Project build notes for the wideband small magnetic loop amplifier

Ross Mackay M0KPI, v1.2, 7/9/2023

The project is a Wideband Small Magnetic Loop ("WSML") amplifier with a Bias Tee power feed via coaxial cable. Both are built on double sided PCB's using through hole components.

Skip to the Assembly and Test section if you just want to get started with the build.

Overview

The WSML is a receive-only antenna system which can improve the signal to noise ratio of received signals when QRM is a problem when using your transmit antenna.

It does this by being less susceptible to the effects of local/near-field QRM that tend to radiate from high impedance "unintended antennas" such as mains wiring and power leads, and through having a well defined null in the loop antenna radiation pattern that can be "pointed at" a QRM source, to reduce it.

Operation

The small loop antenna is defined here as one having a circumference that is less than 0.1 wavelength at the highest frequency of interest. Such loops are most often mounted vertically, to take advantage of the radiation pattern nulls that can be used to reduce local QRM, or interference from a local broadcast station.

A commonly used loop is circular in shape and 1m in diameter, with circumference ~3.14m (pi times the diameter). It will have small loop characteristics up to approximately 30m wavelength, 10MHz.

At such frequencies, the loop is effectively a short circuit to the electric (E-field) of electromagnetic waves and it responds only to the magnetic (H-field), much in the way a transformer works.

Most local/near-field QRM exists on high impedance “unintended antennas”, where the E to H field ratio is higher than that of free space/far-field signals. As the E-field is effectively short circuited by the loop, such QRM is more attenuated than the wanted far-field signals. This makes the small loop antenna appear quiet relative to most open ended wire antennas.

In the far field, radiated QRM has the same characteristics as any other EM wave.

At higher frequencies, i.e. where the loop circumference is more than 0.1 wavelength, the small loop characteristics will diminish with increasing frequency, due to the loop becoming increasingly sensitive to the E-field.

As the small loop antenna has a very low impedance, it requires a current amplifier.

Amplifier

The requirements are to amplify and interface the low impedance loop to the receiver.

The loop current is amplified by a balanced pair of transistors operating in a common base configuration, giving the amplifier a very low input impedance. The signals are further amplified by a balanced common emitter stage to drive the 50 ohm output to the receiver, via the Bias Tee.

Bias Tee

This feeds the 12 to 13.8VDC power input to the amplifier, which draws around 150mA via the coaxial cable connection.

It is protected by an input diode against reverse polarity and by a resettable polyfuse against short circuits on the coaxial cable.

A high SRF (self resonant frequency) inductor is used to maximise the amplifier frequency range.

Performance

A 1m diameter loop will perform well from below 100kHz to 10MHz, the range most often affected by QRM.

Loops can be optimised for higher frequencies by using smaller loops connected in parallel.

It makes a good general coverage SWL antenna that does not require any tuning.

Installation

The amplifier is intended for receive-only operation therefore switching should be provided to avoid transmitting into it.

The amplifier loop inputs are diode protected and very low impedance, however it should be located away from transmit antennas and ground radials where possible, to reduce the risk of damage to the amplifier and to avoid coupling QRM into the loop or into your receiver via its connecting cable.

The loop is intended to be vertically mounted. It does not need to be mounted high up though doing so may help reduce QRM or improve signal strength. A suggested minimum height above the ground is 0.25x the loop diameter.

The loop can be horizontally mounted however it will lose the ability to null out interfering signals and QRM, and it may appear to be deaf unless it is mounted high up. It will however become omnidirectional.

If possible, avoid placing the loop close to large conductive objects, including antennas and radials, as they can couple QRM into the loop which can give the appearance of QRM that cannot be nulled out.

A practical loop

A standard 3m length of 10-15mm diameter copper pipe can be formed into a circular loop that is just under 1m in diameter and rigid enough to hang from a tree or fence with minimal support. It will have small loop characteristics for all signals having a wavelength of 30m or more, i.e. from VLF frequencies up to approximately 10MHz.

A more detailed look

Skip to the Assembly and Test section if you just want to get started with the build.

Materials

Loops can be constructed from any conductor that can be formed into a loop. Examples are tubing, wire, coaxial cable and ducting.

Copper tubing will weather to a dark brown colour that is easy to hide in most gardens. Aluminium may be better for high mounted loops as it is much lighter and less visible against the background sky. Coaxial and wire loops are inexpensive though more likely to require a support frame.

Loop Shape

When considering loop shape, a single turn circular loop is the optimum as it has maximum enclosed area and minimum circumference and inductance.

This does not rule out using other shapes e.g. square or triangle, but there will be some impact on performance as they have a greater circumference for a given loop area which increases inductance and reduces the maximum frequency for small magnetic loop mode of operation.

Loops should be flat when viewed from the side and symmetrical about the vertical axis, as this will give the best depth of null. The simplest way to achieve symmetry is to mark a reference point on the loop material halfway along its length, before bending it into a loop. The mark will indicate the exact centre and the top most point of the loop, for mounting purposes.

Gain

For a given loop area, anything that can reduce the total loop inductance will increase gain and reduce the noise floor, by increasing the loop current into the amplifier. This can be achieved in a number of ways:

- Use thick/fat loop materials
- Connect thin wires in parallel (>20mm spacing)
- Connect multiple loops in parallel

Combinations of these parameters can be used.

Multi turn loops should be avoided as their inductance will increase by the square of the number of turns, which will reduce the loop current into the amplifier.

Very large loops may overload the amplifier or your receiver.

Maximum Frequency

The maximum frequency of interest should dictate the loop circumference, hence the loop area.

Multiple identical loops can be connected in parallel to increase the effective loop area.

Examples are 2 loops arranged to resemble a figure ”8”, or 4 loops arranged in a 4-leaf clover shape.

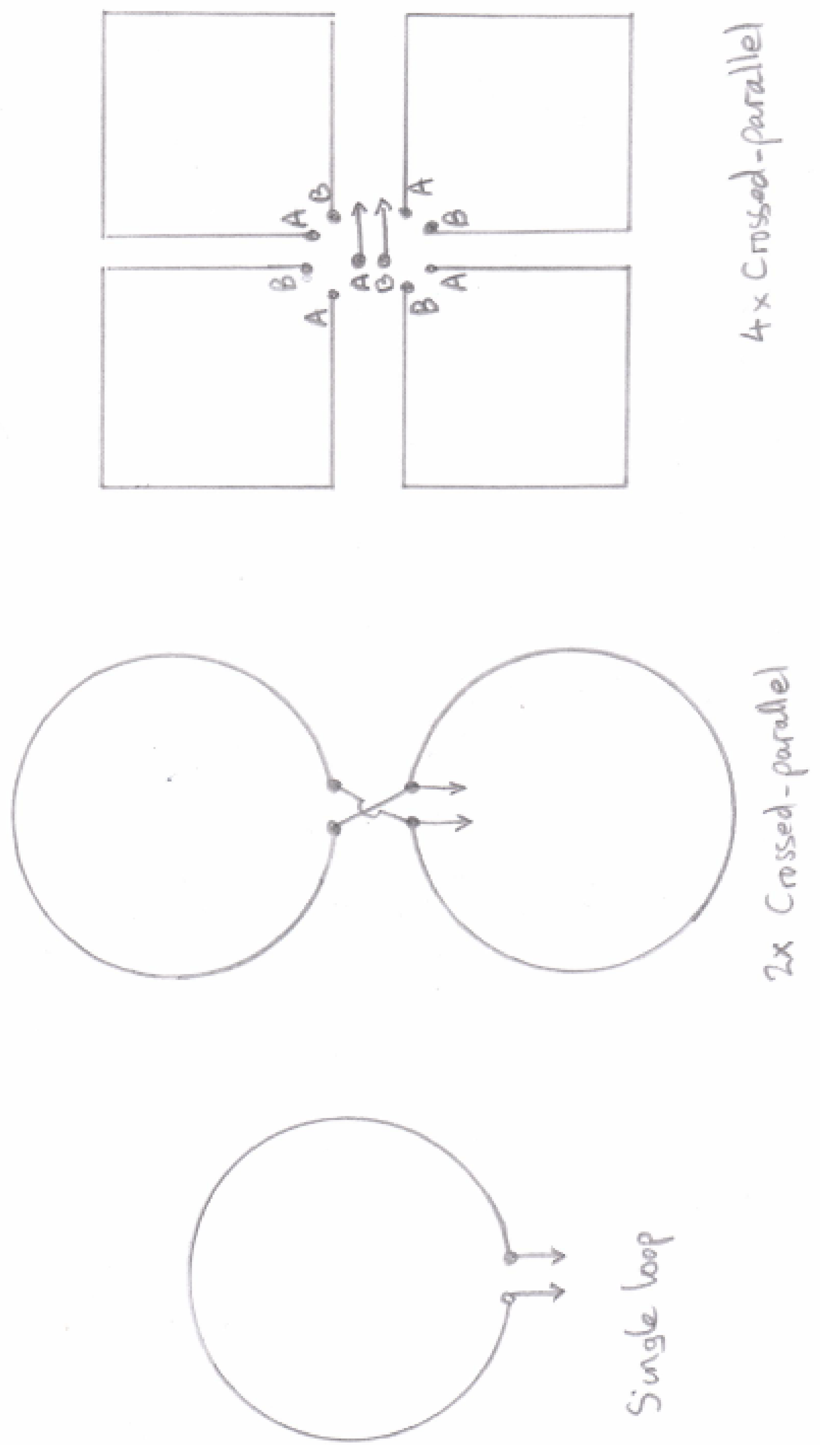
The currents in each loop must be connected in phase, by connecting the clockwise ends of the loops together as one amplifier input and the anticlockwise ends as the other input.

Such loops may be more conveniently built as 2 or 4 square shape loops, in which case the parallel edges between loops should be spaced apart >20mm.

Small loop characteristics will apply based on the circumference of one loop, regardless of how many loops are connected in parallel.

Example loop configurations

The arrows indicate the connections to the amplifier input.
For the 4 loop configuration, connect all points marked ‘A’ together (the anticlockwise ends of the loops), and all points marked ‘B’ together (the clockwise ends).
The amplifier should be mounted centrally between adjacent loops, with the coaxial cable running vertically down until it is clear of the lowest loop. This will help reduce QRM from being coupled to the loop from the coaxial cable.



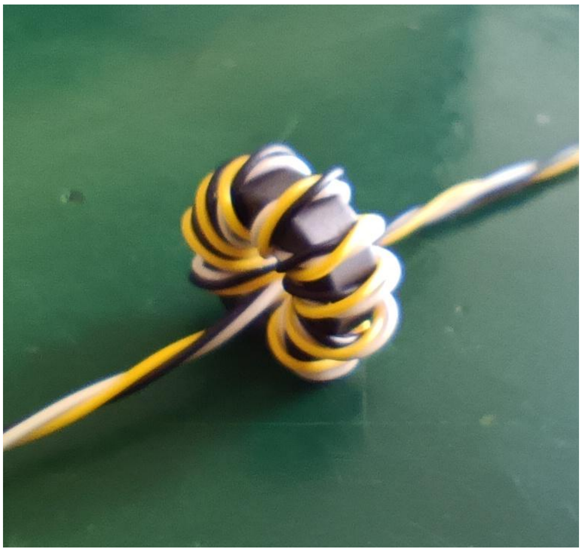
Assembly & Test

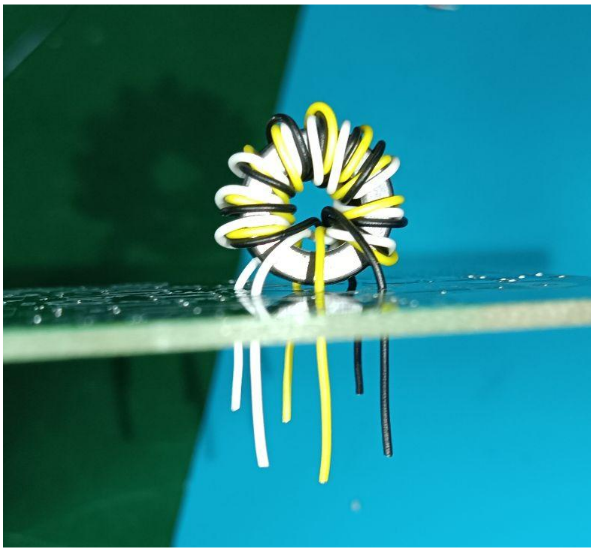
It’s simple to build but…

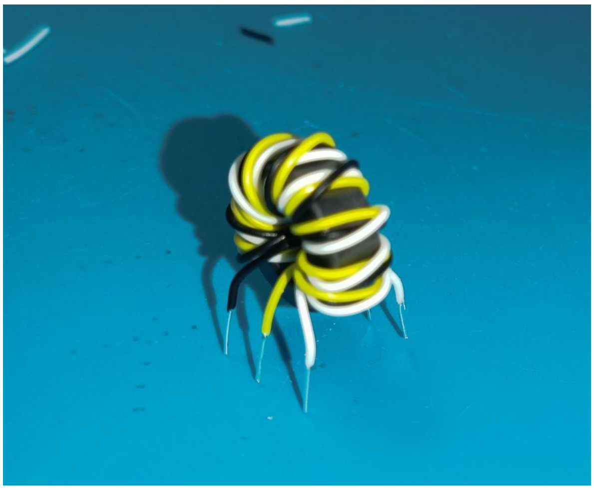
To avoid those “doh!” moments, read the assembly notes before starting.

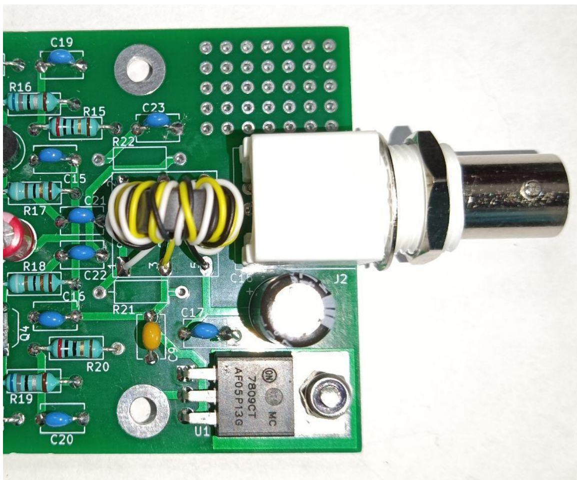
TR1 transformer assembly

- ☐ It’s easier to form the transformer leads and strip the insulation ready for soldering when the PCB is empty, so prepare it before starting on the PCB assembly.
  Do not solder it to the PCB at this stage as it will get in the way of construction.









Construction

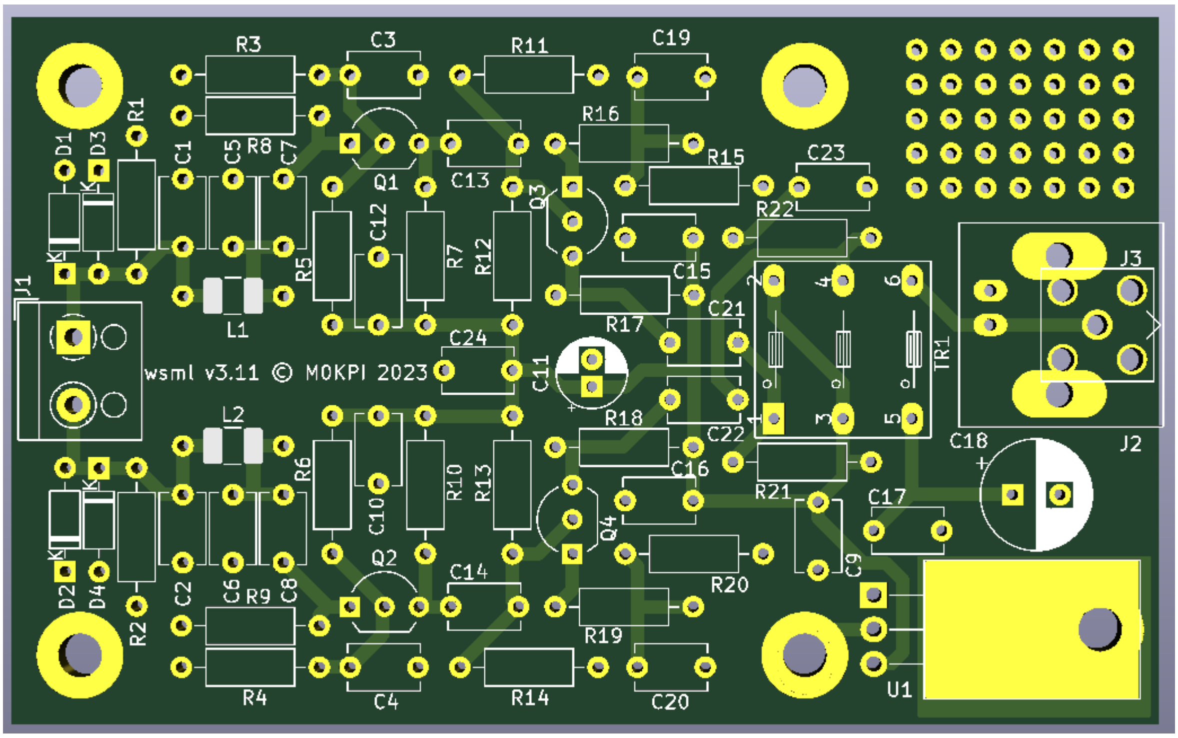
- ☐ Twist 3 pieces of 26awg Kynar insulated wire together, 30cm long, approximately 1 twist per 15mm. To aid identification, 3 wire colours are used.
- ☐ Wind 10 turns of the twisted wires on the toroidal core. If you keep each new turn tightly against the previous one, then the 10 turns will fill the circumference of the toroid without overlapping. Each time the wires pass through the hole in the toroid, it counts as 1 turn.
- ☐ Form a small gap between the first and last windings by gently pushing them apart, to allow the toroid to stand vertically on the PCB (see photo). Don't worry if you don't end up with much of a gap, it won't affect performance, it just helps the core to sit flat and upright on the PCB.
- ☐ The finished transformer should have 3 wires, 1 of each colour with approximately 2 inches/5cm of wire sticking out from each side of the toroid.
- ☐ Prepare the transformer for mounting. It is mounted vertically, in line with the BNC connector (see photo).
- ☐ The PCB is marked with 6 pin numbers. One colour is wired across pins 1-2, the next across 3-4 and the last across 5-6. Prepare the wire ends but don't solder them to the PCB at this stage.

Enclosures

- ☐ An IP55 or better rating plastic enclosure should keep the amplifier dry from rain and spray from the garden hose.
- ☐ Use the blank PCBs as templates to mark your enclosures for drilling, or to make paper templates.
- ☐ Be aware that some enclosures have sloping vertical sides, in which case the BNC connectors should be fitted to the PCB at an angle to match the slope, to prevent the PCB and solder joints being stressed when the fixing nuts are tightened.

Amplifier assembly

- ☐ All components are marked with their value and polarity where relevant, or colour coded. The ceramic capacitors have tiny writing on them so identification can be aided by the quantity supplied. The 10nF part (marked “103”) and the 470nF part (marked “474”) might be more difficult to identify as both have a quantity of one.
- ☐ Refer to the parts list for the value of each component. Note that the value of some parts is “dnf”, i.e. they are not fitted.
- ☐ The circuit reference and orientation of each component is printed on the PCB.
- ☐ Fit wire links across L1 and L2. Use resistor lead offcuts.
- ☐ Before soldering the voltage regulator, mount the tab directly against the PCB using an M3 screw and locknut. Do not over tighten. In use, the device gets warm, but not hot enough to worry about a heatsink.
- ☐ The supplied transistors have already been matched for gain and forward voltage drop, so they can be used in any position Q1 to Q4.
- ☐ Fit the transformer last, as it tends to get in the way of construction. For extra support, it can be glued to the PCB after the amplifier is verified as working.


R3
C3
R11
C19
R1
D1
D3
C1
C5
R8
C7
Q1
C13
Q3
R16
R15
C23
R22
K
R5
C12
R7
R12
C15
J3
J1
L1
C24
R17
C21
C11
TR1
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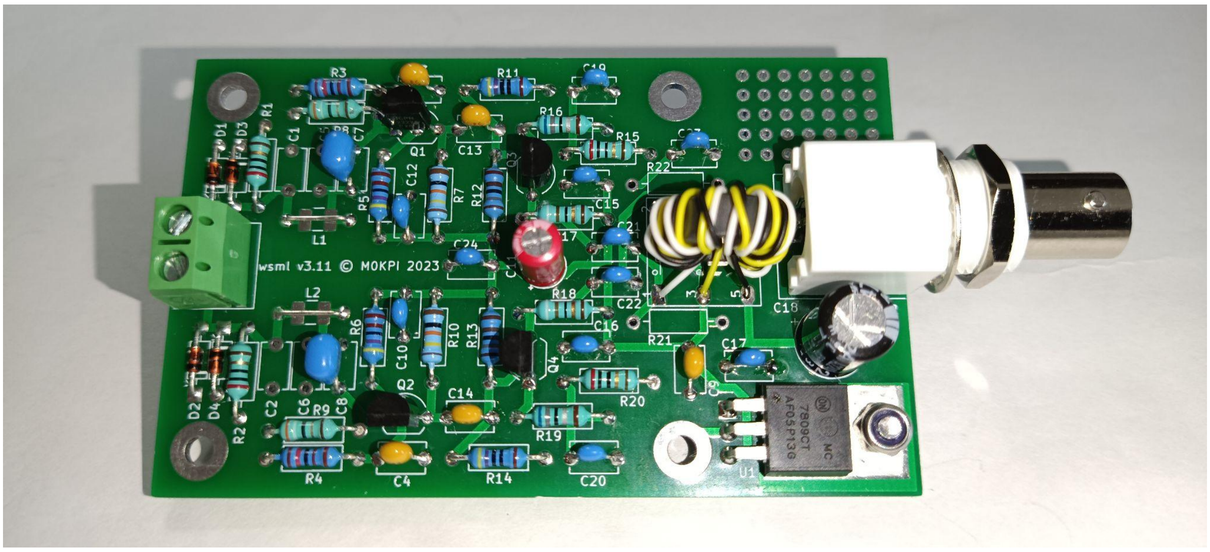
L2
R18
C22
C18
J2
R6
C10
R10
R13
C16
R21
C17
Q4
D2
D4
C2
C6
R9
C8
Q2
C14
R20
C9
R2
R19
U1
R4
C4
R14
C20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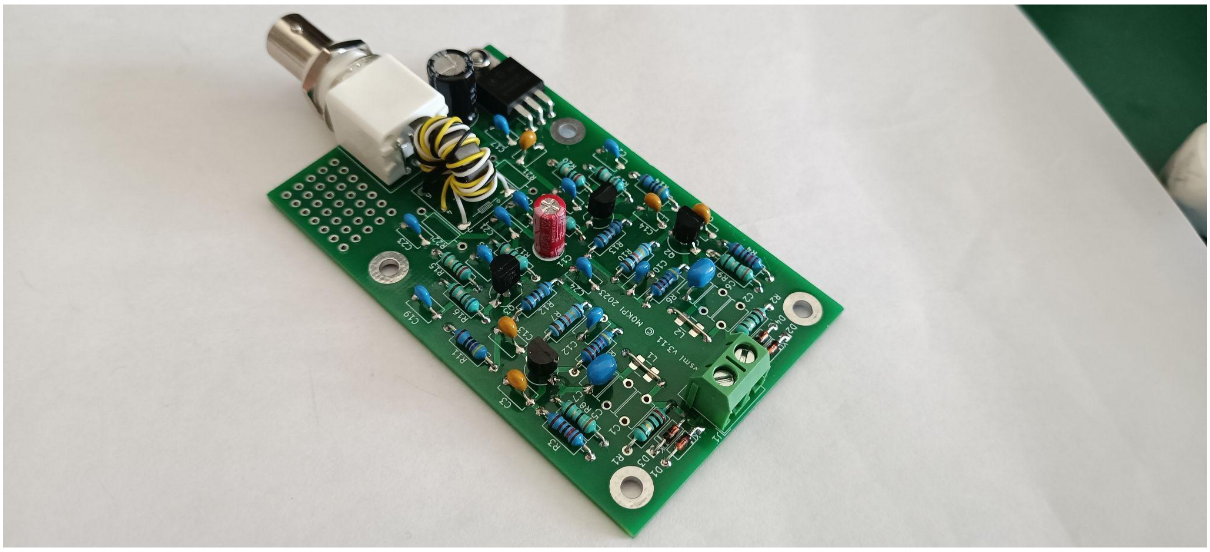
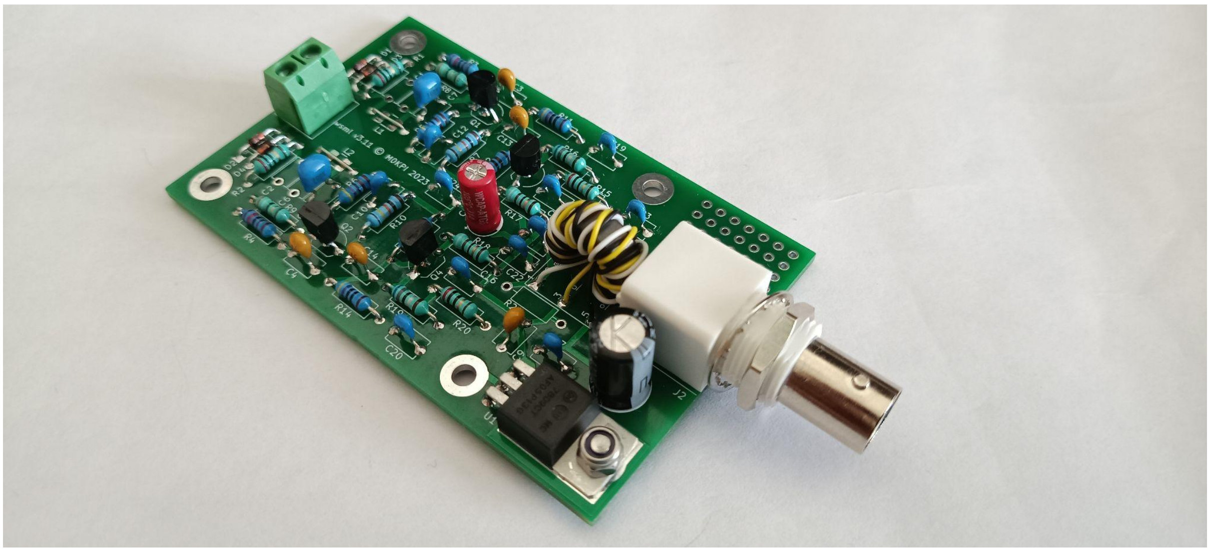
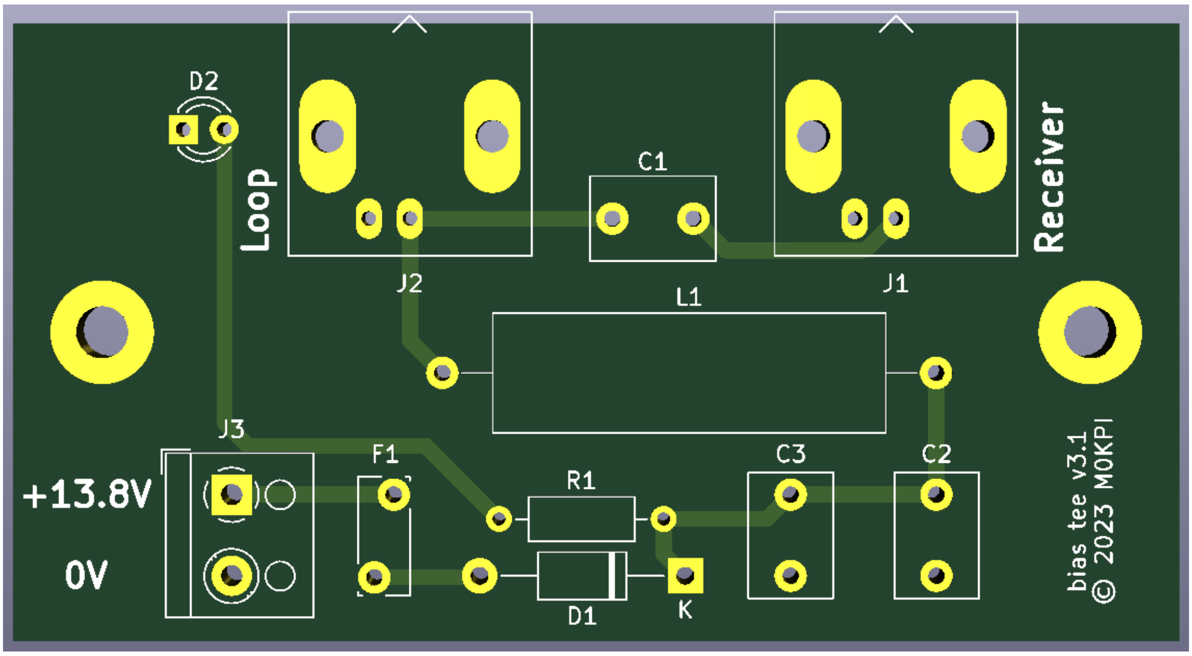
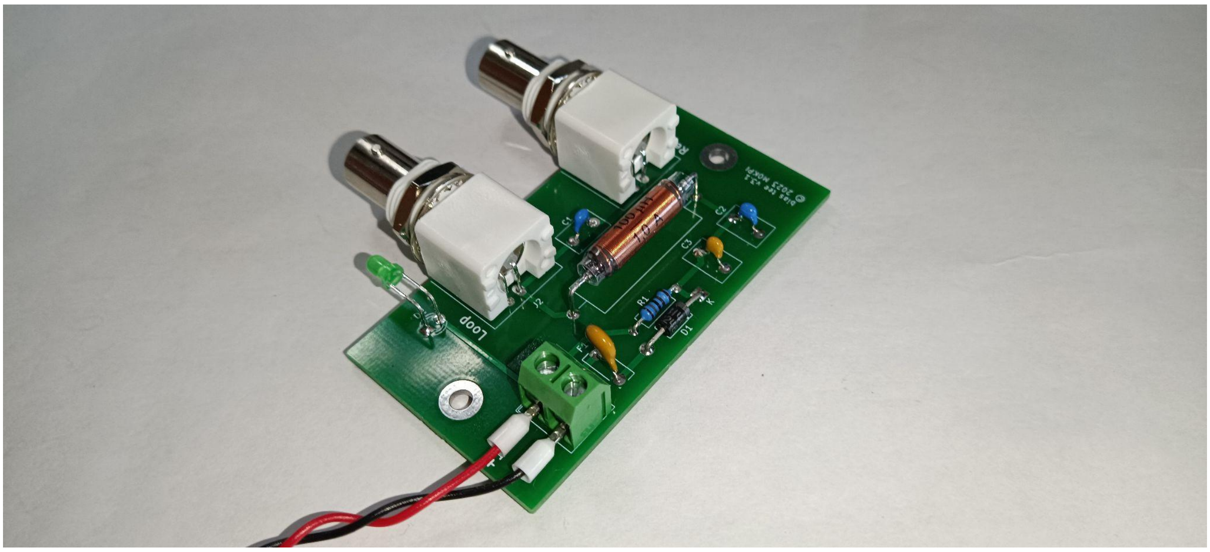


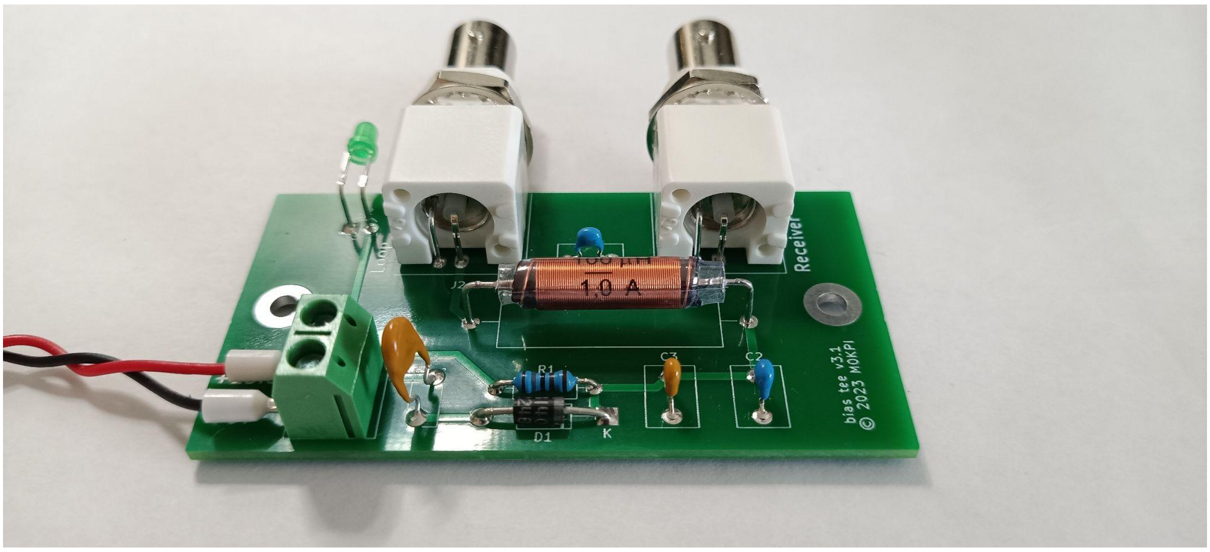


Bias tee assembly

- ☐ Inductor L1: To avoid damage to the inductor wires, don't bend the leads hard against its body. The data sheet states "When bending the leads, take care that the bending point is at least 3 mm apart from the face ends of the core and that the start-of-winding areas are not subjected to any mechanical stress".
- ☐ Inductor L1: Leave a 3 to 5mm gap beneath L1 when fitting it, to reduce stray capacitance to the PCB ground plane.
- ☐ Don't apply excessive heat to the polyfuse F1 during soldering.


D2
Loop
C1
Receiver
J2
L1
J1
J3
F1
R1
C3
C2
+13.8V
0V
D1
K
bias tee v3.1
© 2023 M0KPI





Test

Bias Tee test

- ☐ Verify that there is no short circuit across connector J3 between terminals 1 and 2.
- ☐ Apply +12 to +13.8VDC power to the bias tee via J3, noting the polarity.
- ☐ Verify that the LED is on.
- ☐ Verify that slightly less than the applied voltage is present on the “Loop” connector J2 centre pin, due to D1 voltage drop.
- ☐ Verify that no voltage is present on the “Receiver” connector J1 centre pin. A small voltage may be indicated due to capacitor C1 charging via the test meter.
- ☐ Remove power.

Amplifier test

- ☐ Verify that there is no short circuit between U1 pins 1 to 2, and pins 2 to 3.
- ☐ Connect the amplifier to the bias tee J2 “Loop” connector via a coaxial cable fitted with BNC plugs.
- ☐ Apply power to the bias tee.
- ☐ Verify that the DC power supply current draw is 150mA ±15mA.
- ☐ Verify that 9V ±0.1V is present at U1 pin 3.
- ☐ Verify that 5.2V ±0.2V is present at the collector (pin 3) of each transistor, which is the right hand pin when looking at the flat face of the transistor.
- ☐ Remove power.

Performance test

To verify the amplifier performance and to fix and debug boards, a project test evening can be arranged at the club.

Quick test

To verify basic operation, connect a 0.7 to 1m diameter loop antenna to the amplifier and verify that the local MW transmitter is received, e.g. 909kHz Radio 5 Live from the Titchfield transmitter. Peak the signal by rotating the loop in azimuth and note the signal level. Rotating the loop 90 degrees should null the station by 20 to 30dB.

Version history

V1.1	5/6/2023	Initial version
V1.2	7/9/2023	Minor corrections, clarifications and updates