Some thoughts on very small dish 10GHz EME

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Small dish 10GHz EME is now a reality, bringing opportunites for intercontinental DX on 3cm to relatively modest stations. Microwave EME is no longer just the province of those with significant technical or financial resources.

So what do I mean by modest? For the purpose of this note, I'm exploring the practicalities of making EME contacts with a typical 10W, 1m dish station using contemporary modulation schemes, particularly JT4 and JT65. Although I've been active on 10GHz 'off-the-Moon' quite successfully in the past on CW (and have been able to reliably copy my SSB echoes ...) with 50W and a good 2.4m offset dish, I'm likely to use a smaller system for a while after my planned move, both while I develop a better mount/positioner for my 'big' dish to make operation on the higher frequency bands practicable, and to acclimatise my new neighbours to the presence of antennas ... A ground-mounted 1m dish also seems to fit into the Welsh planner's (and presumably those of other parts of the UK) ideas of 'permitted development'.

It would be good to encourage other people to involve themselves in similar projects. For far too long, EME has been seen as an activity which only the most technically gifted or affluent radio amateurs could indulge in. It isn't. EME is just another propagation mechanism which anyone who has built a good 10GHz system can use.

These notes aren't a rigorous analysis; see (1, 2) for a more detailed treatments of the 'interesting' aspects of 10GHz EME. These notes are being written to share some of my thoughts, to get people thinking, and hopefully, to persuade them into doing something: it's not a complete handholding 'how-to' guide, though.

Path Losses

The EME path at 10GHz is pretty well understood. At 10GHz, the path loss at perigee (when the Earth and Moon are at their closest) between isotropic antennas, is about 288dB, so discounting signal spreading effects, with a 1m dish (~38dBi) on receive and transmit, and 10W (+40dBm) at the feed, the received signal power expected at the antenna feed in an echo test would be:

$$Prx = P(tx) + Ga(tx) - L(p) + Ga(rx)$$

$$= 40 + 38 - 288 + 38$$

$$= -172\text{dBm}$$

This is a small signal by any standard, but what receive sensitivity can we achieve? I'll assume a 2.5kHz bandwidth, as that fits-in with the WSJT EME reporting scheme.

A receiver with a noise figure of 1dB (which is relatively easily achievable at 10GHz) equates with a noise temperature of ~75K. To that we need to add the noise temperature of the dish, which for a properly fed satellite TV dish will be about 30K, the losses due to T/R switching (20K) and the noise stemming from thermal radiation from the Moon, which for a 1m antenna can be estimated as about 10K. Add these all together, and the overall receiver noise temperature can be estimated as 135K.

$$Pn = kTB$$

where: k = Boltzmann's constant (1.38e-23)
T = noise temperature (T)
B = bandwidth (Hz)

$$= 1.38\ 10e\text{-}23 \cdot 135 \cdot 2500$$

$$= 4.66\ 10e\text{-}18\text{W}$$

= -173.3 dBw

= -143.3dBm

The difference between the received signal level and the receiver noise floor gives a signal level, in the WSJT reporting format, of -28.7dB, tantalisingly close to, if not at, the levels at which decodes are possible in the absence of libration induced spectral spreading. If the system can be improved by a better receive noise figure, say 0.7dB, and the switching losses effectively eliminated by using a waveguide switch, the signal level will improve by nearly 2dB, making 1m-to-1m dish EME QSOs between 10W stations possible, if the path geometry is right.

As a sanity check, I've compared my calculations against results from the VK3UM EME planner (3), and they pretty much concur.

It seems certain that a reasonably optimised 1m dish/10W station could detect its own echoes, and make a fair number of initial QSOs with larger stations via EME on 10GHz. With some planning and luck, it should be possible to work another 1m/10W system.

Getting On

Many EME projects have failed due to an excess of ambition: starting small with equipment you are already comfortable with is much more likely to produce results than an attempt to put a big system on the air from a standing start.

One of the reasons for the growth of EME activity on 144MHz in recent years is that the coming of the JT modulation schemes has made initial EME QSOs possible for stations with what would have previously have been seen as modest tropo/MS capability. With a few EME contacts in the log, it's amazing to see the way in which stations seem to develop! The same can be true of 10GHz.

Steering the dish.

So, what's the catch? I guess that the most difficult part of the process for most people is finding and tracking the moon with microwave antenna beamwidths. Unless you have a willing slave who is willing to sit by the dish and to track the Moon by hand, you'll need some form of electro-mechanical help.

With a big dish, Moon noise provides a useful way of confirming that the antenna is pointing in the right direction. But even with a very good receiver the cold sky/Moon noise that you'll see with a 1m antenna will be small, perhaps 0.5dB. In practice, it becomes rather important to get the tracking right. Fortunately, a 1m dish has a 1dB beamwidth of about ±1° which implies a required pointing accuracy of maybe 0.5°. With care, it's not too difficult to track the Moon by dead-reckoning.

The EME mainstream tends to use azimuth - elevation tracking, largely because big commercial dishes tend to be made that way, and I'll be going down that route with my new system for just that reason. However, there's an advantage, if you need, or want, to build something from scratch, to using a polar mount (4). G3LTF has used a polar mount (also known as an equatorial mount) for his 50 years of moonbouncing. By far the majority of astronomical telescopes and motorised satellite TVRO dishes are mounted that way. One of the chief advantages of that approach is that it's only really necessary to drive the Right Ascension axis continuously. The slow changes to the Declination setting (<2°/day for the Moon) can easily be made manually. The disadvantage is that it's not really possible to use the mount for terrestrial communications – unless you live at one of the poles!

The use of a polar mount can save a lot of computation. Figures for Right Ascension and Declination of the Moon are given in any ephemeris, including that of WSJT, and classically the Nautical Almanac (aka 'The Naughty Book' to those who were taught astronavigation by the same Ancient Mariner as 'dgu.)

Adapting a computer controlled telescope mount such as those sold by Optical Vision (5) would probably work, but I'm not sure how well they would survive with even a 1m dish as a load.

Luckily, the satellite television industry has probably come to our rescue by providing low-cost hardware for a small dish polar mount. Dish motors, such as the 'Icecrypt Satellite Motor', available from CPC (6) for £38 (+VAT), or its heavier-duty cousins from specialist satellite suppliers (7), should make a usable basis for a polar mount. It's possible to hack the DiSEqC control system, (didn't Sam,G4DDK, go into that a few years ago?) but that's possibly a bit of overkill. The positioner seems to use a simple DC motor. An alternative might be to buy a low-cost DiSEqC controller (8) and hack it. It wouldn't be difficult to design a PWM controller to move the dish at ~ 15degrees/hour. The 'satellite motors' seem to use some form of turns counting on the motor to provide positional feedback, but I haven't yet investigated further. For years, astronomical telescopes, with very much smaller beamwidths than my 2.4m dish at 24GHz, were successfully tracked open-loop without angular feedback: a simple DC motor and a rheostat determining the rate. The existence of a high-powered amateur EME beacon (DL0SHF, 10.368.025 MHz+/- doppler) also simplifies things a little.

The System

Many current 'tropo' systems have adequate performance to exploit WSJT effectively for 10GHz EME. Very good frequency stability and accuracy are needed. This probably means locking to a GPS-steered oscillator or a Rb source, but isn't that pretty standard now? Software exists to control transceiver tuning dynamically, eliminating the need to chase the doppler shift, however some people have successfully tracked JT signals on 10GHz manually. Coaxial relays are likely to introduce significant losses in microwave EME systems, so a waveguide based antenna switch, feed, and preamp start to make a lot of sense. Choose a preamp design where the input match is performed in the waveguide, and not like one well known commercial design, where a microstripline amplifier simply sits between a pair of MS-WG transitions and masquerades as a 'waveguide preamp'! Small losses ahead of the preamp can make surprisingly big inroads into overall receiver sensitivity with a small dish, as the background noise temperature with a small dish forms only a small part of the overall receiver noise temperature. As the Moon begins to fill the antenna beamwidth, its thermal radiation at ~210K reduces the need for a very low noise temperature.

Moon noise makes a good metric for receiver system performance. I finally managed to achieve about 1.8dB with my 2.4m dish (where, as the Moon filled about a quarter of the solid angle of the beamwidth, the Moon noise component was about 50K) and my old coax-based front-end. I've seen claims of >2dB from a similar dish. My own projection of what could be achieved with a fully optimised system, based on losses and errors I knew I could eliminate, was about 2.3dB.

A major problem is making the measurement, particularly when the Moon noise is only about 0.5dB above system noise. I use an old 'total power receiver', built in the 1980s as part of a noise figure measuring system. This is basically a broadband noise receiver operating at about 30MHz, consisting of a strip of tuned dual-gate mosfet amplifiers, with a square-law detector which looks at the output of a downconverter from my 432MHz IF. The TPRx integrates the Moon noise over 1MHz, and the detected signal is then passed through a low-pass filter with a bandwidth of about 100Hz, resulting in a good, flicker-free indication on a high-quality analogue meter.

If I didn't have the old TPRx, I'd almost certainly take the approach used by Martin, G8FEK, in his commercial noise measuring kit, (9) and linearly downconvert the noise to baseband where it can be measured by a true-RMS detector or suitable software in a PC. Some modern SDR receivers, such as the SDR-IQ running under Spectravue also have a noise measurement, sometimes called a 'continuum' mode. There are also 'proper' instruments, such as some power meters and spectrum analysers, which can also be used, although that requires some care.

Sun noise – which is probably more familiar - is not altogether reliable, unless you factor-in the solar flux at the time of the measurement, and even then it can be misleading.

Doppler

You and your QSO partner and the Moon are in constant relative motion. So doppler shift is inevitable. In order to counter this it's necessary to compensate. This (just!) can be done by hand, but it's not too difficult to calculate the frequency offsets to a few Hz, and use that information to tune your receiver. Software to do this for a number of common transceivers exists courtesy of VK1XX (10).

Dish Feeds

To get good performance from a small dish, you need to think carefully about the feed. Its pattern needs to be matched to the dish f/D ratio: if the feed has too wide a pattern, the dish will be 'overilluminated' and significant energy will be collected (reflected or dissipated) beyond from the dish surface. On receive, in particular, this will mean that part of the energy entering the feed will be at local ambient temperature, and will be lead to an excess noise temperature. If the feed has too narrow a pattern, the whole reflecting area of the dish will not be used effectively, and gain will suffer. This is inevitably a compromise: usually the solution chosen is to select (or to design) a feed which will have a response around 10dB down at the dish edges, and is why many feedhorn designs are specified at their -10dB beamwidth. It's easier, and more efficient to feed a large f/D dish than a deeper dish with a small f/D: hence the widespread use of offset dishes with f/D ~ 0.7 for satellite TV reception.

Don't confuse the feedhorn design with other features, such as a means of establishing circular polarisation. As an example the so-called 'septum feed' is effectively a piece of open waveguide, and is only a useful feed for deeper dishes. It's worth a careful read of the online W1GHZ microwave antenna book (11). While simple pyramidal horns are fine for tropo, the noise temperature of the horn-dish system will probably be a bit high. For standard TV offset dishes with f/D ~ 0.7 effective feeds include the designs of W2IMU. Some versions of the latter, when made with plumbing fittings may not work properly. I used the W2IMU 1.8WL aperture dual-mode horn on my 0.8 f/D, 2.4m dish quite effectively, before moving-on to a Skobelev-based feed: another form of dual-mode structure. You should also look at the designs of RA3AQ who has taken Skobelev's work further.

If you are using waveguide at 10GHz, you're not forced to use WG16/WR90! That stems from the days of easy availability of surplus components for 9GHz radar, and from military projects. Nowadays WG17/WR75 from 12/14GHz earth station systems seems to be more available from various surplus sources. While it has very slightly larger losses at 10.4GHz (due to operation closer to its cut-off wavelength) it is entirely usable. It's also smaller and lighter than WG16!

Polarisation

Unlike the lower-frequency microwave bands, the vast majority of active 10GHz operators use linear polarisation. In order to circumvent spatial polarisation changes, European stations use local vertical polarisation, North Americans, horizontal, and antipodeans, vertical. As there is some spread of polarisation due to the way in which signals are reflected from the Moon, small differences in linear polarisation result in very small differences in received signal. I suggest that, at least initially, any new 10GHz EME system employs that convention. Of the relatively small proportion of stations currently using CP on 10GHz, most have sufficient reserves of system performance to work small linearly polarised stations.

CP has been a 'hot topic' amongst 10GHz EME'ers for well over a decade! If you read the classic W2IMU EME notes, he has details of a CP antenna for 10GHz. There are a number of reasons why CP hasn't really caught-on at 10GHz, apart from inertia. One of the chief of these has been that, until relatively recently, good, reproducible, recipes for achieving circularity without introducing too much loss have been few and far between. Another reason is simply that the current linear polarisation protocol works very well indeed.

PAs

I used a Mikom 10W SSPA, which now forms part of my tropo system, to make my first CW EME QSOs on 3cm with my 'big' dish.

10GHz power amplifiers are very expensive - if you buy, or even make, modern SSPAs. However, surplus TWTAs still turn-up, but seem to be ignored by many microwavers. Why? Suitable 20W units - with very high quality power supplies - have been almost ignored at recent roundtables. I can understand the concerns regarding high voltages, but with military/avionic/telecom power supplies this shouldn't be a problem, although, of course, a modicum of care is required.

I replaced my SSPA with a 50W TWTA and a switching power supply of my own design - which cost about £80 in components to make. Modern TWTs, run at the manufacturer's design voltages, and properly cooled, are highly reliable devices, and used in amateur service should last several lifetimes!

Summary

If you don't have ambitions to have a close relationship with a 3m+ dish, small dish 10GHZ EME is easier than you might think. Don't just sit there thinking that you could never do it! In the immortal words of Mrs. Doyle … (12) 'G'wan, g'wan, g'wan, g'wan' You'll enjoy it!

Links

(1) <http://home.planet.nl/~alphe078/whatis.htm>
(2) <www.physics.princeton.edu/pulsar/K1JT/small_station_eme.pdf>
(3) <http://www.vk3um.com>
(4) <http://www.satsig.net/polmount.htm
(5) <http://www.opticalvision.co.uk>
(6) <http://cpc.farnell.com>
(7) <http://www.systemsat.co.uk/satellite-motor.html>
(8) <http://www.cardman.com/diseqc.html>
(9) <http://www.rfdesignuk.com/
(10) <http://www.vk3hz.net/microwave/doppler141.zip
(11) <www.qsl.net/n1bwt/contents.htm>
(12) 'Father Ted' Channel 4 TV, and countless repeats.