Digital QRP SWR/ Power Meter

A KD1JV "Melt Solder" kit

Index:

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Features

- 160 to 6 meter operating range
- 9.9 watt and 990 mw power scales
- Peak Hold mode (9.9 watt scale only)
- 1:1 to 9.9 : 1 VSWR scale
- Accuracy 5 % of reading
- Sensitivity, 20 mW min
- Manual and auto shut off
- Self contained, fits in Altoids tin
- Two digit, BCD encoded display
- Single push button operation
- Powered by two "AAA" batteries
- Ideal for portable and field use
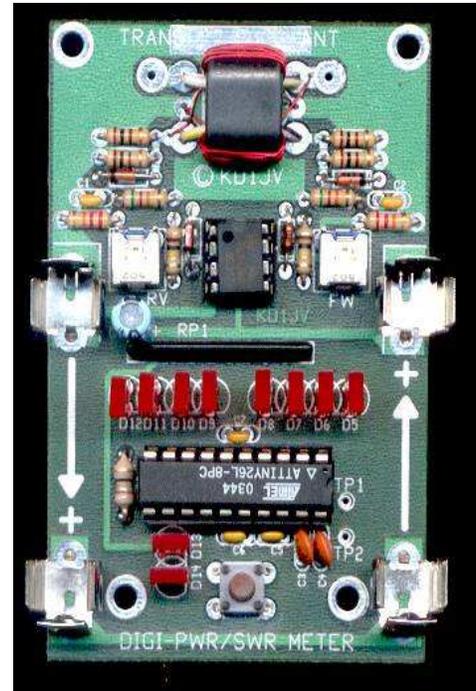
Operation:

Power on and off:
Click the "Mode" push button to turn the meter on. The meter will power up in the same operating mode as it was when turned off.

Manual turn off:
Click and hold the "Mode" push button closed for 2 seconds. The eight display LED's will flash for a moment to indicate it is turning off.

Automatic turn off:
If no forward power is detected for 4 minutes, the meter will automatically turn off. Each time forward power is detected, the auto-turn off timer is reset.

Operating mode indicators
Operating mode is indicated by the two LED's located next to the switch. Click the push button to step through to the desired operating mode.

10 watt (9.9) power scale L1 on, L2 off
Forward power is displayed on the two digit binary encoded LED display, with 100 mw resolution. Reading are taken about twice a second.

Overflow indication Depending on battery voltage, the 9.9 watt scale can potentially measure up to 13 watts. The # 8 LED of the 10's digits will start to blink if the forward power is equal to or greater than 10 watts. Therefore, add 10 to the number displayed when the # 8 LED is blinking.

990 mw power scale L1 off, L2 <mark>on</mark>

This scale reads in 10 mw increments. This mode is effectively a "display shift," displaying the 100 and 10 mw digits. Therefore, you can switch between the 9.9 watt and 990 mw scales to see the extra digit of resolution.

Due to op amp input offset voltage and a software correction which is made to the lower power readings, it is likely the 10 mW or possibly the 20 mW digit will be lit when there is no forward power input.

Peak Hold L1 <mark>on</mark>, L2 <mark>on</mark>

This mode can be use with SSB transmitters to see your PEP output. In peak hold mode, the readings are taken as quickly as possible and the highest power measured is displayed. Peak readings are reset about two seconds after a peak has been detected.

VSWR   L1 off, L2 off.

VSWR is calculated using the formula $(V_{forward} + V_{reverse}) / (V_{forward} - V_{reverse}.)$

Due to op amp offset, stray coupling and minor bridge imbalances, some reflected voltage will be detected, even when there is a perfect match. Therefore, the smallest VSWR indicated maybe 1.1 or 1.2, depending on the amount of forward power. VSWR reading with zero power input will also depend on op-amp offsets. If reverse voltage is equal to or greater than forward voltage, the display will blank. If the forward voltage is greater than the reverse, the display will generally indicate a 1.0 VSWR, but it has been seen as high as 2.1. As soon as actual transmitter power is applied through the meter, the proper VSWR will be displayed. About 500 mW of forward power is required to get accurate VSWR readings.

Reading the display:

The display consist of two groups of four LED's, displaying two digits. Decimal digits are displayed in a BCD format.
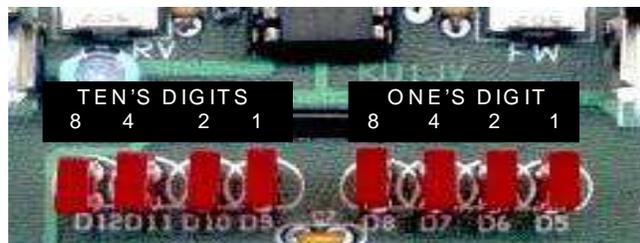
This diagram shows how the LED's light to display digits 1 to 9. Zero, (0), is all LED's off. With just a little practice, you will be able to instantly read the digits they represent.
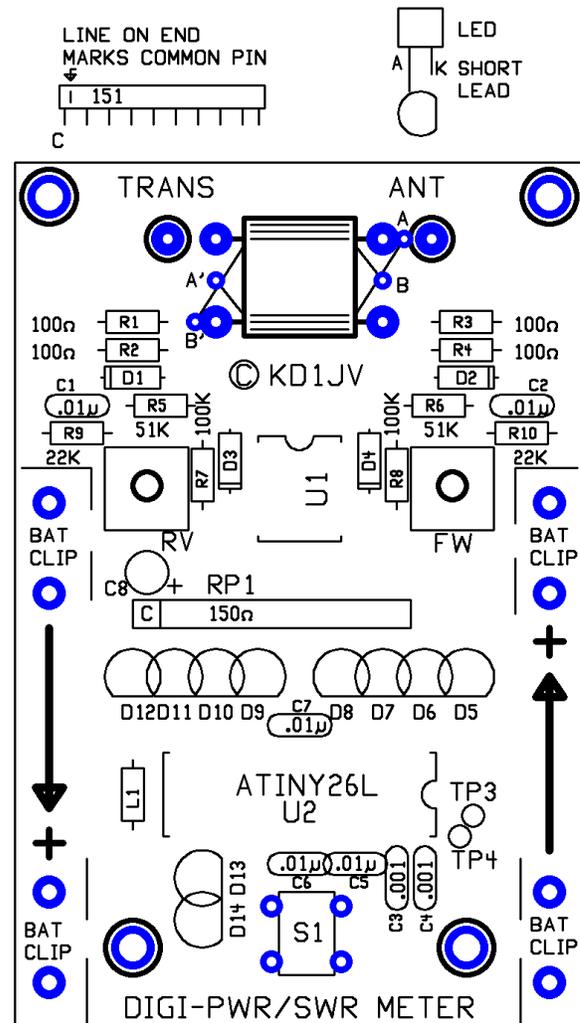
Construction:

The parts are listed on the parts list in the recommended order of insertion. But before you start building, take a look at the packaging section, as this might affect how you decide to install the battery clips and LED's.

To install the battery clips, insert one mounting tab into hole, then press the other mounting tab into the other hole, by rocking the clip. The clip should then snap into place. DO NOT bend the mounting tabs, as they will break off.

The display LED's are spaced off the board by the height of the battery clips. Insert the LED's, flip the board over and place on the work bench top. The top of the LED's will now fall to the height of the clips. However, you will want to set the D13 and D14 LED's closer to the board, as this will give easier access to the mode switch.

The meter is calibrated before the last few parts are populated. See calibration instructions on following page. It would be a good idea to clean the solder flux off the bottom of the board. This can be done with 95% Isopropyl alcohol, if you have no industrial strength flux remover handy. The op amp has a very high input impedance and very low input currents. Flux in the area of the op amp may cause leakage paths and upset the balance of the inputs.

D1-4	SD103	SHOTTKY
R5	51 K	GRN-BRN-ORG
R6	51 K	GRN-BRN-ORG
R7	100 K	BRN-BLK-YEL
R8	100 K	BRN-BLK-YEL
R9	22 K	RED-RED-ORG
R10	22 K	RED-RED-ORG
C1	.01 μF	MONO 103
C2	.01 μF	MONO 103
C3	.001 μF	DISK 102
C4	.001 μF	DISK 102
C5	.01 μF	MONO 103
C6	.01 μF	MONO 103
C7	.01 μF	MONO 103
L1	12μH	BRN-RED-BLK-GOLD
RP1	150 Ω	10 SIP PACK
RV , FW	5 K Ω	TRIMMER
20 PIN	SOCKET	
8 PIN	SOCKET	
(4)	BATTERY	CLIPS
C8	47 μF	electrolytic
D5-14	RED LEDS	RECTANGLER
S1	PB SWCH	6mm TACT
U1	TS942	op-amp
U2	ATTINY26L	processor
* DO	METER	CAL *
R1-4	100 Ω	BRN-BLK-BRN
WIND	XFORMER	
MOUNT	XFORMER	

LINE ON END
MARKS COMMON PIN

| 151

C

LED

A |k SHORT
     LEAD

TRANS   ANT

A

A'

B'   B

100Ω R1   R3 100Ω
100Ω R2   R4 100Ω

C1   C2
.01μ R5 51K   100K   100K   R6 51K .01μ

R9   R10
22K   R7 D3   © KD1JV   D4 R8   22K

BAT   RV   FW   BAT
CLIP   CLIP

C8 + RP1
C   150Ω

D12 D11 D10 D9 C7 D8 D7 D6 D5
                .01μ

+   +

BAT   L1   ATINY26L   TP3   BAT
CLIP   U2   CLIP

                 .01μ .01μ   TP4
            D14 D13 C6   C5

            S1   C3 C4 .001 .001
BAT   BAT
CLIP   CLIP

DIGI-PWR/SWR METER

Calibration:

- Before inserting the batteries to power up the board, take a few minutes to double check your workmanship. Verify correct parts placement and look for missing solder connections or shorts. Also check the + battery terminals for shorts to ground. Shorted batteries get very hot!

- To do the calibration, you will need to add a temporary jumper to connect together the two large pads in line between R2 and R4. This will connect the anodes of D1 and D2 together.
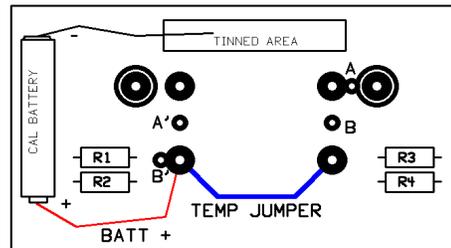

- Calibration is done using a fresh 1.5 V alkaline battery. The battery should measure close to 1.600 volts. The battery could be a "AAA" or "AA". In either case, it's a good idea to hold the battery in a single cell battery holder. This will make it easier to connect to the meter board. Of course, you could also just solder tack some wire to the battery, if this saves you a trip to Radio Shack. If you have an adjustable power supply, this could be used instead of the battery.
    - Install two fresh "AAA" batteries into the battery clips on the board. Be sure to observe correct battery polarity, as the meter is not reverse voltage protected. The "L1" LED should come on.
- Connect the "calibration" battery to the board, (-) to ground and (+) to one of the pads with the temporary jumper soldered to it.
    - Adjust the FW trimmer to make the display read 4 8 (#4 LED of ten's digit on, #8 LED of one's digit on)
- Now connect a DVM between TP1 and TP2. Adjust the RV trimmer to obtain a 0.00 volt reading on the DVM. This sets the reverse detector voltage to exactly the same value as the forward detector voltage.
- The meter is now calibrated. Remove the batteries and temporary jumper.
- Install R1-4.
- Proceed to winding and installing the transformer.

Calibration can be repeated after R1-4 and the transformer have been installed, but you must disconnect the secondary winding connected to R1/2 first, or it will short out the calibration battery. Also, since there will now be a 25Ω load across the battery, using a fresh C or D cell would be recommended.

Calibration could also be done or verified using an Oscilloscope, 50 Ω dummy load and transmitter. Calibration at 8 watts is ideal (56.46 V p-p). Using a "Big Rig" with it's linear amplifier would be preferred over a typical QRP rig, as the big rig is more likely to hold it's output level without significant "creep" and have a true sine wave output.

Transformer winding.
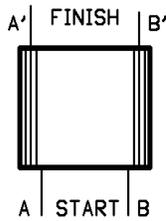
As shown in the diagram to the left, wind 13 turns of #26 magnet wire (15") around the outside edge of each side of the core. The wire should pass through the core's hole 13 times. Start each winding on the same end of the core, as shown. Try to keep the wire reasonably flush to the inside and outside of the core and try not to overlap turns.

Mounting the Transformer.

A short piece of #22 Teflon insulated stranded wire is passed through the hole of the core, then soldered to the adjacent pads. This secures the core to the board and forms the primary winding.

     The easiest way to strip the insulation from the short piece of wire is to slice through it with a sharp hobby knife blade, while gently rolling the wire on the bench top. Try not to nick the wire with the blade.
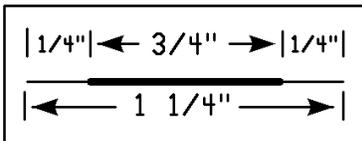
     Once the core is mounted to the board using the primary windings, solder the secondary windings to the appropriate pads, as shown below. For clarity, one winding is shown in red, while the other is in blue. The
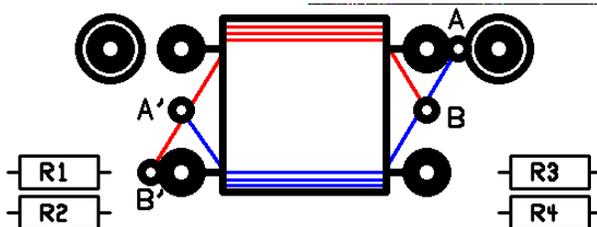
magnet wire is heat strip-able, but must be tinned before inserting into the pad.

Packaging the meter:

     The board is sized to fit into a standard Altoids tin. There is very little clearance between the battery clips and the side of the tin. Put some plastic electrical tape along the sides of the tin to ensure the battery clips don't short to the tin. The board can be fastened to the tin using #4-40 hardware, but be careful around the battery clips at the bottom of the board. A 4-40 nut can short to the clips when a battery is installed. Using 2-56 hardware will reduce this problem, or use nylon nuts and/or screws for the battery end board mounting.
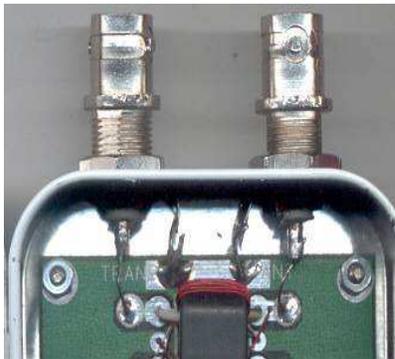
There is just enough room for the end of a BNC jack between the top of the board and the side of the tin. You may have to use two nuts, one on either side of the tin wall, to mount the jack.

The ends of the BNC ground lugs need to be soldered to the board's ground. A tined area just above the transformer provides a place to solder the lugs to. Resistor lead clippings can be used to jumper from the board to the center pin of the jack.

Alternative Packaging:

The board will also fit into a "Whitman's Sampler" tin, available at Wal-Mart in many areas This tin is deeper than the Altoids. This makes it possible to mount the batteries on the bottom of the board instead of the top. It also makes it possible to add a third battery, using a single cell battery holder, to extend operating life. (see next section) The only problem is changing batteries will be a little harder to do.

If packaging in a Whitman's tin, you will want to mount the LED's flush to the board. Also, the electrolytic, C8, will need to be mounted lying on it's side. Mount the board with threaded spacers, so that you may more easily gain access to the batteries under the board. ½" spacers are a tad (1/16") too short, so use a lock washer or nut for additional spacing. 4/40 spacers will short circuit to the battery clips on the bottom of the board, so you will need to drag the mounting holes towards the center of the board a little with a rat tail file. The coax connectors will end up under the board, so use flexible wire to jumper from the connector to the board. Make the wires as short as possible, but long enough you can tilt the board out to of the tin.

Of course, other types of tins or enclosures could also be used to package the meter. The amQRP BLT tuner cabinet would work, your own custom box made from aluminum or copper clad circuit board material.

Battery Life:

The processor will work reliably down to 2.6 volts. However, it is likely the internal reference voltage for the A/D will drop out of regulation well before this. The nominal reference voltage is 2.52 volts and the data sheet specifies a typical range of 2.3 to 2.7 volts. However, the reference voltage has been seen to be as high as 2.85 volts in some units, with about 2.7 volts being typical for a sample of 25 tested. The supply voltage needs to be about 50 mV's higher than the reference to keep it in regulation. Therefore, if the reference voltage is running

on the high side, regulation will be marginal when the battery drops to 1.4 volts. As the battery voltage drops farther, the voltage reference will drop out of regulation and the power calibration will change. This will be most pronounced at higher power readings, but readings will stay reasonably accurate at typical QRP power levels up to 5 watts. VSWR is not affected, as this is calculated based on the ratio of forward and reverse voltages.

Provided your packaging makes it possible, adding a third battery to power the meter will give longer operating life, brighter LED's and ensure power measurement accuracy. It will also enable the meter to measure up to 16 watts. To add a third battery, cut the track connecting the two board mounted batteries at the bottom of the board and insert the third battery there, using a single cell battery holder to hold the new cell.

Yet another option is to use four batteries,. In this case, eliminate the board mounted battery clips entirely and use a common four cell battery holder. A diode in series with the batteries will be required to drop the voltage slightly, as four fresh batteries will slightly exceed the voltage rating for the processor. The diode also has the benefit of adding reverse voltage protection.

When off, only a few micro amps of current is drawn by the processor and op-amp. Current will go up slightly when forward transmitter power is present, as the op amp will be active and driving the diode compensation load resistor. If the meter is not to be used for extend periods of time, it is recommended to remove the batteries. Alternatively, you could slide a piece of paper card stock between one end of a battery and the battery clip to act as an on/off switch.

Accuracy:

A meter of this type is only accurate when a true sine wave is being detected. While this can generally be assumed, it is not always the case. An over driven Class C amplifier can produce a distorted sine wave and possibly non-symmetrical output signal, even after it has gone through the low pass filter. In this case, the meter will indicate a power level somewhat higher than the true rms power. You must also be using a 50 Ω dummy load or have a 1:1 SWR.

| RMS	DQSP	%	RMS	DQSP	%	RMS	DQSP
watts			mW			mW	
9.900	9.8	1					
9.000	9.0	0	900	890	1	90	90
8.000	8.0	0	800	780	2	80	80
7.000	7.0	0	700	690	1	70	70
6.000	6.1	2	600	590	2	60	60
5.000	5.1	2	500	500	0	50	50
4.000	4.1	2	400	400	0	40	40
3.000	2.9	3	300	300	0	30	30
2.000	1.9	5	200	200	0	20	20
1.000	1.0	0	100	100	0		

This table shows a comparison of the power readings obtained by the Digital QRP SWR / Power meter (DQSP) and a True RMS power meter, which is based on an Analog Devices AD8361 RMS detector chip. Tests were performed at 7 MHz. A DDS signal generator was used to drive a linear amplifier, with an adjustable and AGC stabilized output.

Converting to 7 segment LED display:

Since the outputs of the µP are in BCD format, it is possible to add a BCD to 7 segment LED display decoder for a true digital display. A CMOS 4511 decoder would be a suitable choice. The BCD data at the processor pins is inverted, active low, which is needed to light the LED's. The signals need to be inverted to active high to drive the 7 segment decoder . A 4011 NAND gate in the schematic below provides this inversion.

Of course, this new display would need to built on a separate board, and a larger enclosure than an Altoids tin used. You'd probably also want to move the mode switch and mode indicating LED's onto this new display board. Since the 7 segment displays will consume more current, using three "AA" batteries to power the meter or adding a 5 volt regulator and using a 12 volt supply is recommended.

The schematic below shows one of the two digits required. Pin out for the display isn't shown, as it will depend on the type of display chosen, and if you use two single digit displays or one dual digit display. Inputs to the NAND gate inverters come from the processor's pins 1,2,3 and 4 for the one's digit and 7,8,9 and 10 for the ten's digit.
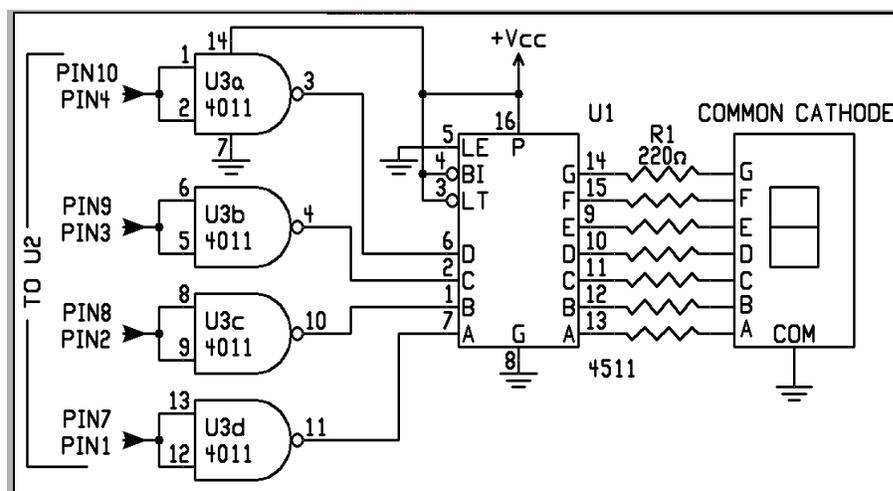
Circuit Description:

A classic "Stockton" directional coupler is used as a sensing element. What is somewhat unusual is the coupler is wound on a single binocular core, rather than two separate cores, which is most commonly done. What makes it possible to use the binocular core is the fact there is very little coupling through the core between the two holes. There is some coupling between the secondary windings, due to their close proximity to each other, but not enough to be a serious problem at the power levels this meter is meant to be used with.

Diode compensation:

Diode detectors have some problems which must be overcome in order to make accurate voltage measurements. First, there is the inherent voltage drop across them and the non-linear behavior of the diode at low levels. W7EL came up with a clever circuit which does a good job of compensating for these diode deficiencies.

By putting a diode in the feedback loop of a non-inverting amplifier, the output of the amplifier will mirror the actual input voltage of the detector diode. To be perfectly accurate, the current flowing into both the detector diode and the compensation diode needs to be identical. In addition, both diodes should be perfectly matched. In practice, neither of these conditions can be entirely ensured.

The problem is that significant current only flows into the detector diode for a few cycles, as the filter cap is being charged, and for half cycles at that, while current is always flowing into the compensation diode. The W7EL circuit, and that used in the OHR WM-2, uses a compensation diode load abut 10 times smaller in value than the diode detector load. Tests using a WM-2 meter showed this value was good at low power levels, but resulted in errors at higher power levels. It was found that making the compensation diode load twice as large as the detector diode load brought the higher power readings in much closer to what they should have been. However, the low level power readings developed a significant amount of error. This was corrected by using a routine in software which calculates and adds a compensation value to the voltage reading before power is calculated.

There is one other artifact produced by the diode compensation amplifier, which has no real solution. This occurs when there is no voltage input to the amplifier from the detector diode. In this condition, the diode in the feedback loop of the op-amp appears to be a very large value resistor. This then causes the input off set of the op-amp to be amplified, which in turn causes some minimal power to be displayed by the Micro Controller.

Micro Controller:

       An Atmel AVR series AT Tiny26L is used for the "brains" of the meter. This is a powerful micro-controller, which contains a 10 bit, 10 input channel A/D converter, 2 K of FLASH program memory, 128 bytes of EEPROM (which is not used in this application), 128 bytes of static RAM, a built in R/C clock, timers and over 100 instructions, most with true one clock cycle execution.

       Two of the multi-channel 10 bit A/D converter ports are used to input the detector voltages for processing. The forward voltage is multiplied by four for scaling. This sets the full scale equivalent to 4048 counts, or 40.48 volts when scaled to the input voltage seen at the antenna terminal. The maximum power which can then be measured is then 16 watts.

       Power is calculated by squaring the peak forward voltage and then dividing by 100. This formula isn't as precise as rms voltage squared, then divided by 50, but is close enough given the overall accuracy of the meter. The above calculation is done in binary to 32 bit precision. The results are then converted into packed BCD and outputted to the display LED's.

       Supply voltage to the analog circuits inside the micro controller is supplied through a L/C low pass filter to reduce digital noise from getting into the A/D converter. In addition, the core of the processor is put into "Sleep Mode" during a conversion, which also improves the accuracy of the conversion by reducing noise generated internally of the processor.

Schematic, Bride and Diode Compensation amp

Controller and display schematic