—PC-mount, three-circuit (stereo) 1/8-inch jack
Misc: Stereo 1/8-inch cable, 6 feet long, male plug ends, enclosure, hardware.

Hardware

Most of the hardware is in the display unit. U1 is an MC68HC11E9FN microcontroller. Inside the chip are 12 kB of one-time programmable EPROM (for assembly language program space), 256 bytes of RAM for data storage, 512 bytes of nonvolatile EEPROM to store user settings, an 8-bit output port, an 8-bit input/output port, an 8-channel, 8-bit A/D input port and an 8-bit timer port. The chip also contains a serial port (useful for RS-232 connections) and a high-speed serial peripheral interface (SPI), but they are not used in this application.

The eight A/D inputs of U1 port E are used to read up to four sensors; each sensor has a forward and reverse output. Port C, the 8-bit output port, drives the LCD. The user-interface pushbuttons (S2 and S3) and LEDs (DS1 and DS2) are controlled via port A. Each power sensor's **FWD** input also drives a voltage sensor (a section of quad comparator U2) that triggers a hardware interrupt (IRQ). This alerts the 68HC11 that a transmitter is active.

U1 and the other active devices operate from a 5-V dc source delivered by U3, an on-board 7805 regulator. The combined current consumption of U1 and the backlit LCD is only about 60 mA. The total current drawn by the DWM-4 depends upon whether or not the alarm relay is energized, the maximum drain being about 90 mA.



Inside view of the DWM-4 multichannel wattmeter.

Software

The DWM-4 software is written in 68HC11 assembly language.[3] The main routine monitors an interrupt line that lets the processor know that one of the channels is detecting forward power. Once U1 knows a sensor is active, it looks at the A/D inputs to see which one is active and makes the necessary calculations to display the results on the LCD.

User Interface

The user interface consists of the LCD, one toggle switch (S1), two pushbutton switches (S2 and S3) and two LEDs (DS1 and DS2). The LCD provides the operator with a series of menus. Each menu offers information about each of the four sensor inputs. Some items are common across different menus.

There are two basic wattmeter modes: setup and operate. During setup, you can select bargraph or numeric display, peak or average display, set SWR alarms and select which sensor type is connected to each input along with a power range for each sensor.

In operation, the display shows forward or reverse power (as a bargraph or numeric display), SWR (in digits) and status.

Menus

The heart of the user interface is the menu system. There are seven menus through which you can scroll to set the functions of each channel (see Table 1). Under normal operation, you start at the **MAIN** menu. This menu displays the forward and reverse power, SWR, active channel and alarm status. Pressing the **SELECT (SEL)** button, S3, cycles the displayed channel from **1** to **4** and

Table 1
Menu System of the DWM-4

Menu	*Select*
Main Menu	**1 2 3 4 A**
Display Readout (Bargraph or Numeric)	**BAR / NUM**
Sample Report (Peak or Average)	**P** or **A**
Alarm Threshold (SWR)	**OFF, 1.1 to 10.0**
Relay Threshold (SWR)	**OFF, 1.1 to 10.0**
Relay Reset	**AUTO® / MANUL®**
Sensor Type HF High or HF Low VHF or UHF	**HH / HL/ VH / UH**

A. Option **A** stands for automatic operation. When in automatic mode, the display is automatically switched to the channel that is currently sensing forward power.

Pressing **MENU** button S2 cycles through the menus for the selected channel. The **DISPLAY READOUT** menu chooses between **BAR** and **NUMBER** for the forward and reverse displays. The **SAMPLE REPORT** menu chooses between a **PEAK** and **AVERAGE** for the forward and reverse power. There are **PK** and **AV** icons on the status line to show the selection.

The **ALARM THRESHOLD** menu selects the point at which the front-panel yellow LED illuminates to warn of high SWR. Pressing and holding the **SEL** button turns on the alarm and counts from 1.1 to 10.0 for the alarm threshold. Pressing the **SEL** button again turns off the alarm.

The **RELAY THRESHOLD** menu is separate from the **ALARM THRESHOLD**. The **SEL** button works as it does with the **ALARM THRESHOLD**, but only controls the relay, K1. The **RELAY RESET** menu chooses between **MANUAL** and **AUTO** reset. In **MANUAL** reset, you must press the **SEL** button to deenergize the relay. In **AUTO** reset, the relay is reset when the SWR drops below the **RELAY THRESHOLD** value.

The **SENSOR TYPE** menu allows you to select one of the four sensor types available. The sensors and ranges are **HF HI** (0 to 150 W), **HF LOW** (0 to 15 W), **VHF** (0 to 150 W) and **UHF** (0 to 150 W).

At any time, pressing the **MENU** and **SEL** buttons simultaneously returns you to the **MAIN** menu.

Errors

There are three error conditions for the DWM-4: (1) The forward maximum power level has been exceeded; (2) the reverse maximum power level has been exceeded, and (3) the reverse power level is greater than the forward power level. The display indicates these errors as they occur. When the error condition is removed, the display returns to normal.

Construction

Assembly is straightforward. Place each sensor in a shielded enclosure to reduce exposure to stray RF fields. PC boards are available for the main board and each sensor type.[4] The sensors are built on PC boards and connect directly to SO-239 connectors mounted on the boards. Within the enclosure, the SO-239 connectors support the sensor PC board.

A ribbon cable connects to the front-panel toggle switches, pushbuttons and LEDs (J7/P7) to the main board. Another ribbon cable (P8) connects to the LCD module. Be sure to refer to the schematic when wiring the LCD. When installing U1, take the precaution of using a static-discharging wrist strap. Once in its socket, U1 is well protected.

In the HF sensor, be sure to orient T1 properly. If connected incorrectly, the forward and reverse power indications will be exchanged. In the VHF/UHF sensor, some of the components are attached "dead bug" style with the leads tack-soldered to the PC board traces.

Adjustments

Most of the adjustments are on the main PC board. As mentioned earlier, each forward and reverse line is equipped with a variable resistor for calibration. The HF sensor also has a balancing capacitor on its PC board. There are no adjustments to be made within the VHF/UHF sensor.

Observe proper safety practices when adjusting the sensors. Keep your fingers away from the wires and traces that carry RF. An RF burn from a 100-W transmitter can be quite painful. Keep each sensor's enclosure cover in place during operation.

At a minimum, a 100-W HF radio and 50-Ω dummy load can be used to calibrate the unit. Even if you know how much power your radio emits, consider using an additional wattmeter of known accuracy to assist you during the calibration process.

Start by setting R1 through R8 to their center positions. Connect the HF sensor to **INPUT 1** on the main board. Attach a voltmeter between ground and the reverse test point of the HF sensor. Apply 100 W through the HF sensor to a dummy load or resonant antenna, adjust C1 in the HF sensor for minimum voltage. The minimum reading should be just about 0 V. A reading of 0.1 V or less is fine.

Again apply 100 W and adjust R1 on the main board so that the forward display reads 100 W. Be sure to use the menus to set the proper sensor type and set the LCD to display numbers instead of the bargraph. Swap the input and output leads of the HF sensor and again apply 100 W. Adjust R2 to read 100 W on the reverse display. An error message (**REV>FWD)** will appear, but the display is still visible between error-message flashes.

For the QRPer using the 15-W HF sensor, repeat the preceding adjustments, but choose the **HF Low** setting from the **Sensor Type** menu and use a power level of 5 W. Adjust the variable resistors to display 5 W for the forward and reverse readings.

For VHF and UHF, connect a VHF/UHF sensor to one of the other channels. Apply RF power and adjust the corresponding variable resistor to obtain a correct forward power display. Swap the input and output leads and repeat for the procedure for reverse power. Repeat the foregoing process for the other channels by connecting the appropriate sensor to each input and adjusting the corresponding variable resistors.

Accuracy—a Virtual Bird

The accuracy of the DWM-4 is directly related to its calibration. The displayed values are derived from a huge look-up table stored in the microprocessor. These table values were taken from the readings of a Bird 43A wattmeter. The table was derived by comparing the A/D reading supplied by the HF and VHF/UHF sensors for various RF readings on the Bird meter. The Bird readings were then graphed, and extrapolated where needed to fill in the gaps.

The resolution of the DWM-4 is about 1 W on the 150-W scale and 0.1 W on the 15-W scale. Although the overall accuracy as compared to a Bird wattmeter is better than 0.1%, the actual accuracy still depends on the calibration.

Acknowledgments

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Notes

[1] Doug DeMaw, W1FB, Ed., *W1FB's QRP Notebook*, (Newington: ARRL, 1991, 2nd edition), pp 149-151.

[2] John Grebenkemper, "The Tandem Match—An Accurate Directional Wattmeter," *QST*, Jan 1987, pp 18-26, has some pointers on diode matching used in that unit.

[3] The software, including the source code, is in *HFVHFWAT.ZIP*. This file can be found on the Internet at the ARRL download site http://www.arrl.org/files/qst and is available from the author: Send a 3½ inch IBM preformatted diskette and a self-addressed, stamped disk mailer to Dwayne Kincaid, WD8OYG, 1445 Parran Rd, St Leonard, MD 20685.

[4] A complete parts kit (without enclosures) including a *programmed* 68HC11, PC boards, and one remote sensor (please specify HF or VHF/UHF) is available for $89 plus $8 shipping in North America. A complete kit and one sensor with pre-punched and silk-screened enclosures are available for $139, plus $10 shipping. additional rempte sensors are available for $19 each without enclosure, or $29 each with enclosure. Please specify sensor type, HF or VHF/UHF. A *programmed* 68HC11 is available for $25. Send your order to LDG Electronics, 1445 Parran Rd, St Leonard, MD 20685; tel 410-586-2177, fax 410-586-8475. Major credit cards are accepted.

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