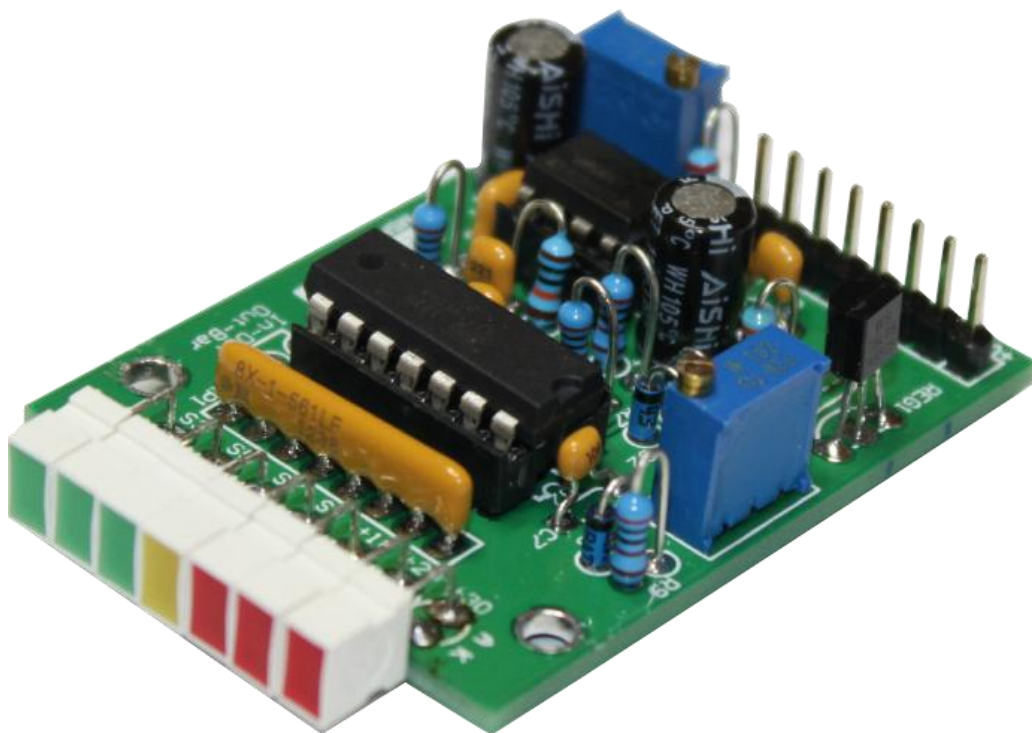


# LED S METER



## CONSTRUCTION MANUAL

 [www.ozQRP.com](http://www.ozQRP.com)

# **Important**

## **Please read before starting assembly**

### **STATIC PRECAUTION**

**The LED S Meter kit contains components which can be damaged by static discharge:**

**Do not remove these components from the protective anti-static packaging until you have taken precautions against static discharge.**

- **If possible use an anti-static wrist strap and conductive mat. These can be purchased readily from electronic retailers.**
- **If these are not available then at least ensure you have discharged yourself by touching an earthed metal surface before handling the devices.**
- **Try not to directly touch the pins of the devices.**
- **Ensure your soldering iron has an earthed tip.**

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# 1 INTRODUCTION

The LED S Meter is a small microcontroller add-on board designed for the MST transceiver. It displays receive signal strength and transmit power on a colourful 7 LED array.

LED S Meter Features:

1. Bright multi-colour LED display.
2. During receive displays 'S' levels S3 through to S9+30dB.
3. During transmit displays output power from 0.25W to 5W PEP.
4. Default LED display is bar, but may be configured for dot display to minimize supply current.
5. Automatically switches between receive S unit and transmit power displays.
6. While specifically designed for use with the MST, can also be adapted to suit many other QRP rigs.
7. Quiescent current only 8.5mA at 13.8V DC. In dot mode with one LED on the current is 14mA and in bar mode with all LEDs on the current is 46mA.
8. High quality double sided PCB with ground plane, plated through holes, solder mask and silk screen.
9. Simple and easy to build using all through hole components.
10. Small PCB mounts to front panel with a small angle bracket.

A full kit containing a PCB and all onboard components including a pre-programmed microcontroller is available from [www.ozQRP.com](http://www.ozQRP.com).

The kit does not include mounting hardware.

## 2 RECEIVE SIGNAL METER

### 2.1 S UNITS

HF receivers use a standardized system called S units to indicate receiver signal strength. S9 is considered to be 50uV RMS across the antenna socket. S8 is 6dB lower or half the antenna voltage of S9. S7 is 6dB lower than S8 and so on down to S1. Signal strengths above S9 are given in 10dB steps, so that S9 plus 20dB equates to an antenna voltage of 20dB greater than 50uV or 500uV.

### 2.2 THE MST AND SIGNAL STRENGTH

The MST transceiver differs from most Superhet designs in that it does not have Automatic Gain Control or a gain controlled IF amplifier.

This means that the gain is essentially constant from the antenna socket through to the AF gain control. The gain does vary from one MST to the next due to receive bandpass filter tuning and component tolerances but on average is around 1000 or 60dB.

Table 1 shows the relationship between voltage at the antenna socket, S units and recovered audio across the AF gain control for a typical MST transceiver.

The thing to notice is that the range of signal levels is very large (1:25000 or 88dB). To facilitate this large range the MST gain must be set to provide a usable audio signal with tiny S1 levels, yet not overload the audio stages on strong signals.

If we were to simply add a linear reading audio level meter across the AF gain control the indicator would spend most of its time cramped at one end as levels S1 to S9 would only occupy about 1% of the scale.

Antenna voltage (RMS)	S unit	Audio level across AF gain control (pk to pk)
0.20uV	S1	0.56mV
0.40uV	S2	1.1mV
0.79uV	S3	2.2mV
1.6uV	S4	4.5mV
3.2uV	S5	9mV
6.3uV	S6	18mV
13uV	S7	37mV
25uV	S8	71mV
50uV	S9	141mV
160uV	S9+10dB	450mV
500uV	S9+20dB	1.41V
1.6mV	S9+30dB	4.5V
5.0mV	S9+40dB	14.1V

Table 1 MST antenna voltage, S units and recovered audio

## 2.3 LED S METER BASICS

The LED S meter overcomes the large dynamic range problem and increases the resolution by dividing the signal range into two smaller ranges and displaying one range at a time depending on the signal level. This is only practical through the use of a microcontroller.

The audio input signal is applied to two separate audio amplifiers, one amplifier has high gain and used with low level signals (S9 and below) while the other has low gain and used for high level signals. The negative peaks of the audio waveform from each amplifier are sampled by a microcontroller Analog to Digital Converter (ADC). The microcontroller selects the high gain amplifier by default, but if the negative audio peaks are over range then the signal from the low gain amplifier is selected instead. The microcontroller averages and smoothes the peak readings and drives the LED display to indicate receive signal strength.

Note that the LED S meter does not display the full range as shown in Table 1. This is done for a couple of reasons. Firstly to keep the number of LEDs to a manageable number only S3, S5, S7, S9, S9+10db, S9+20db and S9+30dB are displayed. Secondly the minimum S meter indication is S3 due to the limitation of this circuit to detect very small signals, and the maximum is S9+30dB because signals larger than this cause slight clipping in the MST audio preamplifier stage.

The oscilloscope screen shots below show typical amplifier outputs. Figure 1 is for a signal level of S7 and Figure 2 is for a signal level of S9+20dB. The top trace in each screen shot is the high level amplifier output while the bottom trace is the low level amplifier output.

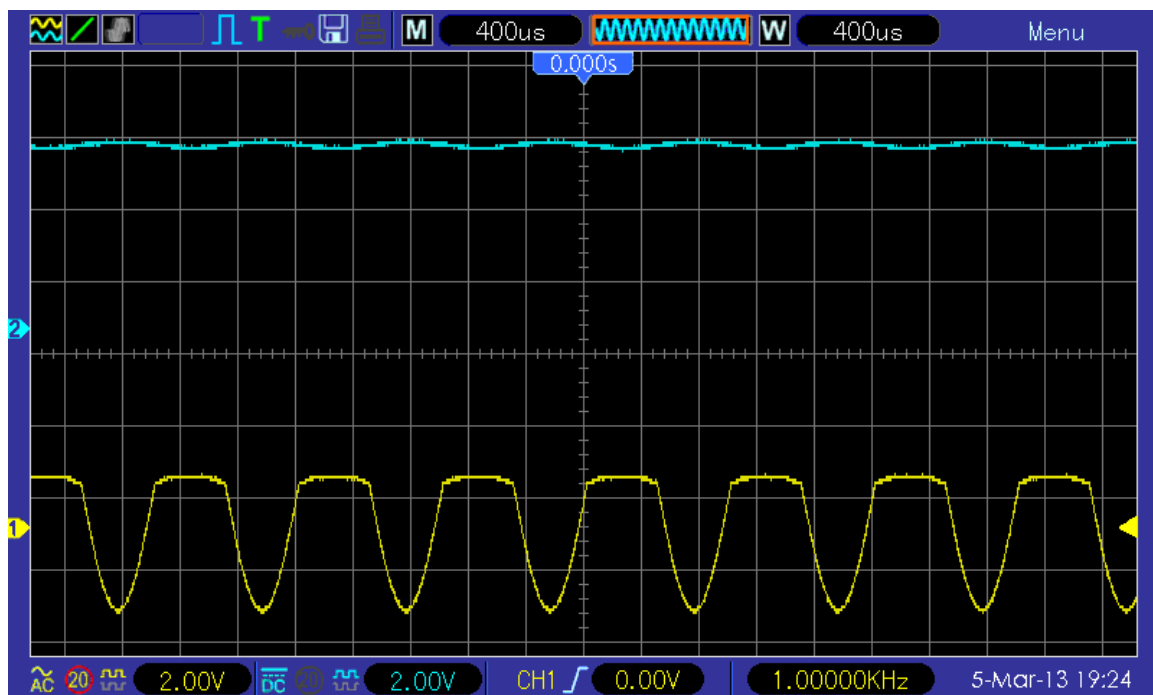


Figure 1 Op-Amp amplifier outputs for S7 signal.

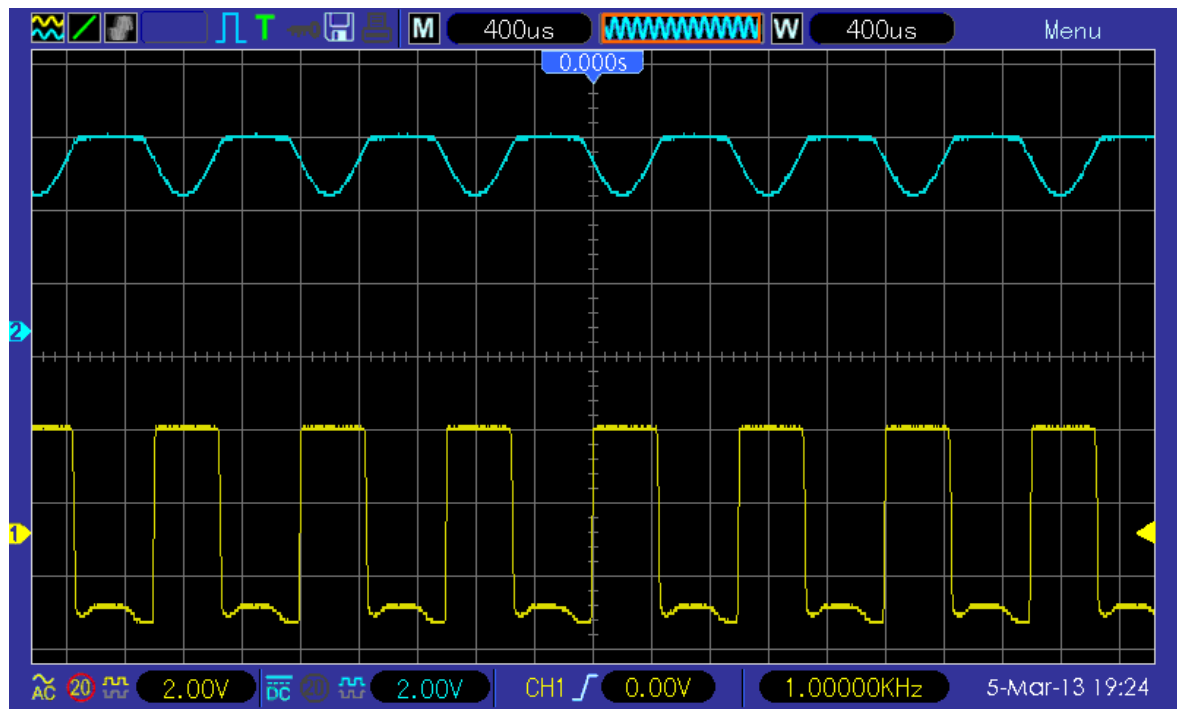


Figure 2 Op-Amp amplifier outputs for S9+20dB signal.



### 3 TRANSMIT POWER METER

The LED S meter defaults to receive S meter mode, however there is a third input to the ADC which the microcontroller uses to monitor the transmitted signal. If a voltage is detected on this input the LED S meter switches to power meter mode. The microcontroller averages and smoothes the RF voice peaks and drives the LED display to indicate transmitted power.

The range of power readings available is shown in Table 2

Power (Watts PEP)	Antenna Voltage (peak)	LED on
0.25	5	S3
0.5	7.1	S5
1	10	S7
2	14.1	S9
3	17.3	S9+10dB
4	20	S9+20dB
5	22.4	S9+30dB

Table 2 Power meter range

## 4 CIRCUIT DESCRIPTION

The circuit diagram is shown in Figure 3. The incoming audio signal is fed to the low gain op-amp U1A. This stage has an input impedance of around 100K to minimise loading the external audio stages. The gain of this stage can be set between 0.22 and 5.22 by trimpot VR1 to compensate for different receiver gains and is used as a calibration control. The output of U1A is fed to the high gain op-amp stage U1B which has a fixed gain of 50 set by the ratio of R5 and R6. Capacitors C3 and C5 provide some low pass filtering to limit high frequencies and pulse noise and aid in stability.

A 78L05 5V regulator supplies a reference voltage for the non-inverting inputs as well as the power rail for the microcontroller and LEDs.

With no signal the DC voltage at the op-amp outputs is 5V. When an audio signal is present the AC component of the waveform extends above and below the 5V reference point. The LM358 is chosen because it allows the maximum negative excursion to be very close to 0V. Current limit resistors and clipping diodes are used to protect the microcontroller Analog to Digital Converter (ADC) inputs from the positive excursions of the op-amp outputs. The diodes conduct when the signal goes above the 5V supply rail and limits the voltage at the ADC inputs to between 0V and about 5.25V.

The microcontroller firmware monitors each op-amp output in turn and determines which one to use for signal measurement. For low level signals (S9 and below) the output of U1A will be very small, however the output of U1B will be much larger. In this case U1B would be used to determine signal strength and LEDs S3 to S9 would be active. If the signal level increases beyond S9, the negative excursions from the output of U1B will be reaching 0V and clipped. In this case the firmware uses the output of U1B and LEDs S9+10 to S9+30 will be active.

The microcontroller is an Atmel ATtiny24 which takes the analog signals, converts them to a number in the ADC and through the internal firmware calculates the signal level and drives the LEDs. One function of the firmware is to act like a capacitor quickly charging to the peak of the audio signal and decaying at a slower rate. This makes the display appear more natural and pleasing in use. The program timing is non-critical, and to save space, and components, U2 uses an internal RC clock rather than an external crystal.

When the MST is transmitting the RF detector circuit on the main board provides a varying current directly related to the power level. In normal use this is used to drive a front panel LED which increases in brightness as the power level increases. When used with the LED S meter the front panel LED is removed and the line is applied to VR2 which converts the varying current to a voltage. VR2 is adjusted to calibrate the power range. R9 and D3 limit the positive voltage to 5.25V to protect the ADC input.

When used with the MST, R8 is not installed and bypassed with a link. If the LED S meter is used with other rigs that supply a voltage feed, R8 may need adding to allow scaling of the detected RF voltage.

The LED S meter firmware operates in a loop that samples the outputs of U1A on pin 12 of U2, U1B on pin 11 and the transmit power input on pin 13. If no voltage is detected on pin 13 the firmware switches to receive signal mode. When the MST transmits, a voltage will be present at pin 13 and the firmware switches to transmit power mode. At the end of transmission the voltage on pin 13 returns to zero and the firmware returns to receive mode.

U2 Pin 7 is normally held high by an internal pull-up resistor. When the pin is detected high the display is in bar mode. This means that as the signal increases the lower LEDs remain on.

If pin 7 is held low the display is in Dot mode. This means that only the LED representing the signal level will be on. All other LEDs will be off. This feature is included to minimise supply current if required.

Connections to the LED S meter are through an 8 way connector and the pins are arranged to allow easy integration to existing MSTs.



## 5 PARTS LIST

Quantity	Comment	Designator
2	220pF 50V monolithic ceramic	C3, C5
1	10nF 50V monolithic ceramic	C4
2	100nF 50V monolithic ceramic	C7, C8
1	220nF 50V monolithic ceramic	C6
2	100uF 25V electrolytic	C1, C2
1	0R (see text)	R8
1	330R 1/4W 1% resistor	R1
4	2K 1/4W 1% resistor	R3, R6, R7, R9
1	22K 1/4W 1% resistor	R2
2	100K 1/4W 1% resistor	R4, R5
1	560R 8 pin SIL resistor array	RP1
1	1K multi-turn trimpot (see text)	VR2
1	500K multi-turn trimpot	VR1
3	BAT43 Schottky diode	D1, D2, D3
3	Rectangular LED 4mm x 7mm Green	S3, S5, S7
1	Rectangular LED 4mm x 7mm Amber	S9
3	Rectangular LED 4mm x 7mm Red	+10, +20, +30
1	78L05 +5V 100mA regulator	REG1
1	LM358 dual op-amp	U1
1	ATtiny24 microcontroller	U2
1	8 pin IC socket	-
1	14 pin IC socket	-
1	8 pin male header	SK1
1	PCB	MSPM0113-A

## 6 CONSTRUCTION

### 6.1 GENERAL

The LED S meter is built on a high quality fiberglass PCB. The PCB is doubled sided with tracks on both sides along with a ground plane. The holes are plated through and so it is not necessary to solder both sides to make connections. To assist construction the component overlay is screen printed on the top side and a solder mask is included to guard against solder bridges.

The ground plane is substantial and can sink quite a bit of heat from low wattage soldering irons so ensure you use a good quality iron that can sustain the power required. You may find that sometimes solder doesn't appear to flow through to the top side. This is not necessarily a problem because the plated through holes make a connection to the top side automatically.

Another point to consider is that plated through holes consume more solder than non-plated holes and makes it more difficult to remove components.



Double check the values and orientation of components before installation.

The construction steps that follow describe installing an 8 pin male pin header for the input connections, and IC sockets for the two ICs.

If preferred the header can be ignored and the wires directly soldered to the board. Alternatively you can install your own connector. The PCB layout uses a standard 0.1" pin pitch so a large range of connectors will be suitable.

The IC sockets while convenient are not essential as long as you are confident with your work. They will however prove handy if fault finding is necessary as they allow easy removal of the ICs. Using sockets also has the advantage that the ICs, especially the microcontroller, can be installed after initial testing and soldering is complete.

The resistors and diodes, apart from R8, are inserted vertically in the PCB to allow a more compact board. The PCB could have been even smaller if designed with SMD components, but this would make the construction much more difficult for builders inexperienced with surface mount devices.

## 6.2 CONSTRUCTION STEPS

Refer to the parts list and the component overlay in Figure 9 when installing the components.

### Step 1: Non-polarised capacitors

Install the non-polarised capacitors with minimal lead length. These are small ceramic monolithic types and look alike so check the values using the table below before installing.

Part	Marking	Value
C3, C5	221	220pF
C4	103	10nF (0.01uF)
C7, C8	104	100nF (0.1uF)
C6	224	220nF (0.22uF)

### Step 2: Resistor network

The 8 pin resistor network goes in next. The common pin has a dot on the side of the case. This lead goes to the bottom of the PCB where a dot is printed on the overlay for reference.

### Step 3: Resistors



The values of 1% resistors can be difficult to read, so if in doubt check with a multimeter before soldering.

Apart from R8 the resistors are mounted vertically. The leads are formed as shown in Figure 4.



Figure 4 Resistor preparation

Once formed to shape, pass the pigtails through from the top of the board and bend out slightly underneath to hold them in place. Turn the PCB over and then solder. Cut off the excess pigtail with side cutters.



When the LED S meter is used with the MST resistor R8 is not installed and a short wire link is soldered in its place. Ensure the bare wire does not make contact with the groundplane.

### Step 4: IC sockets

Both IC sockets are installed with the notch facing the top side of the PCB. Ensure they fit flush with the PCB before soldering.

### Step 5: 8 pin header

The 8 pin male header is installed next and the shorter pins are inserted in the PCB. Solder one end pin first and check it is at right angle to the board before soldering the remaining pins.

### Step 6: Electrolytic capacitors

The two electrolytic capacitors are polarized and must be inserted correctly. The location for the positive lead is identified on the overlay with a '+' sign.

### Step 7: Diodes

The three diodes are mounted vertically in a similar way to the resistors. The leads are formed as shown in Figure 5. Note the Cathode lead which is the lead at the banded end. This lead is inserted in the PCB hole with the '+' sign shown on the overlay.

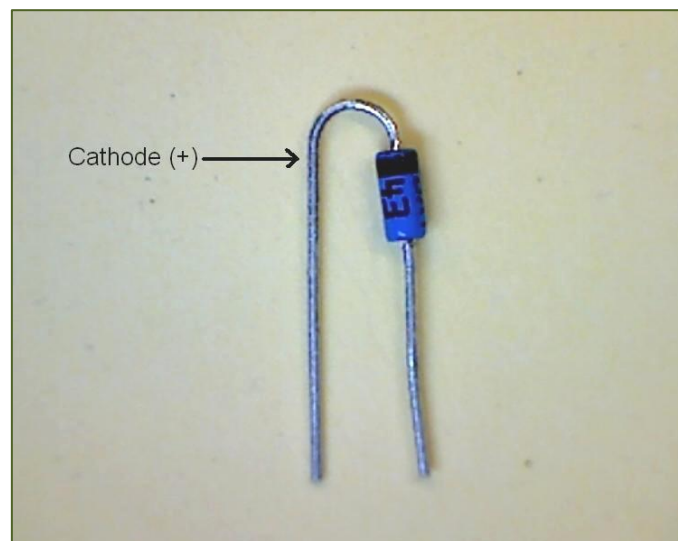


Figure 5 Diode preparation

### Step 8: Trimpots

Insert the trimpots so that they sit neatly on the PCB and then solder. Note the different values and also the orientation so that the adjustment screws align with the PCB overlay.

### Step 9: 5 volt regulator

The 78L05 +5V regulator must be installed the correct way. Ensure the flat face of the body is towards the edge of the board.



## Step 10: LEDs

The LED display uses high quality rectangular LEDs with a white plastic surround to provide a professional looking finish.

LEDs S3 to S7 are green, S9 is amber, and LEDs S9+10 to S9+30 are red.

The LED lead identification is shown in Figure 6.



The LED Cathode lead is the longer lead. This is reverse to most LEDs.

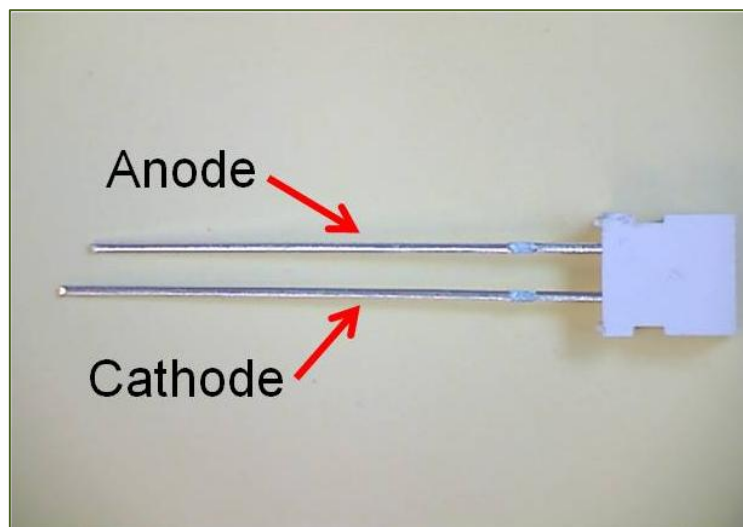


Figure 6 LED lead identification

To make the assembly as compact as possible the LEDs are installed with minimal lead length and positioned so the rear of the LED touches the edge of the PCB. To achieve this, the leads must be bent at right angles as shown in Figure 7. Take your time and ensure the leads of each LED are bent the same otherwise the LEDs will not be inline once soldered in place.

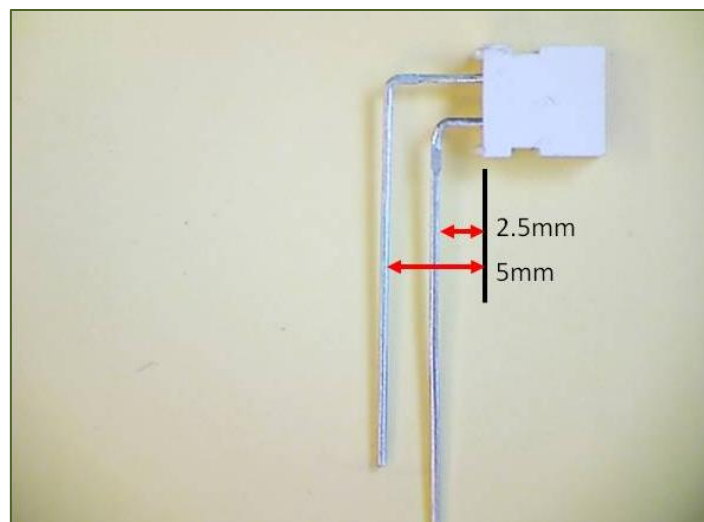


Figure 7 LED with formed legs

Install the end LEDs first (S3 and +30) to act as alignment guides for the remainder. The object is to get the 7 LEDs appearing as though they are a single LED array.

Push the leads through the board and lightly solder one lead first to double check the positioning. Once satisfied, do a final solder of both leads.

A LED mounted and soldered to the PCB is shown in Figure 8.

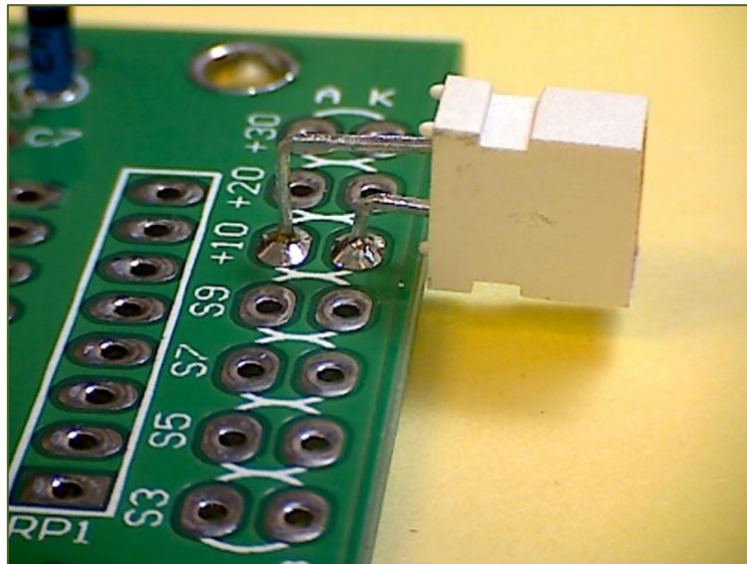


Figure 8 LED mounted to PCB

## Step 11: ICs

Remove the LM358 and ATtiny24 microcontroller from their protective packaging and insert into the IC sockets ensuring pin 1 is at the end of the socket with the notch.



## 7 POWER UP TESTING

Before applying power check the board over one more time. Look for solder bridges and components in the wrong way. A moment spent here may save a lot of frustrating time later on.

Once you are satisfied connect the LED S meter to a power supply between 8 and 15V DC. If the power supply has current limiting set this to about 100mA.

Apply power and check that all LEDs initially come on and then progressively turn off. Getting this far is a good sign that all is well.

Now that all LEDs are off check the power supply current. It should be around 8 to 9mA.

Anything far from this indicates a problem and needs to be corrected before proceeding. Also check with a multimeter that the output of the regulator is between 4.75 and 5.25V DC. Once again if the readings are way outside this range turn off immediately and look for problems.

## 8 WIRING

The connections to the LED S meter are via an 8 way header. When installed in an MST the existing DDS VFO power wires are removed and diverted to the LED S meter. A second set of pins on the header is wired in parallel on the PCB and used to feed power onto the DDS VFO.

A shielded cable feeds the S meter input from across the AF gain control. The power meter input uses the wires which were intended for the front panel power LED. The wiring is shown in Figure 10.

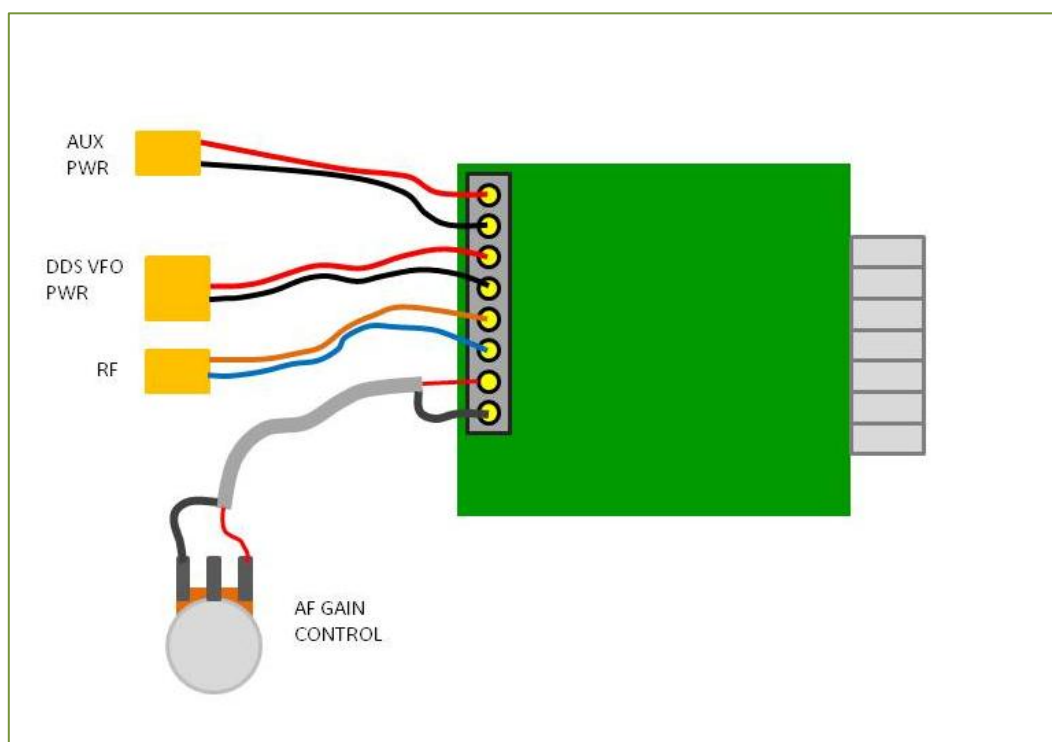
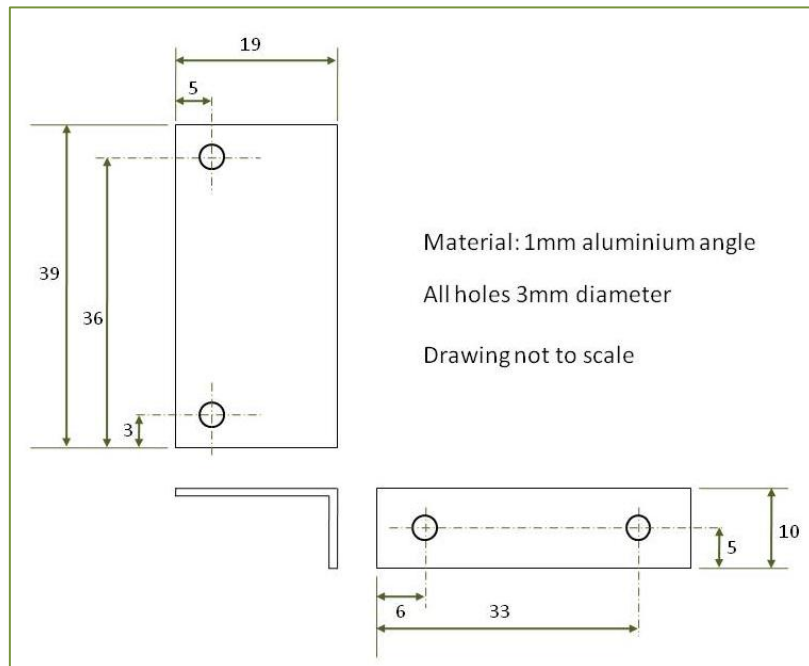


Figure 10 LED S meter wiring diagram

## 9 MOUNTING

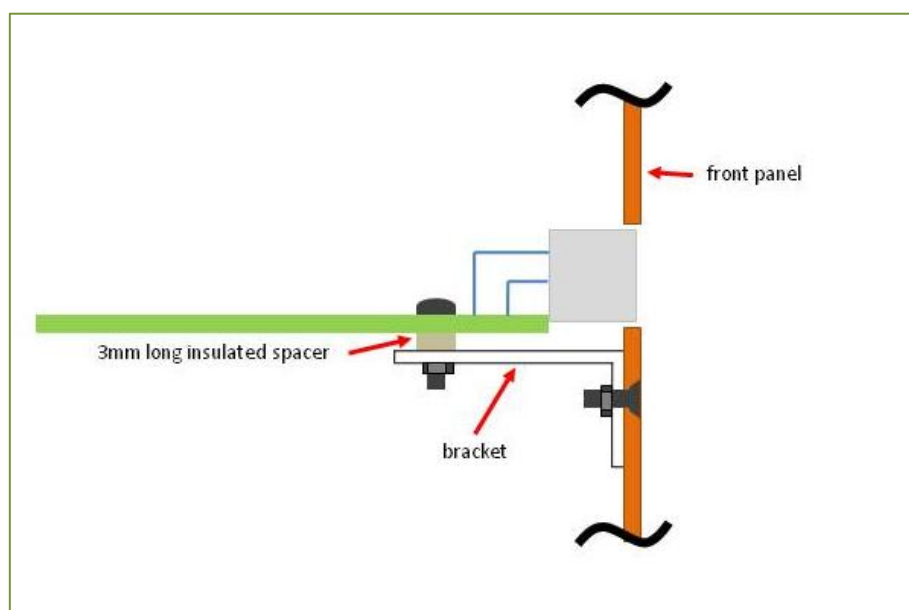
The LED S meter is intended to be mounted at right angles to the front panel. The LEDs fit inside a rectangular cutout in the front panel behind a transparent label if provided.

To mount the LED S meter a small aluminum angle bracket must be constructed as shown in Figure 11.



**Figure 11 Mounting bracket**

The PCB is mounted to the angle using 3mm screws and nuts and 3 or 4mm long insulated spacers. The bracket is then secured to the front panel using countersink 3mm screws and nuts. The arrangement is shown in Figure 12.



**Figure 12 Front panel mounting**

## 10 CALIBRATION

Once the LED S meter is installed in your MST you will need to calibrate the ranges. This is quite easy to do and some suggested methods are described below.



While the LED S meter display accuracy is entirely adequate for amateur radio use it is not intended to be a precision device.

### 10.1 SIGNAL METER

#### 10.1.1 METHOD 1

Equipment required: Calibrated RF signal generator.

1. Using a small bladed screwdriver slowly rotate the screw in trimpot VR1 counter clockwise until the end is reached. You should be able to hear a click as the stop is passed. This is to ensure the gain of the amplifier is set to minimum at the start of calibration.
2. Rotate the AF gain control back to about one quarter volume.
3. Power on the MST.
4. Connect an RF signal generator to the antenna socket with a frequency in the middle of the band and set to 50uV output.
5. Tune in the signal until you hear a clear tone in the speaker and adjust the AF gain control for a comfortable speaker volume.
6. Slowly rotate the screw in trimpot VR1 until the S9 LED comes on. If the trimpot is set at the edge of S9 detection the LED may flash intermittently, so rotate the trimpot screw a turn or two further to ensure the LED is fully on.

#### 10.1.2 METHOD 2

Equipment required: Second receiver with an accurate S meter, un-calibrated RF signal source (e.g. crystal oscillator), 50 ohm RF step attenuator.

1. Connect the signal source to the input of the step attenuator. Connect the output of the step attenuator to the second radio antenna socket.
2. Tune the radio to the signal source frequency until a clear tone is heard in the radio speaker. Note that depending on the attenuator range and the level of the signal source, you may need to add some attenuation so that the receiver is not overloaded.
3. Adjust the attenuator settings until the second radio S meter reads S9.
4. Using a small bladed screwdriver slowly rotate the screw in trimpot VR1 counter clockwise until the end is reached. You should be able to hear a click as the stop is passed. This is to ensure the gain of the amplifier is set to minimum at the start of calibration.
5. Rotate the MST AF gain control back to about one quarter volume.
6. Power on the MST.
7. Disconnect the signal source and attenuator from the second receiver antenna socket and connect to the MST.
8. Tune in the signal source frequency until a clear tone is heard in the MST speaker. Adjust the AF gain for a comfortable volume.
9. Slowly rotate the screw in trimpot VR1 until the S9 LED comes on. If the trimpot is set at the edge of S9 detection the LED may flash intermittently, so rotate the trimpot screw a turn or two further to ensure the LED is fully on.

## 10.2 POWER METER

### 10.2.1 METHOD 1

Equipment required: QRP power meter, AF signal generator.

1. Connect the QRP watt meter to the MST antenna socket. Connect the AF signal source to the microphone socket.
2. Set the output of the AF signal source to about 1KHz at 50mV rms.
3. Rotate the Mic Gain control fully counter clockwise.
4. Using a small bladed screwdriver rotate the screw in trimpot VR2 counter clockwise until the end is reached. You should be able to hear a click as the stop is passed. Then rotate clockwise until in the middle of the range (about 12 turns).
5. Power on the MST.
6. Short the PTT line to ground to place the MST in transmit.
7. Rotate the Mic Gain clockwise until 5W is indicated on the watt meter.
8. Slowly rotate the screw in trimpot VR2 either direction until the 5W(S9+30dB) LED comes on. If the trimpot is set at the edge of 5W detection the LED may flash intermittently, so rotate the trimpot screw a turn or two further to ensure the LED is fully on.

### 10.2.2 METHOD 2

Equipment required: 50 ohm 5W dummy load, oscilloscope, AF signal generator.

1. Connect the dummy load to the MST antenna socket. Clip the oscilloscope probe across the dummy load or if not accessible across the antenna socket. Connect the AF signal source to the microphone socket.
2. Set the output of the AF signal source to about 1KHz at 50mV rms.
3. Rotate the Mic Gain control fully counter clockwise.
4. Using a small bladed screwdriver slowly rotate the screw in trimpot VR2 counter clockwise until the end is reached. You should be able to hear a click as the stop is passed. Then rotate clockwise until in the middle of the range (about 12 turns).
5. Power on the MST.
6. Short the PTT line to ground to place the MST in transmit.
7. Rotate the Mic Gain clockwise until the oscilloscope reads 45V pk-pk.
8. Slowly rotate the screw in trimpot VR2 either direction until the 5W(S9+30dB) LED comes on. If the trimpot is set at the edge of 5W detection the LED may flash intermittently, so rotate the trimpot screw a turn or two further to ensure the LED is fully on.

# 11 INSTALLING IN ANOTHER RIG

While the LED S meter has been designed for the MST transceiver board it will be possible to use with many other rigs. Installation is straightforward however there are a few requirements that must be considered.

## 11.1 RECEIVER

The LED S meter is essentially an auto-ranging audio level meter that connects to a low level audio stage in the receiver. Typically this is across the AF gain control.

- The receiver audio level applied to the LED S meter should be about 50mV RMS for an S9 signal at the antenna. The calibration trimpot allows some variation, but the range should be between 25 to 100mV RMS.
- The receiver must have fixed gain between the antenna and audio stages where the LED S meter is connected. This means receivers that attempt to maintain the audio level for varying antenna signals (AGC) are not suitable.
- If a receiver has fixed gain but has a manual RF gain control or attenuator, then this must be taken into account when reading the display. For example if a 20dB antenna attenuator is used and switched in, then all displayed signal levels would be 20dB lower than normal.

## 11.2 TRANSMITTER

The MST power LED driver provides a variable current source. As power output increases so does the current through the front panel LED and hence the brightness. When the LED S meter is used with the MST, the variable current is simply converted to a voltage by passing it through a 1K trimpot. The trimpot is adjusted so that the correct voltage is input to the microcontroller ADC.

If used with another rig you will need to provide an RF peak detector to provide a voltage corresponding to the peak of the modulated RF output. As this signal will be a voltage source resistor R8 will need installing and the link removed from the PCB. It may also be necessary to change the value of trimpot VR2 to provide correct scaling and raise the input impedance. The LED S meter turns on the 5W LED when the input to the microcontroller ADC is approximately 3.5V DC.

Each circumstance will be different and you will need to calculate the values accordingly, however a typical circuit is shown in Figure 13.



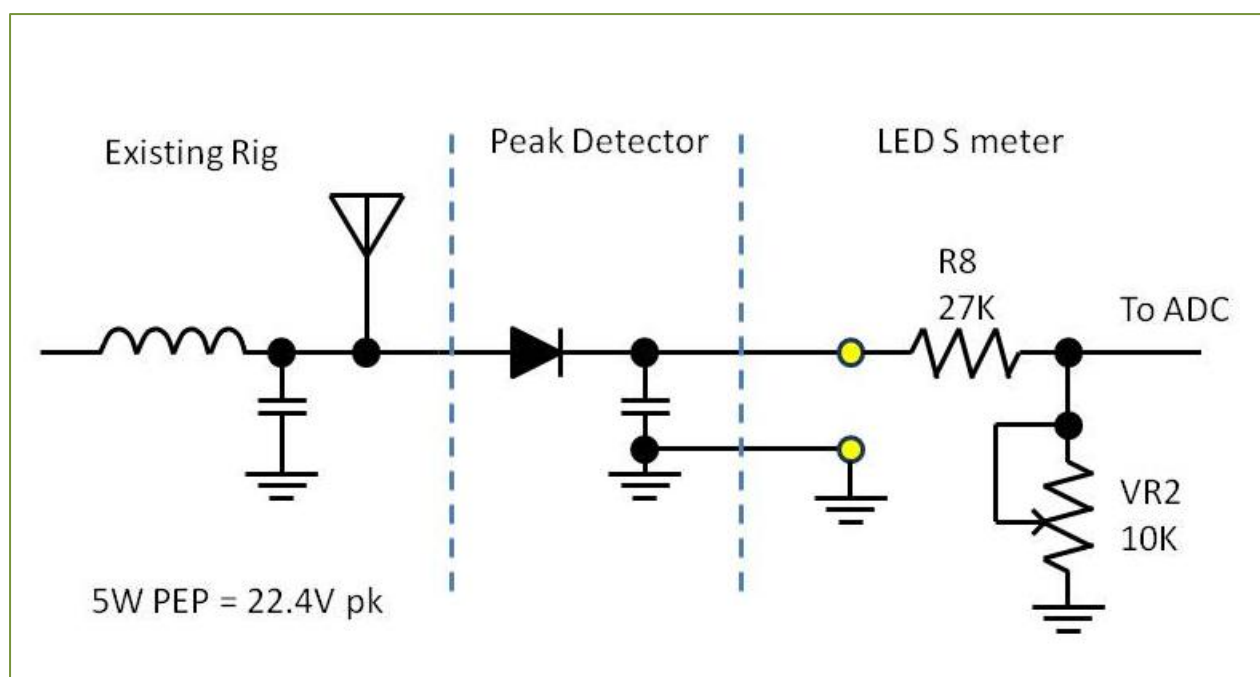


Figure 13 Installing in another rig