24 GHZ EME - CONQUERED
47 GHZ EME – THE NEXT FRONTIER

Al Ward (W5LUA) and Barry Malowanchuk (VE4MA)

On August 18, 2001 at 14:19 UTC VE4MA and W5LUA completed the first 24 GHz Earth-Moon-Earth (EME) QSO. This paper will discuss efforts over the past several years by Barry VE4MA and Al W5LUA to make the first moonbounce contact on 24 GHz and subsequent experiments and QSOs since the initial QSO.

Moonbounce QSO's have been accomplished on all amateur bands from 28 MHz through 10368 MHz. Over the past 10 years, EME contacts on all microwave bands through 10368 MHz have been very common place and occur monthly. The next highest amateur band at 24 GHz represents an enormous technology change from the lower frequencies. Most of the standard construction techniques 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.

Figure 1 VE4MA and 2.4 Meter Dish for 24 GHz

Figure 2 W5LUA and 3 Meter Dish for 24 GHz

The following will review the challenges in more detail and highlight 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.

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 & 2.4 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 2.4 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.

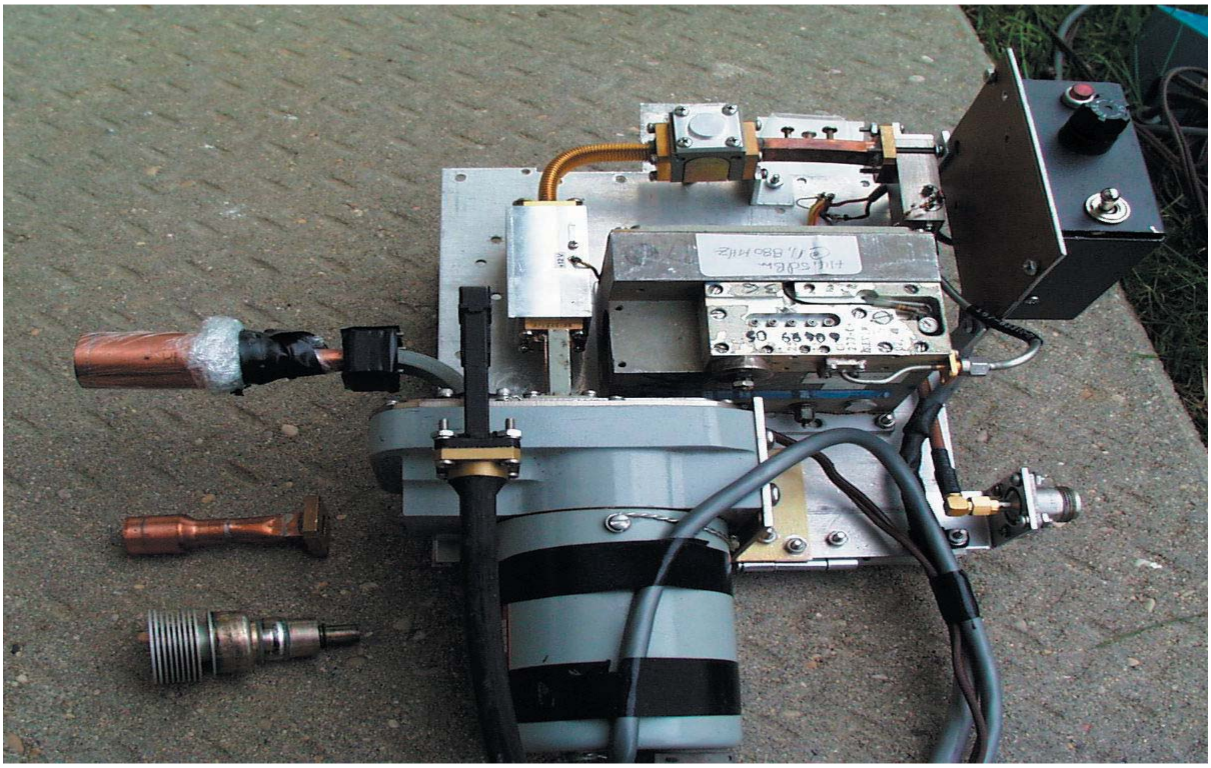


Figure 4 24 GHz Feed Assembly (Rx Converter & WG Switch) & Lower Gain W2IMU Feedhorn

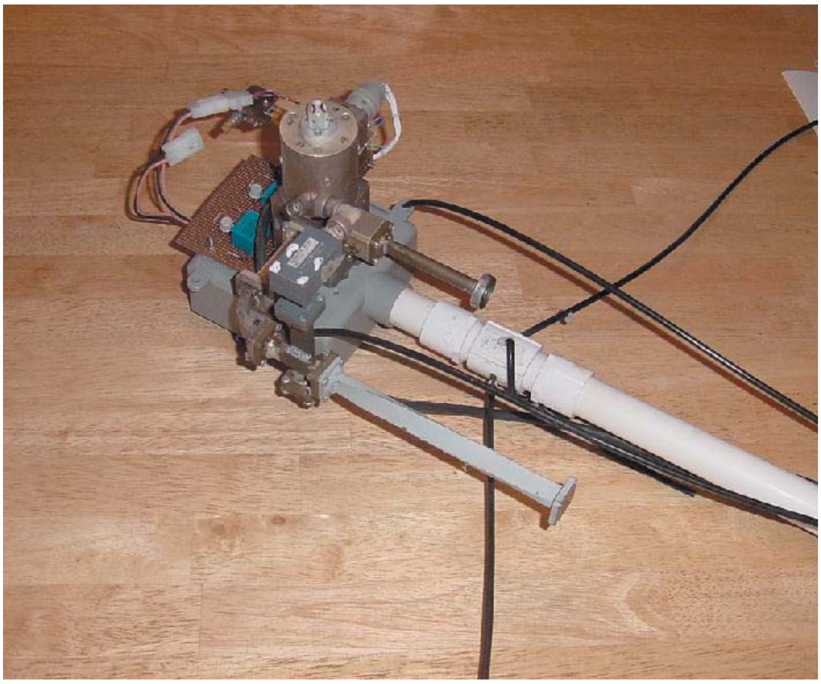
W5LUA

The antenna at W5LUA is a 3 meter Andrew 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 Figures 2 and 6.

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.

Figure 6 Waveguide Relay, LNA and Feed Assembly at W5LUA

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.

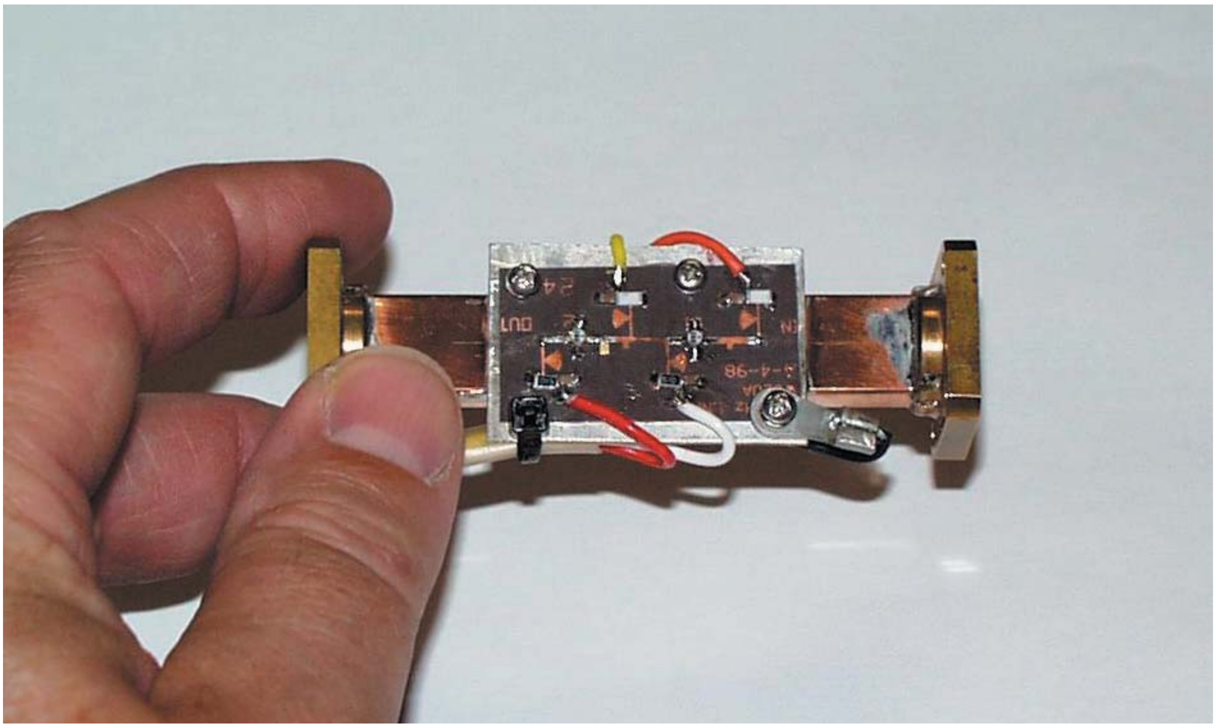


Figure 7 VE4MA 24 GHz Waveguide 2 Stage Preamplifier

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 7). This preamplifier was used with the initial tests with my 3m dish.

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. The WR-42 waveguide input also provides a convenient method of tuning for lowest noise figure with screws at the appropriate positions

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 cascaded 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 8 & 9.

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.

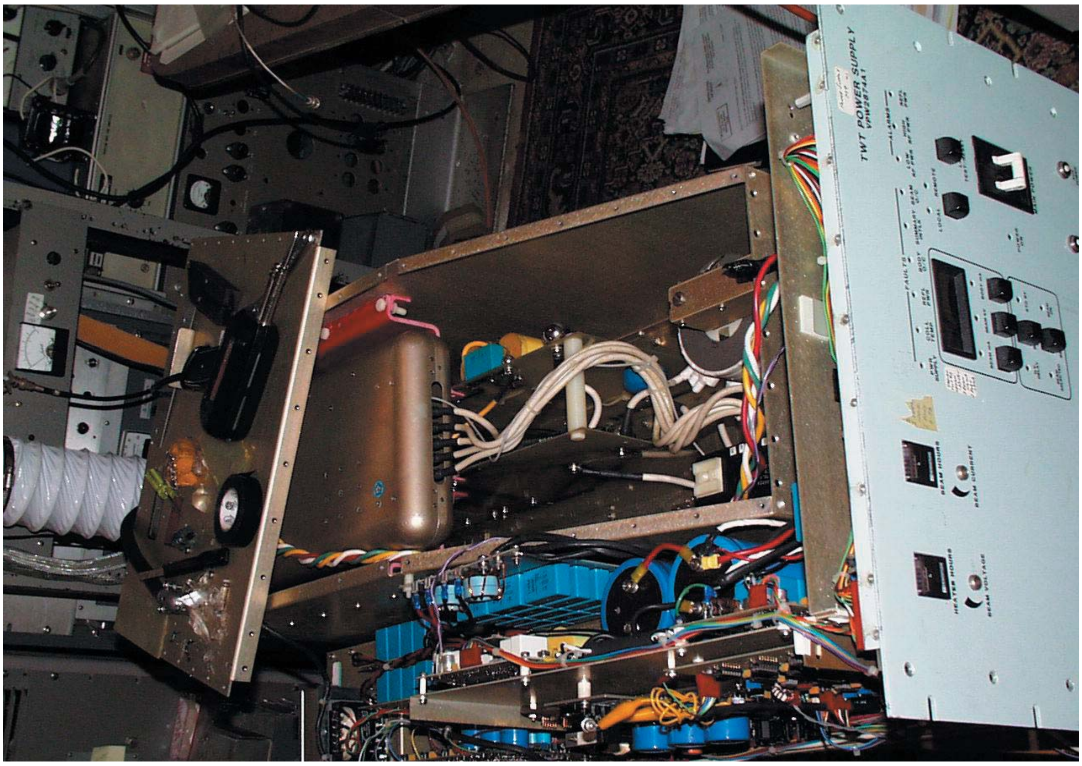


Figure 8 Varian 23 kV Switching TWT Power Supply

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 10 below. It provided 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 up to 14.7 kV. Presently, I am using an NEC LD7235A producing 110 watts output in the shack and the resultant power at the feedhorn is approximately 70 watts after a run of EW-180 waveguide.

Figure 9 Varian 100 Watt 28 GHz TWT

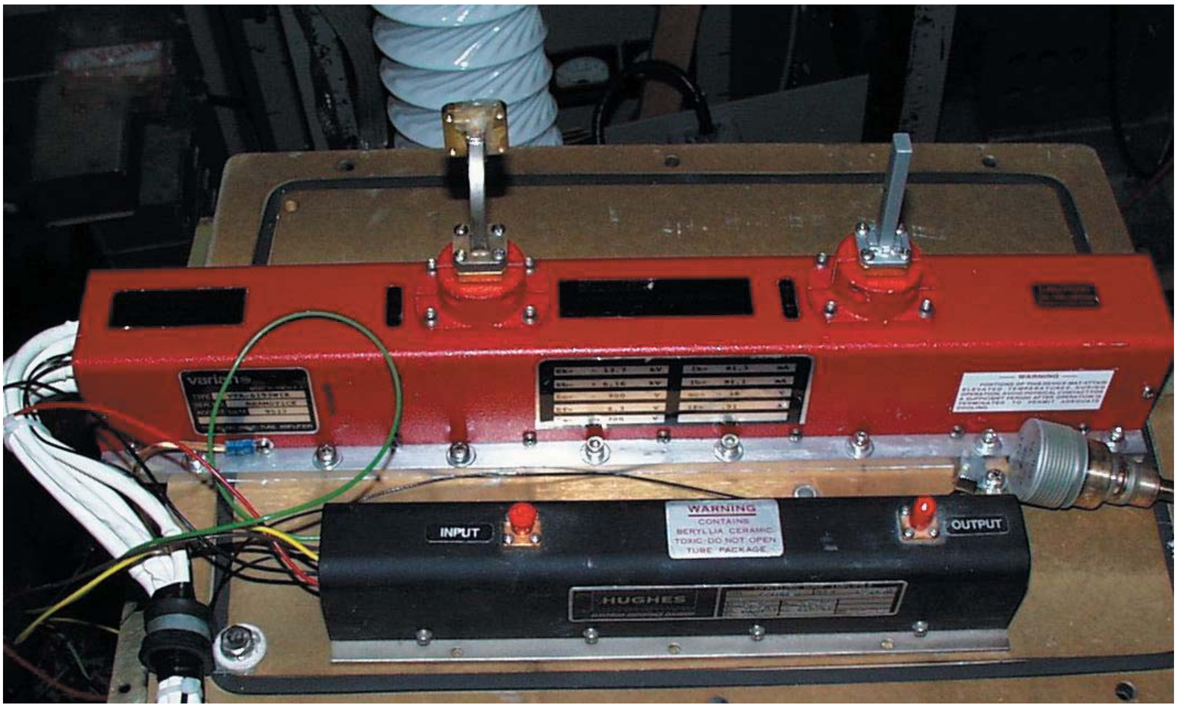


Figure 10 80 Watt 32-38 GHz Varian TWT, Hughes 10 Watt TWT & Glass 2C39 Tube

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 11. I decided to try to see if this tube could be pushed to 24 GHz. Most TWTs can

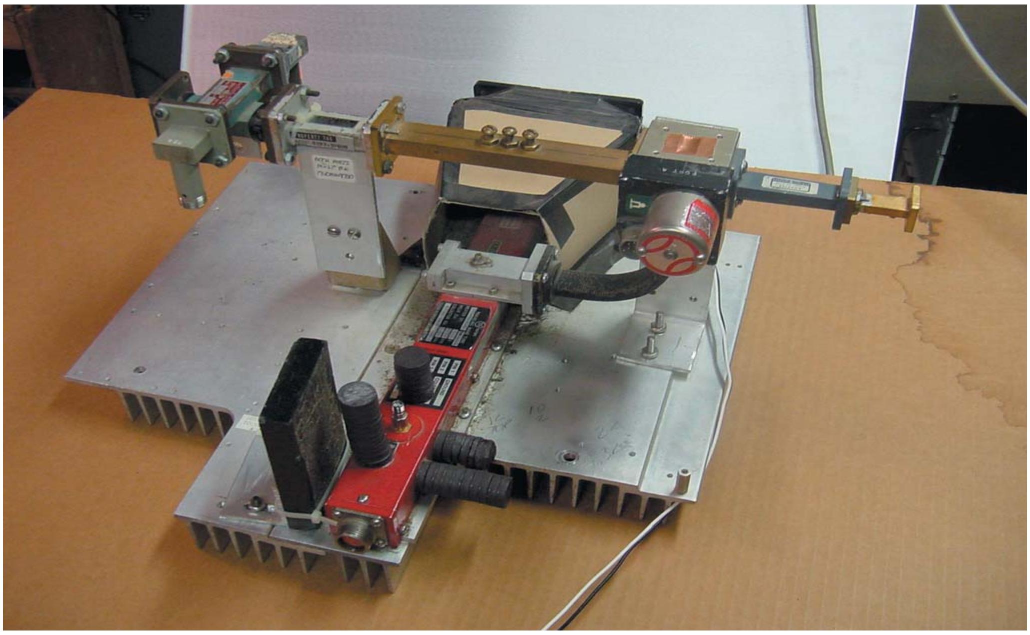


Figure 11 VTU-6191 TWT Bandswitched for 10 and 24 GHz

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. With generous use of small "refrigerator magnets" and some waveguide tuning, 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 11.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 TWT, designed for the 28 GHz band, to produce 80 watts at 24 GHz without any additional waveguide tuning. See Figure 12. 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.

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 (Figure 13) 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 for 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 07:00 in the morning, the power supply decided to act up. It took me 3 weeks of disassembly and rebuilding of this transformer to solve the problem. After consultation with WA5TKU, I realized that most switching power supply transformers consist of 2 "E" section ferrite cores and 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 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!

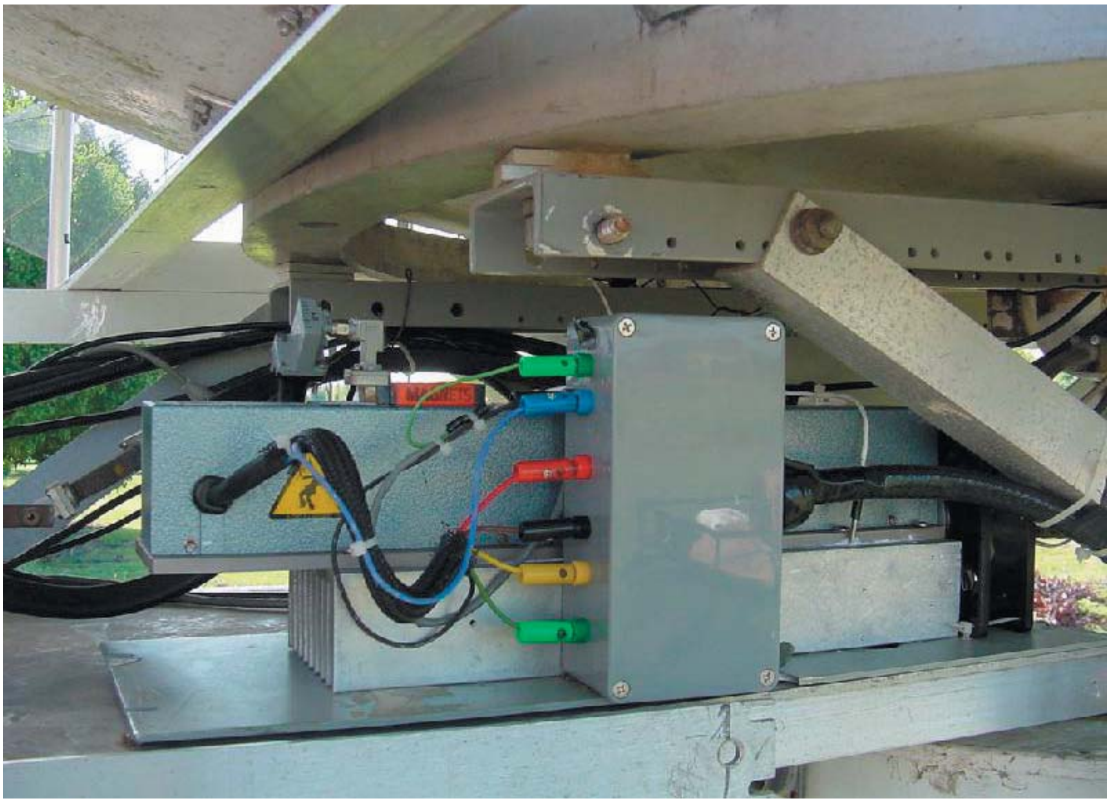


Figure 12 TH-3864C TWT Mounted Behind Dish. Note high voltage junction box and magnet

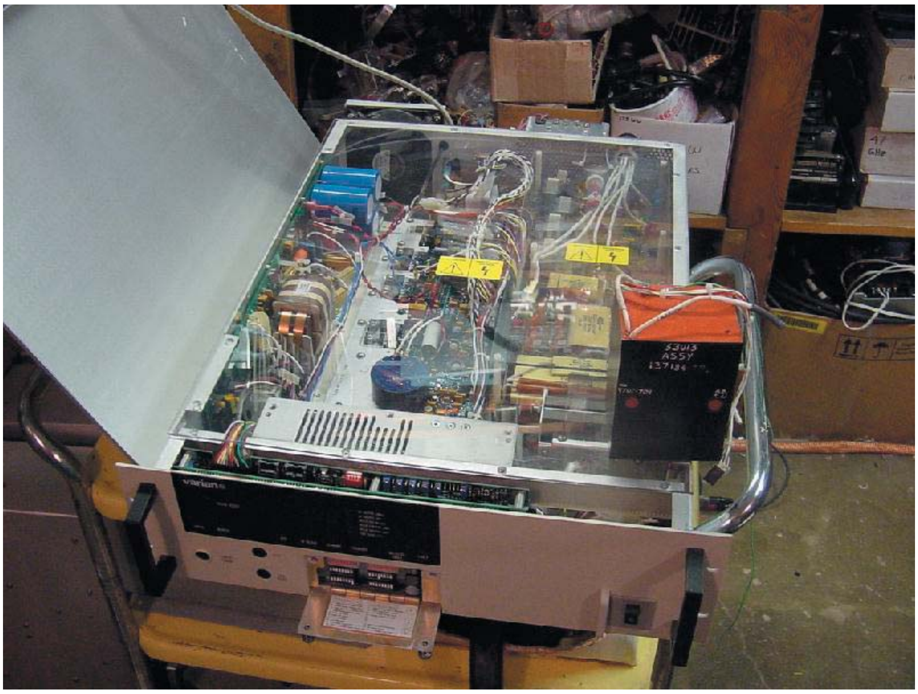


Figure 13 Varian VPW2931B2 TWT Power Supply

Initial Operating Results

First Echoes

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". System noise figure was 2.25 dB and power level at the feed was 18 watts. I was able to uses the AF9Y DSP software to get a picture representation of my first "echoes". See Figure 14. The black area represents the time period in which I was transmitting. The blue noise represents the receive passband. The white area shows the received echo, which is slowly drifting down in frequency as the moon sets in the western sky. Jim WA7CJO has also heard his echoes with 11 Watts along with some "urban legend" DL station that could not be identified

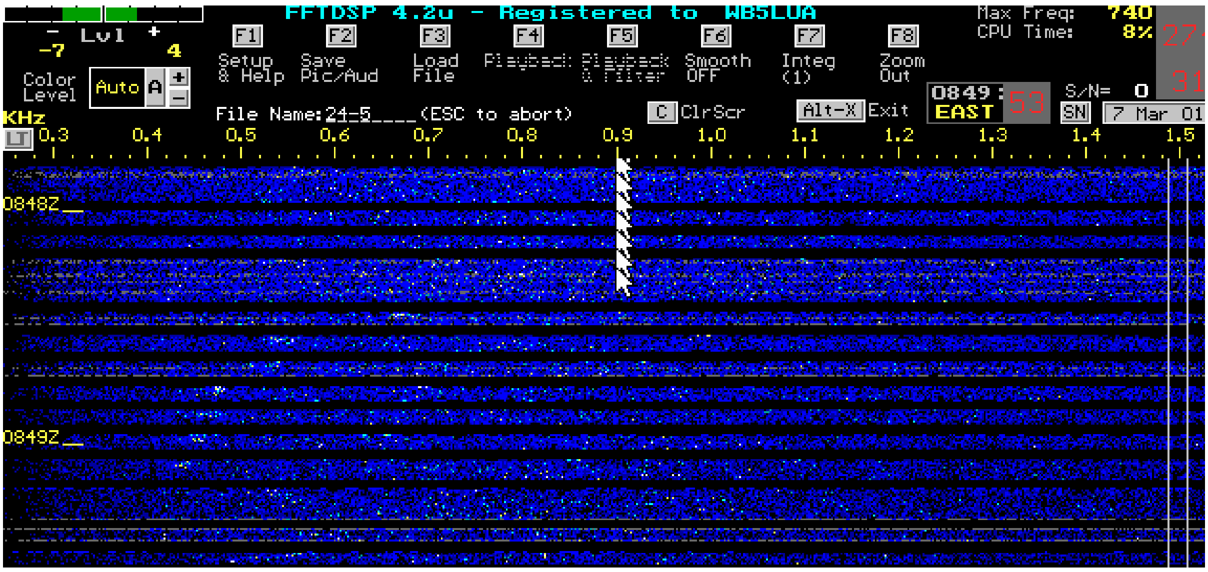


Figure 14 AF9Y DSP Software Used to Document W5LUA's First 24 GHz Lunar Echoes

Frequency Determination & Doppler Shift

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 the transmit frequency for their echoes to fall on the echoes of the first transmitting station. Keep in mind that for a 10 or 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.

The First 24 GHz EME QSO

On August 18, 2001 W5LUA and VE4MA completed the first 24 GHz EME QSO after exchanging M/M reports. W5LUA had 70 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.

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

Station Improvements

Once we got the frequency issues worked out the biggest challenge was in tracking the moon. As mentioned earlier, both have to update our antenna tracking at least every 60 seconds.

At W5LUA the original az-el positioner was manufactured by the Andrew Corporation. It was used to rotate test antennas for pattern measurements and was quite worn out. After a quick look by Gerald, K5GW, he concluded that with some rework, my original az-el positioner could be rebuilt. The heart of the original positioner was a pair of 70:1 right angle gearboxes but they were driven by some fairly high rpm 24 Volt dc motors. Needless to say the motors swung the antenna way to fast. I managed to find a pair of 5 rpm dc motors and with some sprockets and chain was able to attach the motors to the gearboxes. The resultant antenna speed was now reduced about 0.5 degree per second.

The positioner had a precision transducer for the azimuth readout, which has a 0 to 8 Volt output for 0 to 360 degrees azimuth rotation. For elevation, I use a precision 270 degree potentiometer with a 4 to 1 reduction obtained using small sprockets and plastic chain from the Berg Corporation. The output voltages from both positioners are fed to an old IBM A/D board that I installed in my old HP Vectra 486 computer. I am able to track a 0.1 degree change in both azimuth and elevation. With the new tracking system, I am able to update the dish in 0.1 degree increments while transmitting. This is quite an improvement over the original tracking system and is also quite a bit better than what I use on my 5 meter dish for the lower microwave bands.

At VE4MA the manual dish aiming method remains however a TV camera with telephoto lens is used to provide operator feedback. This avoids having to pause during the middle of a 2.5 minute transmit period to re-peak on received moon noise. The weather in Manitoba is normally very clear however in the past 6 months I have only been able to use the camera 2 times {global warming/ changing climate?).

Further Operating Experience

As tough as it was to make the first 24 GHz QSO in August of 2001, QSOs have become quite routine since then. Barry and I have made skeds just about every month since then and we have since worked each other a total of 10 times with "O" copy signals most of the time. We used this time to test improvements to our systems, encourage other stations to listen and learn more about 24 GHz EME conditions.

Reception Reports

Since our initial QSO we have been heard by G3WDG, RW3BP, VE7CLD and AA6IW. RW3BP has been hearing both Barry and I almost every time we have been on. All stations have been using dishes that range from a 2.4 m offset fed to a 4.5m prime focus unit, and are using preamplifiers of approximately 2 dB noise figure. Just as the EME experience at 10 GHz has shown, moon noise at 24 GHz limits the ultimate receiver sensitivity, so that a large dish and a "really good" preamplifier do not produce significantly better received signals. "Small" receive stations should be able to hear signals, however in order to be heard above the moon noise, the transmit ERP cannot be reduced.

In addition to the stations providing reception reports mentioned earlier, several other stations in Europe such as LX1DB, CT1DMK, OH2AUE, OK1UWA and more recently PA0EHG are capable of receiving but lack the transmitters with above 1 Watt output. Others interested in the AO-40 satellite should be able to receive 24 GHz EME signals.

Notably VE7CLD, AA6IW and WA7CJO have TWTAs capable of producing power in the 100 watt class. RW3BP has received a high power TWT and currently has it operational with a homebrew power supply! G3WDG has a tube but is awaiting the results of some TWT power supply testing that should be completed in early summer. With so many stations nearing operation many new 24 GHz QSOs are expected later this year.

Power Level Testing

Barry and I ran power level tests in January that help give some insight as to how high above threshold our signals are. For reference both Barry and I run about 70 watts at the feed. My TWT is mounted just behind the dish and Barry's TWT is located in the house and actually runs about 110 watts and with waveguide losses delivers about 70 watts as measured at the feed. We ran an hour sked and proceeded to reduce power very 15 minutes. The first 15 minutes was easy "O" copy at the 70 Watt level. The next 15 minutes was using 35 watts output. Signals were still "O" copy. The third 15 minute period was run at the 17 watt level. Signals were "M" copy and about at the same level as my echoes were in March 2001. "M" copy is about the minimum level required to hear a complete set of calls. We did not lower the power level any further. I would guess that at 10 watts at the feed, signals would be identifiable especially if one were to place their echoes on top of the stronger signal. Hunting for a 10 watt station calling CQ at 24 GHz, would be a challenge.

Signal Spreading

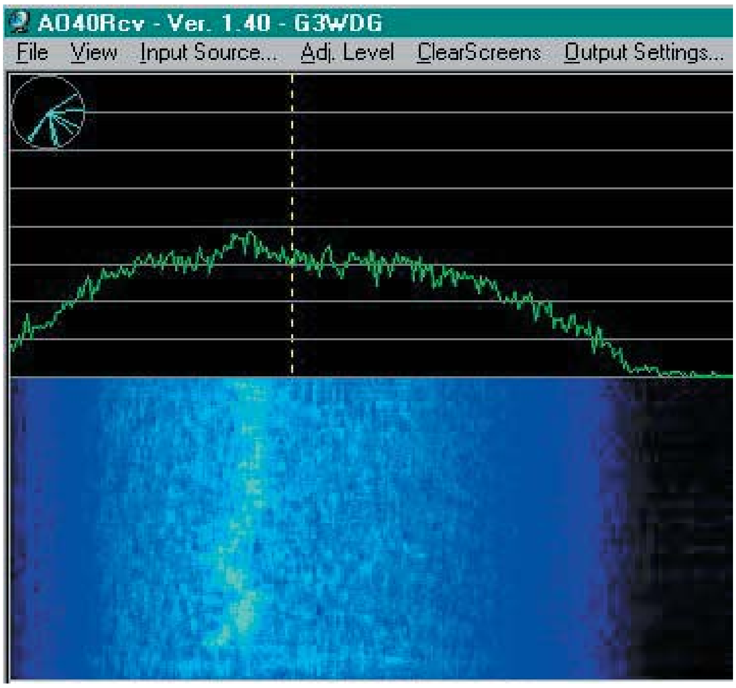


Figure 15 24 GHz EME Signal Spreading

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 being less than the subtended angle of the moon, i.e. less than 0.5 degree, seems to actually produce less spreading than at 10 GHz. The characteristic buzz always sounds like 10 GHz EME (or 2m Aurora), but is less severe. The musical notes heard on 5.7 GHz have not appeared at 24 GHz. The spreading (or smearing) of the signal is at a minimum near the horizon (when the Doppler is at a maximum) and increases to a maximum as the moon passes directly south (Doppler minimum).

To illustrate the spreading of signals please see figure 15, which is a spectrum display received from Charlie G3WDG. Clearly the CW signal shown from VE4MA is widely spread. The horizontal scale is 3.5 kHz. The moon at the time was about 30 degrees above the horizon at both ends, so that the spreading is probably about what can be normally expected. As the moon gets closer to directly south the spreading is much more severe and readability is severely affected. Conversely at moon rise/ set the spreading is at a minimum. Sergei RW3BP has observed signals with only a 7.5 degree elevation on a setting moon. At the time signals from VE4MA (moon getting close to south ~ -25 LHA) while for AA6IW the moon was very low in the Eastern sky. Sergei noted almost no spreading (a very sharp signal) from AA6IW, while VE4MA was very distorted. At this time VE4MA observed a high amount of spreading on all signals.

Effect of Seasons & Elevation Angle on System Performance

There is a large water absorption peak (resonance) in the atmosphere just below 24 GHz. The loss going through the atmosphere will thus vary with the amount of water vapor, which is related to the ambient temperature and the weather. In the colder atmosphere at VE4MA it should be expected that the water vapor level and hence absorption will be significantly less than at W5LUA (Dallas area). The absorption in the atmosphere has 2 effects, pure path attenuation and an increase in sky temperature. A receiver looking at a 4 degrees Kelvin cold sky will see a sky temperature increase from the "temperature" of the path attenuation as well as perhaps some back scattering from the warm earth.

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. The receive performance had dropped in summer due to the combined effects of increased atmospheric absorption and the rise in ambient operating temperature. Please consider that for the winter tests the ambient temperature at VE4MA was ~ –30 C vs. +25-35 C in summer! For Al W5LUA the moon noise received peaked at about 1.6 dB for only a relatively short period in February and March, before the higher temperatures and water vapor returned.

Since clouds are water vapor it would be expected that they would have a significant effect. The first reception of W5LUA by VE4MA and also the first QSO between W5LUA and VE4MA occurred through high altitude clouds at VE4MA that were thick enough to obscure visual tracking of the moon but had no apparent effect on reception. Some time earlier on the occasion of the first sun/moon noise checks at VE4MA, the tests were conducted during a hot summer day that had low and thick cloud cells producing local rain showers. As the clouds passed the moon noise was observed to be very erratic with significant drops. This weather is unusual at VE4MA but served to show the effects.

The local elevation angle of the moon was found to be very important. All stations have observed that the moon noise is reduced below about 30 degrees elevation. This is surely due to the effect of the atmosphere discussed earlier and perhaps some ground noise pickup from sidelobes of the dish. Even at lower frequencies the antenna temperatures increase with elevation angles less than 30 degrees. Considering the higher receive noise figures (system temperatures) of 24 GHz systems the increase in antenna temperature should not be a significant contributor.

More QSOs

As mentioned above several new stations were preparing for activity on 24 GHz EME. All of the work culminated in a major rush of activity in April 2002 as follows:

April 18 RW3BP QSO'd W5LUA "M/M" Initial QSO for RW3BP
April 20 RW3BP QSO'd VE4MA "O/M"
April 20 VE4MA QSO'd VE7CLD "M/M" Initial QSO for VE7CLD
April 20 RW3BP QSO'd AA6IW "M/O" Initial QSO for AA6IW
April 21 VE4MA QSO'd AA6IW "M/M"

The QSO between RW3BP and AA6IW is note worthy since the QSO ended with only 7.5 degrees of elevation at RW3BP. Atmospheric attenuation should have been higher and Sergei's receive performance degraded, but it seems that the low level of signal spreading compensated for it. This also sets a new distance record of 8392.9 km from KO85ws to CN87vi. Unfortunately W5LUA was away for April 20/21, so the May weekend should provide some great activity.

New Station Details

RW3BP

Figure 16 RW3BP 3 Meter Dish for 24 GHz

Figure 17 Water Cooled TWT at FeedPoint

Sergei RW3BP is the third station to have a successful 24 GHz QSO. He is using a 2.4 m offset fed dish, with an Alelco 100 Watt water cooled TWT mounted right at the feedpoint as shown in figure 17 . The high voltage power supply was built by Sergei using parts from X Ray machine power supplies and is remotely connected to the feedpoint mounted TWT through extension cables. A 1.6 dB noise figure DB6NT preamplifier provides consistently more than 2 dB of moon noise and 15 dB of sun noise. Sergei has copied nearly all VE4MA & W5LUA 24 GHz QSOs. Sergei uses an ingenious mechanical scheme to move the transmit and receive feedhorns into the proper position , thus eliminating the need for a waveguide switch. During transmit periods the receive feedhorn opening is covered by lossy rubber as an extra safety measure.

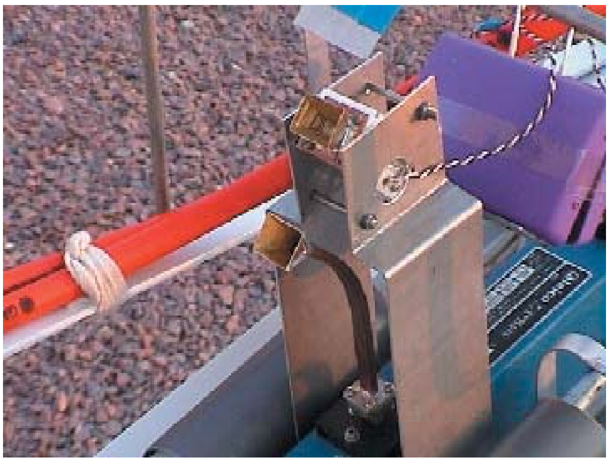


Figure 18 Mechanical TX/RX Switching at Feed

AA6IW

Lars became the fourth station to complete a 24 GHz EME QSO and is using a Prodelin 2.4 m offset fed dish similar to the one used by VE4MA. Lars has a 1.6 dB noise figure DB6NT preamplifier and a 100 Watt class Varian TWT amplifier. His dish is computer controlled and has readouts accurate to ~0.005 degrees but he has noticed tracking problems with many of the available tracking programs. Lars and Sergei have both noticed that the Doppler predictions from tracking programs have significant errors, but will require further study.

Figure 19 AA6IW 2.4 m 24 GHz Dish

Figure 20 AA6IW Feed Assembly c/w TWTA

VE7CLD

Figure 21 VE7CLD 4.5 Meter Dish for 24 GHz

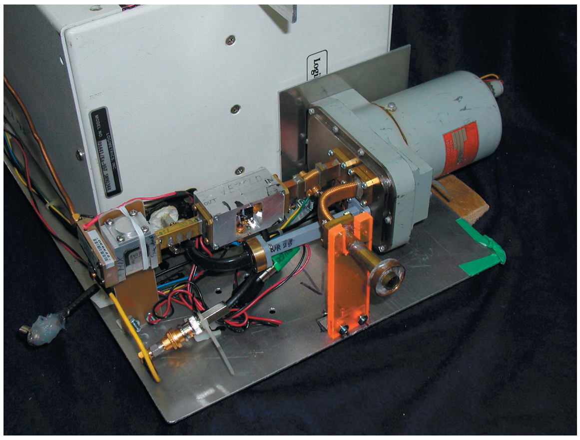


Figure 22 RX Converter & TWT at Feed Point

Gunter is using a beautiful 4.5 m prime focus Andrew dish (see figure 21) along with a home brew DB6NT preamplifier with a noise figure of 2 dB. He has a Logimetrics TWTA that is mounted at the feedpoint of his dish along with all tranverter equipment (see figure 22). He is seeing about 1.2 dB of moon noise and 12-13 dB of sun noise.

What Could Possibly Be Next? 47 GHz EME……Naturally!

As much of a challenge that 24 GHz EME was, 47 GHz is going to be exponentially tougher. At this frequency everything is more difficult to do and the availability of good test equipment and parts is limited. The creation of components for a 47 GHz EME system is virtually beyond amateur construction capabilities so the use of military/ commercial pieces is essential.

Antennas

From the EME work at 24 GHz it appears that a dish approximately 1.2 m diameter will be needed to provide similar gain (beamwidth ~0.3 degrees) . This is probably the minimum size required and finding anything larger that will provide good efficiency will be difficult. There are a lot of 1.2 m offset dishes around from commercial satellite service, and Prodelin even sells a 30 GHz rated model that should work very well. The offset dishes of course tend to be higher efficiency and facilitate mounting the electronics right at the feed without blockage.

The 2.4 m Prodelin dish at VE4MA was tested at 47 GHz and provided a little over 4 dB of sun noise however the noise figure of the receiver was poor at 9 dB. Sergei RW3BP has tested his 2.4 m dish (illuminating only 1.5m)and found 4.9 dB of sun and even 0.6 dB of moon noise using a 8 dB DSB noise figure DB6NT converter.

W0EOM and AD6FP are also working on a 47 GHz system and getting good sun noise with a relatively small 1 m precision antenna. Yet to be tested are several 1.2 m prime focus ,"plastic" and metal offset dishes at VE4MA as well as the 3m dish at W5LUA.

Receivers

At 24 GHz we have been able to achieve "state of the art" 1.6 dB noise figures with amateur construction methods. At 47 GHz the ability to build preamplifiers disappears. There has been a lot of work trying to get packaged devices to work with no apparent success. This is the region of the microwave integrated circuit chips. There are many chips available from Raytheon, Agilent, UMS, etc that are primarily designed for commercial microwave service at 40 GHz and more recently to support the next generation of fibre optic systems at 40 Gbps. These chips offer reasonably gain still at 47 GHz and certainly better noise figures than mixers (4-5 dB but the chip and wire technique for using these devices is out of the reach of most amateurs. DB6NT recently wrote an article on the use of microwave chip amplifiers on 47 GHz and good results were obtained (see the DB6NT Web page), however this is unlikely to become a standard DB6NT offering.

A big obstacle appears to be the relatively poor noise figure performance of harmonic mixers. With a 15 to 20 dB mixer NF the preamplifier gain requirements to overcome the high noise figure, represent a real barrier. Thus recent efforts at VE4MA and W5LUA have focused on reducing the mixer noise figure by using fundamental mixing. At W5LUA, the best surplus mixer found to date is the Phillips ML202938-002 up-converter. The mixer was designed for the 39 GHz market and incorporates an internal X3 LO multiplier for fundamental injection into a singly balanced mixer. Although Phillips manufactured both up and down converter mixers, both mixers are passive and therefore bilateral and can be used for both transmit and receive applications. I use a 13 GHz LO which produces a first IF in the 8 GHz frequency range. (47 – (3 X 13) = 8 GHz). Since the RF match on the mixer was optimized at 39 GHz, I used a short piece of WR-28 wave-guide and several 0-80 screws to optimize the match at 47 GHz. I was able to reduce the conversion loss from 15 to 20 dB down to something near 10 to 12 dB.

The next problem is obtaining sufficient image rejection. A high IF is thus desirable however this also results in higher conversion losses. This image problem is likely to be a further aggravated with use of "low frequency" 40 GHz amplifiers being stretched to operate at 47 GHz. The use of harmonic mixers creates a further problem with images of the 3rd / 4th harmonic products falling within the 33-50 GHz waveguide operating frequency range. Image filtering at low loss is required and few easily reproducible filter designs have existed until recently. Surplus 39 Ghz filters are often very narrow band and not easily tuned up in frequency. At W5LUA, I was fortunate enough to be given a 51 GHz diplexer by W0EOM. The diplexer consisted of 2 filters that were tuned somewhere above 50 GHz. Cutting the diplexer in half with a hack saw yielded 2 filters. My borrowed Agilent 50 GHz network analyzer could barely see activity until I was able to start walking the filters down in frequency. With a lot of work , I was able to tune both filters to 47 GHz. I measured losses at 1.5 dB for one and 2 dB for the other. The passband response was good enough that 1296 MHz IFs would be do-able. My system uses a 7920

MHz first IF but this was chosen based on where my mixer performance was optimum.

Recent advertisements in the “trade” magazines are now showing commercial preamplifiers at nearly 1 dB noise figure. Further some surplus preamplifiers are in the hands of amateurs so there may be hope for prospective EME use. Certainly a level of preamplifier noise figure performance less than 5 dB will be required for 47 GHz EME systems as the dish gains and transmitter output performance are unlikely to compare with 24 GHz values.

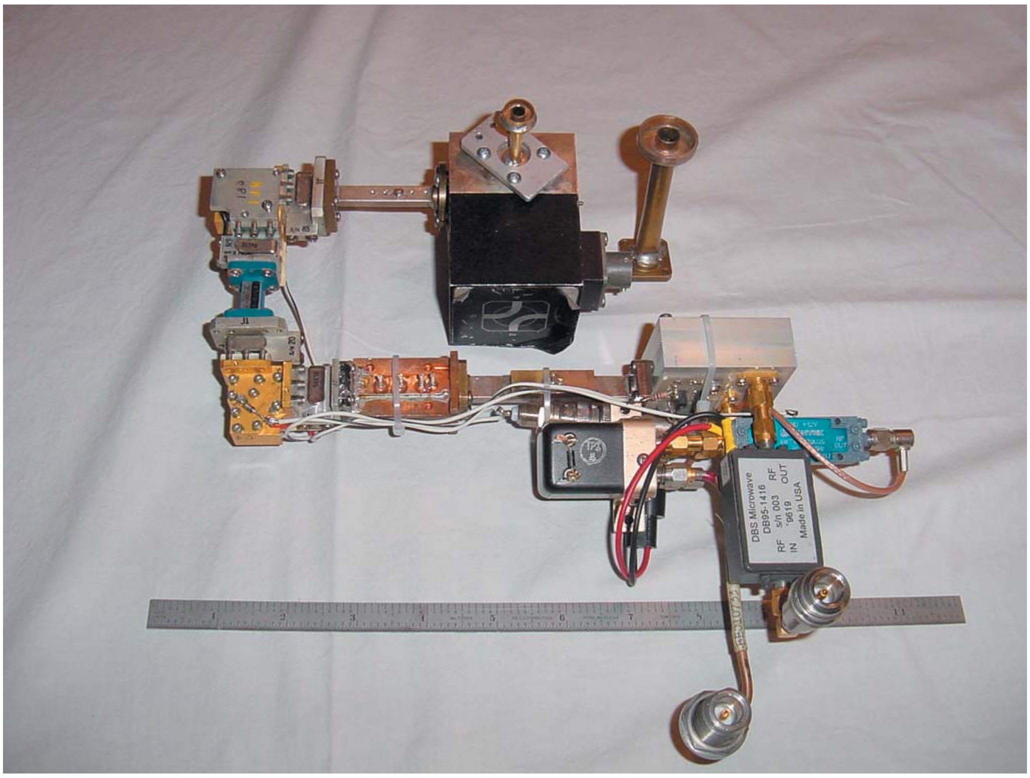


Figure 23 47 GHz Transverter and Feedhorn at W5LUA shown with 24 GHz Feedhorn for reference

The 47 GHz low level transverter at W5LUA is shown in Figure 23. The receive side uses 2 surplus LNAs ahead of the mixer/filter combination. At the fist IF of 7920 MHz, I use a 2 dB NF Avantek amplifier which is connected to a transfer relay so that the amplifier can be reversed on transmit so as to provide IF drive for the 47 GHz mixer. My feedhorn is a scaled down version of the 24 GHz scalar feedhorn. The 24 GHz feedhorn is shown for a size reference. I designed the system such that the 47 GHz feedhorn and WR-22 waveguide relay occupy the same space as just the 24 GHz feedhorn, thereby allowing an easy change between the 2 bands.

Transmitter Amplifiers

High powered TWT amplifiers for 47 GHz are very scarce, but they are made for military satellite programs at 44.5 GHz. Tubes up to 250 Watts are shown in the Thales (Thomson) catalog listings. Occasionally high power TWT tubes have been found on the surplus market. Al W5LUA has found a Hughes 932H 32 watt CW TWT (Figure 24) and Gary AD6FP has a 100 Watt unit designed for 45 GHz, which should work just fine on 47 GHz. The Hughes 932H is a dual suppressed collector type for higher efficiency but unfortunately will require a little more power supply work. VE4MA has already achieved 9 watts output on 47 GHz with his 80 Watt 32-38 GHz Varian TWT.

Based on the use of a good 1.2 m offset dish and a 4.5 dB noise figure receiver 47 GHz EME QSO’s should be possible with 25 Watts at the feedhorn, but it will not be easy. I guess if it weren’t such a challenge, then everyone would be doing it!

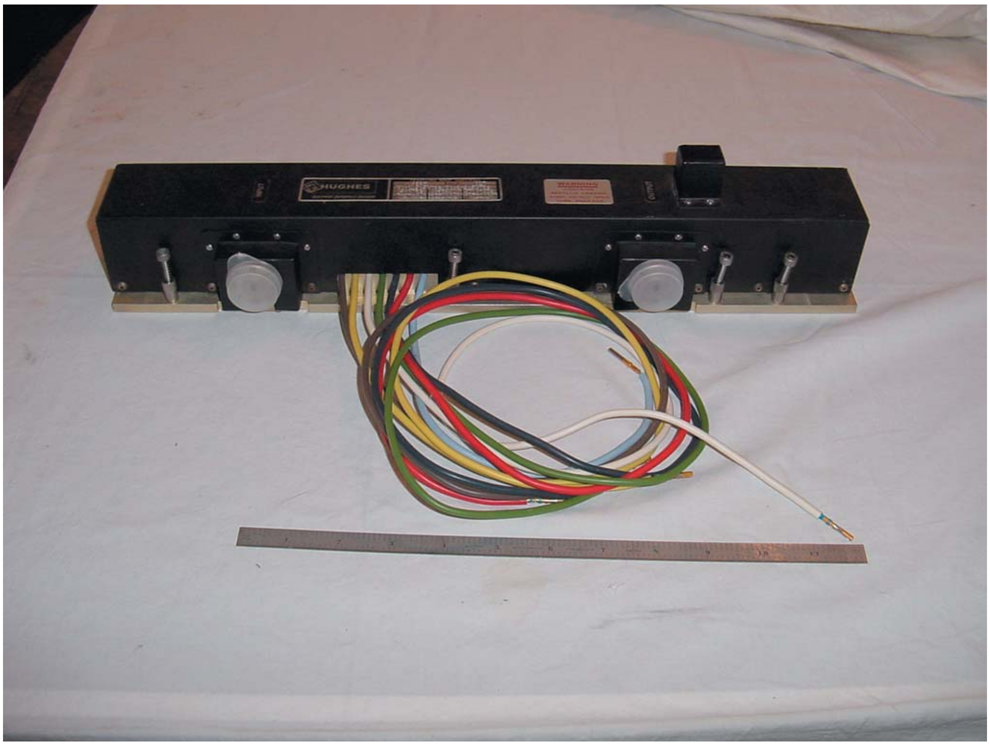


Figure 24 Hughes 932H TWT for 45 GHz

Conclusion

It seems unlikely that moonbounce operation at 24 GHz will ever become as routine as on the lower frequencies, but now that several additional stations have become operational , regular repeated QSOs will be accomplished. The preparation work that is required for these 24 GHz QSO's will remain very high. The ability to generate RF power will still restrict the possibility of 24 GHz EME to a small number of people fortunate enough to find a 100 Watt TWT tube. Hopefully more big TWTs will be found and there will be more stations that accept the challenge.

73 de VE4MA and W5LUA May 8, 2002

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 WN9QZE 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 is currently the President of the NTMS. 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.