Inaccuracies leading to a Deficiency in Your System's Performance

or… Why the other guy seems to do better than yourself

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Comet McNaught below the VK3UM dish, 2007

How often have you said, "Conditions were terrible"?

How often is this given as a reason for why someone did not work as many stations as they had hoped? The newcomer to EME will first be amazed at what he hears, but after the initial euphoria one can quickly come to realise that others may be doing better with a similar setup.

Were your "conditions" really worse than everybody else's? Most likely they were no different and there were other reasons limiting your capabilities. You may have assumed some aspects of your station were just fine. This paper is intended as a reality check of some aspects that just may have escaped your attention.

We all know of that dreaded Murphy who appears in so many ways and in all manner of insidious disguises at the worst possible time, but I will not address him in this paper!

Perhaps it is time to go back to basics and analyse how you may be able to improve your system and gain that extra little bit that can mean so much. This paper will concentrate on the practical ways to improve your station's performance and provide practical tips along the way.

Before We Start

Before starting down the path of EME you can save yourself a great deal of anguish because the performance of your proposed station can be closely predicted before you even spend a single Dollar or Euro or Pound! The *VK3UM EME Calculator* [1] was written for this very purpose.

Your QTH (and XYL) will most likely set the scene for both the size of your antennae and the band you will eventually choose to operate. In suburban situations your problems will be compounded by neighbours, building restrictions, available horizon and not least the risks of Electro Magnetic Radiation (EMR) affecting your family and neighbours.

You probably have come to realise that maybe a dish will provide the best solution and that it will present you with the potential for multi band operation. With practical dish sizes, that would push you towards the higher bands, 432MHz and above. Then again if you can't get a dish high enough, Yagis and a lower band may be your only alternative for EME.

Dish Antennae

Probably the first decision you should consider is shall the mount be an azimuth / elevation or a polar type mount? A polar mount has advantages for EME (your tracking will be simpler) but it will have distinct disadvantages for terrestrial work as you will have considerable azimuth / elevation limitations.

Choosing the right dish feed

This will depend upon the f/D of the dish you chose and is a decision you will need to make from the very beginning if you intend to build a dish from scratch. The choice will be between a dish with a large f/D, which will provide a better noise performance, or a smaller f/D that will provide optimum forward gain. Between these extremes will lay your answer.

As a rule of thumb it is general practice to design your feed, or choose a feed type, that places at the edge of the dish at the –9dB point of your feed's radiation pattern. If you increase this 'edge taper' to –15dB for example, it will reduce your forward gain (as you are not illuminating the entire dish) but it will lower the noise temperature of the dish through a lower spillover component. This is often a better option and one that most large Radio Astronomy dishes are designed upon – in other words, realized performance rather than raw gain. Like many others, I have deliberately chosen this option in my 23 cm and 70 cm dual feed system [2, 3].

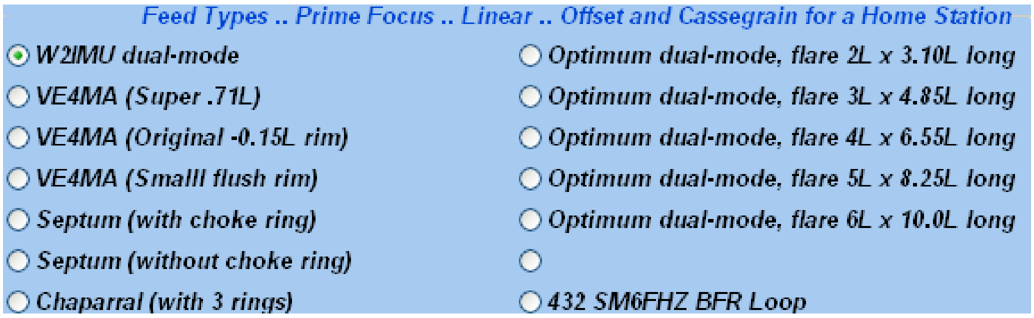
The type of mesh is another decision that has to be made before construction is commenced, or if you are purchasing a dish, because the mesh size will determine the useful upper frequency of the dish. The smaller the feed-through, the better the performance… but the higher will be the wind loading!

For 23 cm and above, circular polarisation is the desired option and this comes back to two basic options and their variations. These are the W2IMU dual mode horn [3] and the Septum or Kumar [4] type feeds. Each can be very suitable but your choice will now depend on the f/D you have chosen and what edge taper you have decided to use. The

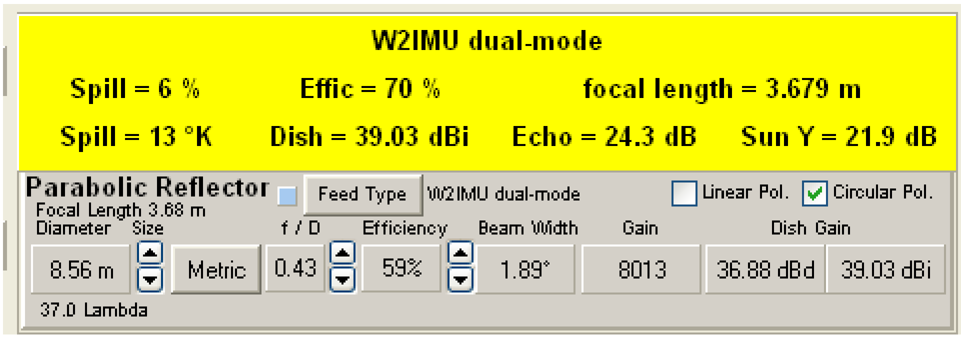
VK3UM EME Calculator has provided a very easy way to make your. The Help file will explain how to select a feed type, vary the f/D and see the change in efficiency (forward gain) and spillover. This tool enables you to try all the options and know the end result you will achieve before you start construction of the dish or your feed… and before you potentially make a mistake

Here are some examples of what the *EME Calculator* can provide [1].

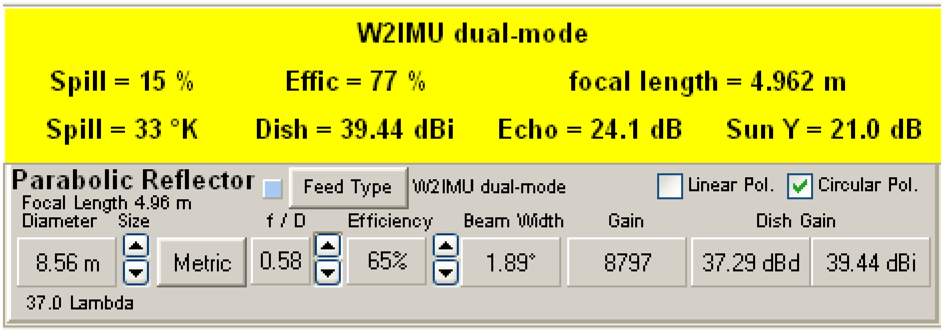
First, it provides the option to select several well known types of feed, with pre-calculated radiation patterns:



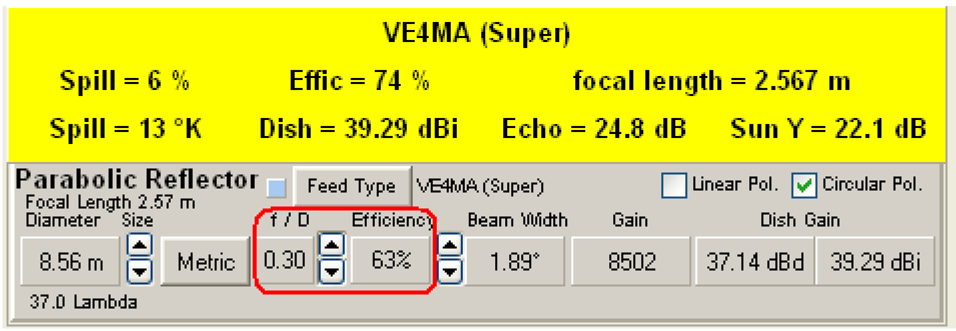
In the following example for 23 cm, a W2IMU feed type has been selected and the variable f/D has been adjusted to 0.43 for the 8.56 metre (28 ft) diameter dish. The efficiency is 70% (not optimum) but the spillover is quite low at 6%. This equates to an edge taper of about –13dB.



For the next example, with the same dish and the same feed type, the f/D has been varied to provide maximum gain or 77% efficiency. It is clearly visible that, although the gain has risen from 39.03dB to 39.44dB (small at best), the spillover has risen to 15% and the level of the echo has actually *dropped* (as also has the Sun Y factor, the ratio between Sun noise and cold sky). This is a clear demonstration of the advantage of designing for optimum performance as opposed to maximum gain; optimum performance will mean a ‘quieter’ dish with less spillover and less unwanted noise.



Now an example for a deeper dish, f/D of 0.30. A VE4MA (Super) feed was chosen to provide the minimum spillover of 6% and slightly higher gain. By clicking the **f/D** button you can also fix the focal length and see the effect of increasing the size of the dish. This is particularly useful if you contemplate increasing the size of your existing dish; this function will let you see the changes and decide if it will be beneficial.



Aiming your Antenna

The fundamental problem for anyone who starts out in EME is “Where is my antenna pointing?” You quickly find that whenever you want to use it, the weather will be cloudy and visual tracking is not an option. We need an accurate means of knowing just where the antenna system is pointing. Most of this section applies to dish antennae with azimuth/ elevation mounts, but it applies almost equally to Yagi arrays on az/el mounts, and to some extent to polar mounts as well.

There are many readout options available, but be realistic and choose a system commensurate with your beamwidth and mechanical positioning accuracy. It’s no use going for 0.1° resolution if your beamwidth is 5°, or if the mount can move several degrees in the wind. Also avoid readout systems that require you to recalibrate every time you wish to use your system. You require an absolute position readout system where you just turn on the power and are ready to operate.

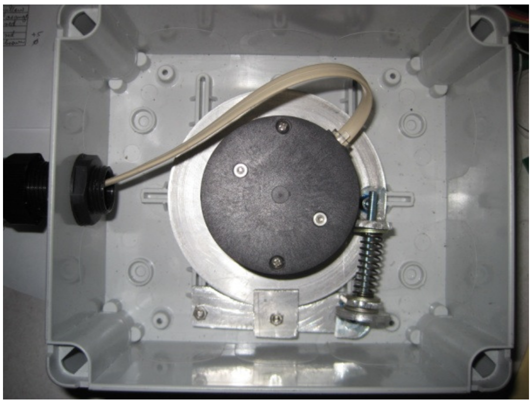
Azimuth and elevation indicators

Absolute encoders are the preferred your choice of position indicators. You can spend up big here and you will always get what you pay for. Remember to install the wiring in shielded cable and always use a single point earth for your tower and shack. Check out

John VK5DJ's web site [5] for a system that will fulfil your needs. I use John's hardware coupled to my VK3UM control software [6].

You will also have to couple your azimuth and elevation indicators to your structure. This requires a mechanical connection to both the fixed and the moving parts of the mount. Most systems will require a flexible belt drive and here it is necessary to select a small toothed timing belt or similar that does not stretch, slip or deteriorate in the environment. That had always been my concern with Yagi arrays in the past, and led to joint design with Graham ZL3AAD, our digital Gray code interface that provided theoretical 0.5° accuracy. This was never achieved due to inherent latency of the wheel. All the same I achieved better than 1.5° absolute accuracy which was adequate for my Yagi arrays at the time.

I used the Gray code wheels on my current 28 ft dish for several years until, from frustration caused by failures of the LEDs and lack of accuracy, I then changed to a US Digital A2 absolute rotary encoder [7] for azimuth and the A2T Inclinometer for elevation [8]. These encoders provide absolute angle data with 0.1° resolution and I can now track with similar precision. That required a very slow azimuth drive (0.1° per 3 seconds) and a hydraulic elevation system adjustable to similar speed.



US Digital A2 encoder with fine adjustment screw

Even with such accurate encoders available off the shelf, installation and calibration required serious attention. The azimuth indicator is attached directly to a stainless steel shaft in the middle of the dish but setting that to 0.1° was not easy. The following photo shows how I manufactured a mechanical fine adjustment and a similar method is used on the elevation encoder. To set them up precisely from beneath the dish I used the US Digital remote display [9]. All of this may seem like over-kill, but it provides total repeatability in tracking and noise measurements – and above all, peace of mind to let me concentrate on making QSOs.

So how do I calibrate it?

First you need to know exactly where on Earth your antenna system is. It is relatively simple these days to find this using GPS. GPS will also give you to a fair degree of accuracy the height above sea level, something that is most useful to accurately determine your exact horizon. If you don't have a GPS then Google Earth or many other national mapping services will help to determine your antenna location with a high degree of accuracy.

Next we need to know where our antenna system is pointing. The Sun position is a good source and the astronomical software (including the *VK3UM EME Calculator*) will be as good as you require under normal circumstances.

But there are a few traps!

If you are using a prime focus dish feed it is convenient to view the shadow of the feed in the centre of the dish and note the azimuth and elevation of the Sun at the time. You will need to watch this moving shadow in real time, so you must be able to control the dish from close by, as well as from the shack (or employ your XYL and commence a 'conversational shouting match'). When you are happy that you have got the shadow centred you then can mark the azimuth and elevation positions on the dish mount as a future reference point. Simple, easy and quick to do? No – like most of us at some time, you may have just fallen into a fundamental trap!

What have I missed? The shadow of the feed does not represent a close enough answer to the true beam direction. In my own case I have a square reflector for the 70cm feed and the cylindrical W2IMU dual mode feed within. It is difficult by eye to be sure the square you are seeing is *truly square*; or if you have just the cylindrical feed-horn, if the shadow is *truly circular*. It will get you close but not close enough to provide the optimum in performance. This can quite easily lose you 3 dB or more in certain circumstances.

To prove the point, now try re-peaking your dish on Sun noise. Does it peak precisely in both elevation and azimuth as you have calibrated? There is a fair chance that it won't. The reflector plate may not be at right angles to the dish and the horn inside may also be slightly off-axis. In both cases the resulting error in beam direction is *twice* the error in feed alignment. To correct this requires finesse and a lot of patience. It often happens that the weather is fair but the Sun is not visible for cloud, and is always the greatest angular distance from the dish parking position where you can access the feed! Get the feed alignment correct first, I use a laser pointer taped to the horn that shines onto the heart of the dish hub. In this way I can get the feed aligned to the centre of the dish in both planes. I first set it at the bottom of the horn and then rest it on the polarisation screws so I get a 90° difference. Given the length of the W2IMU horn it does not need much error in the mounting screws to throw the entire feed off-line. I try to do this part of the job at night, or at sunset on a cloudy day.

Next you need to move the feed inward and outward along the central axis of the dish to peak on Sun noise – and obviously you need a mounting system that allows you to move the feed only along that one axis, without letting it wander off-centre and destroying the careful alignment that you have only just completed. Again, this is a slow and tiring procedure. All the time you are searching laboriously, step by step, for the position of maximum Sun noise, you are also relying on your system stability and Sun noise remaining relatively constant. You don't need to see the Sun during this process and the positioners will probably require re-calibration afterwards. You can always mount the whole feed on an actuator and move it remotely, one SM2 amateur did. That really is probably the only way to have final confidence you are actually spot-on. Otherwise you have to live with it being 'close enough'!

Getting the antenna system correctly aligned and accurately tracking is one of the most important setup procedures you can perform on your installation.

Minimizing Losses

This section shows the wrong way the right way to handle two major areas where losses can occur.

Yagi feed losses

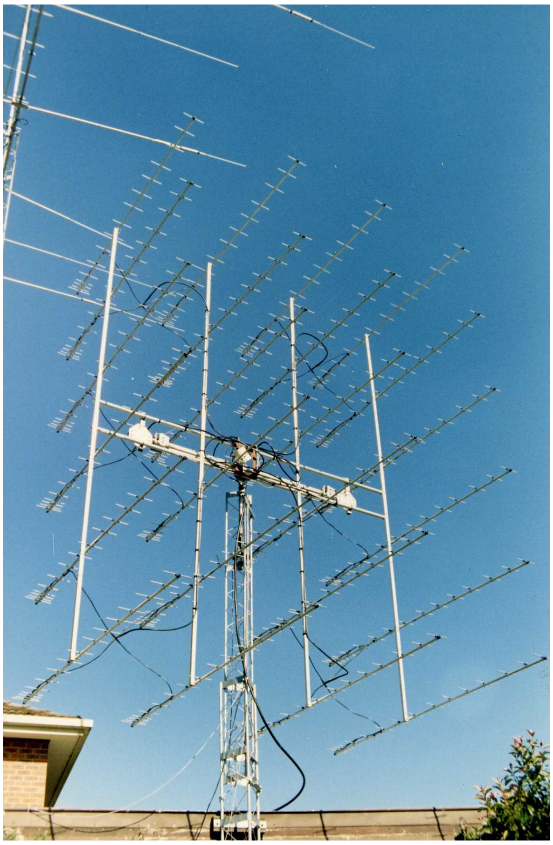
We have learned a lot about feeding multiple Yagi arrays in recent years. In particular, there is a major breakpoint between 2 m and 70 cm. Techniques that you can get away with on 2 m will destroy the performance of your array on 70 cm. Obviously the same basic principles apply to both bands, but the numbers play out very differently.

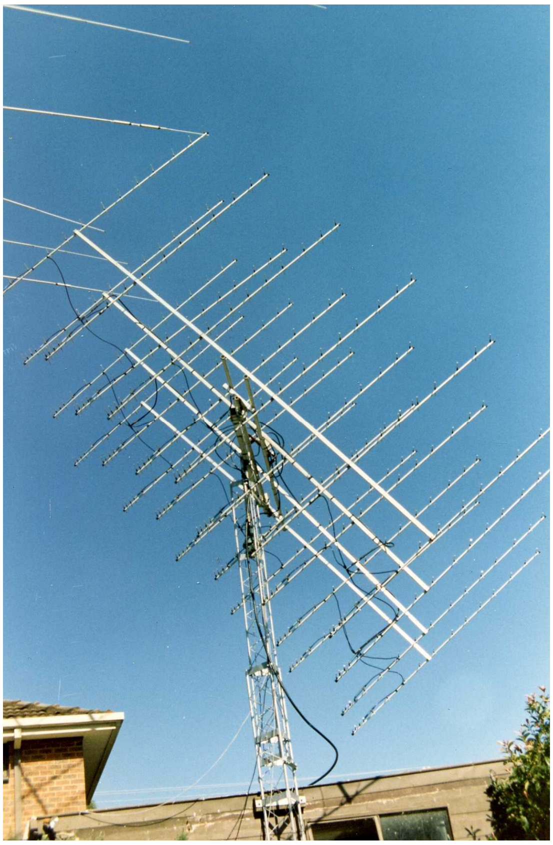
The wrong way for 70 cm

The photos on the next page are of the 24 bay 70 cm array used in the late 1980s and early 90s at my previous Chirnside Park (Melbourne) address. It consisted of 24 x KLM16LBX antennae fed with 1:1 coaxial baluns, 6 and 2 way coaxial combiners all interconnected with 9913 coaxial cable. Although the forward gain was about 28 dBd the internal losses were very significant and thus the noise temperature was very poor. This produced an ‘alligator’ situation where I was heard very well but my achievable receive sensitivity was very poor, due to the losses in the phasing system ahead of the LNA.

This method works for 2 m terrestrial and EME, and also for 70 cm terrestrial operation, for the same reason in both cases. The losses are ‘affordable’ because antenna noise temperatures are much higher than they are on 70 cm EME.

***The wrong way** for 70 cm EME: coaxial cable phasing with large feedline losses*

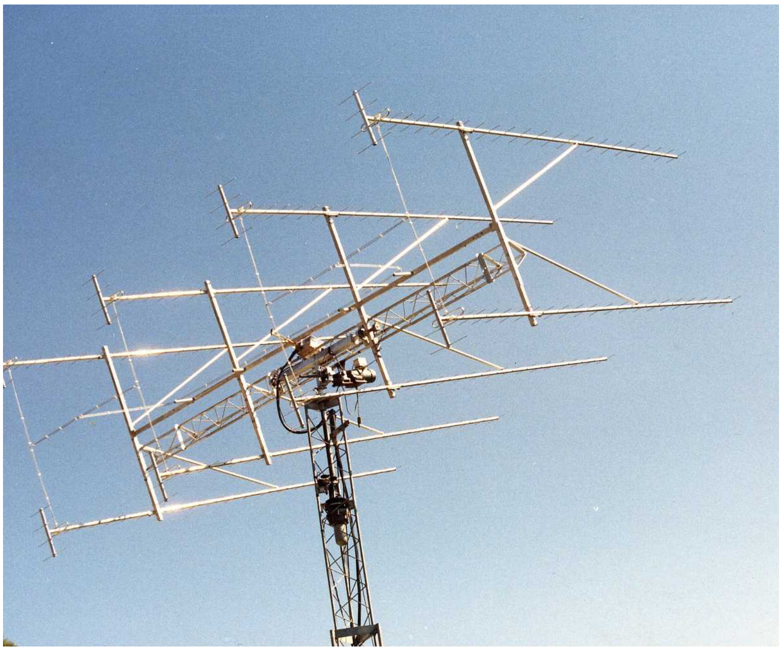




The right way

The next set of photos show the correct approach for 70 cm EME. The use of open wire line had already been pioneered by Jan DL9KR, but building the line from 5 mm aluminium tubing to reduce the losses even further was new at the time. Also new was the use of just one double-ended balun (N7ART design). This required my first venture into aluminium soldering. The Yagis were designed by Rainer DJ9BV (SK) from the available materials I had at that time. The improvement in performance over the 24 bay KLM array was simply spectacular! It achieved just about the best noise performance possible with Yagis.

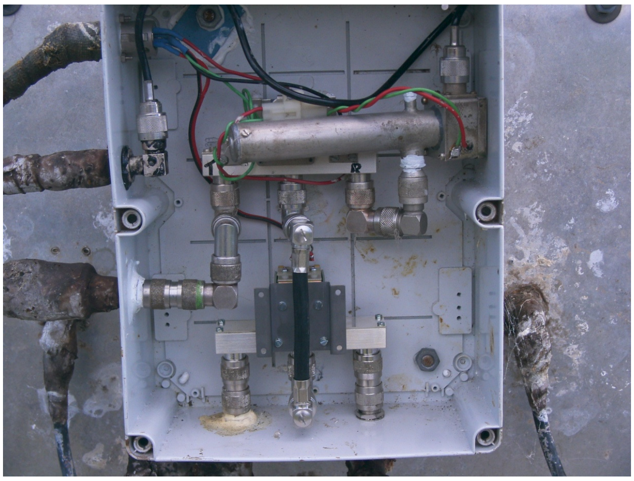
The right way *for 70 cm EME:*
parallel line and absolute minimum of coax ahead of the LNA



Losses inside the LNA box

Polarization switchable dual dipoles make a great dish feed for 70 cm, but again there are wrong and right ways to do it.

The wrong way: too many unnecessary connectors ahead of the LNA.

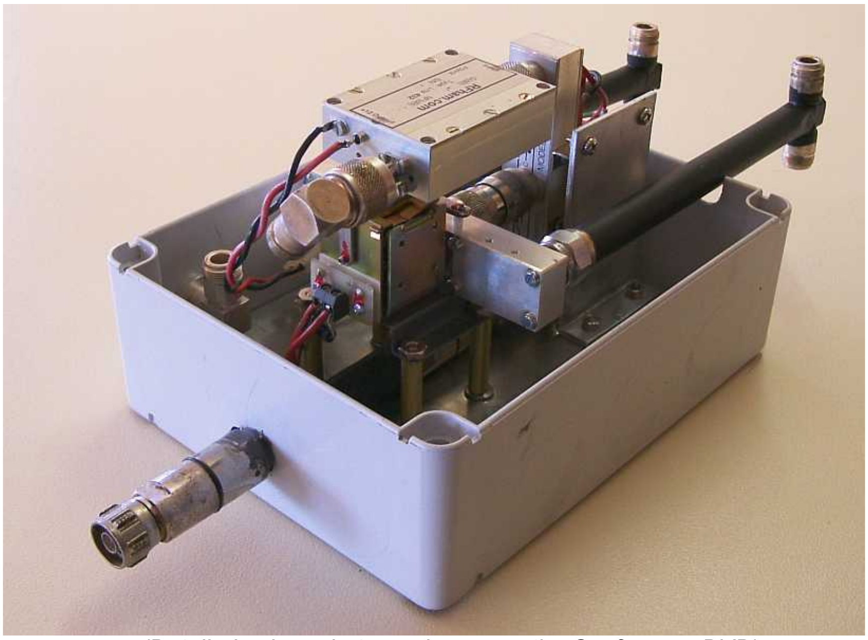


25 connectors eliminated in the re-design!

The right way

This shows how the same can be achieved with no unnecessary adapters or jumpers.

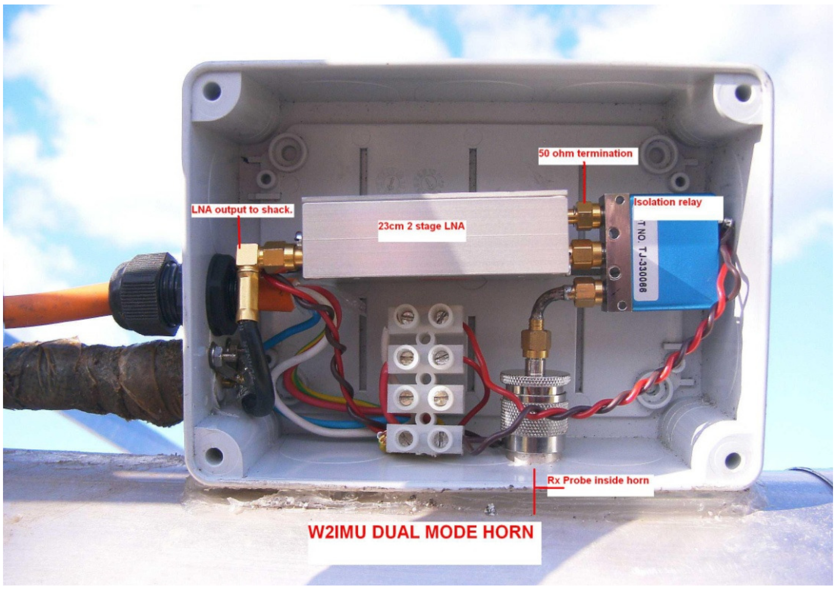
At the far end of the box a pair two-way combiners feed the horizontal and vertical pairs of dipoles through the absolute minimum lengths of coax. The combiners connect directly to the polarization changeover relay (the horizontal relay in the middle of the box). Immediately behind this is the main Tx/Rx changeover relay, with the LNA (top) attached directly to its Rx port. The output of the LNA is fed to the shack in a separate cable, not present in this photo. Finally, the transmitter feed enters at bottom left and goes directly to the Tx port of the changeover relay. No avoidable losses this time!



(Detailed colour photographs are on the Conference DVD)

23 cm

With these lessons learned from 70 cm, the 23 cm LNA box is attached directly to the side of the W2IMU dual mode feedhorn. The connector configuration of the isolation relay is the main obstruction to reducing input losses even further.



Proving Your System

The gain of your antenna will be the main uncertainty in calculating the true performance of your complete EME system from scratch, but a very good measure of the overall performance is to compare noise levels between a ‘hot’ source and a ‘cold’ source. The ratio between these noise power levels is known as the Y factor.

The most common hot source is the Sun, and for those with small systems this will most likely be your only option. The problem with Sun noise is that it is variable, and obtaining repeatable levels is not always possible. However, it remains a good method of comparison if you can look up the solar flux at the time the measurement was made. If you have sufficient antenna gain, measuring Moon noise or noise from a stellar source such as Cygnus A will provide a more absolute indication of your system’s performance. The detail on how to perform such measurements is beyond the scope of this paper but I refer you again to my *EME Calculator* [1] that provides the levels you will expect to measure for your specific station, and also my paper on *Sun Noise: Solar Flux and Measurement Methods* [10].

Another trap: beware, when using a resistor as a hot noise source. The Y factor value may not be accurate because of the change in impedance seen by the LNA when switching between the feed and the termination resistor. This will affect the gain and noise figure of the LNA. However, it is an excellent routine measurement to check that everything is working ‘as normal’.

Operating Techniques

The first key to operating success is to **listen to the other station and follow his lead**. Try to match his sending speed and timing. He may be following a timing sequence and sending fast or slow to match Faraday or libration conditions.

Do not assume that the other station is copying you as well as you are copying him. If you are not running to a time sequence you can gauge how well he is copying when you put it by. If there is a delay in him responding (beyond the usual 2 x 2.5) then it is obvious he is having trouble receiving you. It may then be beneficial to go to a timed sequence. Using an elongated K is always good practice to end an over.

Also use the recognised codes to help the QSO along:

- **YYY** means **send only <u>your</u> callsign** – he has already copied his own callsign, so waste no more time sending it.
- **VVV KKK 333 UUU MMM** is a request to repeat each character **<u>in both callsigns</u>** three times.

Always use an exaggerated space between repeats of all callsigns.

In pileups, spread out and try **not** to zero beat. Move off even as much as a kHz, because most experienced operators will tune either side looking for a quick QSO with station who can be copied with no QRM.

Do not 'steal' someone's frequency by calling the station he has just worked. Do the right thing – move a little to one side to give sufficient elbow room, and call there.

If you are a 'weak station' who has responded to a CQ from a stronger station, remember that other stations may be listening to the QSO. They may be wanting to want to work you next, so after you complete the QSO, always listen for follow-on callers on either side. The original frequency belongs to the station you just worked, so if you do hear someone calling you on the side, net your own echoes onto his and carry on from there. Even if there are no immediate follow-on callers, make this your moment to move to the designated weak signal area and call CQ there. You are still quite likely be rewarded by someone who had been listening on the previous frequency.

Beware of the times when ground noise interference which can severely limit the receiving capability at either end. On your moonrise, this applies to you! Try to avoid calling CQ on popular frequencies immediately after your moonrise; wait until you have lost the ground noise and are receiving with full sensitivity.

Try not to become an Alligator – a station with a big mouth and small ears! As you develop your station, try to keep your transmitted power and receiver sensitivity in a good balance. Going over the top with excessive power will not enhance your reputation and only harm others on the band. Switching to SSB in the middle of the active portion of the band during a CW contest will certainly do your reputation no good either. Be thoughtful to others – there's nothing worse than a willie-wagger *.

And finally:

Remember the safety of your family, your neighbours and yourself. No EME (or terrestrial QSO for that matter) is worth endangering yourself or other people. Know your own safe working distances for Electromagnetic Radiation (EMR) and keep everyone outside of those boundaries [11].

* Australian for "exhibitionist".

References

1. http://www.vk3um.com/eme%20calculator.html
2. http://www.vk3um.com/VK3UM%20Dual%20Feed.html
3. http://www.w1ghz.org/antbook/ch6_5-1.pdf
4. http://www.w1ghz.org/antbook/conf/SEPTUM.pdf
5. http://www.vk5dj.com
6. http://www.vk3um.com/autotrack.html
7. http://www.usdigital.com/products/a2/body_index
8. http://www.usdigital.com/products/inclinometers/absolute/a2t
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