

Digital RF Wattmeter with LC Display

for 1 kHz to 1 GHz

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www.webx.dk

Any radio amateur knows the importance of an accurate RF power meter. A wattmeter can be used to measure gain in amplifiers, bandwidth in filters, field strength from antennas, transmitter power, SWR, return loss and many other things.



Specifications

Frequency coverage:	1 kHz to 500 MHz (calibrated) 1 kHz to 1000 MHz (uncalibrated, for relative power measurements only)
Nominal input impedance:	50 Ω
Input power range:	-60 dBm to +30 dBm (1 nanowatt to 1 watt).
Input power range using 50-dB attenuator:	up to 100 kwatts.
Dynamic range:	90 dB with good RF shielded case.
Resolution:	0.1 dBm (1 dBm on bar-graph)
Input return loss:	@300kHz: -35dB @100MHz: -27dB @500MHz: -25dB
Input SWR:	@ 300kHz: 1.036 @ 100MHz: 1.094 @ 500MHz: 1.12
Accuracy before calibration:	±1 dB from 1 MHz to 450 MHz.
After calibration:	±0.2 dB at each calibrated frequency.
DC Voltage Measurement:	0 to 20 volts.
DC Voltage Resolution:	20 mV
DC Voltage accuracy after calibration:	±20 mV
Power supply:	9 to 20 VDC
Current consumption:	with no LCD light: 30 mA; with normal LCD light: 120 mA.

This RF wattmeter uses an AD8307 to measure the power level. The AD8307 front end circuit is both frequency compensated and optimised for return loss to give optimum input SWR over a wide frequency range.

A pre-programmed microcontroller type PIC16F876 with built-in 10-bit analogue to digital converters is used to convert the analogue voltage output from the AD8307 into digital values. Next, a set of lookup tables are used to convert the dBm values into RF voltage and RF power (watts). The readout of all values including a bar-graph appears on a large 20x2 LCD display with back light. There is also a DC voltmeter with minimum and maximum peak

storage, plus many extra features, see the software description further on in this article.

The decibel milliwatt (dBm) unit

In RF technology 0 dBm represents 1 milliwatt into 50 Ω. Similarly, 0 dBW represents 1 watt into the same impedance.

So, +10 dBm = 10 mW; +20 dBm = 100 mW; +30 dBm = 0 dBW = 1 W and so on.

The term 'dBm' is used at any professional radio development, repair and servicing facility as well as by radio amateurs, to describe (relative) RF power levels. Some

engineers are conversant with the dBm unit, others prefer 'watts' and still others like to talk about 'RMS voltage'. This meter displays all three units at the same time...

About the AD8307

The AD8307 monolithic logarithmic amplifier from Analog Devices was first described in the article RF Decibel Meter, see *Elektor Electronics*, January. For reference purposes, the block diagram of this hugely successful IC is given in **Figure 1**. The AD8307 is a relatively low cost component — at least according to the datasheet — in practice, the author paid about €13 (approx. £8.50) for one off plus postage.

The author initially tried the DIL version of the AD8307 — this is also the type used in the previously mentioned article. Although it is easier to solder and use than the SMD chip, its longer connecting pins make it unusable for frequencies higher than about 100 MHz. Several experiments were carried out using this type before it was found that the SMD type could be used up to about 500 MHz. Again several experiments were set up, boards where made, input resistors and capacitors where changed to optimise the lot.

At frequencies above 300 MHz input power should not exceed +20 dBm (100 mW) to maintain accuracy. This is a documented weakness of the AD8307. Not a big problem, really, if you are aware of it — it is just a matter of using the right input attenuation, to reduce the actual RF power applied to the chip to a level below 20 dBm and so guarantee optimum accuracy.

The author is grateful to all the radio amateurs and skilled engineers who have contributed with their experience, good ideas, help with measurements, and lending out expensive equipment so that it was possible to construct this input circuit.

Circuit description

The circuit diagram of the RF Wattmeter is given in Figure 2. It consists of four sections, which will be discussed briefly below, leaving a bit more space in the article to ponder on the second main components — yes that's the PIC16F876.

The RF voltage converter is draw as a separate unit around the AD8307. The 'log' equivalent of the voltage representing the RF power applied to socket K4 appears on K5 in the form of a step level between 0 and 2.5 V. The input resistor network is dimensioned for 50 Ω input impedance which is the *de facto* standard in RF work. The input network can handle power levels of up to 1 watts. C1 and

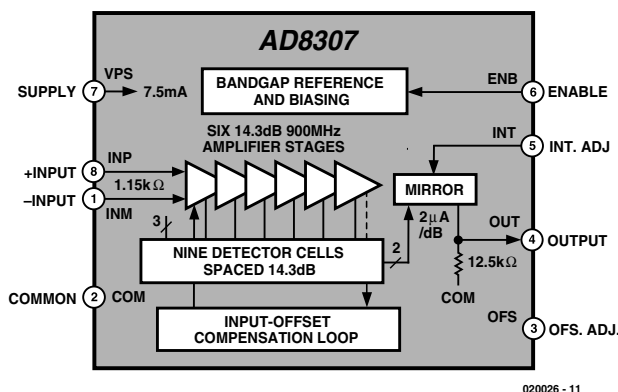
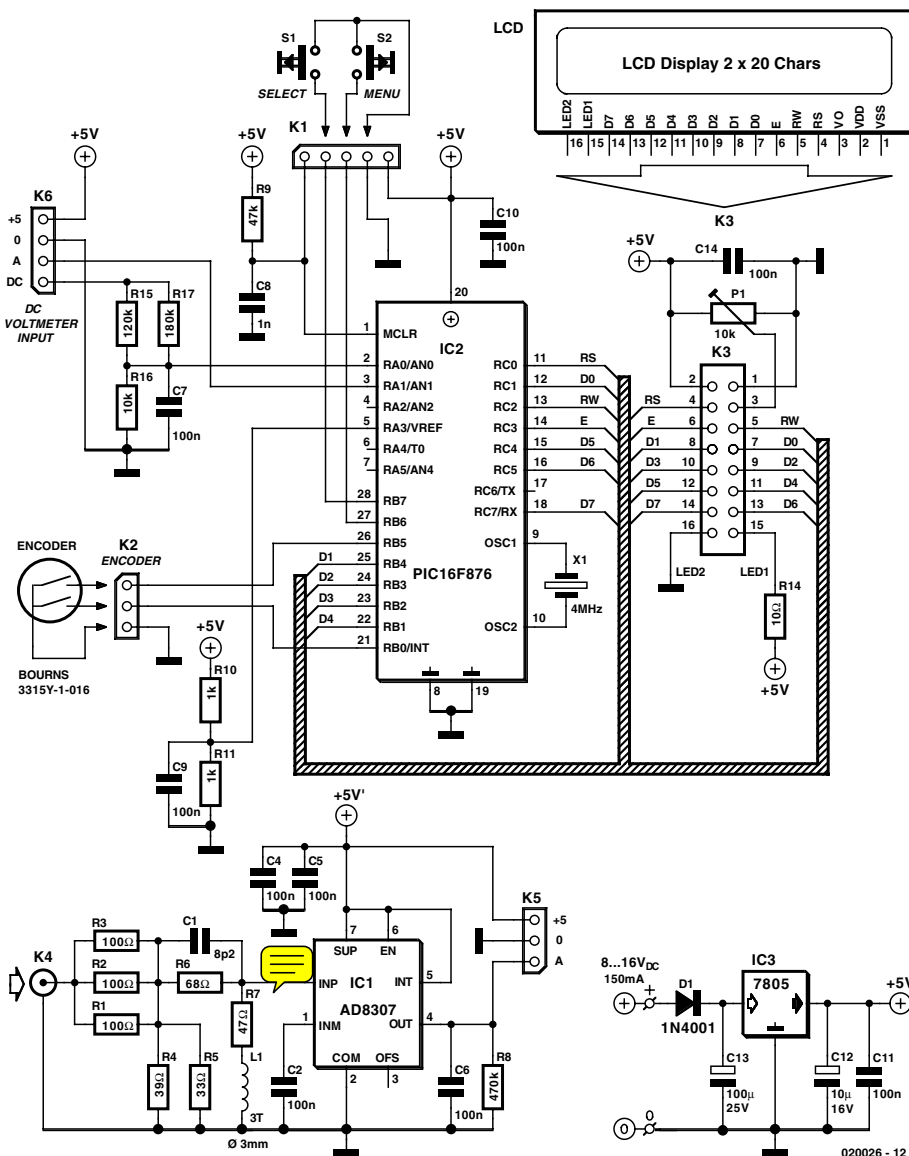


Figure 1. Block diagram of the AD8307 (courtesy Analog Devices).



type for ease of software development and debugging. Furthermore, 4 digital inputs, 2 for the pushbuttons and 2 for the encoder, 7 outputs to the LC display in 4-bit mode or 11 outputs in 8-bit mode. The Microchip 16F873 and 16F876 PIC microcontrollers with 4 and 8 kwords of Flash program memory proved an excellent choice. Their price being almost the same, the author went for the larger 8 k type.

The 16F876 has 5 analogue inputs with 10-bit resolution, representing a range of 0-1023 in discrete values when the input voltage goes from 0 to 5 volts. The DC signal from the AD8307 covers 0 to 2.5 volts for the entire operation range. To get full digital resolution the ADC inside the PIC could use an external positive reference for the full-scale voltage. This function is implemented by R10 and R11 which create a 2.5-volt reference from the 5-volt power supply rail. This voltage is not super critical, if there is a small error, it will be calibrated in software with a zero dBm offset point.

A good and simple programmer for this PIC was designed by Johann Aichinger and is called PROPIC, schematics and software may be downloaded at <http://jaichi.virtualave.net/>. Many other PIC programmers support the 16F876 type, including 'IC-PROG' by Bonny Gijzen. This one also works fine and supports almost any IC that can be programmed. You'll find it at www.ic-prog.com

The wattmeter software was developed using the Microchip 'MPLAB' PIC programming suite in combination with an external C compiler called PICC from HI-Tech, their web site is at www.htsoft.com

where you can download a free trial demo version. If you need to re-compile the software for this wattmeter, you can change the start up screen to display your name or callsign if you like. The wattmeter software source code files can be downloaded from the Free Downloads section of the *Elektor Electronics* website. The relevant file number is **020026-11** (October 2002). For those without access to the Internet (raise your hand please), the files are also sup-

Figure 2. Circuit diagram of the RF Wattmeter. The two main components are the AD8307 in the input converter and the PIC16F876 in the controller section.

L1 serve to cancel stray capacitance and inductance and so optimise the input SWR for higher frequencies.

The second unit is the digital controller around IC2. This 'black box' runs software written by the author to handle the following functions:

process the output from the AD8307 into a format we earthlings can read and understand;

read the user controls (pushbuttons S1, S2 and the rotary encoder on K2);

drive an LC display, enabling it to present menus, values, etc.

The PIC is reset at power on by R9-C8. It is clocked by a 4-MHz ceramic resonator.

The third unit is the LCD. Here, a 2-line by 20 character type is used. Preset P1 is used

to adjust the contrast.

The fourth unit is the power supply around IC3. Totally conventional in design, the supply should not require further discussing. Input power may be obtained from any old mains adaptor capable of sustaining a current demand of 150 mA or so at 8 to 16 VDC.

About the PIC16F876

The requirements for the digital section of this projects included a cheap micro controller with 10-bit analogue to digital converter (ADC), a cheap and simple programming interface and program memory of the Flash

plied on floppy disk through our Readers Services.

Construction

An instrument like the present RF Wattmeter should be built with due consideration given to mechanical aspects as it will never function properly when screening is neglected.

To begin with, the double-sided and through plated circuit board shown in **Figure 3** should be cut in two to separate the controller section from the input board.

Input Board

This board (**Figure 4**) employs SMDs (surface mount devices) because small components better handle high frequencies. Read the following paragraphs if it is the first time you build up a board using SMDs.

If you are soldering with your right hand, first add a small amount

of tin on the right-hand solder pad.

Place the component carefully with your left hand using tweezers, solder the right-hand side while holding the component perfectly straight. Now simply solder the left-hand pad to the left-hand side of the component.

To solder the AD8307, carefully and quickly pre-tin pad number 3 on the board. Then keep the IC pressed in place when applying heat to pin 3, joining it to the solder pad by pushing gently with the solder tip. If necessary re-align the IC and then solder the other pins.

The input board has specially designed shapes with generous pads that allows both 1206 and 0805 style SMD components to be fitted.

Inductor L1 consists of 3 turns of 0.5-mm enamelled copper wire (ECW). The internal diameter of this inductor is 3 mm and the turns are spaced about 0.5 mm apart.

The input board needs to be mounted directly onto the flange of a

BNC socket with four M2.5 threaded mounting holes. Some BNC sockets have a 3-4 mm long Teflon® isolation piece around the centre pin. Cut this isolation away, and cut the

COMPONENTS LIST

Resistors

- SMD case 1206 or 0805:
- R1,R2,R3 = 100Ω (R3 on top of R1/R2)
- R4 = 39Ω
- R5 = 33Ω
- R6 = 68Ω
- R7 = 47Ω
- R8 = 470kΩ
- R9 = 47kΩ
- R10,R11 = 1kΩ
- R15 = 120kΩ
- R16 = 10kΩ
- R17 = 180kΩ
- R14 = 10Ω 1W
- P1 = 10kΩ preset

Capacitors

- SMD case 1206 or 0805:
- C1 = 8pF2
- C2-C7,C9,C10,C11,C14 = 100nF
- C8 = 1nF
- C12 = 10μF 16V radial
- C13 = 100μF 25V radial

Inductor

- L1 = 3 turns, 0.5mm dia. ECW (SWG #30), turns spaced at 0.5mm, internal dia. 3mm.

Semiconductors:

- D1 = 1N4001
- IC1 = AD8307AR (SMD)
- IC2 = PIC16F876-04/SP, programmed, order code 020026-41, see Readers Services page
- IC3 = 7805

Miscellaneous:

- K1 = 5-way SIL pinheader
- K2,K5 = 3-way SIL pinheader
- K3 = 16-way SIL pinheader
- K4 = BNC socket with flange
- K6 = 4-way SIL pinheader
- S1,S2 = pushbutton, 1 make contact, chassis mount
- PC1,PC3,PC8,PC10,PC12 = solder pin
- X1 = 4MHz ceramic resonator (3 pins)
- LCD module with 2 lines of 20 characters, e.g., LM032L (PC2002LRS-BEA-C)
- Rotary encoder type 3315Y-1-016 (Bourns)
- Mains adapter socket, chassis mount
- IC socket, 28 pins, narrow
- PCB, order code 020026-1 (see Readers Services page).
- Disk, source code files, order code 020026-11 (files also available from Free Downloads)

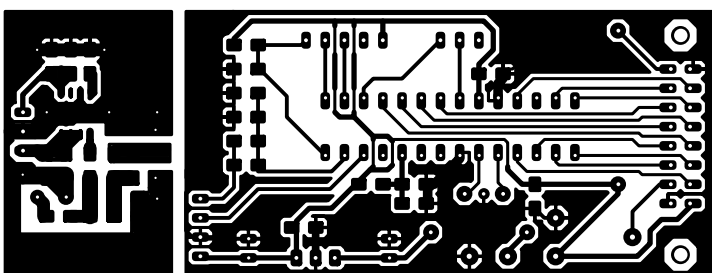
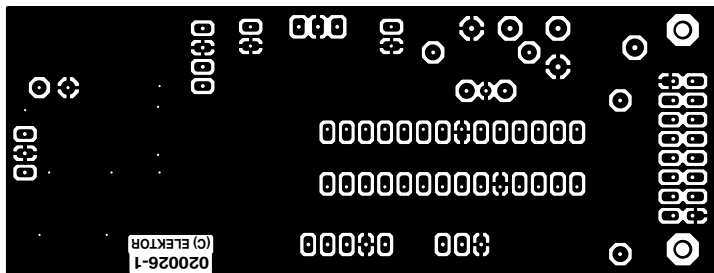
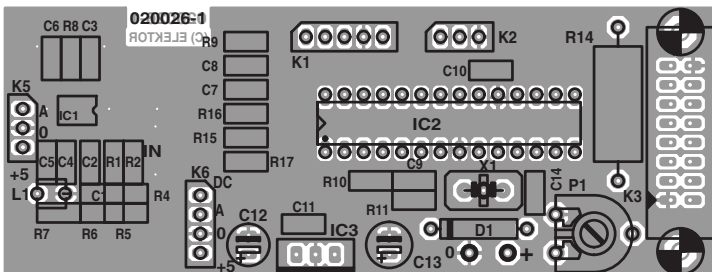


Figure 3. PCB design for the instrument. The board is double-sided, through plated and available ready-made through the Publishers' Readers Services.

centre pin so that it is about 2 mm long.

Check that it is possible to solder the rear side of the flange. If not, remove any protective layer by scratching it with a tool so that soldering is possible. Now mount the input board, don't be economical on the solder tin, solder it all the way, including at the bottom side of the board.

Controller Board

An early prototype of this board is shown in **Figure 5**. If the PIC16F876 is mounted in an IC socket, you should use one of undisputed quality, say, one with turned pins. However, those of you with access to suitable PIC programming tools may also solder the PIC directly on to the controller board as the chip can be updated in-circuit with new software when available.

The ceramic resonator frequency is 4 MHz, this is not critical. If you don't want to use the optional serial output discussed in the 'menus' inset, use a 3-pin type with built in capacitors. A normal 2-pin version will also work fine.

The controller board is mounted on the rear side of the LCD module, using two stand-offs with a length of about 10 mm or whatever you have available.

Four stand-offs are needed to mount the LC display to the case front panel.

Resistor R14 is a 1-watt type, which controls the LCD backlight level. A value of 10 Ohms will give normal light but if you want to use batteries to power this instrument it will be a good idea to increase the value of R14 to 20 Ohms or so, or maybe mount an switch so you can disable the light when the meter runs battery powered.

The 7805 voltage regulator will run a bit hot if the input voltage exceeds about 10 V. Either bend the regulator down to the case and secure it using an M3 screw, or mount a heatsink to its metal tab. A small click-on type will be enough.

Rotary encoder and switches

The rotary encoder is a cheap double contact type supplying Gray code. This encoder is used as a dial to select options from the menu and to change different settings, see the software description further on. If the encoder appears to turn the wrong way, simply reverse the wires at the two data output connections.

The two switches S1 and S2 must be push button types. S1 is used to pick options from the menus and S2 is the menu access button.

Initial testing (hardware)

At this point it is assumed that both boards are ready assembled. If the PIC is in a socket:

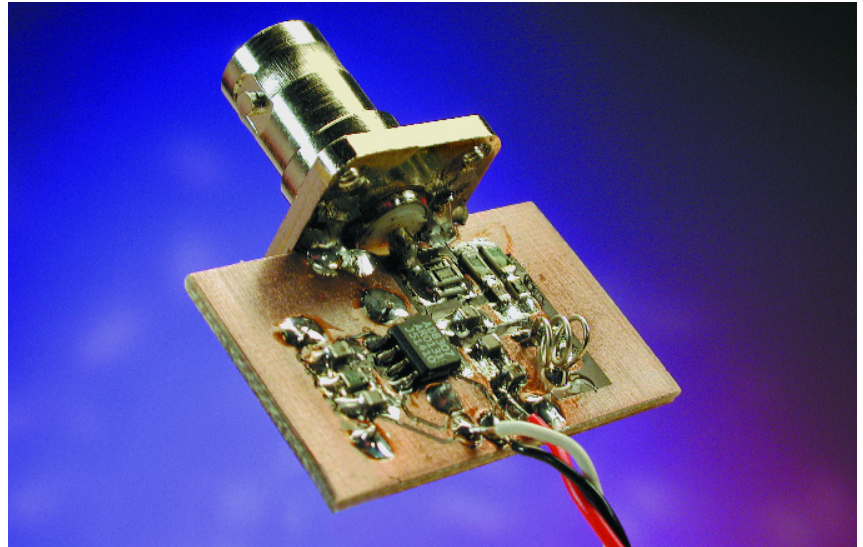


Figure 4. Input board with BNC flange socket attached by soldering along the edge.

remove it, if the PIC is soldered in the main board, a variable DC power supply should be used for the testing described below.

Start with just the controller board, with the 7805 fitted and maybe also the PIC. The display and the input board are not yet connected.

Before proceeding you need to verify that the 7805 regulator is working okay. Supply the board with 9 volts, check for +5 V at the pad for the input board near C12. Check for +2.50 volts at IC1, pin 5.

Check for +5 V at IC1 pin 1. Switch off, connect the display, insert the PIC, and switch on again.

Turn P1 counter clockwise so that the display get zero volts on the

adjust pin 3. This will yield maximum contrast so that you can see the LCD is alive. Adjust P1 for best contrast at your viewing angle. Check for green backlight in the display and you will see the display writing the RF Power Meter's welcome message (see inset). Touch the input A terminal with a finger, this will give a response on the display. Switch off.

Double check all the soldering on the AD8307 and the input board, then connect it to the main board using shielded audio-style cable or whatever you have to connect the signal from the input board to the controller board. Apply power again and check that current consumption is under 150mA.

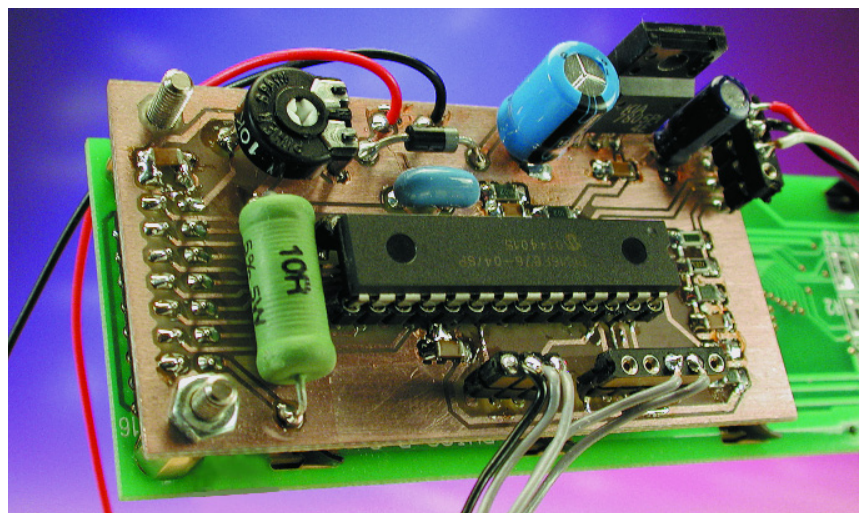
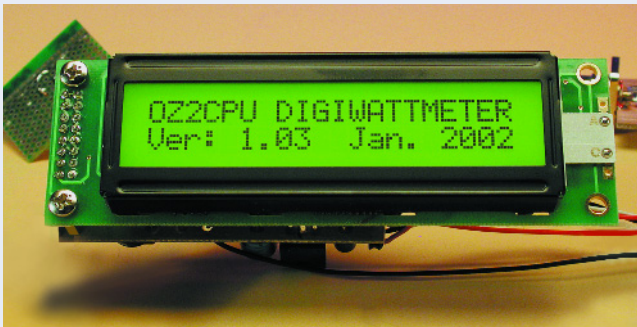


Figure 5. Controller board attached to back side of LCD module.

Using the menus (software v. 1.03)

All intelligence vested in the instrument resides in the software developed by the author and Flashed into the PIC microcontroller. Those of you with access to suitable PIC programming software and equipment will care to know that the source code files for this project are available free of charge from the Publisher's website (Free Downloads, item 020026-11, October 2002). Ready-programmed PICs are also available under order code 020026-41.

The instrument's welcome screen should look like this:



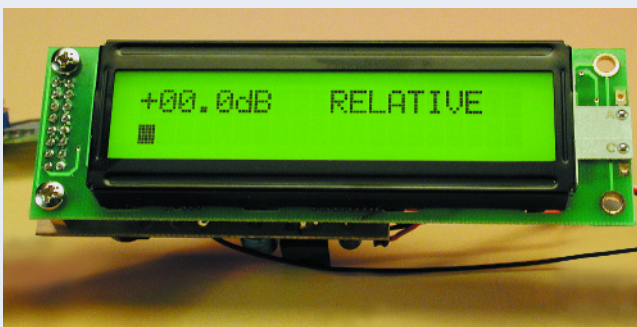
The main start up screen shows: dBm, status, RF-voltage Bar-graph, RF-power watts



If no attenuation is used, the dBm readout goes from -63 dBm (noise floor) to +30 dBm (1 W).

The status readout shows the selected frequency band, and attenuation mode. Use the band dial to change between LF, HF, VHF, UHF and SHF calibration memories. It is suggested to calibrate the wattmeter's 0 dBm reference at: LF = 3.5MHz, HF = 14 MHz, VHF = 145 MHz, UHF = 430 MHz, SHF = 440 MHz. Of course, you can calibrate at your own favourite frequencies for best performance.

In the RF power meter menu, use the SELECT button to enter



RELATIVE mode. In this mode dBm and bar-graph is shown, when entering this mode the dB read out is zeroed.

The menu

To enter the menu / settings use the MENU button. When in a menu, use the rotary encoder to get the desired setting. At the right setting, use SELECT to activate, this is also shown on the display.



Available menu entries:

- 0: 0 dB, no attenuator mounted, 1 W max.
- 1: -10 dB attenuator mounted, 10 W max.
- 2: -20 dB attenuator mounted, 100 W max.
- 3: -30 dB attenuator mounted, 1 kW max.
- 4: -40 dB attenuator mounted, 10 kW max.
- 5: -50 dB attenuator mounted, 100 kW max.
- 6: DC Voltmeter, actual and min. and max.
- 7: RF Power Meter, the default start up screen.
- 8: SSB PEP (peak envelope power) Wattmeter, with peak hold and variable decay.
- 9: Return loss with SWR readout, usable with a SWR bridge.
- 10: Calibrate 0 dBm in the selected band.
- 11: Read all calibration values.
- 12: Zero all calibration memories.
- 13: Display update delay 2-80 ms, peak hold and decay speed.
- 14: About Info, shows software version and so on.

DC voltmeter

Nothing gets burned if the input polarity is reversed. In the DC voltmeter screen, actual voltage, minimum and maximum are displayed. To reset min. and max. readings, press the Select button. The voltmeter can be used to monitor the battery voltage if a battery supply is used, or whatever you want to measure, but remember the input impedance is about 80 kΩ.

Extra features

Some enthusiasts requiring additional features may find a serial output a useful extra. On pin 17 the PIC outputs a serial datastream which may be converted to RS232 levels using a MAX232 IC in its usual configuration. The datastream produced by the PIC may be connected to a free RS232 port on your PC. Any communications or terminal emulation program like HyperTerminal should be able to read the datastream. The comms settings are: 38400 Baud, 8 bit ASCII, no parity, 1 stop bit. In short: 38K4 8 N 1.

If you do not have an RF test generator to calibrate and test with, put a normal resistor pin in the BNC input plug, and transmit with your VHF, UHF rig or whatever (PMR) radio you have available, the closer you take the radio to the wattmeter, while transmitting of course, the higher the readings on the instrument will become.

With this initial test completed okay, use, lend, or get access to a good RF signal generator. This will enable you to calibrate your new digital wattmeter and use it to for accurate measurements in your own shack. But first you need to build the electronics into a properly shielded cabinet. The calibration will be done later.

Cabinet? Home made or..

Sure, you want the cabinet to fit exactly to the LCD display, BNC, switches, DC connector and so on. So why not try to make a cabinet of unetched single-sided copper clad board? This material is cheap, easy to cut and drill.

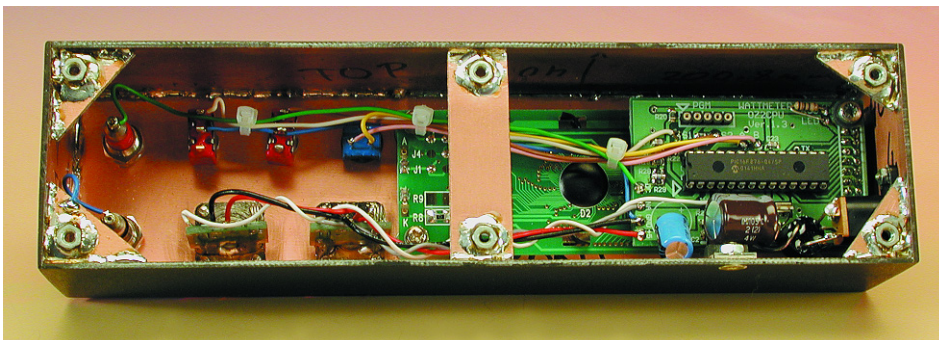


Figure 6. As a suggestion, a screened housing for the instrument may be made from pieces of one-sided copper clad board soldered together along the edges. This method of construction, popular among radio amateurs, even allows securing nuts to be provided for mounting the assembly onto a larger case.

Some extra care and time was spent on the rectangular clearance for the display. The sides of the case can easily be attached using soldering. The completed case may be painted black with spray paint, with white lettering added later using 'Seno' transfer symbols. A coat of clear lacquer spray was used to secure the fragile lettering. Such a cabinet costs nothing except time and paint. The author's version is shown in **Figure 6**.

Calibration of RF input and DC input

The RF meter is calibrated in software, by applying 0 dBm to the input terminal. First select the corresponding band memory using the dial encoder, then press Menu, choose

Calibrate 0 dBm and press the select button.

The 0 dBm signal strength is saved in the meter's internal memory. From now on, it will measure within ± 0.2 dB in that frequency band. This is repeated for all the other bands you need. There are five band memories called LF, HF, VHF, UHF and SHF. Remember, you can calibrate at any frequency you need, at any time, over and over again.

The DC voltmeter is calibrated in hardware. You need to fine tune the voltage divider top resistor R15 in parallel with R17 and the bottom resistor R16. You'll find that an accurate DC digital voltmeter is needed besides a variable DC power supply.

Change the wattmeter display screen to DC Voltmeter mode using Menu -> Dial -> Select.

Apply 20.00 volts to the DC input and look at the LCD reading. If it dis-

plays a value smaller than 20.00, mount a 10 megohm resistor in parallel with the top resistor R17; if it reads more than 20.00, just mount it to the bottom resistor R16. Remember to disconnect the 20 volts source and the wattmeter power supply while soldering inside the instrument. If you short out R15 or R17 while 20 V is applied to the input DC terminal, you will need a new micro controller!

Caveats

RF voltages of a couple of volts, especially from UHF transmitters, can cause burns and other skin dam-

age. **Never touch any terminal carrying transmitter output power.**

The AD8307 can not survive +5 V erroneously applied to its output pin, so be extra careful to double check your wires from the main board.

Be aware of the fact that **the input board is designed for input power levels not exceeding 1 watt.** If you apply more power, the reading on the display actually goes down! If you are careless and apply more than 1 watt to the instrument, then you might blow up your AD8307. Never rely on the input resistors to burn out first, because they can handle much more than specified (even for several minutes, and by that time your AD8307 will have given up the ghost). **So there is no input overload protection!**

If you want to test a transmitter, use an attenuator pad, directional coupler or a power tap. The author has a homemade 30 dB attenuator capable of handling 50 watts continuous RF power. Its frequency response is flat from DC to 700 MHz. None of his VHF or UHF transmitters can output more than 50 watts so no problem. However, an HF rig will require the use of a 50 dB 'tap' type attenuator which is also home made. This one allows measurements up to one kilowatt with no problems. More details may be gleaned from author's website.

Conclusion

The author has been using this wattmeter for over a year and found it usable for many purposes involving radio signals.

The marginally higher accuracy, larger frequency range and dynamic range of professional RF wattmeters comes at a cost of 20-40 times that of the instrument described here.

As a future extension, two input boards could be mounted with a software routine subtracting input B from input A, to display the forward and reflected power along with the calculated SWR value. This is just an idea, however, and actually the reason for the presence of two input BNC plugs called input A and B on the cabinet of the author's RF wattmeter.

(020026-1)