Overview

The FM Rev3.05K is a professional quality phase-locked-loop (PLL) based FM transmitter designed to operate in the frequency range 87.5 to 108 MHz. The FM 3.05K has the following features, it:

- Uses a half-frequency oscillator, to get round the feedback problems that an at-frequency oscillator can suffer from in RF hot environments
- Is built from the minimum sub-set of components, to keep the cost of getting all the parts together as low as possible
- Doesn't use lots of expensive or difficult-to-get-hold-of parts
- Can accommodate different output transistors (such as the 2N4427, MRF237 and similar)
- Can use a range of transistors for most of the parts (such as the BF199, MPSH10 and similar)
- Will produce around 1 Watt across the band with as little fiddling as possible (or more depending on the output transistor)
- Has an output that is legally clean enough to either be connected directly to an antenna, or amplified to high power (nothing over 60dB below the carrier)
- Keeps the digital and analogue parts of the circuit as separate as possible to minimise digital noise on the modulation
- Doesn't require any micro-controllers and thus does not require any software to be written/blown
- Has out-of-lock power-down to stop transmissions on unwanted frequencies whilst the phase lock loop is settling down
- Is straightforward to set onto the desired frequency
- Can be easily tested and maintained (to the extent that it could be built in stages, testing each along the way)
- Has a flat frequency response from around 3 Hz to at least 100 kHz, providing superlative modulation
- Does not need any tuning (other than setting the VCO frequency)
- Can have its output quickly disabled (i.e. for connection to a high SWR detector)
- With some component changes, can be made to work on Band-I too (the design will work down to about 52 MHz)

The FM 3.05K uses a half-frequency oscillator, meaning that even when amplified to high powers, the impact of any radio frequency (RF) feedback is minimised, improving stability and reducing buzz when the transmitter is located close to the antenna.

Using a standard output transistor, the design will produce around well over 500 milliWatts with a 12 Volt supply rising to 1 Watt with a maximum 15 Volt supply across the whole frequency range. Other output transistors can be used, with output powers of over 2 Watts possible.

Compared to many other similar transmitters, the FM 3.05K uses a very low PLL loop frequency. This means that the PLL does not attempt to 'correct' bass modulation and together with the careful design of the circuit, means that the frequency response is flat to from around 3 Hz to over 100 kHz, ensuring very clean and accurate modulation.

An out-of-lock power down circuit ensures that there is no output from the transmitter until the PLL is locked, preventing emissions on frequencies other than that to which it is set (which can be disastrous for high power amplifiers when connected to a narrow-band antenna).

The output of the transmitter is filtered by a 7 pole low pass filter, reducing all spurious outputs to at least 60 dB below the main carrier. This exceeds the harmonic output requirements of Ofcom's Site Engineering Code for Analogue Radio Systems.

Please read the instructions in full before beginning construction (especially noting the fitting of the BB809 varicap diodes and the variable capacitor).

Important Notice: A licence is normally required to connect this transmitter to an antenna. Please ensure that you have the necessary authorisations before using this device with an antenna.

Construction

To construct the kit you will need:

- A soldering iron, preferably with a narrow tip
- Solder
- A pair of snips or side cutters to trim component leads once devices are soldered to the board
- A 4mm former for winding coils (the smooth end of a 4mm drill bit is ideal for this)

Check that you have all the parts by comparing those supplied with the parts list and familiarise yourself with which components are which.

In general, when loading components into a PCB, the principle used is to start with those with the shortest profile (i.e. diodes and resistors) and end with those with the tallest profile (i.e. electrolytic capacitors). All components should be mounted as flush to the PCB as possible.

Start by fitting all of the diodes, including the varicap diodes which sit next to the place identified for the circular toroid.

IMPORTANT NOTE: The varicap diodes (BB809) should be installed with the bar on the diode the opposite end to that displayed on the PCB (i.e. pointing away from where the 22pF variable capacitor sits). This is an error on the PCB silk screen.

Next fit all of the resistors and the two 1 uH inductors (which look like slightly thicker resistors). Help with identifying resistor colour codes can be found online at:

- www.wirelesswaffle.com/resistors/

Continue by fitting the TO-92 style transistors (do not, at this point, fit the output device). Note the orientation of the transistors as marked on the board. In all cases, it should be possible to mount these transistors flush to the circuit board. The 6.4 MHz crystal can also be fitted.

The small ceramic capacitors should be installed next (not the tall electrolytics). These should be fitted as close to the board as possible, ideally with any excess leads above the board no longer than 1mm long.

At this point decide whether you intend to use the IC sockets or to solder the ICs directly to the board. If you intend to socket the IC's then install the sockets now. Do not install the IC's themselves at this point.

Continue by installing the 10 way switch, the 100nF capacitors and the three LED's (carefully noting the orientation of the LED's). Next install the electrolytic (tall) capacitors, the negative lead (marked on the side of the capacitors with a stripe) should be in-line with the solid bar marked on the PCB. Finally connect the LM317, the side with the metal tab facing the outside of the PCB. This should push down to be flush with the PCB.

At this point, some initial tests of the board can be conducted. Connect a 12 to 15 Volt supply to the board (the positive goes to the square hole labelled '+12V' and the negative to the round hole next to it). With the power connected, the following can be checked (note that 'left hand' and 'right hand' refer to the board as viewed from the top with the IC's at the top of the boardO:

- The '+9V' and 'LCK' LED's should light up.
- If you have a receiver capable of receiving a frequency of 6.4 MHz (short wave), you should be able to hear a silent carrier on this frequency.
- Check that the following voltages are as indicated (anything within half a Volt of these values should be more than adequate)

Measurement Point	Approximate Expected Voltage
4046, pin 16	9.6 V
74HC4020 (any), pin 16	7V
74HC4020 (left hand IC, near to the LED's), pin 10	3.5V
74HC4020 (right hand IC, near to the LM317), pin 10	3.5 V

Disconnect the power and fit the 4046 IC (but not the others), taking care as this device can be sensitive to static, noting the orientation of the IC. Re-connect the power and check the following:

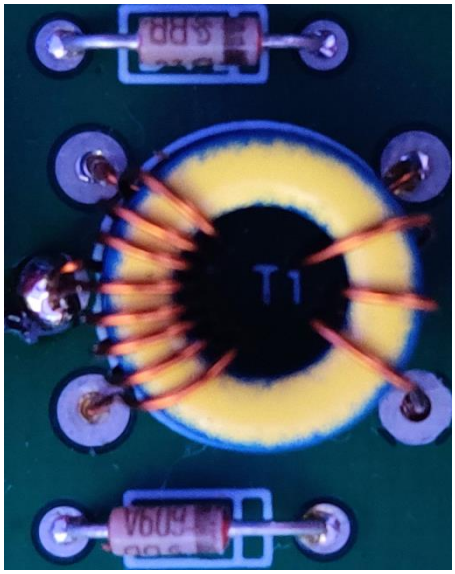
- The '+9V' LED should light, but the 'LCK' LED should no longer be illuminated.
- Check that the following voltages are as indicated

Measurement Point	Approximate Expected Voltage
74HC4020 (any), pin 16	6V
74HC4020 (left hand IC), pin 10	3V
74HC4020 (right hand IC), pin 10	3V

The toroidal transformer should be fitted next. This is critical to the correct functioning of the transmitter and careful attention must be paid to winding it. Begin by taking the thinner enamelled copper wire provided and folding it over on itself in the middle (creating a tight 'U' turn). Carefully strip the enamel from the centre of the wire where it has been folded and tin it with solder.

Starting from the centre point you have created, tightly wind 4 turns in each direction around the toroid core, such that you end up with a total of 8 turns, with the centre you formed in the very middle (i.e. 8 turns centre tapped). Cut off excess wire leaving enough to solder the ends to the PCB. Remove the enamel coating from the ends left on the core and tin these with solder to make them easier to mount on the PCB.

The secondary of the transformer is 3 turns wound on the opposite side of the toroidal core to the winding you just made (use a piece of the remaining thin copper wire). It does not matter whether these 3 turns are wound in the same direction as the previous winding or not. Again, remove the enamel and tin the ends of the winding ready for soldering to the PCB. The completed transformer, when mounted on the PCB should appear similar to in the picture below, with 8 turns showing on the main winding and 3 on the secondary (note that this picture is for an earlier board and shows the varicap diodes installed the correct way, and the silk screen the correct way).



Once you have soldered the toroid in place, re-connect the power and check the following voltages.

Measurement Point	Approximate Expected Voltage
Right hand side of both 470 Ohm resistors next to the MPSH81s	5V

If the above voltages are correct, it may be possible to hear the oscillator on an FM radio, however the exact frequency of oscillation will depend upon a number of factors and is difficult to predict as the PLL is not operating at this point.

The three 74HC4020 IC's should be installed next, again taking care as these IC's are sensitive to static and carefully noting their orientation.

Set the switches on the 10 way switch to 'Off-Off-Off-On-On-On-Off-Off-On' (reading the switches from left to right where left is closest to the 4046 IC), this should set the PLL to a frequency of 108.0 MHz. Re-connect the power.

Ideally at this point the following should happen:

- The '+9V' LED should initially light. After a few seconds, the 'LCK' LED should also light.

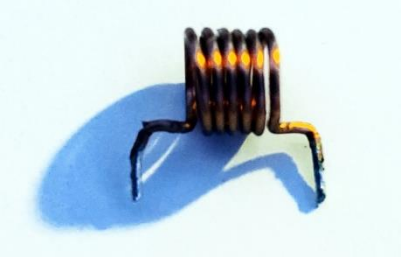
If this happens, then everything is working, you should be able to hear a silent carrier on 108.0 MHz on a nearby FM receiver, and you can proceed to installing the hand-wound inductors and conduct the checks associated with them. If not, check the following voltages.

Measurement Point	Approximate Expected Voltage
74HC4020 (any), pin 16	6V
TP1	Anywhere between 2 and 8 Volts

It is now time to wind the five coils with the following number of turns:

- L1 has 6 turns
- L2, L3 and L8 have 5 turns
- L5 has 8 turns
- L7 has 2.5 turns

All of the coils should be wound tightly on a 4mm former (such as the shaft of a 4mm drill bit, or a piece of 4mm wooden dowel) using the thicker (0.56 mm diameter) wire. Leave enough additional wire at the end of each coil to form legs that can be used to mount the coils on the board. Remember to strip the insulation off each end of the enamelled wire so that it can be soldered. The finished coils should look something like the picture below (the example shown has 6 turns).



Once all the coils are wound and installed, re-connect the power and check the following voltage:

Measurement Point	Approximate Expected Voltage
Left hand side of the 47 Ohm resistor next to L5	1V

It is now time to fit the output transistor (2N4427 or whatever is your preference). This should be mounted so that it is flush with the top of the PCB, with the metal lug on the transistor in the same position as the lug indicated on the PCB (note that the position may need to be reversed for some alternative transistors). This transistor needs to be fitted with the supplied heatsink. The easiest way to do this is once the transistor is firmly mounted on the board, prise the heatsink ever so slightly open using a screwdriver and slip gently over the transistor. The screwdriver can then be removed such that the heatsink now clasps tightly against the transistor.

At this point, do not fit the 22pF variable capacitor next to the toroid transformer. Note also that the 22pF tuning capacitor next to the 6.4 MHz crystal is not required.

You should now have mounted all the components on the PCB (with the exception of the 22pF tuning capacitor).

Ensure that you have a 50 Ohm load connected to the RF output and re-apply the power. The following should now happen:

- The '+9V' LED should light immediately. This should be followed, after a few seconds, by the 'LCK' LED and quickly thereafter the 'PWR' LED should glow. Note that the 'PWR' LED is often dimmer than the other two.

If this happens, then you have successfully completed assembly of the transmitter and can move to setting the frequency. If not, check the voltage at TP2. This should be at least 0.25 Volts.

Setting the frequency

Now is the time to install the 22pF variable capacitor that sits next to the toroid transformer.

The positions of the DIP switches required to set the transmitter to a particular frequency can be found at:

- www.zynq.uk/tx/

When you have set the switches to the correct positions for the frequency you wish to use, re-apply the 12V power source. Gently rotate the variable capacitor until the 'LCK' LED lights. Once it has lit, measure the voltage at TP1 and again slowly rotate the variable capacitor until this is in the range of 5V to 8V. This will ensure optimum modulation performance and completely reliable lock.

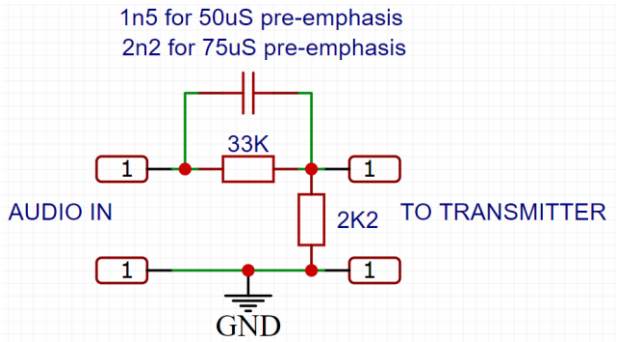
If using a frequency towards the bottom of the band and the voltage at TP1 will not rise as high as 5V, add an additional 10pF (or thereabouts) capacitor in the holes next to the 22pF tuning capacitor.

Carefully compress or expand the turns of inductor L5 (8 turns) to maximise the brightness of the 'PWR' LED. This will maximise the output power of the transmitter. Some people have found that very slightly expanding the turns of L8 can also increase output power.

No other adjustments are necessary. The output power of the transmitter should exceed 500 mW for a 12 Volt supply. With a 15 Volt supply the output power should reach 1 Watt. Do not exceed 15 Volts on the power supply.

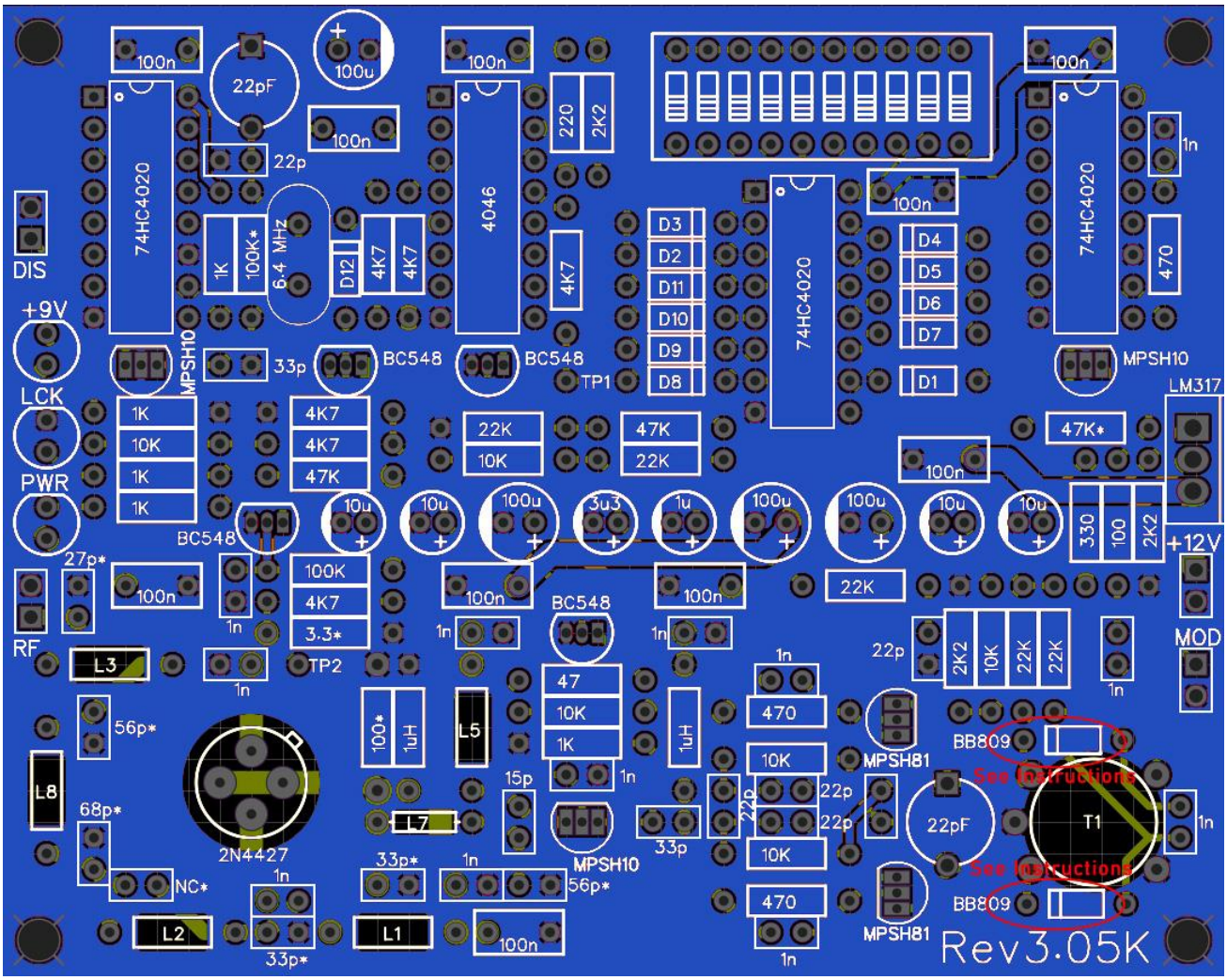
Note: Some people have found that replacing the 15 pF capacitor next to L7 with an 18 pF capacitor can increase the output power at the lower end of the band (i.e. below 90 MHz).

The modulation input to the transmitter is very sensitive, only a few hundred milliVolts of audio are required for full deviation. Note that the input is not pre-emphasised and is intended for a pre-emphasised input (or a stereo MPX input). If pre-emphasis is required, please use the following circuit at the audio input to the transmitter (components not supplied).



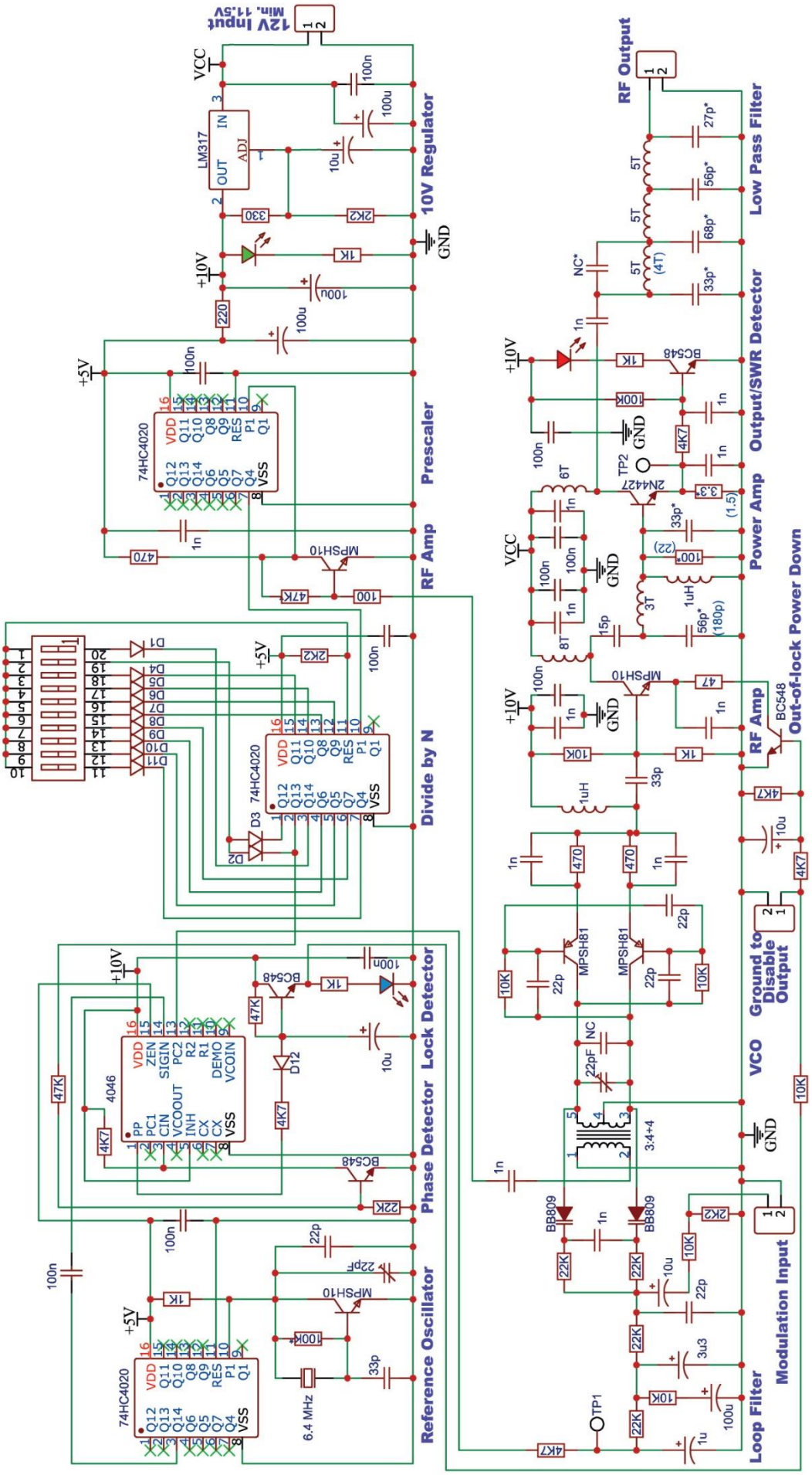
PCB Layout

The layout of the PCB is replicated below for reference (as installing the components can cover up their label on the PCB).



Circuit Diagram

The circuit diagram of the transmitter is provided on the next page. There are a few components marked 'NC' (not connected). These are not necessary for the correct functioning of the transmitter over its normal frequency range, and are only needed when the unit is used for special purposes.


12V Input
Min. 11.5V
10V Regulator
Prescaler
RF Amp
Divide by N
Lock Detector
Phase Detector
Reference Oscillator
Low Pass Filter
Output/SWR Detector
Power Amp
RF Amp
Out-of-lock Power Down
VCO
Ground to Disable Output
Modulation Input
Loop Filter
RF Output
LM317
74HC4020
4046
MPSH10
MPSH81
BC548
2N4427
BB809
6.4 MHz

Parts List

Capacitors	Number
100nF Box Capacitor	10
100uF 25V Electrolytic	4
10uF 25V Electrolytic	4
1uF 50V Electrolytic	1
3.3uF 50V Electrolytic	1
1nF Ceramic	12
22pF Ceramic	5
33pF Ceramic	2
68pF Ceramic	1
27pF Ceramic	1
56pF Ceramic	2
15pF Ceramic	1
Resistors	**Number**
3.3 Ohm, ¼ Watt	1
47 Ohm, ¼ Watt	1
100 Ohm, ¼ Watt	2
220 Ohm, ¼ Watt	1
330 Ohm, ¼ Watt	1
470 Ohm, ¼ Watt	3
1K Ohm, ¼ Watt	5
2.2K Ohm, ¼ Watt	3
4.7K Ohm, ¼ Watt	6
10K Ohm, ¼ Watt	6
22K Ohm, ¼ Watt	5
47K Ohm, ¼ Watt	3
100K Ohm, ¼ Watt	2
Semiconductors	**Number**
1N4148 Diode	12
BB809 Diode	2
LED (Any Colour)	3
BC548 Transistor	4
MPSH10 Transistor	3
MPSH81 Transistor	2
2N4427	1
LM317 Regulator	1
CD4046 IC	1
74HC4020 IC	3
Miscellaneous	**Number**
0.56mm Copper Wire	
0.4 mm Copper Wire	
1uH Axial Inductor	2
Transistor Heatsink	1
10 Way DIP Switch	1
T37 Toroid	1
22pF Trimmer Capacitor	1
6.4 MHz Crystal	1

Alternative parts

If building this kit from your junkbox, the following substitutions can be made:

Original	Alternative	Notes
1N4148	1N914 Any small signal silicon diode	
BB809	1SV68 1SV124 BB609	Different varicaps may alter the tuning range slightly. If it is not possible to tune to the bottom of the band, a small value (i.e. 10pF) capacitor may be added in the space next to the 22pF tuning capacitor.
MPSH10	2SC3355 BF199 BF224 / BF241 (need to be installed rotated 180 degrees from that illustrated on PCB) Any TO-92 VHF/UHF RF transistor whose pinout is C-E-B when viewed from left to right when installed on the PCB.	Changes may need to be made to the component values of the 47K and 100K resistors on the PCB marked with a '*'. These may need to be adjusted so that the voltage on the collector of the replacement transistor is around 3 Volts.
BC548B	Any general purpose TO-92 NPN transistor whose pinout is E-B-C as viewed from the left to right when installed on the PCB.	
MPSH81	BF451 Other PNP VHF/UHF transistors can be used but may have different pinouts and need to be installed with their legs contorted.	
2N4427	2N6255 2SC730 2SC1947 2SC2329 MRF227 MRF237 MRF607 SD1127 TP2314 Carefully check the pinout of the transistor as some require the transistor to be mounted with the 'tab' 180 degrees away from where it is indicated on the board	These alternatives may all produce a slightly higher power output (between 1.5 and 2 Watts). If higher output power is not achieved, the following changes may need to be made to accommodate them: • The capacitor marked 56pF* close to the 15pF capacitor should be replaced by a 180 pF capacitor • The resistor marked 100* should be replaced by a 47 Ohm resistor (this is only necessary if any instability occurs) • The 3.3 Ohm resistor can be replaced by a 1.5 Ohm resistor • L2 should be replaced with a coil with 4 turns (instead of 5)