The Challenges of 24 GHz EME

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EME communication on all of the microwave bands is at an all-time high. The 24 GHz band is finding increased activity from many 3 cm amateurs looking for the next challenge. The availability of very low noise amplifiers and improved higher efficiency feeds and even solid state power have all contributed to increased interest and growth in 24 GHz EME.

This paper will talk about some of the history of 24 GHz EME, stations operational, equipment, techniques and the challenges that lay ahead.

History

The first 24 GHz EME contact took place on August 18th, 2001 between W5LUA and VE4MA. This was the result of several years of hard but very rewarding work. Finding the right parabolic reflector and feeding the dish properly was the first chore. Building the transverter was accomplished by collecting and optimizing various surplus and commercial components. Each piece of the puzzle provided its own set of challenges. We built our own LNAs using available devices, and through the generosity of Paul W2PED we were able to produce the missing link, the TWT. Details of this project have been documented in *QST* [1, 2].

By 2008, several other stations became operational including RW3BP, AA6IW, VE7CLD, OK1UWA, LX1DB, G4NNS, DK7LJ, DF1OI, OK1KIR, PA0EHG and DL7YC [3].

Recently there has been renewed interest in 24 GHz EME with several new stations being added to the list. Included are F2CT, OZ1FF, RK3WWF, IK2RTI, F1PYR from Europe, and JA6CZD – the first Asian to make a 24 GHz EME QSO. Congrats!

Frequency Allocations

The 1.25 cm amateur radio band in the USA extends from 24,000 MHz to 24,250 MHz. The original EME activity occurred on 24192.1 MHz plus or minus as this was the center of terrestrial operation in the US and Canada. Early on, European stations that became operational followed suit at 24192 MHz. In the last 5 years or so there has been a push to migrate all EME operation to 24048.1 MHz as this is a primary allocation in Europe and also where their weak signal work takes place. Not wanting to have another split band like we have on 13 cm and for some time on 9cm, the small number of North American stations on 1.25 cm EME have since migrated to 24048.1 MHz.

Antennas

Most solid reflector antennas that are used on 10 GHz have a good chance of working to some degree on 24 GHz. My first 24 GHz EME antenna shown in Figure 1 was an Andrew 3.0 m prime focus dish that was designed to work to 30 GHz with the proper back structure. I ultimately had to add a back structure that was capable of fine tuning the shape of the reflector. It was a relatively deep dish with an F/d of 0.3. I fed the dish with a VE4MA style feed with a single scalar ring. LX1DB is also using a 3 m prime focus dish with excellent results.

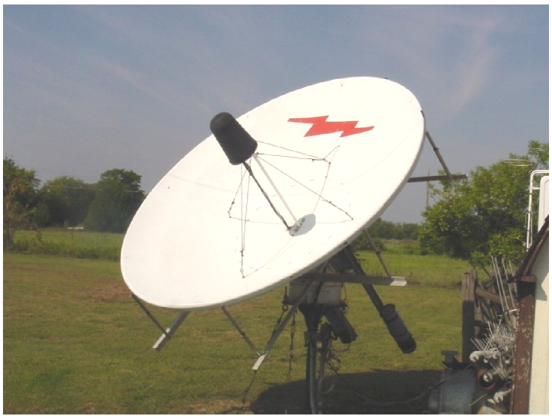

Figure 1: 3.0 m prime focus dish at W5LUA

Figure 2: 2.4 m offset fed dish at W5LUA

I have since acquired a 2.4 m offset fed dish (Figure 2) which I had initially been using for making a 47 GHz EME QSO. The dish is fiberglass and I had applied aluminum foil in an attempt to make the surface smoother at 47 GHz. I am now using this 2.4 m offset fed dish on 24 GHz and feeding it with a W2IMU style feed with a 1.8 λ diameter opening. I am also experimenting with a small flare on the horn and have been seeing at least a half dB improvement in sun noise.

Transverters and LNAs

The original approach at W5LUA made use of surplus DMC components from 23 GHz commercial systems, some of which are shown in Figure 3. Shown are an LO, an up-converter, a down-converter and a power amplifier. The down-converter was designed to be used with a 1500 MHz IF while the up-converter had a 310 MHz IF. The amplifier in the up-converter was used by itself and has about 6 to 8 dB gain and puts out +18 dBm. The power amplifier has a little more gain and puts out similar power.

Figure 3: Surplus 23 GHz DMC modules

The first LO was a DMC-110366 which is a synthesized microwave source. Some time ago, both Brian Yee KD6LI and Rex Allers KK6MK published information on setting these units up for amateur use. It was a nice source but since it had two internal reference oscillators, it did have some drift. With Bryan's help it was set up at 21888 MHz to generate a 2304 MHz IF. The higher IF also allowed surplus filters to be retuned for 24 GHz and still obtain adequate image rejection and LO rejection.

Since the DMC LO had two outputs, I decided to use two mixers, one for transmit and one for receive. Having separate mixers means that one could be optimized for power and the other for low noise. I had a surplus MACOM mixer with 3.5 mm connectors that worked very well. I was also pleasantly surprised that some Avantek and WJ 18 GHz mixers worked at 24 GHz. Conversion loss may have been 12 dB, but they still convert!

I used a conventional 2304 MHz transverter to further down convert to 2 m and ultimately 10 m. Early on I used a Drake R7 for my receiver and also used the 10 m output to drive a GR 1216 or GR 1236 IF amplifier. The GR IF amplifiers are basically a high gain IF strip that drives a large analog meter for measuring Sun and Moon noise. I might also add that being able to constantly measure Moon noise while receiving is an excellent way to stay on the Moon. Don't let any lack of auto-tracking keep you from simply using Moon noise to track. The first 30 years of my EME career was spent in manual tracking, even when I made my first 47 GHz EME QSO. If a GR-1216 or 1236 is not available, DF1OI suggests a Moon noise meter designed by S57UUU [4]. It has options of 1dB or 10 dB steps with 0.05 dB accuracy.

Being a home brewer at heart, I decided to design and build my own LNAs. I patterned my first EME LNAs after ones that I produced in 1997 for the ATF-36077 [5]. This particular article also discusses a 12 to 24 GHz multiplier using the ATF-36077 and a 24 GHz converter using an HSMS-8202 SOT-23 plastic packaged mixer. The best noise figure that I could do at the time when Barry and I made our first QSO on 24 GHz was about 2.25 dB but I was very proud of that attempt. After all, some of my first homebrew 24 GHz LNAs had a smashing noise figure of 6 dB and similar gain!

Once we decided to migrate to 24048 MHz, I decided to redesign my transverter. The new transverter converts directly to 2 m and takes advantage of more recently acquired surplus components. Several varieties of available modules are shown in Figure 4. More on these later.

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Figure 4: Various 23 GHz Modules

Most notable are the 24 GHz WR-42 diplexers sold on the surplus market by "Pyro-Joe". The diplexer is manufactured by BSC Filters with a part number of 1028871-0001 A. The diplexer is actually a 3-port dual filter device designed to allow received signals through on one port and the transmitted signal on the other port. One port of the filter is designed to pass 24.25 to 24.45 GHz and the other is designed to pass 25.05 to 25.25 GHz. The filter as-is will just pass 24192 MHz through the low frequency port and it can be easily re-tuned to 24048 MHz. That filter gave more than 30 dB of image rejection, but because I was going to be driving a high gain TWT I chose to cascade an additional filter to reduce the LO leakage and improve the image rejection. With these new filters, it was possible to convert directly from 24048 MHz down to 144 MHz.

Having a lower IF allowed me to use a down-converter similar to the one shown in the upper right-hand corner in Figure 4. It is a simple diode mixer with an IF amplifier. I was also able to use the mixer in the DMC up-converter shown in Figure 3 to convert from 144 MHz to 24 GHz, and then run through an external filter and back into the amplifier stage.

I decided to use a Frequency West local oscillator at 11952 MHz with a 99.6 MHz reference which was GPS locked in the shack. I then used a surplus x2 multiplier similar to the one shown in the lower left-hand corner in Figure 4 to provide my 23904 MHz LO. The revised 24048 MHz transverter is shown in Figure 5. Noise figure is a nominal 5 dB which makes it a nice second stage for the 1.6 dB noise figure LNA mounted right at the feed. Power output of the transverter is +17 dBm which is adequate to drive my TWT.

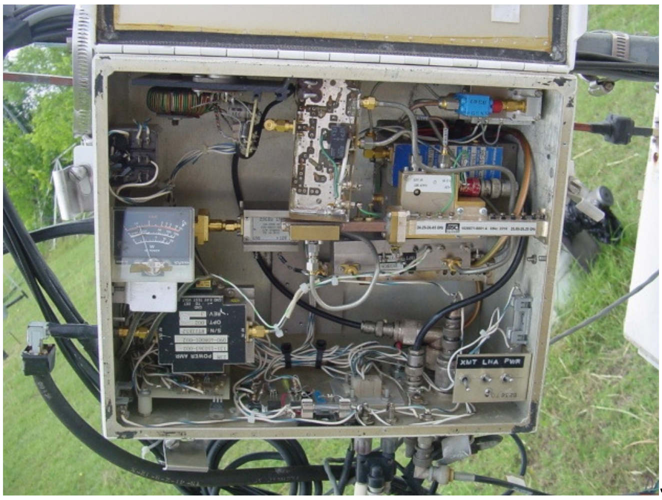

Figure 5: 24048 MHz transverter

Another approach to building a 24 GHz transverter is to use the P-COM up-converting and down-converting modules. One such module is shown in the upper left-hand corner of Figure 4. The RF port is WR-42 and the LO port is SMA and incorporates an internal x2 multiplier for the LO. Although they are designed for around a 2.8 GHz IF, they work well with a 2304 or a 3456 MHz IF. I reported on my results on several of these units at a previous Microwave Update conference [6]. The up-converters can provide up to +18 dBm of power while some of the down-converters have a SSB noise figure of 3 dB. However they do require filtering to reject the image and 2x LO.

Commercially, DB6NT provide some nice modules for 24 GHz including transverters and power amplifiers. DB6NT also has one of the lowest noise figure LNAs available. I am presently using one of Michael's LNAs with a 1.6 dB noise figure. Another option are the 24 GHz modules that Paul Drexler W2PED has designed and is making available [7, 8].

Generating Power

Most of us are using Travelling Wave Tubes to generate power. I use a Thomson TH-3864 mounted on the support arm of the offset fed dish (Figure 2). These tubes were originally designed for 28 to 30 GHz and most of them have WR-28 flanges. The tubes run a nominal 12 kV helix voltage with a suppressed collector. I use a Varian power supply in the shack with a 30 m length high voltage extension cord (7 conductors) running underground to the dish. I did some tuning with magnets as shown in Figure 6 and I measure 100 W at the feed.

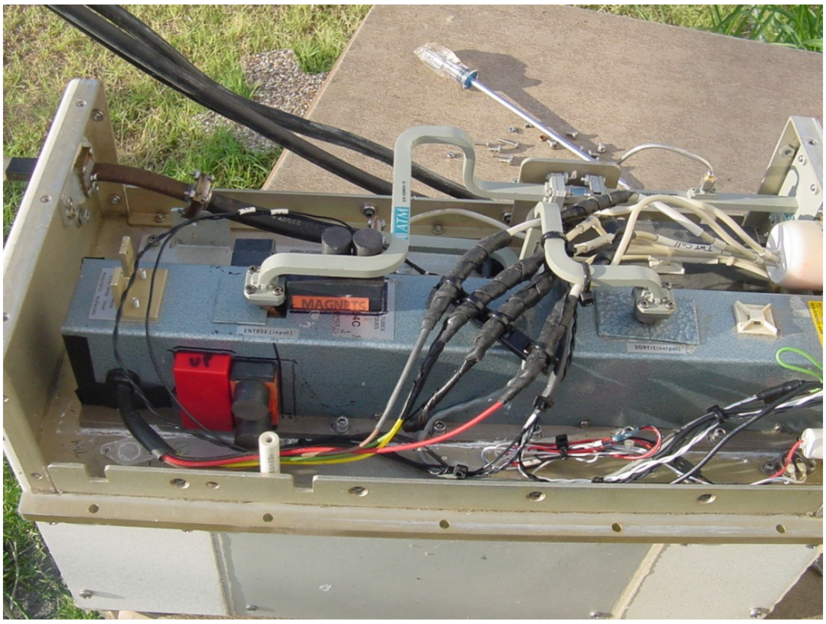

Figure 6: Tuning a TH-3864 TWT with magnets

Other stations including G4NNS and DF1OI use modified 12 GHz Siemens TWTs such as the RW1127 to generate between 25 and 40 W of power. Willi LX1DB generates 42 W of solid state power by combining two modules at the feed.

Some Additional Challenges

Now the biggest thrill is making QSOs. Most of the scheduling and coordination takes place on the HB9Q logger. This is a fine tool to help with coordination and finding out if your rig works. You will find a fine group of technical folks there to help you and to send test signals.

In this section, I will discuss some additional topics that create their own challenges including Doppler shift, spatial offset and moisture absorption.

Doppler shifts, self and mutual Doppler

Doppler shift scales proportionally with frequency and at 24 GHz it can be greater than 60 kHz! Since the relative angular velocity of the Earth is faster than the orbit of the Moon, the Doppler is at a maximum at both moonrise (positive) and moonset (negative) and passes through zero around zenith. There is also a slight 'hook' effect where the shift can reverse right after moonrise and before moonset.

Random operation is pretty straightforward. You simply 'net' your own echoes on the frequency of the station calling CQ. Even if your station is not big enough to hear your own echoes, you still know from the tracking software where your echoes would be if you could hear them. If multiple stations are calling, then each station will have its own 'Self Doppler' offset based on its geographical location.

When running a schedule, we need to take great care to transmit and listen on the right frequencies, because the Self Doppler frequencies can differ appreciably between stations at opposite ends of a long E–W path. So when running a schedule, we look for each other on the 'Mutual Doppler' frequency which is the arithmetic mean of the two individual stations' Self Doppler frequencies.

For example, if Station A is in Europe and has a Self Doppler frequency of –30 kHz, while Station B in North America has a Self Doppler of +38 kHz, then the calculated Mutual Doppler offset is (+38 – –30)/2 = +4 kHz. If both stations transmit precisely on the agreed schedule frequency of 24048,100 kHz, and then each station should listen for other on 24048,104 kHz. This makes it easy to find the station that you are scheduling – but only if both stations are transmitting precisely on the schedule frequency. Most if not all 24 GHz and above operators have their LOs GPS locked, so frequency accuracy is not a major issue. What you *don't* want to do is to correct your transmit frequency based on the Mutual Doppler, because every time you change your transmit frequency, it makes it double hard for the other station to find you!

Spatial offset

Spatial offset refers to rotation of a linearly polarized signal as it is sent to the Moon and reflected back to Earth at a different spot on earth. It has been shown that there is virtually no Faraday rotation at frequencies above 902 MHz, so the only polarization shift between operators in different areas of the world is due to spatial offset. That problem has been resolved on the 23, 13 and 9 cm bands by the use of circular polarized feeds. On the 9 cm band most of us have migrated to circular polarization, but on 3 cm the movement to circular polarization has been slower. Stations that are still running linear polarization include myself.

Fortunately with the placement of the continents and the major areas of EME activity on Earth, there is close to a 90° spatial offset between North America and most of Europe. The early accepted protocol for 3 cm EME has been for North America to be horizontally polarized and Europe to be vertically polarized. This convention has also been used on 24 and 47 GHz. Recently OK1KIR made the first ever EME QSO on 24 GHz with JA6CZD (congrats also to the OK1KIR team!) and the offset was nearly 90°. The theoretical loss due to spatial offset is $20 \log_{10}(\cos \theta)$ where θ is the spatial offset in degrees. A 20° polarization mismatch equates to a 0.5 dB loss of signal while a 45° offset has a 3 dB penalty. This might suggest having a way to fine tune the polarization. The station at W5LUA has only an option of a 90° twist, but I may have to put in a 30° twist to work JA6CZD based on our nominal 60° spatial offset. Paying attention to this detail when making schedules can be important.

Moisture absorption

The biggest detriment to 24 GHz propagation is being near to the 23 GHz absorption line of atmospheric water vapor. An increase in moisture absorption will show up as degradation in system sensitivity. To get a rough idea of the degradation, I generally make note of my 50 Ω to cold sky ratio in dB. I simply actuate the waveguide relay and put a 50 Ω termination on the LNA and measure the dB difference with my GR-1236 IF amplifier. (The ideal measurement would be to look at the ratio of ground to cold sky but I can not aim my antenna below about 10°.) A typical number for 50 Ω termination to cold sky for my station would be about 3.4 dB. When atmospheric moisture is present, you hear some thermal noise from the relatively warm water vapor so this ratio will get worse. If you make the measurement in pouring rain at 24 GHz, you will find that the sky temperature is close to ground temperature or 290K, not a good time to run 24 GHz. In Texas during the summer months, it is rare to get dew points below about 23°C (74°F) and hence my 50 Ω to cold sky can be less than 3 dB which indicates almost a half dB of degradation. Hence the best time for us here is in the middle of winter when dew points are significantly lower.

I generally get the quietest sky at elevation angles greater than 45°. At lower angles, one is cutting through more of the earth's atmosphere and absorption increases. Using VK3UM's *Atmosphere* program version 1.18, you can evaluate the effect of moisture absorption on both terrestrial and EME or slant paths. Using nominal default values for the basic parameters for a pair of antennas aimed at an elevation angle of 45°, the additional absorption due to water absorption amounts to about 1 dB. When one station is looking at a 20° elevation angle the moisture absorption increases an additional 1.1 dB. Decreasing the elevation angle down to 5 degrees, loss increases an additional 3.2 dB. Having the ability to switch in a 50 Ω termination in place of the antenna allows you to make a quick determination of this additional loss at sked time.

Summary

The 24 GHz band is a very challenging but rewarding EME experience. Come join us.

References

1. A Ward W5LUA and B Malowanchuk VE4MA, ‘The Journey to EME on 24 GHz, Part 1’, *QST*, October 2002, pp 28-32
2. A Ward W5LUA and B Malowanchuk VE4MA, ‘The Journey to EME on 24 GHz, Part 2’, *QST*, November 2002, pp 43-47
3. B Malowanchuk VE4MA and A Ward W5LUA, ‘Update of 24, 47 & 77 GHz EME Activity’, Proceedings of Microwave Update 2008, pp 262-274
4. http://lea.hamradio.si/~s57uuu/eme/noistrk.htm
5. A Ward W5LUA, ‘Inexpensive Components for 24 GHz’, Proceedings of Microwave Update 1998, pp 246-256
6. A Ward W5LUA, ‘Using Surplus 23 GHz Modules at 24192 MHz’, Proceedings of Microwave Update 2000, pp 27-35
7. P Drexler W2PED, ‘A x4 Subharmonic Mixer for 24 GHz’, Proceedings of Microwave Update 2008, pp 275-289
8. P Drexler W2PED, ‘A 6 GHz Synthesized Local Oscillator for the W2PED 24 GHz Subharmonic Mixer’, Proceedings of Microwave Update 2009, pp 70-77.