A Short Primer on Getting Started on 13 cm EME
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This short primer will hopefully provide some insight into Earth-Moon-Earth (EME) operation on the 13 cm band. I have included numerous references and web links that should help provide additional information and guidance as you begin your journey up in frequency. I covered Microwave EME in an earlier paper [1]. This paper will deal more specifically with the 13 cm band.

Introduction

The most popular "microwave" EME band is certainly 1296 MHz or the 23 cm band which it is commonly called amongst EMEers. Over 300 stations have been operational over the past 30 years or so and during a typical contest, upwards of 100 stations have been worked in a single weekend. The mode of choice on 1296 MHz is CW but there is still considerable active using the WSJT mode. With the new rigs that have 1296 capability and newer LO schemes that are phase locked, frequency drift in WSJT signals is becoming less of an issue. What is even more interesting is that most small stations on the microwave bands don't have to resort to CW to make contacts. The entry level station on 1296 MHz EME might consist of a 3 meter (10ft) TVRO type dish and several hundred watts of power. Feedhorn designs and LNA designs have matured to the point where echoes are easily heard and communication between two 3 meter dishes is common place.

So the big question is what's next after 1296 MHz? The next band up is the 13cm band which offers a multitude of challenges and some nice benefits as well. The most significant advantage is that if we have the same system noise performance and the same power at the feed of our 3 meter dish, the echoes on 2304 MHz will be nearly 5 dB stronger than on 1296. This is due to the narrower beamwidth on the higher frequency resulting in higher gain to more than offset the additional path loss even though the antenna aperture is the same. This can be easily shown using VK3UM's EME Planner http://www.ve1alq.com/vk3um/
. In reality, we can nearly achieve the same noise figure on 2304 MHz or at least within a tenth of a dB, If we were running a pair of 2C39s or a GS-15b on 1296 MHz running 200 watts at the feed, we can easily achieve the same power level on 2304 MHz with a solid state PA that can also be more easily remote mounted than a tube amplifier. As further evidence to support this theory, with my 5 meter dish, most of the time, my echoes on 2304 MHz are little better than my echoes on 1296. My equivalent power at the feed is about 750 watts on 1296 MHz and about 300 watts on 2304 MHz.

Most of the upper microwave bands are classified more by their wavelength than their frequency. Even though we always talk about going to 2304 MHz when we are chasing a terrestrial signal up the bands, it is not that simple when we are trying to communicate internationally on some of our microwave bands. Fortunately on 144 MHz, 432 MHz, and 1296 MHz, everyone worldwide has frequency allocations in the same parts of the band. In the

United States, our 13cm allocation is split in to two bands, one covering 2300 to 2310 MHz and one covering 2390 to 2450 MHz. 2310 to 2390 MHz was taken back up by the government to be used by our XM and Sirius satellite radio that a lot of us enjoy amongst other services. All weak signal work in the US resides down at 2304 MHz. In Europe, the terrestrial operating frequency has been nominally at 2320 MHz so a good number of countries must also operate EME at 2320 MHz. To further complicate the worldwide issue, Japanese amateurs operate at 2424 MHz and if that is not enough, VKs can not operate above 2302 MHz. But not all is lost. There are solutions that are in use to make 13 cm a real top notch EME band none the less. We will discuss these "equipment" issues later in this paper.

Antennas

A 3 meter TVRO dish makes a nice entry level EME antenna for any band from 902 MHz through 3456 MHz. The same TVRO dish is designed to run efficiently through 4.2 GHz so operation at both 2304 and 3456 MHz should be very do-able. The only limitation is decreased beamwidth as frequency is increased. Doubling the frequency will half the 3 dB beamwidth. Therefore our 3 meter or 10 ft TVRO dish with a 3 dB beamwidth of about 5.6 degrees will scale to about 3.1 degrees at 2304 MHz. The first null between the main lobe and the first side lobe appears at about 4 degrees off the main lobe. What this means is that we probably need a "real" rotator to turn this antenna so we know where it is aimed. The Ham-M type rotor with its 4 or 5 degree breaking increment just won't cut it. On top of that the indicator is almost worthless for being even remotely accurate. So what is the solution? The best solution is a gear box and motor arrangement. I use an old "prop pitch" rotor which does a nice job of turning large dishes. A good solution is the Yaesu G-2800DXA rotor which has a friction break instead of the Ham-M and Tailtwister break wedges. Although the Yaesu rotors have a 5 degree increment on the readout, the pot driving it appears to be more linear than the pot in the Ham-M. A good solution for a digital readout for rotors that have potentiometers that produce a linear voltage with increased beam heading is a nice solution by Dave Robinson, WW2R. Dave describes a nice digital readout circuit with 1 degree resolution http://g4fre.com/rotator.htm. Although some digital readout schemes read out in only 1 degree increments, this is still better than 5 degree increments and guessing in between.

My first choice would still be to go a scheme where I know within a 0.1 degree where I am pointed. As you wonder up the bands, this will become more obvious as antenna beamwidths decrease.. I use US Digital absolute encoders which give me 0.1 degree readouts with K5GW's software. http://www.usdigital.com/. I use the US Digital model A2-S-S for azimuth and the A2T-S inclinometer for elevation. The absolute encoders can also be read by F1EHN's program. See VE1ALQ's website for an abundance of EME related information including a link to F1EHN. http://www.ve1alq.com/f1ehn/. A less expensive approach is the use of US Digital's incremental encoders and one of W2DRZ's controller boards. See Tom's website for more details. http://www.w2drz.ramcoinc.com/ K1RQG has been using one of Tom's systems for several years now and it has worked very well according to Joe.

Another approach to indicating elevation is the use of one of the drafting or builder's levels on the market. One such device is the "smart level" sold by Sears and probably others. Tony Emanuele WA8RJF did a modification of one and wrote it up for a MUD proceedings [2]. The level is capable of 0.1 degree readout. Calibrating it to an exact known elevation would be a mechanical adjustment of the level as there is no ability to electrically zero the level.

Now that we have a good handle on aiming our dish, how do we confirm that we are pointed where we think it is pointed? The best way to start is to calibrate on the sun. How much should we expect? If all is working well, a 3 meter dish should provide 10 to 11 dB of sun noise on 2304 MHz when the solar flux is in the low 70s. Although any receiver can be used to determine a peak on sun noise, the best solution may appear to be a little old fashion but it is still the best approach and is in use by many. The GR 1236 or 1216 I-F amplifier is a broad band IF amplifier with a large analog meter that can readily measure noise accurately in dB. The standard IF amplifier is tuned for 30 MHz but it can be easily retuned for 28 MHz. I also use my Flex-Radio SDR-1000 www.flex-radio.com to measure sun and moon noise and others use the SDR-IQ software defined radio in the continuum mode http://www.rfspace.com/SDR-IQ.html. On the microwave bands, the reference for the peak in sun noise is usually cold sky. Although there are some spots in the sky that are quieter than other, I usually just offset my dish 10 or 20 degrees from the sun to establish a local noise minima. As an added measure of performance, I always install a relay in series between the feedhorn and LNA so that the LNA can be switched into 50 ohms. This serves two purposes. The first is to provide added protection for the LNA on transmit and secondly to provide a means to establish a noise ratio in dB of a 50 ohm termination with respect to cold sky. Having a switch to periodically put the LNA into 50 ohms during normal operation provides a means to determine if the system is still working by providing a known reference.

Another advantage of moving up in frequency is that it is easier to measure moon noise with a 3 meter dish on 2304 MHz than on 1296 MHz. Since the subtended angle of the moon which is roughly 0.5 degree is becoming a smaller portion of the beamwidth, we can now begin to easily see moon noise. A typical 2304 EME setup with a 3 meter dish can achieve up to several tenths of a dB of moon noise which is easily discernable on the GR meter. Being able to determine a peak is an ideal way to insure that our dish is tracking the moon. Moon noise on 1296 MHz with a similar size setup may be incapable to determine a usable amount of moon noise.

Faraday Rotation

If you have ever operated EME on 6M, 2M, or 432 MHz then you understand the consequences of Faraday rotation. Simply put, at low frequency a linear polarized signal can go through several rotations as the signal exits our atmosphere, bounces off the moon and then re-enters the earth's atmosphere. Therefore if one is running linear polarity such as a horizontally polarized yagi array on 2M, if the signal comes back cross polarized or vertical, then most likely you will not hear your echoes. If the offset is only 45 degrees, then the echoes will only be down 3 dB or so. The period of the faraday rotation varies with frequency and is about 5 minutes on 6M and 15 to 20 minutes on 432 MHz. This means that on these bands you may see a signal pop up out of the noise very 5 minutes on 6M and 15 minutes on 2M. On 432 MHz, the period of rotation is even slower and at some times, a station or ones echoes can be locked out for hours making QSOs quite a challenge unless one has the ability to rotate or switch polarity. One might then conclude that faraday rotation lockout may be even worse on 1296 MHz but in reality even at 902 MHz, there is very little faraday rotation. I use horizontal linear polarization on 902 MHz and as long as I am pointed at the moon, my echoes will also be there. The same will be true on 1296 MHz but the bigger problem is that of the spatial offset between 2 stations. This is a minor concern on 902 MHz considering that the only stations operational at the moment are in North America.

However when you analyze the difference between a station in North America and Europe one finds about a 90 degree spatial offset due to the difference in longitude between the two continents. A similar offset occurs when going west to Asia. The solution to the faraday issue on the lower bands and the spatial offset is the use of circular polarization. The established convention has been to use left hand circular polarity (LHCP) on receive and right hand circular polarity (RHCP) on transmit. 99.9% of all stations active on 1296, 2304, 3400 and 5760 MHz EME use this convention. On 10368 MHz, the migration to circular is slower and I am one of those that is slow to convert for no particular reason other than the time to build a new feed. We used linear polarity on 24 and 47 GHz just for simplicity and the fewer number of stations active on these bands. When using linear polarity, we just have to adjust the feed polarization to offset the spatial offset.

Feedhorns

The feedhorn is a very important part of the system. For a dish to attain its expected efficiency, the dish must be properly illuminated. An excellent on-line antenna book has been written by Paul Wade W1GHz. http://www.w1ghz.org/. In his book, he analyzes the predicted efficiency of various feedhorns vs dish F/D. Both he and Tommy WD5AGO have authored some really nice papers on building various feeds for different F/D ratio dishes. F/D is the ratio of the focal length to the dish diameter. Therefore the same feedhorn that illuminates a 24 ft dish with an F/D of 0.5 will also illuminate a 12 ft dish with the same F/D. The typical TVRO dish as an F/D in the range of 0.35 to 0.375. This is easily illuminated with the popular VE4MA type feed. The also popular W2IMU feed is generally used for higher F/D in the 0.5 to 0.6 range. Circular polarity can be achieved in several different ways but the most popular is either the polarizer screw approach or the more recent septum polarizer approach. Numerous articles by various authors have been written describing the advantages of each design. [3],[4],[5],[6],[7]

Amplifiers

VE4MA has done significant work in the past with generating 13cm power with the 2C39B family and others. Fortunately solid state power has recently become available thanks to the availability of higher power solid state devices at 2 GHz. The most notable is the Spectrian amplifier. This commercial grade amplifier that is capable of 200 watts in amateur service was designed as a highly linear amplifier at much lower power levels. As a result, the weak link in a lot of these amplifier is quite often the etch used in the output combiner and the isolator. If you are going to run a continuous duty mode like WSJT, then I would suggest a lower power level like 150 watts or less. The modifications of the Spectrian amplifier are documented by Steve N5AC [8]. Having done one of these conversions myself, I can say that the modifications are pretty straightforward. Just to be on the safe side, one might want to keep the 36A circuit breaker in the 24V line until you have decided the full capabilities of this amplifier and have all your drive levels set properly. One of the nice things about the solid state PA is that it can be mounted out near the feed to minimize feedline loss on transmit.

The 13 cm Cross Band Issue

Let’s now go back and take a look at the different frequency allocations around the world. .I use my terrestrial transverter for 2304 MHz. My IF is the Flex-radio SDR-1000. I either use the split VFO mode or XIT to take into account Doppler shift which can be up to +/- 5 kHz at 2304 MHz. The typical 2304 MHz terrestrial setup will work just fine. With 2304, you will work all of North America and quite a few different European countries. ZS6AXT has also been active on 2304 MHz to represent

Africa. Now what is required to work the remaining Europeans is a receive converter for 2320 MHz. It is possible that your present 2304 xvtr will also pass 2320 MHz through the RF front end. This implies that if 2304 MHz is down-converted to 144 MHz with a 2160 MHz LO, then 2320 MHz will be down-converted to 160 MHz. Several of the multimode VHF/UHF rigs out there like the Yaesu FT-847 and FT-100D will tune 160 MHz.

The accepted practice to working stations at 2320 MHz is then to look for stations that are 16 MHz higher in frequency than where you are on 2304 MHz. In other words, if you are calling "CQ up" on 2304.080 MHz then the European station knows that he should transmit on 2320.080 MHz after adjusting for his Doppler. After a while the technique becomes second nature.

Most OSCAR Mode S down-converters can be re-crystaled to receive the JAs at 2424 MHz. A similar procedure is used to work JAs on crossband.

Since the VKs can not transmit above 2302 MHz, they decided to use 2301.975 MHz as their nominal EME frequency. The standard procedure is then for the VKs to look for stations in the US on 2304.075 MHz and Europeans on 2320.075 MHz. Since US can transmit on 2301.975 MHz, I have on occasion re-tuned my Klystron to work the VKs but re-tuning is not my first choice. Stations using the Spectrian amplifier should be able to operate just fine down at 2301 MHz. As you can see, there are a few allocation challenges but they are all quite do-able today.

Low Noise Amplifiers

A good stable low noise amplifier (LNA) is one of the most important components in any EME system. Because of the low sky temperatures afforded to us at the microwave frequencies, a tenth of a dB decrease in noise figure can provide many tenths of dBs improvement in system sensitivity. Without question, the LNA must be placed as close as possible to the feedhorn. This also applies that the isolation relay and its associated cables and adapters must have very low loss. In addition to being low noise, a reasonable amount of gain (maybe 25 to 30dB) is required to overcome the sum total of the noise figure of the transverter or transceiver in the shack plus the coax connecting the LNA. WD5AGO and myself have spent considerable time designing and optimizing LNA designs over the years [9],[10]. For 13 cm EME shoot for as low a noise figure as possible, i.e. something less than 0.4 dB. Tommy WD5AGO manufacturers completely built and test LNAs and Sam G4DDK manufacturers kits [11] both of which have worked very well on 13 cm EME.

Coordination

As it turns out, most of the 13 cm operators are also operational on 23cm. Considering the greater number of operators on 23cm, most random activity on 13cm will occur during the major operating events of the year. Two of the major organizations that sponsor EME contests are the ARRL and DUBUS magazine. The next major event which is sponsored by the ARRL occurs every fall. The weekends of October10-11 and December 5-6 are reserved for 50 MHz through 1296 MHz and the weekend of Nov-7-8 has been reserved for 2.3 GHz and higher. More details are available at http://www.arrl.org/contests/rules/2009/eme.html. The DUBUS EME contests occur in the spring. Additional information can be found at http://www.dubus.org/.

In between contests, activity is coordinated either via HF, newsletter, or the internet. The 432 MHz and Above EME NET meets at 1500Z on both Saturday and Sunday on 14.345 MHz. The NET control is Joe, K1RQG who has been our NET control for well over 25 years. Joe also coordinates skeds with DXpeditions that occur quite often throughout the year. There is also a group of VHFers that meet on 3.846 MHz nightly after about 0000Z during the summer months. We also have a monthly newsletter called the 432 MHz and Above newsletter published by our long time editor Al K2UYH. Each month , the newsletter is available for download at http://www.nitehawk.com/rasmit/em70cm.html thanks to Rein PA0ZN.

The HB9Q loggers also provide a good way to stay in touch with fellow operators. They are available at http://hb9q.ch/joomla/index.php. Dan has set up individual chat pages for the various bands. One is dedicated to 2304 MHz and above and is used to coordinate both CW and digital activity.

Summary

I hope to see you on 13 cm some day. Although it does provide some challenges, the results can be very rewarding. Nearly 100 stations have been active on 13cm EME since Paul Wilson W4HHK worked W3GKP for the first 2304 MHz EME contact in 1970. In addition all continents and many countries have been activated. Come join in on the fun!

73 de W5LUA June 15, 2009

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