The First 24 GHz MOONBOUNCE QSO

By Barry Malowanchuk VE4MA and Al Ward W5LUA

Introduction

On August 18, 2001 at 14:19 UTC VE4MA and W5LUA completed the first 24 GHz EME QSO. The following will discuss efforts over several years by Barry VE4MA and Al W5LUA to make the first moonbounce contact on 24 GHz.

Moonbounce QSO's have been accomplished and have become a routine event up to the 10 GHz band. The next highest amateur band at 24 GHz represents an enormous technology change from the lower frequencies. Most radio technologies don't work very well at 24 GHz, and moonbounce requires very high performance systems, thus moonbounce at 24 GHz represents a supreme technical challenge!

The recent improvements in low noise microwave transistors allow good low noise amplifiers to be created, although this still takes a great deal of skill and patience to achieve. The commercial satellite industry at 14 GHz has created efficient parabolic antenna reflectors that might be useful with reduced efficiency at 24 GHz but obtaining high transmitter power still represents the biggest individual challenge. High power TWTs are not commonly available and low frequency units would be hard pressed to produce the gain and output power needed. As all the radio technologies are challenged to perform well at this frequency, strict attention to details are necessary.

Beyond the technology challenges the high path loss adds a further barrier. The minimum EME path loss to the moon at 24 GHz is approximately 297 dB. Furthermore the 24 GHz band is also severely affected by water vapor absorption in the atmosphere.

The following will review the challenges in more detail and highlights the efforts by VE4MA and W5LUA to assemble the systems required to make a 24 GHz EME QSO possible. Figures 1 and 2 show VE4MA and W5LUA with their 24 GHz EME antenna installations

Figure 1 VE4MA and 2.7 Meter Dish for 24 GHz

Figure 2 W5LUA and 3 Meter Dish for 24 GHz

Antenna System and Moon Tracking

VE4MA

I initially planned to use an Andrew 3.0m (10ft) (See Figure 3) dish that I have used recently from 1296 to 10,368 MHz. I migrated from a larger homebrewed 3.7 m (12ft) dish a few years in order to gain extra performance at 10 GHz. This 3.0m dish was made for 14/12 GHz satellite terminals however the unit I acquired had some surface inaccuracies that could be a performance problem at 24 GHz. The theoretical gain at 24 GHz was expected to be near 55 dB over an isotropic radiator and with a beamwidth of 0.28 degrees!

Figure 3. 3.0 Meter Andrew Prime Focus & 2.7 Meter Offset Feed Dishes at VE4MA

Antenna pointing is a significant problem as the dish has a 1dB beamwidth of 0.16 degrees and the moon moves across the sky at a rate of 15 degrees per hour. Hence the antenna pointing must be updated about every 60 seconds minimum! Peaking of the antenna is accomplished manually and is assisted through the use of a "Moon Noise Meter" which displays the relative value of the moon's thermal noise being received. The moon being at an average temperature of 250 degrees Kelvin (273 deg. K = 0 deg. C), radiates thermally generated radio noise, and is quite bright compared to the 4 degree background temperature of space. After careful adjustment of the feedhorn position approximately 0.6 dB of moon noise was seen on this 3.0m dish with the receiving system of the time at 24 GHz (more discussion later). The moon noise meter has a 1 dB full-scale deflection, so that the movement is quite dramatic. Larger dishes would not see any more noise because the moon illuminates the whole antenna beamwidth, and thus this thermal moon noise actually limits the ultimate sensitivity of the receiving system. More antenna gain from a larger dish would help on transmit, however antenna pointing becomes very critical as you must hit the centre of the moon to ensure that the reflection comes straight back and not get bounced of the side and into space!

Later I had the good fortune to acquire a Prodelin 2.7 m (8 ft) offset feed dish originally intended for 14/12 GHz remote broadcast uplinks. Looking like one of the direct broadcast mini-dishes, this reflector is very flat and in theory might provide very high efficiency and perhaps even as much gain as the larger 3.0m centre fed Andrew dish (see Figures 1 and 3). A fringe benefit of the offset fed dishes is the ability to locate all the electronics at the feed point without introducing blockage of the dish's capture area. Initial Sun noise checks with the reflector using a sub optimum feed were encouraging and a proper feed with much higher gain for the shallow reflector (f/D=0.7) was required. Using one of W1GHZ's computer programs a higher gain W2IMU feedhorn was created and built using plumbing parts and sheet copper. Please see Figure 4, which shows the initial & final W2IMU feedhorns.

The final results with the new W2IMU feedhorn, carefully optimized in front of the reflector was 2.3 dB of moon noise (previously 0.6 dB) and 15 dB of Sun noise! This was truly outstanding and the basis of much optimism.

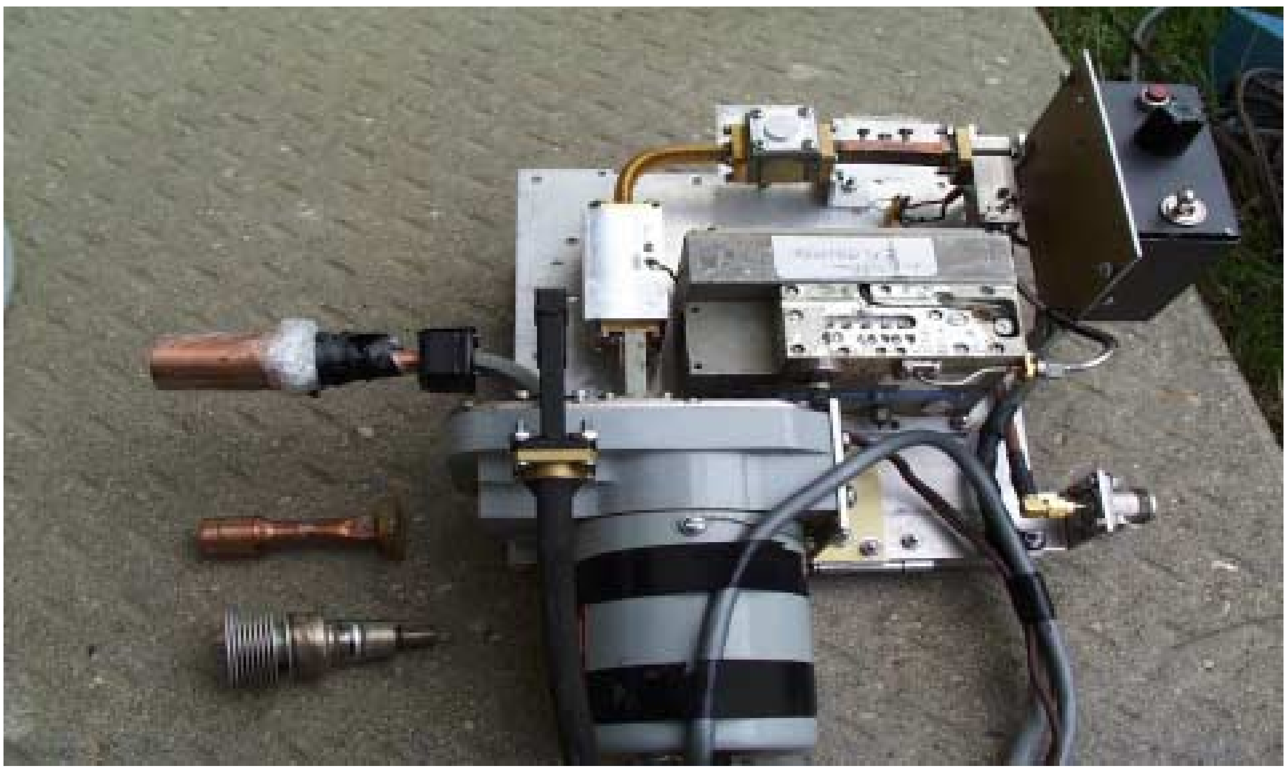

Figure 4. 24 GHz Feed Assembly (Rx Converter & WG Switch) & Lower Gain W2IMU Feedhorn

W5LUA

The antenna at W5LUA is a 3 meter Andrews prime focus dish with an F/D of 0.3. See Figures 2 and 5. According to Andrews, the 3 meter dish is rated to 30 GHz with proper back structuring to optimize the dish's surface. The dish really began to perform when I added a back structure which looks like a tic-tac-toe board mounted to the backside of the dish. The eight points of the back structure allowed me to optimize the dish's surface by pushing or pulling on the back of the dish to enhance the accuracy of the dish's surface. As opposed to the using the popular "string test" to optimize the plane of the dish, I merely used my GR IF amplifier to measure sun noise and based any improvement on changes in sun noise. The end result was improved sun and moon noise. In the March timeframe, when I first received my echoes, I was receiving 12.5 dB of sun noise and 1.3 dB of moon noise. The sun noise is a 3 dB improvement over what I was obtaining prior to optimizing the dish surface. My system noise figure at the time was 2.25 dB. My feed is a scalar feed optimized per the "W1GHZ On-Line Antenna Handbook".

I used a piece of PVC pipe to support the feed and relay/LNA combination. The PVC pipe is guyed back to the dish in 4 directions by the use of insulated Phillystrand cable. I attempted to keep as much metal and conductive material away from the feedhorn as possible. See Figure 2

Figure 5. Back structure for 3 Meter Dish at W5LUA

Transmission Lines

Transmission lines are VERY lossy at this frequency. Most large diameter low loss coaxial cables no longer operate efficiently at this frequency, due to the undesirable propagation modes resulting from the significant distance between the inner and outer conductors in terms of a wavelength. Smaller cables such a “141” or “085” semi-rigid cables will work however the loss is unacceptable for a high power transmit system but is usable after the first preamplifier for inter-stage connections. Elliptical and rigid waveguide are the transmission lines of choice but still exhibit losses of 6 to 9 dB / 100 ft! Thus transmission lines must clearly be kept as short as possible.

WR-42 rectangular waveguide is the best choice for rigid lines and it exhibits a loss of about 11dB/100 ft. WR-28 and WR-62 could be used for short runs (a few centimeters or 1 inch).The Elliptical waveguides offer lower losses and being flexible also offer ease of use over rigid waveguide. There are two choices for elliptical waveguides Andrew EW220 and EW180 and equivalents from other manufacturers. EW180 is rated from 14-20 GHz but with care (no sharp bends) will work and can produce losses of under 6 dB/100 ft. EW220 is designed for 17-24 GHz and is specified with a loss of about 8.5 dB/100 ft.

EW180 is used at VE4MA for the transmit feedlines from the feedpoint of the dish to inside the ham shack in order to avoid exposing transmitter equipment to extreme weather. The very high voltage TWT power supplies do not like high humidity while the tubes themselves do not take well to cold temperatures.

With very large prime focus dishes, the transmitter feed line loss from the dish feedpoint back to the operating position could be prohibitive, and thus great effort is often put into mounting the transmit power amplifier as close as possible to the dish. Ideally it should be mounted along with the receive preamplifiers and relays right at the feedpoint of the dish but that is usually is impractical for prime focus dishes. This is where the offset or rear fed dishes excel by having the feedhorn outside the capture area of the dish. At W5LUA, I use a combination of rigid and flexible waveguide to connect the output of my TWT to the waveguide relay. I use a 3ft piece of rigid WR-42 waveguide from the waveguide relay at the feed to a point just behind the dish where I continue with a 12 inch length of WR-42 flexible waveguide to the TWT. The TWT and transverter are mounted on a shelf which is attached to the back of the dish. There is an advantage of a low 0.3 f/d dish, i.e. short length from feed to back of dish! Regardless of what type of antenna is used, every effort must be made to minimize transmit feedline loss by keeping it as short as possible and even putting the transmitter out by the dish if practical.

Receiving and Low level Transmitting Equipment

VE4MA

The system is homebuilt and the use of surplus components for the up/down converters significantly minimized the work required. My station starts with an old Icom IC-490 70cm Multimode transceiver, which works into a transverter to convert the signals to and from 24 GHz. I also use a separate 70 cm receive converter down to 28 MHz to drive an HF receiver and the moon noise meter. The system is linear and highly stable so that CW, SSB and even FM could be used if signal levels permitted.

The receiving preamplifiers can be home built but achieving the very best noise figures can be extremely difficult. I have created a good noise figure measurement system and believe I am reasonably skilled at tuning these preamplifiers with small copper tabs. I have built about 6 waveguide input/ output preamplifiers using a variety of devices and achieved mixed results. The best results of 2.3 dB NF were with an Agilent ATF36077 PHEMT FET (see figure 6). This preamplifier was used with the initial tests with my 3m dish.

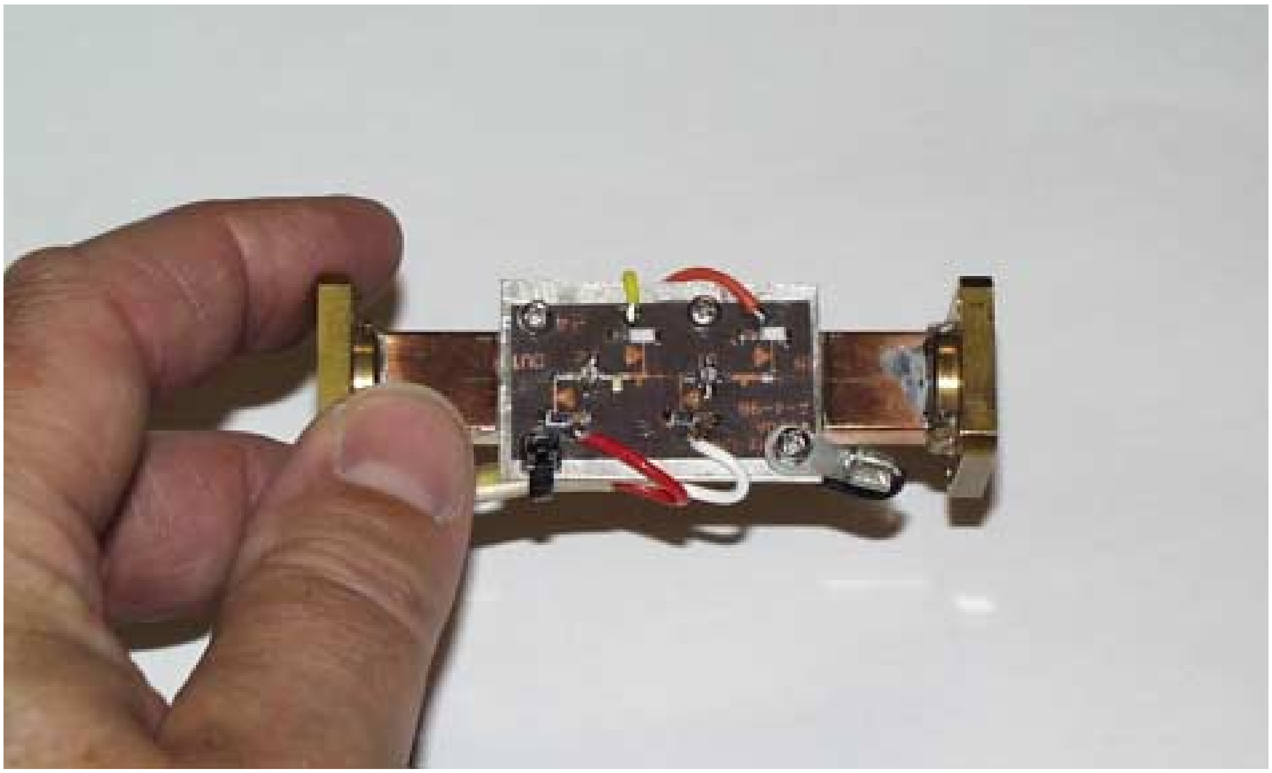

Figure 6 VE4MA 24 GHz Waveguide 2 Stage Preamplifier

There are designs published and PC boards, parts and even assembled units can be obtained if desired from a few European suppliers. As discussed earlier coaxial cable is extremely lossy so that the input to the moonbounce preamplifiers must use WR-42 rectangular waveguide.

In the interest of improving things further and moving on to the power amplifier work, I purchased a 3 stage preamplifier from DB6NT. This unit delivers an extremely impressive 1.55 dB NF @28 dB gain and represents the state of the art and was well worth the cost!

W5LUA

My transverter is also homebrew and mounted out behind the dish on a shelf along with the TWT. The transverter uses a DMC LO and a DMC power amplifier providing 50 milliwatts on transmit. I use several homebrew LNAs to set the system noise figure. The LNA that I used to hear my first echoes on 24 GHz is a homebrew 2 stage W5LUA design using a pair of Agilent Technologies PHEMT devices which provided a 2.25 dB system noise figure. I have since acquired some lower noise figure devices which has produced a 1.75 dB system noise figure. The transverter is dual conversion with a first IF of 2304 MHz and a second IF of 144 MHz. The 144 MHz is piped into the shack. My IF radio is an ICOM IC-271. I sample some of the 2 meter IF signal and down-convert even further to 28 MHz. The 28 MHz feeds both a GR-1216 IF amplifier for measuring sun and moon noise and also a Drake R7 receiver. Although I have used my IC-271 for nearly every EME and tropo QSO I have made through 10 GHz, I must admit the R7 receiver produced an easier to copy signal off the moon on 24 GHz. The Drake R7 receiver was originally used by W4HHK for his IF on 2304 MHz EME so it is carrying on the EME tradition.

Transmitter Power Amplifiers

Transmitter power is the most difficult thing to achieve. Modern solid-state amplifiers are available on the surplus market up to about ½ Watt, but above this we must rely on traveling wave tube amplifiers (TWTA). Most 24 GHz rated TWTAs that become surplus are instrumentation units that at are only rated at 1 Watt output, while lower frequency TWTAs (e.g. 12-18 GHz) are usually rated to about 25 Watts. All TWT amplifiers are usually capable of considerably more power if the focusing voltages are optimized for the specific frequency of interest.

VE4MA

My initial power amplifier work focused on trying to get Varian and Hughes 18 GHz instrumentation amplifiers to move up to 24 GHz. Unfortunately these surplus amplifiers units are often surplus because the power supply and or the TWT itself are defective. I spent many weeks time in reverse engineering switching power supplies, only to find that the tubes are also bad. My best results with a Hughes 1177 10 Watt amplifier was a best of 5 Watts out with only about 17 dB of gain. Notably the low frequency minimum gain specification is 30 dB. With such low gain a driver of about 100 mW is required. I have also tried to use the Hughes 1277 (20 Watt) with very poor results The best results were obtained with a Hughes 1177 amplifier driving a Logimetrics 10 Watt 8-18 GHz amplifier (ITT tube) to achieve 11 Watts on 24 GHz.

I was fortunate to acquire some 4 Varian 100Watt 28 GHz TWTs and power supplies. Unfortunately these TWTs proved to be narrow band "cavity coupled" tubes and produced no output at 24 GHz. The power supplies are very impressive providing a regulated 23 kV, 12 kV at 150 mA, etc. from a 220V single-phase line. Physically these are hidden behind a 14 inch high 19 inch rack panel and are about 30 inches deep and weigh over 100 pounds. Fortunately there was a complete set of schematics for these power supplies, which has proven to be very important for future work. Please see figures 7 & 8.

After the original tubes did not work out, Al W5LUA was able to acquire 4 different 100 Watt + 26-30+ GHz TWTs that are wideband Helix based tubes. These tubes were donated to the EME effort by Paul Drexler, W2PED. Many thanks to Paul for his generous donation! After modifying the 23 & 12 kV sections of the big power supply to create 15 and 6 kV and compensating for filament and control anode voltage changes, I tested an NEC 150 Watt tube with a rated gain in excess of 50 dB! Unfortunately this tube proved to have an open helix.

My focus was then on further power supply modifications to match the 3 remaining tubes. The second unit I tried is rated at 80 W output from 32-38 GHz so that it was not clear how well it would operate at 24 GHz. See Figure 9 below. It now provides 75 Watts at 24 GHz after the addition of external waveguide tuners, extensive use of extra magnets for refocusing and dramatic adjustment of the Helix voltage from 13.6 to 14.7 kV.

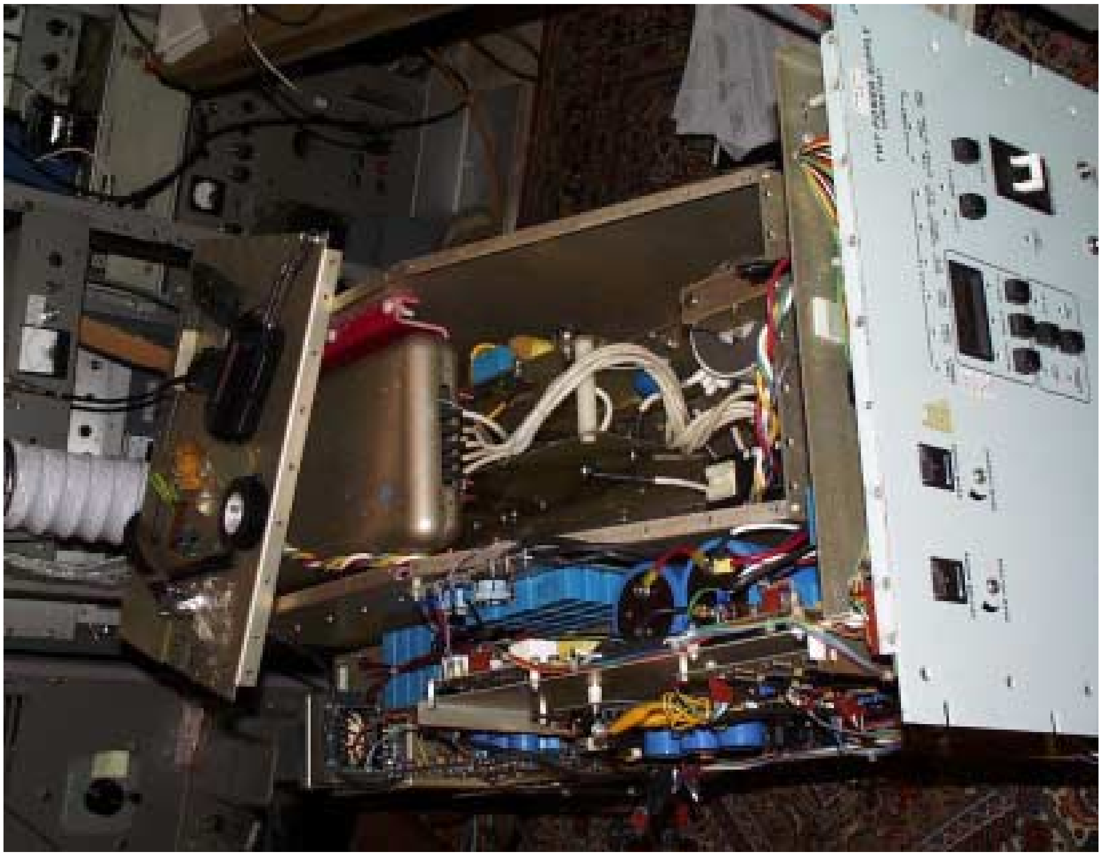

Figure 7 Varian 23 kV Switching TWT Power Supply

Figure 8 Varian 100 Watt 28 GHz TWT

Figure 9   80 Watt 32-38 GHz Varian TWT, Hughes 10 Watt TWT & Glass 2C39 Tube

W5LUA

My initial success in generating power on 24 GHz came after re-tuning my VTU-6191 TWT. The VTU-6191 TWT is a 14.5 GHz 80 watt tube which works very well at 10368 MHz producing 100 watts with some additional waveguide tuning. See Figure 10. I decided to try to see if this tube could be pushed to 24 GHz. Most TWTs can be coaxed up in frequency by lowering the helix voltage. Unfortunately lowering the helix voltage down towards the lower specified limit of the tube will generally raise the helix current and cause trip-outs if not careful. Generous use of small "refrigerator magnets" and some waveguide tuning and I was able to generate nearly 10 watts at 24 GHz with 50 milliwatts of drive. One day I was having a discussion with John Schroeder, K5ZMJ, about tuning my TWT with magnets. John made the comment that he had some very big magnets. So I thought well why not try one and see what happens. The first thing that happened was that I noticed it was a lot easier to trip out the helix current when placing the magnet in the "wrong" position! After careful positioning near the input waveguide connector, I was able to get nearly 20 watts output, a gain of 3 dB over my previous best. At this power level , I was able to hear my first echoes off the moon in March 2001. Also note the bandswitch between 10 and 24 GHz as shown in Figure 10.When I operate 10 GHz, I MUST remove the large magnet!

As mention earlier, Paul Drexler donated several TWTs to the EME cause. I was able to bring up the Thompson TH-3864C which was design primarily for the 28 GHz band. The tube as-is produced 80 watts at 24 GHz without any additional waveguide tuning. See Figure 11. The only problem encountered with the tube was high helix current. The normal no-drive helix current was very near the 5 mA absolute maximum limit. I was able to place a magnet about the size of a domino at a location very near the input waveguide flange which reduced the helix current in half without adversely effecting output power.

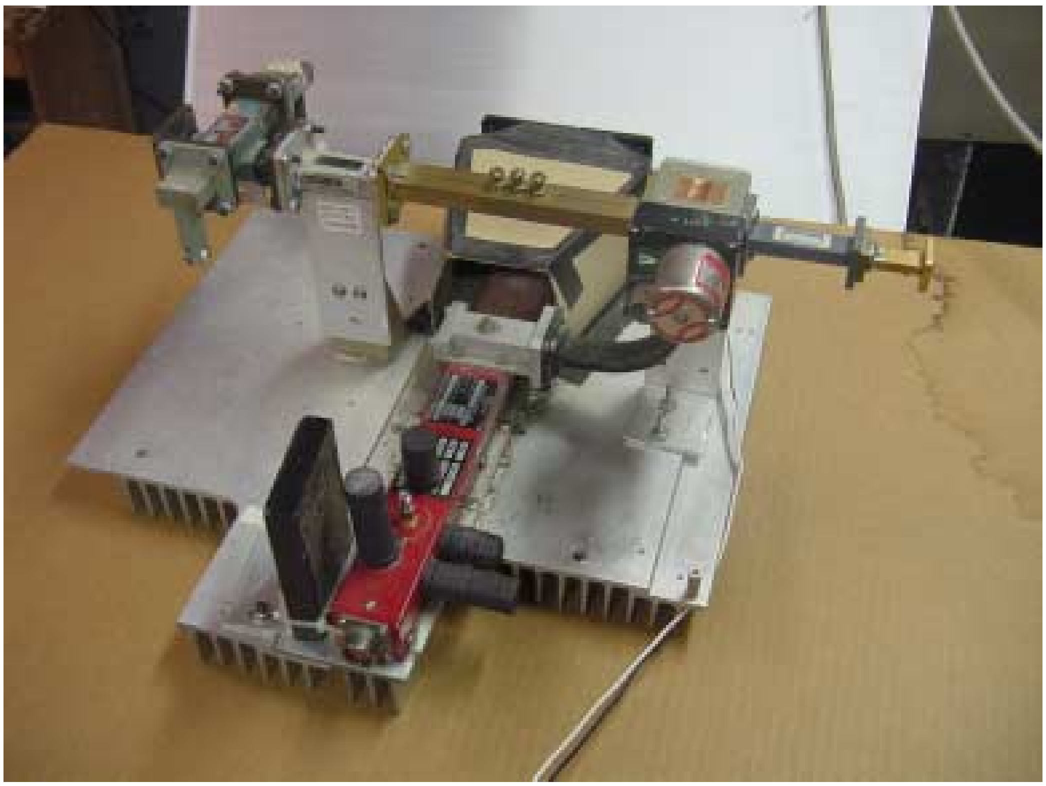

Figure 10 VTU-6191 TWT Bandswitched for 10 and 24 GHz

Several weeks prior to our first QSO, Barry and I had a sked in which Barry was Q5 at my location when he was running 55 watts. I had just remoted my TWT power supply out near the dish and was preparing for and excited about making our first QSO. Upon application of the standby to transmit push button, the power supply proceeded to arc over at one of the transformers. It was the beam forming electrode supply transformer which supplies either –900 volts or –20 volts to the TWT to switch between standby and transmit. However, when the power supply cycles to the transmit mode, it places the beam forming electrode supply at a –12,000 volts with respect to ground! Up until this time, I had had no problems with high voltage arc over in the shack, but due to the 75 to 80% humidity that we had at 0700 in the morning, the power supply decided to act up. It took me 3 weeks of disassembly and rebuild of this transformer to solve the problem. After consultation with WA5TKU, I realized that most switching power supply transformers which consist of 2 “E” section ferrite cores can be easily taken apart leaving only the windings. After removing the 2 “E” section ferrite cores I was left with the transformer windings which were wound around a plastic form. At this point I used some high voltage “pooky” (W5ZN likes this word so I use it) to increase the insulation resistance from the winding to the ferrite core. The best solution was found to be Red-X

Figure 11 TH-3864C TWT Mounted behind dish. Note high voltage junction box and magnet.

Corona Dope by GC Electronics. It is rated at 15,000 volts per 0.01” thickness. Having solved the high voltage problem, Barry and I were ready for a QSO! While waiting for the various layers of Corona Dope to dry, I was also performing the VE4MA modifications to the power supply that originally powered the 28 GHz couple cavity TWT. As of this moment, I am still working on those modifications as a backup!

Operating Results

Al W5LUA was first able to copy his echoes on March 6th of 2001 and they were weak but CW readable and not just “imagination”. Jim WA7CJO has heard his echoes with 11 Watts along with some urban legend DL station that cannot be identified.

You have to appreciate the efforts required to do these tests. Both stations use moon noise peaking on receive, which requires interruption of transmit periods about every 30 seconds. W5LUA can use a visual moon for aiming and both of us need decent weather to be able to keep the dishes pointed.

Not unexpectedly the high values of moon noise achieved in winter dropped dramatically to as low as 1.2 dB (vs. 2.3 dB) at VE4MA and down to 0.8 dB (vs. 1.3dB) at W5LUA. Thus the receive performance had dropped in summer due to the combined effects of atmospheric absorption and the rise in ambient operating temperature. Please recall that for the tests in winter the ambient temperature was ~–30 deg C vs. +25-35 in summer!

A significant problem in originally finding signals had been frequency co-ordination and Doppler shift. Al's signal was 14 KHz away from where I expected it! This is especially troublesome when tuning slowly for a really weak signal and combined with the dish aiming problems! Al has a calibrated Rubidium source which is used a reference for an HP signal generator. At the time of our QSO both stations were within a few kHz of where we expected to find each other. 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!

There is a maximum of +/- 70 KHz of Doppler shift at this frequency and this is easily predicted however there are significant difference in the values predicted by different programs. Mike Owen W9IP's old Real Track program seems to be within 500 Hz. With the difference in Latitude between VE4MA and W5LUA the Doppler shift between us differed by a maximum of approximately 12 kHz. Frequency setting can be confusing although it is easiest if the first receiving station corrects their transmit frequency for their echoes to fall on the echoes of the first transmitting station.

It is interesting to note that at this frequency, the rough texture of the moon's surface produces a spreading of a signal as it does on the lower bands. The effect varies with the band for example at 2.3 GHz the loss of symbols within a character can make copy of an otherwise strong signal very difficult. Progressing up to 5.7 GHz a CW signal sounds quite musical and is easy to copy with several discrete carriers being heard close together. At 10 GHz it is somewhat like Aurora on 10m or 6m. The big question was, will 24 GHz be worse than 10 GHz? The answer is no, the narrower antenna beamwidth seems to actually produce less spreading than at 10 GHz. We need more operating time to be sure that this is always true.

On August 18, 2001 W5LUA and VE4MA completed the first 24 GHz EME QSO. W5LUA had 80 Watts at the feed while VE4MA had 60 Watts. The weather was cool & clear at VE4MA, while it was cloudy, hot and humid at W5LUA.

Conclusion

It seems unlikely that moonbounce operation at 24 GHz will ever become as routine as on the lower frequencies, but now that first ever QSO has been completed many more will follow as WA7CJO and AA6IW become fully operational. The preparation work that is required for these 24 GHz QSO's will remain very high. The ability to generate RF power will restrict the possibility of 24 GHz EME to a small number of people but given the future availability of more 100 Watt TWT tubes, there will be more stations that accept the challenge. Several stations in Europe G3WDG, LX1DB, CT1DMK, OH2AUE, OK1UWA and no doubt others are capable of receiving but lack the transmitters with above 1 Watt output.

Barry Malowanchuk. VE4MA, Winnipeg, Manitoba, Canada
Barry graduated with a BSEE from the University of Manitoba in 1974. Since 1974 Barry has been with Manitoba Hydro (an electric utility) and is now the Sr. Communications Engineer. Barry was first licensed as VE4MA in 1975, and was active on 432 MHz in 1966 and on 10 GHz in 1968. Barry has been on EME since 1974, and is equipped to run EME on all bands from 432- 24 GHz. Barry has authored and presented many amateur conference papers on feedhorns, solid state and vacuum tube power and low noise amplifiers. Barry received the Central States VHF Society John Chambers Award in 2000.

Al Ward, W5LUA, Allen, Texas
Al graduated with a BSEE from the University of Illinois in 1973. He was a System/Circuit Designer at Texas Instruments from 1973 to 1987, and has been a Semiconductor Applications Engineer with Hewlett Packard and now Agilent Technologies since 1987. Al was first licensed as WA9QZE in 1965 and presently holds the Amateur Extra Class ticket. Al operates all frequencies from 1.8 MHz through 47 GHz. Al has WAS on 50, 144, 220, and 432 MHz, WAC on 1.8, 50, 144, 432, and 1296 MHz. and has worked 41 states on 1296 MHz. Al has completed EME QSO's on all bands, two meters through 24 GHz. Al was instrumental in the formation of the North Texas Microwave Society and was President of the NTMS from its formation through 1989. Al has received the Central States VHF Society John Chambers Award, and was the recipient of the 1997 Dayton Hamvention Technical Excellence Award. Al has also received the ARRL's 1999 Microwave Development Award.