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Satellite Tracking for the Radio Amateur

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INTRODUCTION

During the last few years, there has been an increased interest in communication via the amateur satellites familiary known as OSCAR (Orbiting Satellites Carrying Amatour Radio). At present the activity is restricted to 10M, 2M and 70 CM bands. In the future additional bands are likely to be included so that most of the amateur population can take part.

This activity has created more interest in communicating through the linear repeaters in satellites beyond direct line of sight encountered in normal VHF/UHF. Each newcomer has many questions concerning just how to get started:-

What are the timings in which the satellite is available ?
Which band should be used ?
How much power is needed ?
How good should the receiver be ?
What kind of antenna should be used and how big should it be ?

The above questions directly concern each ground station. In the process of determining antenna parameters, it is necessary to know how to find and track the satellite. In addition, the type of antenna mount, the aiming system and physical location of the antenna on the available space are a function of the path of the satellite.

Many articles have been published which will answer these questions and help the beginner and old timer alike. Much other data that are available may not be within the reach of many hams, especially in India. It is the aim of the author to collect and reproduce in one place the literature necessary to allow the potential Indian ham to make the basic decisions to start the "Satellite tracking and communications" project.

DEFINITIONS

A ham who desires to enter into space technology will come across a number of new terms which must be clearly understood. A few of the terms which are important for a ham are listed below in the alphabetical order with their standard definition.

Acquisition : The process of locating the orbit of a satellite or trajectory of a space probe by properly pointing an antenna or telescope as a preliminary step to the gathering of tracking or telemetry data.

Aerospace : (From Aeronautics and Space) Earth's atmosphere envelope and the space beyond, domain of operations for airborne vehicles, rocket vehicles and space craft.

Altitude : Elevation angle of a cosmic body above the horizon, measured on the vertical circle passing through the body.

Apogee : On the earth orbit of an object, the point farthest from the earth.

Ascending Node : The point at which an object's orbit crosses the reference plane (usually the ecliptic) from South to North.

Command : A signal that initiates or triggers an action in the receiving device.

Communication Satellite (Comsat) : A Satellite designed to reflect or relay electromagnetic signals used for communication.

Diplexer : A device permitting an antenna system to be used simultaneously or separately by two transmitters. (Compare with Duplexer)

Doppler Shift : The change in frequency with which energy reaches a receiver when the source of radiation (or a reflector of the radiation) and the receiver are in motion relative to each other. The Doppler shift is used in many tracking and Navigation systems.

Duplexer : A device permitting a single antenna system to be used for both transmitting and receiving.

Eccentricity : Ratio of distance between foci (of conic section) to length of major axis.

Inclination : The angle by which the orbital plane of an object in space is inclined to the plane of reference (usually the equator in geocentric orbits, or the ecliptic in heliocentric orbits)

Kepler's Laws : An astronomical theory advanced by Johannes Kepler (1571-1630) on the basis of extensive mathematical analysis of the copious observational records made by Tycho Brahe summarized in the following three laws :

1. The orbit of any planet is an ellipse with the sun at one focus.
2. The line joining the sun and the planet will sweep over equal areas in equal intervals of time.
3. The ratio of the squares of the periods of any two planets is equal to the ratio of the cubes of their mean distances from the sun.

Multiplexer : A mechanical or electrical device for time sharing of a circuit by two or more coincident signals.

Node : Intersection of orbit plane and reference plane such as equatorial or ecliptic plane.

Perigee : On the earth orbit of an object, the point nearest to the earth.

Perturbation : A disturbance in the regular motion of a celestial body, as the result of an additional force to those causing the regular motion.

Real time : The display, recording or reporting of events simultaneously with their occurrence in contrast to the recall of stored data.

Satellite : Attendant body revolving about another (primary) body; in the solar system, a secondary body, or moon, that revolves about a planet. A man-made object revolving about a cosmic body, such as a space craft orbiting about the earth.

Sensor : Instrument component that converts an input stimulus into a measurable output.

Solar radiation : The sun radiates as a black body at temperature of about 5700 K; with 99.9 percent of its energy within the wave length interval from 0.15 to 4.0 microns ; 50 percent within visible spectrum 0.4 to 0.7 micron; and most of the rest in the near infra red.

Solar Wind : Streams of plasma flowing approximately radially outward from the sun.

Space : The part of the universe lying outside the limits of the earth's atmosphere. More generally, the infinite domain in which all celestial bodies move, including the earth.

Space craft : Devices, manned and unmanned that are designed to be placed into an orbit about the earth or into a trajectory to another celestial body.

Station Keeping : Orbital maneuvers to maintain a vehicle in a predetermined orbit.

Synchronous Satellite : A satellite orbiting the earth at periods equal to, or multiples of, the earth's rotational period ; i. e. making one, two, three etc. orbits in a 24 hour Period.

Telemetry : The science of measuring a quantity or quantities, transmitting the measured values to a distant station, and there interpreting, indicating, or recording the quantities measured. Data transmitted by means of electro magnetic propagation.

Tracking : The process of following the movement of a satellite or rocket by radar, radio and/or photographic observations, generally for the purpose of recording its trajectory or for improving the reception of signals from the body.

SATELLITE AVAILABILITY

Armed with some understanding of the special terms of space technology, we are now in a position to peep into space to locate and understand a satellite and its orbital characteristics. We will limit our studies to space craft orbiting around the earth.

Fig 1 indicates Satellite A in circular orbit and B in eliptical orbit around the earth. The time taken for the satellite to come once around the earth is called the orbital period (P) and the radius is 'a' as indicated. The earth is assumed to be revolving with its North pole on top and due to this assumption, the journey of the satellite from South pole to the North is known as the ascending orbit and North to South as the descending orbit.

Kepler's third law can be written as

$$\frac{a}{p} = \frac{GM}{4\pi} \quad \ldots\ldots\ldots\ldots \quad (1)$$

where

a = orbital radius (height) of the satellite from the centre of earth.

p = orbital period

G = Gravitational constant

and = 6.668 X 10- cm. gs.

M — mass of earth 5.980X 10 [illegible] grammes

The right hand side of the equation (1) is a known constant for a given condition. If one of the two quantities on the left hand side of the equation is known, the other can be easily computed. For an earth orbiting satellite like the OSCAR :

$$\frac{a^3}{p} = 3637 \times 10 \ldots \quad (2)$$

where 'a' is given in km and 'p' in minutes. Taking the orbital period of Oscar 6 as 115 min ; a = 7834 km. Subtracting the earth's radius of 6370 km, the orbital height of the satellite above the ground is 1464 km (910 miles). This formula holds good for all earth orbiting satellites. (You may work out for Arya bhatta). The complete satellite orbital characteristics can also be computed from Doppler measurement of satellite signal and is quite involved.

Assuming that we have managed to know 'a' and 'p', let us progress further. We know the earth is revolving on its own axis once every 24 hours and from West to East. Let us stop the rotation of the earth (we cant !) and allow the satellite to continue the orbit. For simplicity, let us assume the period as 2 hours.

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That means, the satellite will be over every place (sub satellite point) on the earth along the satellite track once in every 2 hours. Suppose we start with the satellite over the equator at a longitude of 82°E at Zero hour and allow the earth to rotate. After 2 hours the satellite would be over the equator on completion of the first orbit. But the earth would have rotated towards east by this time. We know that the earth covers 15° for every one hour and so after 2 hours, the earth would have passed 30 degrees easterly which woud bring the satellite over (82° – 30°) 52° E Longitude at equator after the first orbit. For all practical purposes we can assume the satellite moving west ward by an amount in Longitude equal to the earth's rotation in the period p. For this purpose, the conventional notation of marking the longitudes from Greenwhich as 0 to 180° E and 0 to 180° W becomes cumbersome and a general practice of 0 to 360°W is adopted. These details along with satellite tracks are given in fig 2

Now is the appropriate time to apply all we have learnt and work out the satellite tracks. The published orbital data on Oscar gives the following information :

(i) Orbit serial number and date

(ii) Time (GMT) when the satellite crosses the equator in ascending part of orbit.

(iii) The longitude (in degrees West) over which the satellite cros-

(Contd. on page 17)

ses the equator in ascending part of orbit.

(iv) Orbital period (p = 114.9946078 min)

(v) Increment in longitude per orbit. (28.7486519 degree/orbit)

(vi) Inclination to equator (101.7°)

The new orbits can be calculated by adding orbital period and longitude increment to the corresponding quantities of the reference orbit consecutively. Table 1 gives the orbits of Oscar 7 for a typical day and can be easily understood.

India is centred on (82°E) 278° W longitude. The line of sight range with the satellite being about 2500 miles, the ascending orbits occuring between 250°W to 300°W are suitable for operation. Hams located in Assam or Srinagar have to adjust a few degrees east and west suitably. Similarly operation through descending orbits is also possible. Ascending orbits passing between 65°W and 115°W (over USA) provide satellite communication during their descending portion over Asia. Fig 2 indicates the typical coverage of a station centred at Bangalore with ascending and descending orbits.

On an overhead pass, the satellite gives a communication of about 20 minutes and less on the other passes. Oscar 6 and Oscar 7 are launched at a time window such that the ascending overhead pass occurs at 9 PM local time and the descending overhead pass at 9 AM.

WHICH BAND ?

"Which band to operate"? As on today Oscar 6 and Oscar 7 are active and operating facilities are given in Table 2.

Oscar 6 has a linear translator, functioning very much like a receiving converter. It receives over the band 145.9 to 146.0 MHz, and down converts to 29.450 to 29.500 MHz. Within this band, what you put in on two metres is what you hear on 10 metres; if you transmit on CW you hear CW; if you transmit upper side band, you hear upper side band. Oscar 7 works the same way, except that it has two translators abroad, one for two to-ten meters, the other 432 MHz in, 145 MHz out. With Oscar 6, if you transmit on 145.950 MHz (neglecting Doppler), you should hear yourself through the satellite on approximately 29.5 MHz; if you transmit 20KHz lower, you will hear yourself 20KHz lower on ten meters. Oscar 7's two meter input and ten meter output work in exactly the same way as Oscar 6. The 432 MHz translator aboard Oscar 7 is a little different, since it employs frequency inversion; if you transmit lower side band, you will get upper side band back. Because of Oscar's altitude, you will have a maximum two-way communication range of approximately 5,000 miles when properly positioned. The ground station requirements are arrived at refering to Table 2. Receivers for 10 meter and 2 meter reception and Transmitters for 2 meters and 432 MHz are required.

The beacons are in-band operation and require special receivers out for 435 and 2304 MHz.

Different amateurs will like to have different systems depending on their needs and inclinations. If you have none and want to start new, the best choice is a ten meter receiver and two meter transmitter. This will enable operation both with Oscar 6 and Oscar 7.

HOW MUCH POWER ?

To work through the two-to-ten meter translator, an effective radiated power (ERP — transmitter output minus transmission line losses plus antenna gain) of approximately 100 watts is required. Under ideal conditions, it has been done with as little as 10 watts ERP, but 100 watts ERP is the recommended level which is sufficient to provide horizon to horizon access to the satellite. If you need more than this to hear yourself, that is positive proof that your receiving system needs more work! As an example of this calculation, a transmitter having 50 watts output into a transmission line having 2 dB loss, and an antenna having 6 dB gain would give 100 watts ERP; the correct level at two meter. The use of a 8 to 10 watt transmitter output to an antenna of 15 dB gain seems to be the most economical.

A stable, well calibrated VFO or VXO is of great convenience (though not an absolute requirement), since most Oscar users answer calls at or near the caller's frequency—the better to hear their own signals while working.

HOW GOOD SHOULD THE RECEIVER BE ?

Oscar's transmitter power is quite low and must be shared among all the stations using the satellite at any one time. To work through the satellite successfully, you have to be able to hear it well. Beyond any doubt, the greatest single cause of failures in Oscar communication is inadequate receiving capability.

On ten meters, many receivers, even the most expensive, can benefit from a simple low noise MOSFET pre-amplifier, adjusted for the Oscar output band. If you are not using a good pre-amplifier, you might also gain satisfactory performance by realigning the receiver's ten meter circuits for optimum performance at 29.5 MHz. World War II surplus receivers may not come up to the required sensitivity and a MOSFET pre-amplifier seems to be the only alternative for most of us. An FET amplifier followed by a MOSFET Mixer will be required in most cases using the BC 348 series of Receivers. A crystal oscillator may be used to provide a suitable converter output frequency at 7 MHz band where the equipment will be hot. The over all sensitivity of 1 uv for 10 dB S/N ratio will be satisfactory.

WHAT KIND OF ANTENNA ?

For receiving purposes a variety of antennas are used, from long wire, dipole, to beams mostly dictated by the receiver sensitivity. Quite satisfactory results have been obtained with less than beam

TABLE 1

OSCAR Typical Orbit data

Date 10 Mar 77 Orbit No.	Equator Crossing Time (GMT)	Longitude West
10365	0104.2	56° W
10366	0258.1	94° W
10367	0454.0	123° W
10368	0648 9	15°2 W
10369	0843 8	18°1 W
10370	1038.7	210° W
10371	1233 6	239° W
10372	1428.4	268° W
10373	1623.3	297° W
10374	1818 2	326° W
10375	2013 1	355° W
10376	2208.0	24° W

such as whips, dipoles and wire arrays. Of course for best results at low elevation angles, when the real Dx is worked, a beam simply cannot be beat. A simple dipole of 16'6" will be good enough for making a start. Stretch it East-West since the satellite goes North-South, though this direction is not absolutely necessary if space is not available.

For the VHF and UHF frequencies, experience has shown that beams of four to eleven elements (9dB to 15 dB gain) give the best results. Larger arrays, being more directional, are more difficult to keep properly aimed at the moving satellite than beams of fewer elements. Again, if you cannot put up a beam, you still can work through Oscar if your transmitter puts out enough power; or you are not aiming to achieve a Dx record. A limited performance is always a possibility with limited resources and enough to make a start.

A four element cubical quad giving 15 dB gain in 2 meter band is a good choice. The beam can be constructed on a boom of 48". The antenna consists of four square loops, made from medium thickness copper wire, held in position by wooden spreaders. The driven element is 20 inches on all sides, cut in the centre of the lower leg, where an insulating piece and co axial socket is fitted. A reflector of 21 inches on all sides closed circuit (i e. a continuous length of wire) is spaced 16 inches behind the driven element. The first director, 19 inches on all sides is placed 16 inches in front of the driven element and the second director is 18½ inches on all sides, again spaced 16 inches. The overall length is thus 48 inches. Coaxial cable of 50 ohms impedance is to be used. The author has constructed this type of beam with bamboo under Rs. 10/ .

In reading through the literature on Oscar, you will constantly come across references to circular polarisation and azimuth elevation rotators. These are desirable but not absolutely essential. Without circular polarization on two meters with Oscar 6, the signal will encounter fading due to Faraday rotation; the Oscar 7 receiving antennae are designed to make this unnecessary. Circular polarisation at ten meters is for most amaturs easier said than done, because of ground reflection effects. If you can put up a cross yagi or helical array, by all means try it, but don't think you really need one. With linearly polarized antennas, the signal will fade up and down as the polarisation is rotated in the ionosphere. You may use either vertical or horizontal polarization; it makes no difference. If you use a beam antenna and do not have azimuth-elevation rotators, it is recommended that you mount the beam to point upward approximately 20 to 30 degrees from the horizon and leave it there, rotating in the horizontal plane when needed. 20 to 30 degrees fixed elevation has been found by many users to be an excellent compromise, making further attention to elevation unnecessary.

CONCLUSION

With my experience on Satellite tracking, I have attempted to convey the problems and solutions that an individual is likely to come across, in this article. The subject is very vast and every point cannot be covered in a single article. The aim will be achieved if it takes you one step closer to satellite tracking.

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TABLE 2

Operating Frequencies of OSCAR 6 and OSCAR 7

	Input (Up link) MHz	Output (Down link) MHz	Beacon (Telemetry) MHz
Oscar 6	145.900-146.000	29.450-29.550	29.400 435.100 (Silent)
Oscar 7	145.850-145.950	29.400-29.500	29.500 145.980
	432.125-432.175	145.975-145 925 (inverted)	435.100 2304.100

Courtesy: Radio (Feb-March 1977)