A Simple Low-cost 5760 MHz Transverter for the Rover

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When I first designed the "Multiband Microwave Transverters for the Rover[1]," the Local Oscillator concept covered all microwave bands from 1296 to 10368 MHz using a readily available computer oscillator, except 5760 MHz, which might be our least used microwave band. Later enhancements added 902 MHz and 1296 MHz with the IF right-side-up using other oscillator frequencies, but I never found an oscillator suitable for 5760. More recently, synthesizers like the A-32 by N5AC have become readily available at a reasonable cost, so that most usable LO frequencies are realizable and a 5760 transverter becomes easier. Since the frequency is programmable and easily switched, one synthesizer may be used for several bands to keep the overall cost down.

Gain is Cheap

The simple Multiband Microwave Transverters have a design philosophy that **gain is cheap.** My initial version of a transverter[2] for 5760 MHz was developed before this realization. The ERA series of MMIC had just become available and it was a revelation just to have gain at 5760 without complex circuitry. But the rest of the design was microwave thinking – expensive Teflon PCB for minimum loss, pipe-cap filters[3], minimum number of devices, and printed mixers using diodes chosen to operate with minimum LO power. Since the LO chain had a high multiplication factor, limited LO power was available. The thin Teflon PCB also added mechanical complexity since additional stiffening was required for adequate rigidity.

More recently, I used ordinary FR-4 PC material for the "Personal Beacon for 10 GHz[4,5]" with good performance, demonstrating that expensive PCB materials are not required even at 10 GHz, as long as cheap gain is available to make up for losses.

Obviously the FR-4 PC material should work fine at 5760, so several years ago I redid the old transverter on an ExpressPCB[6] Miniboard, planning to use a synthesizer at 1123 MHz as the LO source. There was not enough room for separate printed mixers for transmit and receive, so I ordered a couple of Minicircuits mixers in a package that I thought I could hand-solder.

The prototype transverter did not meet expectations – I could never get enough LO power from the onboard LO chain to properly drive the mixer. A typical mixer likes at least +7 dBm drive, and I couldn't get more than about +5dBm, probably enough to operate but not likely to be reproducible. Since gain is cheap, I tried to cram another stage into the layout but wasn't successful.

Personal Beacon for 5760 MHz

Since the 10 GHz Personal Beacon has proven to be popular, a 5760 MHz version would be useful and might help to increase activity on this band. It would also help me to understand and improve the multiplier chain. A quick adjustment of the 10 GHz layout on another ExpressPCB Miniboard had some boards in my hands within a week. Details are given in a separate paper.

I tried the boards with various multiplication factors to reach 5760 MHz, both directly and in two steps, for instance, X2 followed by X3 to multiply by 6 times from 960 MHz. Good output power, typically +5 to +10 dBm, was available with input frequencies as low as 936 MHz, so the personal beacon board could make a good LO multiplier as well.

The most difficult multiplication factor was X5, from 1152 MHz. At first, only very low output was available. Then I remembered that harmonic frequencies at the input sometimes impedes good multiplication, so I tried both a low-pass filter and an Altoids filter for 1152 before the multiplier. Either filter improved performance and output power, showing that a clean input signal is important.

The first step in tuning up a personal beacon board is tuning the two pipe-caps to frequency as a straight-through amplifier at 5760 MHz. In this configuration, the board has about 25 dB gain and with a saturated output power around +10 dBm – perfect for both transmit and receive sides of a transverter.

For a simple transverter, all we need are two of the personal beacon boards to provide both gain and filtering, a mixer, and a power splitter. A commercial packaged mixer simplifies the design and saves space – with a bit of layout shuffling, all this fits comfortably on an ExpressPCB Miniboard, shown in Figure 1. Keeping the LO separate simplifies tuneup and allows a choice of LO sources – on another personal beacon board or even an old PLL brick oscillator would work fine if you have one.

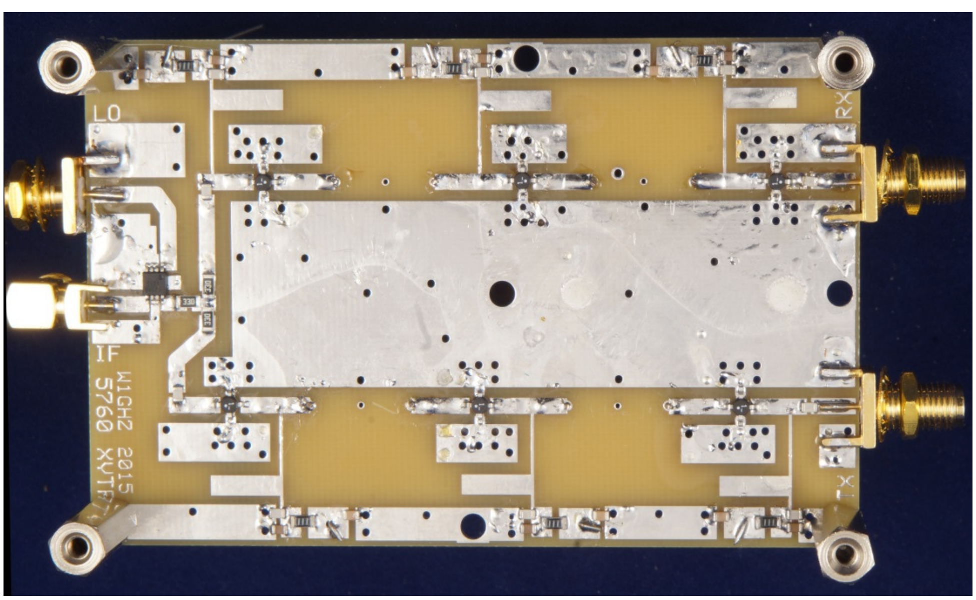


Figure 1 – 5760 MHz Transverter

Gain is cheap, but mixers are not

Several factors go into selection of a commercial mixer: reasonable price and availability, a package that allows hand assembly, and a supplier that is likely to keep it available for more than a few weeks. While there are many mixers available for frequencies below 3.5 GHz, at higher frequencies there are few choices in easily solderable packages. I used the Minicircuits MBA-591 mixer in my unsuccessful prototype, but now there is a 10-piece minimum quantity, and few hams will need 10 mixers.

Another attractive mixer is the Hittite HMC218BMS8, in an 8-pin SMT package similar to a common SOIC package. The signals are on the corner pins, simplifying layout. Hittite also required a 10-piece minimum quantity, but they were recently acquired by Analog Devices, so the mixers are now readily available from DigiKey in single piece quantities for about $7.

New Transverter

The complete transverter, shown in Figure 1, has three gain stages separated by pipe-cap filters for transmit and the same lineup for receive, with a single mixer and a simple resistive power splitter. The LO and IF are both untuned, so any IF frequency up to 1.6 GHz is possible. The transverter is intended for 5760 MHz, but limited only by the mixer and the tuning range of the pipe-cap filters – perhaps 3.5 to 7 GHz. It might even work at 3.4 GHz, but the mixer performance curves look worse at the lower end of the range.

In the spirit of simplicity and minimum parts count, I used the same ERA-1 MMIC type for all six gain stages, so there are only two resistor values and three capacitor values needed. The schematic is shown in Figure 2. The ERA-1 does have a 20-piece minimum quantity, but at $1.42 this doesn't seem onerous, and they are very useful. Note that the ERA-2 and ERA-3 appear to offer more gain, but at 6 GHz and above, all three types have similar gain. Any of them might work, but the extra low-frequency gain can cause trouble.

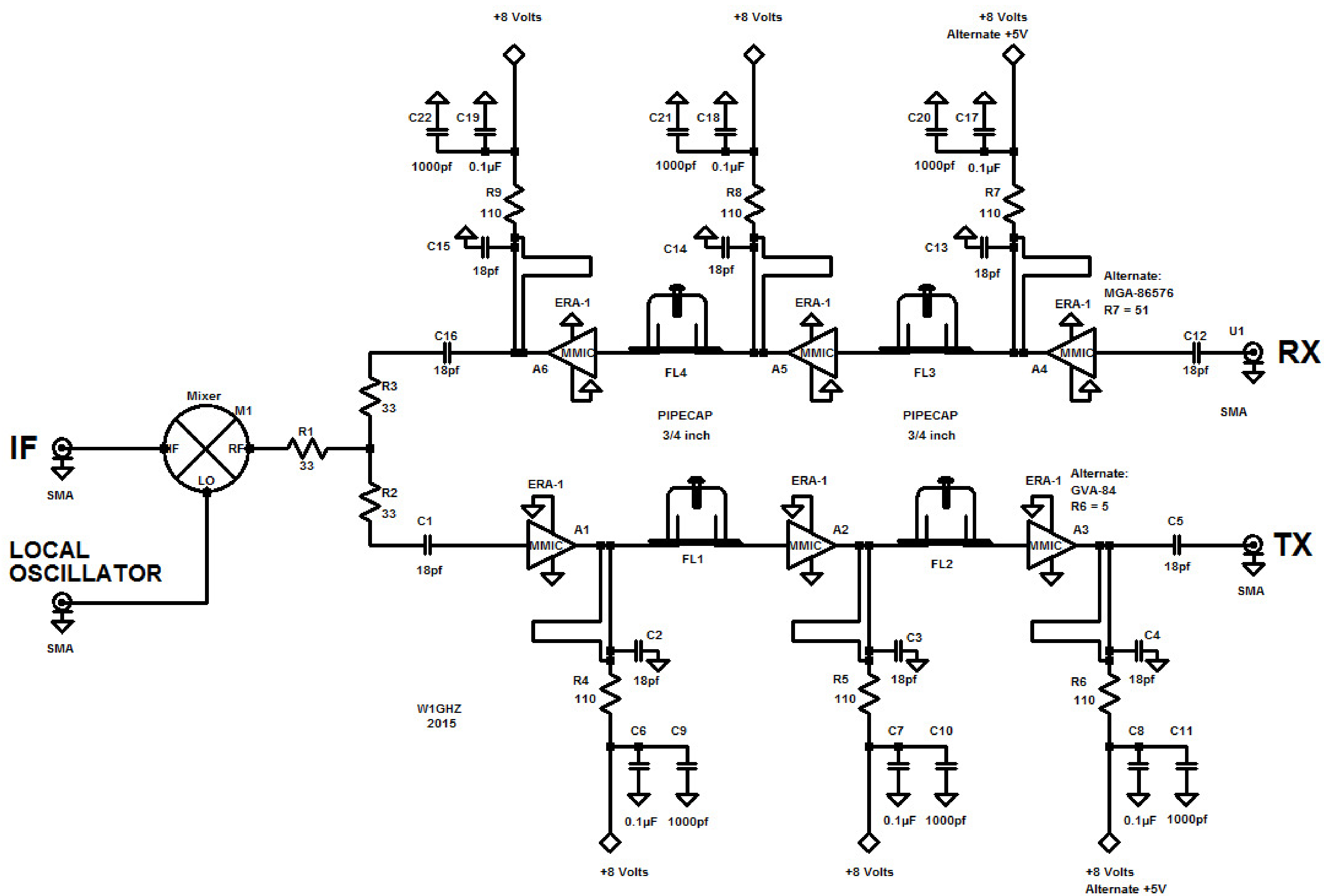
I did the initial tuning of the pipe-cap filters before installing the mixer, just using a wire jumper from the LO connector to the power splitter, tuning the transmit and receive chains to 5760 MHz. After fiddling with the probe depth, I settled on roughly 8mm, which put the 5616 MHz LO frequency down about 34 dB.

After adding the mixer, I tried the transmit side with signal generators for both LO, at 5616 MHz, and IF, at 144 MHz. The LO power was set at +10 dBm as specified on the mixer data sheet, and an IF input power of -10 dBm yielded -3 dBm output. Increasing IF input to 0 dBm gave +6.2 dBm out, and +5 dBm input produced +9.9 dBm out, pretty well saturated. The LO leakage with no IF input was about -30 dBm.

Changing the LO frequency to 5328 MHz for a 432 MHz IF produced similar performance.

More important was the LO power sensitivity. Increasing the LO power by one dB produced about 1 dB more output. Reducing the LO power to +7 dBm, like a typical mixer, reduced the output by about

Figure 2 - 5760 MHz TRANSVERTER



6 dB and made the response non-linear, with the output changing 4 to 5 dB for a 3 dB change in IF input power. Conclusion: the data sheet recommends +10 dBm of LO drive for good reason.

Receive performance was reasonable, with noise figure of about 7 dBm as long as the LO drive is at least + 10 dBm.

Higher performance

The performance of the first prototype is pretty good for a simple transverter, but we might be able to improve on it. The output power is limited by the ERA-1 MMIC. Reviewing some data sheets, the Minicircuits GVA-84 offers both more gain and more output power at 6 GHz – and I had some on hand. The noise figure is probably also limited by the ERA-1, so a better device might help here also. I have used the HP/Avago MGA-86576 with good results, and it offers better gain and noise figure. The device is a bit more expensive, but improved performance might be worth a few dollars.

I assembled another transverter using the GVA-84 for the transmitter output stage and the MGA-86576 for the receive front end, shown in Figure 3. The probe depth in the pipe-cap filters was changed to 7.5 mm as a result of some tests on single pipe-cap filters.

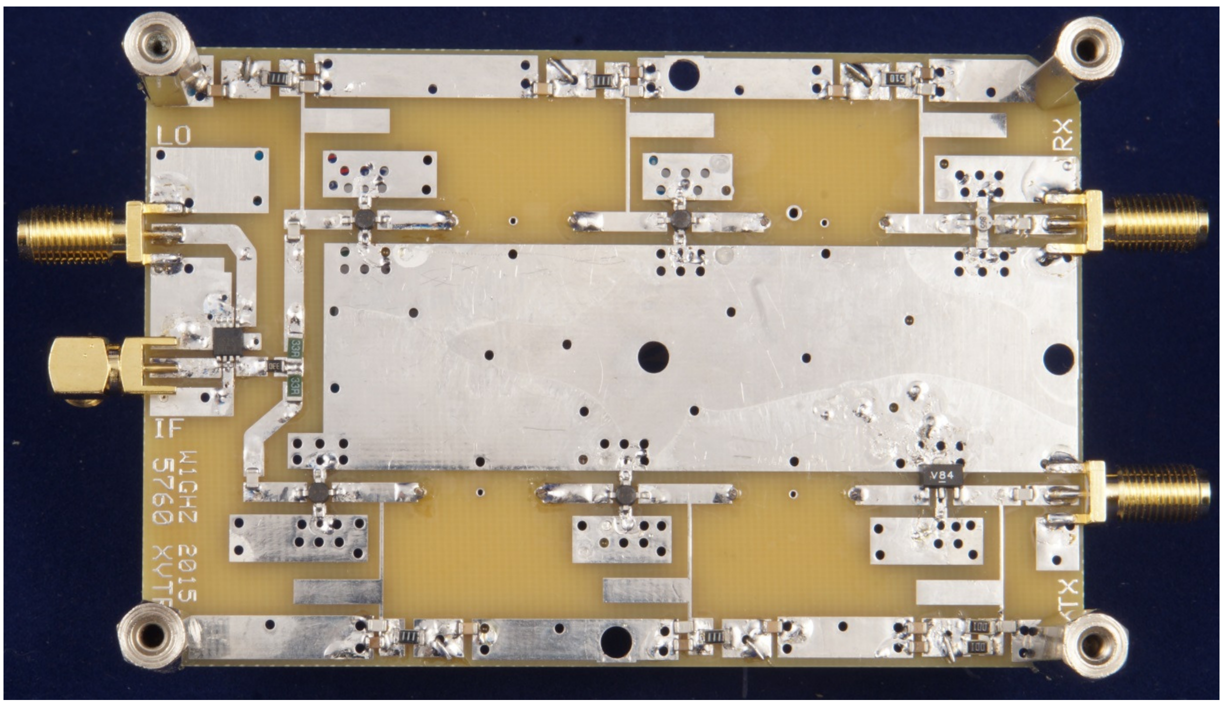


Figure 3 – 5760 MHz Transverter configured for higher performance

Tuneup of this version was pretty straightforward. The pipe-cap filters in the first prototype tuned with one or two threads of a 3/4 inch brass screw showing above the locking nut, so I simple set the screws by eye. With no IF drive, I tuned the transmit filters for LO feedthrough at 5616 MHz. Then I backed them out one turn, applied IF drive and tuned for maximum output – no spectrum analyzer needed.

Then I set the receive filters to the same depth with a ruler, applied a signal at 5760 MHz, and tuned for maximum output at the IF.

Transmit performance of this version showed some improvement, with about 0.1 dBm out for -10 dBm of IF input. Increasing the IF drive to 0 dBm produced +9 dBm out, roughly 1 dB compression. The output saturated at about +15 dBm out with +11 dBm of IF drive. Like the other prototype, performance deteriorated with at LO levels less than +10 dBm.

Receive performance showed significant performance, with a noise figure of about 4 dB. Tweaking the voltage to the MGA-86576 from 5 volts to about 5.7 volts reduced the noise figure to about 3.5 dB. These noise figures were with a 144 MHz IF noise figure of about 3 dB; increasing the IF noise figure to about 10 dB, more like a typical transceiver, increased the transverter noise figure to about 4.5 dB. This suggests that the transverter has adequate gain.

The Return Loss at the LO input is about 4 dB, suggesting that nearly half of the LO drive is reflected. Tuning might improve the situation and reduce the drive requirement – a bit of poking suggests that a small capacitance right at the SMA connector helps. However, in the interest of simplicity, it is easier to just increase the LO drive power and to be aware that different cable lengths may affect performance.

LO Multiplier

My plan was to use the 5760 MHz Personal Beacon board as an LO multiplier to 5616, but the output saturated at +10 dBm or less. Since the GVA-84 provided more output from a transverter, I put together two more personal beacon boards with a GVA-84 output stage, shown in Figure 4. The first board, with both pipe caps tuned to 5616 MHz, provided much more output power, saturating at +16 dBm as a straight-through amplifier at 5616 MHz.

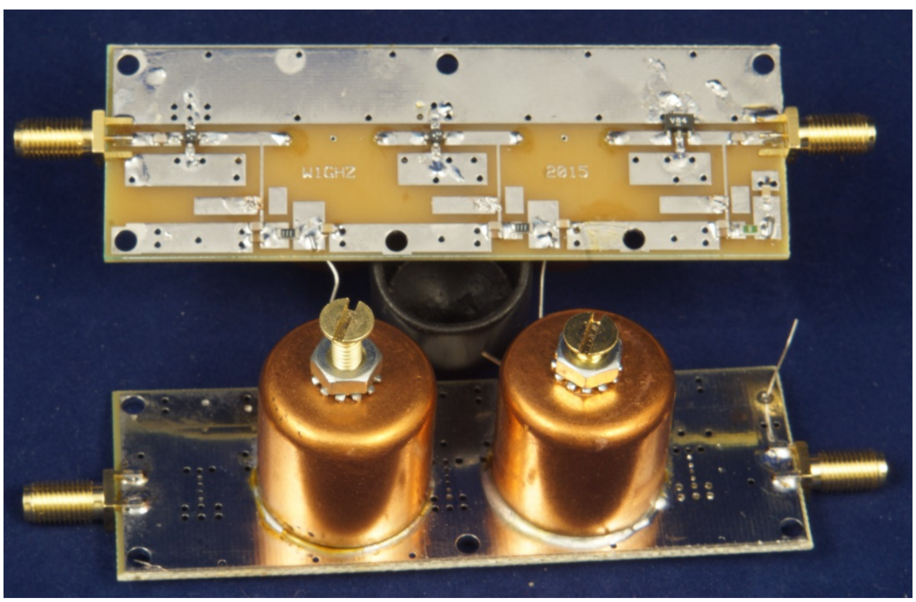


Figure 4 – LO multiplier boards

As a multiplier, the board also provided good output power as a doubler from 2808 MHz, +16 dBm, and as a tripler from 1872 MHz, +14.5 dBm. However, multiplying X5 from 1123 MHz, performance was poor, with only about +1 dBm output (another copy produced ~+4dBm). I wasn't surprised – I've always had difficulty multiplying by five, and don't think it can be done reproducibly. On the other hand, gain is cheap and we could just add one more stage.

Using the multiplier board as a tripler with about 0 dBm input at 1872 MHz provided adequate LO drive for full performance of the transverter as described above. The test setup is shown in Figure 5.

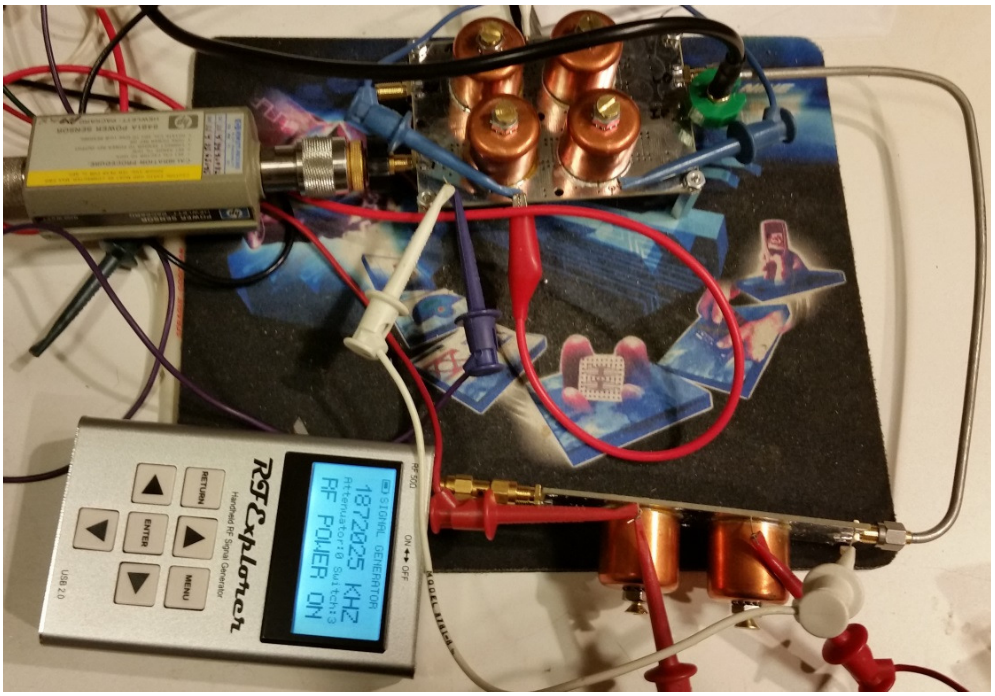


Figure 5 – Testing 5760 Transverter with LO multiplier

A second board with the first multiplier and pipe-cap tuned to 2808 MHz was also tried – the lower one in Figure 4. This one had a GVA-84 from a different batch and saturated at +13 dBm with a 2808 MHz input. With lower frequency inputs, the first and second stages are both acting as multipliers; with 1404 MHz or 936 MHz inputs, the saturated output was about +12 dBm, so either of these source frequencies would also be usable. Lower source frequencies requiring higher multiplication factors produced much less output.

Summary

This transverter is easy to build, the parts are available at reasonable cost, and it works quite well, as long as it is provided with adequate LO drive power, greater than +10 dBm. What we don't have yet is a good synthesizer or other source for the LO frequency. A good synthesizer at 1936 or 2808 MHz would be a great help here, but 1404 or 936 MHz would also be useful. With a GPS-locked synthesizer, these boards could be the heart of a high-performance system. *Update – I have since acquired an excellent 2808 MHz synthesizer from Reactance Labs (KC6QHP).*

Revision B

The first lot of boards sold out at Microwave Update 2015. Most of the folks who attend Microwave Update have the skill and test equipment to find a way to provide enough LO drive for the Hittite mixer, but the goal is to make the transverter simple enough to get more station on the band. A more forgiving mixer is needed.

I went back to the unsuccessful prototype mentioned above and modified it for an external LO source driving the MBA-591 mixer. Testing showed that this mixer operates reasonably well with LO drive as low as +2 dBm, so the onboard LO might have worked – but it was a struggle to get this marginal output level. The conclusion here is that the Minicircuits MBA-591 mixer performance is more forgiving and allows many more LO options. I also found that the lead pitch is twice as great as the Hittite mixer, which makes soldering much easier.

I decided to redesign the transverter board for the MBA-591 mixer. Only the mixer area is changed, since the rest of the transverter seems to work quite well. Then I ordered another small batch of boards and also ordered ten mixers.

Revision B Performance

I assembled a Rev B board as a higher-performance version, with a GVA-84 output stage and an MGA-86576 RX front end, shown in Figure 6. This version works well over a wide range of LO drive – I tested it with LO input from 0 to +10 dBm. The RX noise figure, about 3 dB, hardly varied over the range of LO drive. The transmit power output saturated at slightly lower levels with low LO drive, as seen in the curves in Figure 7. Maximum power output of about +10 dBm is slightly less than the earlier version, probably because the mixer output saturates at a lower level. Using a higher gain MMIC in the intermediate stages would probably increase the power output a few dB.

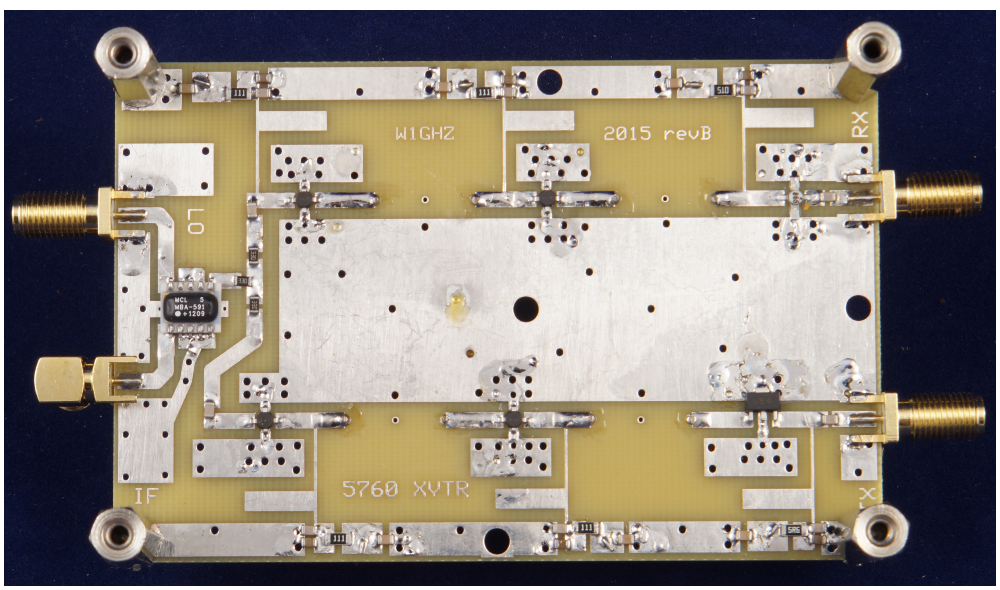
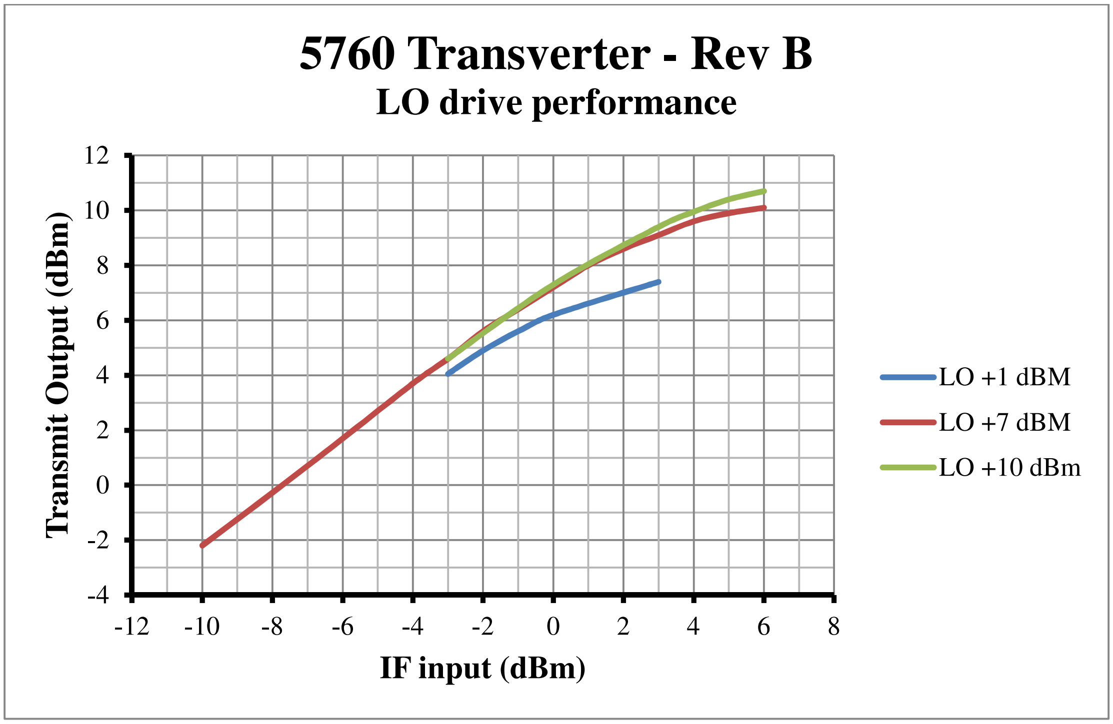


Figure 6 – 5760 Transverter Rev B



Selectivity with the two stages of pipecaps is also pretty good. The 3 dB bandwidth is about 28 MHz with 8mm probes in each pipecap, and the LO frequency, 5616 MHz, is about 36 dB down, so image rejection is probably even better. Since the IF is untuned, the transverter works equally well with 144 or 432 MHz IF, or any other frequency you choose by providing the appropriate LO frequency.

Revision B Summary

With the MBA-591 mixer, the transverter works well and is much more forgiving of low LO drive. This makes it possible to use the popular A-32 synthesizer at 1123 MHz, multiplied by five in the LO multiplier board. The transverter is easy to build and the parts are available at reasonable cost, and PC boards are available.

What about 10 GHz?

I [am] ***WAS*** confident that a similar transverter for 10 GHz would also work well. It would involve changing the pipe caps to ½ inch, adjusting the lengths of the bias decoupling networks, and changing the mixer to a Hittite HMC220, with the same footprint. However, this mixer also requires plenty of LO drive; the 10 GHz Personal Beacon board may provide enough power.

In fact, a 10 GHz prototype did not work well. There were two serious problems:

1. The Hittite HMC220 mixer did not downconvert well, so RX performance was very poor. I also tested a mixer alone, and found it met specifications as an upconverter (TX) but was far below spec as a downconverter (RX).
2. The thick PC board radiates badly, so that anything within about 5 inches affects performance, and interstage leakage is a problem. I did notice some radiation on the 10 GHz Personal Beacon, but the lower frequencies in the multipliers don't radiate and the desired 10 GHz is easily contained in a metal box.

Note: the 5760 transverter does not have a serious radiation problem – objects must be closer than about ¾ inch to have any affect. This is about the same distance as the 1296 MHz transverter.

3456 MHz

On one of the first lot of boards, I replaced the Hittite mixer with a Minicircuits ADE-18W mixer, swapping the LO and RF ports to fit on the mixer footprint. Then I used longer screws to tune the pipe-caps down to 3456 MHz, with no other changes to the PC board – the bias stubs are still tuned to 5760 MHz. Performance was pretty good, about +15 dBm output on TX and about 5 dB noise figure for RX. It also worked fine at the 3400 MHz EME frequency.

Since the Minicircuits MBA-591 mixer used in the Rev B board is specified for operation down to 2800 MHz, it should also work fine at 3456 just by using longer tuning screws.

Construction

The first step in assembly is to solder the pipe caps to the board, after drilling and tapping the 8-32 screw holes in the top of the caps. Each pipe-cap location on the PC board has a hole at the center, halfway between the probe locations. I scribe lines on the bare board half the pipe cap diameter away from the center hole, making a square to line up each pipe cap. Then I put a bit of paste flux on the rim of each cap, place the caps in position, and put a ring of wire solder around the base of each cap. I solder the caps one at a time, holding the one being soldered in position with a screwdriver while heating the top of the cap with a hot air gun. The copper conducts the heat down to the board; when the joint reaches temperature, the ring of solder melts and flows around the base of the cap, without overheating the board. As soon as the solder flows, remove the heat, let it cool until the solder solidifies, then move on to the next cap. A torch could also be used, but tends to oxidize the copper.

A note on pipe caps. I have found three different brands at local stores, shown in Figure 8. The two on the left, NIBCO and Mueller, are taller, about 24mm high, and the third, EPC, is about 21mm high. What they all have in common is that the open end is not very uniform, so sanding on a flat surface with 220 grit Wet-or-dry sandpaper is needed to make them sit level and solder cleanly. About 20% of them are so bad that too much sanding is required, so I toss them.

Figure 8 – ¾ inch Copper Pipe Caps

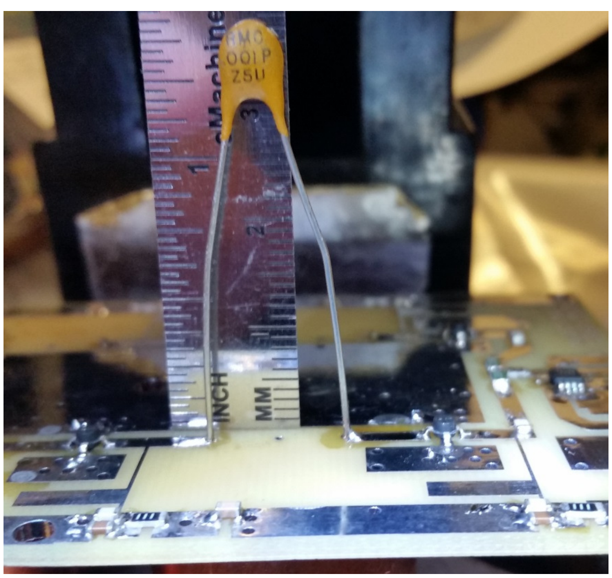


Figure 9 – Installing probes in Pipe-cap Filter

Brass screws are preferred for pipe-cap tuning, and I like to use a KEP nut, with attached lockwasher, as the locknut. The probes are just bits of wire – I keep them straight and the desired length by using leads from an ordinary disc capacitor, as shown in Figure 9. Measure the full lead length, then insert it until the desired length is inside, and allow another 1.5 mm for the board thickness. With the taller (~24mm high) NIBCO pipe caps at 5760 MHz, the best probe length inside the pipe cap is 7.5 to 8 mm, while about 10 mm probe length is good for a 2880 MHz stage in the LO multiplier. With the shorter (~21mm) pipe-caps, the best probe length for 5760 MHz is about 6 to 6.5 mm.

All the other parts are surface mount are easily soldered with a fine-tip iron and thin solder. The RF chip capacitors and resistors are the medium 0805 size, while the DC resistors and 0.1 µF bypasses can be the larger 1206 size. The only ones that require anything special are the Hittite mixer and the GVA-84, which have a ground pad.

For the Hittite mixer, I put just a touch of paste flux on the bottom ground pad and some solder on the board where the pad sits, then place the mixer on the board and solder down the RF lead, pin 8. Then I apply a larger soldering iron to the ground metal next to the mixer and push down on the mixer with a Q-tip until the solder has melted under it. If it won't lift up after the solder cools, the joint is adequate – this isn't a heat sink. Then solder the other leads as shown in Figure 10.

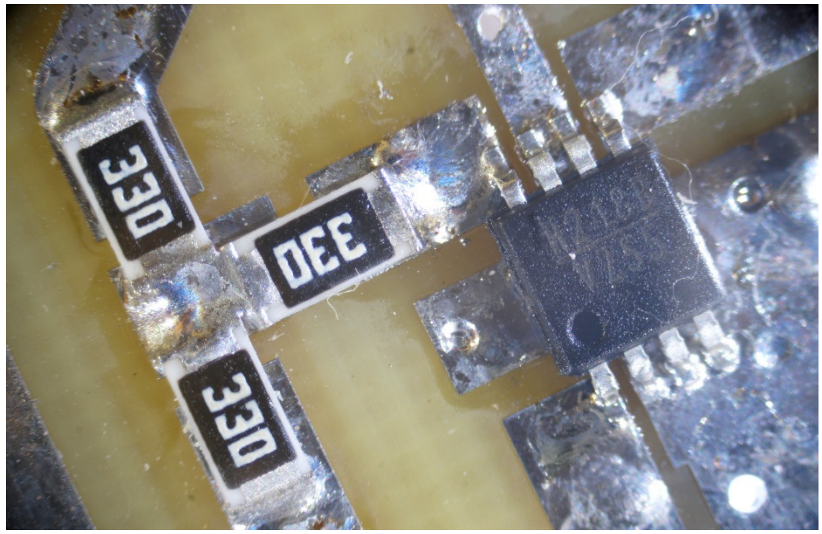


Figure 10 – Detail of power splitter and Hittite mixer

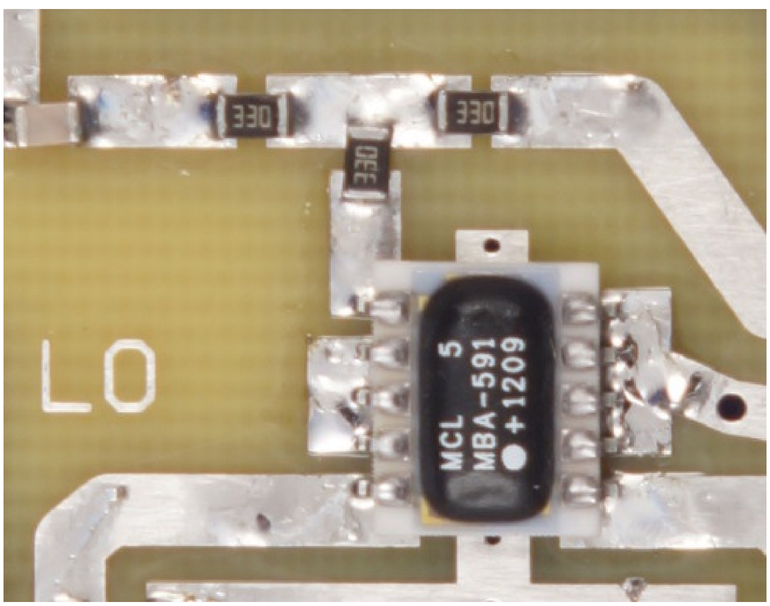


Figure 11 – Detail of power splitter and Minicircuits mixer on Rev B board

The Minicircuits mixer used in ***Revision B*** does not have a bottom ground pad, and the leads are more widely spaced, so it is much easier to solder. Figure 11 shows the detail.

The GVA-84 does dissipate some power, so the ground pad also provides heat sinking and needs a good solder joint. The pipe cap on the other side provides a good heat sink, which is evident when soldering – it is hard to get enough heat for the solder to flow. The good news is that parts don't get overheated when the temperature barely gets above the melting point of solder.

For SMA connectors, I have been using connectors from China found on **ebay**, which cost about a dollar. The edge mount PCB versions shown fit snugly on the board and provide adequate mechanical strength. Right-angle connectors are convenient, but I only use them at lower frequencies. And I only use female connectors from China – too many snap rings fail on the male types.

References

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