Preparation for 78 GHz EME

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Introduction

The first 24 GHz EME QSO occurred 10 years ago on August 18, 2001 between VE4MA and W5LUA, and the first 47 GHz EME QSOs between RW3BP, AD6FP, W5LUA and VE4MA happened in early 2005, and this paper will discuss the progress made towards making EME tests on the next ham radio frequency allocation at 78 GHz.

Previous Work on 24 & 47 GHz Bands

EME QSOs have become relatively "routine" now on 24 GHz with more than 12 stations having accomplished at least one QSO. The receive LNA noise figures have improved approximately 1.2 dB and much has been learned on when the signals are best (signal spreading distortion is at a minimum, which yields the narrowest signal & thus the best signal to noise ratio). The system requirements have been reduced somewhat but still need a minimum of 10 watts at the feed point of a really good 3m prime focus or 2.4 m offset dish under optimum propagation conditions with low humidity at both stations.

There has been no activity on 47 GHz since the initial QSOs. Receive noise figures were approximately 4 dB and today there might be a small improvement possible with newer chips. The biggest obstacle remains to be transmitter power with at least 30 Watts required at the feed of a good 1.8m or 2.4 m offset dish. Practically this power still can only be achieved with the use of a very rare travelling wave tube. Even at this power level the moon signals were too weak to be heard and a sophisticated time averaging CW software routine was used with 10 minute repetitive transmission periods, in order to gain 10 dB on receive. The software is called "Millimeter Wave CW Signal Exchanger" was created by Sergey RW3BP and Vladimir Barchukov and is available for download from www.ve1alq.com as well as a compatible simulator program and a user manual. Using this software could bring millimeter wave EME capability to many more stations that cannot generate enough power or cannot find a big enough dish, however the program does require precise frequency setting and automatic Doppler correction over the entire transmission period. Please see the main display of an actual 47 GHz EME signal in Figure 1.

78 GHz EME Work

The apparent lack of transmitting tubes for 78 GHz did certainly not bode well for possible EME work, however in about 2006 Sergey RW3BP performed the first 78 GHz sun/ moon noise experiments. Sergey has a very good metal 2.4m offset dish on top of his apartment block in Moscow (see Figure 2) and was able to get a single CHA1077 UMS chip packaged as an amplifier which produces about 16 dB of gain and using a fundamental (vs. harmonic mixer), was able to achieve a system DSB noise figure of approximately 6.5 dB. Sergey was able to detect 5.8 dB of sun noise and about 0.53 dB of moon noise. Please see Sergey's dish in Figure 2 and his 78 GHz receive setup in Figure 3.

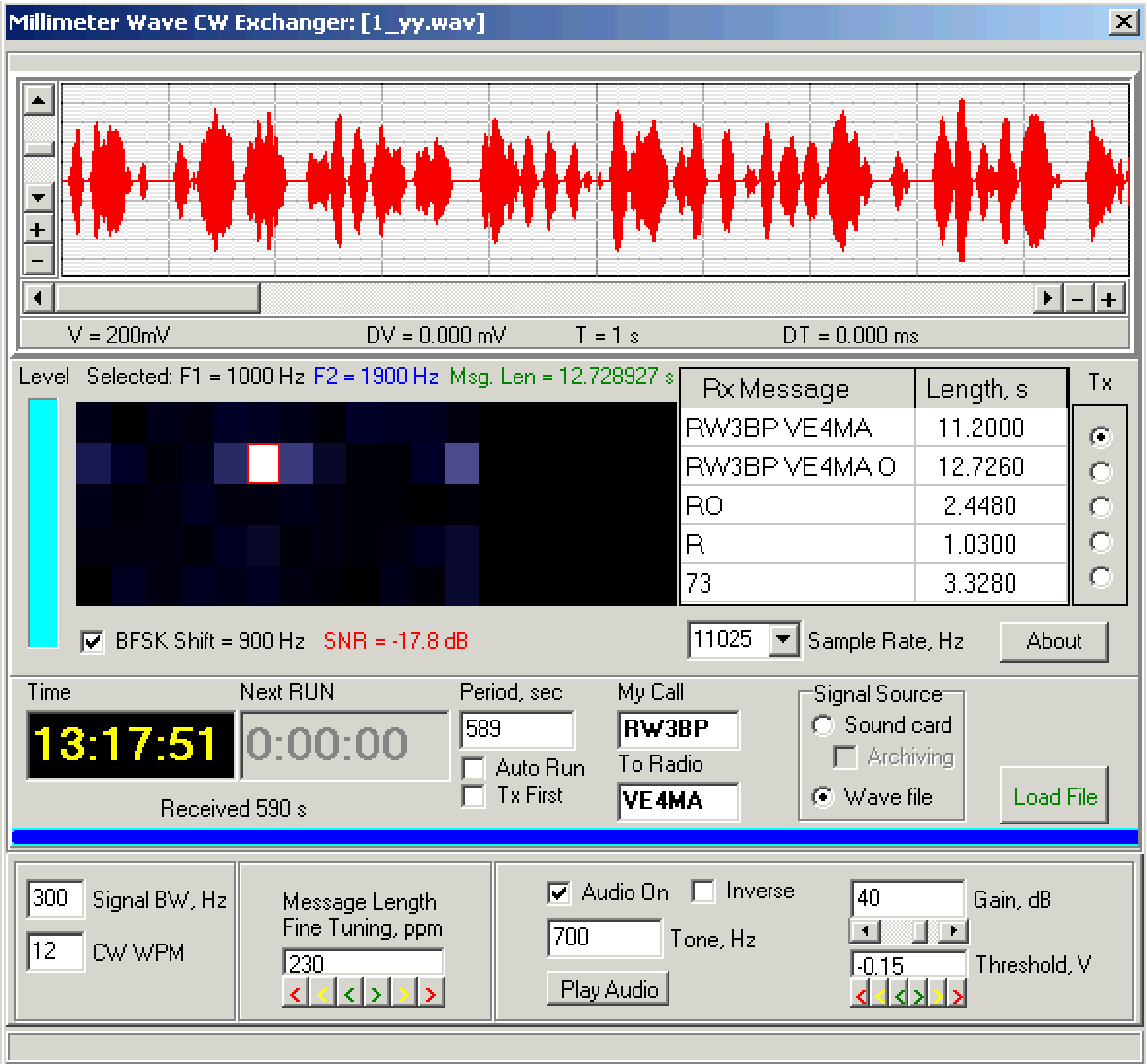

Figure 1 Weak Signal Software Display

Sergey's work coincided with the start of a project at WA1MBA in creation of some prototype LNA's using two (2) of the same CHA1077 chips. Tom's development challenges in creating these amplifiers have been described in the Microwave Update Proceedings over the past few years, but in 2010 he was able to create a few prototype units that have been under test by W5LUA and me using a calibrated noise source. The units have "excess gain" (>40 dB) near 70 GHz and the noise output has been found to be sufficient to allow self-mixing in the receiver i.e.: no LO power is required to get an output! There is also some input matching adjustments required but the results are outstanding with about 3.1 dB noise figure at an associated gain of 25 dB. Although this is good …it still requires a very good mixer behind it in order to achieve a good system noise figure (more later).

The basic amplifier assembly under test by W5LUA is shown in Figure 4. From right to left there is a noise source c/w ferrite isolator, a short WG tuning section to optimize the NF, the WA1MBA amplifier, an output isolator, a 47 GHz BPF (which works well on a higher mode at 78 GHz with a 432 MHz IF, and finally a section of WR08 waveguide which acts as a high pass filter to cut down the 70 GHz noise power. The amplifier I have used required the same external correction hardware to achieve good results.

Figure 2 RW3BP 2.4m Offset Dish

Antenna Systems

While there is 1 ft. diameter “80 GHz” wireless dishes available to amateurs at reasonable prices these are not big enough to be seriously considered for EME. The efficiency of these antennas is likely not very high but it’s a beginning and serves as a basis for comparison.

The commercial satellite industry has created efficient parabolic antenna reflectors that are useful at 30 GHz. The initial work at VE4MA and W5LUA made use of lower frequency prime focus dishes but later tests proved that the offset feed dishes offer better (outstanding) results at 24 GHz (and 47 GHz under some circumstances). However in recent years there is more commercial emphasis on antennas for 26-30 GHz satellite operations and there has been more dishes available that provide excellent results. These dishes often use sub reflectors but now there are also prime focus dishes available. Prime focus dishes present some additional challenges with having to put the electronics out in front of the dish with the potential to create significant blockage and deterioration of these very high gain antennas. Typical gains at 24 GHz are near 55 dB over an isotropic radiator and with a beamwidth of 0.28 degrees.

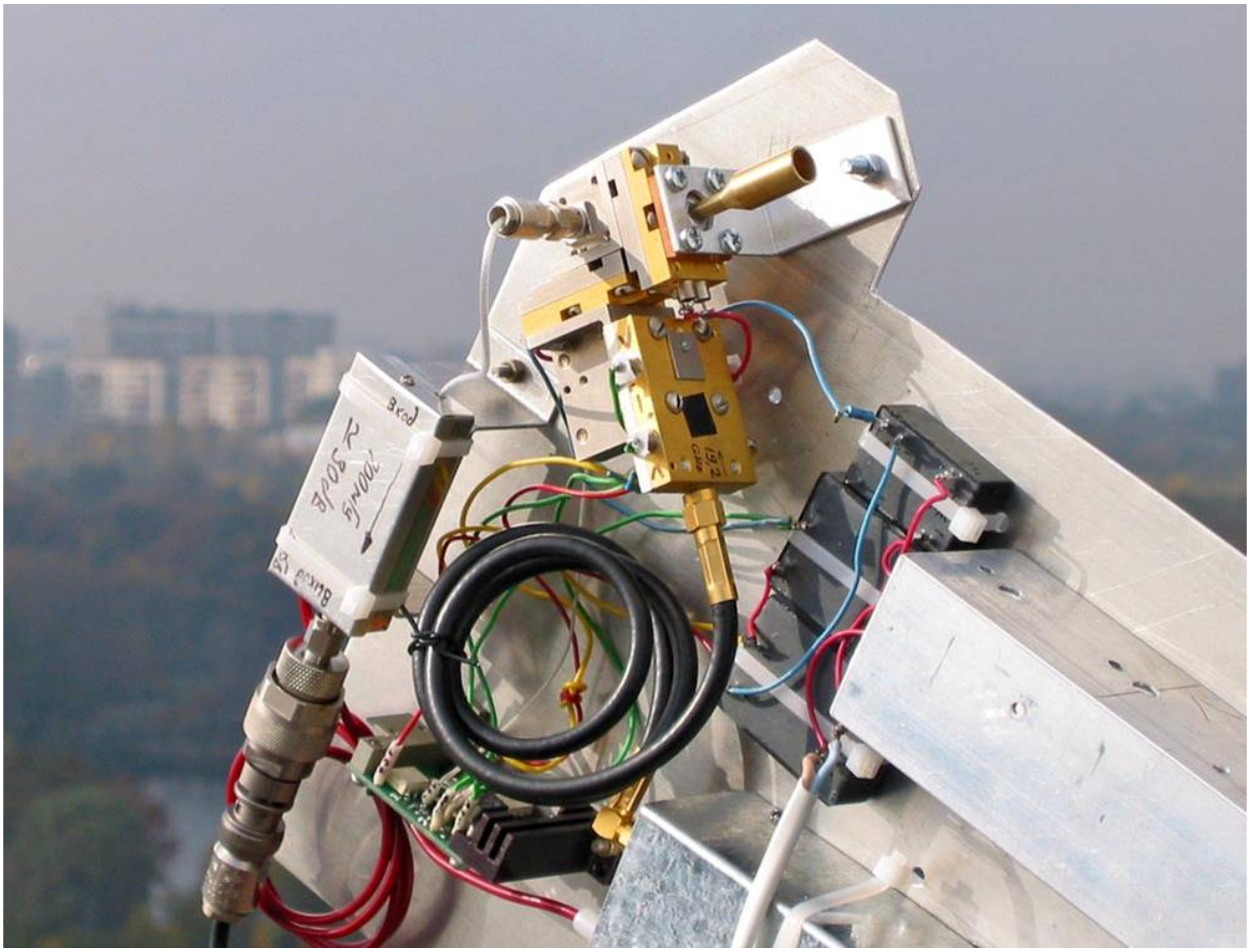

Figure 3 RW3BP 78 GHz RX on 2.4m Dish (2006)

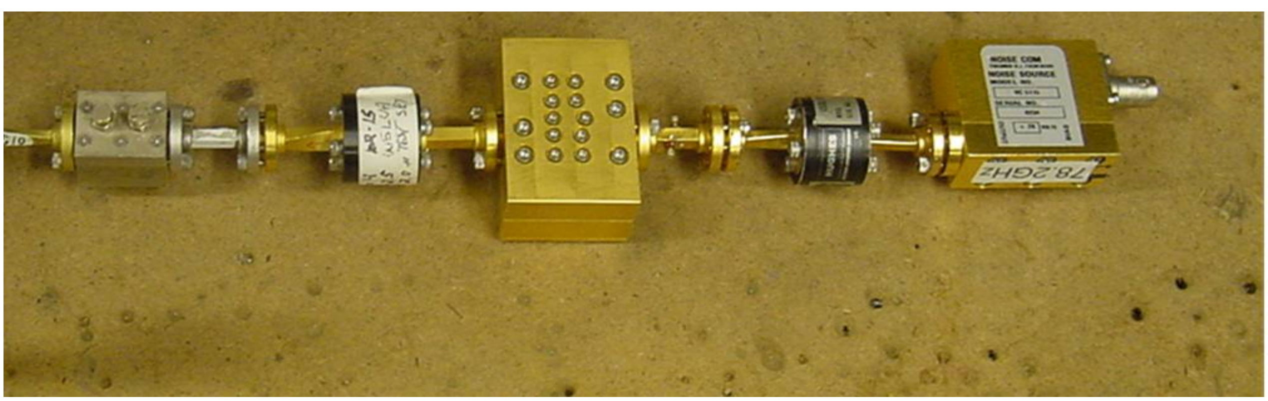

Figure 4 WA1MBA Amplifier Testing

We had seen that the 1.8 m dish at AD6FP provided better results on 47 GHz than either of the 2.4m Prodelin dishes at VE4MA or W5LUA. With that we conducted Sun / Moon noise tests to see what worked the best. Al W5LUA was able to detect 1.1 dB of sun noise using his 2.4 m dish using just a harmonic mixer that was carefully optimized and which produces an estimated noise figure of 16.4 dB. Preamps are badly needed for harmonic mixers but Sergey's fundamental mixer noise figure was very close to that with the preamp. So it certainly looks like fundamental mixer operation is worth pursuing.

Later W5LUA used his 2.4m dish and also a 1m metal TV dish and the best results achieved of 7 dB from the Sun and 0.75 dB from the moon from the 1m dish! Both of these results are better than RW3BP's results from 2006 and are a good indication of the superb performance achieved with the WA1MBA prototype amplifiers. Al used a clever mounting arrangement to install the 1m dish as shown in Figure 5.

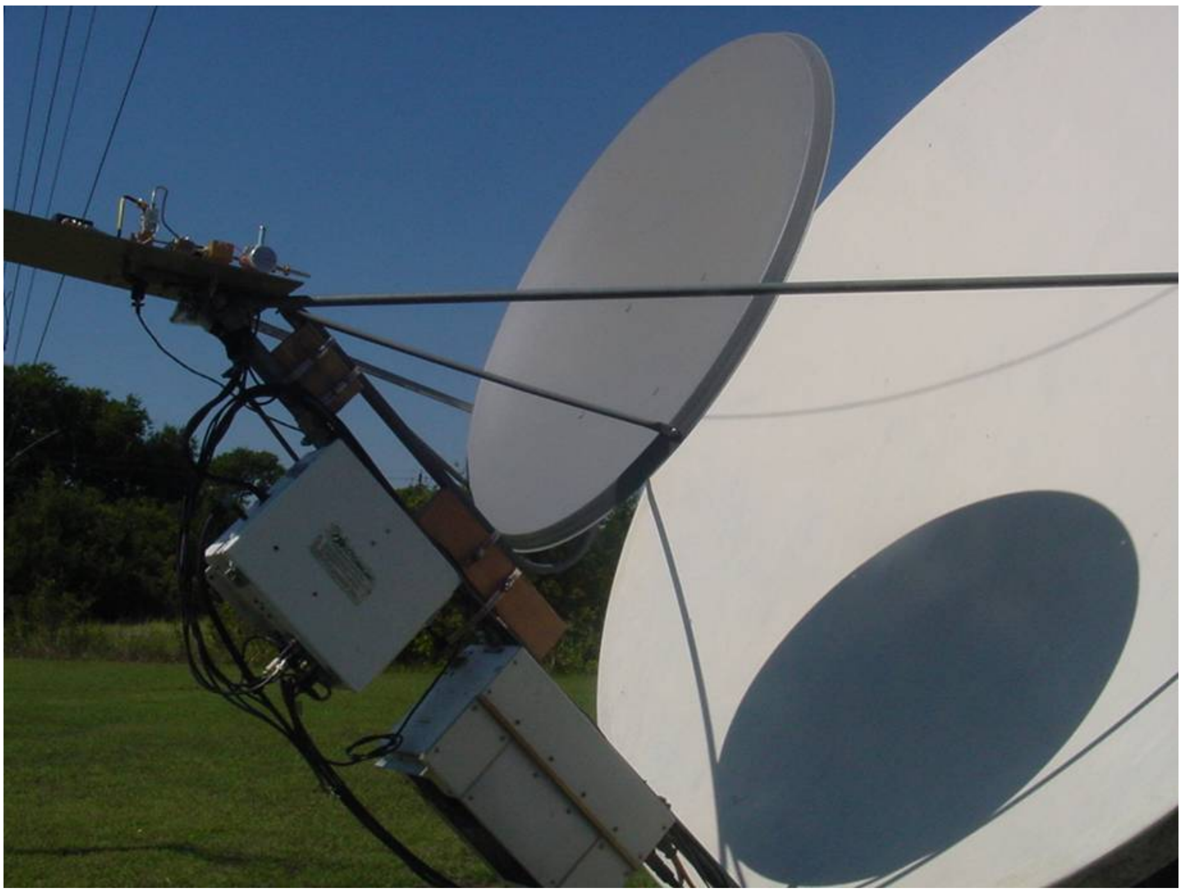

Figure 5 W5LUA 1m Dish Installed on 2.4m Mount

At VE4MA there were more dishes available to test. At the time of the test in October 16, 2010 I was struggling with poor mixer performance so that my system noise figure was only 6.1 dB. Thus my tests were only useful to evaluate the relative dish performance.   With my 2.4 m dish I achieved 3.5 dB of Sun noise and so I looked forward to testing a 33 inch (0.84m) metal dish and was very disappointed to only achieve 2.8 dB of Sun noise. This is still a very good number but apparently my 2.4 m dish works reasonably well (see Figure 6).

I also had 1.8m and 1.2 m offset dishes available. I should point out that the 2.4m dish has a layer of domestic aluminum foil glued to its surface and this provided a large improvement at 47 GHz. For testing of the 1.8 m and 1.2 m dishes the same treatment was required. With the lateness of the season (by the end of October we usually have snow remaining on the ground) I decided to test only the 1.2m dish shown in Figure 7. After the addition of the aluminum foil I achieved 4.8 dB of Sun Noise still using a 6.1 dB noise figure. The dish was part an old Hughes DirecWay “Ka” satellite system.

Figure 6 VE4MA 2.4m Dish Tests

Figure 7   VE4MA 1.2m Dish Tests

78 GHz Transmitter System

Based on the 47 GHz EME work it appeared that something near 100W output would be needed for real-time echo reception. There appeared to be few or no options but in 2008 we discovered that CPI Canada was making 80-100 Watt Extended Interaction Klystron (EIK) tubes for 78 GHz (see Figure 8 for a typical tube and power supply). Please see the CPI site for further information. There is a link on that page to some papers on EIKs that are very interesting reading and one in particular called “Extended Interaction Klystron Technology at Millimeter and Sub-Millimeter Wavelengths”. They make EIKs capable of 50W CW at 140 GHz and 6 W at 220 GHz and there is another interesting document at www.cpii.com/docs/library/7/general.PDF which shows more about the devices shown in Figure 8.

Upon contacting CPI I discovered that the tubes are custom made to order and there were no extras around in the lab. They had produced some tubes for a high resolution airport runway debris radar system. Apparently this system was built in the aftermath of the Concorde disaster. The cost of a new tube and power supply is in excess of $100,000….so the prospects of 78 GHz EME continued to remain very small.

In early 2010 I had the good fortune to locate a 78 GHz Extended Interaction Oscillator tube that was rated for 73 Watts output on 78,160 MHz (see Figure 9). This tube is free running oscillator but could be phase locked to +/- 82 MHz of that frequency and it would need to be modulated for FSK CW keying. There was no power supply but the voltage requirements appeared to be similar to that of mm wave travelling wave tube. A copy of the original factory test data sheet was obtained so that the exact voltage requirements are known (9.5 kV on the cathode and 5 kV @ 100mA on the collector. This tube is water cooled with very high water purity requirements. The search began for a suitable supply that would work, perhaps needing only minor modifications. I was able to find a supply that looks identical to the one in Figure 8……so it should be simple now! Unfortunately this supply was built to match a different EIK/ EIO tube as the cathode voltage range is from 11 to 15 kV. With only having found a limited amount of operating information there is no way to consider any modifications.

Figure 8 CPI Canada mm Wave Klystron & Power Supply

Figure 9   78 GHz 73 W Klystron Tube

Another option that I started to pursue is the building of a supply using a set of CT1DMK boards. I was able to procure a few sets of boards, but I have found it difficult to obtain many of the discrete components (high resistance trimpots and 2-3 kV electrolytic capacitors). I am sure there is not much demand for this sort of item, so that there is not much stock is available, but I may have enough material to create one. I will need to order larger transformer cores and figure out how to wind these things.

The best option for creation of a suitable supply is to once again modify the Varian power supply I originally used for 24 GHz. This supply is well documented now, and is conducive for the incorporation of the phase lock and FSK input circuitry. This supply is very large using a 14 inch rack panel and is about 3 ft. (0.8 m) deep as shown in Figure 10. I have been trying to get another supply to replace this one on for the 24 GHz TWT.

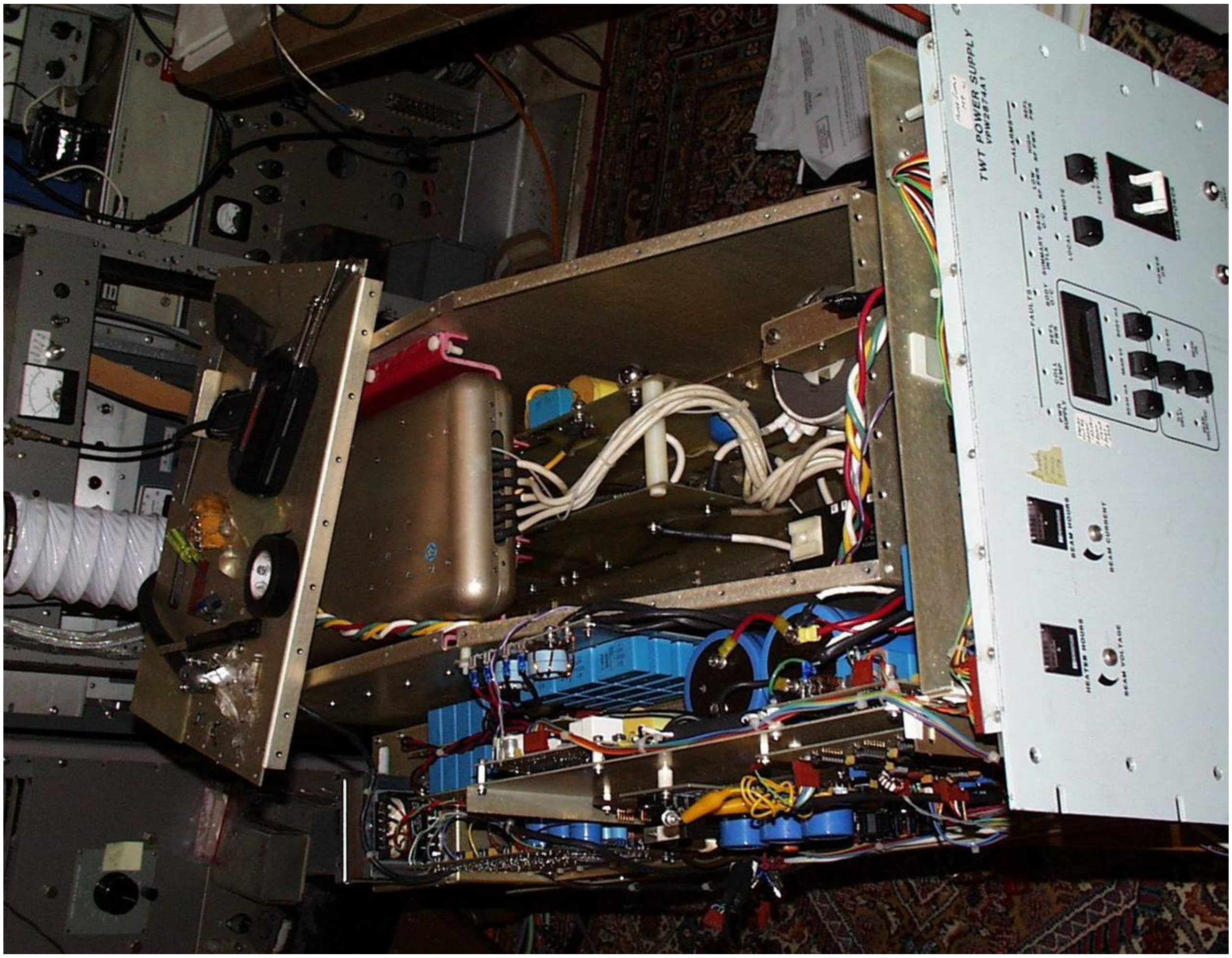

Figure 10 Old 24 GHz Varian Power Supply

I have tested the tube using the standard tests to determine filament activity and gas in the tube. I had to use discrete pins to connect to the tube's non-standard HV socket and ultimately will need to build an HV connector in order to interface to a power supply. The tube filament looks good but there is gas in excess quantity even after 24 hours of "baking it in". This may require factory work to restore the vacuum. I will be consulting with the factory to see how to proceed but suspect that I may need to go back to work to fund my hobby!

Receive Improvements

As indicated earlier my original receiver made us of a Hughes WR-15 mixer modified to accept a 39 GHz local oscillator input to support sub-harmonic mixer operation. This mixer was a big improvement over the basic operation as a harmonic mixer but still inadequate for achieving the best system noise figure. I had obtained an old Honeywell (now Spacek) sub-harmonic mixer and also achieved good results with this, slightly better than the Hughes sub-harmonic mixer. In my attempts to optimize the mixer (for transmit power in terrestrial service) I damaged it with too much LO power. Fortunately Spacek offers a repair service for their products to amateurs and they charge a nominal $100 per device to replace the diodes and even optimize on a particular frequency.

The big step for me was to finally get a good fundamental mixer operating. I was able to obtain a Marconi mixer that was built for the same system as the EIO tube. The mixer has bias ports and using a Spacek frequency doubler for the LO power, I have been able to get good results with an LO power of only +1 to +2 dBm. I tried to achieve higher LO power but damaged the diode in trying. Now that I know the operating specs for this doubler I am operating conservatively.

With the Marconi mixer I was able to achieve a DSB noise figure of 5.8 dB at 10.2 dB conversion gain using a 432 MHz EME preamp on the IF. The mixer is just slightly better with a 144 MHz IF but the RF BPFs we are using will not support this low IF. The retuned 47 GHz filters we are using on 78 GHz) have very low insertion loss and an 8.9 dB SSB noise figure was achieved. With the optimized WA1MBA prototype preamp I have on loan, I have achieved a system noise figure of 3.15 dB with a gain of 33 dB. The preamp alone with its high pass filter and output isolator still nets a gain of 25 dB. A picture of my test setup imbedded in my stripped down terrestrial 78 GHz transverter is shown in Figure 11.

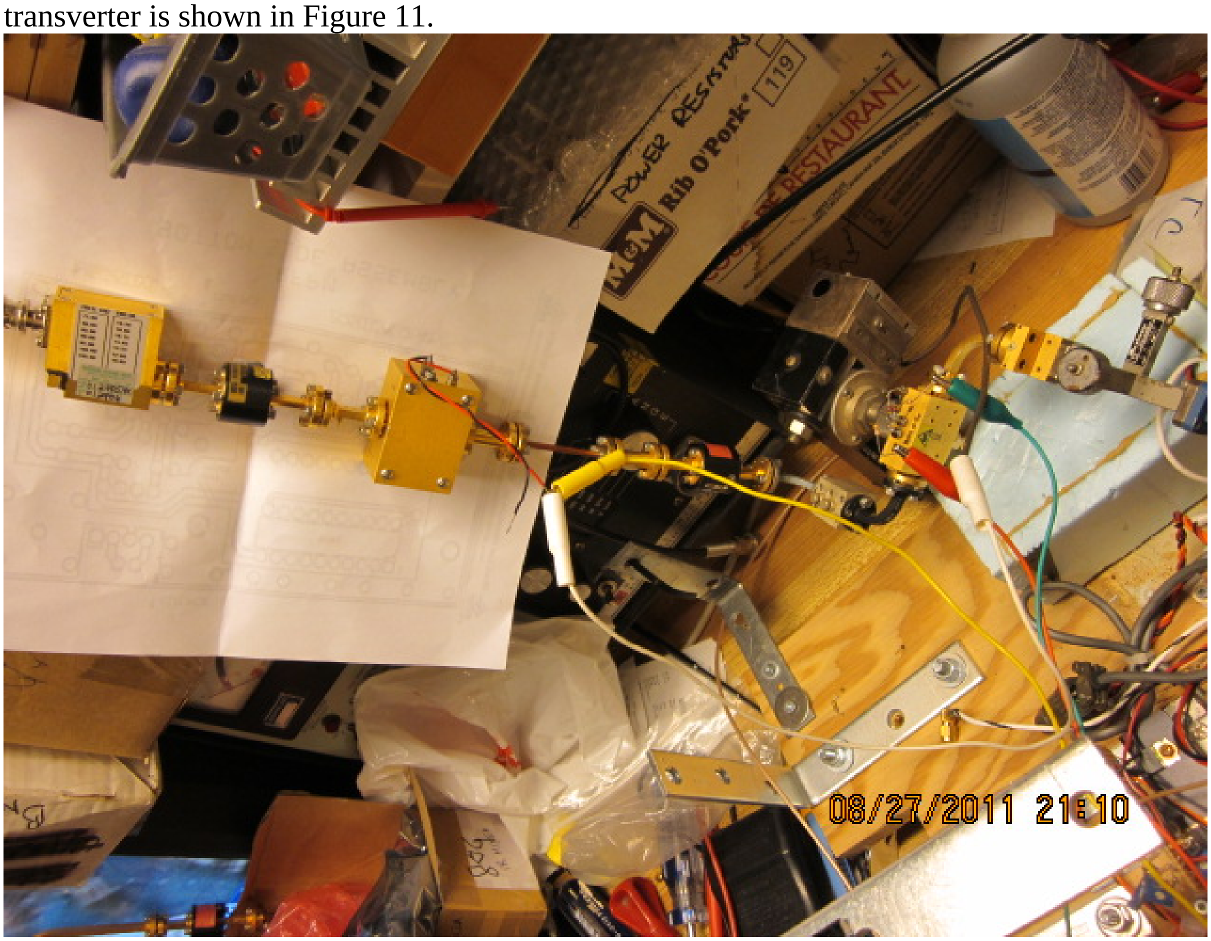

Figure 11 Fundamental Mixer Under Test

I had continued to evaluate other mixer assemblies in an attempt to do better. I have two (2) 78 GHz image reject mixer assemblies, one with a possible 144 IF and another with use of a 28 MHz IF. I have been unable to get these mixers to come alive in the noise figure setup. I need to go back and connect my test weak signal source to see if I can get them to work. The lack of sufficient LO power is suspected to be the problem. I have a 78 GHz Gunn oscillator to repair when time permits that should satisfy this requirement but I will have to phase lock it if it works out.

Frequency Determination & Doppler Correction

A significant problem in originally finding 24 GHz signals was frequency co-ordination and Doppler shift. As with all narrow band microwave work, frequency calibration and stability is a detail that cannot be overlooked. Completion of many moonbounce QSO's on the lower microwave bands was easy…after finding the signal! At 24 GHz and above the weaker signals make this much more difficult to accomplish if you do not deal with frequency calibration and Doppler calculation properly.

Fortunately the issues of frequency calibration and basic frequency stability are much easier to deal with now and make 24 GHz and above operation much more routine. Frequency accuracy has improved remarkably through the use of synthesized local oscillators with GPS or other precision reference signals. Even if the local oscillator is not synthesized, if it is in a stable environment and it can be compared to an accurate (GPS or similar) reference periodically this may be sufficient. My operation with 2 -78 GHz portable stations with really good external crystal references leads me to think that full phase lock to a precision reference signal will be required.

I have obtained a partially stripped Hughes phase locked assembly for 39 GHz and have been able to obtain phase lock. I still need to lock this to my precision reference and use it for locking the EIO onto frequency. The Hughes PLL assembly is shown in Figure 12.

At 24 GHz there is a there is also a large amount of Doppler shift (up to 70 kHz at moon rise) which can create issues for finding signals if the Doppler calculations are inaccurate as was found to be the case back in 2001. In recent years Philippe F2TU has created a more precise Doppler calculation algorithm that is accurate within 20 Hz at 10 GHz (see http://pagesperso-orange.fr/f2tu/). This algorithm has been incorporated into the F1EHN moon tracking program, which is highly recommended and freeware. It can be downloaded from the http://www.f1ehn.org/ site. Of course the Doppler shift at 78 GHz will be in excess of 200 kHz at moon rise so precise Doppler correction is critical, and especially if the signals are sub-audible as they were at 47 GHz.

Beyond the software there is an education process required. With such large Doppler shifts there needs to be considerable thought given on how to set your transmit frequency in order to respond to a station calling CQ on random or where to look for a scheduled station. The issue is determining the "Mutual" Doppler between you and the other station. This can only be accurately determined if you know where the other station is…that is from Europe or from North America and the more precisely you know the coordinates the better. The F1EHN program allows you to enter the station call sign (for known stations) or the call area and it will calculate the mutual Doppler in real time. Keep in mind however that for a 24 GHz EME schedule between 2 stations on the exactly the schedule frequency but who are not at the same location, a third observer will not hear both stations on the same frequency due to the difference in Doppler shift from each location. A presentation on Mutual Doppler has been prepared by Al W5LUA and is available from the North Texas Microwave web site www.ntms.org under presentations from the 2008 EME conference.

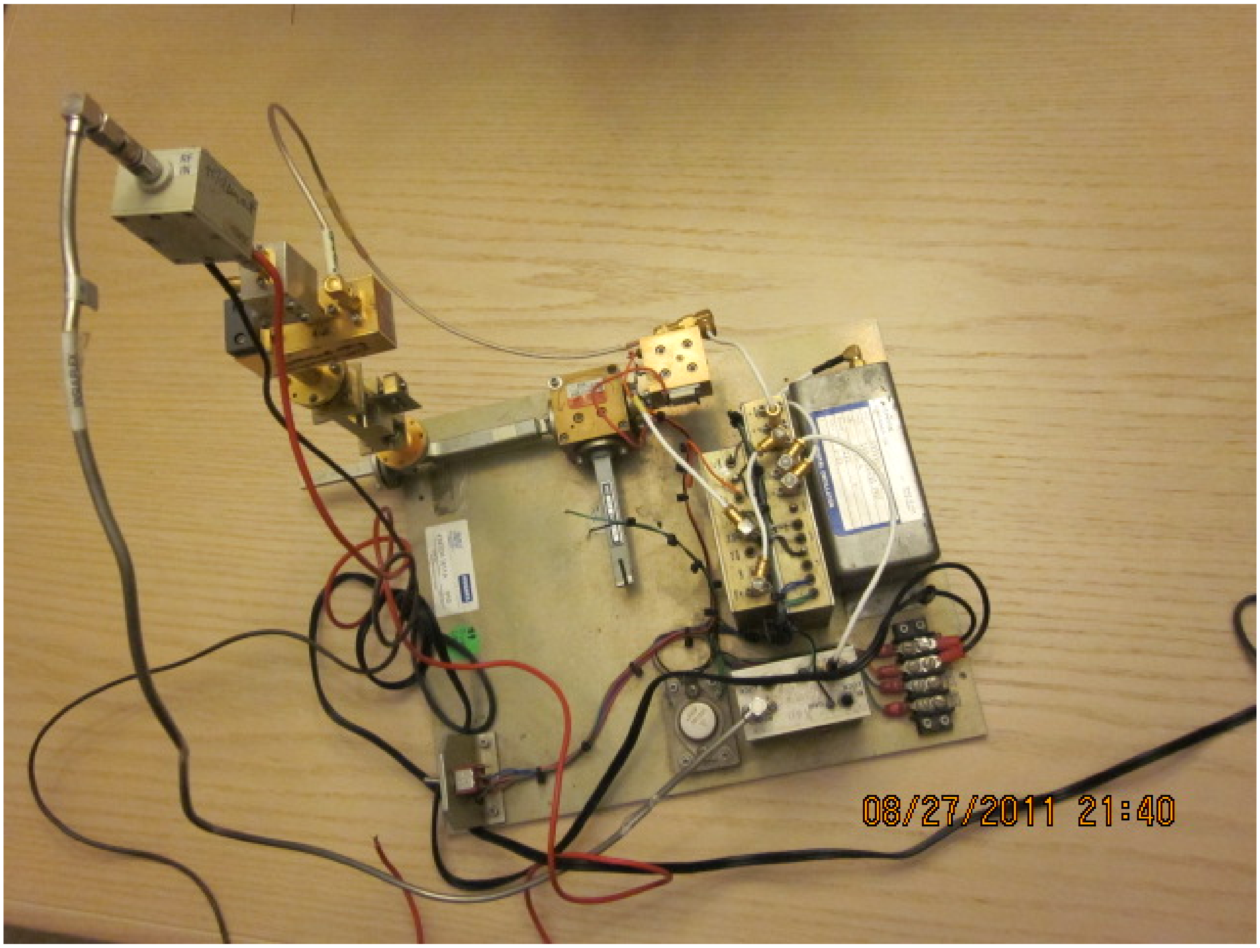

Figure 12 Hughes PLL System

Station Improvements & Further Work

Moon Tracking

In 2001/2 a significant challenge was in tracking the moon, having to update our antenna tracking at least every 60 seconds. At W5LUA and VE4MA we have gone from having to heavily rely on peaking on moon noise during receive periods (and half way through transmit periods) to having complete computer control of our dishes.

We both used a software program created by K5GW to give us automatic tracking at 47 GHz. The program also calculates the Mutual Doppler and can control the receive frequency in order to compensate for the rapidly moving Doppler frequency shift. As discussed earlier the F1EHN program is able to do this also and uses the more precise F2TU Doppler correction algorithm. The F1EHN program certainly is the recommended solution going forward although K5GW has recently made changes to make it as good as the F1EHN program.

An important factor in being able to do this is through the use of US Digital Absolute Encoders. Although the units we employed are overkill for our needs with a resolution of 0.01 degrees the use of absolute encoders helps to get set up initially and later determine where we are if we lose calibration. Practically we found that for our dish mounts the highest resolution we could use was 0.1 degrees due to mechanical uncertainties and vibrations. At VE4MA I have still encountered some situations where a mechanical error has been introduced into the mount that needs to be calibrated out before schedule time. The nature of the problem appears to be related to use of a flexible shaft for coupling the AZ information to the encoder. I will need to come up with something else anyway for a new 1.2m dish mount.

EIO Power Supply and Tube Revitalization

I have struggled trying to find a simple power supply solution …..There is no easy way out….I can do this but it will take more time!

I need to deal with the excess gas problem in the tube. My bank account cannot handle the expected hit right now and I do not have time to deal with it as I try to complete renovations to my son’s home prior to travelling to Arizona for winter. This renovation work and southern vacation has destroyed my original schedule for completing this project.

Cooling of Low Noise Amplifier

Some stations on 24 GHz have reported a significant increase in receive noise figures with the high ambient temperatures inside weatherproof enclosures. Thermo electric cooling and water-cooling of preamps has reduced noise figures by more than 0.2 dB. It has not been confirmed the extent of noise figure reductions with extra cooling, but this is an interesting area to experiment with further. I will obtain some dry ice and possibly a thermoelectric cooler to test and report at the conference.

Conclusion

Hopefully when my time is my own again and my finances have recovered I will be able to move forward more quickly to completing on–the-air tests in 2012. I would like to thank WA1MBA, W5LUA, WA1ZMS/4 and W0EOM for their support with this work.