70cm / 432 MHz Transverter Project

January 2010

After the 2009 Spring VHF/UHF Field Day, I decided that I had to improve the performance of the 70cm / 432 MHz equipment. I needed a lower noise figure on receive and more transmit power than was being achieved with an old Microwave Modules MMT432-28 transverter. More importantly, I wanted something small and almost self-contained - much like my 23cm transverter. I had bought 2 diecast boxes and 2 heatsinks at that time so that pre-decided the overall "package size" for me.

The 23cm transverter project had also exposed me to the use of surface mount components more than previously so I thought that it was time to update the technology used in this project to catch up with the times (it is 2010 after all !). I searched around and found sources of 0603, 0805 and 1206 resistor and capacitor 'packs' plus bought in some MMICs, SMT diodes & transistors and some RF chokes etc.. In effect I topped up the 'parts box' with this style of part.

The next step was to confirm a circuit design. I downloaded the DEM 432/28 transverter manual and I ended up merging parts of it's concept with an extract of the Minikits 23cm transverter concept. Ok, after a lot of deliberation I effectively had a basic schematic to build to. The DEM transverter used either the 30 watt or 60 watt Mitsubishi RAxxH4047M RF power block without any other circuit changes and since both were available from Minikits in South Australia, I had to decide which PA I would use. The difference in cost was 30 watt RA30H4047M @ about $65 or the 60 watt RA60H4047M1 @ about $95. Since I wanted the greatest transmit power that I could achieve in a small package with field days in mind, I bought the 60 watt version. The front end was going to be a MGF1302 because I had some on hand plus I knew of many others who used these in their masthead amplifiers at 70cm & 23cm - and if it was a low enough noise figure for them, why not for me too. Fortunately I had pre-bought 4 of the TOKO 430-450MHz helical filters last year because they were destined for this project & Minikits no longer has any stock !

I now had all of the bits I needed to make it up, SMD-style-mounted antenna changeover relay included. Now for a PCB... I have previously used the ExpressPCB software (http://www.expresspcb.com/) for creating PCB layouts for my PICAXE projects so it was the natural choice for me to use that, particularly as it had SMD components in the supplied library. I had to create new components too but that was ok. It was going to be a bit simpler than doing a 23cm version because there weren't going to be any PCB-style tuned lines, and with the lower operating frequency, track lengths could be longer. Even so, I knew I still had to make sure of effective earthing so that the MMICs & PA remained stable.

The outcome was to be a PCB using surface mount techniques, single sided on a double sided PCB material so that I could use wire-through grounding 'vias' to improve the 'grounding' and thus the stability of the MMICs on the PCB. The technique I aimed for was that all components would be mounted exposed side up and that the back-plane would actually be screwed down to the diecast box so that the RF power module on one end could just be attached through a cutout directly onto the heatsink (in a similar manner to the 23cm transverter).

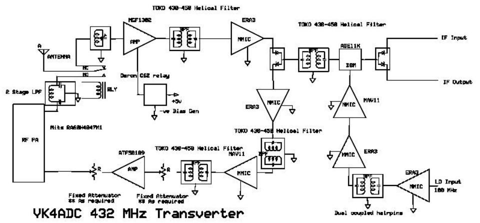
I am not planning to actually supply the schematic on this web page but below is the configuration in block and layout form. It may not look complex until you start to do a maximum-copper PCB layout with minimal actual jumpers. I have lost count of the number of changes that I made in positioning parts, then re-positioning other parts to make everything fit. The aren't any actual jumpers required on the board & all of the wires to/from the PCB are actual input, output or power connections.

One thing that is not on the PCB is the actual local oscillator (L.O.) - only the multiplier / amplifier chain. The L.O. will be one of two styles - either a standard Butler-style crystal oscillator - or - a PLL synthesiser locked to my GPSDO 10MHz frequency source. The other factor involved in the LO design is that I wanted a lot of flexibility as to whether I used the I.F. set to either 14 MHz, 28 MHz or 145 MHz. To achieve this, the actual LO injection into the mixer will be at 418.000 MHz, 404.000 MHz or 287.000 MHz respectively for a 432.000 operating frequency. I chose to use wire hairpin loops (L2 & L3) above the PCB rather than on-PCB tracks so that I could easily adjust the inductances and thus the resonance range with the on-board trimmer capacitors. Before anyone argues that you shouldn't use 145MHz as the 3rd harmonic will be generated at the mixer output and remains within the bandpass of the transmit output filtering, my research indicates that the 435.300 (eg 3 x 145.100) level will be at least 35 (and more likely 45 - 50) dB below the on-frequency product (at 432.100) when using the ADE11X mixer. Given that the driver mode is primarily USB, anything radiated at around 435.3 will be low level and very spasmodic in nature.

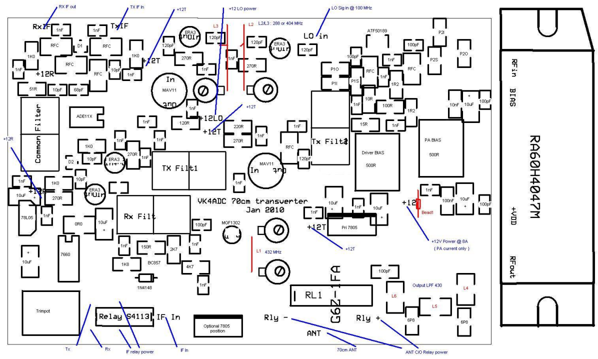
At this stage, I am leaving my options open as to whether I will use a 14, 28 MHz or 145 MHz I.F. in the finished unit - in other words the design has to flexible enough to allow any I.F I want.

(/~vk4adc/web/../tvtr-synth/TVTR3%20upd.jpg)---

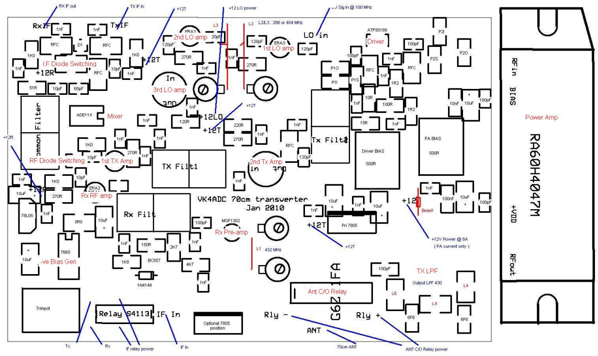
Mouse-over the graphics for larger detail.



This is the simplified overall transverter block diagram. There are a few details not included like the on-board voltage regulators, an additional relay for I.F. changeover etc...



The parts layout looks something like this.
The actual PCB size is 103mm x 70mm



This image has had "tags" added in red print to indicate the part of the circuit...
Mixer, RF Pre-amp etc..

The research, planning & creating the PCB layout of the transverter occupied varying amounts of time during Dec 2009...
enough that the XYL commented "haven't you finished that YET ?" when she kept on seeing the PCB layout being worked on on screen...

1st January 2010 : Making the PCB....

The positive artwork from ExpressPCB was generated by printing on Celcast Inkjet-style transparencies (IJ21-50) on my Canon R210 inkjet printer. The printer was pre-set to default to photo mode and for inkjet transparency media before attempting to print because there are no printer setup options within ExpressPCB !

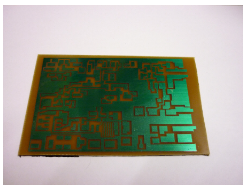
I had previously tried printing on my Kyocera laser using laser copier/printer transparency media (Celcast 600-100) as well but it did not seem to be 'black enough' and there were obvious 'fault and shading lines'. By using the inkjet on photo mode, the resulting print was completely black - without lines or visual blemishes. Just a suggestion, leave the inkjet transparency overnight so that the ink is properly dry before trying to contact print with it.

I used some old Kinsten positive resist double-sided PCB (date coded back in 1999 !) that I used in my old contact print frame and took it outside for exposure to the sun, but initially with a cover over it . I removed the cover for a timed 20 secs for direct sunlight then quickly re-covered it to stop further exposure.

The PCB was then developed in weak caustic soda solution (NaOH) - about 2-3 minutes until the green wisps disappeared indicating that all of the light-exposed area had been processed. The board was then rinsed thoroughly under cold running water.

The board was then etched in fresh Ferric Chloride (FeCl) solution at room temp (28 degrees C today), taking about 6-7 minutes before being washed off properly, again with running water under the tap.

Just a note for those who noted that it was a double-sided piece of PCB material : the protective adhesive plastic layer was left on the second side during exposure, developing & also during etching.

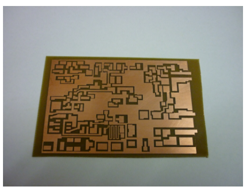


This is the untrimmed etched PCB still covered with the green positive resist.

After etching, the PCB was cleaned off with steel wool, again under running water. The other side (plain copper) then had the protective plastic layer removed and then the positive resist removed - again with the steel wool.

After drying, both sides were sprayed with a clear protective PCB lacquer. The board was then left overnight for the lacquer to dry properly.

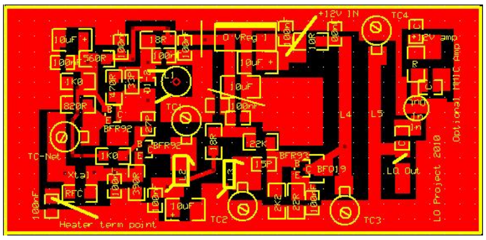
Note : some PCB positive resists can be left on the board and used as masks to prevent future corrosion of the copper tracks - and can be soldered through. I had not tried that particular characteristic of the Kinsten board so elected to remove the resist coating and use the clear lacquer as I have done many times previously - very successfully.



This photo was taken a few minutes later after the resist was removed with steel wool.

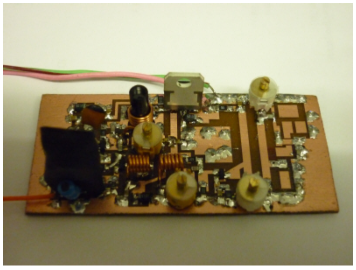
See also my making PCBs page for other details about this process.

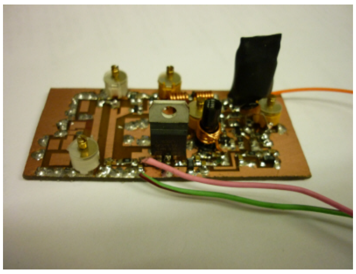
It became pretty obvious at this stage that I wasn't going to get the PLL synthesiser project ready in time for the field day so it was "full steam ahead" to build a 'work/look-similar' to the Minikits-EME65 L.O. (see my 23cm transverter page for more details) up as an interim 400 MHz local oscillator. The schematic was changed a little to suit my approach and the parts list was a little different too. As with the other projects, this was as close to SMD-style as I could make it. That meant that the transistors were SMD's and primarily the big items : trimmers, crystal, 3-terminal regulator and coils weren't, and it all was to take place on just one side of a double-sided piece of printed circuit board. It took less than a day to create the PCB layout from the altered schematic, produce an actual PCB, mount the components on it and power it up.



Actual PCB size 65mm x 38mm

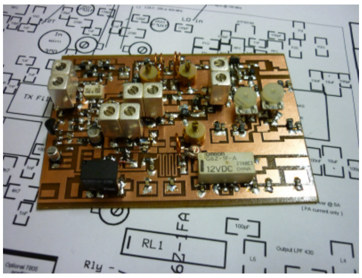
The photos below show the 69.666 MHz crystal shrouded in a sleeve of black heatshrink, over a previously shrouded sleeve (so double thickness heatshrink), and that enclosed a PTC resistor heater element too. My initial consideration on the lengths of the tuned lines was somewhat in error (or I didn't use the trimmers that I should have) in that the trimmers were initially in full mesh coming up to the peak in output at 418 MHz. That was solved simply by adding a 4p7 SMD NPO capacitor across each trimmer and, from the top photo below, you can see the trimmers came back to mid-mesh. Of course if I had been using it up around 500MHz (or so), it would have been fine. The pair of enamelled wire coils plus associated trimmers resonate at 209MHz while the coil on the Neosid former to the left of the 3-terminal regulator was tuned to 69 MHz. Not visible in the top photo is the frequency adjustment trimmer (behind the crystal/shroud), but shown in the bottom photo.


Pink/green wires were +12V supply & ground, orange was heater power.


Rotated view showing the frequency adjustment trimmer at RHS

The RF output level at 418.000 MHz was around +10dBm.
Tests for actual frequency drift showed that it was marginally better with the crystal heater powered on (& after stabilising for a period) - as against with it unpowered - but of course the frequency was different for each 'mode' (hot/cold) so required re-trimming to frequency for each evaluation..

The components were mounted on the transverter PCB as per the above board layout and finally powered up one section at a time, starting with the local oscillator (LO) segment. The photo below shows the PCB at a stage a little before completion - there are still components like the MGF1302 RF amp, the voltage regulator and the 7660 negative supply device still missing. If nothing else, it gives you an idea of how the main transverter PCB was put together.



Needless to say, the project was not without it's issues. The LO output from the separate PCB output was over-driving the transverter-LO multiplier simply because it no longer needed to frequency multiply (as was planned, with those inherent losses). It was now just a buffer amplifier and after a good deal of testing, just one MMIC stage was left in place between the external LO and the ADE11X mixer, thus dropping out the 2 x ERA3 stages plus the L/C filtering between them. Exit two trimmers, coils & some SMD parts.

I decided that it was going to be easier to get the receive side working first so put +12V onto the couple of RX supply pins, connected a receiver to the IF output and a signal generator to the receive input and proceeded. I could hear the generator at 432 MHz with a fairly low input level and as I tuned the common 430 MHz helical filter and then the receive-only 430 MHz helical filter, the sensitivity improved more. The final tuning point was at the input of the MGF1302 receiver RF preamp and that was a matter of adjusting a series trimmer and a parallel resonating trimmer for best performance consistent with what could/should be the best noise figure. Final results will be tabulated later. In real terms, the receive side was pretty straightforward - it tuned easily, was stable, and was quite sensitive.

The transmitter side was a completely different story. I put RF from the sig gen at 0dBm into the transmit IF port, +12V onto the TX supply pins, used the R7100 receiver at 432 as well as my spectrum analyser, both connected via a T-piece with the sample point being the output of the second transmit 430MHz helical filters. Both transmit helical filters peaked ok, the spectrum looked pretty clean, output level was about +6dBm, things were looking good. I then connected the ATF-50189 driver stage in line and adjusted the bias for the 280mA of supply current and the stage was unstable - with spurious signals all over the place. Even though it produced around +20dBm output (100mW), it was unusable. I tried different bias adjustment points and eventually found one where it 'seemed' stable. At one stage I even saw about 250mW (+26dBm) out of the thing. I have to explain at this point that the receiver testing and the transmit side (so far) were done with the PCB just on the workbench, but to progress further, I now had to start mounting things into the destination diecast box so that I could connect the RA60H4047M1 60 watt power amplifier block.

Holes were drilled in the diecast box, the PA area slotted to accept the PA block directly onto the heatsink assembly, the heatsink mounted on the top, coax connector holes made. ... etc.. etc.. The physical assembly went well, the transverter PCB positioned properly so that it matched up with the PA leads, heavy duty power leads brought into the box - all of the things you would expect....

Finally it was time to put power on to the transmit side again, this time with the 60 watt PA block in line, and with the transmitter output terminated in the power meter/dummy load and with a sample to the spectrum analyser. Power on - no sparks, fires etc.. Adjust the variable bias voltage on the PA block - it is now drawing about 7 amps at 13.2V - still no fires or sparks. Apply drive at the IF gradually increasing the input level, the RF power meter shows more than 40 watts for a while then drops. Sure the heatsink was warm/hot but then again, that is expected when dissipating the 80-100 watts quiescent power under transmit conditions. Nope, the PA wasn't too hot and is still drawing about 7 amps, down from the 15-odd amps with drive and the RF output. Nothing I do gets me much RF output.

Let's go back to the RA60H4047M1 data sheet - maximum drive 100mW (+20dBm), that SHOULD have been ok - BUT IT WASN'T. It turned out that the input MOSFET stage of the 4047M1 had been overdriven because it really only wants about +6 to +10 dBm drive to achieve maximum output. My ATF50189 was outputting too high a level - a level that the PA block could not accept. Add the possibility that the ATF50189 became unstable / spurious again and created yet a higher power - in excess of the +20dBm rating - even for a short time. Exit one RA60H4047M1 - value just under $100.

I contacted Mark at Minikits and he urgently shipped me a RA30H4047M PA block - the 30 watt version - priced a bit lower at around the $65 mark. I installed that device in place, skipped the ATF50189 stage completely, set IF drive at around -30dBm and powered it up again. By the time I was at -20dBm IF drive, there was about 1/4 watt of RF output and as I increased the IF level, up came the RF output power. I saw about 40 watts output at around 0dBm drive, power level was stable, spectrum analyser looked good. This time around, the transmit side was working properly.

Unfortunately I didn't take any photos through these stages so can't show you the progress... I was more interested in the technicalities !

I still had lots of other things to do : like wire the antenna changeover relay in line, install a presettable attenuator into the TX IF input line, set up the transmit/receiver supply voltage switching, add indicator LEDs to the frort of the box.... but they got done and the transverter reached the stage where it actually looked like a finished unit - and best of all - it looked like it was going to be ready for the VHF/UHF field day. I then set up the I.F. transceiver - my Icom IC-718 - at 1 watt of transmit output power at 14 MHz & the IF input attenuator at 30dB so that the actual transmit IF drive was close to 0dBm.

It was time to do some on-air testing because the 'in-shack' results seemed good. John VK4TJ in Toowoomba, at around 100KM away, came to the rescue with a successful QSO on 432.100 SSB, sounded good each way. I could hear another fellow in Toowoomba and he couldn't hear me so that confirmed the receiver sensitivity was very good - as I had measured. In point of fact, a test with the antenna on and off - a good test of noise figure - was such that upon connecting the antenna (a 24 element yagi), there was an appreciable rise in noise apparent in the receiver. This test was repeated with my Icom AH-7000 discone fed via heliax - same result.

And, yes, it was ready in time for the field day as the photo below shows. The transverter above the IC-718 at the RHS is this 70cm unit, the one on the LHS is the 23cm transverter atop the Kenwood TR751A transceiver.

One thing that did become obvious during the 2010 Summer Field Day was the LO drift issue. Even with the crystal heater powered up, the heating effect of the whole diecast box must have been sufficient to make it move around in frequency. The subsequent periods while I operated on other bands - and thus allowed it to cool - made the frequency unpredictable to a degree. This effect made me divert my attention afterward entirely to the PLL synthesiser project simply because I had the same problem now with both my 23cm and 70cm transverters - frequency drift with time/temperature !