432 MHz Transverter for an SDR

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I've been thinking about a 432 MHz Transverter for some time, to use a Software-Defined Radio like the Flex-1500 with microwave transverters with 432 MHz IF. Recently, I built one of G4DDK's Anglian 2-meter transverters, and I liked the way he used off-the-shelf parts to make filters rather than helical filters, which can be hard to find. Since printed comb filters on PC board have worked well around 200 MHz in Local Oscillators for my simple microwave transverters, I thought the comb filters might be shrunk to 432 MHz and be small enough to fit in a transverter.

Then, at the start of the January VHF Sweepstakes contest, I found my 432 MHz transceiver had crapped out again. I quickly swapped in my IC-706, which worked but may be the worst CW rig around – a signal jumps right out of the passband when switching modes. Finding a weak signal again can be difficult. An SDR would eliminate this problem. Time for a transverter to replace the transceiver.

A transverter capable of operating contests needs more performance than a simple microwave transverter. Using a classical engineering approach, I reviewed the G4DDK Anglian 144 MHz transverter[1] for ideas to steal. Then I worked the comb filter design to a reasonable size and adjusted it to use 18pf chip capacitors, the value I use most in other transverters. I was able to fit three filters, one common after the mixer and one each in the transmit and receive paths, in a PC board size that allowed for reasonable prototype cost. The local oscillator is not on the transverter board – I have learned the value and flexibility of a modular approach.
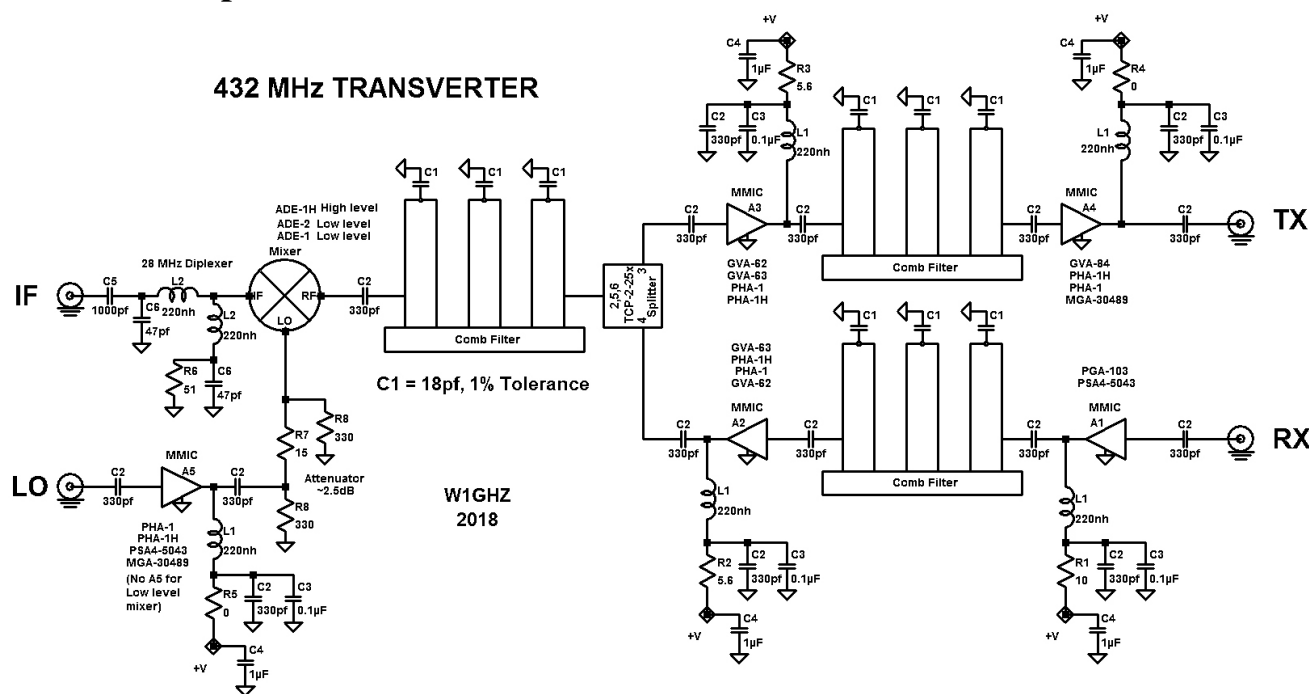
Circuit Description

Figure 1—Schematic diagram of 432 MHz Transverter

On the IF side of the mixer is a 28 MHz diplexer circuit, borrowed from G4DDK, which provides a 50 ohm impedance to the mixer at all frequencies – this is thought to help intermod performance. On the RF side of the mixer is one of the printed 432 MHz comb filters, followed by a Minicircuits power splitter to separate receive and transmit paths. The transmit path has two MMICs, a driver and a power amplifier, with a printed comb filter between them. Rick, KK7B, suggests that the attenuation of a filter between two high-gain MMICs helps keep the circuit stable and well behaved. Similarly, the receive path starts with a low-noise MMIC front end followed by a comb filter and another gain stage.

The high-performance MMICs that I chose have 15 or 20 dB gain each. The mixer has perhaps 7 dB loss, the power splitter 3 to 4 dB, and each comb filter has 3 to 4 dB loss. With various MMIC combinations, taking the sums gives about 17 to 23 dB net gain on transmit and on receive, which is about what I have measured.

Depending on component choices, this transverter can be built for high performance, with a high-level mixer for best IP3, for pretty good performance, or just cheap, using any old MMICs from conference door prizes. MMIC types shown on the schematic are my choices, top to bottom, for each stage. Component values are not critical, except for the capacitors tuning the comb filters.

My first prototype, Figure 2, uses a standard level (+7 dBm) mixer to avoid complications, and no LO amplifier – a zero-ohm resistor is used as a jumper. The performance is pretty good, with >100 milliwatts out and Noise Figure under 1 dB. The initial test showed that the filters were not quite on frequency, as expected (see below), but it still worked.
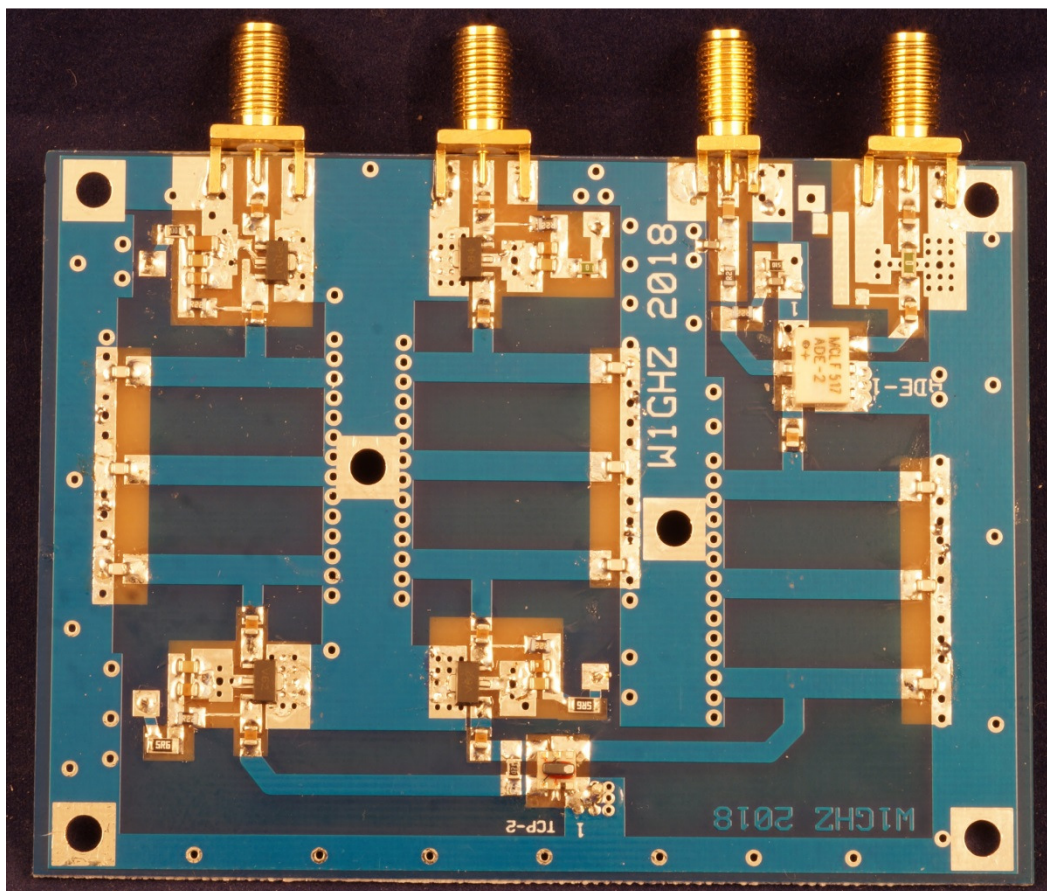

Figure 2 – 432 MHz Transverter prototype

Component Tolerance

Before I assembled a transverter, I chopped up a PC board to test a filter. With 18 pf chip capacitors, the center frequency was a bit low, with 432 MHz a few dB down. As a check, I replaced them with 18 pf capacitors from a different manufacturer – now the center frequency was a bit high.

Aha! While precision chip resistors today are laser-trimmed to exact value, chip capacitors are made in bulk and precision values are selected in test – 5% tolerance is what is left over, so the capacitance is either slightly high or slightly low, never right on. Digikey and Mouser both offer 1% tolerance at about ten times the price, but the total is still far less expensive than helical filters.

While waiting for the 1% capacitors to arrive, I assembled the first prototype and found the same frequency discrepancy. The 1% capacitors put the filters right on frequency, as shown in Figure 3, as well as correcting the prototype board filters.
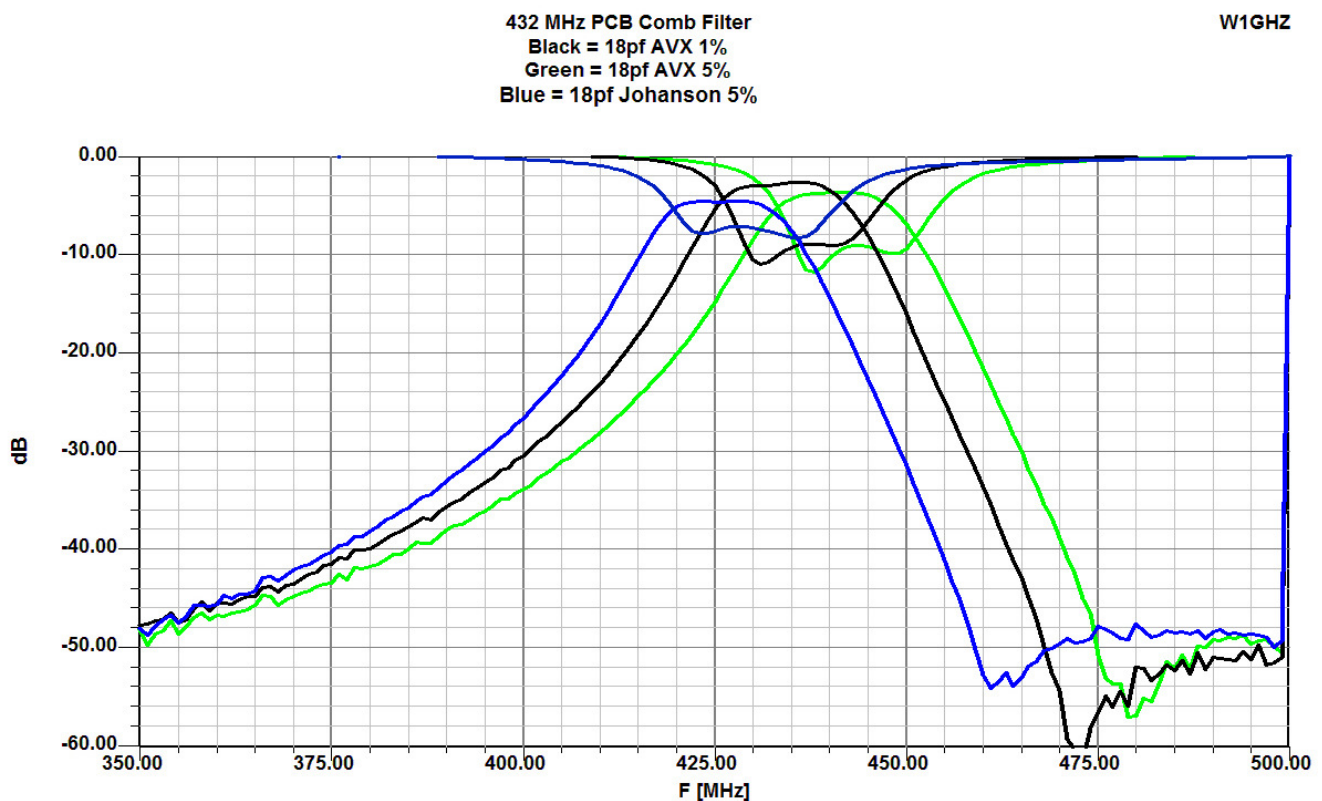

Figure 3—Printed Comb Filter measurements showing component tolerance

With the 1% capacitors, passband of the comb filters is about 428 to 440 MHz – 432 MHz should be within any remaining tolerance variation. The usual local oscillator frequency, 404 MHz, is about 25 dB down. Since the signal path goes through two filters, rejection will be even better. The insertion loss is under 3 dB, and is better with the 1% capacitors, and the return loss is also better. The improved performance is probably because all three capacitors in a filter have closer to equal capacitance values.

Higher Performance

The second prototype, Figure 4, has a high-level (+17 dBm) mixer, a Minicircuits ADE-1H, which requires more LO drive, nominally +17 dBm. This unit does not have the LO amplifier, just a zero-ohm resistor as a jumper, so I could control LO drive level better with a signal generator. Performance is very good, with Noise Figure under 1 dB and power output of about +21dBm at one dB compression.

After this encouraging result, two more boards were assembled with high-level mixers and LO amplifiers. Transmit performance was fine, but the receive results were strange – Noise Figure varied with LO drive level from about 1 dB up to 4 dB and back down again, as drive increased.

To figure out what was happening, I went back to the second prototype and used external LO amplifiers – my simple MMIC amplifier PC boards with various MMICs. I found similar strange results with external LO amplifiers, so I suspected some interaction between the MMIC and the mixer. Since some of the MMICs can produce more than +20 dBm, more than required, I added a 3 dB attenuator between the amplifier and mixer. This cured the problem with some MMICs: the PHA-1, the PHA-1H, the PSA4-5043, and the MGA- 30489. The GVA-84 still had strange results, and the MGA-30689, which G4DDK uses in his Anglian transverter, raised the Noise Figure by about ½ dB at all drive levels. I verified that the good MMICs still worked fine with a 2 dB attenuator as well. The unit in Figure 4 includes the LO amplifier followed by an attenuator.
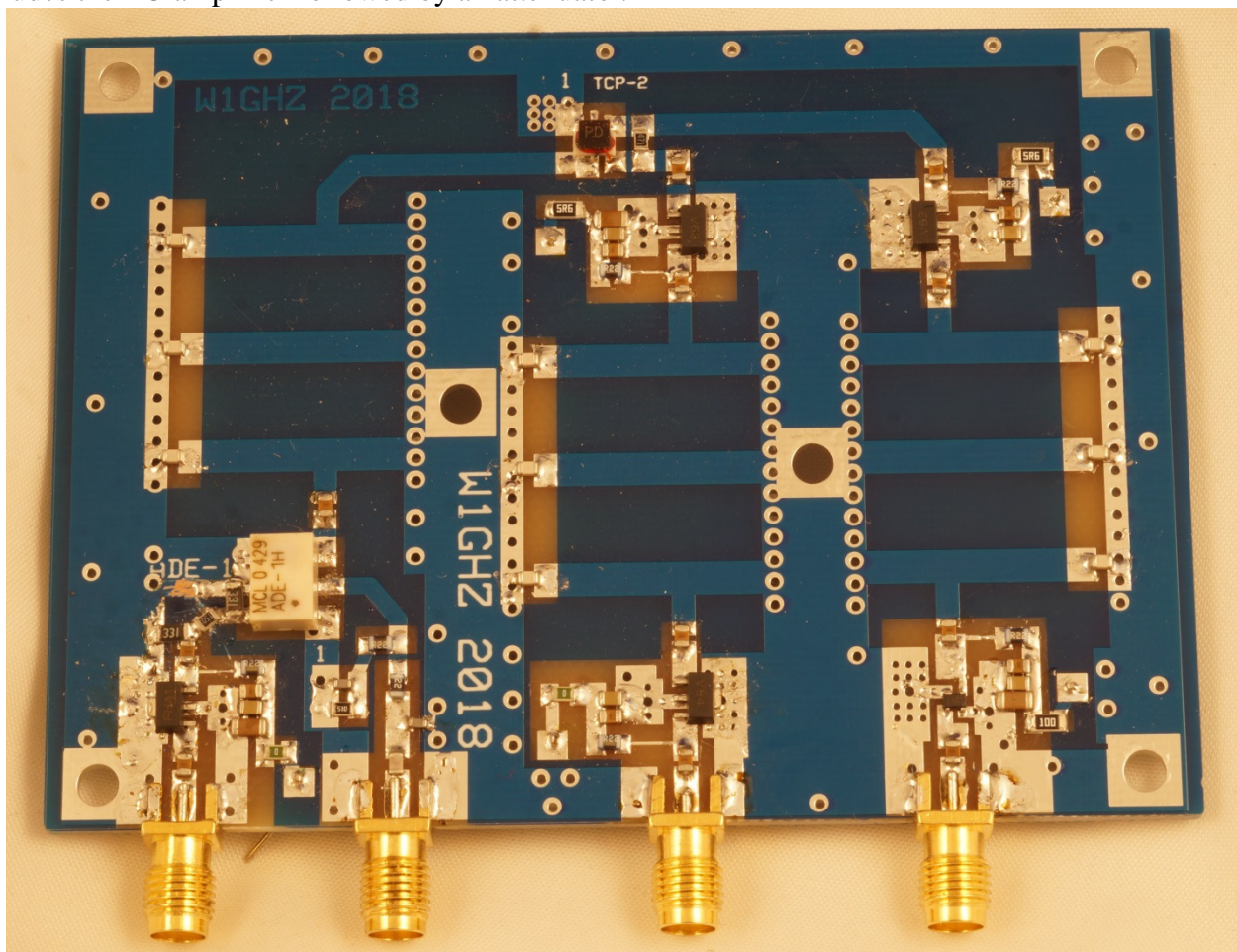

Figure 4 – Transverter with LO amplifer, attenuator, and high-level mixer

I had not made provision for an attenuator on the prototype PCB, so a bit of work with an X-Acto knife was required to fit in three resistors – some convenient values yielded roughly 2.5 dB attenuation. I used a PHA-1 for the LO amplifier on one board and a PSA4-5043 on the other – either will produce adequate power with the attenuator. With these changes, both transverters have Noise Figure under 1 dB with a wide range of LO input. The higher levels of LO power are needed for higher IP3 performance.
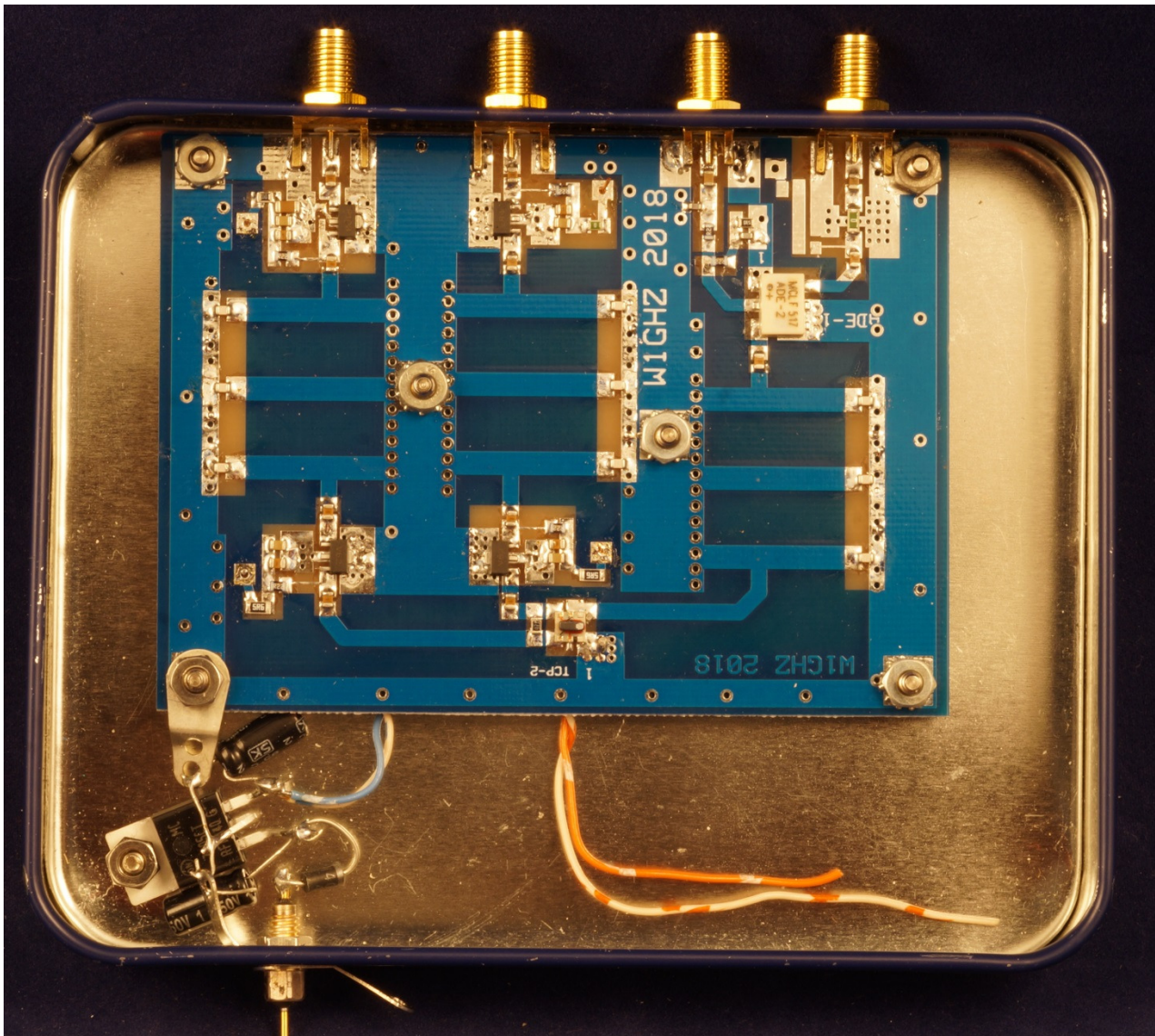

Figure 5- 432 MHz Transverter Prototype in tin box

Transverter system

The transverter board is the heart of a system, but isn't ready to go on the air. Also needed are a local oscillator, and a control circuit to switch between transmit and receive. If the transverter is to operate on 432 MHz rather than to drive a microwave transverter, then a power amplifier will also be needed.

Local Oscillator

Most important is a clean and stable local oscillator, preferably with low phase noise. I have a standalone 404 MHz oscillator chain that I built years ago, with output of about +5 dBm. This is adequate for the standard mixer, so I packaged up the prototype board in the tin box shown in Figure 5. It is shown wired for receive only, to monitor beacons and use with a Noise Figure meter. I've been monitoring a beacon near Montreal, and the frequency wanders about 2 Khz – I don't think all of that is in the beacon.

For a very stable LO, there are several choices: an OCXO, a synthesizer, or a VCXO. I acquired a commercial oscillator at some time which is marked 101.136354 MHz. Multiplied to 404 MHz, this would convert 432.000 MHz to around 27.5 MHz – not a problem with an SDR, since the software can be set to compensate for the offset and read 432.000. For multipliers, a simple doubler board like Figure 6 should work fine (http://www.w1ghz.org/small_proj/Simple_Frequency_Doublers.pdf).
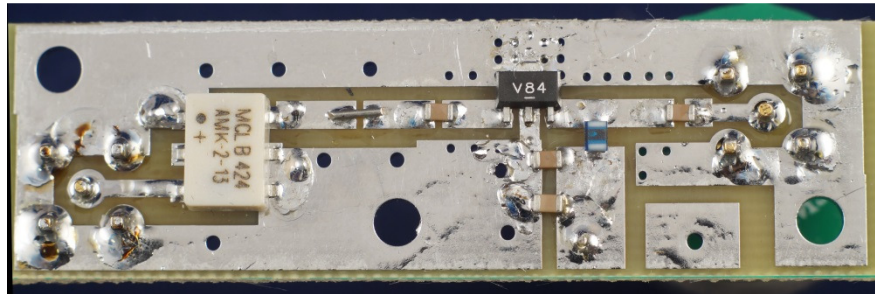

Figure 6-- Simple Frequency Doubler using Minicircuits part

A synthesizer can be both stable and accurate, especially if locked to GPS, and can make a compact package. Phase noise is a bit higher than crystal oscillators, which might be a problem in a strong signal environment – reciprocal mixing can increase the noise floor and mask weak signals. Out-of-band strong signals can be reduced by a good filter, but in-band signals can be difficult for contesting in some locations. I've been experimenting with a new "digiLO" synthesizer from **Q5signal.com** shown in Figure 7. It fits fine in an Altoids tin. The digiLO can also be locked to a 10 MHz reference for stable and accurate frequency control.
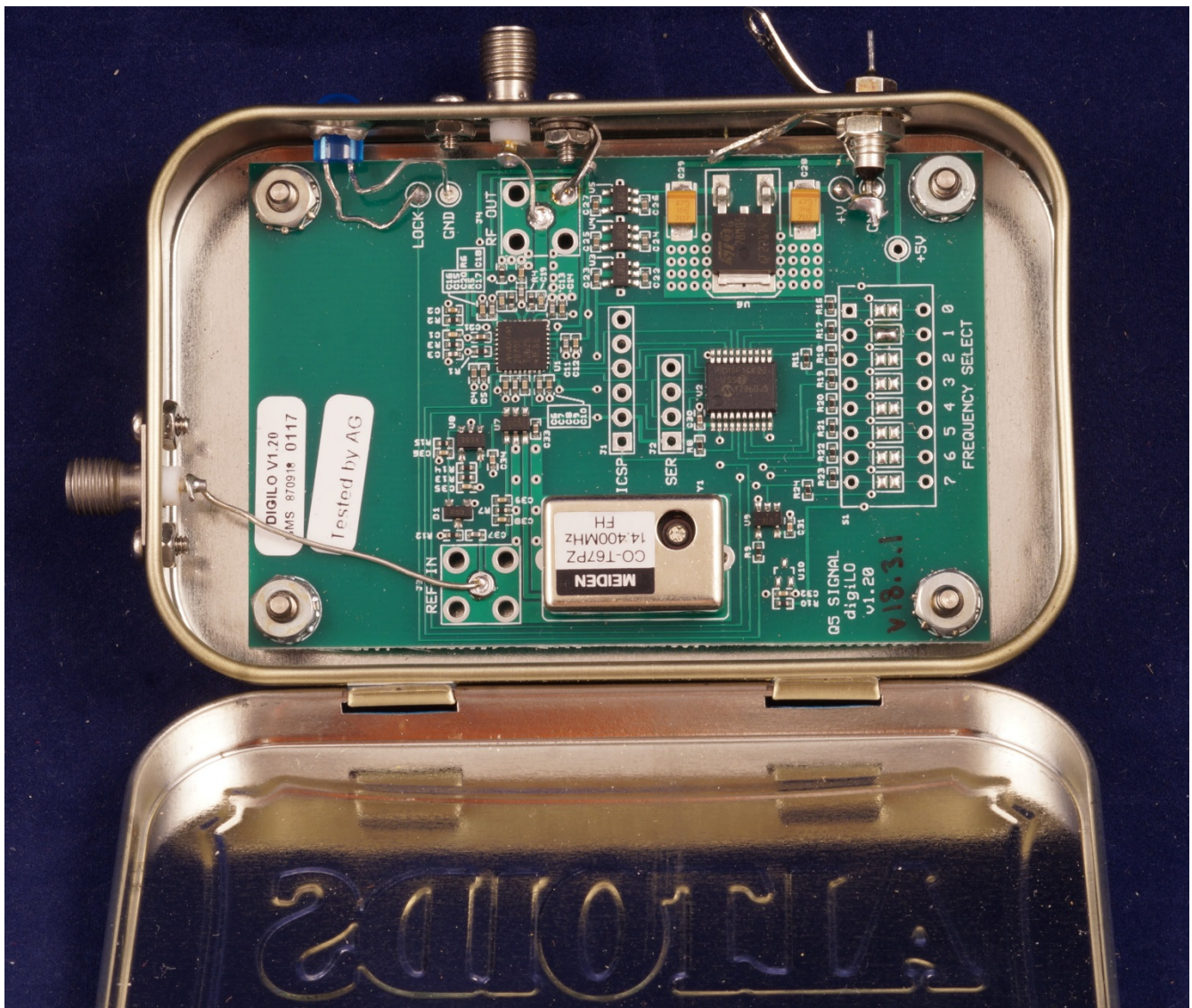
Figure 7 – digiLO synthesizer from Q5 Signal

A VCXO can provide stability, accuracy, and low phase noise, so it seems like the ideal choice. I described a VCXO board several years ago which works with commercial VCXO oscillators at several frequencies to lock the oscillator to a 10 MHz reference, like GPS. For this transverter, the obvious choice is the 200 MHz VCXO in Figure 8, followed by the doubler in Figure 6. The resulting IF frequency is 32 MHz, well within the range of an SDR.
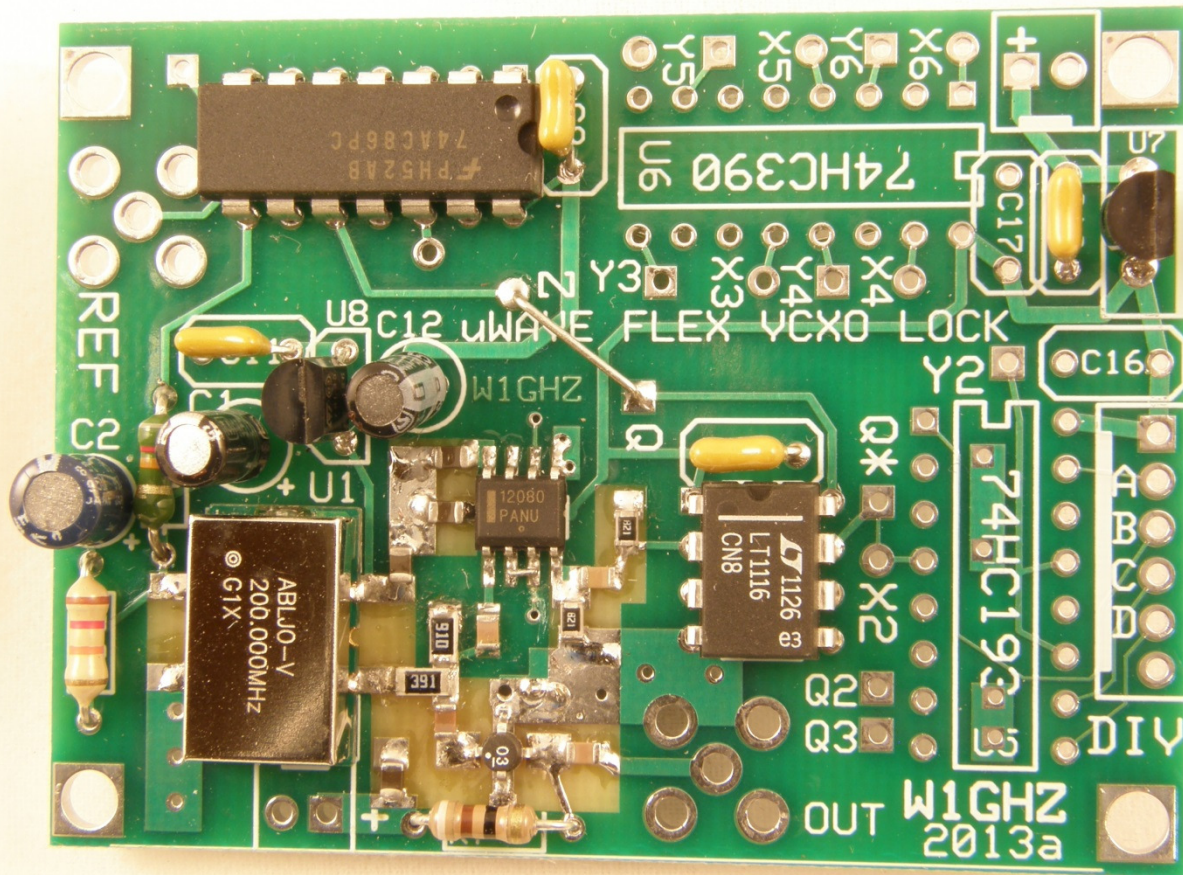
Figure 8 – 200 MHz VCXO

(http://www.w1ghz.org/small_proj/VCXO_for_Microwave_LO_update2.pdf)

Having an odd IF frequency might be an advantage if an SDR is used with several transverters – if each has a different IF frequency, signals on different bands don't leak through and show up as false signals. For instance, the 200 MHz VCXO could be used as the LO for both 222 and 432 MHz, with one IF at 22 MHz and the other at 32 MHz, easy to separate with a simple diplexer.   Another example would be a 100 MHz VCXO providing the LO for 144, 222, and 432 MHz, with widely spaced IF frequencies of 44, 22, and 32 MHz respectively.

Power Amplifiers

The easiest way to generate significant power is a Mitsubishi module. The traditional power level for a transverter is 25 watts, easily provided by a Mitsubishi RA30H4047M1. For a serious station looking for QRO, this power level is problematic – not enough to drive a tube amplifier, but much more than needed to drive a modern solid-state LDMOS amplifier. Since the solid-state amplifiers are easily damaged by overdrive, excess power isn't a good idea.

A better choice is a 7 watt Mitsubishi module like the RA07H4047M. This is adequate power for a solid-state amplifier, and less current and heatsink are required. I managed to fit a small PC board for these modules on the transverter artwork, shown in Figure 9, so I could try one.
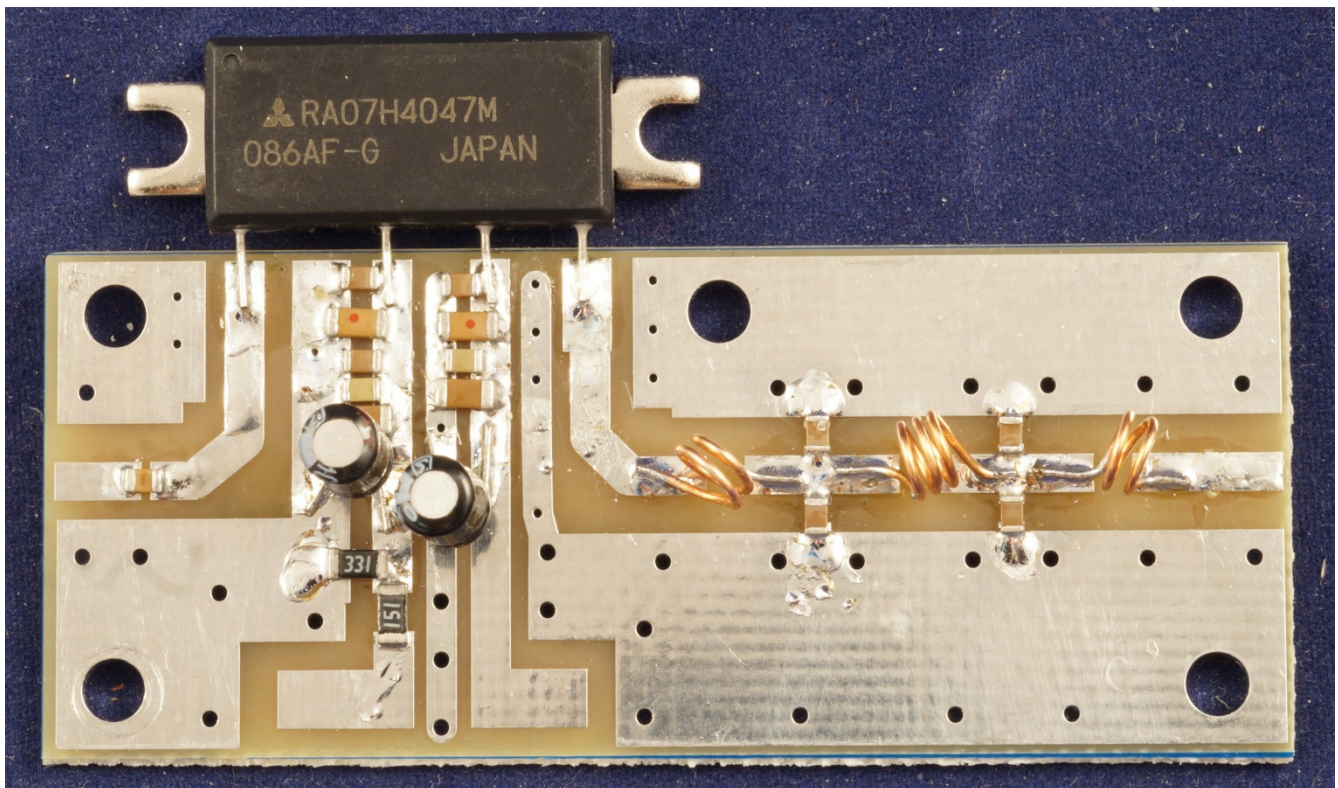
Figure 9 – Power Amplifier on PC board with Low-Pass Filter

The amplifier module needs a low-pass filter to remove harmonics from the output. Using free software, I designed one which provides the desired performance, but the inductor values, shown in the schematic diagram in Figure 10, are quite small.
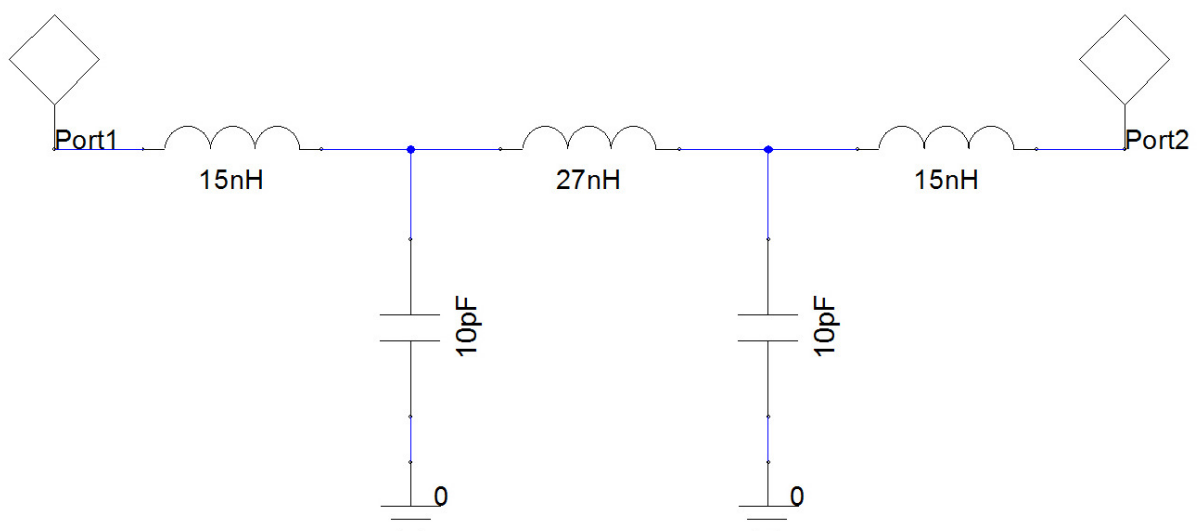

Figure 10 – Schematic diagram of 432 MHz Low-Pass-Filter

I guessed that a small 3-turn inductor might be in the ballpark for the small inductances. I wound one around a Q-tip and soldered it to a scrap of printed-circuit board in parallel with an 18 pf chip capacitor to form a resonant circuit, and added an SMA connector. The resonant frequency was measured with an Antenna Analyzer[2].

Figure 11- Measuring resonant frequency of L-C circuit with Antenna Analyzer to find inductance

The inductor and capacitor form a parallel-resonant circuit, which has high impedance at the resonant frequency and lower impedance at other frequencies. Figure 11 shows the impedance plot **Z** on the antenna analyzer, with the marker at the resonant frequency, 226 MHz.

The resonant frequency calculation is $f = \dfrac{1}{2\pi\sqrt{LC}}$

Turning this around, inductance is $L = \dfrac{1}{C \cdot (2\pi f)^2}$

The inductance to resonate with 18 pf at 226 MHz is 28 nh, close to the desired value for the center inductor – inductance can be adjusted a bit by squeezing the turns together or stretching them apart.

Removing one turn and re-soldering changed the resonant frequency to 289 MHz, for an inductance of 17 nh, which is in the ballpark for the smaller values.

I assembled the low-pass filter from Figure 10 on the amplifier printed-circuit board without the amplifier module, using temporary SMA connectors, to measure the **VSWR** that the amplifier module will see with a 50 Ω termination at the filter output. A low-pass filter should act like a transmission line below the cutoff frequency, but have a high **VSWR** at frequencies above the cutoff frequency so that those frequencies are reflected rather than passing through the filter.

The **VSWR** plot in Figure 12 for the low-pass filter with a 50 Ω termination at the filter output shows a low **VSWR**, like a transmission line, below 432 MHz, and very high **VSWR** above 432 MHz, . Note that I designed the filter for optimum performance at the operating frequency at the expense of a slightly higher **VSWR** at lower frequencies – a very good 432 MHz filter rather than a good low-pass filter. Also, for each 10 pf capacitor, I used two 5 pf chip capacitors in parallel for lower loss.

I must admit that the plot in Figure 12 wasn't the first try. The first one, with the inductors from Figure 11, was slightly high in frequency even after squeezing the inductors – I hadn't allowed for the stray capacitance of the PC board. Winding new inductors with a slightly larger diameter got it right.
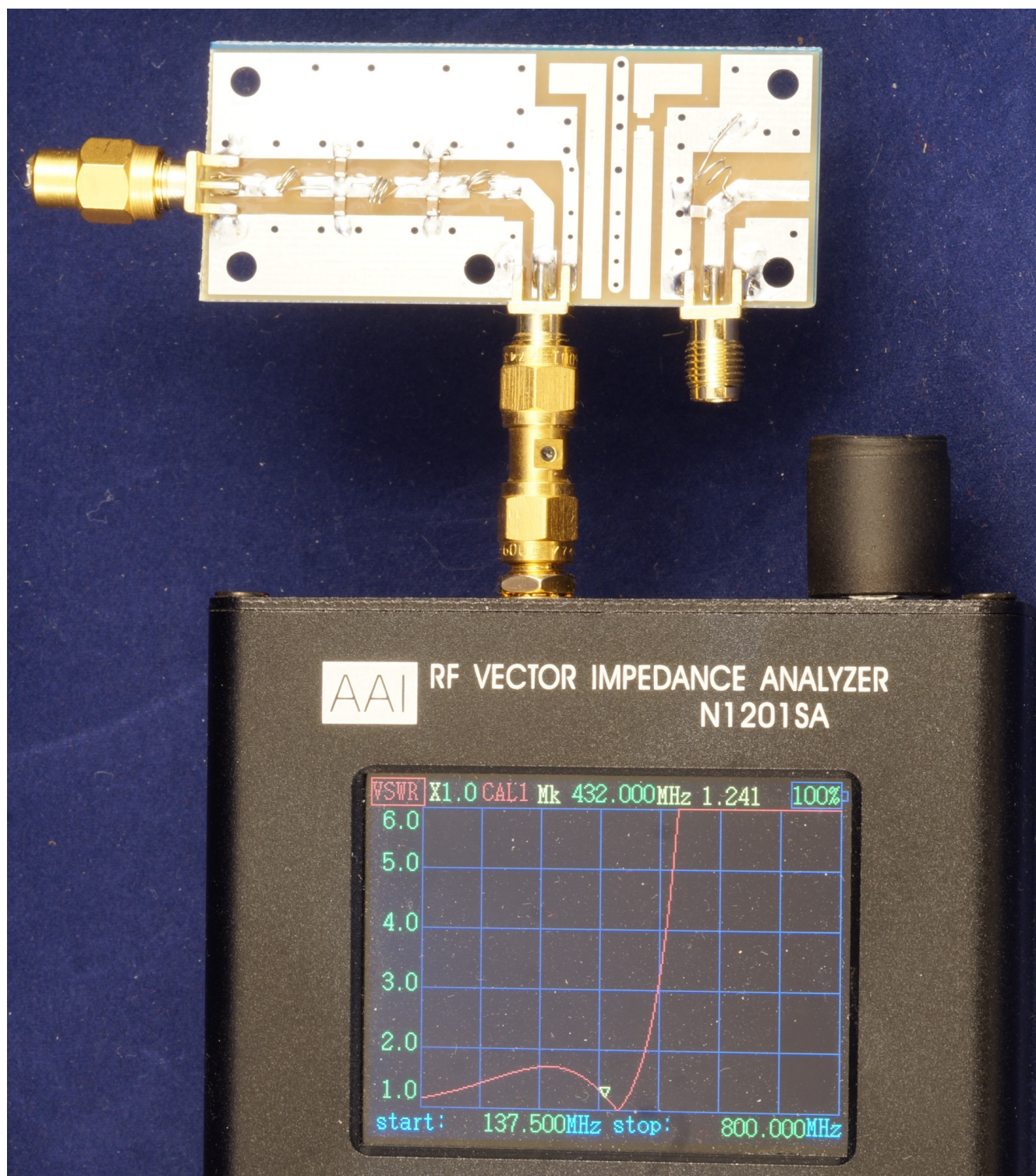
Figure 12 – Measuring VSWR of Low-Pass-Filter with 50-ohm termination using Antenna Analyzer

The completed amplifier was bolted in position on the die-cast aluminum box and fired up. It easily produced 7 watts output with an input of +13 dBm, the maximum available from my signal generator. A key-down test for 72 hours at this level showed stable power output with a reasonable temperature rise.

Control

The control circuit detects the PTT signal from the SDR and switches the transverter from transmit to receive. It can be as simple as a relay to switch the voltages, or as complex as a sequencer which controls the whole station, or at least this band. In anything but a simple QRP station, some sort of sequencer is required.

I chose to use my Smart Fool-resistant Conditional Sequencer[3], which uses an inexpensive Arduino module to provide the smarts. It can be programmed any way you like, as a sequencer or as part of station automation. One possible addition is for the Arduino to load the desired frequency into a synthesizer at power up.

If the IF transverter output is low power, like the transverter port on an SDR, then switching is simplified – the IF can be directly connected to the mixer. My smart sequencer has a PIN diode switch to reduce IF power. Since this is unnecessary for the SDR, I made a smaller PC board without the PIN diode switch, leaving just the Arduino for control, with driver transistors necessary to switch voltages and a coax relay. This version is shown in Figure 9.
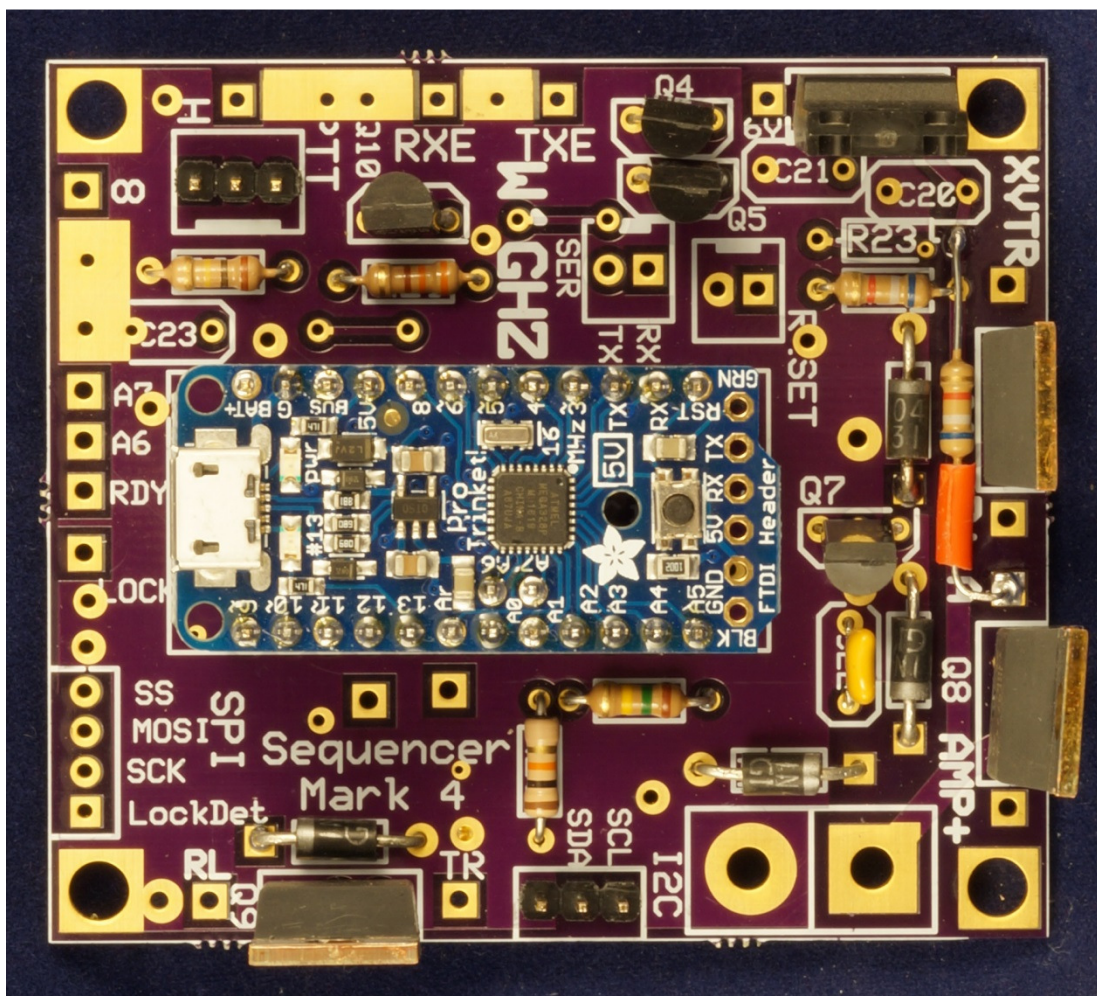
Figure 13 – Smart Fool-resistant Conditional Sequencer with Arduino

http://www.w1ghz.org/seq/Smart_Fool-resistant_Conditional_Sequencer.pdf

Complete Transverter

The transverter PC boards were assembled into an old Microwave Modules transverter box. Few of the parts were worth salvaging, but the die-cast box had the BNC connector holes conveniently drilled. The transverter board is on the right in Figure 14, with the sequencer on the left and the power amplifier on the left hand wall. The LO synthesizer, in an Altoids tin, fits above the transverter board, as shown in Figure 15. At final assembly, it will bolt to the cover. The coax cables are inexpensive on ebay, with many connector choices.
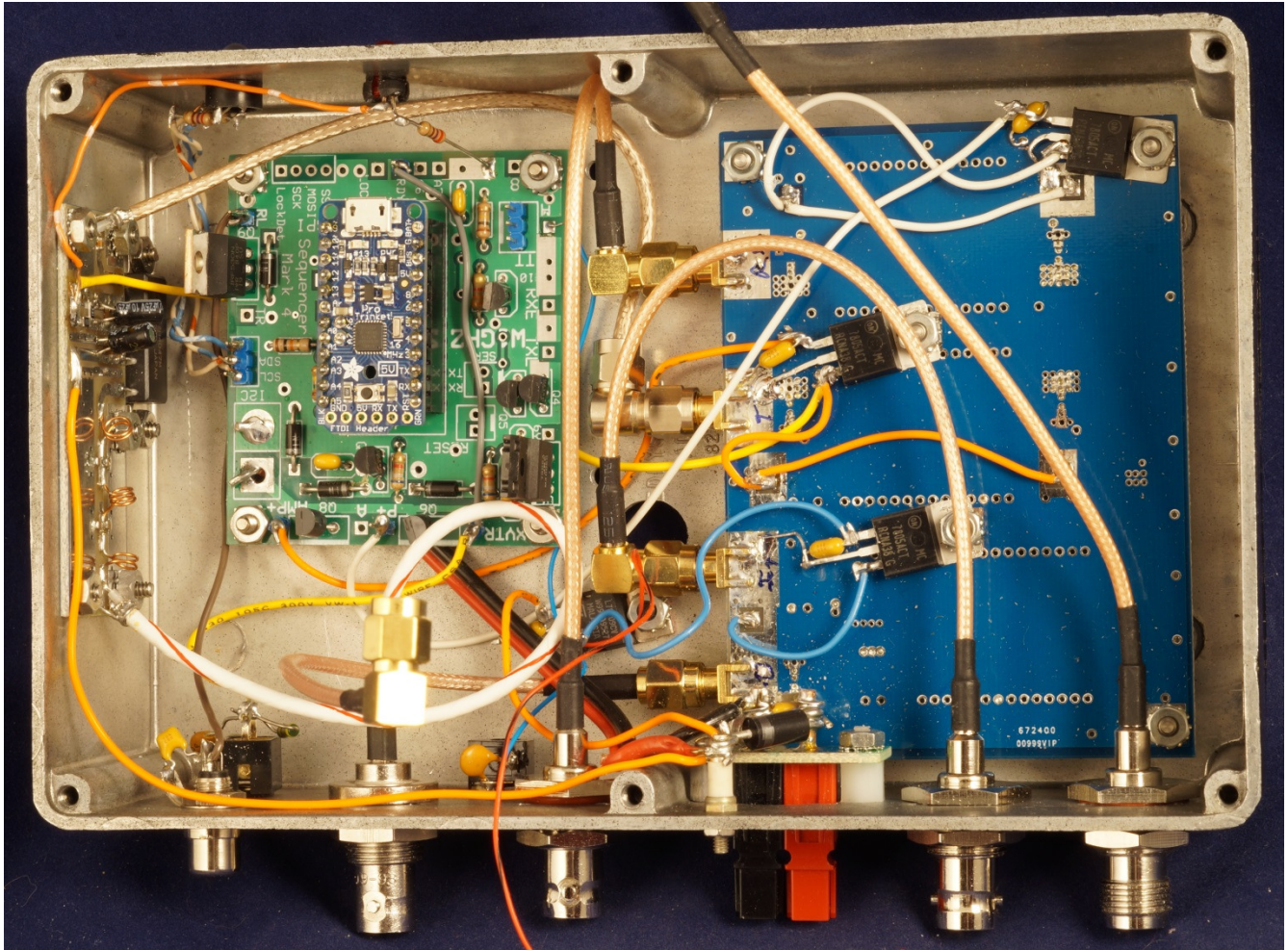
Figure 14 – Transverter assembled in die-cast box before adding Local Oscillator

The first thing tested was the sequencer – using the Arduino makes it easy, by putting large delays in the software so that the sequence can be followed by eye. Then I spent two days chasing down a reversed idiot diode (D8 in the photo) which blew other components and tripped the current limit on the power supply.

Once the diode was snipped out and a switching FET replaced for the third time, everything worked and I was able to verify transmit and receive. Then the Arduino software was upgraded to an operating-speed version.

Figure 15 – Complete transverter in box with LO in Altoids tin, which attaches to cover

Receive sensitivity was good, but transmit gain seemed high – only -11dBm of IF drive was required for 7 watts out. This high gain also amplified the LO leakthrough, so the LO was only about 20 dB down.

Some attenuation was needed between the transverter and power amplifier. I made a quick cut with an X-Acto knife of the input line on the amplifier board, and added ~10 dB attenuation with chip resistors – a π attenuator with 75Ω series and 91Ω shunt. As expected, this reduced the LO leakthrough by 10 dB and required 10 dB more IF drive.
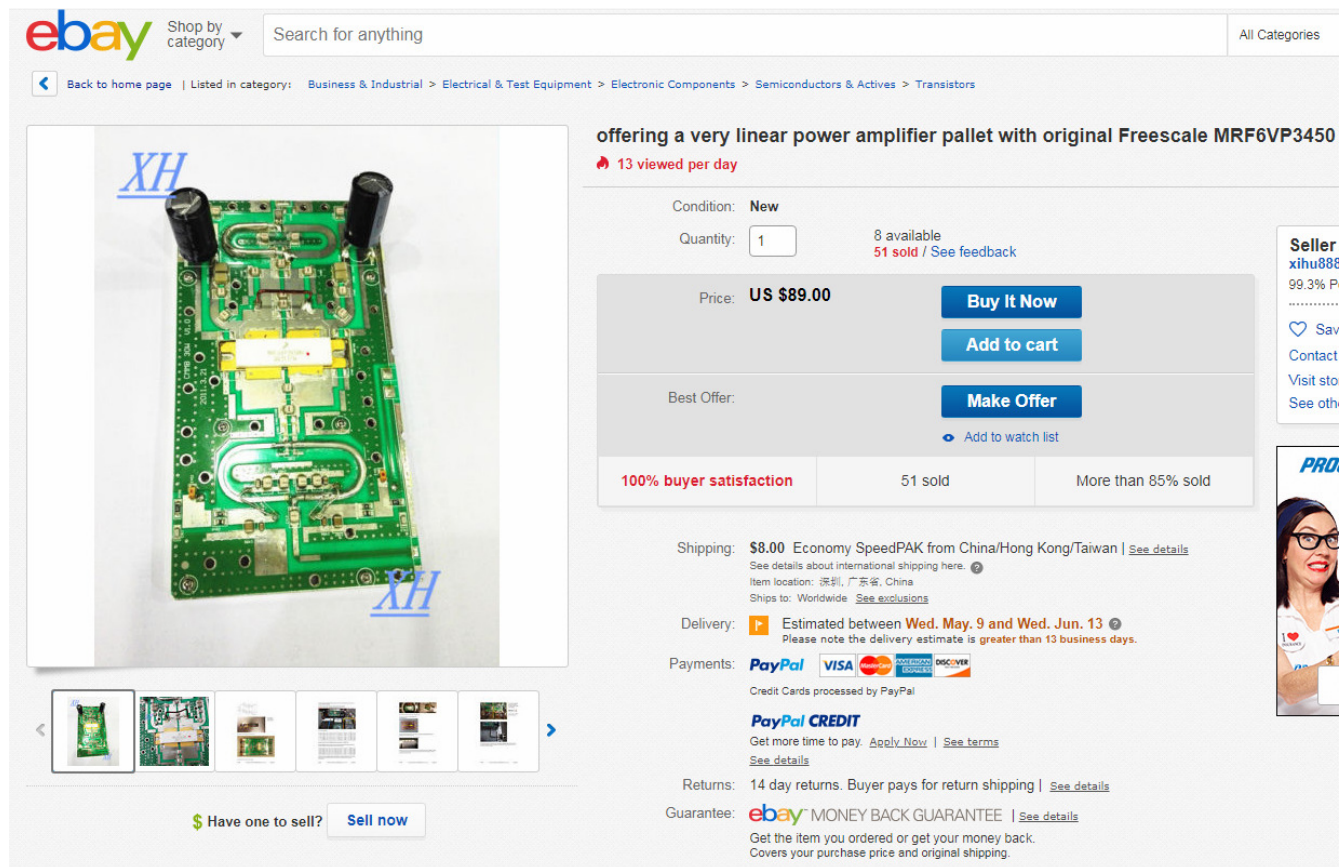
An on-the-air test confirmed that the transverter works. Beacon comparisons suggest that it hears very well. A couple of hours key-down made the box warm to the touch.

Measurements

A spectrum analyzer provides some real numbers beyond "sounds good." All harmonics are more than 70 dB down, so the low-pass filter really works. The LO leakage is about -37 dB, so filtering is needed before an amplifier. And a two-tone test at full power shows third-order products at -27 dB and fifth-order at -41 dB. The power level may be reduced for driving an LDMOS amplifier which should improve IMD performance.

Higher Power

One of the goals was a transverter suitable for driving an LDMOS amplifier. The one in Figure 16 seems like a perfect match, capable of up to 400 watts, at a reasonable price. A few small modifications are required. W1FKF has one of these going[3]. This is obviously my next project, so I can be heard.

Figure 16 – LDMOS amplifier found on ebay

Summary

The 432 Transverter works well with an SDR, providing all the SDR advantages for finding weak signals. It hears well, should have high dynamic range and it generates enough power to drive an LDMOS amplifier. With a 10 MHz frequency reference for accuracy and stability , this can be a serious system.

The transverter could also work with other IF transceivers. For higher-power IF rigs, the sequencer version with a PIN diode switch could be used – it can also separate transmit and receive, if so desired.

PC boards are available for the transverter, PA module, and sequencer.

<u>Notes</u>

1. Sam Jewell, G4DDK, "A high performance 144MHz transverter and PA – The Anglian," DUBUS, III/2014, p. 62.
2. Paul Wade, W1GHZ, "Antenna Analyzer Pet Tricks," *QEX*, January/February 2019.
3. Paul Wade, W1GHZ, "A Smart Fool-resistant Conditional Sequencer," *Proceedings of the 44th Eastern VHF/UHF Conference*, 2018.
4. Don Twombly, W1FKF, "How to Modify E-Bay Amplifier for 432 SSB – 400 Watts PEP," *Proceedings of the 44th Eastern VHF/UHF Conference*, 2018.