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# An Easy Way to Lock your Radio to a Rubidium Reference.

For many of us playing around with microwave transverters the inherent stability and phase noise of our base radios leaves something to be desired. Some manufacturers offer "High Stability" options for their radios but they still fall short of of the ultra stable and clean oscillators required for use at SHF frequencies.

## *Current Solutions*

GPS based 10MHz standards have become ubiquitous with many types available via eBay or other online sales mechanisms. Most are ex Telco equipment and have excellent performance characteristics, many of these have formed the basis of GPS locked oscillators for various radios.

The problem with most GPS based systems is that they're bulky and required voltages other than 12v to operate. If you want to go mobile with your reference you have the additional problems of a second antenna to worry about and most GPS references require themselves to "self survey" once moved, which means they wont have a disciplined output for 30 minutes or more !

Another option is to drive your oscillator with a 10MHz rubidium standard which usually takes 5 minutes or less to produce a disciplined output, but once again the more popular rubidium standards require +24v to operate making portable use harder than it should be.

## *An Easier Solution.*

In researching the different ways I could create to lock my radio ( in this case an Icom IC-910 ) to a reference oscillator, and maintain portability, I stumbled across another ex-telco rubidium reference call the FE-5680A, originally used in Motorola cell sites.

What set this unit apart from all the others was that it would operate from 12v even though its specifications are 15 - 18v, was tiny, and it had a programmable output thereby simplifying the additional circuit requirements to attain the required operating frequency of the radio's oscillator.

A side benefit is that its cost is comparable with purchasing the ICOM CR293 high stability option, currently ~$169.00. This Rubidium standard cost about the same including the box and circuits to complete the build.

Given the programmable nature of this unit, it can easily be used to lock nearly any radio with a minimum additional circuitry and in some cases could be used directly. David, G4HUP, has compiled a list of radios and their LO frequencies. That list can be found here...

http://g4hup.com/XCVR%20MO%20list.pdf

FE-5680A's can be found on eBay from a few sellers at reasonable prices and others at not so reasonable prices, so make sure you do a good search for them. Some have an SMA for the 10MHz output, some have it on pin 7 of the D connector and some require modification to bring the RF out to the front panel. In any case its straight forward to get the RF out of the unit.

More detail on the FE-5680A can be found here....

http://www.freqelec.com/rb_osc_fe5680a.html

*Illustration 1: Typical FE-5680A*

## *Specification Comparison*

The specifications of the FE-5680 are comparable to the popular GPS reference, the Trimble Thunderbolt, as this table of the main parameters show...

| **Parameter** | **FE-5680A** | **Trimble Thunderbolt** |
|---|---|---|
| **Frequency** | 10MHz | 10MHz |
| **Type** | Sinusoidal | Sinusoidal |
| **Amplitude** | +7dBm | +12.5dBm |
| **Harmonic Level** | -30 dBc | -40 dBc |
| **Spurious** | -60 dBc | -70 dBc |
| **Phase Noise @ 10Hz** | -100 dBc/Hz | -120 dBc/Hz |
| **@ 100Hz** | -125 dBc/Hz | -135 dBc/Hz |
| **@ 1000Hz** | -145 dBc/Hz | -135 dBc/Hz |
| **10MHz Accuracy** | $2 \times 10^{-11}$ /day | $1.16 \times 10^{-12}$ /day |
| | | |
| **DC Requirements** | 12V to 18V | +12V, -12V, +5V |
| **Input power** | 11 watts steady, 27 watts peak | 10 watts steady, 15 watts peak |
| **Size** | 25 x 88 x 125 mm | 51 x 102 x 127 mm |
| | | |

It is expected that the accuracy of the Trimble to be higher than the RB unit since its constantly comparing and updating against the standards orbiting above. Also the phase noise of the FE5680 is slightly worse due to its output being that of a DDS rather than directly from a VCXO. The FE5680 does contain a VCXO but that is part of the loop in front of the DDS.

That being said, the specifications of both units are excellent and more than enough for amateur radio applications.

## *Figuring out the FE-5680A*

While the RB is programmable for any frequency between 1Hz and 20MHz, the factory builds a band pass filter for the resultant frequency prior to shipping. Thus if you program a 10MHz unit to some other frequency there is significant reduction in the output of the unit, so much so as to make it unusable.

My first idea was to reprogram the RB to 15.1MHz and simply double it to 30.2MHz to suite the IC-910, but the output was to far down to be usable. My second idea was to program it to 10.06666666 MHz and tripple that to get close to 30.2MHz. In this I was successful.

## *Programming the FE-5680A*

Data on programming the RB can be found here...

http://www.fetaudio.com/wp-content/uploads/2009/10/fei-5680A-pinout-jap.pdf

Alternatively a program has been written to reprogram the FE-5680 and that can be found here..

http://www.redrok.com/FE5680A.zip

## *Building a Low Noise Tripler*

Having looked at various tripler circuits on the internet I stumbled across an excellent article by Charles Wenzel of Wenzel Associates Inc, titled...

"New Topology Multiplier Generates Odd Harmonics"

The article can be found at this link...

http://www.wenzel.com/pdffiles1/pdfs/RFDesign2.pdf

This multiplier is also low noise and contributes little to the overall noise in the system.

Using this circuit I added an additional 7 pole chebyshev, low pass filter and amplifier stage to reduce any residual harmonics and amplify the signal to a suitable level. I also added an LED to show when power is applied.

I've used PCB mounted SMA connectors for the RF and the board is designed so that the SMA's can be mounted from either side of the PCB.

The complete circuit is reproduced in Appendix B.

I first built the circuit using standard components to test the design.

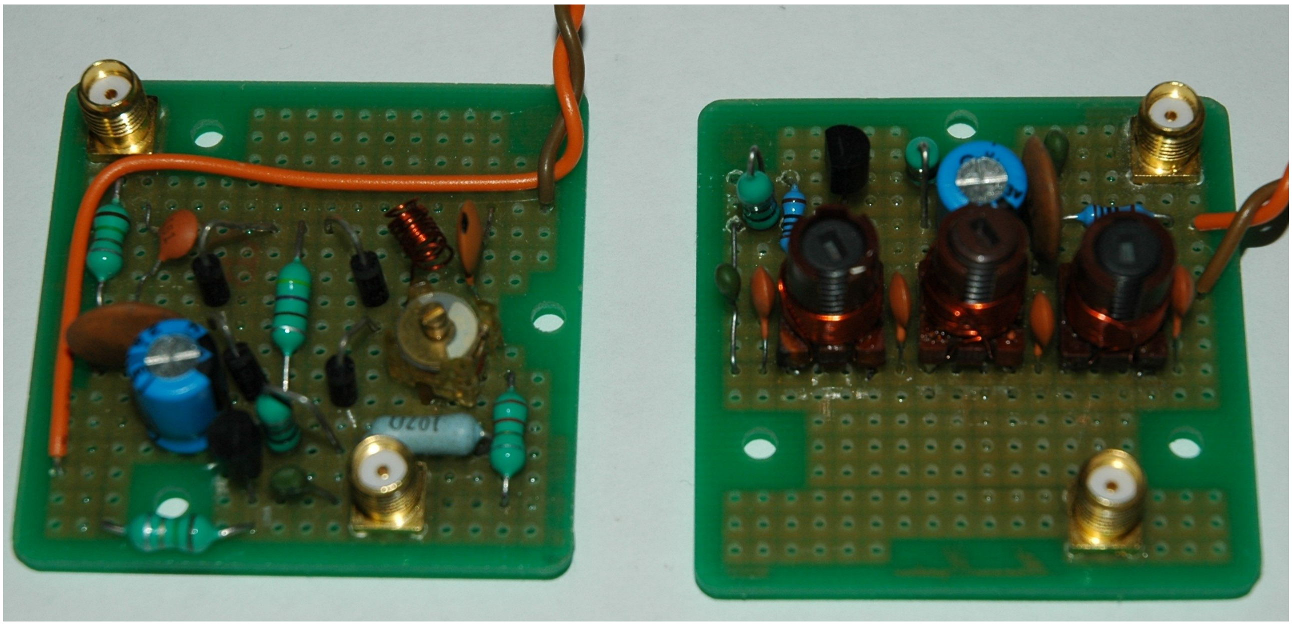

*Illustration 2: Prototypes*

The images show the tripler on the left and the filter amp on the right.

While these worked ok I wanted to do this in SMD and on a single, double sided PCB.  Using the PCB CAD software, DipTrace, I created a PCB pattern for SMD components.

This PCB I then had manufactured by one of the many Chinese FAB plants for a reasonable price. Assembly of the SMD board took about an hour and worked first go. Testing the output of the RB + tripler circuit produced an output within a few millihertz of 30.2MHz. Success !

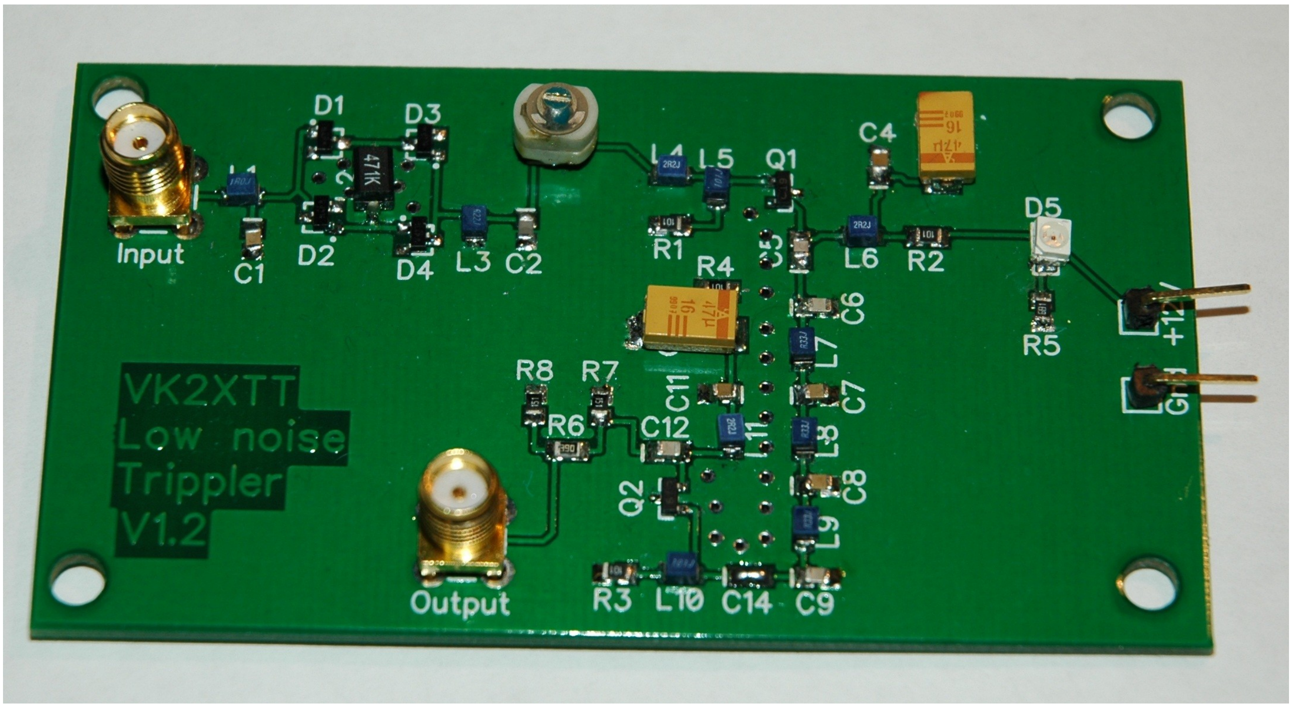


*Illustration 3: Assembled Tripler*

While I've called this a tripler, the circuit is quite capable of being used for other odd harmonics with appropriate changes to various L & C throughout the circuit. Given that higher harmonics will be of much lower amplitude, greater amplification will be necessary.

I intend to build a version of this for higher multiplication factors using a MAR6's or BGA2709's or similar and HSMS-2829 quad pack Schottky diodes  for greater waveform symmetry and lower jitter.

## *Additional Amplification.*

Now not required. When I assembled the unit I didn't realise some my low value SMDs were the wrong value. After building another of these units I found that the output came up to +10dBm which was more than enough to drive trhe IC-910 without the amplifier. I've since removed it.

~~Initial tests showed that I needed additional dBm to drive the LO circuit of the IC-910 so I built an amplifier on an RF Bay Inc. development board, using a MAR-6 to bring the output up.~~

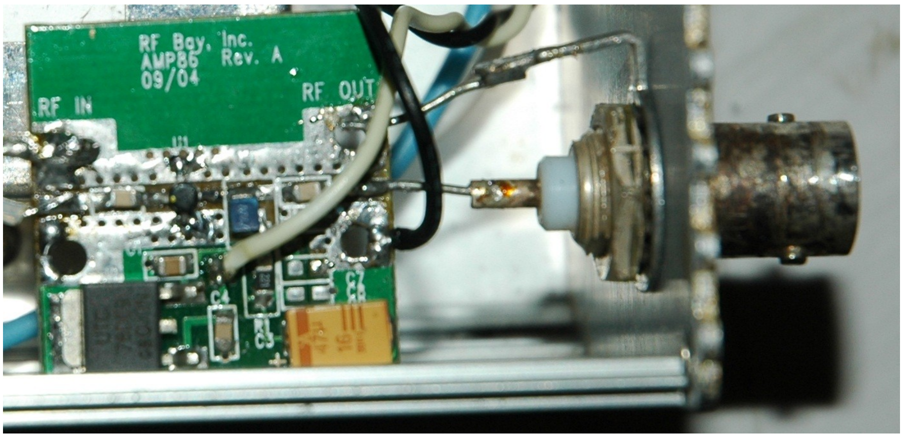


*Illustration 4: MAR-6 amplifier*

~~These board can be bought, four at a time, from their shop on eBay, and can be used for any of SOT-86, Micro-X style MMIC's.~~

~~Their Shop URL is [http://stores.ebay.com.au/RF-Basic-Store?_rdc=1](http://stores.ebay.com.au/RF-Basic-Store?_rdc=1)~~

~~More information on them can be found here.....~~

~~http://www.rfbayinc.com/~~

~~If you build this tripler for your own radio you may or may not need an amplifier for its local oscillator. Do some tests with an oscilloscope and read the service manual for your radio before proceeding.~~

~~The output of the tripler, without the MAR-6 amp, is approximately 0dBm.~~

## *Completing the Unit*

I built the unit into a nice box I found at http://www.rfsupplier.com/

This box gives a tight RF shield and just enough heat sinking for the RB unit.

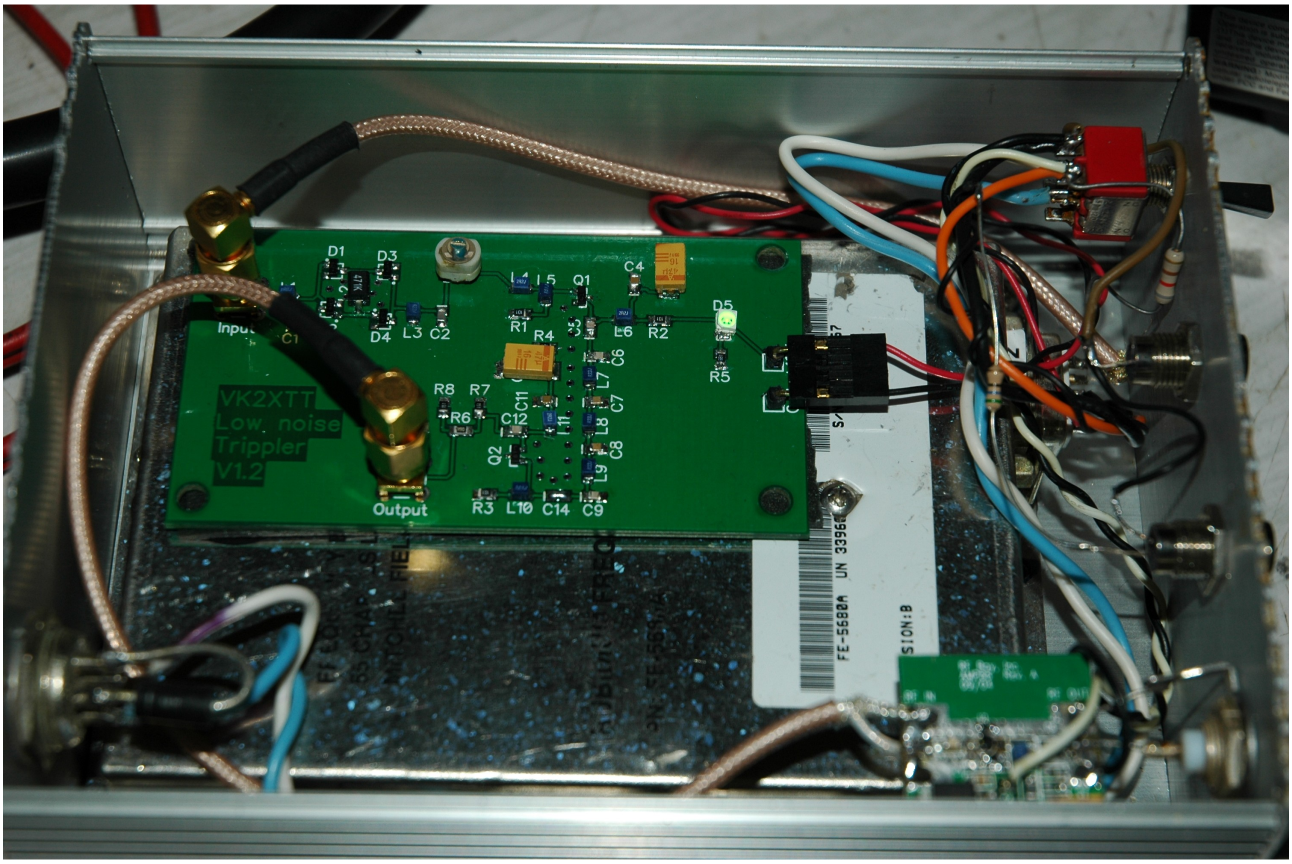

*Illustration 5: interior with everything in place*

As you can see from the picture I mounted the tripler on top of the RB unit with double sided tape and mounted the small amplifier using stiff wire directly to the back of the BNC connector.

I also placed a heavy duty diode on the DC input to avoid the inevitable reverse polarity incidents that always occur on field days and a fuse in the DC lead.

The RB unit has a lock indicator pin that you can run an LED from so I added that to the front panel too.

These RB units run quite warm so a good metal box or aluminium panel is required to mount them.

You don't want to cool it to much you just want to add some thermal inertia to enhance its stability.

In hind site I should have mounted the BNC on the rear of the unit to make the cable run to the rig that much shorter and the shack table a little neater.

The labelling on the front panel I created with laser transfer film. This product allows you to create water slide decal transfers that you can apply to nearly any surface. Once the decal is attached to the aluminium panel you can bake the panel at 180deg C to fix the artwork permanently.

You'll notice a slight scratch on the bottom right corner. This is the result of a slight tear in the film that I didn't notice until it came out of the oven. Its brown tinge was cause by me using my pizza tray. Make sure, that if you follow this path, to use a clean tray to put your panel on lest part of your dinner end up in the art work.

I could have used steel wool to remove the decal but I decide to leave the defect as a reminder not to do that again :)

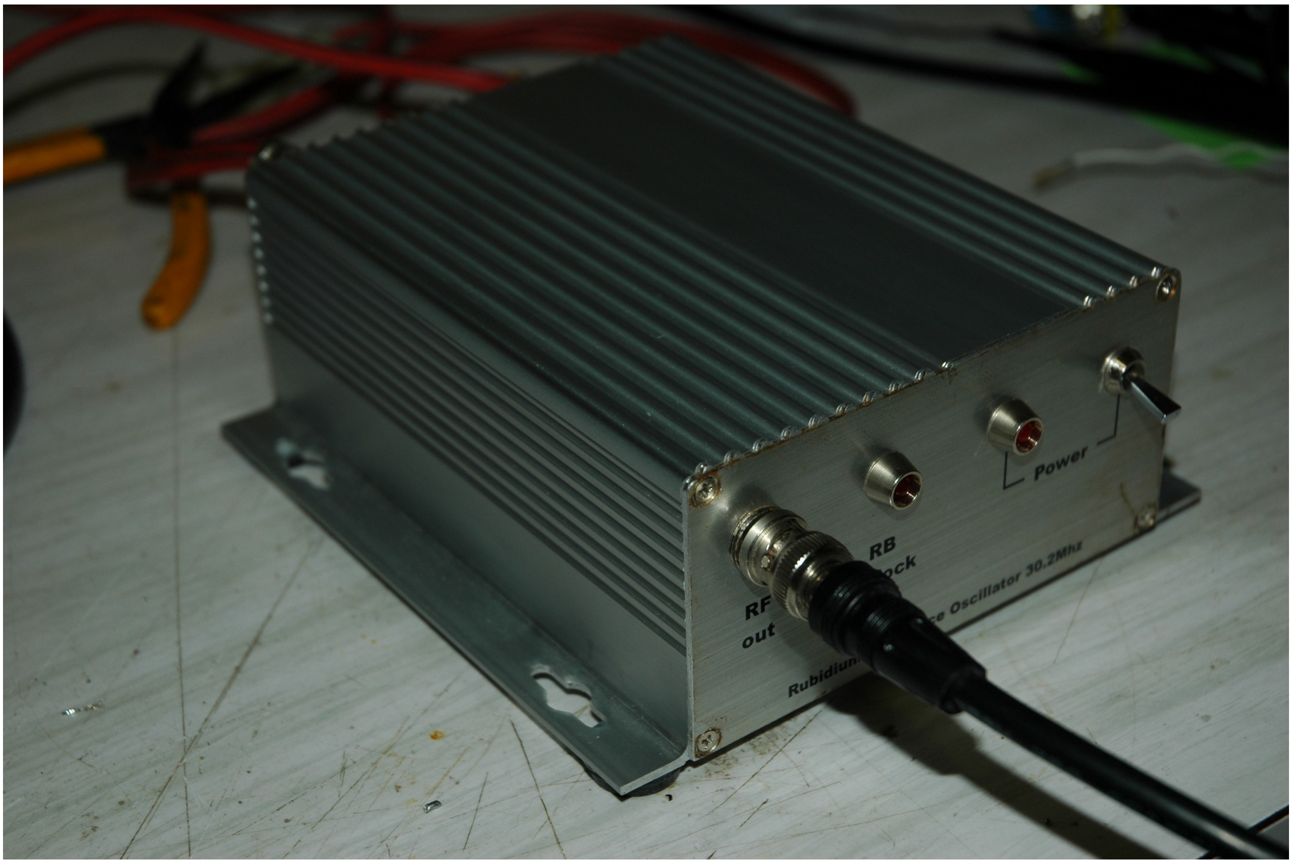


*Illustration 6: Fully assembled, ready for operation.*

You can power on the radio after you've powered up the RB unit but it will take about 5 minutes for the lock light to go out and full stability to be reached. Still much faster than  a GPS unit and far more stable than the high stability options offered with these radios.

Initial testing of the unit involved running it for 72 hours continuously.

My HP5316B reference locked frequency counter has the ability to compare two signals and show any ratio difference between the two. Thus I had my GPS reference locked signal generator plugged in to one channel and the RB unit plugged into the other. Difference between the two signals was immeasurable over the test time.

## *Modifying the IC-910*

Modifying the IC-910 is fairly straight forward so I modified my IC-910 in a similar fashion to how Rex, VK7MO, modified his.

There is a convenient plate covering a hole on the back of the IC-910 that I removed and drilled for the BNC. Its only stuck on by glue so its easily removed and re glued in place. This helps keep metal shavings out of the radio. Schematic mods, drawn by VK7MO, are reproduced below.

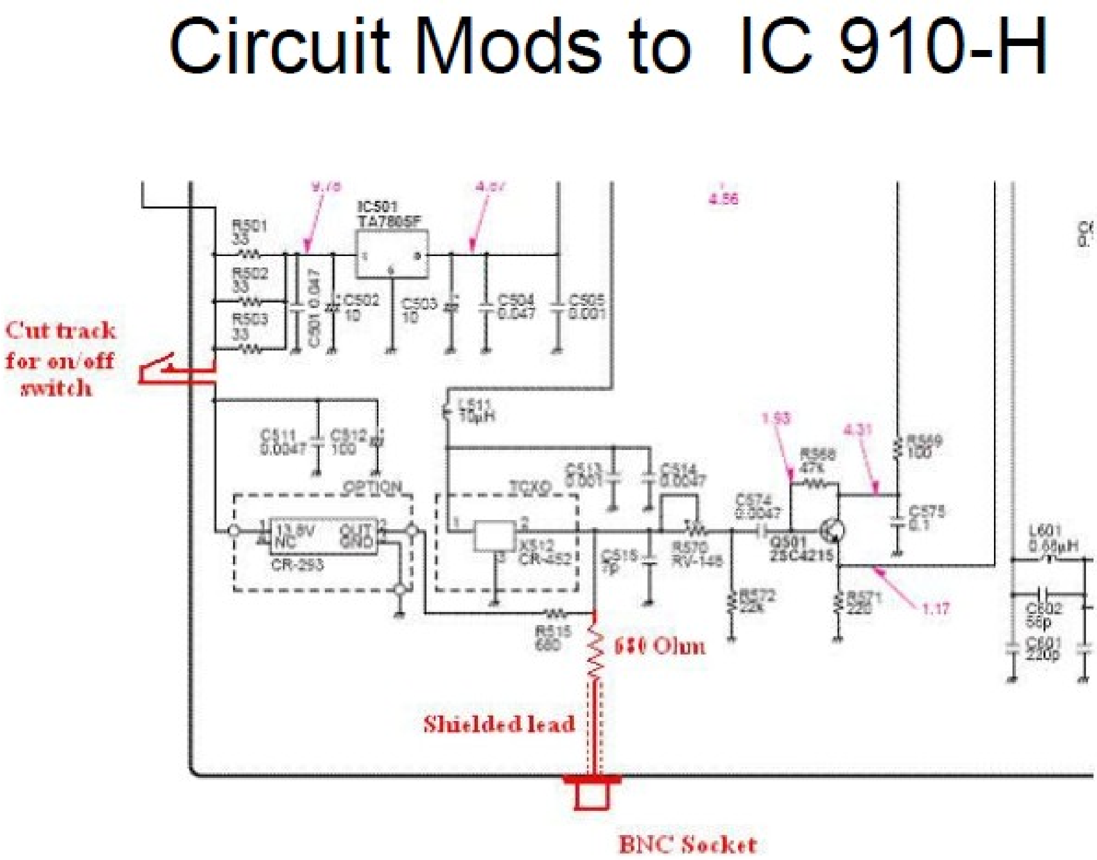


*Illustration 7: Schematic Circuit Modification for the IC-910*

Pictures of the modifications to an IC-910 can be found in the Appendix A of this article.

Modification of other radios is left to the reader but a search of the internet will turn up many articles on modification of the more popular radio's we use.

Testing of the IC-910's frequency on 2m, 70cm and 23cm show its output to be within 0.1 hertz of any selected frequency.

## *Receiver Phase noise measurements.*

Phase noise tests using Spectrum Lab , produced the graph below.

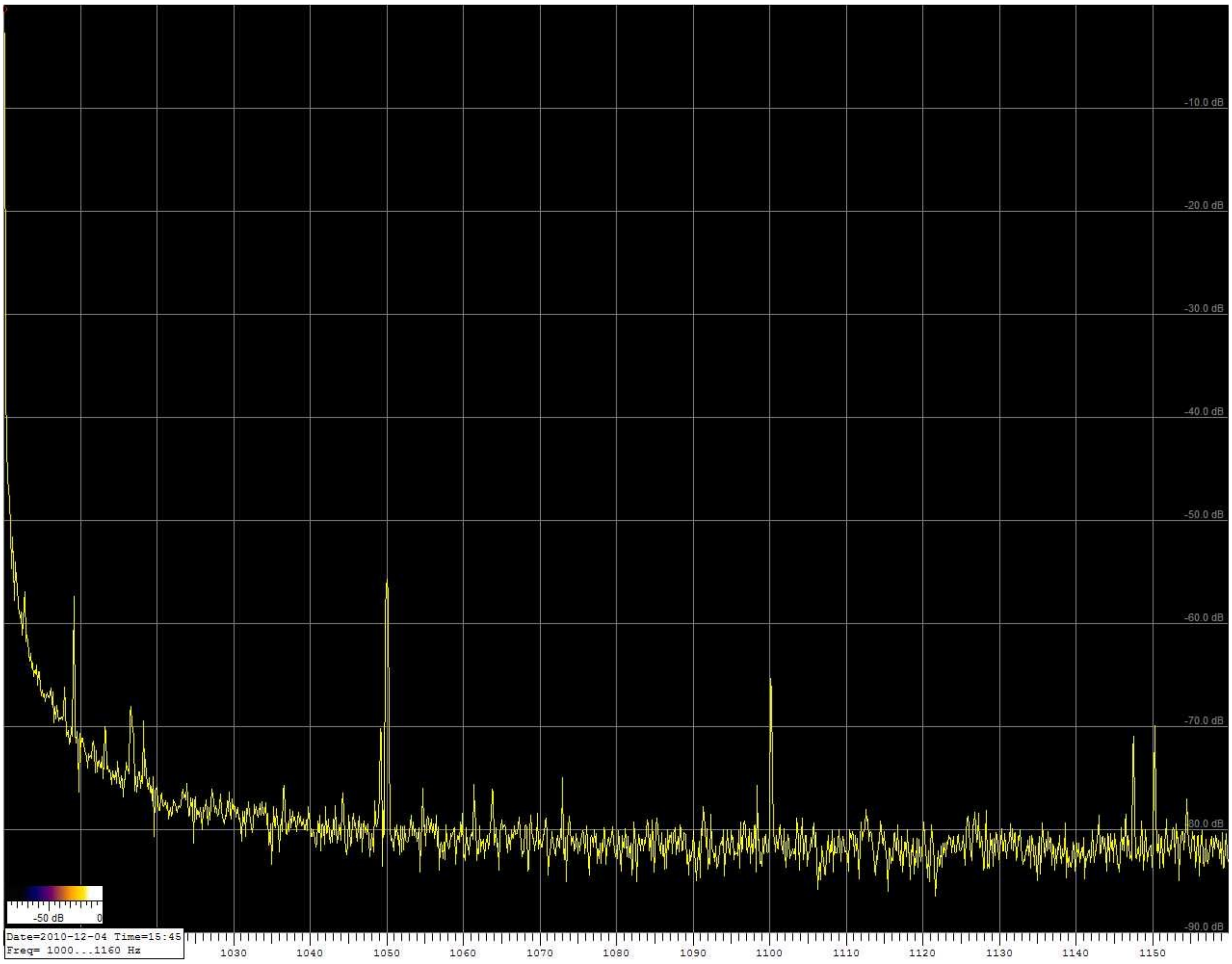

*Illustration 8: RX Phase noise  at 1296.100 Mhz*

Graph scale is from 1kHz to 1.160kHz with the Carrier at 1kHz and 0dBm as the left margin, we can see the phase noise at 5hz is ~ - 65dBc/Hz at 10 Hz its ~ -72dBc/Hz

The spikes at 50hz, 100Hz and 150Hz are hum from the linear supply used to power the rubidium unit thus illustrating the need for a clean supply for local oscillators.

## *Conclusion*

The power supply must be clean to minimise spurs which is not a problem if using a battery.
Accuracy is better than 0.1Hz and is highly stable.
Specifications are comparable to GPS locking methods.
Reference locking your radio is easier than you think and can be cheaper than buying the High Stability option for the radio.

Appendix A – IC-910 Modification, reproduced with permission of VK7MO

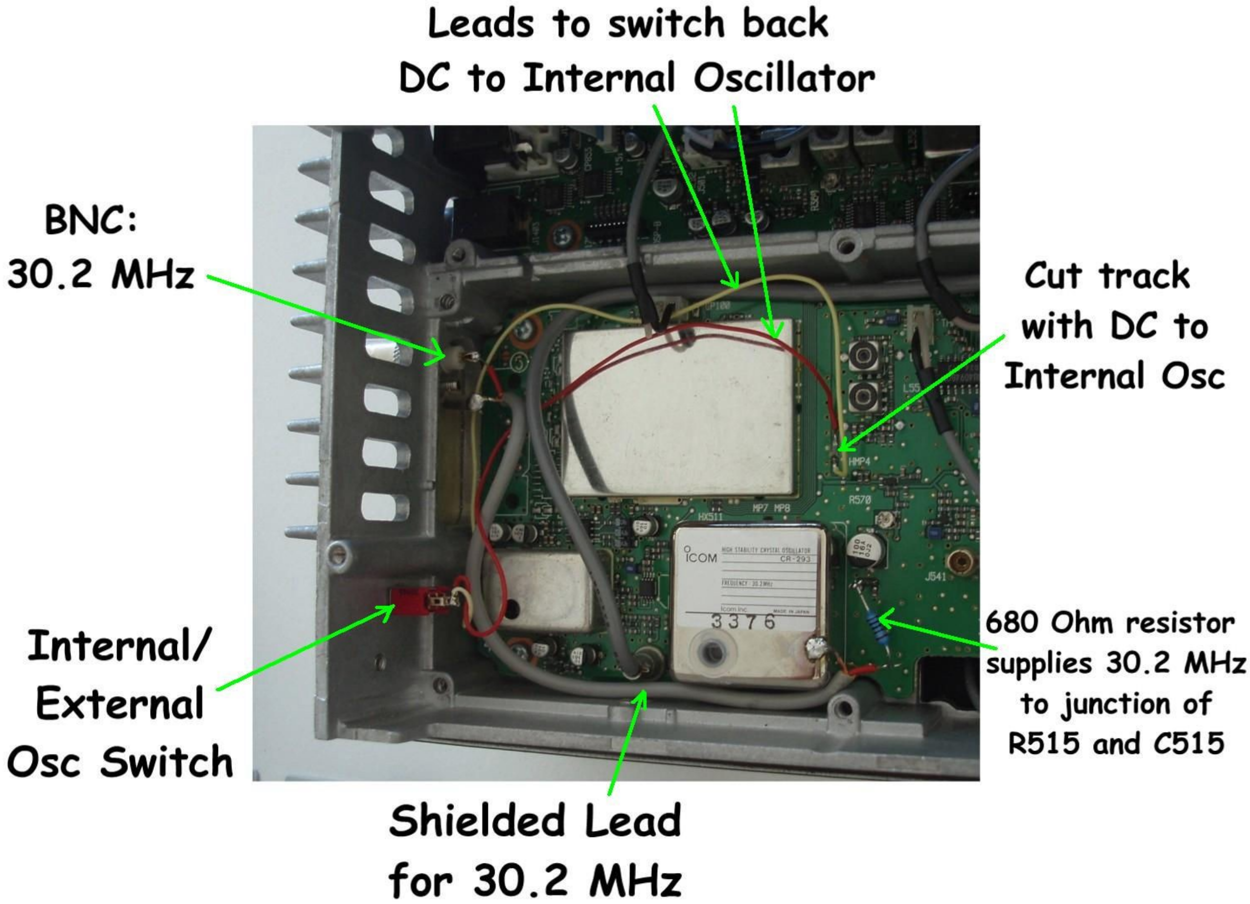


*Illustration 9: Modification of the IC-910*

## Appendix B – Trippler schematic

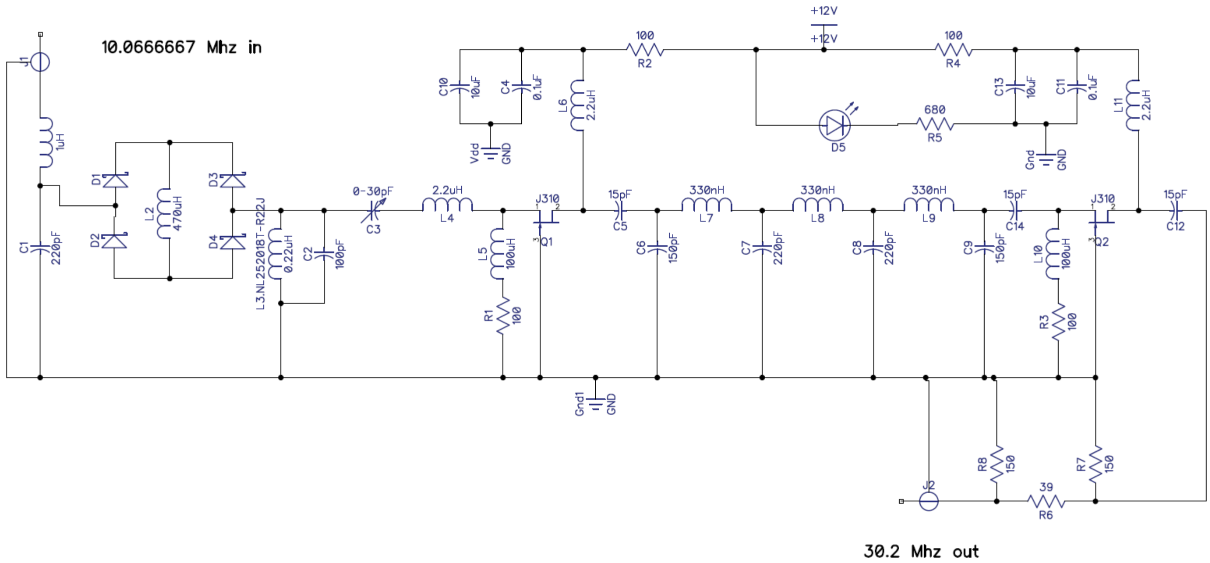


*Illustration 10: Trippler Schematic*

| RefDes | Value | Type | | | |
|---|---|---|---|---|---|
| C1 | 220pF | CAP_0805 | L1 | 1uH | IND_0805 |
| C10 | 10uF | CAP_1210 | L10 | 100uH | IND_0805 |
| C11 | 0.1uF | CAP_0805 | L11 | 2.2uH | IND_0805 |
| C12 | 15pF | CAP_0805 | L2 | 470uH | IND_0805 |
| C13 | 10uF | CAP_1210 | L3 | 0.22uH | IND_0805 |
| C14 | 15pF | CAP_0805 | L4 | 2.2uH | IND_0805 |
| C2 | 100pF | CAP_0805 | L5 | 100uH | IND_0805 |
| C3 | 0-30pF | VARCAP | L6 | 2.2uH | IND_0805 |
| C4 | n/r | CAP_0805 | L7 | 330nH | IND_0805 |
| C5 | 15pF | CAP_0805 | L8 | 330nH | IND_0805 |
| C6 | 150pF | CAP_0805 | L9 | 330nH | IND_0805 |
| C7 | 220pF | CAP_0805 | Q1 | J310 | PMBFJ310 |
| C8 | 220pF | CAP_0805 | Q2 | J310 | PMBFJ310 |
| C9 | 150pF | CAP_0805 | R1 | 100 | RES_0805 |
| D1 | | BAT54 | R2 | 0 | RES_0805 |
| D2 | | BAT54 | R3 | 100 | RES_0805 |
| D3 | | BAT54 | R4 | 0 | RES_0805 |
| D4 | | BAT54 | R5 | 680 | RES_0805 |
| D5 | | LED | R6 | 39 | RES_0805 |
| J1 | | COAX | R7 | 150 | RES_0805 |
| J2 | | COAX | R8 | 150 | RES_0805 |

*Illustration 11: Parts List*

# Appendix C – Construction Notes & Errata

All capacitors except C10 and C13 are NPO ceramic.

C10 and C13 are Tantalum Electrolytics', the schematic and parts list shows their value to be 10uF but I ended up using 47uF 16V units I scavenged from old PC cards.

C3 is a ceramic variable capacitor. Don't use the tiny plastic things with cross head adjusters, they are unstable as the temperature changes. I only had SMD plastic units so I substituted a leaded unit with its leads folded back on themselves to enable it to be surface mounted.

Adjust C3 for maximum output.

L2 the 470uH inductor, can be hard to source in 0805 size but can be found more readily in 1217 size. Carefully removing the green coating from the traces to the pads will allow you to solder a 1217 size unit in place.

D5 – LED. You don't need this for operation. I just like to know when power is present in my circuits. I used an 0805 sized green LED for mine. You can use what ever colour you like provided you make the appropriate change to R5.

J1 and J2 are SMA connectors. You could use SMB if you wanted too, the pin pattern for SMA and SMB is the same regardless of orientation or whether its a vertical or right angle unit.

The +12V and GND pins were salvaged from old pc cards as was the connector. Old PC sound cards have lots of these on them.

R2 and R4 are now 0 ohm rather than 100ohms. This boosts the gain.

D1 thru D4: ensure you get BAT54's not BAT54 A B or C's. The ABC versions are dual diode packs and will not work in this circuit.

C14 is not required and is an error in the circuit. Ether replace it with a 0 ohm resistor or jumper it with solder.

R7,8 & 9 form a 50ohm 3db pad that you can modify for extra attenuation if the output is too high for your application.