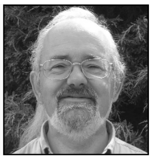
Bonus chapter

Satellites and Space



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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, it sent "HI HI" and was copied by radio amateur around the world.

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 to 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.

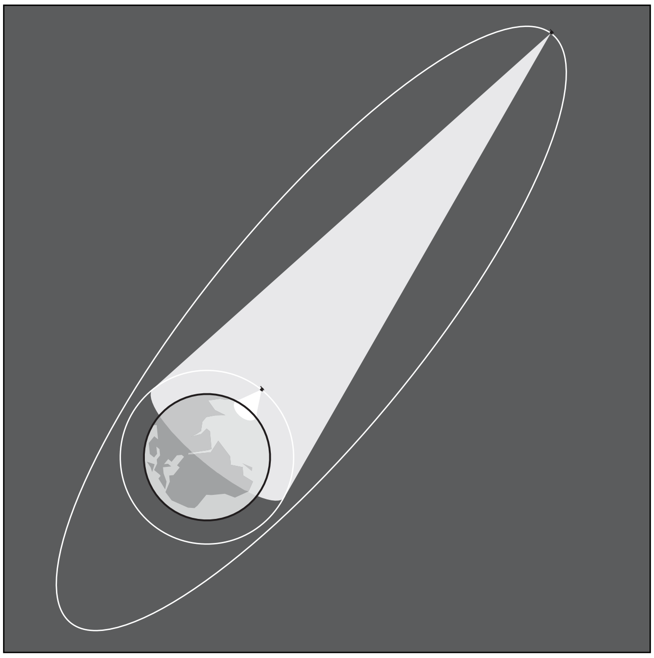

Fig 1: Footprint for high and low altitude orbits: LEO satellite at 1,000km; HEO satellite at 60,000km

SATELLITE ORBITS

Fig 1 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 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 the *perigee.* And 20,000km or more at its furthest distance from the Earth, called the *apogee*. An easy way to remember which term is which: furthest **A**way = **A**pogee.

This orbit is very useful for communications as it has a large footprint for most of its orbit (Fig 1). 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 Molniya 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 Molniya 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.

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 is 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 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 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 programs are 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.

```
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 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 2: Keplerian Elements in the AMSAT format

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 between different software programs, don't expect the predictions to match precisely. The predicted time and position of the satellite depends on the algorithms used by the software, and the particular set of Keps used as the start point.

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 transmitter and receiver. The band combinations and code letters (often referred to as 'modes') are shown in **Tables 3 and 4**.

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 AO-51.

V = 145MHz
U = 435MHz
L = 1260MHz
S = 2.4GHz
C = 5.6GHz
X = 10GHz

Table 3: Satellite operating modes

U/V	.....70cm/2m
V/U	.....2m/70cm
U/S	.....70cm/13cm
U/L	.....70cm/23cm
L/S	.....23cm/13cm
L/X	.....23cm/3cm

Table 4: Uplink/Downlink combinations

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

This equation is often written:

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

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.

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 5: Calculated maximum doppler shift in kilohertz for a variety of frequencies and satellite altitudes

The amount of Doppler shift encountered by a satellite user is a function of the frequencies involved, and the velocity of the satellite. Table 5 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 2. Designed to dismantle easily and pack into a small bag, it is very light and can easily be used on holiday.

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).

Fig 2: Andy Thomas, whilst operating as YL/G0SFJ/P, and working through SO-50 from Riga. He used an Arrow antenna and 5 watts from a Kenwood THD-7E

Fig 3: A Lindenblad type antenna using parasitic elements designed by Anthony Monteiro AA2TX a useful omni for the 70cm band

The cross boom 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 fading caused by reflected signals which tend to have linear polarisation. In practice, the signals arriving from space are subject to large variable polarisation changes as they pass through the ionised layers of the atmosphere caused by Faraday rotation. 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.

Fig 3 shows an example of an omnidirectional antenna for 70cm.

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

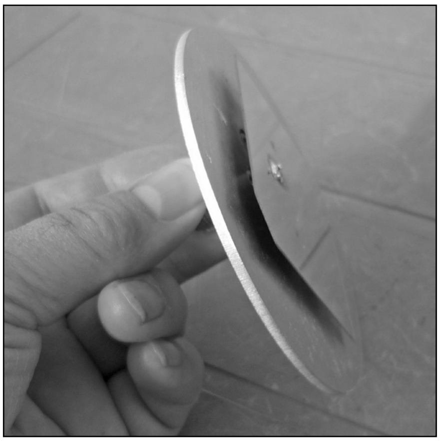

Fig 4: A simple patch antenna for 2.4GHz, Mode S

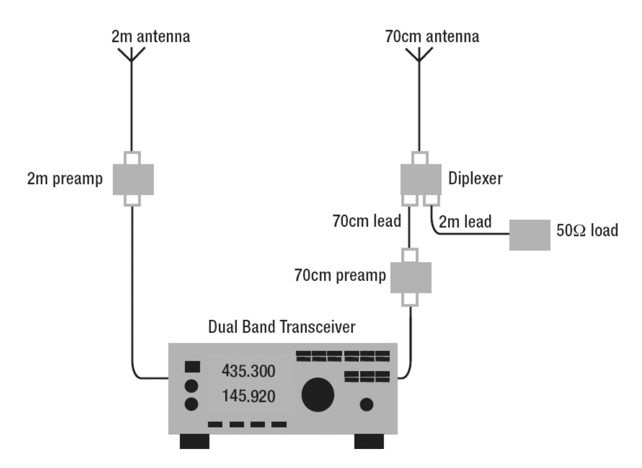

Fig 5: Using a commercial diplexer to reduce receiver desensitisation on mode V/U

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. A simpler alternative is the patch antenna illustrated in **Fig 4**.

Rotators

Combined antenna rotators for both *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 15 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 N type connectors 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-sense") which is caused by the third harmonic from the 2m uplink signal. Changing the layout of the cables and antennas can sometimes reduce the problem but a better solution is to use stub filters such as in **Fig 5** which shows a commercial Diplexer in that role. The Comet CF-416C is reported to work well. The 2m leg of the stub can be left unterminated. Waterproofing will be required if the installation is outside.

	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 6: Frequency memory settings for working AO-51 on a hand-held radio

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 6**). 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.

The AMSAT-NA web site [2] has very good section with operating hints for AO-51, one of the most popular and easy to work FM satellites. Click on the link to the AO-51 Project page and then the link to "12 Suggestions for success in working AO-51 on a Hand Held Transceiver" written by Emily Clarke, W0EEC.

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.

SATELLITE TELEMETRY

Ground control stations need to monitor the health of their satellite and its payload in respect of on board temperatures, battery charge condition, solar array currents, and many other parameters. When transmitted to Earth this data stream is referred to as telemetry (**Fig 6**). The satellite beacon signal often doubles up as the telemetry signal so that the transmission consists of the satellite identifier followed by the data. Various modulation schemes are used from the simplest Morse code beacon on LO-19 to 9600 baud packet from AO-51.

Telemetry study is receive only and can become an interest in itself. It becomes especially exciting when we have a new satellite launch. Generally the telemetry beacon is switched on right at the start of the mission and it's a challenge to be amongst the first to capture the data. Often ground stations welcome the captured data files as it enables them to receive data when the satellite is out of range of their own ground station. Web sites are usually set up where radio amateur can upload their received data.

Software such as *Hamscope* and *CWget* work well for the Morse code beacons. *MixW* is also very good for CW and a wide range of data modes. Packet data can be processed via a hardware TNC or in software with programs such as *AGW Packet Engine*. Look at the satellite's web pages to get details of the telemetry available, the data format and the decode equations. Also visit JE9PEL and DK3WN's web sites [4] and [5], to download excellent and free software to decode your captured data. Satellite telemetry data is regularly posted on DK3WN's blog [6].

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.

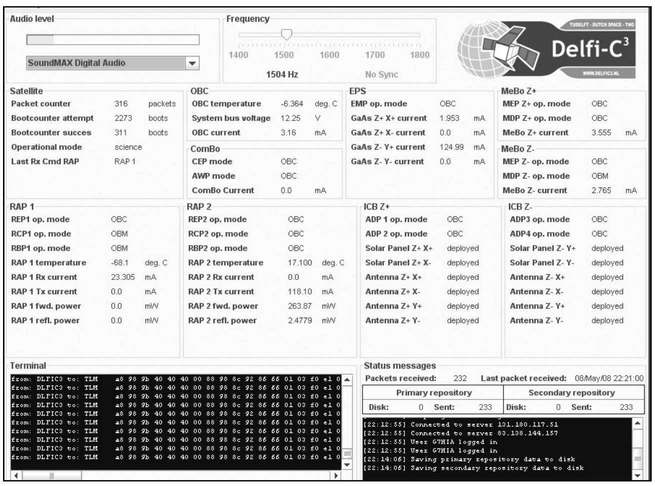

Fig 6: Satellite telemetry decoded on a home computer

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, After many years of service, including useful transmissions from its 2.4GHz beacon, Oscar 11 is now non operational..

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 [7].

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 [8].

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 [9].

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. It 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 [10].

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 - ESEO

Amsat-UK members are currently building/designing a communications system that will be launched on the ESA educational satellite ESEO. This will be a 75kg satellite going into Low Earth orbit.

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

Cubesats

The downlinks are mainly on the 2m and 70cm bands using CW and packet. The low power CW beacons using around 100mW can be copied with a modest ground station. Cubesat teams often welcome telemetry data and beacon reports and some provide QSL cards (**Fig 7**). Delft University (DO-64) provided free software called *Rascal* which enabled radio amateurs to operate as a data capture station with an internet link to the university's fileserver, all valid data frames being uploaded automatically. Hundreds of radio amateurs worldwide contributed valuable data to the Delfi team.

Amateur Radio on the ISS

The International Space Station 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 [11]. Visit the ARISS web site [12] for the latest 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.

A Chinese OSCAR

The First Chinese armateur satellite XW-1 was due to be launched in December 2009 by a CZ-4C launch vehicle. According to Alan, BA1DU, the XW-1/CAS-1 project manager, payloads include a 70cm CW telemetry beacon, Mode J(V/U) linear transponders, FM repeater and 1200bps AFSK Store-Forward transponders base on the Pacsat protocol. China has an ambitious and successful space program, so this may lead to further launches and possibly co-operative projects with AMSAT groups.

Space Walks

The Russian Orlan spacesuits are equipped with VHF FM which creates an interesting opportunity for anyone with modest VHF receive setup. The frequencies are either 130.167, 121.125 or 121.700MHz. Your regular 2m antenna will give good results.

As these frequencies fall within the AM airband allocation, expect some interference from aircraft. This is intermittent so you will get some of the space walker's conversation.

My method is as follows. When there is a Russian EVA, log onto NASA TV on the internet and watch the live coverage. As the ISS comes into range check your receiver to establish which downlink is in use and switch on your recorder. *Note* that this only works with Russian spacesuits, American suits use a different comms system.

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 [13, 14] for more information.

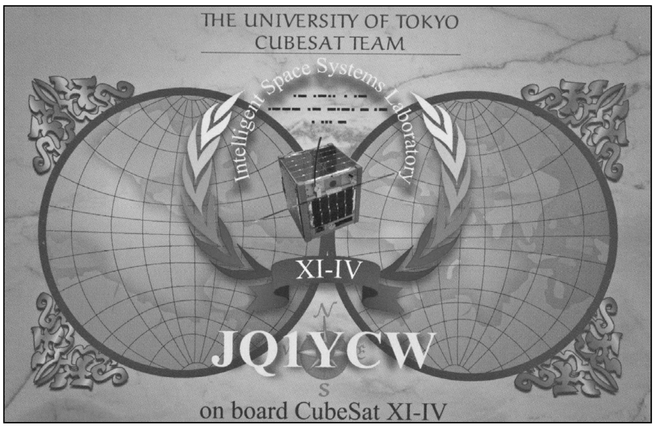

Fig 7: QSL card from Nakasuka Laboratory School of Engineering University of Tokyo. Cubesat XI-IV was launched in 2003 and later designated CO-57 by AMSAT

DIGITAL MODES ON SATELLITES

Popular in the early 1990s but largely superseded by the internet, the digital satellites enabled file sharing between stations across the globe. Gurwin GO-32 still operates digital modes from time to time. Digital modes may also be available on AO-51, CO-55 and as part of the ARISS project, digipeated via the International Space Station.

APRS

OSCAR 44 (NO-44) is solely dedicated to APRS using 1200bps standard packet on 145.827MHz. If you have equipment for terrestrial APRS you can receive and operate through NO-44. Due to a limited power budget, the satellite is not operational all the time so check with the web site for details and tips on correct operation. APRS can also be digipeated through the ISS. Ensure you operate according to the correct protocols otherwise you will block the channel for other users.

RECOMMENDED READING

A Guide to Oscar Operating, edited by 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 [15].

Orbital Mechanics, Dr TS Kelso

Visit www.celestrak.com and click on the box marked "Computers & Satellites Columns". Here you can read articles written for the magazine *Satellite Times* (sadly no longer published). The material is excellent, and takes the reader through the subject in a clear systematic way, and in a highly readable form.

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.

RADIO ASTRONOMY

One of the interesting aspects of space communications is the observing of extra-terrestrial natural objects. For those amateurs who have a large steerable antenna array, such as used for EME, radio astronomy is definitely a possibility. Even for those without an EME-type array, simple antenna systems can still yield good results.

Radio astronomy is a 'receive-only' type of system. The signals received from deep space natural bodies are not in the format of a coherent carrier, such as CW, but rather it is a broad spectrum of noise. Hence, it matters little if we receive on 144MHz, 432MHz etc. Often the biggest problem is finding a portion of spectrum *not* occupied by man made signals.

The science of radio astronomy is a relatively modern form of astronomy. Whereas optical astronomers have been traced back more than 2000 years to the Chinese, radio astronomy only started accidentally around the early 1930s when Karl Jansky of Bell Telephone Laboratories in the USA observed strong signals from an object in the Milky Way we now know as Sagittarius-A. Jansky's simple apparatus operating on about 20MHz detected strong signals. Later Grote Reber, W9GFZ, in Ohio, improved the apparatus and really got the science onto a modern footing

There are portions of the spectrum dedicated to radio astronomy where transmissions are prohibited by international treaty. The most popular portion close to the 144MHz band is around 151MHz and it is simple to modify existing 2m receiver designs and Yagi antennas to work at this frequency.

Because of the possibility of interfering signals from transmitters close to the frequency, we often cannot use the full bandwidth that professional radio astronomers are often able to. Reducing the IF bandwidth has two effects. Firstly, the exclusion of strong, close-by interfering transmissions is easier to accomplish. Secondly, the signal to noise ratio (sensitivity) improves with a narrower IF bandwidth, but only for the case where the wanted signal is a coherent carrier. In the case of a 'total-power' receiver, which is what most radio telescopes are, the receiver output level is directly proportional to the receiver bandwidth. Professional radio telescopes might use 20MHz or more IF bandwidth to collect as much of the noise from a distant object as possible. Reducing the IF bandwidth reduces the total noise power collected and so alternative techniques, such as post-detection signal integration, need to be employed to improve the signal to noise ratio.

A major difference between conventional receivers and radio astronomy types is the use of AGC. In radio astronomy the signals are typically very weak for the most distant objects. AGC is not desirable; an interference pulse from some source such as ignition interference would reduce the receiver gain and the output level. Instead, a fixed gain control is preferred and the receiver gain once set must be very stable with time, variations in ambient temperature or supply voltage. The difference in output level between a non-occupied portion of the sky and one where a weak distant object exists is often as little as 0.1dB. If the receiver gain varies by this amount then the possibility of being certain an increase in receiver output is due to an object becomes more difficult.

The detector stage in the receiver should ideally be a square-law type, such as a diode AM detector. Its DC output voltage then feeds either a paper chart recorder or modern computer data logger and storage via an A-D converter. *Radio-Sky-Pipe* is a program that is ideal for the latter method [16].

For very strong objects such as the Sun, Cassiopeia-A, Cygnus-A or Sagittarius-A etc the signal levels observed can be quite high.

The Sun is the strongest source for observers on Earth but its variable output power causes errors when observed over a long time period. It has periods when solar storms cause the output power to rise by many times from the quiet Sun level. Signal levels measured at 1420MHz using a 5m diameter dish showed an increase in receiver output of as much as 40dB with a quiet Sun compared to the cold-sky value. **Fig 8** shows drift scans of the Sun

If the Sun is observed with a fixed antenna so that the Sun traverses the antenna beam the apparent angular size of the object is the same as the antenna 3dB beamwidth. The Sun has

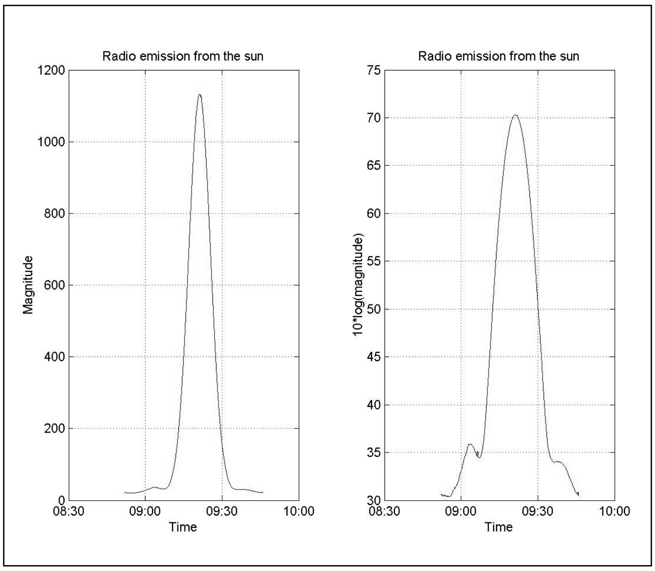

Fig 8: Drift scans of the Sun made with a fixed antenna position; the left-hand plot shows the output in linear format, the right-hand plot is converted to logarithmic and the side lobes of the antenna are clearly seen *[Plots courtesy of Durban University of Technology]*

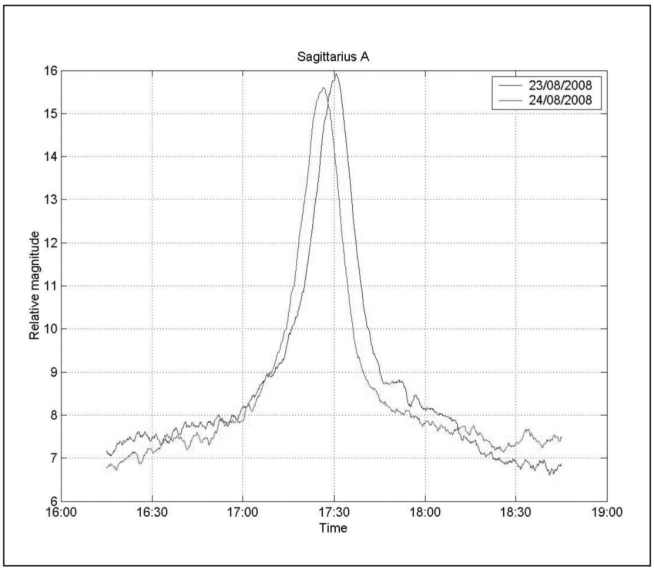

Fig 9: A drift scan of Sag-A *[Plots courtesy of Durban University of Technology]*

an angular size of approximately 0.5° for the radio noise signals, (although the apparent optical size is considerably greater), when observed from Earth. But if the Yagi has a 3dB beamwidth of 20° this is what is measured. Any antenna sidelobes may also cause an error, so the antenna pattern should be as clean as possible. In particular the front to back ratio of the antenna should be as high as possible to reduce unwanted interfering signals to acceptable levels.

The Sun, Moon and many other objects when observed with a fixed antenna appear to traverse the antenna beam at the rate of 0.25° per minute (15° per hour) in azimuth due to the rotation of the Earth. Hence, if a fully steerable antenna is used then repositioning of the antenna can be every few minutes rather than seconds. Only in the case where the antenna beamwidth is similar to the apparent angular size of the object is continuous tracking necessary.

For example, the 21cm (1420 MHz) small radio telescope using a 5m diameter dish (Indlebe SRT at DUT South Africa) has a 3dB beamwidth of 3°. If the object being tracked is Sagittarius-A then the antenna only needs to be repositioned when the object has moved off target by 1.25° and this occurs in a period of 5 minutes [17]. Often the limitation of how often the antenna needs to be repositioned is determined by how slow the antenna rotator can be programmed. In many cases simply 'jogging' the antenna back onto the correct heading every few minutes is acceptable. Fixed antennas should be elevated to the correct angle and azimuth and the object with time will traverse the beam. This technique is known as a 'drift-scan'.

Even a very large amateur EME array for 2m has a fairly broad beamwidth. If four very long Yagis are assembled in a 'box' configuration it is doubtful if less than 15° beamwidth would be achieved. Compared to an antenna such as the Jodrell Bank 76m dish it has a beamwidth of less than 4° at 144MHz and about 1° at 432MHz.

An interesting plot is shown in Fig 9 of a drift scan of Sag-A. This plot shows two consecutive days made with the DUT SRT and shows the transit times varies by approximately four minutes, proving the source is outside of our solar system. The apparent difference in signal amplitude is due to gain variation in the receiver due to ambient temperature changes from one day to the next. This problem has now been resolved.

A factor often not appreciated by amateurs new to EME or satellite working is the possibility of strong interfering signals from objects such as Sagittarius-A. If the Moon is close to the same point in the sky as Sag-A and falls within the antenna beamwidth then signals from it may override the weak echoes from the Moon. If the antenna array has a relatively broad beamwidth, which most amateur antennas are, then interfering noise from Sag-A and other strong extra-terrestrial sources may make communication difficult if not impossible. It is advisable to check with an astronomical prediction software program such as *Radio-Eyes* (see Fig 10) [16]. if such an event may occur during the intended operating period.

For further reading on this subject [18, 19] are a good starting point.

MOONBOUNCE COMMUNICATIONS

An article on moonbounce or EME (Earth-Moon-Earth) communications can be found on the free CD accompanying this book.

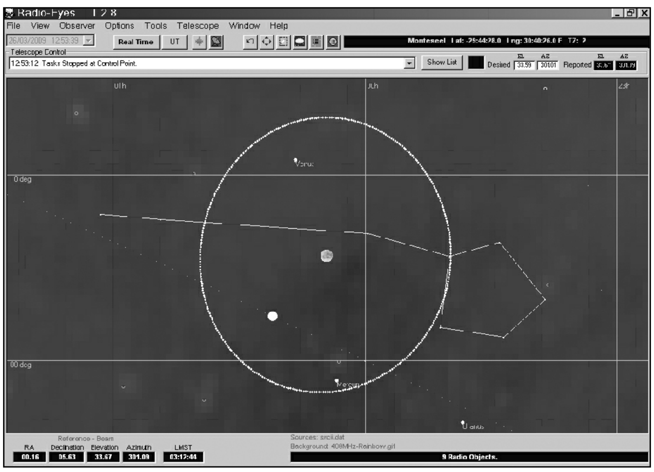

Fig 10: Screen shot from the Radio-Eyes software, with an antenna beamwidth of 15 x 15 degrees pointed at the moon. As can be seen, the Sun is within the beam and the solar noise will cause a problem

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About the Author

First licensed in 1992, John Heath has had a keen interest in the satellite aspect of the hobby from early on. Regularly working the RS satellites and Oscars 10, 13 and 40, FO-20 and 29 and most of the other satellites, he has 98 countries confirmed. An active supporter of AMSAT-UK John was part of the team that made the ISS schools contact from the National Space Centre in Leicester. Current projects are mainly in the areas of satellite telemetry and antenna construction.