VK3AQZKITS

VK3AQZ RF POWER METER CALIBRATOR KIT MODEL CAL1

Introduction and description.

The CAL1 calibrator can be used for the initial calibration of the VK3AQZ RFPM1 RF power meter.

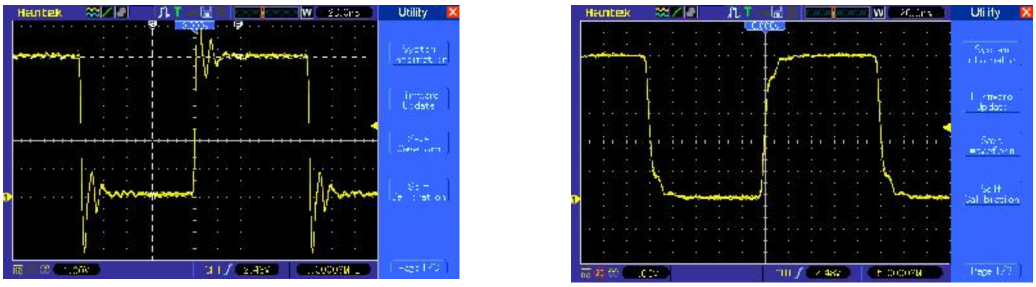
The RFPM1 RF power meter uses the AD8307 RF LOG amplifier IC made by ANALOGUE DEVICES.

The AD8307 converts amplitude variations of an RF input voltage to a DC output voltage which varies as the logarithm of the input voltage changes. It does this from near DC to over 500 MHz, and, over a 92dB input range, with a reasonably high degree of accuracy (+-1dB). A logarithmic relationship between input and output means that a simple linear display device can be used to obtain input signal level changes directly in decibels.

The CAL1 calibrator generates a crystal controlled 5MHz square wave signal with a switchable output level of -20dBm and -30dBm into a 50 ohm load.
The 2 output levels can be adjusted from the front panel and selected with a toggle switch.

The peak to peak amplitude of a square wave with a DC baseline can be measured with a common digital voltmeter by feeding the signal through an RC integrator. The resulting DC represents the average of the square wave.

The CAL1 calibrator uses a common crystal oscillator clock module to produce a 5 volt peak to peak square wave. The 5 volt peak to peak waveform is shown below.



Crystal module 5MHz output on a 200MHz CRO. The ringing on the square wave is around 100MHz and is caused by the 200MHz probe used. The second waveform is with a CRO bandwidth of 20MHz.

The AD8307 has a response which is waveform sensitive. Due to the design of the IC, a square wave RF signal around -20dBm to -30dBm will produce a DC output which is the same as that from a sine wave with a peak to peak amplitude of twice that of the square wave. This relationship is quite accurate (within around 1dB). However, the relationship breaks down at other levels.

This behaviour was documented in an article titled "A Simple RF Power Calibrator" by Bob Kopski in QEX, Jan/Feb 2004 pp 51-54. See Reference 2.

The 5 volts output from the oscillator is too high so a 20dB pad and level adjusting trimpots reduce the square wave down to -20dBm and -30dBm.

It is important that the square wave is as square as possible and swinging from 0V to some positive value. It should be noted that some crystal oscillator modules used as microprocessor clock generators, do not produce a 1:1 square wave and are not suitable for this application.

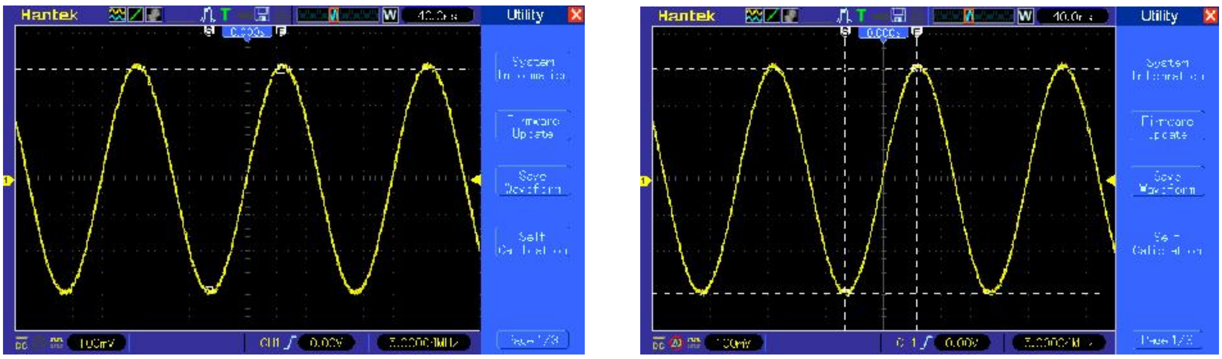
In this application the loading on the module must be light. A low load with reactance will distort the waveform resulting in a different response from the AD8307. The AD8307 data sheets contain a discussion on the sensitivity of the intercept point to waveform shape. See reference 2.

As mentioned, the accurate relationship between a sine wave and a square wave only holds for levels around -20dBm. The AD640, a similar IC, contains graphs in the datasheet which show the variation in the relationship at other levels.

So in order to test the linearity of the power meter, a clean sine wave test signal is recommended.

To help check the linearity of the RF power meter, the CAL1 also puts out a sine wave which is adjustable in level from around +13dBm down to around -40dBm.

This sine wave is derived using a 2 section, 50 ohm, 5MHz low pass filter.



The sine wave output set at 0dBm, 50 ohm load. The 2 voltage cursors are set to 630mV. The left is with a 200MHz bandwidth CRO whilst the right is with the 20MHz bandwidth set.

The sine wave, in conjunction with a good quality stepped attenuator, can be used to check the linearity over the range of the RFPM1.

The AD8307 can work beyond 500MHz so the attenuators need to be accurate to 500MHz. Switchable attenuators using standard components may not be suitable for the linearity test due to inaccuracies at UHF. Leakage and parasitic resonances can cause the AD8307 intercept point to shift resulting in output variations.

You can use high precision individual attenuators but good ones are quite expensive.

The CAL1 sine wave output is quite good but it is not perfect. Because it is derived from a square wave through a lowpass filter, some harmonic energy exists on the output.   However, it is a reasonably good low cost simple solution. For amateur use it is quite okay.
If you wish to test the linearity further you can pass the sine wave through an external 5MHz filter. If you do add a second filter, you may notice a further improvement in the linearity.

You may also use a good quality signal generator. However you must bear in mind that in order to test the linearity over the entire frequency range you need test equipment which is confirmed flat and accurate. Such test equipment needs to be laboratory standard which is not always readily available.

There can be many reasons why a power meter may have bumps in the response at different levels and frequencies. Some of these include the mounting of the IC, resonances in bypass and coupling components, temperature, RF connector inaccuracies, RF leakage from nearby oscillators, and so on.

Unless you can eliminate these possible causes of response variations, you have no way of knowing the actual linearity and frequency response of an AD8307 RF probe.
The manufacturer's data sheet is probably as close as you can expect.

However, for amateur radio use, the accuracy achieved with the RFPM1 is quite good, particularly so when considering its reasonably low cost.

In order to set the levels of the -20dBm and -30dBm square wave signal, there are 2 banana sockets at the rear of the CAL1 case for use with an accurate DVM.
The banana sockets are 2mm which match most multimeter probes.

The rear panel also contains a third socket which is connected to the internal 9 volt battery pack and is used to measure the battery voltage without opening the case. Current consumption is 15mA.

Switching between the square wave output and sine wave output is performed by 2 separate toggle switches. Both switches need to be operated. It was found necessary to use 2 separate switches in order to achieve a low enough level of leakage between filter input and output. A single DPDT switch placed at the input and output had too much leakage at 500MHz resulting in a sine wave with significant level of square wave component. Relays could have been used but most relays draw significant power from the battery. Simple toggle switches are lower in cost, consume no power, and are simple to implement. Ideally a couple of high quality coaxial relays would be ideal but they are expensive and not readily available. So separate toggle switches were used.

The output change over switch is actually a DPDT type. The second pole is used to switch the DVM terminals to read either the square wave level or a diode rectified sine wave level.

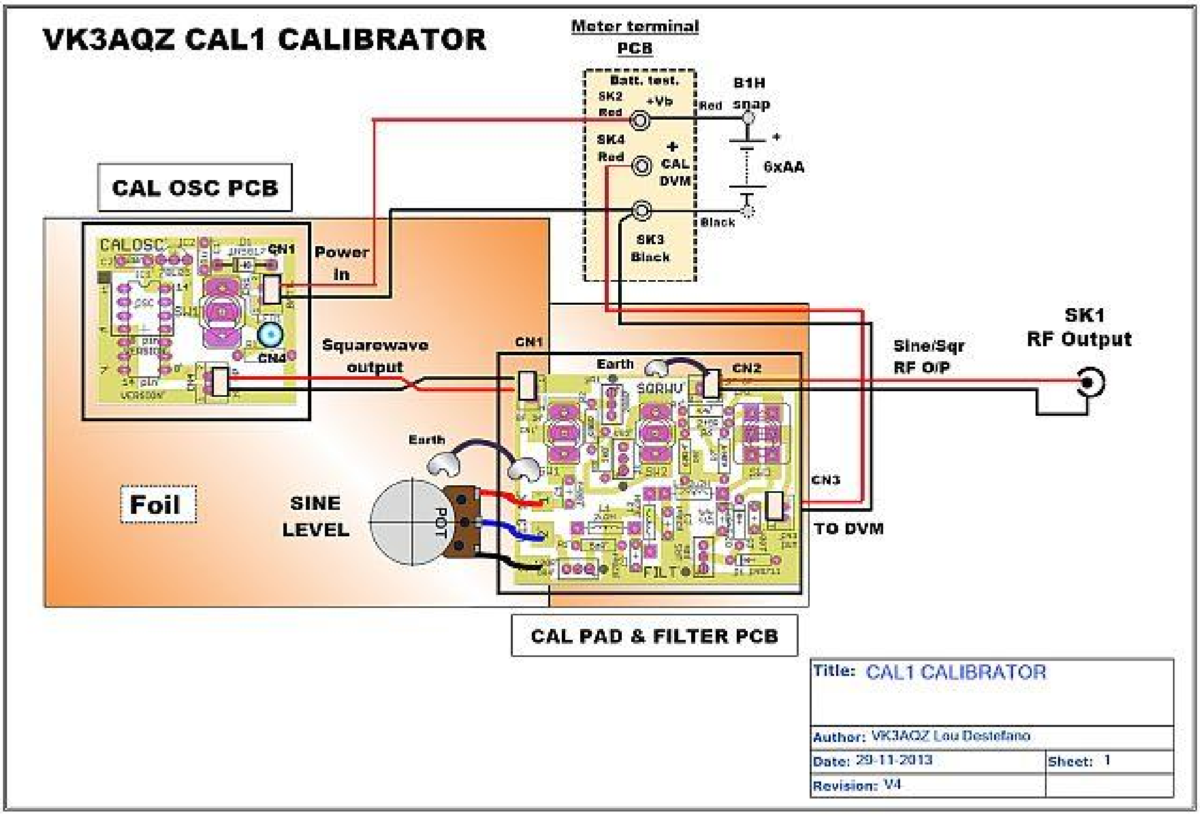
The rectified sine wave level can be used to set the sine wave output to a specific amount without having to use the RFPM1 power meter. A simple chart or table with the RF sine level DVM reading versus RF dBm output can be used. This is convenient if you wish to use the 5MHz sine wave for testing other circuits such as mixers, filters, etc. The frequency of the crystal clock generator and low pass filter can be changed to another frequency if required.
Or maybe used as a QRP transmitter with a very accurate output level.

Please note that this calibrator will read -23dBm on a conventional RMS RF power meter.
The reason for this is that the AD8307 RF detector IC responds to the instantaneous voltage level of the RF signal at it's input. A conventional power meter reads the heating effect of the signal which is the RMS value of the waveform.

The discrepancy in the reading comes about by the relationship between a square wave and a sine wave input to the AD8307. Although the AD8307 responds to a voltage, the resulting DC output can be equated to a power provided the termination impedance is known. In the RFPM1, the termination is 50 ohms so we can say that a sine wave of 632.3 mV peak to peak will cause a current in the termination which when multiplied by the voltage can be read as a power in dBm.
The reading on the meter for that voltage across the load can be marked as 0dBM.
And that is what the square wave output of the CAL1 will read if the square wave peak to peak amplitude was exactly half of 632.3mV, which is close to 316 mV.

CAL1 circuit description.

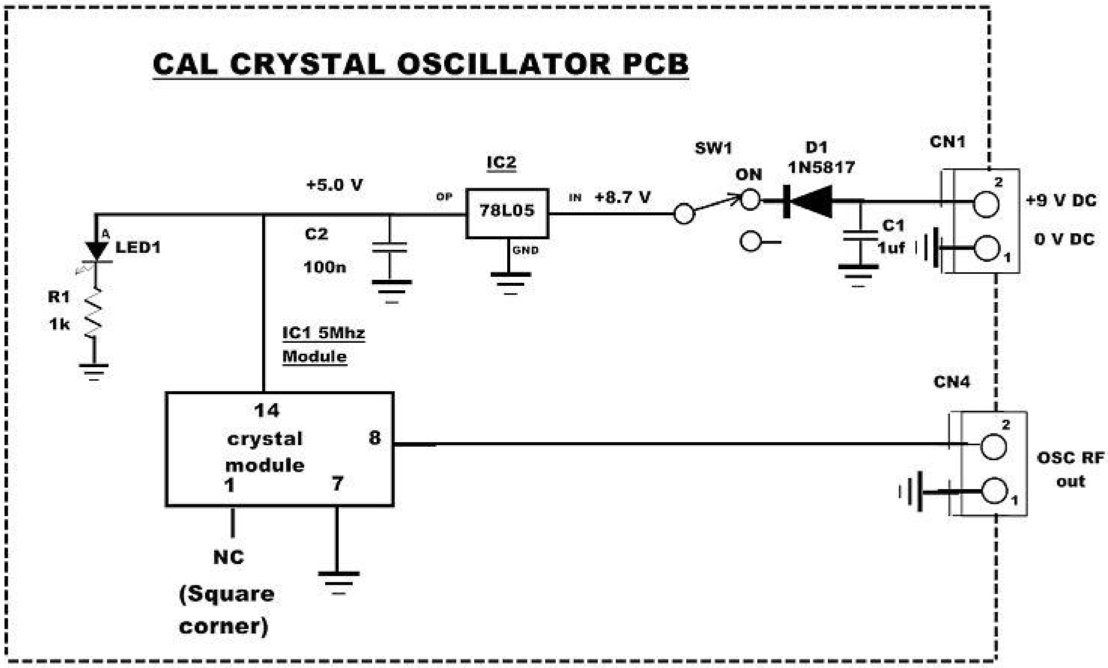
The CAL1 calibrator consists of 2 modules as shown in the block diagram below.



CAL1 Block circuit

The 2 modules are the crystal oscillator, and the “Pad and Filter”, section.

The crystal oscillator is shown below.

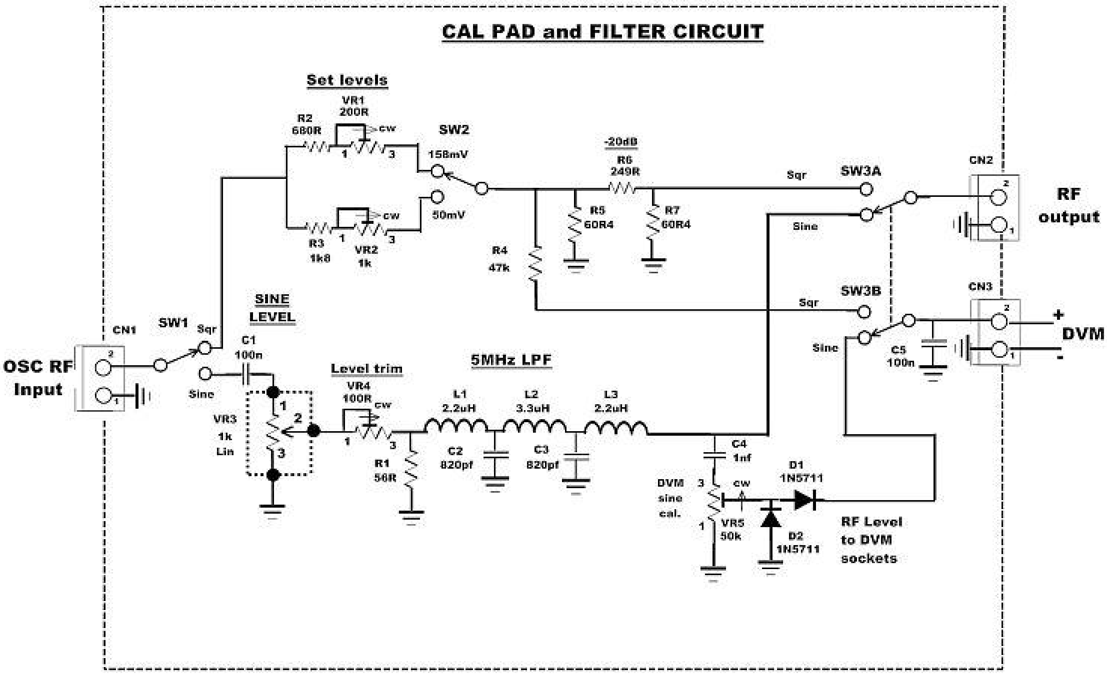


This consists of a 5MHz TTL crystal clock module. 9V DC is fed into the unit via CN1 and turned on by SW1.
The +9V is regulated down to 5V by IC2, a 78L05 regulator.
The PCB has provision for modules with either 14 pin DIL cases or 8 pi DIL cases.
An IC socket can be used for the module.
However, the module pins are not flat but round thin wire. The IC socket should only be used if you wish to change the module at any stage.
The reliability will be improved if the module is soldered directly onto the board.

The 5 volt peak to peak square wave signal is fed to CN4.

CN1 and CN4 are XH2.54 type connectors.

The output of the oscillator feeds the PAD and FILTER PCB shown below.



CAL1 PAD and FILTER unit

The square wave signal enters the PCB via CN1 and can be switched to either the square wave adjustable attenuators or the 5MHz low pass filter, via SW1.

The “Sqr” output of SW1 feeds a couple of multi turn trimpots acting as adjustable attenuators.
VR1 is used to adjust the 5 volt square wave down to 0dBm whilst VR2 adjusts it to -10dBm.

SW2 is used to select the 0dBm or -10dBm signals and feeds it into the 20dB, 50 ohm, fixed pad.

This results in a switchable output level of either -20dBm or -30dBm.

The exact levels are adjusted using an accurate DVM connected to the case via a pair of 2mm banana sockets.

R4 and C5 form an integrator which converts the square waveform into a DC voltage which is the average of the peak to peak amplitude.

To produce a -20dBm output, VR1 is adjusted for a reading of 158mV. VR2 is adjusted for a reading of 50mV to produce the -30dBm output.

The actual levels at the output of the 2 trimpots are 0dBm and -10dBm.

A sine wave of 0dBm has a peak to peak amplitude of 632.3 mV. So the equivalent square wave amplitude for the AD8307 is half this amount which is 316.1mV peak to peak.

The integrator feeding the DVM, delivers the average of the square wave which is half the peak to peak and is 158 mV. Hence VR1 is set for a reading of 158 mV. This is then reduced to -20dBm by the fixed pad to produce a square wave of 31.6 mV peak to peak. With this input, the AD8307 will output a DC voltage equivalent to a sine wave of -20dBm which has a peak to peak of 63.23 mV.
In a similar way, VR2 is set for a pre pad level of -10dBm which has a peak to peak of 100 mV and an average reading of 50 mV.

This results in post pad square wave output of 10 mV peak to peak which has an equivalent sine wave peak to peak of 20 mV. Please note that the 20dB pad consists of 1% resistors so some error in the absolute output level, though small, can be introduced by the pad.

When SW1 is switched to the sine wave position, the square wave from the crystal oscillator is fed to VR3. The wiper of VR3 feeds a 5MHz low pass filter. A series trimpot, VR4, provides a fine adjustment of the signal level. Please note that due to an original PCB tracks misplacement, a clockwise adjustment of the trimpot causes the signal level to fall rather than rise.

The insertion loss of the filter is negligible at 5MHz and over 40dB at the second harmonic of 10MHz. See the video demo titled “Power meter filter response measurement.mpg”.

This produces a reasonably smooth sine wave which can be used to test the linearity of the RF power meter.

The output of the filter is rectified by D1 and D2 which are small signal RF diodes.
The resulting DC is fed to the DVM sockets, via SW3B, for monitoring using an external DVM.

SW3A feeds the calibrator output. As mentioned previously, a separate switch is required to switch between square wave and sine wave signals to reduce leakage at UHF.

The 2 modules are fitted inside a small plastic case. A metal case would be better but in order to keep cost and weight down a plastic case has been selected.

XH2.54 mini connectors are used to couple the 2 modules, supply power, and feed the output RF connector.

The modules are mounted on the lid of the case using the toggle switches. This helps reduce the cost and tends to simplify the assembly.

Because the case is plastic, some signal is radiated outside the case. In addition, hand effects can cause slight alterations to the output level. These variations are picked up by the wide bandwidth and sensitive RFPM1 probe.

Adhesive backed copper foil on the inside of the lid helps reduce hand capacitance effects.

The battery is located in a section of the case and can be packed with foam to stop it moving around.
A separator plate in the case slots keeps the pack in one area.

Kit contents and tools.

Before starting to assemble the kit, check that all the components have been supplied.

Refer to the “Component list” for details.

Assuming all the components are there, and correct, you can commence the assembly process.

You will need the following tools:

A soldering iron with normal tips, a pair of fine tipped side cutters, small and medium sets of pliers, a set of cross head and flat blade screwdrivers of various sizes, a 3mm nut driver, an alignment tool set with a small flat blade for trimpots. Spring crossed tweezers are also very handy.

A 12 V PC fan running from a battery, or plug pack, maybe suitable for blowing away fumes if the soldering rate is low enough.

Tools







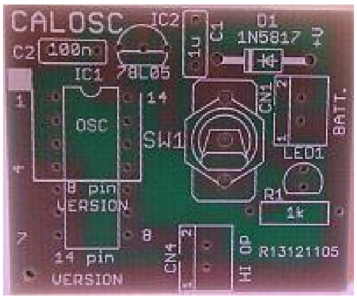





Test equipment

Optional

Assembly.



Commence with the assembly of the PCB components.

1. Commence with the oscillator PCB.

2. Low profile parts: R1 = 1k, D1 = 1N5817 check orientation.

3. Mono ceramic capacitors: C1 = 1uf, C2 = 100nf

4. IC1 14 pin IC socket. The use of the socket is only recommended if you wish to change modules. The module pins are not suited to IC sockets so maybe unreliable.

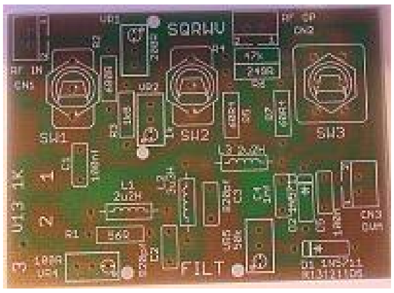
5. IC2 = 78L05. Flat face toward middle of board and the top about 8mm above board.

6. LED1 = 3mm Blue LED. Flat on body towards R1. Position the top of the LED about 10mm above the PCB.

7. Fit CN1 and 4, XH2.54, 2 pin male PCB connectors. Double check the orientation. Removing these connectors if incorrectly oriented is not easy and can be damaged due to excessive heat.

8. Fit SW1. Clean the contacts first. They tend to not take solder well. Excessive heat can damage the internal plastic levers so solder quickly and cleanly.

9. At this stage you should wait until you have checked the 5 Volt rail before fitting the crystal module. An error in the regulator can destroy the module.



That should complete most of the oscillator PCB.

10. You can now fit the components to the Pad and Filter PCB.

11. Mount all the low profile parts first.
R1 to R7. The 20dB pad resistors are 1% and the colours are somewhat difficult to read. Use a multimeter to confirm each value if necessary.
D1, D2 = 1N5711. Check orientation.
C1 = 100nf, C4 = 1nf, mono ceramic.
Fit L1, L3 = 2.2uH, and L2 = 3.3uH. Check the colour code carefully to ensure they go in the correct positions.
C2, C3 = 820pf green caps.

12. Fit the 4 trim pots taking note of the orientation. Solder one lead first then push down on the top of the trimpot whilst melting the solder on that lead. The trimpot needs to sit flat so that it does not wobble when you try to adjust it.

13. Fit the CN1, 2, 3. The XH2.54 mini male PCB connectors. Check orientation.

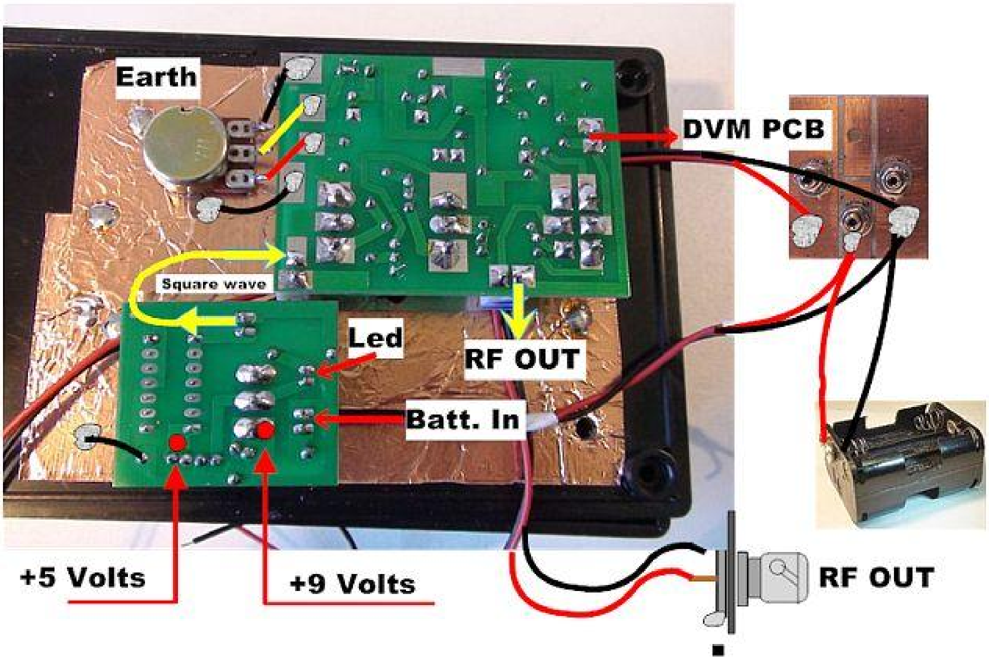
14. Fit the 2 switches. Clean the contacts first and solder quickly.

That should complete the Pad and Filter PCB.

Assemble the meter terminal panel.

15 Fit the 2mm banana sockets to the DVM PCB. This PCB mounts at the rear of the case using a 3mm x 10mm dome screw, washer, and nut. However you may wish to mount this board to the case after you solder the leads to the board.

16. Plug the 2 wire XH cables into the XH sockets on the 2 PCBs. The short lead goes into CN4 on the oscillator board and CN1 on the pad and filter board. You may want to colour code the plugs and sockets with some coloured Texta pens.



17. You can now mount the PCBs to the front panel using the toggle switch shafts. Place the star washers on the shafts inside the lid. Do up the nuts on the shaft firmly but do not strip the threads. The oscillator PCB will be pulled back out after testing in order to fit the crystal module. Fit the front panel label at the same time. Use a black 3mm dome screw at the bottom centre to locate the label. The switch shafts and potentiometer will also help to keep it in place. The handles should be fitted now as the filter PCB gets in the way of one of the handle screws. However the video shows the handles been fitted at the end necessitating the PCB been pulled back. You may choose to do the same.

18. Fit the potentiometer to the panel. Solder three short lengths of wire to the terminals as per the drawing. These can be soldered to the Pad and filter PCB. Also solder a short length of wire from the copper foil to an earth pad on the PCB near the potentiometer pads.
You may also attach a short earth between the RF out earth on the PCB down to the foil.
Extra earth can help improve the shielding.

19. Attach the RF connector to the case. Use a solder lug under one of the mounting screws

20. The 2 wire XH lead plugged into CN1 on the oscillator board is the power feed and is soldered to the DVM PCB. The battery snap also solders to the DVM PCB. This allows you to meter the battery voltage.

You can solder both leads now to the DVM board. The black wires both go to the copper with the black 2mm banana socket.
The 2 red leads both go to the middle pad with a red 2mm banana socket.

21. The 2 wire XH lead plugged into CN3 on the Pad and Filter PCB goes to the DVM PCB also. The red led goes to the remaining red 2mm banana socket and the black lead goes to the pad with the other black leads.

22. The leads are fragile so use a zip tie to hold them together and maybe a wire loop on the PCB to anchor the zip tie.

You can now mount the DVM PCB in the case at the rear as per the diagrams.

23. Mount the RF connector to the case using 3 x 10mm dome head screws. Fit a solder lug under one of the nuts. Use shake proof washers.

24. The 2 wire XH lead from CN2 on the Pad and Filter PCB goes to the RF connector. The red wire goes to the RF connector centre terminal. The black wire goes to the solder lug.

25. Fit a splined knob to the pot. Line up the cursor with the appropriate mark on the label.

26. Attach the handles.

That completes most of the assembly of the unit.

UPDATE 1:

From Peter Westgarth, VK3APW, with thanks.

To reduce harmonic leakage from the square wave signal when using the sine wave output, you can run a short wire from a convenient earth point on the oscillator PCB to the metal case of the pot. Scrape clean an area on the pot and use a hot iron.
Twisting the wires going to the connector and fitting ferrite beads on each wire at the connector end will also help.

TESTING AND CALIBRATION

At this stage do not apply power to the unit.

Commencing with the oscillator PCB:

1. With a multimeter, check for short circuits or very low resistance on the +8.7 V rail.
   The bottom of the PCB is easily accessed. The pole (middle terminal) of SW1 is the +9 V rail and the anode of D1 is the 8.7 V rail.

2. In order to avoid damage to the crystal module, double check your work around the regulator and that the crystal module area.
   If the voltage on the module is much higher than 6 volts, it can be destroyed.

   If the module is not soldered in, you can now plug the battery snap on and turn SW1 on.
   The blue LED should come on. If not check the orientation of the LED.
   Check the +5V rail. If it is not 5 Volts then switch off and check again.

3. Having confirmed that the +5 V rail is correct, turn the unit off and plug or solder the crystal module into the PCB. Make sure the square corner is in the right spot.
   Turn unit on.
   You may tune a receiver to 5MHz or use a CRO to check that the oscillator is working.

4. Attach a 50 ohm load, or the RFPM1 RF probe, to the output connector.
   Switch both signal switches to square wave.

   Attach a multimeter to the DVM sockets. The top red one is for the square wave level.
   Select -20dBm with the square wave level switch.

   Adjust the -20dBm trimpot for 158mV. If you have the RFPM1 power meter you should be able to adjust the CAL M1 and M2 trimpots for -20dBm on the meters.

   Similarly, switch to -30dBm and adjust that trimpot for 50mV on the DVM.

   The RF power meter should now read -30dBm (if the slope has been set correctly).

   PLEASE NOTE: Without a load, the readings will be about 3mV higher due to reflected impedance change through the 20dB pad.

5. Having set the square wave outputs the main calibration is complete.
You can now use the unit to test the RFPM1 as per the instructions in the RFPM1 manual.

6. You can test the sine wave section. The DVM terminals will give a reading as you adjust the level with the potentiometer. I tend to set +10dBm as 1 volt on the meter.
You can feed the signal into the RFPM1 and use the trim control to do fine adjustments of the level you may want to test with. A CRO is quite useful when testing the sine wave output.

7. You can now complete the project.
Slide the battery separator into the case and pack the battery holder with some foam or packing.
Fit the lid to the case.

That completes the CAL1 unit.

References:

1 R. Kopski. K3NHI. A Simple RF Power Calibrator"
QEX, Jan/Feb 2004 pp 51-54

2 Analogue Devices website: http://www.analog.com/en/index.html

AD8307 data:
http://www.analog.com/en/rfif-components/detectors/ad8307/products/product.html

Some AD applications documents:
http://www.analog.com/library/analogDialogue/archives/33-03/ask28/index.html

http://www.analog.com/static/imported-files/faqs/201551981Detector_FAQ.pdf

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