21 Satellites and space

Radio Amateurs have always been keen to exploit new means of communication and within only three years of the launch of Sputnik 1 a group of radio amateurs in the USA had designed and built the first Orbiting Satellite Carrying Amateur Radio (*Oscar*). The first non-military, non-governmental payload to go into space, Oscar 1 was launched on 12 December, 1961 from Vandenberg air force base in California. Carrying a small CW beacon transmitter (Fig 21.1), it sent "HI HI" and was copied by radio amateur around the world.

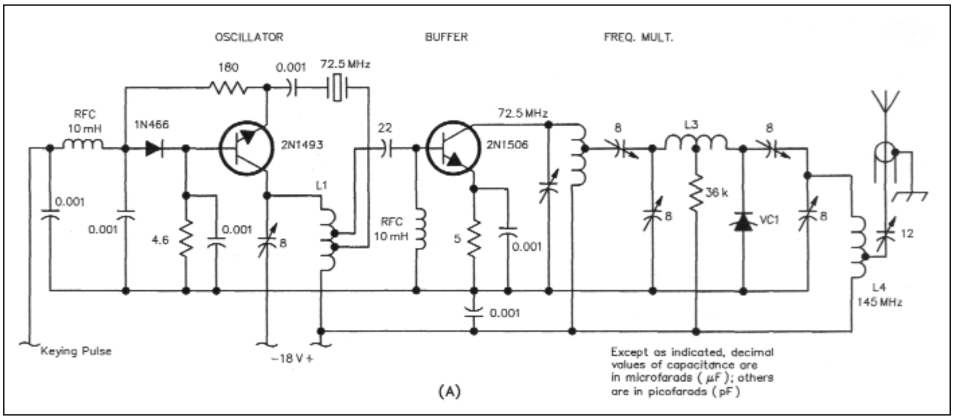

Fig 21.1: Oscar 1 beacon transmitter that delivered 140mW at 145MHz

With over 40 years of experience in designing and building satellites the amateur radio community has pioneered many new techniques and contributed greatly to the science and engineering of spacecraft and space communications. Today we have a whole range of very capable satellites for CW, voice and data communications. The manned space missions, the Shuttle, and the International Space Station (ISS) also play their part. Amateur radio satellite groups are active in many countries including AMSAT-UK (United Kingdom) [1], AMSAT-NA (USA) [2] and AMSAT-DL (Germany) [3]. AMSAT groups provide a structure for planning, designing and building satellites and the programs are always ambitious. AMSAT-DL is looking beyond Earth orbit with their plans for a satellite to go to Mars.

THE SATELLITE SERVICE

The Amateur Satellite Service is a separate user service (from *the Amateur Service*) under the terms of international licensing regulations. Fortunately this does not mean that a separate license is required. All licensed radio amateurs are welcome to use the satellites according their own licence conditions.

Amateur radio satellites are costly to build, launch and operate. Just about all of this funding comes from the amateur radio community, so if you do use the satellites, please consider joining AMSAT-UK or one of the other AMSAT groups and help to fund new satellites for us all to enjoy.

SATELLITE ORBITS

Fig 21.2 shows some of the fundamental concepts. Footprint is the term used to describe the area of the Earth which is in radio reception range of the satellite.

In amateur radio terms any stations within the footprint can communicate via the satellite. The area of the footprint is determined by the height of the satellite with the best DX contacts being available between stations on the extreme edges of the footprint.

Geostationary

Geostationary, or more correctly geosynchronous, satellites are located at around 40,000km into space. Orbiting at the same rate as the Earth, they appear to the Earth-bound observer to be stationary. At such a great distance they have a large footprint. They are familiar as TV and communications satellites. It takes a lot of launch energy, and therefore cost, to get a satellite into this orbit and to date there are no geosynchronous amateur radio satellites. GEO does offer the possibility of fixed antennas and communications 24 hours a day, seven days a week.

LEO, Low Earth Orbit

This is where we find most of the amateur radio satellites. There is no fixed definition of LEO, but typically the satellites are in orbits of about 800km altitude. LEO is very useful for weather satellites, science satellites, environmental monitoring satellites, and amateur radio. If the orbit is chosen to go over the poles then the satellite will pass over all parts of the globe several times each day. Messages can be collected in one part of

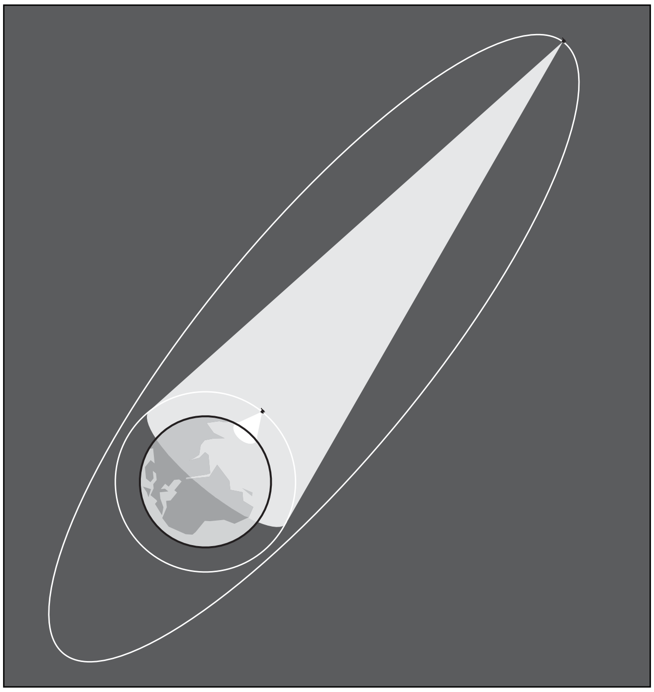

Fig 21.2: Footprint for high and low altitude orbits: LEO satellite at 1,000km; HEO satellite at 60,000km

the world and then re broadcast over another, this is known as *store and forward*. Similarly, the satellite can collect scientific data throughout an orbit then broadcast it as it passes over the control ground station; described as *Whole Orbit Data* it can be of considerable scientific value.

LEO orbits are the easiest to achieve in terms of launch energy. From a communications standpoint they are limited. At these low altitudes the satellite will be in range of a ground station for only a maximum of 15 minutes or so. This makes for short contacts, but a lot of fun with the possibility for UK based stations to work many countries.

HEO, High Elliptical Orbit

This is typically around 300km at the point of closest approach to the Earth, a position on the orbit called *perigee*, to 20,000km or more at its furthest distance, *apogee*. It is easy to remember: furthest **a**way at its **a**pogee.

This orbit is very useful for communications as it has a large footprint for most of its orbit (**Fig 21.2**). From the ground station's point of view, as the satellite approaches and leaves Apogee it appears to 'hang in the sky', simplifying antenna tracking.

A specific variant of the HEO is the Molynia orbit. By positioning the ellipse of the orbit in a particular way, the ground track repeats each day. First used by the Russians in April 1965 for a communication satellite, the orbit had a perigee of 309km and an apogee of 24470km.

This gave the benefit of long periods of reliable communications over a large part of the Northern Hemisphere. The special characteristics of the Molnya orbit have been exploited for amateur radio HEOs, OSCARs 10, 13 and 40. Quite large payloads can be put into HEO with far less energy than needed to reach GEO.

The International Space Station

Orbiting at around 350km altitude the ISS is a particularly low LEO. The orbit is frequently boosted using the thrust from the regular supply vessels. Without this intervention, the ISS would lose altitude and re-enter the atmosphere.

Sun Synchronous

A particular type of LEO, this orbit is chosen to keep the spacecraft in sunlight as much as possible. Space is an extreme environment; power management and thermal stability are both vital factors in ensuring the long life of the satellites payload. A sun synchronous orbit ensures that batteries are kept charged by the solar panels and the spacecraft warmed by the Sun. Imparting a spin to the craft helps with temperature stability.

TRACKING SATELLITES

If you don't know where the satellite is you can't work through it. In the pioneer days, radio amateurs produced ingenious graphical methods and charts such as the 'Oscarlocator' to find a satellite's position. Today we use computers.

The satellite travels around its orbit independently of the earth. Given the co-ordinates of our ground station, some facts about the geometry of the orbit, and a reference point from which to start the calculation, we can predict the satellite's position several hours, days and weeks into the future.

The basic data needed for tracking comes in two parts. The first is a set of parameters that define the shape and size of the orbit, and its location in space relative to the Earth. The second is a recent observation which tells us where the satellite was on this orbital track at a precise moment in time.

```
FO-29
1 24278U 96046B   04364.77938403 -.00000040  00000-0 -18814-5 0  8617
2 24278  98.5724  71.0280 0349969 255.1477 101.0648 13.52906415413283
```

Table 21.1: A set of keplerian Elements for Fuji Oscar 29, downloaded from the Internet

Satellite: FO-29	Satellite name
Catalog number: 24278	Satellite number
Epoch time: 04364.77938403	Year day and time of the observation
Element set: 861	Sequential number
Inclination: 98.5724	0 = equatorial, 90 = polar
RA of node: 71.0280	Astronomical term
Eccentricity: 0.0349969	0 = perfect circle 1= infinite ellipse
Argument of perigee: 255.1477	Astronomical term
Mean anomaly: 101.0648	Satellite's position around its orbit 0-256
Mean motion: 13.52906415	Number of orbits per day
Decay rate: 0.00000040	Drag factor
Epoch rev: 41328	Orbit number

Table 21.2: Keplerian Elements in the AMSAT format

This set of numbers used for satellite tracking are known as *Keplerian Elements* and are named after the 17th century astronomer Johannes Kepler, who worked out the equations that described planetary motion. Popularly called 'Keps', they originate from NORAD (North American Aerospace Defense Command) in Cheyenne Mountain. The satellite positions are determined by radar and optical methods and a set of Keps are constructed to give the best approximations to the observations. Not all sets of observations are equally good so the careful satelliter will take care to keep the previous element set, just in case the new set proves to be less reliable.

A set of Keps downloaded from the internet will typically be a text file made up of entries like the one shown in **Table 21.1**.

The last digit in each row, 7 and 3 in this case, are not part of the satellite data. Each is the modulo 10 check digit for that line. The check digit ensures that if there have been errors in transmission of any of data your tracking software will report it.

Known as NASA two line elements they are ideal for computers but not very human friendly The AMSAT format, shown in **Table 21.2**, is easier to work with, especially if you want to read them over the air. Some of the figures relate to astronomers' terms which describe the orientation of the orbital plane in space.

There is no room here to deal with orbital mechanics, so here are a few practical tips when using elements and tracking software.

- Use recent element sets, forward predictions become less valid the further you go from the reference data. Satellites in LEO are affected by atmospheric density; even though the atmosphere is incredibly thin the speed of the spacecraft makes atmospheric drag a factor.
- Take care with the ISS. Often the orbit is boosted, so always use the most up to date element set you can get. With the exception of the ISS you don't need to renew your element sets daily; weekly is OK.

- Keep accurate time in the shack. Radio synchronized clocks are cheap now and ideal. Also there are plenty of time services on the net. For most applications, accuracy to within a couple of seconds is fine.
- Make sure your computer's internal clock is set to match the shack clock. It is not unknown to be waiting for a predicted pass of a satellite at the wrong time, through not checking the computer clock.
- If you edit any downloaded element sets make sure your word processor can output a text file, otherwise it may add control characters which your tracking software won't recognise. If in doubt, use something simple like *Notepad*.

Tracking Software

There is plenty to choose from, running under Windows, DOS and Linux. Some is free to download from the Internet. If you purchase software from AMSAT groups, part of the proceeds go towards providing future satellites.

One of my favourites is *Instantrak* donated to AMSAT by Franklin Antonio, N6NKF. Running under DOS, the code was written to be very fast because old PCs were much slower. Consequently it will run perfectly on old laptop computers and discarded office PCs, leaving the main shack computer free for other duties. *Instantrak* will run under Windows, including XP Home and Pro.

When choosing software, look for the ability to feed output to rotator interfaces. You may want to automate your station and have the computer tracking software provide the signals to drive your rotators. The other feature to look for is Doppler Tracking. Modern transceivers have CAT ports so that they can be controlled from computers. Linking your radio to your tracking software lets the computer tune the radio for you, adjusting the frequencies to compensate for Doppler shift.

Here are a few tips in setting up any tracking software.

- Time: Check that your PC has accurate time. Look for any time zone setting requirements in the setup notes. Most trackers will default to an off set from UTC.

  Decide how to deal with time zones in your shack. I set my tracking computer clock to UTC since this is the time reference used in all satellite work. In DOS the command line to put into your AUTOEXEC.BAT file is SET TZ=0. Make a backup copy of the file first.
- Location: You will need to specify your location using Latitude and Longitude. The software may require this in degrees and minutes or decimal degrees. Carefully check to see if a plus or minus sign is needed to designate east or West of Greenwich, there is no agreed convention for this.
- Keplers: Don't expect the software to be shipped with up to date elements pre loaded.
- For useable predictions you will need to update the Keps file. In modern trackers this can often be done automatically by the software over the Internet. There should also be a facility to read a text file from a disk. Recommended sources of Keplerian elements are Space-Track.com, Celestrak.com and of course AMSAT.

The web site www.heavens-above.com is very useful if you need some satellite pass times and don't have tracking software. For example, If you are keen to listen for a few satellites before getting involved with your own software, or want predictions for visible satellites or the ISS on a clear evening. It also gives the opportunity to get some comparison pass times.

It can be very frustrating listening for a satellite that does not turn up because your tracker is not properly set up. If you do make comparisons with heavens-above, or with other tracking software don't expect a 100% match with predictions. The predicted time for the satellite depends on the the algorithms used in the calculations and the reference orbit data.

USING SATELLITES FOR COMMUNICATIONS

Frequencies

Transmitting to the satellite is known as the *Uplink*, and the signal we receive from the satellite is known as the *Downlink*. In satellite work, the uplink and downlink are in two different bands. There are several reasons for this, but one of the simplest is that if using the same band a very large cavity filter would be needed on the spacecraft to give the required isolation between its transmiter and receiver. The most used amateur bands are 2m and 70cm with 2.4GHz (S band) coming along rapidly as a good choice for the downlink. This is part of a general migration to higher bands for satellite work, moving away from crowded frequencies, and to much smaller antenna arrays, both on the spacecraft and at ground stations. Uplinks on 1.2GHz are also in use, particularly on SO-51.

The frequency allocations for satellite working need to be taken into consideration. The L band allocation for satellite working is 1260-1270MHz, not the same as the terrestrial amateur allocation. At the ground station, extensive use is made of up-converters and down-converters, and with the availability of new PA designs and RF efficient devices it's often practical to mount up-converters near to the antenna to reduce feeder losses.

Doppler Shift

Doppler shift is the observed change in frequency due to the relative motion of the object and the observer. The usual example given is the change in note of the siren as a speeding police car approaches and recedes. The amount of Doppler shift is related to the speeds involved and the frequency.

An observer that is at rest with respect to a transmitter will measure a frequency f_0 while an observer who is moving with respect to the transmitter will measure a different frequency f*. The relation is given by:

$$f^* = f_0 - \frac{v_r}{c} f_0$$

where

f_0 = frequency as measured by an observer at rest with respect to the source (source frequency)

f^* = frequency as measured by an observer who is moving with respect to the source (apparent frequency)

v_r = relatively velocity of observer with respect to source

c = speed of light = 3×10^8 m/s

Beacon Frequency	* Earth Rotation	ISS 370 km	AO-16 800 km	HEO sat. Perigee 2545 km	HEO Sat. Apogee 36365 km
29.5MHz	0.045	0.76	0.7	0.52	0.09
146MHz	0.226	3.76	3.45	2.56	0.45
435MHz	0.67	11.2	10.3	7.6	1.33
1.27GHz	1.97	30.7	30.1	22.2	3.9
2.4GHz	3.72	61.8	56.7	41.9	7.4
10.5GHz	15.5	269.5	247.4	182.8	31.5

* Contribution due to the Earth's rotation

Table 21.3: Calculated maximum doppler shift in kHz for a variety of frequencies and satellite altitudes

This equation is often written:

Doppler shift: $\Delta f = f^* - f_0 = -\frac{v_r}{c} f_0$

Note that v_r is negative when a spacecraft is approaching. The apparent frequency will therefore be higher than the source frequency. When a spacecraft is receding, v_r is positive and the apparent frequency is lower than the source frequency.

The practical consequences during communications via a rapidly moving satellite are that the satellite receives our uplink signal on a shifting frequency; we receive the satellites downlink on a shifting frequency. It was expected that SSB communications would be very difficult under these conditions but in practice, small compensation adjustments during the QSO keeps both stations on frequency. Using computer control of the transceiver automates the process as the software calculates the Doppler shift and updates the radio every second or so.

An interesting fact is that the satellite's speed and direction will be different for each station in the footprint. Consequently, the Doppler shift experienced by each of the partners in the QSO will be different.

The amount of Doppler shift encountered by a satellite user is a function of the frequencies involved, and the velocity of the satellite. **Table 21.3** is based on a mathematical calculation, and gives an indication of the maximum shift for a variety of frequencies and satellite heights. The height or altitude of the satellite is a factor simply because to stay aloft satellites at low altitudes must travel faster than satellites at high altitudes.

Antennas

The choice of antennas will be determined by the type of operation envisaged; fixed station, portable or hand held. It would be very easy to get bogged down here in the science and engineering aspects of the perfect antenna array for a satellite ground station. However, as radio amateurs we generally have to take a practical approach and work within budgetary and other constraints. Fortunately, its quite possible to 'home brew' effective antennas for space communications. It is also possible to purchase good equipment commercially.

The newer generation of FM satellites can be worked with a hand-held radio with 2m and 70cm with 5 watts. Some skill is needed though, and results are much better with a small dual band Yagi which can be hand held. Using such equipment, contacts from the UK into North America happen regularly. The Arrow antenna, available from AMSAT-UK [1] is ideal for this sort of work as can be seen in **Fig 21.3**. Designed to dismantle easily and pack into a small bag, it is very light and can easily be used on holiday.

Fig 21.3: Andy Thomas, operating as YL/G0SFJ/P, and working through SO-50 from Riga. He used an Arrow antenna and 5W from a Kenwood THD-7E

For fixed stations, probably an early consideration is what can you can do with existing equipment. A cross boom can easily be fixed up to accommodate the 2m and 70cm antennas. If using crossed Yagis for circular polarisation, mount them in the X configuration to reduce interaction with the cross boom (see the VHF/UHF Antennas chapter for more on circular polarisation and crossed Yagis). This can be either aluminum or fibreglass. Fibreglass is often recommended, but experience has shown that when the antennas are mounted as suggested there is no discernable interaction with a metal boom. The professional satellite engineer puts circular polarisation antennas at both ends of the link, satellite and ground station. This reduces the effects of fading, and attenuates reflections which tend to be of linear polarisation. In practice, the signals arriving from space are subject to large polarisation changes as they pass through the ionized layers of the atmosphere. There is a wide variation in antenna configurations used by satelliters, including many with simple linear polarisation. Don't let the additional complexity of producing circular polarisation on 2m and 70cm put you off; give linear polarisation a try first.

At 2.4GHz and 1.2 GHz you will probably be using a small dish antenna. When the signal is reflected off the dish the polarisation is reversed. A Right Hand Circular Signal arriving at your dish needs to see a Left Hand Circular Polarised feed. There are plenty of designs around for dish feeds, with full constructional details. Those from G6LVB and G3RUH for example.

Rotators

Antenna rotators for *azimuth* and *elevation* are costly. That level of purchase is not recommend until you are sure of a long term interest in satellite working. Instead, use an azimuth rotator and angle your antennas up by about 20 degrees. Unless you are a very serious DXer, the effect on terrestrial work will not be noticeable and you will be able to work through plenty of satellites when at low elevation. (If you recall the footprint discussion, these are the times for the best DX).

Rotator Controllers

Most proprietary rotators can be interfaced to the PC to give automatic satellite tracking. Howard Long, G6LVB, has developed a low cost design which is available in kit form from Amsat-UK [1].

Pre-amplifiers, Feeders and Connectors

Use the best cable you can afford, and the best connectors. A well constructed set up will last 10 years or more so it's worth the investment. Cable such as RG58 is pretty useless at the frequencies in question and even RG213 is quite lossy at 70cm. Study the cable specifications at various frequencies, and the cost of the cable before deciding what to purchase. Westflex 103 is very popular with satelliters being a good compromise between cost and performance.

The centre core is too big for standard N connectors, buy the special Ns or file down the centre core. If you decide to file, don't allow the filings to fall inside the cellular structure of the cable. Use good quality N connectors, they will last for years. For receive only applications, satellite TV cable gives good results at low cost.

Mast head pre-amplifiers may be needed if you have a long cable run. High gain pre-amps designed with the terrestrial DXer in mind sometimes give problems with desensitisation ("de-

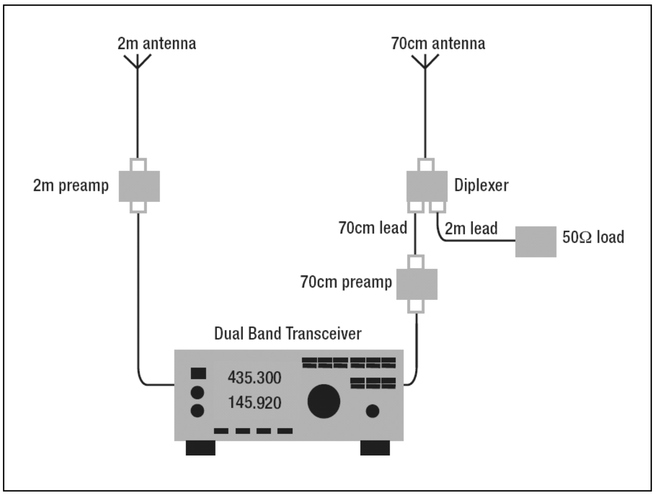

Fig 21.4: Using a commercial diplexer to reduce receiver desensitisation on mode V/U

sense") which is caused by the third harmonic from the 2m uplink signal. Changing the layout of the cables and antennas can sometime reduce the problem but a better solution is to use a stub filter as shown in **Fig 21.4**.

TRANSCEIVERS FOR SATELLITE WORKING

Hand Helds

A Dual band, 2m/70cm radio with about 5W output will be suitable for working the FM LEO satellites. If you are interested in digipeating APRS (Amateur Position Reporting System) via satellite, a built in TNC is useful.

Full duplex is recommended so that you can hear your own downlink from the satellite whilst transmitting. Doppler compensation is dealt with by using the radio's programmable memories to set the transmit/receive frequency pairs. The operating technique is to receive about 10kHz HF of the published frequency at the start of the pass, and click through the pre-set memories as the pass progresses (**Table 21.4**). Always have the squelch fully open; not doing so is often the cause of frustration for new operators. A recording device is a good idea to help with logging.

Fixed and Portable Stations

It's not essential to buy the latest fully featured multi band transceiver for satellite working. Many stations use two separate radios; one for transmitting and one for receiving, this gives full duplex working and in some respects can be easier than learning to operate a multi band rig with lots of features. A secondhand transmitter or receiver might be all you need to get you going.

Modern multi-band transceivers come with many operating features for the satelliter. Radios with a VHF/UHF heritage seem to offer the best range of added satellite features but study the specifications and see what other people are using successfully on satellites.

Whichever route you choose here are a few pointers:

- Transmit power should be variable, ideally from full to a few watts. With modern high power radios the full output is seldom required for satellite working.
- If buying a combined transceiver, the 2m and 70cm sections should each be separately controllable during a contact.
- Computer control or a CAT port will be useful, if not when you first start then a bit later on. Most modern radios only need an RS232 cable to link the radio to the PC. Older radios may need an interface. Check that these are still available or that you can home brew one.
- Packet ports are a useful feature for 9600 and 1200 baud data applications, and are essential if your main interest is in digital satellites. They are also useful if you want to capture telemetry, as 9600 is becoming the preferred data rate on newer satellites. If you have an older radio you may need to make some internal modifications to successfully use data modes.
- Built in doppler tracking is a useful feature if not using external computer control. When using SSB, this synchronizes your uplink and downlink frequencies. Then, as you move up and down the band the rig adjusts the transmit frequency. Only minor re-tuning will be needed to be on frequency.

	Rx	Tx
AOS	435.310	145.910
	435.305	145.915
TCA	435.300	145.920
	435.295	145.925
LOS	435.290	145.930

AOS =Acquisition of signal, the start of the pass
TCA = Time of closest Approach
LOS = Loss of signal, the end of the pass

Table 21.4: Frequency memory settings for working SO-51 on a hand-held radio

SATELLITE SUMMARY

The information for this section came from a variety of sources, but principally from AMSAT [2]. It was accurate at the time of writing, but satellites have a finite life, so for the most up to date information check the amsat.org web site.

AMSAT Oscar 7 (AO-7)

Launched in 1974, AO-7 suffered battery failure in 1981. In 2002 its shorted battery cells became open circuit enabling the spacecraft to run directly off its solar panels. Semi-operational, this satellite can still give some good contacts when it is in sunlight.

UoSAT Oscar 11 (UO-11)

A University of Surrey (SSTL) built satellite, launched in 1984, Oscar 11 is now operating in default mode. It continues to send ASCII telemetry data for 10 days with a 10 day break. Operation can be terminated at any time by the ground controllers. The 'mode S' beacon is on continuously transmitting on 2401.5MHz with an unmodulated carrier. Beacon reception reports are welcomed by Clive Wallis, G3CWV [4].

Radio Sport (RS-15)

One of the last of the successful RS series of Russian amateur radio satellites, RS-15 is only semi-operational with its CW beacon occasionally heard. Some contacts have been made via RS-15.

AMSAT Oscar 16

Launched in July 1991, Oscar 16 was a major store and forward digital satellite. It now operates only in digipeater mode.

LUSAT Oscar 19 (LO-19)

Launched in 1991, the BBS is non operational. The CW telemetry beacon is fully operational producing strong signals.

UoSAT 5 (UO-22)

Launched in July 1991, and built by the University of Surrey, UO-22 was a major digital satellite handling large volumes of traffic at 9600 baud. It is currently semi operational whilst SSTL are trouble shooting. Operating only when in full sunlight, operations could be terminated by the ground controllers at any time.

AMRAD Oscar 27 (AO-27)

AO-27 was launched September 1993, as part of a commercial satellite. With limited battery capability, AO-27 switches to analogue operations six minutes after coming into sunlight. After six minutes of analogue there is one minute of digital telemetry. The operating schedule changes frequently. Latest information from the control operator, N3UC, can be found at [5].

Fuji Oscar 29 (FO-29)

Launched in August 1996 on a Japanese H2 launcher from Tanegashima Space Centre Japan, FO-29 failed briefly in June 2003, probably due to a major solar flare. Now operational again, FO-29 is a popular SSB/CW satellite. From time to time the transponder is switched off and an automated voice message is broadcast so that school children in Japan can hear the message from space as part of their science course. The message generally starts "This is Jas two.......", followed by a bird call.

Gurwin TechSat1b (GO-32)

TechSat1b was launched in July 1998. Users may be able to use the BBS. Check the GO-32 web site and satellite beacons for updates [6].

AMSAT Oscar 40 (AO-40)

After providing several months of excellent contacts and experiments, since its launch in November 2000, AO-40 suffered a catastrophic failure of its onboard systems. Recovery efforts continue but it is unlikely to return to service. See Amsat bulletins for the latest information [7].

Saudi Oscar SaudiSat 1a (SO-41)

Launched in September 2000, SO-41 is semi operational, turned on by an internal timer programmed to activate the satellite over land masses. Sporadic operation.

PCSAT Navy Oscar 44 (NO-44)

Launched September 2001, NO-44 is currently semi operational because the battery is not maintaining sufficient charge for operations in eclipse. Used extensively for 1200 baud APRS digipeating from handhelds and mobile stations, NO-44 could return to full service when the eclipse period decreases.

Tiung SAT (MO-46)

Malaya's first micro-satellite was built in co-operation with SSTL and launched in September 2000. It carries commercial land and water imaging as well as FM, FSK amateur radio data communications using a 38k4 baud downlink.

Saudi Oscar SaudiSat 1c (SO-50)

Launched in December 2002, SO-50 requires a 74.4Hz CTCSS tone to turn on the transponder. This activates a 10 minute timer. All transmissions then need a 67.0Hz CTCSS tone to access the transponder. Another 74.4Hz tone will reset the timer for another 10 minute period.

AMSAT Echo (AO-51)

Launched June 2004, AO-51 has FM voice, PSK 31 and data modes. This is a new generation microsat with many advanced systems on board. Wednesday is experimenter's day when different configurations of uplink and downlink frequencies are enabled. Visit the web site for up to date operating information [8].

Amateur Radio on the International Space Station

The ISS carries a variety of voice and packet equipment and SSTV may be added. Amateur radio is an approved recreational activity for the crew, many of whom become licensed radio amateurs prior to the mission. Schools contacts with the ISS are arranged via ARISS but random contacts are always a possibility. Check out the crew's work and rest schedule at [9]. Visit the ARISS web site [10] for the latest information.

Mozhayets (RS-22)

This is a training satellite, built by students at a military academy in St Petersburg. The CW beacon sends telemetry at around 5WPM with a 10 second break between transmissions. Data blocks start with "rs22" This satellite is sometimes wrongly attributed in sets of Keplerian elements. The NASA catalogue number corresponding with RS-22 is 27939.

SSETI EXPRESS

A European Space Agency (ESA) satellite built by engineering students, it is expected to be launched in 2005. Several AMSAT groups, including AMSAT-UK have assisted students with the design and construction of the amateur radio payload. It will carry an FM transponder and packet radio. There will be downlinks on 2.4GHz and 70cm with data rates of 38k4 and 9k6 respectively. ESA will be offering a prize for the station that captures and e-mails them most telemetry.

Hamsat VUSAT (VO-52)

Hamsat, built by Amsat-India and ISRO, was launched in early 2005. It carries beacons in the 2m band and two 1W analogue transponders for CW and SSB.

Amsat Eagle

A future launch, this is a major International AMSAT project led by AMSAT-NA. In a high elliptical orbit it will offer long operating times and a large footprint. Visit [2] for latest information.

ESA Sputnik 50

In 2007, to celebrate the 50th anniversary of the launch of Sputnik 1, ESA plans to launch 50 student/university built satellites.

Cubesat

An initiative for Universities, this project provides launch opportunities for tiny science and engineering satellites, measuring 100mm cube and weighing up to a kilo. Several universities have flown cubesats and their telemetry and data can be copied on amateur frequencies. Put "cubesats" into an internet search engine or visit [2] for up to date information.

P3E

This is an AMSAT-DL led project to build an HEO satellite similar to the very successful AO-13. For more details, visit the AMSAT-DL web site [3] which is available in English.

P5A

An ambitious project from AMSAT-DL [3] to take amateur radio to Mars.

Weather Satellites

The NOAA polar orbiting weather satellites transmit in the 137MHz band. They are easily copied on amateur radio equipment. Visit the GEO and RIG web sites [11, 12] for more information.

RADIO ASTRONOMY

The well equipped amateur radio station already has many of the facilities needed for radio astronomy. The shack PC, soundcard, and software such as *Sky-Pipe* gives access to DSP and data recording techniques that at one time only existed in University departments. Visit the JOVE website [13] for more information.

RECOMMENDED READING

A Guide to Oscar Operating, edited Richard Limebear, G3RWL

Available from AMSAT-UK [1], this comprehensive guide is kept at a low price to assist beginners. It contains much valuable information based on years of practical satellite operating.

The Radio Amateur's Satellite Handbook, Martin Davidoff, K2UBC (ARRL)

Essential material for beginners and for the experienced operator. The author, an experienced satelliter, covers the whole subject in a practical and accessible way from antennas to orbital mechanics. The mathematics are well explained with worked examples. A book to dip into on a regular basis. Available in the UK from the RSGB [14].

WEB RESOURCES

A major source of information is the AMSAT-UK web site [1], and also the AMSAT NA site [2]. All of the topics covered briefly in this chapter are fully explained. The AMSAT-NA web site has a section entitled: 'New to Satellites' which is a good place to start.

Also, try putting a satellite's name into an Internet search engine. This will in many cases take you to radio amateurs' own web sites where you can find operating hints and tips from someone who regularly uses a particular satellite.

MOONBOUNCE COMMUNICATIONS

Moonbounce or EME (Earth-Moon-Earth) communications presents one of the most significant challenges in amateur radio. Stations who wish to communicate simply point their antennas at the Moon which is then used as a passive reflector. After a number of tests by the US military and others in the 'forties it was fairly soon realised that EME propagation was within the reach of amateur stations. The first two-way amateur contact took place in 1960 between W6HB and W1BU on 1296MHz and has now been followed by others on every amateur band from 28MHz to 10GHz.

From the basic radar equations and the knowledge of the reflectivity of the Moon (about 6%) it is quite easy to calculate the propagation loss which ranges from 242dB at 50MHz to 276dB at 2320MHz. This on its own would call for exceptional station performance but, with the addition of somewhat unpredictable propagation through the Earth's ionosphere, EME communications really does require the ultimate from an amateur station. It not only places strenuous demands upon the station but also requires excellence in weak-signal operating. Although SSB operation is sometimes possible, nearly all EME operation is on CW so be prepared for long periods of 'rushing' and 'ringing' in the headphones.

In line with terrestrial activity the majority of EME operation is on the 144MHz band closely followed by 432MHz. 1296MHz is popular among those already active on one of the lower bands, leaving the other bands with very sparse activity - QSOs on the microwave bands occur only as a result of prearranged schedules. Despite all of these difficulties there are currently several hundred amateurs across the world who are regularly active on this mode with a handful or so at the forefront having attained DXCC via EME.

Propagation

The principle of EME communications is simple - both stations must be able to see the Moon, they point their antennas in the right direction and communications should be possible. In practice it is not quite that simple as there are a large number of other factors which need to be taken into consideration.

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 one-half degree to a terrestrial observer. On all but the higher microwave bands this is significantly less than the beamwidth of most amateur antennas used for EME. This means that when the antenna is directed towards the Moon it will be significantly illuminated by the cosmic background. This background is not quiet - it 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 ruled out 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 all amateur signals.

The Moon as a reflector

Another source of loss comes as a result of the Moon being an imperfect reflector and the relative motions between the Earth and the Moon called *librations*. In simple terms, 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 EME path

First let's consider how much signal gets lost on the trip to the Moon and back. The basic path loss can be calculated from the radar equation and the average lunar reflectivity, approximately 7%. A small complication is that the Moon has a slightly elliptical orbit but this only results in a 2dB additional loss at apogee. **Table 21.5** shows the EME path loss for the most popular bands when the Moon is at its at closest approach, ie at perigee.

Spatial offset

Most amateur VHF and UHF stations use linearly polarised antennas, normally horizontal for DX working. Even if all operators were

Frequency (MHz)	50	144	432	1296	2320
Loss (dB)	244	252	261	271	276

Table 21.5: EME path loss when Moon is at perigee

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 polarisations. 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. This would suggest that for successful EME communications antenna systems would need fully rotatable polarisation. Fortunately ionospheric effects cause rotation of polarisation which makes communications between amateurs with fixed polarisation arrays possible.

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 is often reported during ionospheric storms, there are many reports of strange signal enhancements. What is sure is that when the ionosphere is disturbed EME conditions can never be described as 'normal'.

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 *birefringent*, that is to say it has multiple refractive indices. These occur as a result of the effect of the Earth's magnetic field upon ionised electrons in the ionosphere.

These refractive indices are normally calculated for propagation directions longitudinal and transverse to the Earth's magnetic field. Faraday rotation occurs as a result of radio waves passing through this birefringent layer in the ionosphere (remember for EME you get two passes, one in each direction). The refractive indices are not fixed but vary directly with the solar input to the ionosphere which gives rise to the great variability. Hence during the daytime the Faraday rotation is far greater than at night - typical values of Faraday rotation for a single pass through the ionosphere are given in **Fig 21.5**.

One of the important things to remember is that when the signals reflected back from the Moon pass back through the ionosphere (even through the same volume such as when listening to one's own echoes) the Faraday rotation doesn't 'unwind' the rotation. Instead, it 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 in the reception of EME signals.

With linearly polarised antennas a 90º 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 rotatable receive polarisation.

EME Station Equipment

Frequency stability & accuracy

Although contacts have been made with relatively simple equipment the basic requirement is for a transceiver or a separate receiver and transmitter with excellent frequency stability and readout.

The main receiver should have good CW capabilities, preferably with a range of narrow IF filters and a well-calibrated IRT. As the majority of EME operators use a quality HF transceiver with VHF/UHF external transverters these too must have good frequency stability. It can be really annoying if the station which you are listening to fades down in QSB only to reappear 15 minutes later outside your receiver passband. Likewise you might not be able to complete a contact if you drift by only a few hundred hertz and your QSO partner fails to re-tune his receiver.

Sorting out drift in a transverter can be a lot more difficult especially with kits and small commercial units - some can take as long as an hour before they settle down and often the exact frequency changes with external temperature. Whilst not a universal cure the addition of one of the cheap Murata clip-on crystal temperature regulators can help a lot. These regulators heat the crystal casing up to about 35°C and then maintain it at this temperature. The result is greatly increased drift for the first few minutes after switch-on but this is followed by excellent medium-term stability even on the microwave bands.

Another very desirable and essential feature for those looking for EME schedules 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 expedition 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. This will need to be carried out or repeated via any transverter used in order to determine the true transmitter frequency.

Receivers, audio filters and headphones

The vast majority of modern HF and many all-mode VHF transceivers will meet the frequency stability and readout criteria - apart

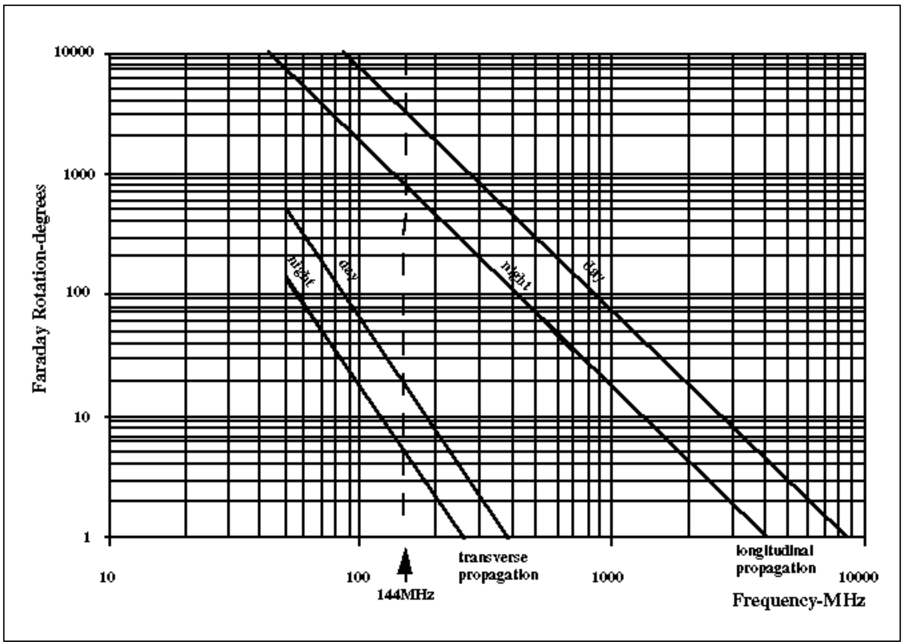

Fig 21.5: Typical values of Faraday rotation for one pass through the ionosphere constructed from data obtained from [15]

from a good CW IF filter the other features come down to user choice. An important issue with any rig used for EME operation is operator comfort and this means choosing your filters carefully.

An IF filter is almost essential, with 300-500Hz bandwidth being commonly used - filters which are too narrow or peaky can result in undesirable ringing which can be a real pain. In addition to a good IF filter most operators use an external audio filter, usually tuneable and often with variable bandwidth. As computer technology has advanced so have DSP audio filters, and as they have improved the majority of operators have changed from using more traditional analogue audio peak filters. When calculating EME station performance an audio filter bandwidth of 100Hz is often assumed, but it can be argued that 'natural' filtering by the ear and the brain results in an effective receiver bandwidth of about 50Hz. A part of the receiver that is very often forgotten, but very important for EME operation, is the operator interface - the headphones. As you will be dealing with weak and noisy signals for long periods of time the issues here are comfort and keeping out background noise. While there are many 'communications' types on sale, many of the hi-fi types can often offer superior performance at lower cost.

Preamplifiers

A low-noise masthead preamplifier is near essential for any successful EME operation. Although shack-mounted preamplifiers may well produce acceptable results for terrestrial and amateur satellite operation, the addition of the feeder loss in front of the preamplifier will always result in an inferior, sub-optimal noise figure.

If you are considering serious EME operation you should also consider mounting your main transmit/receive changeover relay at the masthead. High-performance, high-power coaxial relays generally have lower insertion loss than preamplifiers with on-board relays. The choice of preamp is relatively easy - go for the lowest noise figure that you can afford. If you can't afford to buy a commercial unit there are designs available for all of the VHF, UHF and microwave amateur bands which 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 rallies or conventions where noise figure measurement facilities are provided.

Although GaAsFET preamplifiers are not renowned for exceptional dynamic range, the majority of strong-signal problems are generated in the later RF stages of the receiver. 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 filters in front of the preamplifier will almost certainly degrade your hard-won receiver noise figure.

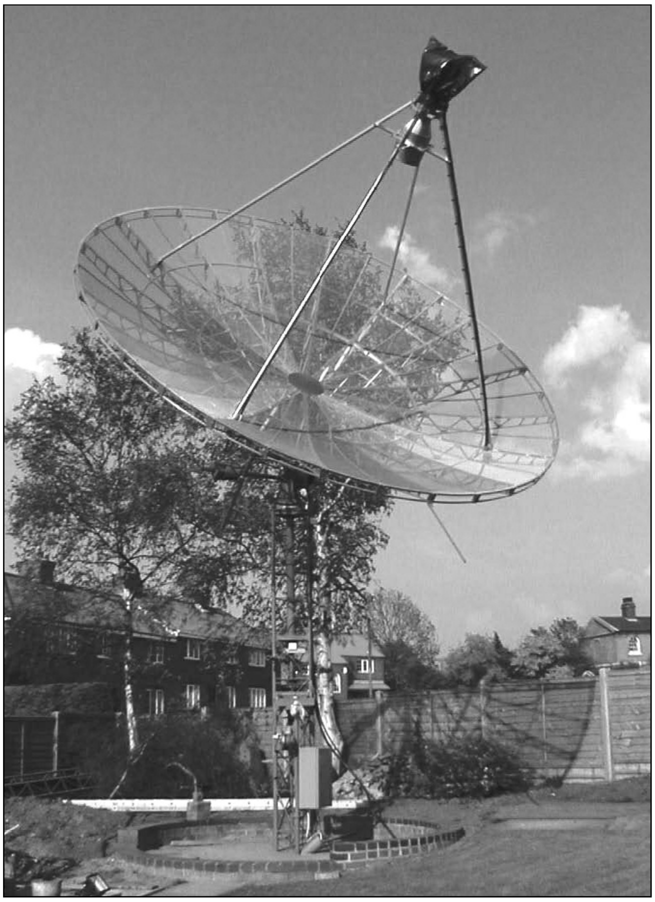

Fig 21.6: The 5.4m dish antenna built by G4CCH for 23cm moonbounce

Transmitters and amplifiers

As you will have already realised, the very high path losses mean that high output power is essential for all EME operation. This means that whenever possible you will need to be running close to the maximum permitted licensed power at the antenna. On the microwave bands, where high-power generation is difficult, most EME stations increase their antenna size to compensate. There are also trade-offs which can be made between feedline loss and transmitter power output but lower-loss feeder usually turns out to be the most economical answer. There are suitable designs for high-power amplifiers in this handbook and in elsewhere. If you are going to build an amplifier and are contemplating EME operation make sure that it has adequate cooling to cope with the heavyweight duty cycles required when running schedules.

When running high 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 especially with regard to harmonic output, and a low-pass filter is a 'must'. A number of high-performance filters capable of high-power operation have been published.

Keyers

Although a few stations still prefer to use a straight key the majority of EME operation is made using some form of memory keyer. There is no doubt that precise, well-formed characters and regular rhythm can help improve readability at very low signal strengths. Information is usually sent without punctuation and regularly repeated for the duration of a transmit period, making keyer programming an easy job. Although there are a number of commercial models available, and you can even use your home computer to perform this function, many EME operators choose to build one of the many designs available.

Computer

EME operation is made easier by using customised computer software (eg WSJT) to make the most of this mode. Furher information is available from [16]. A computer is invaluable to arrange skeds by e-mail and through special interest groups. It can also be used to help align an antenna system with the moon.

Antennas

The antenna system is probably the most important part of an amateur EME station - it is often very large and requires significant effort in its construction. Most texts usually include calculations based on the path loss (**Table 21.5**), maximum legal power at the antenna and system noise figure to arrive at the minimum antenna gain to detect echoes. These calculations result in a gain requirement of approximately 20dBd at 144MHz and 23dBd at 432MHz. On 144MHz four stacked 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 echoes. However, many stations have had very good results with 3dB less antenna gain - this is mainly because the lunar reflectivity of 7% is only an average and libration fading will produce signal peaks several decibels above 'normal' signal levels. Operation with sub-optimal antenna systems will usually require narrower receiver bandwidths and well-honed operating skills. On 1296MHz and above the majority of EME stations use dish antennas ranging from 3m C band TVRO to 12m ex-commercial systems. These antenna sizes are made on the assumption that the station is capable of a contact with a station of similar size - there are a number of amateurs that have systems up to eight times larger than those quoted above. As a result even the most simple one-Yagi stations are capable of EME QSOs with such 'big-guns'.

As for amateur satellite operation, EME antenna systems also require elevation control in addition to azimuth rotation. Because of their size and weight EME arrays usually require the largest heavy-duty rotators. Lightweight elevation rotators, such as are used for amateur satellite antennas, are rarely adequate for EME arrays.

Although there are specialised chain-drive elevations systems available, many amateurs build their own elevation systems, often using 'screw-jacks' used for pointing TVRO dishes. One feature that can ease construction of an EME elevation system is that in the UK the Moon only reaches a maximum elevation of 60º. Pointing accuracy depends upon the antenna beamwidth; simple direct-reading meters are usually OK for Yagi arrays but greater accuracy, preferably with digital readout, is required for dish antennas.

Ground gain

As with HF antennas, reflections from the ground can give VHF and UHF antennas additional gain with a small upwards tilt in the main lobe. This additional gain can often make EME QSOs possible between stations which would otherwise not be able to hear each other. It is by using such 'ground gain' that many smaller 144MHz stations gain their first experience of EME. It is very 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 S/N.

Operating

The majority of those who operate on EME started off by listening - although not essential, 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.

More information on EME operation and procedures can be found in [16].

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