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An Introduction to Moonbounce (EME)

Earth-Moon-Earth (EME) is a propagation means which enables world-wide amateur contacts to be established preferably using amateur band frequencies from 144 MHz upwards. These communication distances are extremely large for these frequencies and the technique is fascinating a growing number of radio amateurs owing to the challenge presented by its highly technical nature.

The principle is really quite simple. The transmitter antenna is directed at the moon and the signals, reflected from the moon's surface, are picked up at the distant receiver. At a suitable position for the moon (common window), two stations separated by up to 20,000 km can achieve communication i.e. over a distance of half the world's circumference.

1. HISTORY

The first attested case of an EME contact was reported in July 1960 between two US stations, W6HB and W1BU using 1296 MHz. The first intercontinental EME contact came in April 1964 between Finland (OH 1 NL) and the USA (W 6 DNG).

The following year saw EME experiments using high-powered radio astronomical installations with large parabolic antennas, by various institutes. Foremost among these were the universities of Stanford (WA 6 LET) and Arecibo in Puerto Rico (KP 4 BPZ). In particular, the series of EME experiments conducted by American radio amateurs in June 1964 from the Arecibo radio telescope (KP 4 BPZ) with a 300 meter diameter dish, were very widely known. This is because the unusually high antenna gain of this gigantic antenna installation enabled amateurs to receive SSB and CW signals when using quite simple Yagi antennas.

The initial years of this new propagation method, represented a very large financial and technical outlay for the radio amateur which could only be alleviated by group undertakings. The necessary parametric amplifiers for the receive preamplifier, highly stable oscillators, large antennas and AZ/EL antenna control, had to be home-constructed.

The first moonbounce contacts, using purely amateur-constructed equipment and with one-man efforts at each station, took place in the 70's. The burgeoning development in HF and semi-conductor techniques enabled reliable and cost-effective VHF/UHF, low-noise pre-amplifiers as well as transmit amplifiers capable of high power to be developed. The somewhat difficult, parametric amplifier technology was rendered meaningless by these developments and became obsolete. In short, the best part of an EME station could be purchased from a dealer.

This article will now go on to examine the minimum requirements for the development of an EME station, by way of technical specifications and operating practices, which are particular for this form of communication.

2. BASIC TECHNIQUES

The serious enquirer must first of all be informed that EME contacts, because of the large path distances involved, are undertaken for the most part, with extremely low-level, received signals. The construction of an EME station has, therefore, to be conducted with the utmost care. This applies particularly to the send and receive antenna losses which must be reduced to the absolute minimum possible. In order to be able to optimally equip an EME station, the following factors must first of all be given an airing:

- Frequency range
- Path loss
- Signal/noise ratio
- Transmit power
- Antenna gains

2.1. Frequency Range and Path Loss

The first consideration for a newcomer to moonbounce is the important choice of a suitable frequency band. When this has been resolved, in principle, the whole station equipment, EME transmitter and receiving installation being dependent upon frequency, can then be considered. The propagation loss, earth-moon-earth, also has a bearing upon the choice of band etc.

The basis for calculation is tabulated:–

Frequency MHz	Perigee dB	Apogee dB
144	– 251.5	– 253.5
432	– 261.0	– 263.0
1296	– 270.5	– 272.5
2304	– 276.0	– 278.0

Table 1: EME path losses for various amateur bands

It may be seen from the **table 1** that enormous propagation losses are caused by both the path distances involved and the reflection loss from the moon's surface. **See formulae 1 and 2.**

Owing to the nature of the moon's surface, rocky, sandy and dry, it has a very low reflection characteristic. Experiments in USA (2) have revealed that the moon's surface reflects only 7 % of the energy falling upon it, the remaining 93 % being

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path_loss_dB = 10*LOG (received_pwr_watt/erp_watt)/LOG (10)
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Formula 1: Total path loss calculation

```
free_space_db = 37 + 20*LOG (freq)/LOG (10) + 20*LOG (dist)/LOG (10)
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Formula 2: Free space attenuation calculation
where: freq = frequency (MHz)
dist = distance in miles (km x 0.62)

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erp = tx_pwr_watt*EXP ((ant_gain_db-cable_loss_db)/10*LOG (10))
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Formula 3: The ERP derived from sender-power, antenna-gain and cable-attenuation calculation. (ERP = effective radiated power)

totally absorbed. This proportion varies with frequency, and is more favourable at the lower bands.

Additional reflection losses are caused by the ragged nature of the moon's surface on the incident and the reflected angle (should be equal) of the incoming energy. A massive part of the transmitted energy is also dispersed into space by the electromagnetic field surrounding earth. The total reflection loss can be deduced from the difference between the total loss and the calculated theoretical free-space loss.

The 144 MHz band exhibits the smallest loss on the amateur bands under question, and therefore presents the best pre-requisites for a satisfactory S/N. This band therefore possesses the greatest world-wide EME activity at present. The article will now concentrate on this band as it is clearly the one to be preferred for an introduction to EME.

2.2. Signal/Noise Ratio

In order to cover the 790,000 km (approx.) distance and to overcome reflection losses, a certain radiated power is required. This is known as "effective radiated power" (ERP) and is the product of the transmitter power and the antenna gain (cable losses being taken into account). **See formula 3.**

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k = 1.38E-23 (Bolzmann-Konstante 1,38 x 10^-23 Joule/Kelvin)

              Eingabe-Routine - Systemparameter

path_loss_db = Gesamte Streckendämpfung - dB
rx_width_hz = ZF/NF-Empfängerbandbreite - Hz
rx_noise_fig_db = Empfänger-Rauschzahl - dB
rx_ant_gain_dBi = Empfangseitiger Antennengewinn - dBi
rx_cable_loss_db = Kabeldämpfung - Ant./Vorverstärk. - dB
ant_noise_temp = Antennen-Rauschtemperatur - K
tx_pwr_watt = Sender-Ausgangsleistung - Watt
tx_ant_gain_dbi = Sendeseitiger Antennengewinn - dBi
tx_cable_loss_db = Kabeldämpfung zwischen Ant. u. PA - dB

                   Berechnungs-Routine

tx_pwr_dbw = 10*LOG(tx_pwr_watt)/LOG(10)
total_rx_noise_db = rx_noise_fig_db+rx_cable_loss_db
rx_noise_temp = 290*(EXP(total_rx_noise_db*LOG(10)/10)-1)
sys_noise_temp = rx_noise_temp+ant_noise_temp
rx_noise_pwr = 10*LOG(k*rx_width_hz*sys_noise_temp)/LOG(10)
s_n = tx_pwr_dbw-tx_cable_loss_db+tx_ant_gain_dbi
s_n_ratio = s_n-path_loss_db+rx_ant_gain_dbi-rx_noise_pwr

                      Print-Routine

PRINT "Sender-Ausgangsleistung ";tx_pwr_dbw;"dBW"
PRINT "System-Rauschtemperatur ";sys_noise_temp;"K"
PRINT "Empfänger-Rauschleistung ";rx_noise_pwr;"dBW"
PRINT "Signal/Rausch-Verhältnis ";s_n_ratio;"dB"
```

Fig. 1: Program proposal for calculating signal/noise

System data input	
Path loss	251.5 dB
Receiver IF bandwidth	200 Hz
Pre-amplifier noise figure	1.5 dB
Receive antenna gain	22.1 dBi
Receive cable loss	0.2 dB
Antenna noise temperature	170 K
Transmit output power	750 W
Transmit antenna gain	22.1 dBi
Transmit cable loss	0.5 dB
Calculated values	
Transmit output power	28.75 dBW
System noise temperature	308.94 K
Receiver noise power	-180.69 dBW
Signal/noise ratio	+1.64 dB

Fig. 2:
Calculation example with program from fig. 1

The signals at the receiver input, in order that they are intelligible, must be above the system noise power. This may be considered as being the total received signal-to-noise (S/N).

The signal-to-noise ratio is derived from values for transmit power, path loss, receiver noise figure, receiver bandwidth, antenna gain, antenna noise temperature and coaxial cable losses. The formulae in **fig. 1** have been prepared for a direct input into a calculator in order to obtain the S/N from these factors. Varying the parameters in the program input of fig. 1 will enable various transmission situations to be simulated. **Fig. 2** gives an example. It will be seen that received EME signals, for the most part, lie about the limit of intelligibility. This must be borne in mind during the construction of an EME station. The following will take this into account in the practical considerations for a moonbounce station.

2.3. The Transmitting Equipment

The send power is limited by the authorities for B-licence holders, to 750 Watt at present. This power represents, in connection with the feasible antenna gains, a usable compromise in the achievement of an effective radiated power output. Final power amplifiers in this power class may be obtained directly from a dealer. Before obtaining one, however, it should be ascertained that the rated power output is not attained at the very limits of the linearity characteristics of the final tube(s). Driving such an amplifier to its limits will result in the production of unwanted (and illegal) side frequency products which could interfere with other radio services (TV, radio broadcasting etc.). Furthermore, the longevity of the final tube(s) will also be drastically curtailed. CW allows full ratings to be achieved with reasonable dimensioning of PA cooling and power supplies and is almost the only mode which can be considered.

Home-construction is very often a better technical and economical solution, the necessary components all being available from specialized firms. Some parts may be already in the station store or can be obtained from other amateurs. Nevertheless, in connection with some mechanical parts, particularly the construction of the coaxial tuned circuits, there are a few demands which have to be met.

Suitable construction kits are obtainable from any of the referenced sources (1, 4, 6). The PA driver can be any modern 2 m or a short-wave transceiver, the latter being employed with a down-converter. These units may be regarded as being pre-requisites for a normal amateur station and do not therefore have to be specially home-constructed for EME use.

noise_temp = 290*(EXP (noise_fig*LOG (10)/10) − 1
noise_fig = 10*LOG (1 + (noise_temp/290))/LOG (10)
noise_factor = 1 + (noise_temp/290)

Fig. 3:
Calculator input formula for the conversion to noise temperature, noise figure and noise factor. The value 290 is the reference temperature 290° K i.e. 17° C.

2.4. Receiving Equipment

The following points are to be given special attention in the setting-up of the receive side of an EME station:–

1 Receiving system noise figure (NF)
2. Selectivity of the receive converter
3. Frequency accuracy and stability

For successful EME reception, the optimal noise matching of the receiver to the antenna gain is of crucial importance and has a decisive impact upon the overall signal-to-noise ratio (S/N).

Depending upon both the quality and length of the coaxial feed cable between antenna and receiver, there will be some attenuation of the signal before it reaches the receiver pre-amplifier. This attenuation adds directly to the receiver noise figure (NF). In order to reduce this loss to a minimum, it would be a good idea to place the receiver directly at the antenna output terminals, but this is not practical! As the receiver pre-amplifier is the main item which determines the system noise figure, it is a logical step to install it at the output terminal of the antenna, well away from the receiver.

This philosophy is behind the current state of technology where a so-called mast amplifier combined with transmit-receive switching, is widely employed. This concept enables an optimal signal/noise ratio and offers at the same time the convenience of having the receiving unit in the shack.

A successful EME station should have an NF of better than 1.5 dB. This high specification might

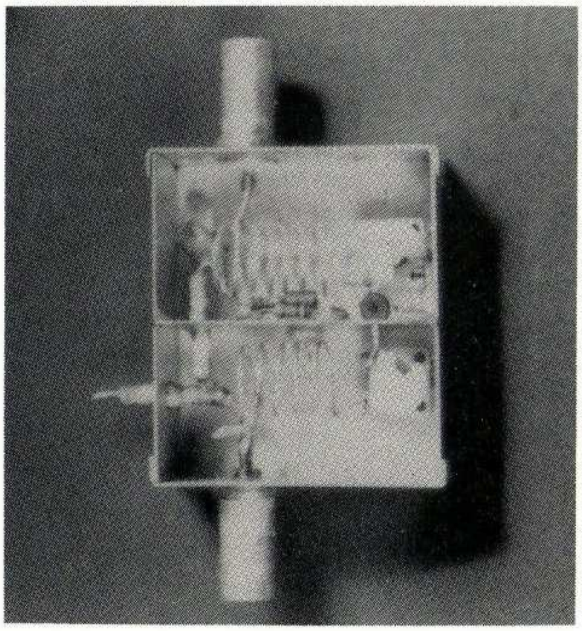

Fig. 4: 144 MHz pre-amplifier using a BF 981

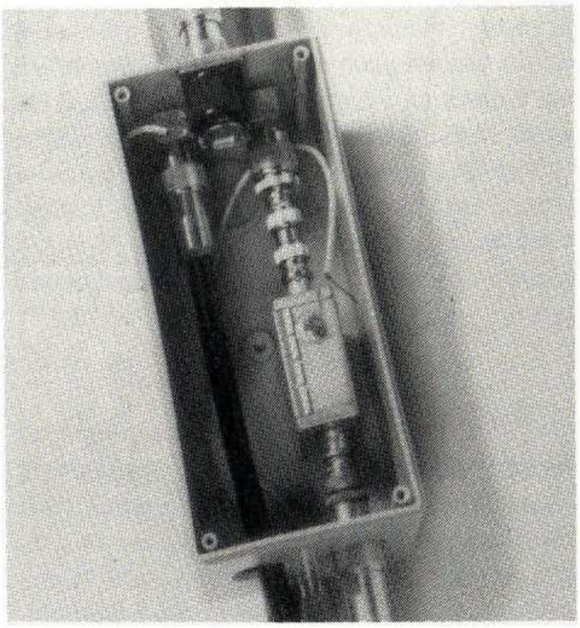

Fig. 5: The pre-amplifier enclosed together with a coaxial relay

seem to be unattainable but the most modern semiconductors achieve an NF of under 1 dB. It must be borne in mind, however, that at 144 MHz, the minimal cosmic noise temperature is already 150 K, i.e. equivalent to a noise-figure of 1.8 dB (**fig. 3**) so it seems pointless to aim for a much lower figure than this. The receiver noise above 1 GHz is higher than the cosmic noise and therefore the lowest possible receiver noise figure should be aimed for (8, 9).

Suitable pre-amplifiers for 144 MHz may be constructed quite economically using the MOSFET BF 981 (**fig. 4**). A constructional article can be found, for example, in (7). Proprietary pre-amplifiers possess, in the main, a really outstanding noise figure. They are fitted with a send/receive relay which all too often does not afford a sufficient degree of isolation between send and receive. This defect has caused the author's pre-amplifier to fail on a few occasions.

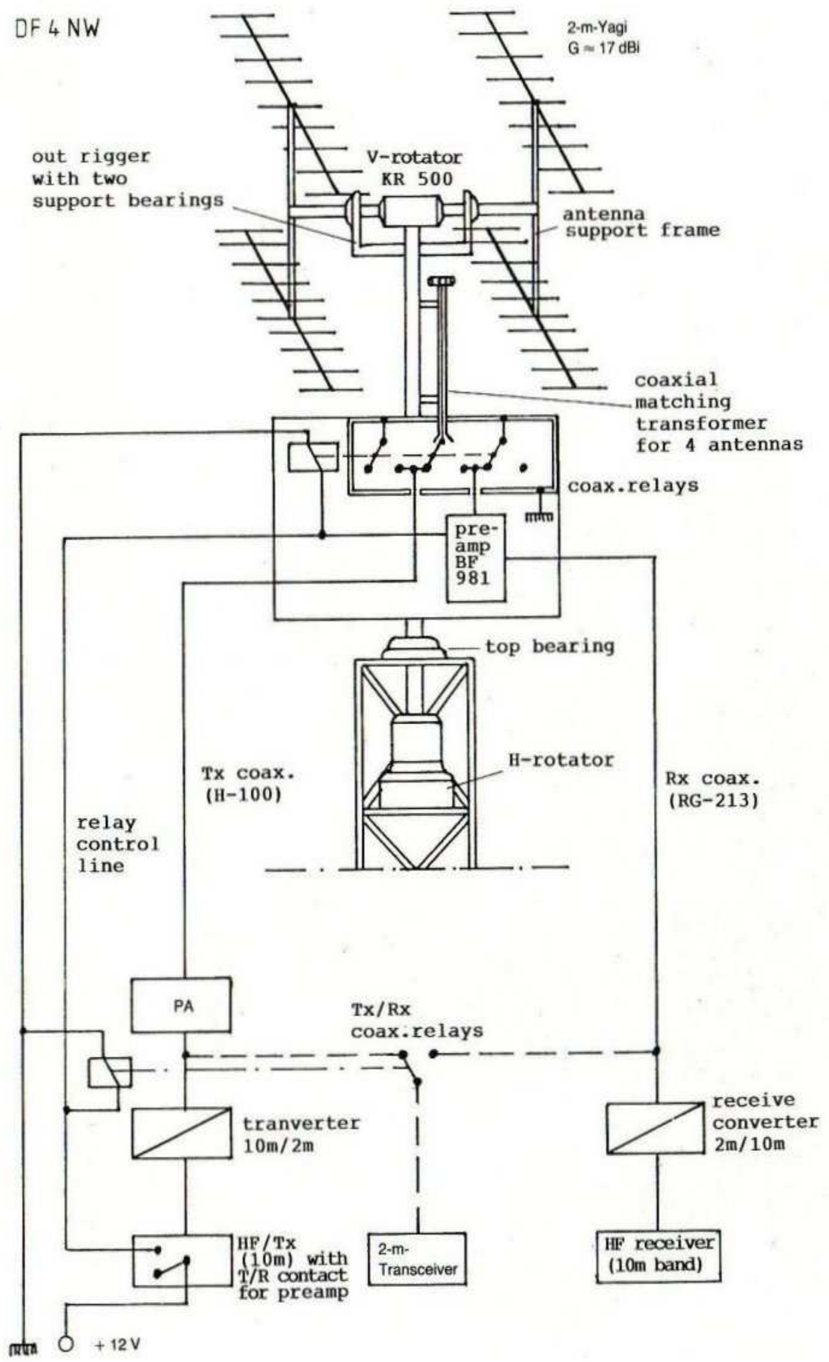

Fig. 6: Example of a 144 MHz, EME installation with either an HF transceiver and 10 m – 2 m transverter or with a 2 m transceiver

The only way round the problem is to change the antenna relay for a high-quality type (**fig. 5**).

By way of protection, the wiring and cabling of this relay's transmit path is taken via an idle contact. This ensures that the output of the PA is switched to the antenna and the receiver input to earth when the relay drops out. A further effective measure to isolate HF from the pre-amplifier, is to use a separate transmit cable from the power amplifier to the antenna relay. A second coaxial relay is necessary at the equipment end to switch the transceiver over the two paths. The arrangement is shown in **fig. 6**.

On grounds of cost, and the low outlay in terms of labour, it is recommended that the pre-amplifier should be home-constructed.

Any modern 2-metre tranceiver, having two VFOs or calibrated receiver fine-tuning, could be suitable. An arrangement such as that shown in fig. 6, with a converter translating 144 MHz down to a short-wave receiver at 28 MHz, is also just as good. The main requirement is good selectivity and frequency stability. As the aerial gain is responsible, in the first instance, for a good signal-to-noise ratio, additional measures are required in order to boost the signal over the noise level. This is achieved by reducing the received bandwidth to that necessary for the reception of CW signals i.e. 300 Hz. This may be done either by filters in the IF or in the audio stages of the receiver.

2.5. Antenna System

As the available RF power is curtailed by law, and the noise figure of the receiver by natural limitations, the most important element of the EME station is the antenna. The well-known axiom that the antenna is the best pre-amplifier, is particularly apt in this application. The construction of

Fig. 7: The author's 4 x 17-el. Yagi, EME array.

a high-performance antenna should utilize all of the available space. The best solution would be to mount it on a dedicated, self-supporting mast. It is possible, however, with not much extra difficulty, to mount an EME antenna on a house or garage roof (**fig. 7**). The height above ground is not the most deciding factor. What is important, however, is the screening of the antenna by nearby objects, such as buildings and trees etc., should be avoided right down to the horizontal plane (0°) if possible. The high-performance EME antenna would then be also suitable for direct terrestrial communications.

Experience has shown that for the 144 MHz band 20 dB_d antenna gain is the minimum that should be aimed for. On the higher bands, a greater antenna gain is necessary in order to compensate for the larger path losses, see table 1.

This gain cannot be realized with one single Yagi antenna. The ideal would be a dish antenna with a suitable paraboloid aperture. This solution is normally precluded on grounds of cost and space considerations.

An economical compromise solution is presented by the antenna array. This can comprise several proprietary Yagi antennas together with the necessary combining and matching networks. In order to fulfill the 20 dB_d gain requirement, four 15 dB_d element Yagis are required for the array. The boom must be at least 5 wavelength long i.e. about 10 metres. A 4-element array, theoretically, has a 6 dB gain advantage over any of the elemental Yagis which compromise it. In practice, this is reduced to 5 dB_d which still amounts to the required total of 20 dB_d.

The 4-antenna array is constructed quadratically in the so-called H-form. This arrangement enables a well-formed, symmetrical radiation lobe thus ensuring the proper illumination of the reflecting zone on the moon's surface. A rule to follow for the location of the elemental Yagis is that they should be disposed symmetrically about the central support and 5/7ths of the boom length apart in both the horizontal and the vertical planes (10).

This construction allows very uncomplicated mounting arrangements for the elevation rotator on the cross support boom. High quality H-100

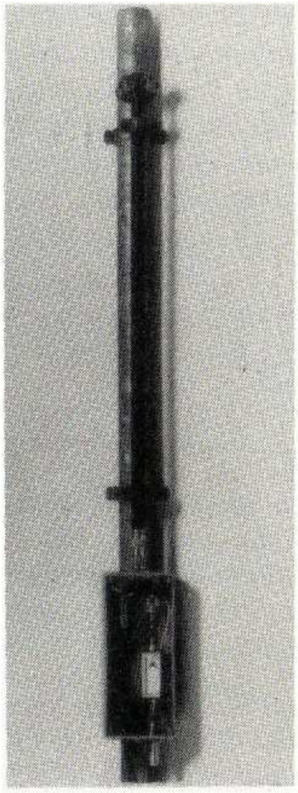

Fig. 8:
The pre-amplifier/relay unit from fig. 5 affixed to a coaxial matching transformer

coaxial cable and N-type plugs and sockets should be used for the feeder and for the transformer connections, see **fig. 8**.

When planning an antenna installation, it may be just as well to consider personnel expectations of the likelihood of EME contacts, with the reality. This is presented in **table 2** in the form of what antenna installation the stations at the two ends of a link are likely to have for a 100 % solid contact.

Basically, it may be deduced that the more attention given to the antenna, thereby increasing

Station A	‹ EME ›	Station B
Number of antennas	Traffic between	Number of antennas
4-ant. array	⟷	16-ant. array
8-ant. array	⟷	8-ant. array
16-ant. array	⟷	4-ant. array

Table 2: EME contact possibilities for various link array combinations

the ERP and the received signal-to-noise ratio, the greater will be the possibility of working large numbers of stations. Naturally, it cannot be ruled out that certain favourable positions of the moon allow a solid contact between two parties both having only four stacked antennas.

3. ANTENNA CONTROL

For EME contacts it is imperative that the antenna is directed accurately at the moon and that it follows the moon in the course of its movements. The construction of the antenna control is based upon the following two principles:

- Polar mounting
- AZ/EL mounting

The polar mounting has the vertical axis (horizontal rotator) pointing towards the earth's- or polar axis, and the vertical rotator towards the axis of the declination. This system is in widespread use for the mounting of astronomical instruments. The system allows, above all, for the antenna to be directed by inputs of only declination and the Greenwich Hour Angle (GHA) for that particular station latitude and longitude. This information may be obtained from astronomical or nautical tables (11). This system has, however, the important disadvantage that the antenna array is limited for terrestrial applications.

The almost universally accepted alternative to the polar mounting is the AZ/EL arrangement. The horizontal axis of the antenna is orientated vertically about the centre point of the earth in this method of mounting.

This is the normal way in which terrestrial antennas are mounted on masts and poles etc. Proprietary motor drives, but always in a more robust version, serve for the AZ and the EL orientation of the antenna array.

Movement in elevation (EL) is particularly well carried out by the rotator KR-500 (A, B). It is recommended, however, that the shaft is extended and extra support bearings fitted to an out-rigger in order that the load is taken off the rotator's die-cast housing and the rotator gearing. Larger arrays require more rotator systems working on a single axis in order to provide the necessary torque.

A large choice is available in dealer outlets for the horizontal rotator. Again here, it is advisable to use an out-rigger and extend the driven shaft to allow the fitting of extra support bearings in order to relieve the load on the rotator mechanism.

To allow a greater starting torque for large arrays, and also to obtain a more precise control over the setting in both AZ and EL, it is desirable to increase the gear ratios of the driver mechanisms. This can be done mechanically by changing the gear train or, the same effect can be achieved by using an electronically regulated supply to the motor. The electronic method is, of course, the one to be preferred, as the mechanical re-arrangements to the gear ratios can cause all sorts of problems. The electronic control of the motor supply is preferably carried out by the pulse technique. The principle is based upon a Triac placed in series with the motor supply current which is controlled at a varying rate by a pulse generator. By changing the impulse duration, a smooth control will be effected.

The highly concentrated beams from these arrays, demand a high setting and monitoring accuracy for the AZ and EL headings. The normally scaled instruments of 5° per division are not adequate for this application. In order to increase the read-out resolution, it would be better to lay out a modest investment in a digital display based upon a digital voltmeter. This can bring up the resolution to 1°. By suitably switching in preset potentiometers, it is quite a simple matter to get the AZ indicator to read 0 - 360° and the EL to read 0 - 90°.

3.1. Tracking the Sun and Moon

Most radio amateurs in the world are almost always obscured by clouds from sight of the sun and moon, when they are required. For this reason, an optical antenna alignment can be ruled out and a mathematical method developed. This is based upon the longitude and latitude of the EME station and calculated from the Greenwich Hour Angle (GHA) and the declination.

Owing to the continuous movement of the moon in its orbit, this calculation has to be continuously updated. This can be done with a pocket calculator but can be enormously time-consuming. However, personal computers are now becoming popular owing to the burgeoning progress in data-processing and find a home in large numbers of radio amateurs shacks. These computers are ideal instruments to undertake the task of calculating this sort of thing. Programs, such as "EME" for PCs, by DF 4 NW, (**figs. 9 and 10**), can process the data with great precision. The DF 4 NW programs can calculate in real-time, once the date and time have been given in GMT (UTC). For two freely chosen locations, the following data is presented:

- AZ and EL angles for sun and moon
- Angle between moon and sun from observer
- GHA and declination for sun and moon
- Semi-diameter and distance to the moon

TUE, 16.FEB.1988		TIME-UTC	07:31:30	
1ST. LOC. LAT.	49.71	LONG.	-10.82	DEG
EL-MOON	8.33	AZ-MOON	140.99	DEG
EL-SUN	8.69	AZ-SUN	121.38	DEG
SPACING BETWEEN MOON & SUN			19.61	DEG
2ND. LOC. LAT.	50.00	LONG.	100.00	DEG
EL-MOON	-55.25	AZ-MOON	47.14	DEG
EL-SUN	-51.79	AZ-SUN	14.84	DEG
SPACING BETWEEN MOON & SUN			32.49	DEG
GHA-MOON	307.17	DEC-MOON	-21.84	DEG
GHA-SUN	289.34	DEC-SUN	-12.57	DEG
SD-MOON	16.675	DIS-MOON	358332	KM

Fig. 9: Screen print-out from the "EME for PCs" computer program. The 12 lines show the following data:

1) date and time
2) first location, latitude and longitude
3) first location, elevation and azimuth
4) first location, sun's elevation and azimuth
5) first location, angle between sun and moon
6)...9) data as above for the second location
10) GHA (hour angle) and declination of the moon
11) GHA and declination of the sun
12) Semi-diameter (SD) and distance (DIS) of the moon (elevation of the moon over the horizon)

DATE : TUE, 16.FEB.1988					E M E - COPYRIGHT BY DF4NW - JAN.1988				
	LAT 49.70	LNG -10.82		LAT 50	LNG 100		DEG		
TIME UTC	EL- MOON	AZ- MOON	SPACING MOON/SUN	EL- MOON	AZ- MOON	SPACING MOON/SUN	DIST. KM	S.D. MOON	DECL. MOON
07:30	8.174	140.6	19.61	-55.4	46.64	32.58	358333	16.675	-21.84
07:45	9.651	143.7	19.59	-53.6	51.44	31.52	358315	16.676	-21.79
08:00	11.02	146.8	19.59	-51.7	55.91	30.34	358297	16.676	-21.74
08:15	12.29	150.0	19.60	-49.7	60.09	29.12	358279	16.677	-21.69
08:30	13.45	153.2	19.61	-47.7	64.01	27.90	358261	16.678	-21.64
08:45	14.49	156.5	19.62	-45.6	67.70	26.71	358244	16.679	-21.59
09:00	15.41	159.8	19.62	-43.4	71.19	25.57	358227	16.680	-21.54
09:15	16.20	163.2	19.61	-41.2	74.51	24.50	358210	16.680	-21.48
09:30	16.86	166.7	19.59	-38.9	77.67	23.50	358193	16.681	-21.43
09:45	17.38	170.2	19.55	-36.6	80.71	22.58	358176	16.682	-21.38
10:00	17.76	173.7	19.48	-34.3	83.65	21.74	358159	16.683	-21.33
10:15	17.99	177.2	19.40	-32.0	86.49	20.97	358143	16.684	-21.28
10:30	18.08	180.8	19.28	-29.7	89.25	20.27	358127	16.684	-21.22
10:45	18.03	184.3	19.15	-27.3	91.96	19.64	358111	16.685	-21.17
11:00	17.83	187.9	18.99	-25.0	94.61	19.07	358095	16.686	-21.12
11:15	17.49	191.4	18.81	-22.7	97.23	18.55	358080	16.686	-21.06
11:30	17.01	194.9	18.61	-20.4	99.82	18.08	358064	16.687	-21.01
11:45	16.39	198.4	18.40	-18.1	102.4	17.67	358049	16.688	-20.96
12:00	15.64	201.8	18.18	-15.8	104.9	17.29	358034	16.689	-20.90
12:15	14.75	205.2	17.96	-13.5	107.5	16.96	358019	16.689	-20.85
12:30	13.75	208.5	17.74	-11.3	110.1	16.66	358004	16.690	-20.80
12:45	12.62	211.8	17.53	-9.17	112.6	16.40	357990	16.691	-20.74
13:00	11.38	215.0	17.32	-7.02	115.2	16.17	357975	16.691	-20.69
13:15	10.04	218.2	17.12	-4.91	117.9	15.97	357961	16.692	-20.63
13:30	8.599	221.3	16.93	-2.85	120.6	15.79	357947	16.693	-20.58

Fig. 10: Print-out from "EME for PCs" program
In this program mode the same data is given as was displayed in the screen mode. Following the input of a freely selectable time-frame, a calculation of the movements of sun and moon may be obtained for the planning of QSO schedules.

4. PREPARATION FOR INITIAL EME TESTING

At this point, it is as well to find out whether or not the whole system is capable of EME operations. The following tests will show, without the use of test equipment, the equipment's capability in this respect.

1. Measurement of the sun's noise
2. Echo trials

The simplest, but also the most effective, method of analyzing the receive system sensitivity is to measure the sun's noise (13). For this measurement, the antenna is directed towards the sun. A high elevation angle (mid-day) will ensure the least, atmospheric and man-made, interference with the test results. The received noise should clearly increase by at least 5 dB using a previously calibrated S-meter. This figure depends upon the sunspot activity in the surface of the sun as indicated exhaustively in ref. (13).

The so-called echo tests are a little more problematical. The antenna is aimed at the moon and a short burst (2 secs.) of CW pulses are transmitted at full power. After a period of 2 ½ seconds, the echo pulses should be detectable in the receiver output if the conditions are optimal. That the return pulses are extremely weak, or indeed, not to be heard at all, should not be taken as poor indication of the system's performance – at least, not yet! There are various factors which could be responsible for a non- or weak return when using only a 4-element array. An EME contact could still be established under such conditions, but only if the distant station is using a 16-element array and/or with high power. Before undertaking either an echo test, or attempting to contact other EME stations, it is advisable to be acquainted with these external influences. The following factors are to be particularly taken into account:

4.1. The Sun's Noise

When the sun is at its closest approach to the moon (new moon), the sun's emitted noise will increase to such an extent, that it will influence the EME reception until it becomes impossible to establish a radio link. The sun/moon separation will cause noise to an extent depending upon the antenna beamwidth. Practical experience has shown that angle distances below 10° are to be avoided. In addition, winter and night-time operations are, of course, favourable.

4.2. Perigee and Apogee

As may be seen from table 1, the path-loss at perigee is 2 dB smaller than at the moon's apogee. This 2 dB, in the context of EME working, can mean the difference between a contact or no-contact! Typical values for a perigee is 360,000 km (SD = 16.5). See fig. 9.

4.3. Angle of Reflection

The optimal antenna orientations at the two stations participating in a contact, is when they have a common elevation angle. This follows from the angle of incidence at the moon's surface being almost the same as the angle of reflection for radio waves.

4.4. Low Angles of Elevation

Low angles of elevation should be avoided in order to minimize reception of earth noise and other terrestrial disturbances. Under favourable conditions, however, a kind of tropo-propagation mode may be encountered, leading to extremely long-distance contact possibilities.

4.5. Declination of the Moon

Owing to the smaller distances involved between observer and moon, northern declinations of the moon, for stations in the northern hemisphere, bring better path conditions. The same applies for southern moon declinations for stations in the southern hemisphere.

4.6. Galactic Noise

Up to 170 K noise temperature is to be expected when the moon, twice monthly for a period of 4 days, crosses the galactic plane. When the crossing occurs in the declination of Orion and Gemini for the northern hemisphere, even higher galactic noise temperatures are to be expected. Likewise, when the moon occults Scorpio and Sagittarius in the southern hemisphere, a higher noise will be received (3, 9, 11, 12).

4.7. Delay Distortion

Owing to the reflection taking place on the rough and uneven moon's surface, the signal experiences path-time variations which are within the reflected wave. This causes random phase distortions such that the return CW signals from the moon sound very rough. SSB voice signals are, nevertheless, readable but only under good signal conditions.

4.8. Faraday Polarization Reversal

A polarity reversal occurs in the earth's atmosphere. This can cause the signal to disappear entirely under certain conditions. This effect can be countered by employing circularly polarized antennas (parabolic, or crossed-Yagis). The extra complication involved at the antenna, particularly using Yagi based arrays, is fairly high but unavoidable.

4.9. Doppler Effect

The moon follows an elliptical orbit around the earth. Within the orbit, however, the moon wobbles, causing a periodical distance variation at a speed of up to 1575 km/h (see par. 4.2.). This causes a doppler phase shift of ± 210 Hz max. in the 144 MHz band.

5. OPERATING TECHNIQUES

In the development of EME contact procedures, a few departures from the normal form of amateur contacts take place using the CW mode. Owing to the use of narrow-band selective receiver filters and the prevailing signal distortion, it is necessary that only low keying speeds are employed. The highest transmitted keying speeds are from 30 to 50 BpM. The use of very low keying speeds also has the effect of a reduction in intelligibility, as a combination of both signal drop-outs and delay distortion could result in a dash sounding like several dots.

EME traffic is conducted mainly at frequencies at the beginning of the band. At 2 metres, this extends from 144.000 MHz to 144.050 MHz. Most activity appears to be concentrated, at or around 144.010 MHz. A similar band plan exists for EME working at 70 cm.

As EME stations were not too frequent a few years ago, it was necessary to pre-arrange a contact. The system went as follows:–

The most eastern station begins to call on the full hour (when other arrangements have not been made). This takes place in an unvarying cycle of exactly two minutes calling, followed by an exact period of two minutes listening. Should a contact ensue, the call-sign is repeated for 1 ½ minutes and a further 30 seconds is taken up by the report (**fig. 11**). Following an exchange of reports, both stations send a final confirmation in turn, by sending a series of 'R's followed immediately by the report, for a period of 1 ½ minutes. The next 30 seconds is followed again by the call sign and the final 'K' or 'SK'.

Contacts in the 432 MHz band are conducted in 2 ½ minute periods i.e. two minutes followed by an information change for the remaining 30 seconds. This procedure is repeated as long as necessary in order to achieve an intelligible contact. The contact is regarded as being satisfactorily completed when, both stations have confirmed the distant call sign and their report by sending an 'R' to the partner station. A comprehensive exchange of information is only possible, normally, under good signal-strength conditions. It happens very frequently that the whole QSO process, as outlined above, could take over an hour under poor path conditions.

Because of the very weak signals and, as a result, the difficult nature of communication, a simple reporting system has been devised for EME working. Instead of the RST system, the TMO system (**fig. 11**) is employed.

A communication net (EME-net) has been established on 14.345 MHz for those wishing to find partners for an EME contact attempt. This net finds its greatest activity at the weekends or holiday periods. If a schedule (sked) cannot be adhered to, it is, of course, morally obligatory to try and let the other party know in good time. This can be achieved by telephone, telegram or via other OMs on the band. Nothing is more annoying, than to listen for hours to receiver noise only to discover later that the other party was not QRV. Be reliable, is the catch-phrase here!

Skeds on the lower-frequency bands (144 and 432 MHz) are only very seldom possible in the

TMO reporting system
T = Signal heard but not readable M = Signal partly readable O = Everything readable
R = Call-sign and report received SK = End of contact

Fig. 11: The EME reporting system "TMO"

weekdays. At 144 MHz, many of these QSOs occur just on the off-chance when the moon is at its perigee. Recently, an annual autumn EME contest has been organized. These contests should be very interesting for any prospective EME operator to hear the extremely rough sounding signals and to become acquainted with the fascinating EME modus vendi.

6. DESCRIPTION OF AN EME STATION

During the course of tests conducted with many stations by the author, the following station equipment was used:–

Receive equipment

1. Home-constructed mast-preamplifier using a BF 981.
2. Receive down-converter 144/28 MHz – Microwave Modules 144 MHz converter.
3. HF receiver – IF bandwidth 4 kHz to 300 Hz – Drake R7
4. AF processor – 3 kHz to 100 Hz; Signatrans Nachrichtentechnik – 7901 Bollingen.
5. Headphones – Sennheiser

Transmit equipment

1. Transmit driver – transceiver: Braun SE 402.
2. Transmitter final – Dressler d200s.
3. Morse-key (electronic memory) – Accu Keyer
4. Morse-key (bug) – Bencher

Antenna installation

1. Test 4 x 13 element, 4.5 m boom-length – Tonna
2. Test 4 x 17 element, 6.6 m boom-length – Tonna
3. Matching network for 4 Yagi antenna – Andes
4. Horizontal rotator – CDE T^2X
5. Vertical rotator – Kenpro type KR 500
6. Vertical rotator support bearings – Kenpro
7. Horizontal rotator support bearings – Kenpro

Owing to the local authorities' reluctance to grant a building permit for the construction of a lattice mast, the antenna had to be mounted on the roof of the author's house. The mast itself, is a proprietary steel telescopic with a diameter of 48/60 mm and 2 x 3 metres long. The array main-frame is constructed from high-strength aluminium tubing (AlMgSi 0.5-tube F22 – 40 x 2 mm dia.) using the necessary cross clamps. A guy-rope system of six wires ensures that the installation stays in place on the roof.

All the HF cabling uses RG-213/U co-axial. In order to avoid losses in the 30 m co-ax between the cellar shack and the mast, the power amplifier was mounted in the attic and remotely controlled. On the receive side also, the cable losses were reduced to the absolute minimum by mounting the pre-amplifier as close to the array as possible. It is to be expected that another few tenths of a dB could have been saved by using a low-loss cable, such as H 100, in the antenna change-over switching and in the transmit leg.

As may be seen from the list of equipment used, tests were carried out using two different arrays. A very interesting trans-continental contact was carried out using the 4 x 13 array but the number of stations contacted increased noticeably when the array was modified to a 4 x 17 antenna.

Finally, it may be said that EME working is entirely feasible with a minimum outlay and offers the experimentally-minded amateur a very wide field. This includes antenna gain, transmit power, receiver noise-figure and selectivity, all of which demand the utmost performance and therefore the maximum endeavour.

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