Simple and Cheap Multiband Microwave Transverters

Paul Wade W1GHZ ©2020

w1ghz@arrl.net

For roughly the past twelve years, I have been working on simple reproducible transverters for all microwave bands from 902 MHz up to 10 GHz, and more recently down to 222 MHz. It took a while to work up to the higher frequencies, with some painful and expensive lessons along the way. I'll describe some of these learning experiences as well as the final results, with the hope that some readers can learn from them and go on to new mistakes instead of repeating old ones.

Back in the 1960s, Loren Parks, K7AAD, published a small magazine called the ***VHFER***. The motto on every issue was "Learn by Doing." I've found this to be a useful approach in many endeavors. When you actual do something, you really learn it, and you remember your mistakes.

My original concept was simple transverters to enable rovers to add additional bands without great expense. Operating on multiple microwave bands in VHF contests will greatly enhance a score, as well as lending some excitement to quiet periods. This is particularly true for rover operation. Hilltopping with the microwave gear can also be a lot of fun between contests. However, buying equipment for many bands is not only a considerable expense, but also results in a lot of gear to carry around. These simple transverters could be part of a compact multiband package. http://www.w1ghz.org/MBT/multiband.htm

A good number of hams have successfully built some of these transverters, not all of them for rovers. Some saw the opportunity to add a new band, while others built them as a second station to loan out. Others just wanted an opportunity to build something, to try something new or just for fun.

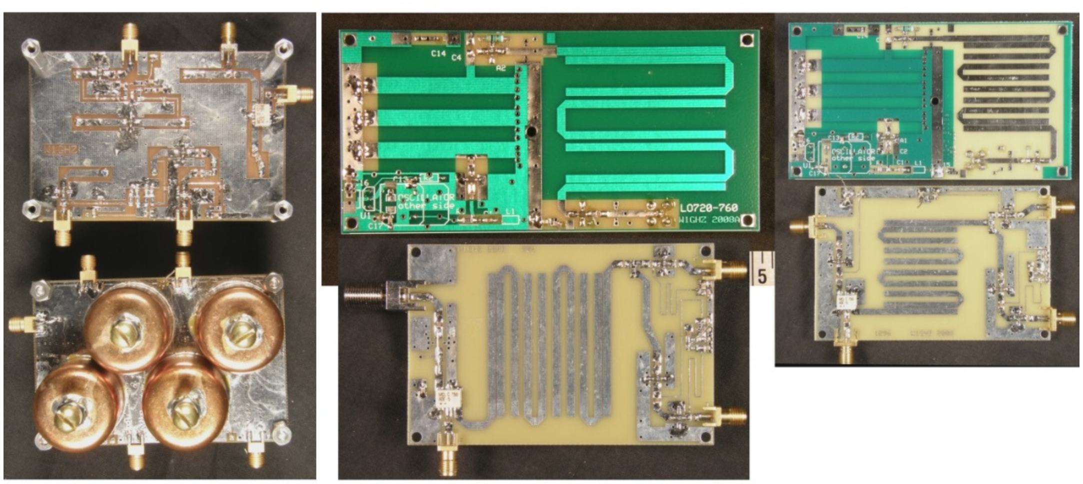


Figure 1 – the original set of Multiband Microwave Transverter boards

A brief description of each transverter follows, with links to more details. I have PC boards available for all of them, as well as some critical parts like mixers that are difficult to purchase in small quantities. All are described in full detail in papers at **www.w1ghz.org**

Design Philosophy

The basic design philosophy is that today, *gain is cheap*. Traditional microwave engineering worked to minimize losses because gain was hard to come by. We don't need to use exotic parts to keep losses down, because MMICs provide cheap gain – less than 25 cents per dB – so if we give up a dB to use an ordinary, readily available part rather than an expensive microwave part, it is a reasonable tradeoff. We start with the PC boards, using ordinary epoxy-fiberglass board rather than Teflon-based microwave material. The loss is perhaps a dB per inch higher, but fabricated boards are readily available without exorbitant lot charges, and the cost per board is reasonable in modest quantities. For capacitors we use ordinary chip capacitors, at a few cents each, rather than microwave capacitors costing a dollar each. In some applications, two ordinary capacitors in parallel rather than one microwave capacitor results in lower loss at lower cost. The final tradeoff is to try and limit the number of different part values, using multiples of each value rather than many different values, since prices are much more reasonable in quantities of 100. Finally, commodity parts that will continue to be readily available are preferred, with vendors like Minicircuits that keep parts available as first choices.

The lower frequency PC boards, up to 1296 MHz, use printed hairpin filters (http://www.w1ghz.org/filter/Recipes_for_Printed_Hairpin_Filters.pdf) so tuning is needed – all the magic is in the PC board. Higher frequencies use copper pipe-cap filters (http://www.w1ghz.org/filter/Pipe-cap_Filters_Revisited.pdf) , which are inexpensive and readily available. but require soldering and tuning.

Most of the MMICs and mixers are readily available from Minicircuits, and now Mouser has some Minicircuits parts available in single quantities. The other parts are available from DigiKey or Mouser. Although they are common parts and readily available, the manufacturer and distributor part numbers keep changing so I have given up trying to maintain parts list with distributor part numbers.

When I first built these transverters, a significant part of the cost was SMA connectors – the least expensive ones I could find were about $5 each. I even experimented with F connectors for the LO and IF connections. Today, there are tons of SMA connectors on ebay, for roughly $1 each, much less if you buy 50 at a time. These seem to work fine up to 5760, but for 10 GHz I chose to stick to name brands – Taoglas from Digikey run about $3.50, or you can go for Amphenol at ~$12. W7GLF tried the cheap ones at 10 GHz with poor results, then switched to the Taoglas connectors and saw an improvement of more than 10 dB.

Another improvement at 10 GHz might be to use the more expensive ATC capacitors – W6QIW reports a 2 to 5 dB improvement. At lower frequencies, the difference should be much smaller.

Even at 10 GHz, the ordinary chip capacitors provide adequate performance for most applications. Just stick to the smaller sizes, like 0805 or 0603 – a ham who shall remain nameless used large 1206 size capacitors at 10 GHz, and got 10 dB more output when he replaced them with 0805 size.

Multi-band Strategy

The original multi-band strategy was for a single oscillator source to provide the local oscillator (LO) to transverters for several microwave bands. This not only reduces the power needed for LO, allowing the oscillator to be powered continuously for better stability, but also enables better compensation for frequency errors, since the frequency error on one band each band is a simple integer multiple of the base oscillator frequency. Thus, once a frequency offset is found on one band, it may be quickly predicted and compensated on other bands.

The microwave LO source frequency is at 720 MHz, generated from an inexpensive 80 MHz computer oscillator. The 720 MHz source is multiplied to provide an LO for 1296, 2304, 3456, and 10368 MHz, with normal 2-meter and 432 MHz IF frequencies. Figure 1 shows the overall frequency scheme; each transverter includes the final multiplication needed for a particular band. Harmonics of 720 MHz conveniently occur 144 MHz away from 1296, 2304, and 3456 MHz, and 432 MHz away from 10368 MHz, except that all but 2304 MHz are above the activity frequency. Thus, the calling frequency lands at about 143.9 MHz or 431.9 MHz, with inverted SSB. This is a minor inconvenience, since most of the common IF transceivers can be readily modified to tune slightly out of the amateur band. Many of us have been tuning upside-down on some of the microwave bands anyway, using surplus "brick" oscillators for the LO, and accurate frequency readout is only a coincidence.

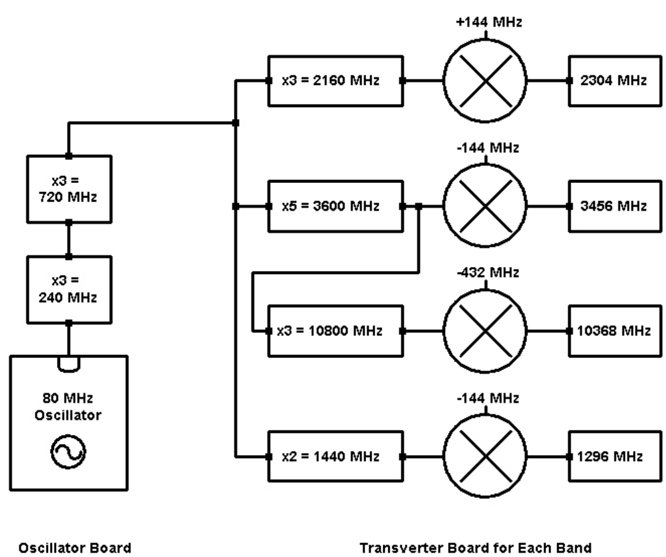


Figure 2. Multi-band Frequency Scheme

1296 MHz

The microwave band with the most activity is 1296 MHz, and this transverter is the most popular. The original multiband strategy with "upside-down" tuning and SSB was not popular at 1296 MHz, and there seemed to be enough demand to make a standalone transverter with a separate LO at 1152 MHz for a normal 144 MHz IF. This transverter is simple to build, and features a printed hairpin filter, so no tuning is necessary.

The latest version (http://www.w1ghz.org/xvtr/1296_Update_and_Enhancements_2016.pdf) has provision to use some of the newer MMICs in SOT-89 packages for higher performance, and a Minicircuits power splitter to separate transmit and receive.

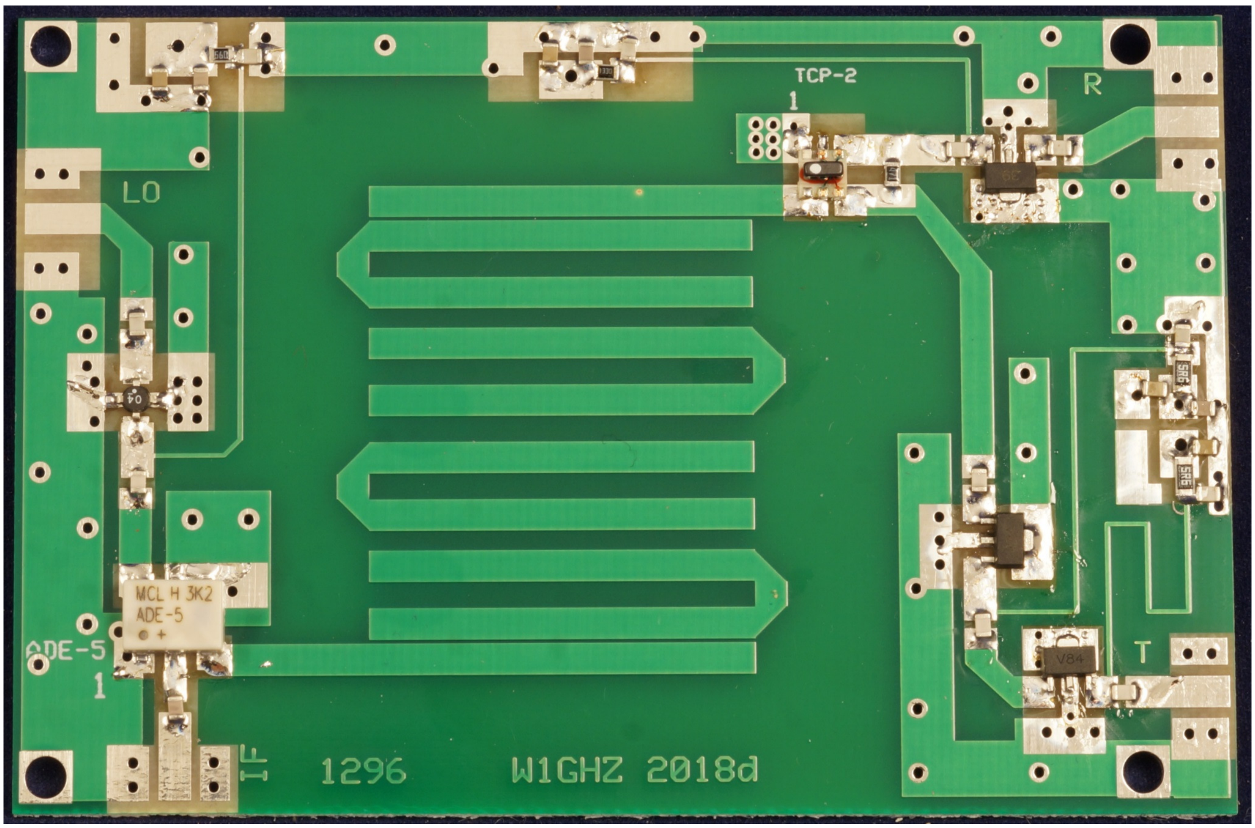


Figure 3 – 1296 Transverter, Rev d, with power splitter, new MMICs, and soldermask

1152 MHz Local Oscillator Board

The most common LO frequency for 1296 MHz is 1152 MHz, to provide an IF at 144 MHz. A low-cost frequency source is a 64 MHz computer crystal oscillator, which is then multiplied on the board. There are two printed filters: a hairpin filter at 1152 MHz which needs no tuning, and a combline filter at 192 MHz which is tuned by chip capacitors. The tolerance variation in cheap capacitors sometimes necessitates a bit of fiddling for maximum output.

Alternative LO sources also work. One choice is a 64 MHz VCXO locked to GPS (http://www.w1ghz.org/small_proj/VCXO_for_Microwave_LO_update2.pdf) for frequency accuracy and stability with low phase noise. Another possibility is a frequency synthesizer, like the ApolLO-32 from Down East Microwave, or a cheap Chinese one from ebay.

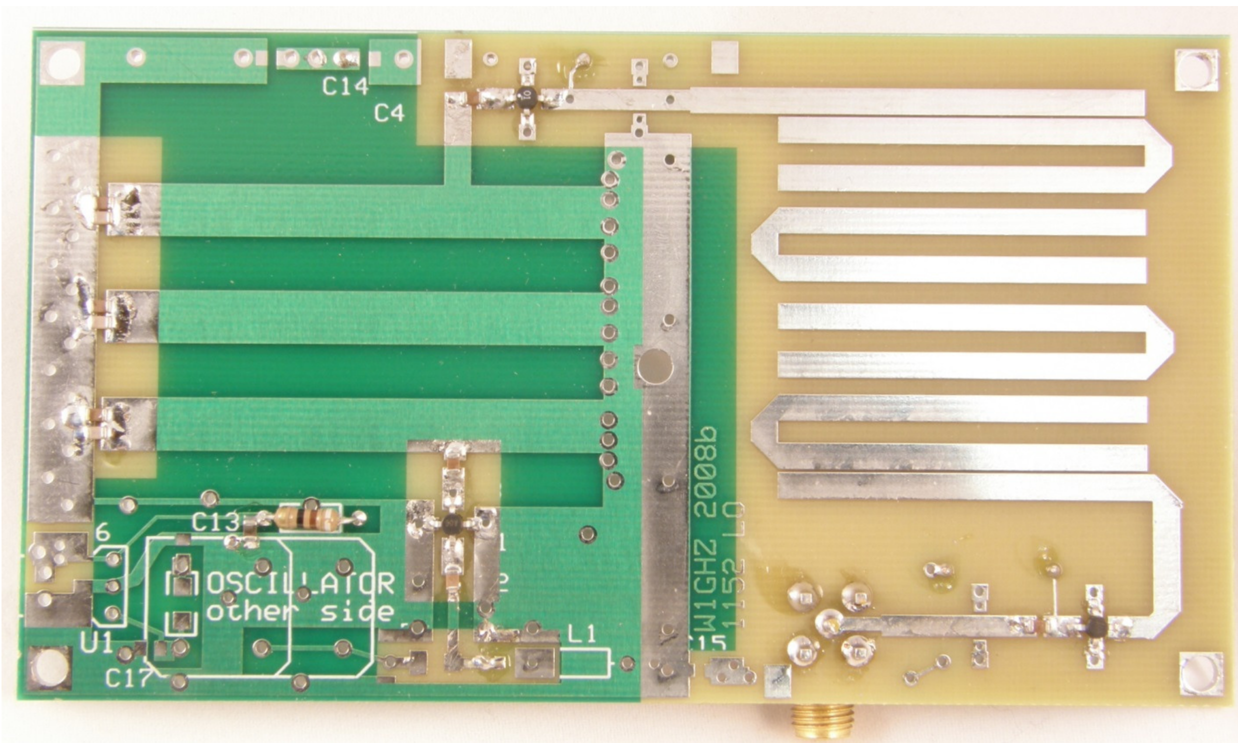


Figure 4 – 1152 MHz Local Oscillator

2304 and 3456 MHz

These two bands use the same PC board – the frequency is determined by pipe-cap filters, which can be tuned to either band, or other calling frequencies in these bands. The board also includes the final LO multiplier and amplifier, with pipe-cap filters for a clean LO signal. The input to the LO multiplier is at 720 MHz, multiplied by three to 2160 MHz for 2304, and by five to 3600 MHz for 3456, providing a 144 MHz IF for both bands. Other input frequencies also work, since the pipe-cap filters have a wide tuning range.

The latest version (http://www.w1ghz.org/MBT/Updating_the_Simple_Low-cost_2304_MHz_Transverter.pdf) has provision to use some of the newer MMICs in SOT-89 packages for higher performance.

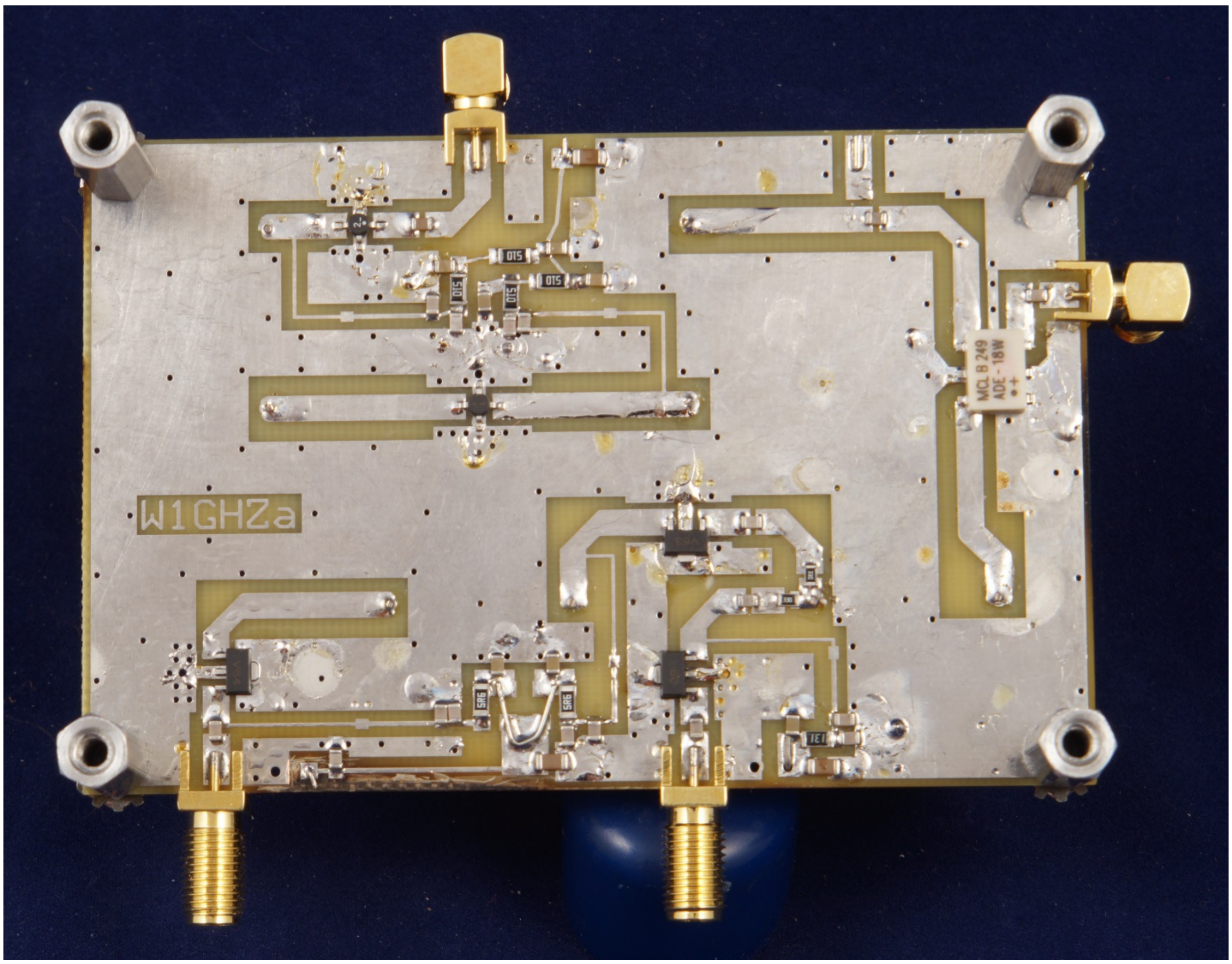


Figure 5 – Transverter for 2304 or 3456 MHz – pipe-cap filter tuning determines band

New S-band Transverter for 2304 and 3456 MHz

With the widespread use of frequency synthesizers, the on-board frequency multiplier of the earlier transverter is not needed. The fourth pipe-cap filter, previously used for the multiplier, can now be used for better receive filtering. The layout is now a symmetrical one similar to the 5760 and 10 GHz transverters, but with one less amplifier stage in each direction, since more gain is available at the lower frequencies.
http://www.w1ghz.org/xvtr/Transverter_for_2304_or_3456_MHz_Mark2.pdf

With a synthesizer, it can obviously work at any of the international frequencies in the 2.4 GHz band with a slight retuning of the pipe caps.

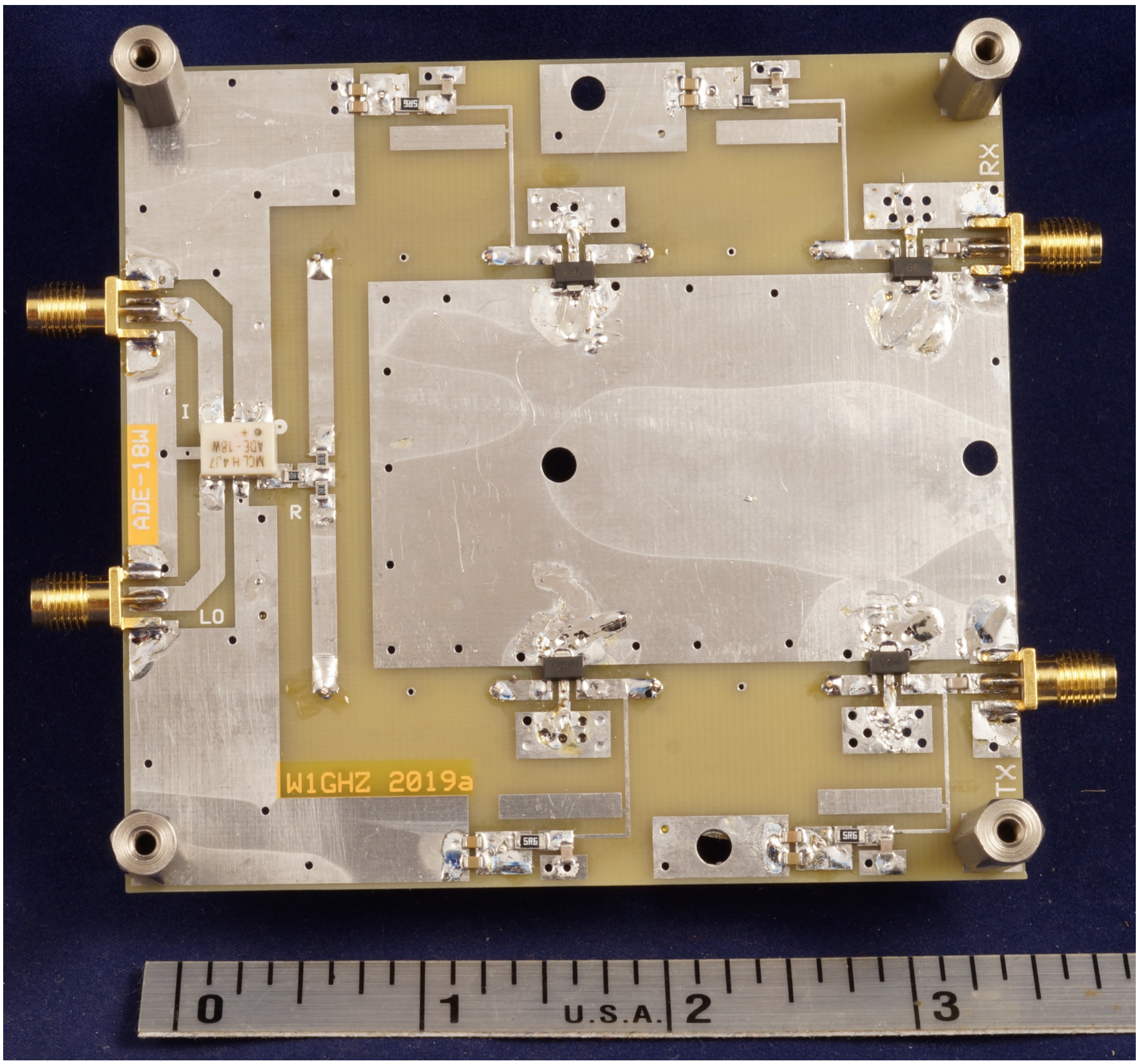


Figure 6 – 2304 and 3456 MHz Transverter, Mark 2

720 MHz Local Oscillator Board

The LO board to generate the 720 MHz signal is similar to the 1152 MHz board, except that the hairpin filter is for 720-760 MHz. The low-cost frequency source is an 80 MHz computer crystal oscillator. The combline filter, tuned to 240 MHz by chip capacitors, seems to be more forgiving than at 192 MHz.

Alternative LO sources also work. One choice is a 80 MHz VCXO locked to GPS for frequency accuracy and stability with low phase noise. Another possibility is a frequency synthesizer, like the ApolLO-32 from Down East Microwave, or a cheap Chinese one from ebay.

The same board may be used for 902 MHz, with a 36 MHz computer crystal oscillator, to generate on LO frequency of 756 MHz. The resulting IF for 902 is 146 MHz.

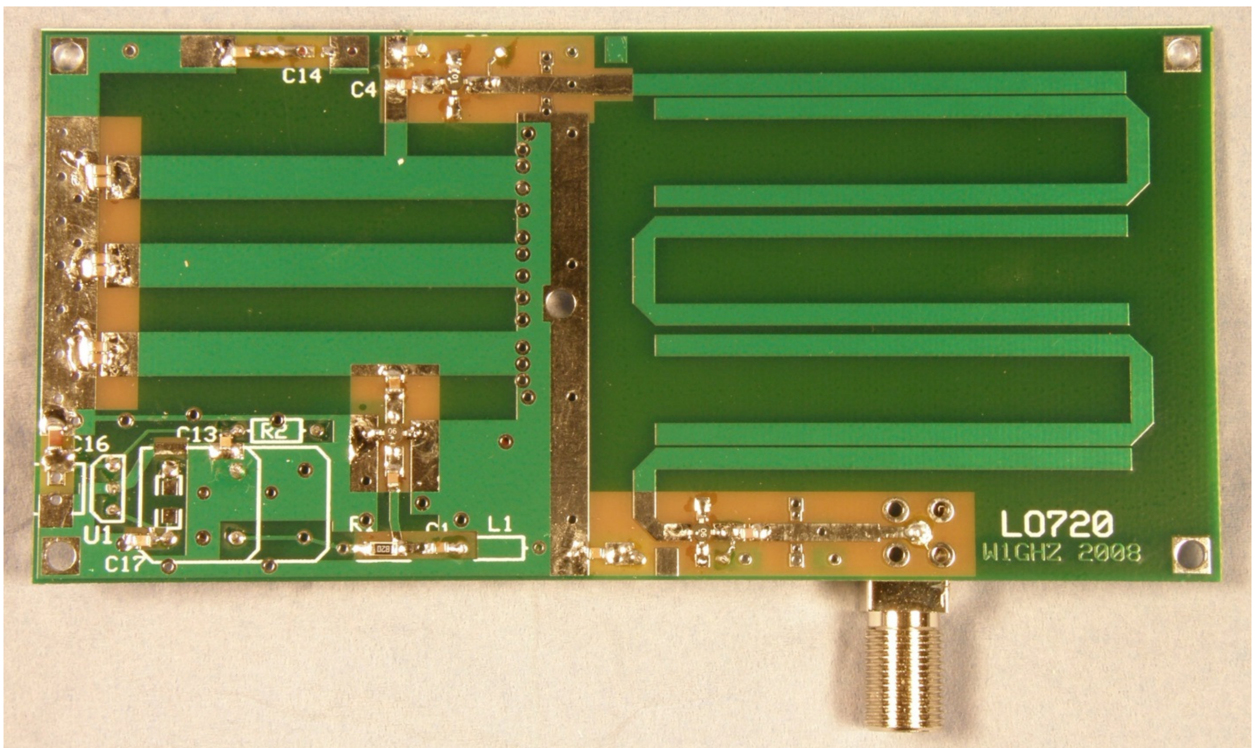


Figure 7 – 720 MHz Local Oscillator board

902 MHz

The next band was 902 MHz. The transverter board was straightforward, just swapping a different printed hairpin filter into the 1296 MHz artwork. The LO was harder, since an appropriate computer oscillator was not available, but I found that a 36 MHz oscillator could multiply to 756 MHz for a 146 MHz IF for 902 or 147 MHz for 903. Then I tweaked the printed hairpin filter on the original LO board to cover 720 to 760 MHz to pass both 720 and 756 MHz so that the revised PC board could be used for both. Of course, a frequency synthesizer is an alternative to eliminate the odd IF frequency.

The latest version (http://www.w1ghz.org/xvtr/Update_and_Enhancements_for_902MHz_Transverter.pdf) has provision to use some of the newer MMICs in SOT-89 packages for higher performance, and a Minicircuits power splitter to separate transmit and receive.

The one in Figure 8 has the LO amplifier MMIC replaced by a zero-ohm resistor (1206 size) since adequate LO drive was available from a synthesizer.

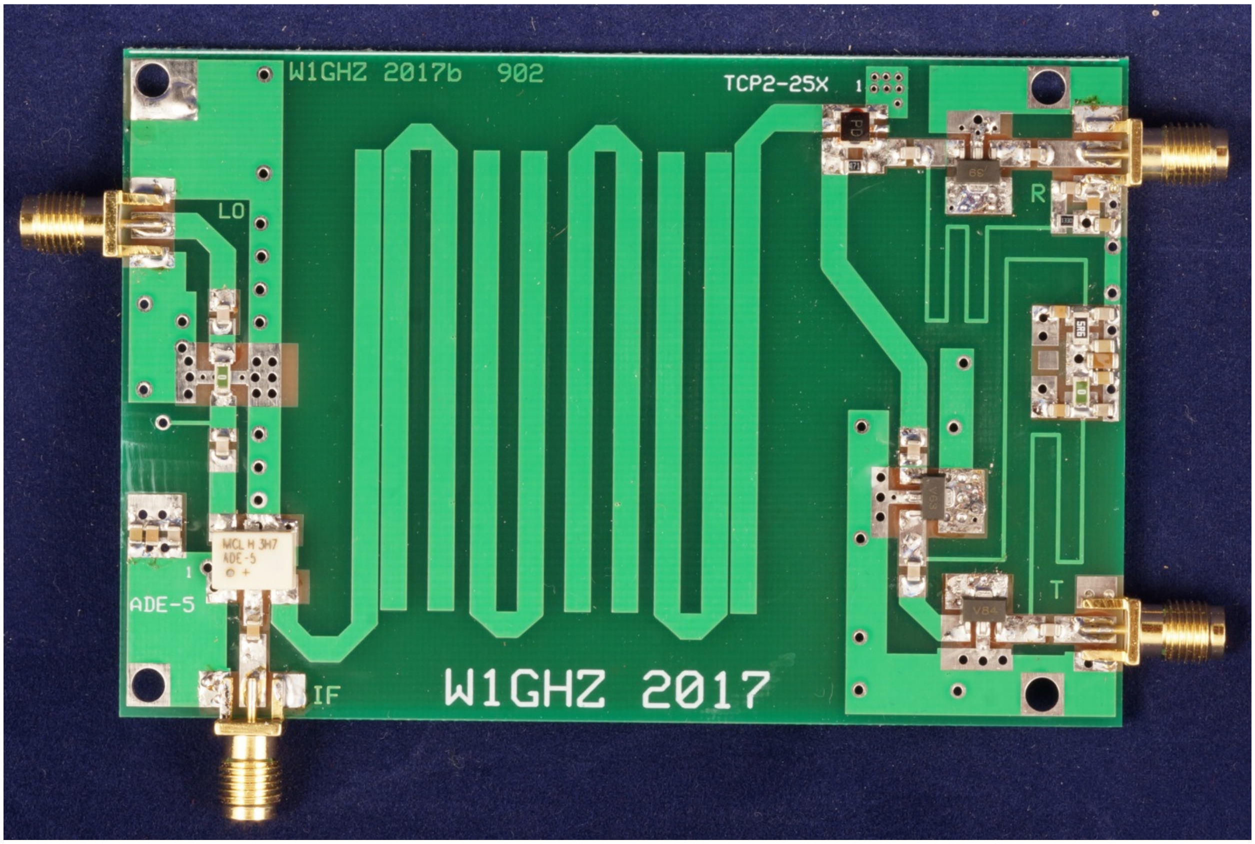


Figure 8 – 902 MHz Transverter

5760 MHz

This band was not included in the original multiband strategy because it didn't fit the LO scheme – 5760 MHz is a multiple of both 720 and 1152 MHz, so a different LO source is required. I never found a suitable computer oscillator, but frequency synthesizers have since become readily available. At this frequency, MMICs have less gain, so I used three stages on both transmit and receive, with a pipe-cap filter between MMIC stages.

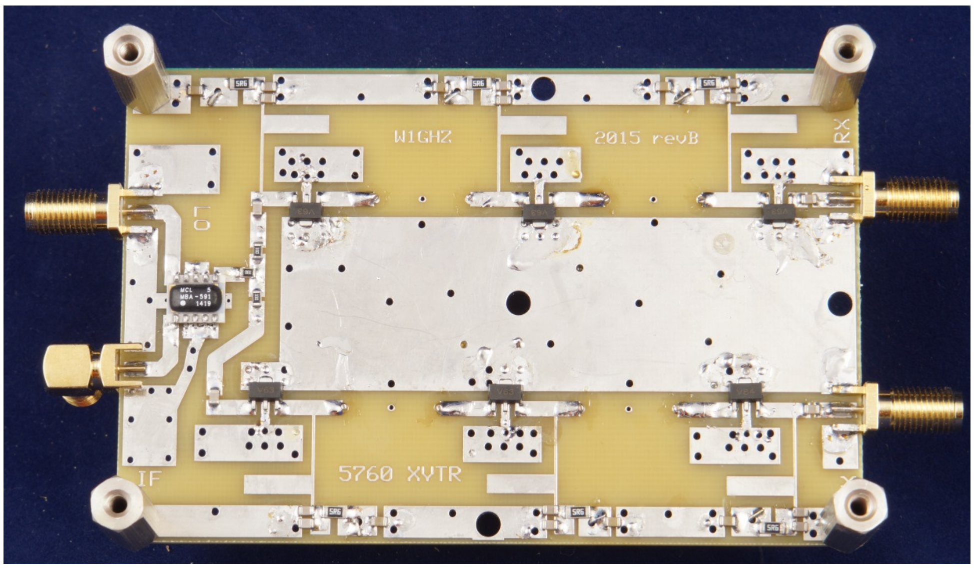


Figure 9 – 5760 MHz Transverter
http://www.w1ghz.org/MBT/5760_MHz_Transverter_Update_March_2016.pdf

3 & 5 GHz LO Multiplier board or Personal Beacon

Appropriate frequencies are readily available using frequency synthesizers, but few go high enough in frequency so must be multiplied up to the 5 GHz range. A simple frequency multiplier board using MMICs and pipe-cap filters does the job, with input frequencies between 1 and 3 GHz. The pipe-cap filters can be tuned low enough in frequency for a 3456 MHz LO or beacon as well.

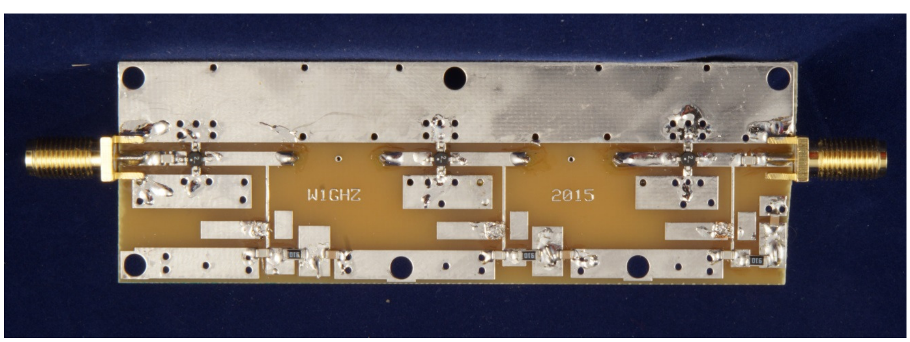


Figure 10 - Multiplier board for 3 & 5 GHz

10 GHz LO Multiplier board or Personal Beacon

http://www.w1ghz.org/small_proj/Update-10GHz_Personal_Beacon.pdf

Whether we use the original multiband LO strategy or opt for a 2 meter IF, a frequency multiplier is needed. I made a frequency multiplier board using MMICs and pipe-cap filters and called it a "Personal Beacon for 10 GHz." This uses ordinary thick PC board material which has significant radiation, but a beacon is supposed to radiate.

However, for an LO, radiation is undesirable. I modified the board for thinner material, and it works well, multiplying by 9 to provide a 10 GHz LO from a source in the 1 GHz range. This board also works well as a Personal Beacon, so the thicker PCB is no longer available.

For higher frequency synthesizers, a smaller multiplier board multiplies by 2, 3 or 4 times to provide the 10 GHz LO.

All these multiplier boards use pipe-cap filters with wide tuning range, so they have other potential uses as well. I heard of one being used to generate a 12 GHz signal.

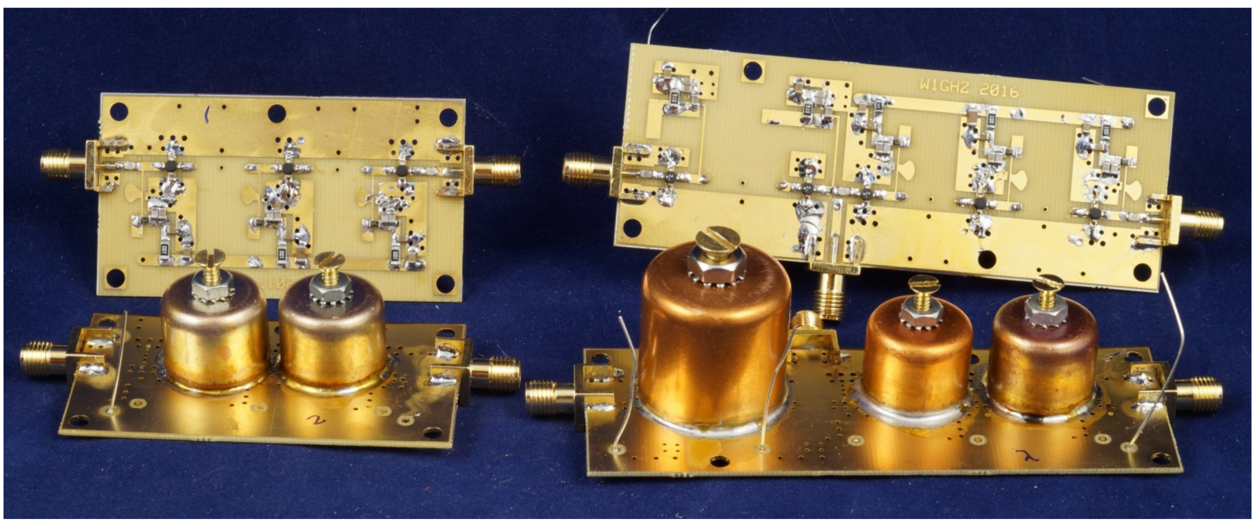


Figure 11 - Multiplier boards for 10 GHz

10 GHz

A simple transverter for 10 GHz proved much harder – ordinary PC board radiates badly above about 7 GHz, and most MMICs run out of gain. The solution was to use thinner PC board material. Development of this transverter was a somewhat painful learning experience – see the paper for details. http://www.w1ghz.org/MBT/Simple_and_Cheap_Transverter_for_10_GHz.pdf

The only MMIC with adequate gain that I have found, the RFMD NLB-310, is available from Mouser, and can be purchased direct at www.qorvo.com. A possible alternative is the NLB-400, available from Mouser.

This transverter was intended to be a simple, low-cost unit to get folks on 10 GHz, but one is being used successfully for EME by CX2SC.

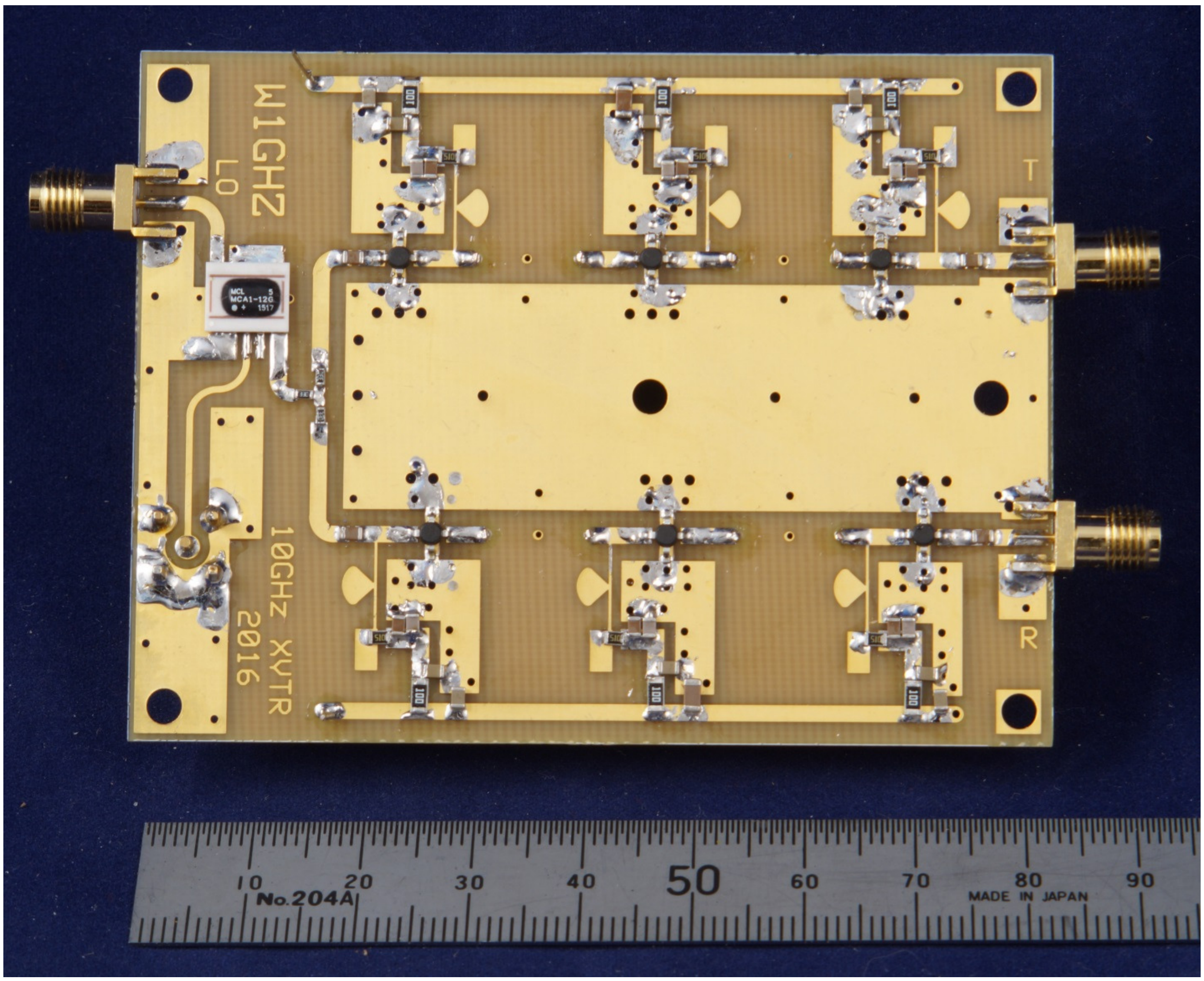


Figure 12 – Transverter for 10.368 GHz

432 MHz Transverter

http://www.w1ghz.org/xvtr/432MHz_Transverter_for_an_SDR.pdf

I needed a 432 transverter with a few watts output to drive an LDMOS amplifier, I also wanted a low power transverter to use as an IF for microwave transverters – there is an advantage to a 432 IF when using 2 meters for liaison. I also wanted to use it with an SDR for bandscope capability.

Since most commercial filters are hard to find in small quantities and eventually become unobtainium, I tried printed filters. A lesson learned is that 1% tolerance capacitors are needed to be consistently on frequency, but they are readily available at slightly higher cost. Otherwise, the board is easy to build with readily available parts. MMICS and mixer are chosen for desired level of performance – a high-level mixer can provide better receive intermod performance, at the cost of higher LO drive.

The local oscillator is provided by a synthesizer; I chose the digiLO from Q5signal.com. This unit has reasonably low phase noise and allows locking to a 10 MHz reference oscillator. Other choices are possible, including a traditional crystal oscillator and multiplier.

A small MOS amplifier module, the Mitsubishi RA07H4047M from RFparts.com, provides up to 7 watts output. The amplifier is on a separate PC board, with a low-pass filter to remove harmonics. The amplifier may be replaced with other options, such as a higher-power module, or omitted for transverter IF operation.

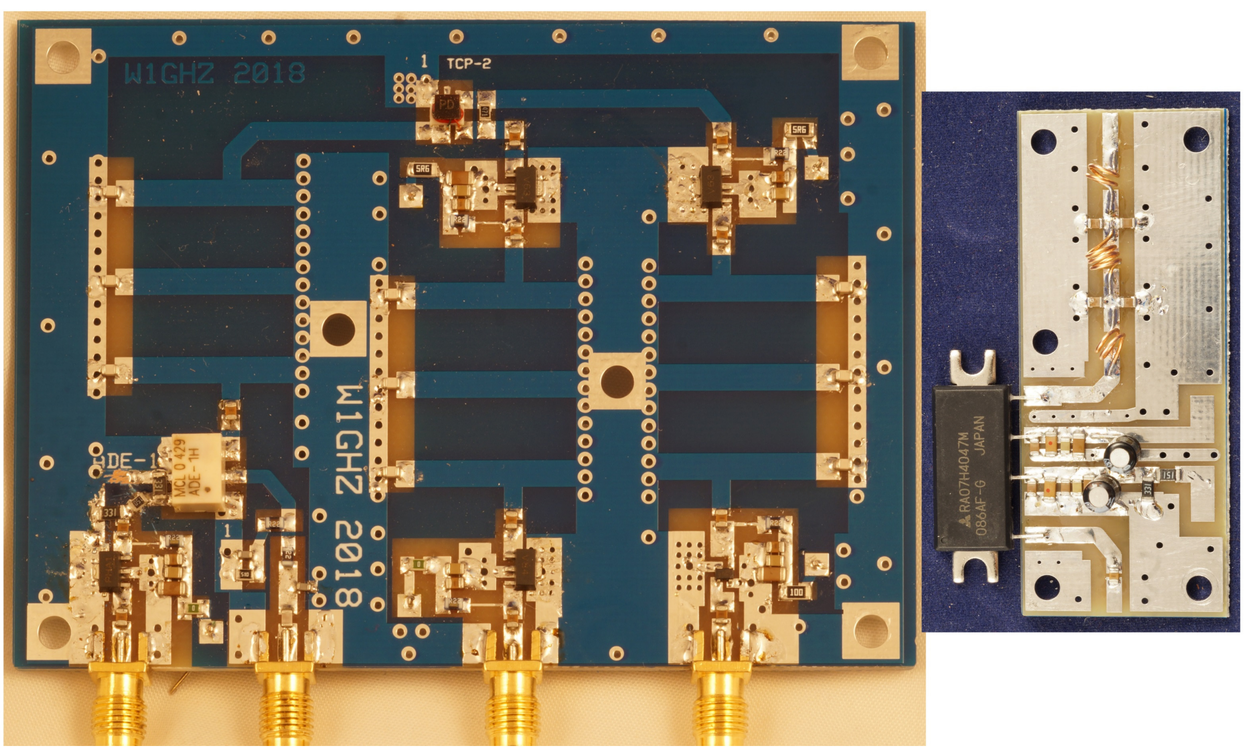


Figure 13 – 432 Transverter and 7-watt amplifier

222 Transverter

http://www.w1ghz.org/xvtr/222_MHz_Transverter_Mark3.pdf

When my old DEMI transverter started acting up and blew up my amplifier with overdrive, I decided to build a new one with lower output power suitable for an LDMOS amplifier.

The filters used in my previous 222 MHz transverters have become unobtanium. I considered printed filters like the 432 transverter, but concluded that too much PC board real estate would be required, making the board expensive. Instead, I borrowed the filter designs from G4DDK's excellent "Anglia" 2-meter transverter and scaled them to 222 MHz. The resulting performance is very good, and only readily available parts are required.

I also made an effort to keep all components on one side of the board, and to label all component locations on the board silkscreen, making assembly easy and straightforward.

A small MOS amplifier module, the Mitsubishi RA07M2127M provides up to 7 watts output, using the same small PC board as the 432 MHz unit. This module seems to be currently unavailable, but I found several on ebay at attractive prices and they all work fine. Otherwise, other options are possible.

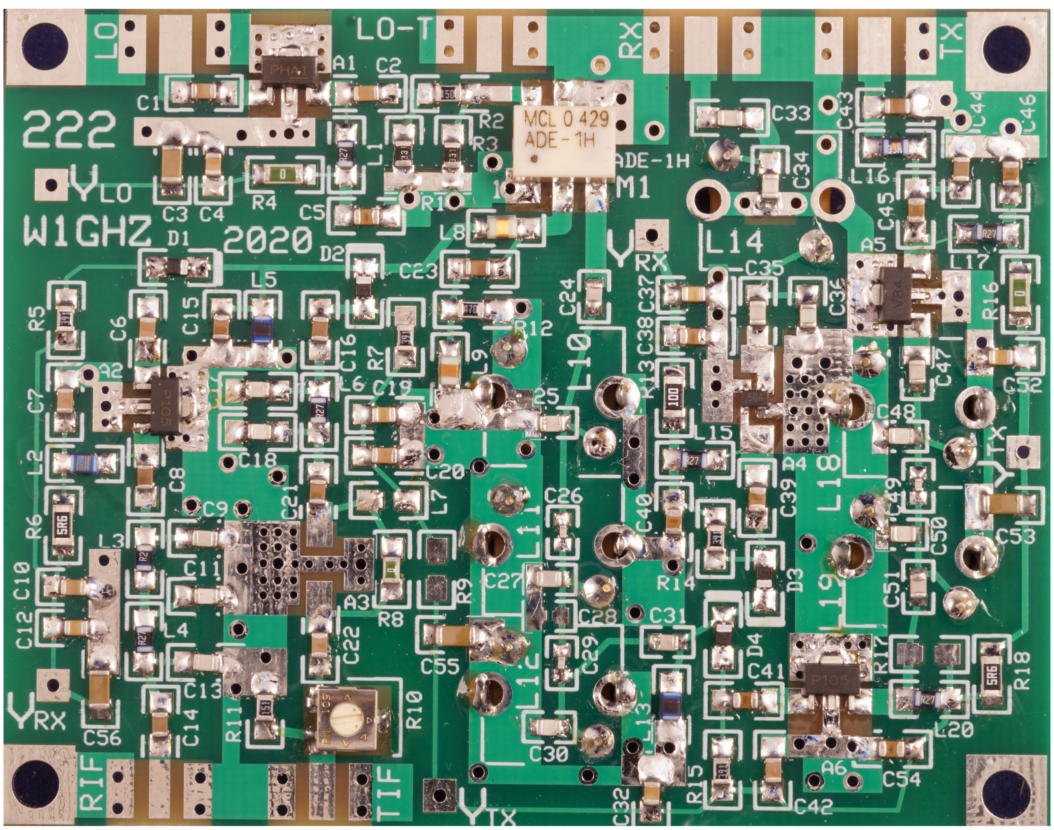


Figure 14 – 222 MHz Transverter

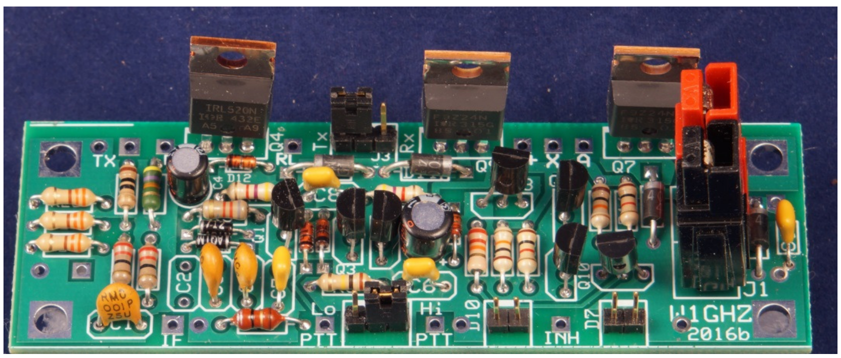
Sequencers

Unless you are only running a basic transverter with a milliwatt IF rig, you need a sequencer. It's cheaper than whatever you will blow up. Most of my sequencers can also provide the IF interface, switching the IF port from receive to transmit and reducing power as needed.

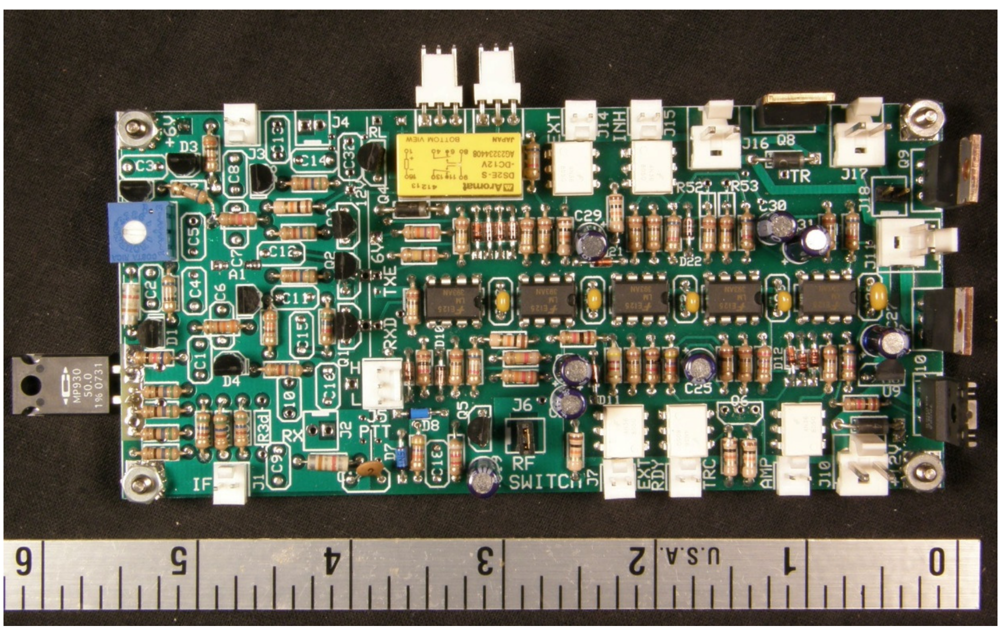
http://www.w1ghz.org/seq/sequencers.htm

I have made five generations of fool-resistant sequencers, and PC boards are available for the last four:

- **Mark2** – a simple sequencer for transverters like those from DB6NT that have the IF interface built in, and only need sequencing of power amplifier and TR relay.

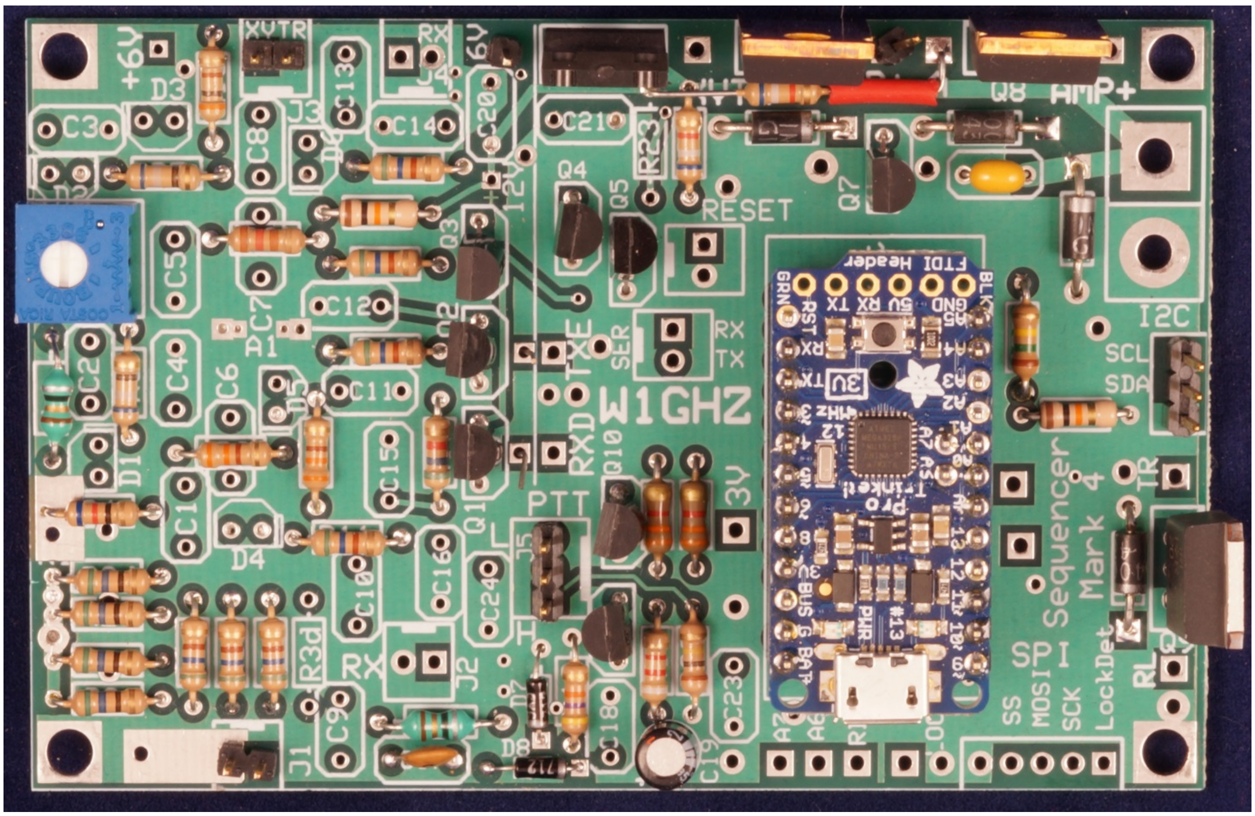


- **Mark3** – is a conditional sequencer with a PIN-diode IF interface that absorbs IF transmit power until switching is complete. A conditional sequencer can wait for external events to complete rather than just operating in a clockwork sequence. This version uses many discrete parts to provide all the needed logic functions.



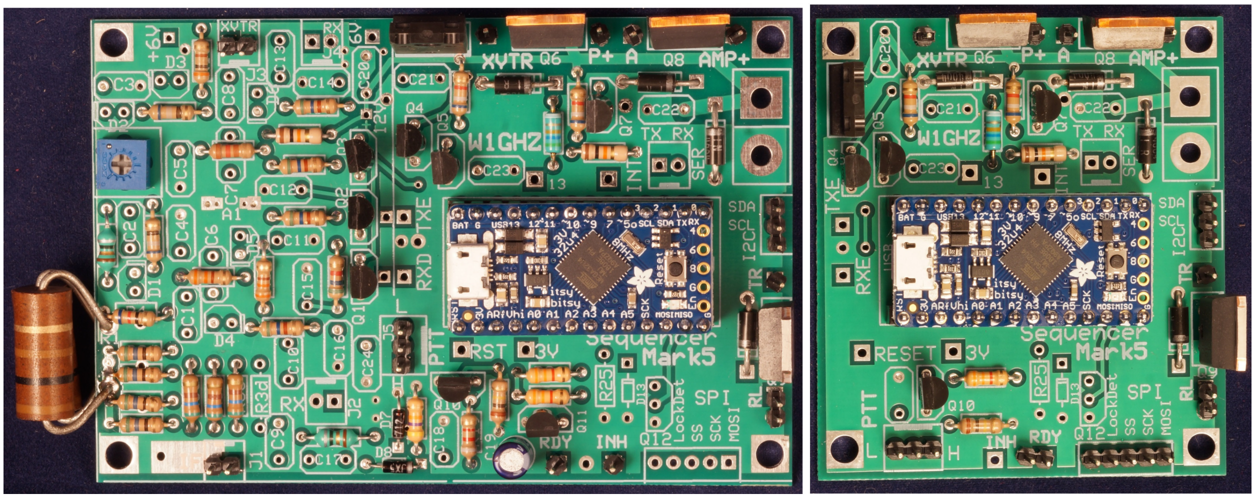
- **Mark4** – a smart conditional sequencer with the same PIN-diode interface. The discrete parts are replaced by an Arduino, easily programmable so you can make it as smart as you desire. Many interface options are available, to program a synthesizer or other external devices.

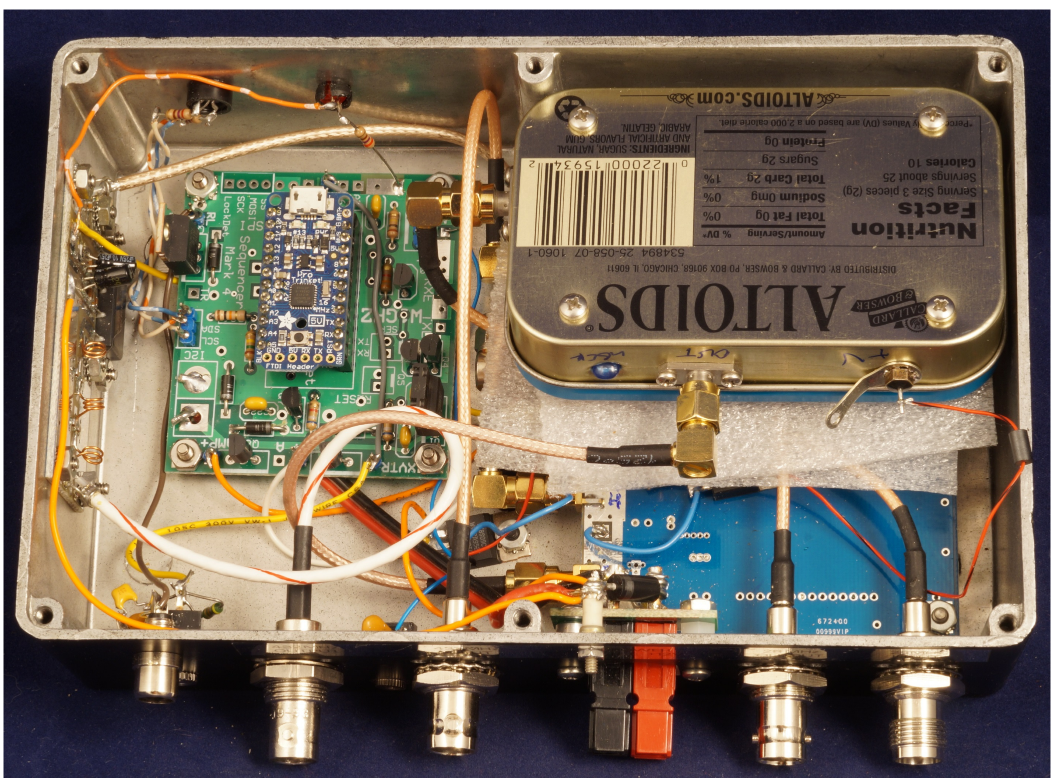
  The Arduino all eliminates many discrete components in the control area, making assembly much easier. The remaining discrete components handle voltages and currents beyond the Arduino capability.



- **Mark5 –** very similar to the Mark4, with an Arduino module that programs more reliably. The new Arduino has more pins available, which are used to provide even more options. There are two versions: with IF interface and PIN diode switch on left, and without the interface on right.

  The version without the IF interface might also be used to control a power amplifier, using the Arduino A/D converters to sense power, VSWR, voltage, current, or temperature.





432 MHz Transverter with Mark4 Sequencer (digiLO synthesizer in Altoids tin)