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An Introduction to Moonbounce

Part 1: one of the more challenging fields of amateur radio

INTRODUCTION. Moonbounce, or Earth-Moon-Earth (EME) communication, presents some of the most significant technical and operating challenges in amateur radio. EME is special because it is only just possible to make contacts. If it were a little easier than it actually is, then every VHF/UHF DXer would already routinely be doing it. But if EME were only a little harder, it wouldn't be practical at all with normal amateur resources. In other words, EME is right on the edge of amateur radio, where every contact has to be worked for and nothing is guaranteed.

In theory it all seems quite simple. Stations who wish to communicate point their antennas at the Moon, which is then used as a passive reflector. If only it were that simple! The stations you are trying to work may be completely inaudible for most of the time and some of the difficulties that need to be overcome include:

- The Moon is a long way away, 360,000 – 405,000km, so the path loss is high
- The Moon is a poor reflector so most of the signal is not returned – typically just 7%
- Relative motion of the Earth and Moon means the aerials must be 'tracked'
- The relative motion causes Doppler shift – it can be in excess of 20kHz at 10GHz
- The motion also causes a special type of rapid fading called libration fading.

All these difficulties make EME propagation different from any kind of terrestrial propagation that you have previously experienced, so some specialised operating techniques are required.

On the positive side, EME contacts can be relatively dependable and you do not need to wait for a tropospheric opening or Sporadic-E. The Moon will always appear on schedule!

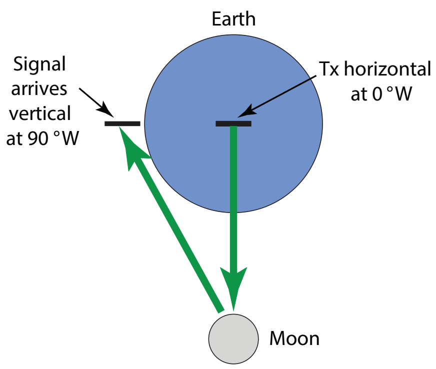

FIGURE 1: How the relative positions between two stations on the Earth will result in changed polarisation of an EME signal due to spatial offset.

PHOTO 1: The 2.3m dish of Sam Jewell, G4DDK shows how a microwave EME system can fit neatly into an average back garden.

However, as you will read later, the EME path loss does change so understanding these rather specialised propagation predictions is essential for success.

After a number of tests by the US military and others in the 1940s, it was fairly soon realised that communication via EME was just within the reach of amateur stations. The first two-way amateur QSO via the Moon took place in 1960 between W6HB and W1BU on 1296MHz and has since been followed by others on every amateur band from 28MHz to 47GHz. However, in recent years, the bulk of EME traffic has been on 144MHz, thanks in part to modern digital communication techniques.

AMATEUR EME COMMUNICATIONS. In the early days amateur EME stations needed huge antenna systems, very high power transmitters and complex receiving set-ups. Today EME operation is within reach of most amateurs with a reasonable VHF station capability.

The propagation loss on the Earth-Moon-Earth path ranges from 242dB at 50MHz to 288dB at 10GHz. This on its own would call for exceptional station performance but there are several features of propagation, some more predictable than others, that add to the challenge. EME communications really do require the ultimate from an amateur station and requires excellence in weak signal operating techniques. Although SSB operation is sometimes possible, much EME operation is on CW and JT65 digital modes. In line with terrestrial activity the majority of EME operation is on the 144MHz band, closely followed by 432 and 1296MHz. Many hundreds of amateurs across the world are currently active on this mode, with a number having attained DXCC via EME.

EME operation does not necessarily mean sleepless nights, as the Moon is visible to radio signals as often during the day as it is at night. Another major advantage for our busy modern lives is that EME operating sessions can be planned in advance, because we always know where the Moon is going to be.

THE EME PATH AND PROPAGATION. Two suitably equipped stations must both be able to see the Moon; this is called a 'common window'. UK stations will have an opportunity to make European contacts on an almost daily basis. The path of the Moon changes day by day; this provides a less frequent common window with more distant countries such as Japan, the USA and South America. The common window for contacting stations in the Antipodes is quite limited and you will need to be on the ball to work VK and ZL for example.

THE MOON AS A REFLECTOR. A source of loss is as a result of the Moon being an imperfect reflector and the relative motions between the Earth and the Moon called librations. Because the surface of the Moon is rough, the reflected wave will consist of a large number of small reflections with differing phases. The signal observed back on Earth will be the sum of these reflections, which is somewhat less than if the Moon were a perfect reflector. As the Moon and the Earth are moving relative to each other so the incident wavefront 'moves' across the surface of the Moon. The result is that the reflected signal becomes the sum of a large number of varying multiple reflections, changing in amplitude and phase from moment to moment. Libration fading is the term used to describe this complex effect, which manifests itself as rapid fluttering with deep fades and occasional peaks. The resulting average reflectivity of the Moon is about 7%.

The basic path loss can be calculated from the radar equations and the average lunar reflectivity. A small complication is that the Moon has a slightly elliptical orbit but this only results in a 2dB additional loss at apogee (when the Moon is furthest away). Table 1 shows the EME path loss for the most popular bands when the Moon is at its closest approach, ie at perigee.

POLARISATION ROTATION. Not only does most of our signal not get returned from the Moon, but during its journey the polarisation of the signal is changed by varying amounts over time. The polarisation changes are caused by the spatial offset of stations around the Earth and by Faraday rotation as the signals pass through the Earth's ionosphere. The combined effects can lead to fading on timescales of minutes to hours, or polarisation 'lockout' where conditions are stuck for periods of many hours. When QSOs fail it is quite normal to blame Mr Faraday – and he is a close relation to the other radio room visitor, Mr Murphy!

SPATIAL OFFSET. Many amateur VHF and UHF stations use linearly polarised antennas, normally horizontal for DX working. Even if all operators were using horizontal polarisation, the curvature of the Earth's surface introduces a problem. When viewed from the Moon, signals from stations from across the Earth's globe will arrive with differing linear polarisation. Therefore the signal from one part of the Earth's surface reflected from the Moon will arrive at another spot on the Earth with a different linear polarisation, as shown in **Figure 1**. This would suggest that for successful EME communications antenna systems would need fully rotatable polarisation. Fortunately ionospheric effects also cause rotation of polarisation, which makes communications between amateurs with fixed polarisation arrays possible.

FARADAY ROTATION. By far the greatest problem and also the most unpredictable effect on the whole EME path is that of Faraday rotation. At radio wavelengths the ionosphere is bi-refringent, that is to say it has two refractive indices, normally calculated for propagation directions longitudinal and transverse to the Earth's magnetic field. These occur as a result of the effect of Earth's magnetic field upon the free electrons in the ionosphere. Faraday rotation occurs as a result of radio waves passing through this bi-refringent layer in the ionosphere (remember for EME you get two passes, one in each direction). The refractive indices of the ionosphere vary directly with solar input, which gives rise to the great variability. Hence Faraday rotation is far greater during the daytime than at night. More information about Faraday can be found in **[1]**. Ian White, GM3SEK developed **Table 2**, which shows how geometric and Faraday rotation can affect signals and result in 'one way' propagation.

One of the important things to remember is that when the signals reflected back from the Moon return through the ionosphere, even through the same volume, such as when listening to one's own echoes, the Faraday rotation of the returning signal doesn't 'unwind' but adds onto the twist imparted upon the signal on the way out. It can be readily visualised that it only takes small variations in ionospheric conditions, especially when one ionospheric path is in daylight, to cause significant variation

TABLE 1: The extreme path loss on EME.

Frequency	Average path loss
50MHz	244dB
144MHz	252dB
432MHz	261dB
1296MHz	271dB
2320MHz	276dB
3456MHz	279dB
5760MHz	283dB
10GHz	288dB

The 288dB loss on 10GHz means that only 0.00000000000000000000000000156% of the originally transmitted signal will reach the receiver!

in the reception of EME signals. With linearly polarised antennas a 90° shift will cause complete extinction of an otherwise strong signal. The overall effect is a near continuous 'rolling' of signal polarisation on 144MHz, slow variations on 432MHz and near stability on 1296MHz and above. To compensate for the unpredictable nature of Faraday rotation many operators are tending to use antennas with switchable and/ or rotatable receive polarisation.

OTHER IONOSPHERIC EFFECTS. The biggest source of signal variation on the EME path at VHF comes from the ionosphere. Ionospheric absorption does occur, but its effects are only significant (>0.5dB) at low antenna elevations during daylight hours at 50MHz and below, although strong absorption at frequencies up to 432MHz and polarisation mixing or spreading is often reported during ionospheric storms, when there are also reports of strange signal enhancements. When the ionosphere is disturbed, EME conditions can certainly never be described as 'normal'.

CELESTIAL OBJECTS AND NOISE. Although the Moon is about a quarter of a million miles away from the Earth it subtends an arc of about 0.5° to an observer on Earth. On all but the higher microwave bands this is significantly less than the beamwidth of most amateur EME antennas. This means that when the antenna is directed towards the Moon it will also receive noise from other sources. Noise from all of the sources that can be 'seen' by the antenna contributes to the overall received noise power and indeed there are a number of strong sources especially towards the centre of our own galaxy. These sources are so strong that for several days each month EME operation is made particularly difficult by high galactic noise. Likewise there are days each month when the Sun is in a similar direction to the Moon, which again raises the received noise floor and drowns out many amateur signals.

FREQUENCIES FOR EME. The propagation and background noise effects are frequency sensitive and there is a complex interplay that gives each amateur band its own distinctive characteristics for EME.

At the lower end of the VHF spectrum, local noise sources can be particularly troublesome and antennas with sufficient gain for EME are necessarily very large. This makes EME on 50 and 70MHz something of a rarity. Even so, W7GJ has hundreds of 6m EME QSOs to his credit, including many UK contacts. He has obtained DXCC and Worked All States and given 6m operators several new countries from DXpeditions of his own.

The majority of newcomers to EME begin on 144MHz; less real estate is needed for the antennas, cable losses are still manageable and amplifiers are available off the shelf. Some of the necessary equipment may already be in the shack. As one progresses into the UHF spectrum, generating sufficient power and getting it from the amplifier to the feed point become more of a challenge. At 1296MHz there is also a step change from Yagi arrays to dishes. High power amplifiers, low noise preamplifiers and accurate pointing of high gain narrow beamwidth dishes are just some of the issues faced by microwave EME enthusiasts. It's fair to say that the number of QSOs per £ and per hour invested is quite low; the attraction of microwave EME is mainly the technical challenge.

The USA, Europe and Japan have different 13cm allocations, meaning that EME QSOs take place with split frequency operation.

The first 24GHz EME contacts were made in 2001, between W5LUA and VE4MA. In 2005, EME QSOs took place on 47GHz between W5LUA, AD6FP and RW3BP.

TRANSMISSION MODES FOR EME. The first EME contacts were made using CW because it was the most effective mode available at the time, and this is where the basic QSO techniques were developed. Many QSOs are still made on CW, partly for the personal satisfaction of literally hearing the signals, but also for good technical reasons on 1296MHz and above. In a few instances, signals between larger stations are strong enough to permit QSOs using SSB.

In 2001, Joe Taylor, K1JT began to develop a suite of digital communication software programs, *WSJT* (Weak Signal Joe Taylor) **[2]**. Joe started with FSK441 for VHF meteor scatter and, in 2003, the first version of JT65 appeared for EME users.

It is no understatement to say that JT65 revolutionised EME by providing an effective increase in sensitivity. For the limited purpose of exchanging callsigns, signal reports and modest amounts of additional information, digital EME contacts can be made at signal levels some 10dB below those required for CW. For decoding callsigns, this level of advantage requires the use of 'Deep

Search' mode within the *WSJT* software, which compares the decoded data with a callsign database. This feature, although very popular, has caused some controversy as it clearly requires some prior knowledge of the callsign to be decoded and decoding errors occasionally take the form of a valid, but false, callsign. However, JT65 has undoubtedly given many smaller stations the confidence to attempt contacts via the Moon, and one can see by reviewing cluster spots or discussion groups that dozens of contacts take place every day using the JT65 modes. The original JT65 mode soon spawned a set of sub-modes known as JT65A, B and C. They have been 'tuned' in their tone spacing and decoding abilities to be suitable for the propagation vagaries of the different amateur bands and, for example, JT65B is commonly in use on 2m. Recently Joe Taylor has added further sub-modes which, at the expense of some loss of sensitivity, speed up the QSO process. The sequence used with JT65B2 uses half the time used in JT65B but the decoding sensitivity is reduced by 3dB.

EME STATION EQUIPMENT. An essential feature for those looking for EME skeds with other stations is accurate frequency readout. Although you might be able to make do with 1kHz accuracy on 144 and 432MHz, being able to place yourself within 100Hz will save a lot of time and heartache when looking for DXpedition stations or for those contemplating running schedules. With complex multi-digit transceiver readouts it is important to understand the difference between what the display says and the actual transmitted/received signal frequency. For complete certainty, the true transmitter frequency will need to be measured, especially if a transverter is used.

WSJT contacts are made in a conventional SSB bandwidth. Significant additional filtering takes place within the software and it can be helpful to ensure that the bandwidth presented for *WSJT* reception is not restricted or 'coloured' by audio filters, shift or notch controls. It should be noted that the *WSJT* frequency is quoted as the SSB zero beat frequency (or SSB 'carrier') and that JT65 tones start at 1270Hz above this.

Although QSOs have been made with relatively simple equipment, the basic requirement is for a transceiver or a separate receiver and transmitter with good frequency readout and excellent stability. For CW operation, the main receiver should have a narrow IF filter and calibrated receiver incremental tuning (RIT). Some operators find an internal or external audio peaking filter helpful too. External transverters must have good frequency stability, as must as the transceiver. It can be really annoying if the station which you are listening to fades down in slow QSB and has drifted outside of your receiver passband when it reappears, which may be 15 or even 30 minutes later. You might not be able to complete a QSO if your own signal drifts by only a few hundred Hz. Sorting out drift in a transverter can be difficult, especially with kits and small commercial units. Some can take as long as an hour to settle down and often the exact frequency changes with external temperature. It should also be noted that the CW frequency is the carrier Tx frequency. Calibration practice varies between different transceivers so before starting you need to understand the relationship between the actual CW transmit frequency and the readout.

Doppler shift and perhaps a small amount of drift in your transceiver will make your signal appear to change frequency during a contact. Do not compound the issue by changing your Tx frequency in mid-QSO.

PREAMPLIFIERS. A low noise preamplifier mounted close to the antenna is essential for any successful EME operation. Interestingly, the optimum position varies from band to band. This is because band noise decreases with frequency while cable losses increase, so the numbers for each band play out differently in an EME calculator. On 2m it can be acceptable to locate the preamp at the masthead, accepting some small losses in the phasing cables, because band noise will dominate. On 70cm the preamp is best located at the rear centre of the Yagi array, keeping the cables as short as physically possible. On 23cm and above, the preamp should be right at the feed point.

Most commercial transceivers have a noise figure (perhaps optimistically assumed) of around 6dB. If we also assume a cable loss of 2dB between the antenna and transceiver, the addition of a masthead preamp with a noise figure of lower than 1dB will improve reception capability by around 5dB. This is overly simplified to make the point; experimenting with VK3UM's excellent *EMECalc* program will show the effects of coaxial cable loss, preamp noise figure and so on. It will also give you a totally different perspective about 'the value of a decibel'. On EME, even a 1dB improvement is quite noticeable and 5dB is the difference between good reception and no copy. Although shack mounted preamps can sometimes produce acceptable results for terrestrial and amateur satellite operation, the feeder loss in front of the preamp will always result in an inferior, sub optimal noise figure for EME.

For serious EME operation you should also consider mounting your main Tx/Rx changeover relay at the masthead and using separate Tx and Rx feed lines. High performance, high power coaxial relays generally have lower insertion loss than preamplifiers with onboard relays. The choice of preamp is relatively easy; there are plenty of commercial preamps with adequately low noise figures (though beware of unrealistic performance claims). If you can't afford a commercial unit, there are designs available for all of the VHF, UHF and microwave amateur bands that can realise the very low noise figures (preferably ≤0.5dB) that are needed for EME. Often you may be unsure as to the actual noise figure of your preamp and it is well worthwhile taking it to one of the many Round Tables or Conventions where noise figure measurement facilities are provided. Although some FET preamplifiers are not renowned for exceptional dynamic range, the majority of strong signal problems are generated in later stages of the receiver, which cannot handle the increased signal levels. If you do suffer from local strong out of band signals causing intermodulation or even blocking problems then place a bandpass filter between the preamplifier and your main receiver. Placing any filter in front of the preamplifier will almost certainly degrade your hard-won receiver noise figure.

TRANSMITTERS AND AMPLIFIERS. The very high path losses mandate high transmit power for all EME operation. Whenever possible you will need to run the maximum permitted power at the antenna. Established EME stations in the UK with a good EMC record can apply for a variation to their licence to run higher power, bringing them to similar power levels as that available in some other countries. There are also tradeoffs that can be made between cable loss and transmitter power output, but lower loss feeder usually turns out to be the most economical answer. There are many suitable designs for high power amplifiers, for example see [3]. Although valve amplifiers used to be the norm for EME operation, an increasing number of amateurs are now using a solid state power amplifiers (SSPAs). If you are contemplating EME operation, make sure the amplifier has adequate cooling to cope

PHOTO 2: 'H frame' in use at G4ZTR supporting a four I0JXX Yagi array.


PHOTO 3: How a satellite dish actuator was used by G4SWX to elevate a 4 Yagi antenna system.

with the long duty cycles required when running schedules, especially for modes such as JT65 that run at constant maximum power. There is no excuse for radiating a poor signal; hum and chirp can detract from your readability and key clicks are likely to alienate all of your locals. It is also important to ensure that you remain within your licence conditions with regard to harmonic output; a low-pass filter is a must. A number of designs for high power, high performance filters have been published, including one by G4SWX made from coax [4].

ANTENNAS. Before considering large arrays and bespoke elevation systems, it is worth remembering that most amateurs on EME cut their teeth using their existing VHF antennas – one or possibly two Yagis, used without elevation. Twice a day, for an hour or so, moonrise and moonset allows stations without elevation control to make EME QSOs. But be warned, it can be addictive!

The antenna system is probably the most important part of an amateur EME station. A small improvement in the antenna affects both the transmit and receive performance and is therefore doubly useful. Antennas are often large and require significant effort in their construction. Most texts usually include calculations based on the path loss (see Table 1), maximum legal power at the antenna and system noise figure to arrive at the minimum antenna gain to detect CW echoes. These calculations result in a gain requirement of approximately 20dBd at 144MHz and 23dBd at 432MHz. On 144MHz four stacked and bayed long Yagis will yield the required gain whilst on 432MHz eight long Yagis will be needed. In practice, stations operating using such antenna systems *will* quite often hear their own CW echoes. These antenna sizes are made on the assumption that the station is capable of a QSO with a station of similar size, but there are a number amateurs that have systems up to eight times larger. As a result, even quite basic single-Yagi stations are capable of EME QSOs with such ‘big guns’. Many stations have had good results with 3dB less antenna gain, mainly because the lunar reflectivity of 7% is only an average and libration fading will produce peaks several dB above ‘average’ levels.

There are a great many variables to consider when making a choice of antenna. On the physical side, you need to consider the size, weight and wind loading – and visualise it in three dimensions to ensure that your chosen array will rotate in azimuth and elevation without hitting obstructions. On the electrical side, gain is important and so is the polar diagram, because it is essential that the antenna minimises pickup of signals (which may be interference) from the sides or behind. A box of 4 Yagis will behave differently (usually worse) in this respect compared to a single antenna, so it is essential to choose antennas that have an extremely clean individual pattern. Careful attention to spacing the antennas will help to reduce side lobes and it is quite normal to have different spacing in the horizontal and vertical planes.

The most important pieces of coaxial cable in your system are those that run between the antenna feed points and the preamplifier. They impose a signal loss that can never be recovered, no matter how low the preamplifier noise figure is. These cables should be the best quality you can afford. Look after them by frequently attaching them to the boom or frame and avoid tight bends. Antenna systems using two or four Yagis will normally require two or four equal length cables respectively, between the feed points and the power combiner.

The newcomer to EME will soon see the limitations of a single Yagi and graduate to two or even a ‘box of four’. After this, probably the most common upgrade is to add vertical polarisation, as the first step to reducing the limitations caused by polarisation rotation.

For EME communications using *WSJT*, the antenna and power requirements are considerably reduced. Although a smaller antenna system will often receive greater background noise, there are many 144MHz stations who can detect their own echoes with a single three wavelength long Yagi antenna and 300W. Indeed there are many stations that now operate EME on 144MHz just a two wavelength long Yagi antenna and 100W. Sub-optimal antenna systems involve a steep learning curve but help to hone operating skills.

On 1296MHz and above the majority of EME stations use dish antennas ranging from 3m C band TVRO to 12m and larger ex-commercial systems.

ANTENNA SUPPORTS. The antenna support is very important. If possible, it is good to think ahead about your ultimate antenna system and engineer the support for that scenario, even if you are beginning with a more modest setup. A good solid mount for the antennas is a wise insurance anyway because any repairs to the mounting system will often mean dismantling the whole array and this will put you off the air for an extended period.

Fortunately, especially if you are planning a large array, antennas for EME do not need to be high above the ground. They need a clear view of the Moon, preferably for all the likely trajectories from your QTH. In the UK this means, broadly speaking, tracking the azimuth from northeast through south to northwest and for elevations of up to 60°. Obstructions by buildings will attenuate the signals so much that they will disappear. It’s best to arrange things so that all antennas, whatever their azimuth and elevation angle, are above head height (for obvious safety reasons). But they do not need to be on an 80ft tower at full extension – and history teaches us that the longest-lasting EME arrays are those that don’t try to double as terrestrial antennas as well.

It may sound obvious but all your Yagi antennas must all point in the same direction and must continue to do so regardless of the weather. Alternatively you might decide to become, quite literally, a fair weather operator, choosing to tie down the array in times of storms. For a dedicated EME antenna it is a good idea to be able to lock it in the ‘parked’ position (where it will spend most of its lifetime) to take the strain off the rotators. Parking the antenna in the same position without any external bracing can lead to excessive wear or metal fatigue in the same few gear teeth. The antennas must also continue to point in the correct direction for all anticipated elevation angles.

For a group of four modest size Yagi antennas, a simple H frame with one horizontal boom and two vertical poles will work well. It is much, much easier to use square section material because mounting the antennas in the same direction is almost foolproof. A floppy H frame will not suffice. Size for size (comparing the diameter of a round tube with the across-flats dimension of a square tube with the same wall thickness), square tube is stronger in bending. However, the forces due to wind loading are complex, include torsion and, on balance, round tube fares better. Round tube will also weigh a little less. Most elevation rotators (and there are not very many to choose from) accommodate round tube and not square.

An H frame with two horizontal booms is a useful step up to a more robust solution, with the second boom usefully forming a fastening point for the power splitter and preamplifier. Keep the cross booms well clear of the

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antennas so that the polar diagram is not affected by nearby metal in the same plane. **Photo 2** shows a good example of this.

If available space, cost or other limitations lead you to consider a two Yagi system, life can be made simple by mounting the antennas for vertical polarisation on a tube that passes through an elevation rotator. This avoids the difficulty of trying to do this with horizontally polarised Yagis on an insulating boom with the additional conundrum of ensuring that the coaxial cable does not run in the same plane as the antenna.

ROTATORS. As for amateur satellite operation, EME antenna systems require elevation control in addition to azimuth rotation. Because of their size and weight, EME arrays usually require the largest heavy duty rotators. Don't forget the elevation rotator needs to be just as heavy duty as the azimuth rotator. Lightweight elevation rotators, such as are used for amateur satellite antennas, are rarely adequate for EME arrays.

It is not too difficult to build your own elevation system using an actuator or 'screw jack' of the type commonly used to steer satellite receiving dishes (see **Photo 3**). There are a number of websites describing how to build such an elevation system and a good example is at **[5]**.

One feature that can ease construction of an EME elevation system is that in the UK the Moon only reaches a maximum elevation of just over 60°. The required pointing accuracy depends upon the antenna beamwidth; simple direct reading meters are usually OK for a single Yagi but greater accuracy, preferably with digital readout, is required for dish antennas. A system for determining the elevation angle can be made relatively easily by modifying relatively cheap digital spirit levels. An example of such a system is described on the website of Johan Swienink, PA3FPQ **[6]**.

If you are not able to brew your own, commercial elevation rotators are manufactured by Yaesu, Prosistel, Spid and M^2 Antenna Systems. Today most amateurs operating EME, particularly on the UHF and microwave bands, use a computer program to automatically track the position of the Moon and adjust the rotators. Even beginners can benefit from auto-tracking because it reduces the number of things you need to think about while on the air. A few rotators incorporate a RS232 or USB interface and interfaces such as those from EasyRotor **[7]** can easily be added. There are many Moon tracking software packages available including a utility within the *Ham Radio Deluxe* software **[8]**.

GROUND GAIN. As with HF antennas, reflections from the ground can give VHF and UHF antennas additional gain with a small upward tilt in the main lobe. This additional gain can often make EME QSOs possible between stations that would otherwise not be able to hear each other. It is with the help of 'ground gain' that many smaller 144MHz stations have their first experience of EME. It is difficult to calculate the exact angle at which the maximum ground gain will occur; a common practice is to arrange tests for half an hour from moonrise or before moonset. On 432MHz and above the effect of the ground will also increase the background noise floor, which may well negate the effect of the ground gain on the received signal to noise ratio (S/N). A very detailed explanation of ground gain and a calculation method are available on the website of ON4KHG **[9]**.

OPERATING . As with many other aspects of amateur radio, the wise operator starting out EME will begin by listening – and then listening more. Such an apprenticeship will give you a good idea of the callsigns of the strongest active stations and the procedures in use on that particular band. Of course, be wary that not every station uses perfect procedure for every QSO.

Operational activity peaks on EME contest weekends, on weekends when good conditions are anticipated, and when some choice DX pops up. And yes, there can be pile ups on EME! On 144MHz many operators prefer specific weekends when the background noise temperature is at its lowest. As a result of the complex orbits of the Earth and Moon lowest background noise does not necessarily coincide with minimum path loss. These weekends are well publicised in the VHF community **[10]**. A lot of the difficulty in choosing the best time to operate has been removed by public domain EME prediction packages such as that produced by Doug McArthur, VK3UM **[11]**. All this is not to say that weekdays are quiet; QSOs can take place any day, any time, as long as the QSO partners have a common Moon window.

Monthly newsletters are available for EME operators, produced for 2m by DF2ZC and for 70cm and above by K2UYH and others al **[12]**.

Working nearby stations can be problematic, because you are likely to see signals from stations in the closer parts of Europe being received via EME and via tropo. This is where observing the timing (*WSJT* DT readout) becomes important. The value of DT should be close to zero from the tropo signal and around 2.3 seconds for the EME path. There is more about DT in Part 2.

In the second part of this article, we'll take a look at the practical side and getting started on EME operation. Meanwhile, you might like to take a look at the inspirational web pages of G4CCH, G4NNS, KB8RQ, F1EHN, F5TE and W7GJ.

TABLE 2: The effect of geometric and Faraday rotation on EME signals.

Fixed horizontal polarisation		Geometric rotation (station positions + Moon position)				
		–90°	–45°	0°	+45°	+90°
Faraday rotation (ionosphere)	+90	E hears W W hears E	E hears W W hears E		E hears W W hears E	E hears W W hears E
	+45	E hears W W hears E	W hears E	E hears W W hears E	W hears E	E hears W W hears E
	0°		E hears W W hears E	E hears W W hears E	E hears W W hears E	
	–45°	E hears W W hears E	E hears W	E hears W W hears E	E hears W	E hears W W hears E
	–90°	E hears W W hears E	E hears W W hears E		E hears W W hears E	E hears W W hears E

White background = can hear – polarisations are aligned
Grey background = can hear, but with loss due to polarisation misalignment
Black background = cannot hear – cross-polarised!

WEBSEARCH

[1] Faraday rotation - *Radio Wave Propagation*, Lucien Boithias, North Oxford Academic Publishers Ltd, 1987, ISBN 0-946536 06 6.
[2] http://en.wikipedia.org/wiki/JT65
[3] Designs for high power amplifiers can be found in the *RSGB Handbook* and *ARRL VHF Manual* among other places
[4] Stub Filters Revisited by John Regnault, G4SWX, *Radio Communication*, November 1994, www.ifwtech.co.uk/g3sek/swxfiltr/swxfiltr.htm
[5] GM4JJJ elevation system: www.gm4jjj.co.uk/elev.html
[6] PA3FPQ digital spirit level modifications: http://pa3fpq.nl/elevation.html
[7] EasyRotor Rotator Interfaces: http://easy-rotor-control.com/
[8] *Ham Radio Deluxe*: www.hrdsoftwarellc.com/
[9] ON4KHG: Ground Gain: www.on4khg.be/EME_Gr_Gain.html
[10] www.dxmaps.com/emecalendar.html
[11] Prediction and other software: VK3UM for PC, GM4JJJ for Mac
[12] Newsletters: www.df2zc.de/ and www.k2uyh.com/news.htm