A Low-Power 70cm Mini-Transverter

10 August 2011

Why only low power ?? Anyway, why 70cm ?? What is Mini about it ??

This article is to show you how it can be done - simply and at low cost - so that you can get onto the microwave bands easily using that existing HF or HF/VHF transceiver as an IF.

When your prime intention is to drive a microwave transverter, you only want low driving power - about 10mW (yes, milliwatts) or +10dBm. Higher powers usually have to be attenuated down to around this power level so why not use this final level as the target in the first place. By the way, the concept of this transverter is not a mainstream unit to be used directly on an antenna - it's planned use is into a higher frequency transverter.

Why 70cm ? Actually, for transverters up to 3400 MHz, 144 MHz is quite ok but for the 5.7 GHz and 10GHz bands, you really need a higher IF - Intermediate Frequency. The reasons are quite simple - the higher in frequency, the more difficult to obtain selectivity in the tuned circuits so the higher the levels of the unwanted signals in the transmitter output.

Let's use a few examples about various IFs that might initially be considered for various amateur bands. To "transvert" a HF band to 2m (144-148 MHz), you need to use at least 14 MHz - and preferably 28 MHz - as the IF. The maths are 144 - 14 = 130 so the Local Oscillator (LO) frequency required is 130 MHz. The other mixing product (the image) created is 130 -14 = 116 MHz. The "filtering" in the transverter has to attenuate both the 130 MHz LO) and the "image" signal at 116 MHz to produce a clean output signal and using reasonable LC filtering, this is practicable. Those same sums with 7 MHz as an IF make the filtering very critical and almost impossible. The 28 MHz IF makes the filtering very easy as the LO is then 28 MHz away and the image 56 MHz away. A good rule-of-thumb is that if the LO is < 5% away from the operating frequency, then it is too close to **easily** filter. Why do you need to filter out the LO and the image in the first place ? The microwave transverter that follows it generally has even less bandpass filtering available so signals generated at this stage are amplified in the 144 or 432 transverter and could create unintentional interference to other users of the spectrum.

Transverting to 432 MHz / 70cm now, the IF needs to be at least 28 MHz to allow the LO and image products to be filtered out. A 50 or 144 MHz IF would be even better. The greatest problem with a 144 MHz IF is that the 3^{rd} harmonic falls within the band so a harmonically-rich signal fed in at 144 might pass through the filtering without much attenuation (except for the mixer isolation value of around 40dB). Eg 144.100 would become 432.100 but some output could also be apparent at 432.300 (144.100 x 3). { For info, 28/432 = 6.48%, 50/432 = 11.57%, 144/432 = 33% }

Transverting to 1296 MHz / 23cm, the IF needs to be 144 or 432 MHz, and ditto for 2403 (13cm) and 3400 MHz (9cm) so that the necessary filtering can be achieved.

{ 144/1296 = 11.1%, 144/2403 = 6%, 144/3400 = 4.23%, 432/1296 = 33.3%, 432/2403 = 18%, 432/3403=12.7% }

Transverting to 5.7GHz and 10GHz, a 432 MHz / 70cm (or higher IF) is mandatory so, again, the LO and image signals can be filtered out. { 432/5700 = 7.5%, 432 / 10368 = 4.16% } Even with 432, the 4% LO separation might be a bit close depending on the 10GHz transverter design.

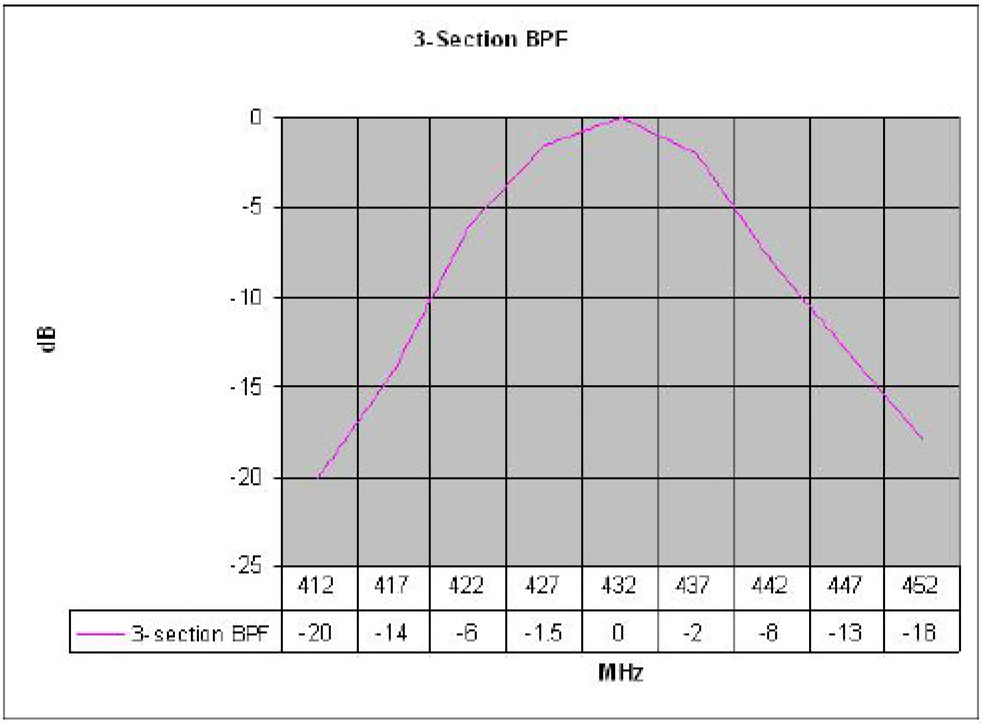
Obviously, the transverter frequency for microwave applications needs to be as high as possible with 70cm being a reasonably easy approach. One might ask why not just buy a transceiver with 70cm inbuilt ?? Simply, we don't all have a lot of funds available to go out and buy "black boxes" - and the build-it-yourself approach also provides a lot more satisfaction too. By the same token, there are lots of HF, HF/6m, and HF/VHF transceivers lying around idle and these could be put into place as the main user-interface for eventual microwave activities.

I wanted to have a physically small device that would generate around 10mW (+10dBm) of RF at 432 and also provide a receive side with a suitable noise figure (NF) and gain so that it could work in with the typical microwave transverter. My PCB layout for the transverter proper turned out around 80mm x 40mm and along with that, a suitable LO generator is required (mine is 45mm x 28mm..). That is why it is a MINI-transverter.....

It is getting very difficult to source parts like helical resonators easily these days so my approach was to implement a "comb filter" BPF using PCB tracks to achieve the selectivity required. I used my copy of the Ansoft Designer, Student Edition, (which was their free one, no longer available) to model some differing ideas about track lengths and widths given the physical constraints I wanted of the PCB. The final design uses 3 tracks 28mm long, 3mm wide, separated 4mm and the fine-tuning is done by "green" 2pF-22pF Philips trimmer capacitors at the "open" ends of the tracks. Double-sided FR4 PCB material was used and the top to bottom connections were made using rivets through 2.5mm holes and then soldered each side, as far as possible around the periphery of the filter section of the board plus others in RF-sensitive positions around the other components.

I 'played' with a 5-section filter both in Ansoft and also on a precursor PCB (ie an evaluation version) and found that it was too difficult to tune properly. The coupling between the sections was so tight that adjusting one for a peak seemingly detuned the next. That meant that you would need a spectrum analyser plus tracking generator to tune it properly - and not many of us have that combination readily available. Quite simply, I needed something simpler to tune up.

Actual measurements on the final 3-section filter gave attenuations of around 20dB at +/- 20MHz and an insertion loss of about 2dB at the centre frequency. A plot of the response is shown below. My absolute measuring technique did not allow me to go below 20dB with any great accuracy but the spectrum analyser showed the attenuation continuing to rise each side to beyond well 40dB.



At a 28 MHz IF, the LO is thus 404 MHz and the filter provides rejection of >20dB at this point. The use of a double-balanced mixer provides a further rejection of about 40dB so that should put the LO signal around -60dBc or better. The image would be at 56MHz (28 x 2) lower than 432 = 376 MHz and the filter response in this area was well over 50dB down. Add to that, any additional filtering in the microwave transverter will only improve the total image rejection.

I must make a point here about how to tune the 3-section BPF because it is quite critical to do properly. Apply a 432 MHz signal from a signal generator etc and use a receiver or spectrum analyser directly on the output of the filter section -or set the transverter into receive mode and follow the same process with an input signal at 432 and monitor the level at 28 MHz (or whatever your IF is set to). You can also do it in transmit mode once you know where to expect the peak in the two outside trimmers (ie a coarse adjustment in receive mode) and while measuring on a low range power meter for the absolute output peak, all the while feeding a signal in at 0dBm at the IF connection.

- Initially the 3 trimmers are set to minimum or maximum capacity - this is most important and cannot be skipped. Apart from anything else, it sets the tuning of the centre section well high or low of the desired frequency.
- Next, adjust the two outside trimmers equally (and alternately) until the output level starts to rise then peak each one for the absolute peak response at 432. There is minimal coupling-style interaction between these two adjustments so peaking is relatively easy. The two trimmers should be very close to the same physical mesh positions.
- Only when the two outside trimmers are correctly set, adjust the centre trimmer for a final higher peak - but do NOT re-adjust the outside trimmers again.

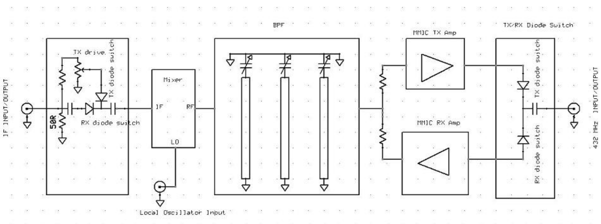
If you need to re-tune the BPF ever gain, set all trimmers to minimum or maximum capacity again and start over from scratch. Do not be tempted to just re-peak any because it won't turn out to have the best skirt shape and lowest insertion loss.

I tried several different styles of trimmer capacitors and the best choice in terms of final insertion loss, best skirt shape and ease of adjustment would have to be the Philips style shown in the image. Others will work in practice but are not recommended.

The next major component to consider is the mixer. My original plan was to use a Minicircuits ADE series device and, in fact, did the PCB layout to suit and then found that I had a couple of their older SBL-1 mixers in my proverbial junkbox so did a little bit of re-laying out the board to suit this style. Both series have similar electrical characteristics (conversion loss & port-port isolation) but considerably different packaging.

Knowing that the mixer was going to have about 6dB conversion loss at 432 MHz, the BPF around 2 dB loss, making 8dB, then the input diode switch would have 1dB or more plus the output diode switch another 1dB or so, the amplification stage would need to have a gain of at least 10-12dB to provide a zero-gain process from the IF to 432. I have quite a lot of BGA2709 MMICs that have 50 ohms Zin, 50 ohms Zout and specs of around 23dB gain - right up to 2.6GHz, +5V supply. That would give me a little bit of gain to play with since I hadn't even counted any physical component, layout or termination losses. The noise figure (NF) of the BGA2709 is rated at around 4dB at 1GHz but the performance of the actual microwave front-end noise overshadows the NF of the following stages so 4dB is really quite satisfactory. Of course, other style and type MMICs could be used in lieu, it just being a matter of an appropriate PCB layout.

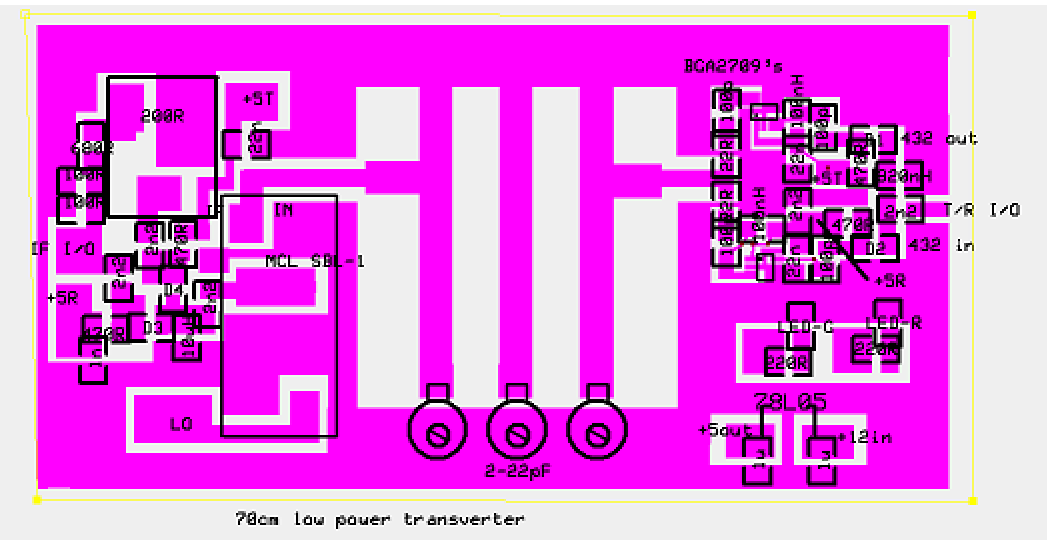
The block diagram below gives an idea of the concept.... Simplistic isn't it ??



On transmit, the IF input is via an preset-able "drive control" and fed via a diode switch into the mixer, through the BPF and then via a MMIC amplifier to another diode switch and then to the input/output connector at 432 MHz. To make the diode switches and the TX stage MMIC amplify, apply +5V at the relevant tracks (marked +5V TX) on the PCB.

On receive, the signal is fed from the input/output connector at 432, via a Rx MMIC amplifier to the BPF and then into the mixer, the output of which is fed via another diode switch to the IF port. To make the diode switches and the RX stage MMIC amplify, apply +5V at the (different) relevant tracks (marked +5V RX) on the PCB.

The external LO signal is fed directly into the mixer device and is common to both transmit and receive functionality. The level needs to be at +7dBm for the mixer to operate correctly. I am not going to go into detail about the LO itself as, in my case, I used one of my X-Locker V3 boards set to 404.000 MHz with the output level set to +7dBm. Others will do the LO part of the project their own way anyway.



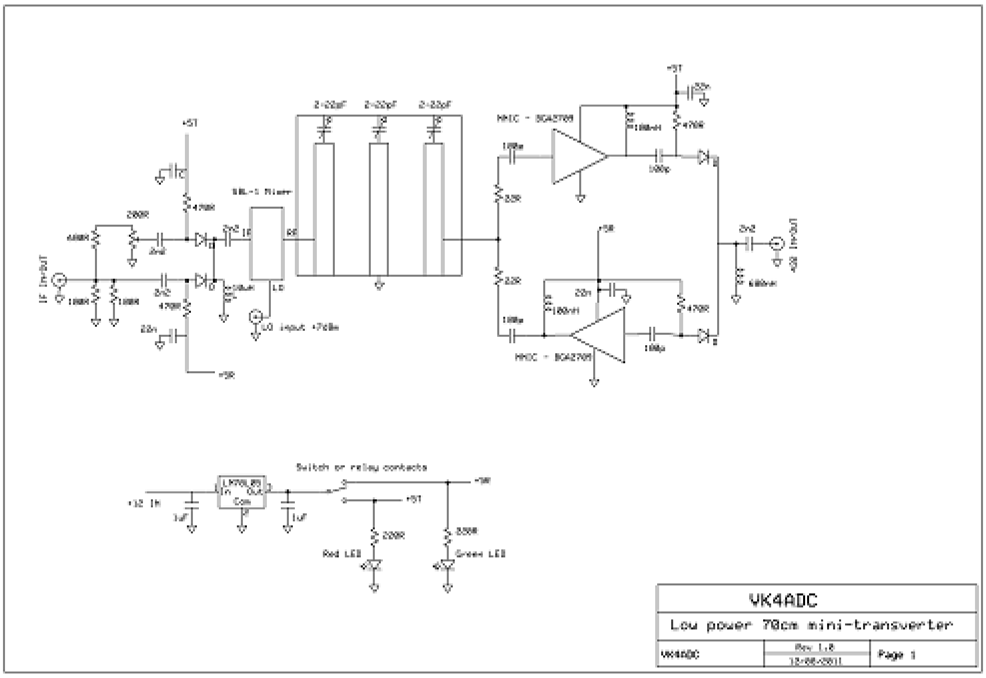
(/~vk4adc/web/images/UserFiles/Image/70cmtvtr1/432 tvtr 2 c1.PNG)

The above image is the PCB layout I used for the project. A larger/more detailed view can be seen by clicking on the above image such that the layout opens in a new window. The final size of this PCB : just 80mm x 40mm !

A small SMD 5 volt 100mA regulator is mounted on the board to make the generation of the +5V very simple. The current consumption is around 25mA per BGA2709 (but only one is powered on at any one time) and 10mA per diode switch (two active at any one time) plus a status LED of about 20mA. That gives a total consumption of about 65-70mA at +5V. The regulator needs at least +7V supplied to it's input to function.

If desired, the diode switching components can be omitted and alternative RF and IF switch implemented (e.g. by DPDT relay) as well as the replacing any T/R voltage switching..

The input at the IF is always terminated in 50 ohms by virtue of the two paralleled 100 ohm resistors connected across the IF input port and the unit will take around ½ watt of RF without damage. If higher RF drive power is anticipated, use physically larger resistors to dissipate the relevant power.



(/~vk4adc/web/images/UserFiles/Image/70cmtvtr1/432 tvtr c schematic large.PNG)

This is the schematic of the project as shown on the PCB layout above. Click on it to see a larger view in a new window. There could still be a few minor changes happen along the way but the schematic as shown here certainly works..

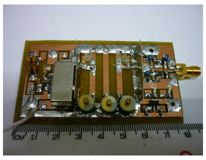
In practice, the receive side works well enough to hear down around 0.3uV (or better) when used with an Icom R7100 receiver set to 28 MHz as the IF and when using a 404MHz LO frequency. The noise generated in the transverter is low enough that there is no sizeable increase evident from transverter power-off to power-on (without an actual input signal present at 432), and on receive the overall "system gain" has been assessed at about 4dB. That means that the receive side will hear a signal from the sig gen about 4dB lower in amplitude at 432 than it does at 28 MHz.

On transmit, the system gain is around 4dB as well. A 0dBm input signal at 28.100 results in an output of +4 to +5dBm at 432.100 - note that this is with the TX Drive trimpot bypassed and the 28MHz transmit IF signal fed directly from the 50 ohm termination into the TX diode switch via a short wire bridge/strap. The output starts to level off at around +8dBm to +9dBm (with +6dBm in at the IF) so a little short of the original design idea but still more than the typical transverter needs.

A word of warning : This is designed to work with just 1mW to 5mW of actual RF from the source transmitter (ie. the IF) at the mixer. The TX drive control "attenuator" circuit will allow you to put more than that into the input port on the board BUT the resistors I used in my prototype are only 1/4 watt versions - two in parallel only takes it up to 1/2 watt of dissipation. You will need to set the RF power on transmit as low as possible to be able to use the transverter without burning up these input termination resistors - so that means an absolute maximum of 1/2 to 3/4 of a watt can be applied. Turn your power control down to 1 watt, or "L" if that is how the rig is marked, and measure what it puts out in a normal dummy load. If it exceeds one watt, you will need to make some changes to the resistor types used at the IF I/O position - 2 x 100 ohm 1 or 2 watt CARBON (or 1 x 47 ohm) - and I don't mean carbon film. Adjust the trimpot accordingly but always start off with the wiper down at the "earthy" end and wind it up slowly while transmitter RF is applied. Mixers aren't cheap !!

Does it work ? Well, yes. I connected an antenna to it and could hear various 70cm repeaters being used, the local 70cm beacon on 432.440 although it wasn't very strong - although it never is! You have to remember the statement right at the beginning of this article : "By the way, the concept of this transverter is not a mainstream unit to be used directly on an antenna - it's planned use is into a higher frequency transverter. " It wasn't designed to have the highest gain plus super low noise on the receive side. You could put a receive preamp ahead of it and it would improve the sensitivity. You could put a 70cm power amp after it and raise the output level on transmit but that wasn't the design intention either.

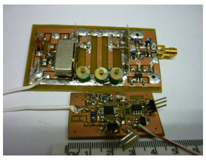
Photos ....



The transverter PCB (80mm x40mm) - made on double-sided FR4 material, rivets soldered through the holes to connect top to bottom since I can't do "vias" at home... (and don't know anybody else who can either !)

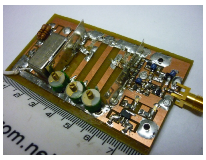
The connections to the tuned lines have been "flexible-ised" to allow me to vary the tapping point for the input and output connections from the filter section to check for lower insertion loss.

The two 100 ohm non-SMD resistors at left are the 50 ohm termination for the transmitting source at the IF.

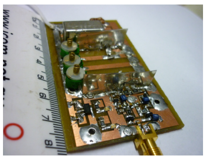


The X-Locker V3 synthesiser PCB connected and at just 45mm x 28mm, it makes an ideal LO for the project. Yes, that is a 10MHz crystal hanging off the PCB - the synth will work stand-alone that way or will lock to the external source if the 10MHz is fed in onto the 2 header pins also there. The 3 pin header at right is for re-programming the PICAXE-08M.

The metal-cased rectangle near bottom left of the transverter PCB is the Minicircuits SBL-1 mixer.



Slightly angled view shows the two tinplate shields fitted either side of the BPF. These were added to reduce any signals that might to bypass the comb-section passband filtering.



End-on view of the input/output section at 432. The SMA connector fitted to the end makes the connections easy for the tests.

The tinplate shields are probably a bit easier to see in this view too.

Postscript : 2nd Sep 2011

You often wonder how a project like this compares to an existing commercial product and that led me to compare this transverter's receive side compared to my Icom IC-706Mk2G in effective sensitivity etc.

I fed the receive side into an Icom IC-718 set to 28.100 MHz and fed in a 432.1 MHz signal derived from my Marconi signal generator. Without the RF preamp switched on in the IC-718, I increased the sign gen output until the 718's S-meter just clicked up to the S9 level at -75dBm. I then fed the sig gen into the 718 directly at 28.1 MHz - and required -69dBm to achieve the same indication. That confirmed an overall receive gain of 5dB.

Next was to see how well it performed in overall sensitivity. The receive side was again interspersed before the 718's receiver and the sig gen level at 432.1 decreased. The sig gen could be heard right down to the -127dBm limit of the generator once the 718's preamp was switched on. In fact, I could just hear the signal even with the Marconi's RF output switched off - and I haven't ever really been able to do that before on any receiver. To me, that indicates a really good system Noise Figure.

The next test was to attach the 70cm vertical collinear to the transverter input. The background noise increase was quite discernible off to on - I connected & disconnected a few times to confirm that effect. I then tuned the 718 to 28.440 and I could hear a weak heterodyne which then began identing : VK4RBB in CW.

I quickly connected the IC-706Mk2G tuned to 432.440 to the antenna in lieu. I could sort-of hear the heterodyne but the overall received noise was far higher, so the "copy" was far poorer. I tried the connect/disconnect effect on the antenna a few times and I could not hear any obvious increase in background noise. My interpretation of this is that the effective system Noise Figure in the 706 is far higher than that of the transverter/718 combo. A look in the Service Manual for the 706Mk2G reveals that the front end UHF RF preamp device is a 3SK291 dual-gate FET and it's Noise Figure (NF) looks to be around 1.5dB at 800 MHz, something lower than that would be expected at 432. Even so, I suspect that I will be replacing it with a BF988 device, similar overall characteristics except for a lower NF, in the near future.