Software Defined Radio at 144MHz

Most ham transceivers at 1296MHz and higher use 2 meters as the IF in order to make the rejection of the image frequency easier. For example, the DB6NT transverter contains an LO at 10224MHz which is low side injection and makes the unwanted X-band image response at 10080MHz. This is still within the amateur band so it is unlikely that a strong signal will be present at that frequency. The pipecap filters in the transverter are sufficient to eliminate noise contribution while receiving and they greatly reduce the transmitted signal at this image frequency.

For decades, we have been using various multimode conventional analog transceivers at 144MHz as the IF radio. In the past, only a few people have experimented with SDR receivers in their portable stations. Lars, AA6IW, has used the DSP-10 and later used a commercial form of SDR that was once made by Tentec. I had modified a Quicksilver QS1R and used this for a few contacts.

Recently I purchased a second Perseus receiver (microtelecom.it) and modified it for undersampling. I incorporated this into my 10GHz portable rig and have successfully demonstrated contacts using it with Winrad running on a laptop computer. Testing confirmed that my new matching network worked very well at 2 meters and also was quite acceptable at 6m and 432MHz. An external preselector and preamp are necessary in order to pass only the desired band to the SDR receiver.

I was invited to give a lecture and demonstration of SDR for microwave applications at the annual IEEE MTT-S (Microwaves, Theory, and Techniques Society) workshop held at the Stanford Linear Accelerator Lab on May 9, 2009. Approximately 100 engineers and students were present. Some watched from their lunch tables and some gathered around the demonstration and viewed Winrad in operation on a very high brightness LCD display that I had set up. The location was not ideal as there were bushes and trees nearby, and some paths to other hams were partially blocked by homes or hills. However, we were able to make good two-way contacts in spite of these obstacles. The following photos will show the paths.

The outdoor presentation by Jeffrey Pawlan WA6KBL

Another view

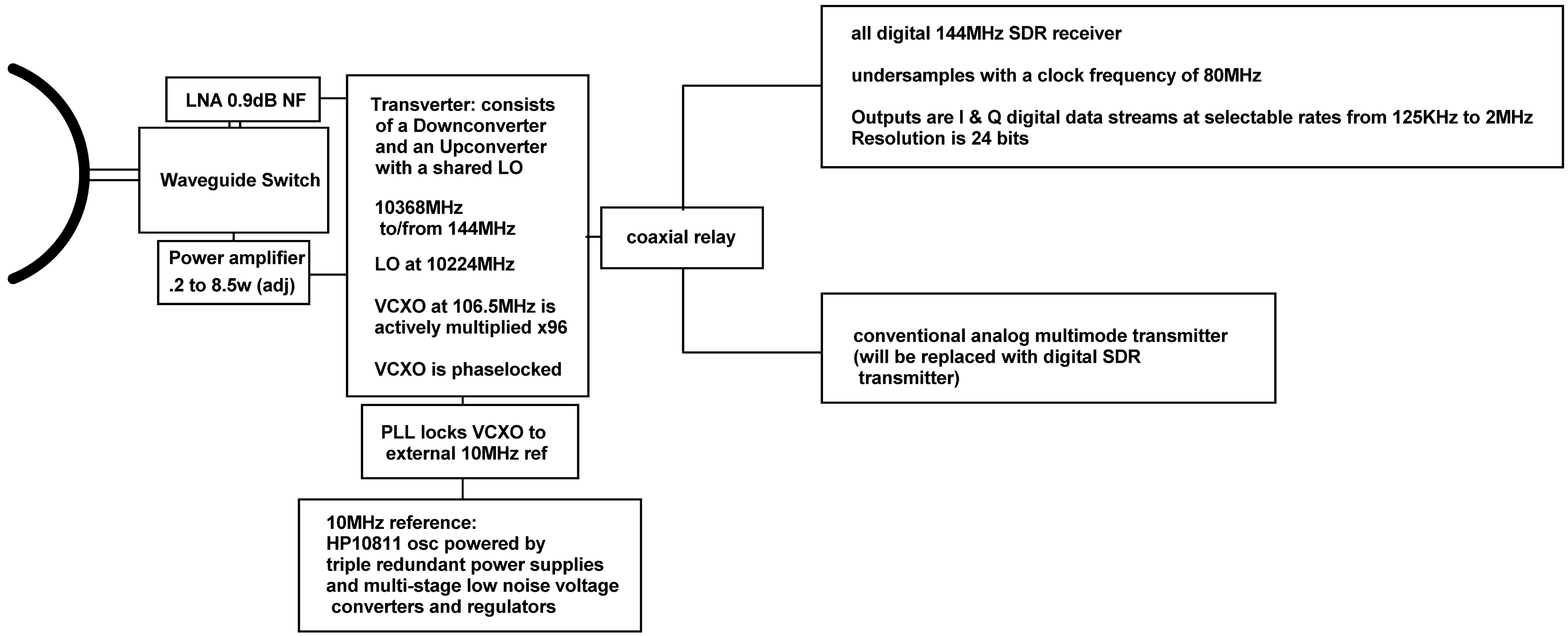
The complete radio (except for the laptop)

Looking towards Diablo through brush

Difficult shot towards the Oakland Hills through a house

Path to AA6HA in South San Jose was a knife-edge refraction though the Stanford Big Dish

Block Diagram of the 10GHz Transceiver:



How Does Undersampling Work?

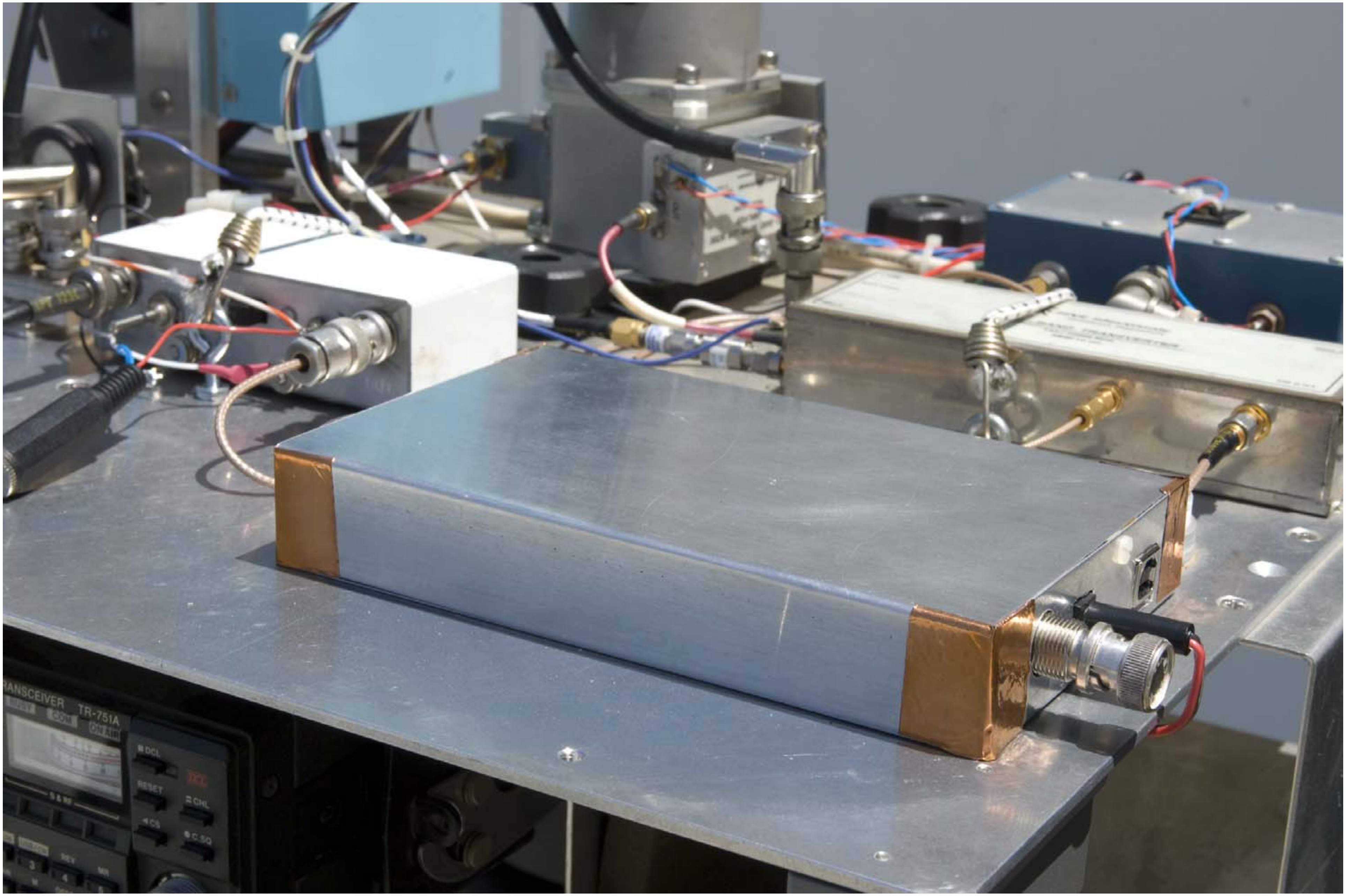
All digital samplers including A/D converters are capable of undersampling. Nyquist's principle is that one may digitally represent and then recover a signal up to one-half of the sampling rate. Therefore the Nyquist frequency is defined as half the sampling rate. All frequencies appearing at the input of any digital sampler including A/D converters will be folded into the spectrum along with the normal frequency range, which we will call Nyquist Region 1. In the case of the Perseus, the sampling rate is 80MHz; therefore the Nyquist Frequency is 40MHz and the Nyquist Region 1 is from 0 to 40MHz. If you turn off the preselector of the Perseus, then you will be able to receive 50MHz (6 meters) at 30MHz. This is in Nyquist Region 2. Even numbered Nyquist regions are folded back on the odd regions, just like high-side LO injection. So the tuning will be backwards. 79MHz, for example, will be heard when the receiver is tuned to 1MHz. The Nyquist Region 3 is from 80MHz to 120MHz. At least one Perseus user heard his local FM station at 95MHz by tuning the Perseus to 15MHz. Since this is an odd-numbered region, the tuning will be direct, not inverted. Nyquist Region 4 is from 120MHz to 160MHz. So when I want to listen to 144MHz, I tune the Perseus to 16MHz and the spectrum would be inverted. We have a new beta version of Winrad that contains the correct algorithms to send the Perseus the correct frequency while displaying the desired frequency. It also knows whether to re-invert the spectrum so that increased receive frequencies appears correctly left to right on the screen and also USB is correctly demodulated as USB and not as LSB. My 144MHz IF frequency is directly displayed on the screen in Winrad. We could also add the fixed offset of the transverter LO so the screen displays 10368MHz but then there would be so many digits that it becomes less readable.

The Modified Perseus Receiver

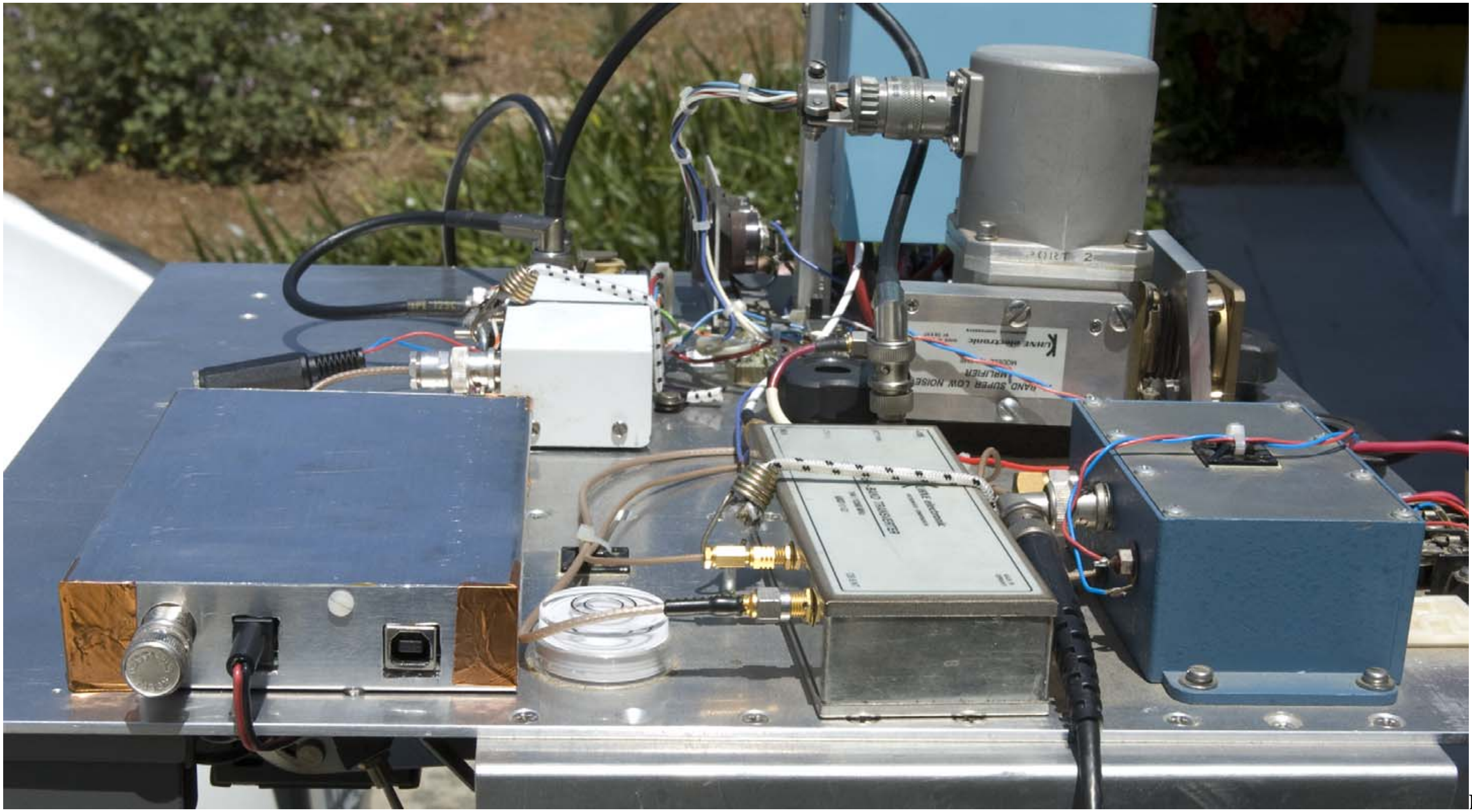
I decided to buy a second Perseus and modify it for undersampling because of several factors. The design of the receiver is very good. The FPGA cores range from 125KHz to 2MHz and they are quite flat and do not have spurs or spurious responses in them. So any spurious responses are all due to the A/D converter and any circuitry preceding it. The drivers for Winrad are excellent and work flawlessly every time. And most importantly, I love to design, build, and test new circuits so this was a good challenge for me.

It is important to note that the Perseus was purchased knowing that once I modified it, then it was mine and could not be repaired by microtelecom. The Perseus contains a differential amplifier that must be disconnected or removed since it does not have the bandwidth for 144MHz. The preselector circuitry ahead of this is also only applicable to HF. The A/D converter is a Linear Technology LTC2206-14 and that datasheet is available at www.linear.com. The datasheet contains enough detailed information to design and make the modifications. The receiver schematic is company proprietary but is not needed for the modification. The problem with the removal of the differential amplifier and its components was that ROHS lead-free solder was used and this melts at nearly 30 degrees C higher than regular solder. Fortunately I have hot air tools that are accurately temperature regulated so I provided heat from the bottom as well as heat from the top through a correctly sized rectangular nozzle. It was not easy to remove those components without damaging the other components on the board.

I added the correct unbalanced to balanced transformer and changed other matching components. The receiver input was now made with a piece of teflon RG316/U coax and the appropriately sized BNC connector. A fitted aluminum shielded box was fabricated in my shop. This is shown in the following photos.



Custom Perseus in shielded box



End

End view of custom Perseus enclosure

Some Notes about Bench Tests

Since this receiver is a direct digital sampling system, it is not applicable to do two tone IMD tests. Instead, the noise floor was measured, and the Minimum Detectable Signal was tested with both the dual stage MOSFET 144MHz preamplifier and with the 10GHz transverter. On 144MHz without any preamplification, the spurious free dynamic range was tested with a single tone. This was found to be approximately 80dB and came from a 4^{th} order product. This is less dynamic range than the LTC datasheet indicates, so it can be improved with a lower jitter clock and with some optimization of the input matching circuitry. However, the MDS on both 2m and on 10GHz was around –140dBm so this system is ideal for operation on quiet bands without large interfering signals. The preamplifier gain was set to 20dB. The older dual gate MOSFETs that I used do not have a huge dynamic range either, but their input and output tuned circuits are high impedance and very selective. It is important that no energy outside of 2m is allowed to reach the A/D converter else this will be added to the wanted band. Bench tests at 432MHz without a preamp showed that the A/D converter and my matching network was only 3dB down from 2 meters. This can be utilized in future projects which need 70cm.

Future Improvements

The Perseus receiver will be modified by using an external low phase noise and low jitter 80MHz clock that is phase locked to the 10MHz reference. This should improve the dynamic range. I am also working on a SDR transmitter which would then completely replace the analog transmitter that is currently used. In the future, affordable direct sampling receivers may become available that have more than 300MHz sampling frequency. Undersampling multiplies both the clock jitter and the inherent noise and problems in the sample and hold circuit within the A/D converter. However, an A/D converter with a very high sample rate may or may not perform better because the effective number of bits and the spurious free dynamic range of converters go down as the sample rate increases.

73,

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Credits

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