PACKET SATELLITES

Maybe the idea of using satellites for packet contacts tickles your fancy. This chapter will attempt to provide some information to help you decide whether you really want to or not.

The author is even less of a packet satellite expert than he is an expert on H.F. He has operated a few times using a digipeater on the MIR space station. That can be really exciting but it represents a very small part of satellite use.

13.A WHAT'S UP?

There are several broad categories of satellites which support packet operation. Here, we will look at these groups of satellites.

13.A.1 Manned Space Stations: The Soviet MIR space station and the U.S. Space Shuttle program have both, at various times, included packet operation. The usual style seems to have been operation in space just like on the surface. Standard AX.25 TNCs with VHF transceivers having a few watts output seem to have been the rule. Two meters seem to have been the most popular band. MIR has frequently used 145.55MHz. Since ordinary TNCs are normally used, they seem frequently set up so that you may connect to a mailbox or use it as a digipeater.

The inclusion of packet on a particular mission seems to depend on whether there are hams among the crew and whether the radio equipment is compatible with the rest of the mission.

On can usually find out about these events by watching BBS bulletin lists. In the case of shuttle flights, bulletins often start showing about a week before launch. U.S. Space Shuttle flights with ham radio are referred to as SAREX (Shuttle Amateur Radio EXperiment) and bulletins usually include the word SAREX in the subject. Shuttle flights seem to frequently be in low inclination orbits; do not expect access much above 45° (N or S) latitude. The MIR orbit is at a higher inclination and is accessible from above 50° (N or S).

Using one of these stations is little different than connecting to your neighbor at home. One very big difference is the coverage area; virtually every other user is hidden to every one else. Also, these events are relatively rare and the user load can be huge.

13.A.2 Geostationary Satellites: Though planned, there are no geostationary ham satellites in space at the time this is being written.

13.A.3 High Orbit Satellites: AMSAT-OSCAR 13 (AO-13) is a satellite in a highly elliptical orbit. This orbit is such that it swings well away from the earth; it is frequently referred to as Phase III orbit. It is visible for an extended period and is relatively slow moving when away from the earth. There are does not appear to be any dedicated packet operation although packet seems to be permitted as a mix with other modes. Because of the rather large satellite-to-earth distances, transmit power and receiver noise figure are major issues. There is a baudot telemetry beacon; the author assumes this mean RTTY.

AO-13 has 4 different modes. Each one represents a particular input-output frequency combination. For example, mode B is uplink on 70cm and downlink on 2M; mode J is uplink on 2M and downlink on 70cm. There are also a pair of modes which translate between 70cm and 2.4GHz. The mode schedule is often broadcast by BBS bulletins. Remember, however, that this satellite, as for most others, uses CW or SSB, not FM!

A new satellite launched in mid-1993 is **ARSENE**. This on is also in a highly elliptical obit going from 36,000km at the maximum (apogee) to 20,000km at the minimum (perigee). Orbital period is about 17hours and 30 minutes. It is expected to have a life of about 3 years. It is not obvious to the author whether it has been given has been given an OSCAR designation.

The expected packet 70cm uplink/2M down link is not operating. There is, however, a 435.100MHz uplink/2400MHz downlink. Transmit requires 500-1000W EIRP (50W into a 10db gain antenna) works. The downlink is some 10db weaker than AO-13, however and the antenna requirement is equivalent to a 6' dish.

13.A.4 Microsats: These six satellites were launched in January, 1990.

The orbits of all four at very similar and all are visible about 15 minutes at a time, 4 to 5 times per day (at mid-latitudes). Their altitude is low. They are simple. Because of their small size and weight, they can be launched at lower cost. The group consists of University of Surrey (England) UoSAT-3 (UO-14) and UoSAT-4 (UO-15), AMSAT AO-16, OSCAR-17, Weber OSCAR-18 (WO-18), and AMSAT LO-19. Lets consider each of these six satellites in numerical order.

UO-14 has one uplink and one downlink, both at 9600 baud. Uplink and downlink are full duplex (on different bands).

The author has no information about **UO-15**; it does not appear to support any special packet operations.

AO-16 is also known as PACSAT. AO-16 has 4 uplinks and 1 downlink running at 1200 or 4800 baud (switchable). A PACSAT modem is required for operation. Uplink is on 145.900, 145.920, 145.940, and 145.960 MHz while the downlink is on 437.025, 437.050, or 2401.143 (full-duplex).

This satellite is basically a flying mailbox. But operation style is very different from earth-bound ones. They forward bulletins by broadcasting to everyone listening. Every bulletin is sent over and over until all of the pieces are received and patched together by everyone interested. It may take several passes for one to be received in its entirety. The ground station must be able to reassemble the individual pieces into a complete message. The satellite continues broadcasting until there are no more requests for repeats or the message is too old and must be purged. Personal messages are handled on a direct connect basis. So is placing a message (personal or bulletin) into the mailbox.

It usually requires moderate-gain directional antennas with full tracking capability. It also requires special software to format messages to meet the satellite requirements and to compress the messages (reducing both connect time and satellite memory needs). The special software is also needed to reassemble broadcast bulletins. When one adds the dual-band radio needed, this is not an inexpensive undertaking!

AO-17 is also known as DOVE (Digital VOice Encoder). Its primary mission is to broadcast digitized audio messages on FM for classroom use. It has a packet telemetry channel which can be decoded by G3ZCZ's WHATS-UP. Telemetry frames are 1200 baud UI frames (in pairs) addressed to DOVE-1>TLM. The downlink appears to be on

145.825MHz.

WO-18 (WEBERSAT) carries a camera. The images are digitized and transmitted on a packet downlink operating on 437.102. A 1200 baud PACSAT modem is required for reception.

LO-19 (LUSAT) is almost identical to AO-16.

13.A.5 Sun Synchronous Satellites: Fuji-Oscar 20 was launched in February, 1990. It is in a sun synchronous orbit which means that it crosses a given longitude at approximately the same time, morning and evening, every day. The Japanese designation is Fuji-2 and the international designation is FO-20 (Fuji-OSCAR 20). The orbital period is about 105 minutes and the expected service time is 5 years.

This satellite is designed for packet operation. It has 4 uplink channels (145.85, 145.87, 145.89, 145.91 MHz) and 1 downlink channel (435.91 MHz). Packet operation requires the same PSK modem as needed for PACSAT. Uplink requires about 100W EIRP. The packet callsign is 8J1JBS.

There are several interesting features for packeteers on this satellite. One is the digipeater. It will digipeat any valid packet heard; you do not have to specify the satellite as a "via" in the connect request. The digipeat is cross-band (that is, the outgoing packet is on the downlink). Another interesting feature is the bulletin board; it carries a large computer memory for message storage. The BBS is accessible with common mailbox-style commands.

The downlink contains telemetry frames which are broadcast as UI packets. They are addressed 8J1JBS>BEACON. If you have a PACSAT modem, you can copy and translate the telemetry with G3ZCZ's WHATS-UP program (see Chapter 19 in Volume 2).

There is a caution about FO-20. It does not automatically disconnect you when the signal is lost. This means that when it goes over the horizon, it considers that you are still connected. The problem is that it permits only 16 simultaneous connects. If it goes over the horizon with you still connected, your lost connection stays on as 1 of the 16. So, please disconnect before signal is lost!

13.A.6 Other Satellites: KITSAT-1, also known as KO-23 was launched early in 1993. This satellite is a Korean effort including 9600 baud packet, earth imaging, cosmic ray experiments, and digital signal processing experiments.

Unlike other packet satellites, this one uses FM on both the up and down links. There are two uplink frequencies (145.850 and 145.900MHz) and a downlink on 435.175MHz. Transmit requires 25-100W EIRP and receive needs a GaAsFET preamp and a small beam. PSK is used as with the PACSATS but at 9600 baud. The packet callsign appears to be HL01-11 (thats zero-one dash eleven). It uses the broadcast protocol very similar to FO-20.

UoSAT-OSCAR 22 (UO-22) is also a packet satellite. It operates at 9600 baud. Beyond this detail, the author has little information.

OSCAR-21 (AO-21) has packet telemetry and voice. It has a downlink on 145.987MHz FM (145.990 works fine) and an uplink on 435.016MHz FM. It is in a fairly low orbit and has viewing times in the neighborhood of 15-20 minutes.

13.B FINDING SATELLITES

After questions of equipment and frequencies, the next most often asked question often seems to be "how can I tell when a satellite is coming over?" You can use one of several tracking programs for computers or you can do some simple estimating. But in either case, you need to start with some basic information about the orbit of the satellite. The standard set of information is called the Keplerian Elements.

13.B.1 Getting Keplerian Elements: Keplerain Elements are available on a regular basis from several sources. A number of telephone bulletin boards around the U.S. have them available in a timely manner. They are also available in Internet. They are also distributed through the radio BBS system in many areas.

13.B.2 Keplerian Element Formats: Once you have a recent set of the elements, the next issue is what they mean. Here, we have a minor problem. They have been issued in two formats, AMSAT and NASA. In 1991, AMSAT format was generally dropped in favor of the NASA format. But many of the older tracking programs expect data files in

AMSAT form. The following conversion information was apparently written by Dr T.S. Kelso, Assistant Professor of Space Operations, Air Force Institute of Technology and was taken from an Internet message dated August 31, 1990.

Data for each satellite consists of three lines in the following format:

```
AAAAAAAAAAA
1 NNNNNU NNNNNAAA NNNNN.NNNNNNNN +.NNNNNNNN +NNNNN-N +NNNNN-N N NNNNN
2 NNNNN NNN.NNNN NNN.NNNN NNNNNNN NNN.NNNN NNN.NNNN NN.NNNNNNNNNNNNN
```

Line 1 is a eleven-character name.

Lines 2 and 3 are the standard Two-Line Orbital Element Set Format identical to that used by NASA and NORAD. The format description is:

Line 2

```
Column     Description
01-01     Line Number of Element Data
03-07     Satellite Number
10-11     International Designator (Last two digits of launch year)
12-14     International Designator (Launch number of the year)
15-17     International Designator (Piece of launch)
19-20     Epoch Year (Last two digits of year)
21-32     Epoch (Julian Day and fractional portion of the day)
34-43     First Time Derivative of the Mean Motion
           or Ballistic Coefficient (Depending on ephemeris type)
45-52     Second Time Derivative of Mean Motion (decimal point]
           assumed; blank if N/A)
54-61     BSTAR drag term if GP4 general perturbation theory was
           used.  Otherwise, radiation pressure coefficient.
          (Decimal point assumed)
63-63     Ephemeris type
65-68     Element number
69-69     Check Sum (Modulo 10)
           (Letters, blanks, periods = 0; minus sign = 1; plus sign
                   =2)
```

Line 3

```
Column     Description
01-01     Line Number of Element Data
03-07     Satellite Number
09-16     Inclination [Degrees]
18-25     Right Ascension of the Ascending Node [Degrees]
27-33     Eccentricity (decimal point assumed)
35-42     Argument of Perigee [Degrees]
44-51     Mean Anomaly [Degrees]
53-63     Mean Motion [Revs per day]
64-68     Revolution number at epoch [Revs]
69-69     Check Sum (Modulo 10)
```

All other columns are blank or fixed.

Example:

```
NOAA 6
1 11416U          86 50.28438588 0.00000140           67960-4 0  5293
2 11416  98.5105  69.3305 0012788  63.2828 296.9658 14.24899292346978
```

Note that the International Designator fields are usually blank, as issued in the NASA Prediction Bulletins.

Additional conversion information was provided by Mike Bilow, N1BEE@ KA1RCI.RI.USA.NA in a BBS bulletin dated February 16, 1992.

```
Note that some software will not correctly read all of the (NASA)
fields, often stumbling over the assumed decimal point in the
eccentricity field.

Also, decay rate or drag is usually given in AMSAT format in
scientific notation, which is not used in NASA format.  To convert,
simply move the decimal point to the left as many places as are
indicated in the negative exponent.  For example, 1.234e-05 becomes
0.00001234, and 6.789e-03 becomes 0.006789; most software will take
this number entered either way.

All epochs are UTC (Coordinated Universal Time).

Example:

STS-35
1 20980U 90106  A 90340.71451300  .00053642  00000-0  37954-3 0   129
2 20980  28.4668 332.8436 0011228 341.6274  18.4530 15.72433683   705

AMSAT Format:
Satellite: STS-35
Catalog number: 20980
Epoch time:      90340.71451300
Element set:      12
Inclination:       28.4668 deg
RA of node:       332.8436 deg
Eccentricity:    0.0011228
Arg of perigee:   341.6274 deg
Mean anomaly:      18.4530 deg
Mean motion:   15.72433683 rev/day
Decay rate:     5.3642e-04 rev/day^2
Epoch rev:              70
```

13.B.3 Using Keplerian Elements: It is possible to make some fairly simple estimates of satellite passes without extraordinary mathematical gymnastics. All that it requires is some simplifying assumptions. The assumptions I have made are: (1) the orbit is circular (which leaves out the Phase III satellites) and (2) many of the more subtle orbital mechanics issues can be ignored for a while after the epoch time.

The method I have chosen is to determine where a crossing of the equator must happen in order that a pass be visible. Then, an estimate of equator crossing times and locations is made. By cross-checking these values, you can determine pass times. You will need to know your latitude and longitude to about 1 degree or so. This method will not provide any antenna pointing information.

Step A: Based on orbit altitude, determine how large an area over which the satellite can be seen. The radius of the circle (on the earth's surface) in which a satellite is visible is given by

$$\mathbf{r} = R * k * \mathrm{atn}\left[\frac{h}{R}\sqrt{1+2\frac{R}{h}}\right]$$

where R is the radius of the earth (6378km) and h is the orbital altitude of the satellite (in the same units as R). The factor k is used according to whether your calculator gives angles in degrees or radians from the atn (arctangent) function. If your calculator gives the answer 45 to the function atn(1), then use k=pi/180 (to convert degrees into radians). But if your calculator gives the answer 0.785, use k=1 since the answer is already in radians.

There is, however, a minor hitch. Orbital altitude is not given in the Keplerian Elements. Orbital period is. And altitude is directly related to period by

$$T^2 = \frac{4\pi^2}{G*M}\mathbf{r}^3$$

where T is the orbital period, M is the mass of the earth, and G is the Universal Gravitational Constant, and r is the radius of the satellite's (circular) orbit.. When we are interested in a satellite orbiting the earth, this equation reduces to

$$\mathbf{r} = 33125 * T^{2/3}$$

if T is in minutes and r is in kilometers. The orbital altitude of the satellite is

$$h = \mathbf{r} - R$$

$$h = 33125 * T^{2/3} - 6378$$

The Figure 13-1 gives radius of satellite viewing circle and the orbital radius (both in km) as determined by orbital period.

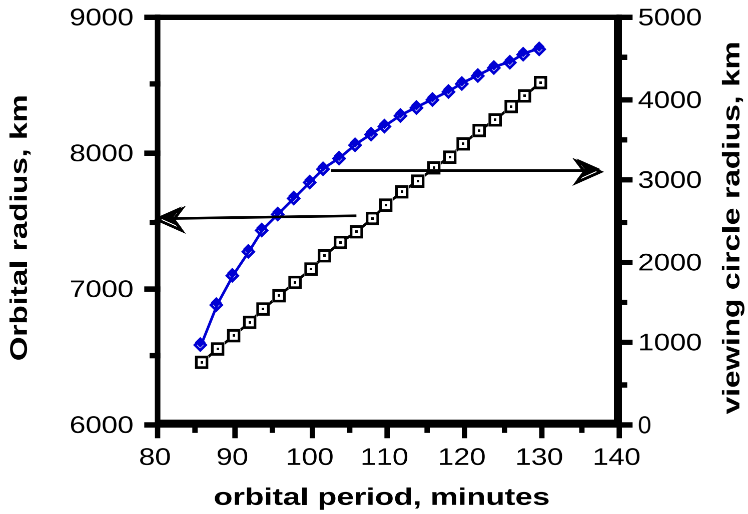

Figure 13-1, View-Circle Radius and Orbit Radius for various Orbit Periods

The final consideration is that the Keplerian Elements do not give orbital period directly. Instead, it gives "mean motion" which is the number of orbital revolutions in one day. To find the orbital period, simply divide this value into 24*60=1440, the number of minutes per day. In the example from section 13.B.2, the orbital period is therefore 91.578 minutes or 91 minutes, 34.68 seconds.

Step B: The second step is to determine how many degrees of latitude and longitude the radius of the viewing circle occupies at your site. Lines of longitude go from pole to pole and all have the same circumference; lines of latitude are parallel to the equator and ones nearer the poles have a smaller circumference. Both longitude and latitude are divided into 360 degrees. What may be confusing to some, however, is the actual measurement of latitude and longitude. Longitude (in degrees) is a measure of how many lines of longitude one has crossed east or west of Greenwich Meridian (that is, while travelling along a line of latitude!) Similarly, latitude (in degrees) is a measure of how many lines of latitude one has crossed north or south of the equator (that is, while travelling along a line of longitude!)

To find the east-west radius, slice the earth at your latitude (circles parallel to the equator). The resulting circle has a circumference which is determined by the radius of the earth and the latitude where the slice takes place. From this, we can determine the distance occupied by one degree of longitude; there are 360 degrees of longitude around this circle which has a radius of R*COS(LAT). Combining this value with the radius of the viewing circle from Step A results in an estimate of the east-west width of the viewing circle in degrees. The north-south radius is the same everywhere on the earth and is found much the same way, except the slice is along a line of longitude.

The number of km in one degree of longitude (lets call it Q_{LON}) at a latitude of LAT is given by

$$Q_{LON} = 2*\pi*R*COS(LAT)/360$$

where R is the radius of the earth. If we combine the constants in this equation, the result is

$$Q_{LON} = 111.2km*COS(LAT)$$

The number of km in one degree of latitude (lets call it Q_{LAT}) is simply 112.2km.

The next figure, Figure 13-2, shows the value of Q_{LON} (number of kilometers in 1 degree of longitude) for degrees of longitude from 0 (equator) to 50. It makes no difference, here, whether you are north or south of the equator.

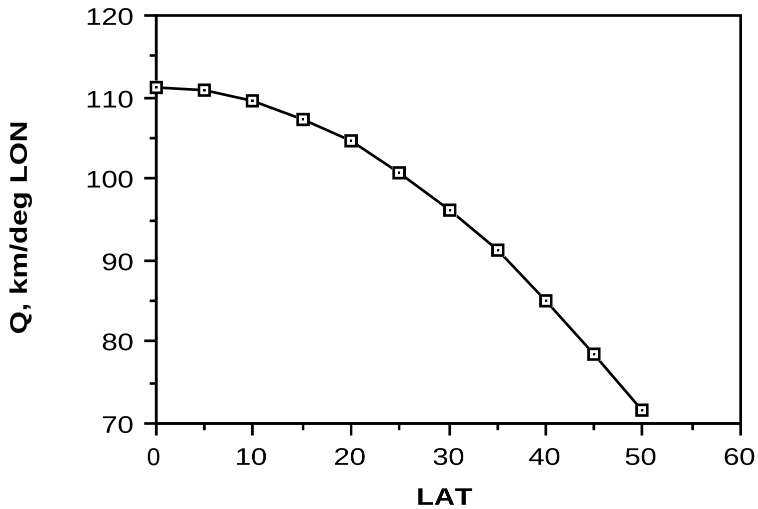

Figure 13-2 Q_{LON} vs Latitude

The last part of this step, which is not convenient to graph, is to divide radius of the viewing circle by Q_{LON}. This gives the east-west radius of the viewing circle, in degrees of longitude. Similarly, divide the radius of the viewing circle by Q_{LAT} to find the north-south radius of the viewing circle in degrees of latitude.

For example, if the satellite in question has an orbital period of 91.578 minutes (in other words, the example satellite), the radius of its viewing circle is about 2200km. If you are at 40 degrees south latitude, your value of Q_{LON} is about 78 km/degree. Thus, the east-west radius of the viewing circle occupies about 28 degrees of longitude; the east-west diameter is twice this, or about 56 degrees of longitude. The north-south radius is about 20 degrees of latitude.

Step C: The next step is to estimate when the satellite crosses the equator. This estimate involves several quantities from the Keplerian Elements.

The first part of this step is to understand what Epoch time means. Epoch time is a decimal time and date value. The example in section 13.B.2 shows an Epoch time of 90340.71451300. The first 3 digits to the left of the decimal point are the Julian day. January 1 is day 001, February 1 is day 032, December 31 is day 365 (or 366 if a leap year). In this example, the day is 340. The next digits to the left of the day number are the least two digits of the year. In the example, these digits are 90 so the day is day 340 of 1990. The digits to the right of the decimal point give time as a decimal part of one day, that is 24 hours. Though it is not necessary for our purposes to convert to hours, minutes, and seconds, we can readily do so. Hours are found by multiplying 24 hours by the decimal part of Epoch time. In the example, the hour part is 24*0.71451300 or 17.148; hours are the integer part, or 17. The portion to the right of this number is decimal part of hours. Multiplying this fraction by 60 (minutes per hour) gives minutes. In the example, the minute part is thus 60*0.148 or 8.88. Minutes could be rounded to 9 or further reduced to seconds. Seconds are obtained by multiplying the fractional part by 60 (seconds per minute). In the example, the seconds part is thus 60*0.88 or 53. Thus, the complete time represented by the Epoch time in the example is 17:08:53 on day 340 of 1990. It is the convention that Epoch time is given in GMT.

The satellite makes each subsequent north-bound crossing of the equator one orbital period time after the preceding crossing. Furthermore, each south-bound crossing of the equator happens one-half of an orbital period after the north-bound crossing. For the satellite in the example, the next north-bound equator crossing is at 91.578 minutes after the Epoch time (17:08:53 GMT) or 18:40:27 GMT. Note that while any individual time need be accurate only to a few seconds, you should maintain several digits to the right of the seconds decimal point since errors will accumulate fairly rapidly. The next north-bound crossing will be at 20:22:02 GMT.

Step D: Knowing when the satellite crosses the equator must be combined with where the satellite crosses the equator. This involves the RA of node data from the Keplerian Elements.

The RA of node has nothing to do with packet nodes. It gives the location, called Right Ascension (in degrees longitude) where the satellite crosses the equator north-bound at the specified Epoch time. An oddity of this value is that given in a range of 0 to 359.9999 degrees positive eastward of Greenwich Meridian. In the example, the RA of the example is 332.8436 degrees. Any value between 0 and 180 may be taken directly as East Longitude. Values greater than 180 may be converted to West Longitude by subtracting from 360. The example thus crosses the equator at 27.156 degrees West Longitude. And it makes this crossing at the Epoch Time which was analyzed in the preceding step.

But what about the subsequent equatorial crossings? Here, it gets a bit complex and several simplifications will be used. There are two components which interact to determine equatorial crossings. One is the rotation of the earth and other is the rotation of the plane of the satellite's orbit in space. It is quite possible to get wrapped up in distinctions between Siderial time and Sun time but for intervals of a few days or less, the error from using Sun time (that is, clock time), is reasonably small. Using this simplification, we will find the number of degrees which the earth rotates during one orbital period. The earth rotates 360 degrees in 24 hours clock time or 15 degrees per hour. It may be simpler to use degrees per minute since orbital period is usually expressed in minutes. Earth rotation in degrees per minute is the degrees per hour value divided by 60 minutes per hour. Thus, earth rotation is also 0.25 degrees per minute. In our example which has an orbital period of 91.578 minutes, the earth rotates 22.895 degrees during each orbit and 11.449 degrees between every equator crossing.

That, however, is not the whole picture. We need to make certain we understand which way the earth rotates. You can visualize what happens by looking at a globe which turns. If you start looking when the Greenwich Meridian is directly below, the numbers along the equator increase in a westerly direction. When you reach the area of International Date Line, the numbers switch to East Longitude and decrease from 180 toward 0. The convention in earth satellite orbital mechanics is eastward positive; thus, the earth's rotation is -0.25 degrees per minute. Then, for our example, the earth rotates -22.895 degrees during each orbit.

One last factor must be considered before the whole series of equatorial crossings can be estimated. This factor is the rotation of the plane of the satellite's orbit in space. If we were to sit in space directly above one of the earth's poles, further out in space than the orbit of the satellite and ignore the rotation of the earth, we would also see that the plane of the satellite's orbit slowly rotates below us. This orbital-plane rotation is called precession and is controlled by the inclination of the orbit. Precession is an effect which is due to the fact that the earth is not a perfect sphere; it bulges at the equator. Inclination is the angle between the equator and the plane of the orbit. The rate of orbital-plane rotation for an earth satellite is given by

$$d\Omega/dt = 9.95\left(\frac{R}{r}\right)^{3.5}\cos(i)$$

This is an empirical equation. The quantity $d\Omega/dt$ is in degrees per day. A positive value indicates clockwise rotation of the orbital plane as seen from above the north pole. In our example, the inclination angle, i, is 28.4668 deg. Given the values of R (earth's radius = 6378km) and r (satellite's orbital radius = 7300km from the figure in Step A), the precession rate is 5.2 degrees per day. Note that a true polar orbit, in which i=90 degrees, (that is, the satellite crosses the equator heading exactly due north) has a precession rate of zero. Also, a satellite with a an inclination greater than 90 degrees has a negative precession and the orbital plane rotates counter-clockwise as seen from above the north pole. An inclination of 45 degrees means that the satellite heads northeast as it crosses the equator north-bound; an inclination of 135 degrees means that the satellite heads northwest as it crosses the equator north-bound.

We really need to know the rotation of the orbital plane during one orbit. Lets call the change in the angle of the orbital plane during one orbit, $\Delta\Omega$. If T is the orbital period, in minutes, then

$$\Delta\Omega = \frac{d\Omega}{dt} * \frac{1}{24} * \frac{1}{60} * T = \frac{d\Omega}{dt} * \frac{T}{1440}$$

Is the rotation of the orbital plane added to or subtracted from the earth's rotation? If the two are rotating in opposite directions, then the change between successive right ascensions is even greater. Thus, since earth rotation counter-clockwise as seen from above the North Pole, $\Delta\Omega$ is subtracted from earth's rotation. For our example satellite, $\Delta\Omega$ is 0.331 degrees per orbit and the total change in RA is -22.895-.331=-23.226 degrees (that is, 23.226 degrees westward). This change is called the orbital increment.

The next RA after the Epoch Time thus happens at the RA given in the Keplerian Elements shifted west 23.226 degrees or 27.156+23.226=50.382 degrees. Each subsequent RA is another 23.226 degrees west of the preceding one.

Step E: The final step shows which orbits are visible and when they occur. Make 2 copies of the Figure 13-3, the ORBITRACK chart, on page 13-16.

On one copy, locate the site of your station. If you are in the southern hemisphere, swap east and west on the equator. Mark out the east-west and north-south extents of the circle of visibility centered at your site.

Connect these four points with a smooth line which might be somewhat egg-shaped. This line is the edge of the circle of visibility. A satellite crossing anywhere within this circle is visible from your site. With a sharp knife, cut along the visibility circle to make a hole. Note the arrowhead mark on the 0° longitude (Greenwich Meridian). Then, trim off the outer part of this copy along the circle where the arrowhead points (equator).

On the other copy, mark the orbit. For convenience, start with a mark at Greenwich Meridian (0 on the equator). If the orbital inclination is less than 90 degrees, find the point along the 90°E longitude line at a latitude equal to the inclination angle. If the inclination is greater than 90 degrees, find the point along the 90°W longitude line equal to (180-inclination). For our example satellite with an inclination of 28.4668 deg, mark on the 90°E longitude line about 28.5 degrees north of the equator (not very far north!). If the inclination had been 110 degrees, the mark would have been on the 90°W longitude line 70° north of the equator. Make a third mark on the equator near the 180° point. If the orbital increment is negative, place this mark clockwise of the 180° line a distance of one-half the orbital increment. If the orbital increment is positive, place the mark counter-clockwise of the 180° line a distance of one-half the orbital increment. For the example satellite which has an orbital increment of -23.226 degrees, make this mark about 12 degrees CW of the 180 mark (or 168°E). Make a smooth arc connecting these three points. Cross each latitude line only once between 0° long and 90° long and only once between 90° long and 180° long. Color the half between Greenwich Meridian and the 90° longitude line green and the other half red. Green indicates moving away from the equator and red, toward the equator. Extend these red and green lines out to the outer-most circle (which has no longitude lines).

Now, place a pin though the center mark of the first copy. Put this copy over the second copy (the one with the orbit marked) and pin them together so that they rotate relative to each other. Notice that as they are turned, there are positions where the orbit shows through the viewing-circle hole and other positions where the orbit is hidden. There may be two discontinuous settings of the top disk where the orbit is visible; this is usually the case only with orbits which have inclinations near 90° and when this happens, the point where the orbit changes from green to red cannot be seen inside the hole.

Rotate the two disks until the green orbit line just becomes visible in the hole. Make a green mark on the edge of the upper disk opposite the 0°

mark of the lower disk. Continue to rotate the disk. If the point where the orbit changes from green to red shows in the hole, continue to turn the disks until about equal lengths of red and green line show. Place a mark (red or green) on the edge of the upper disk opposite the 0° mark of the lower disk. If the green line disappears from the hole, place a green mark on the upper disk opposite the 0° mark of the lower disk at the point where the orbit just disappears. Do the same with red marks where the red portion of the orbit just appears and disappears. Color the top disk green between the green marks and red between the red marks.

Next, align the arrowhead mark of the upper disk with the 0° longitude line on the lower disk Write down the range of longitudes where the green coloring is and where the red coloring is (using the longitude scale along the equator of the lower disk since it was cut off of the top disk).

An RA anywhere within these longitude values produces a satellite pass which is visible from your site. If the RA is one in the green range, you will see the satellite moving from the equator toward the pole; if the RA is in the red range, it is moving from the pole toward the equator. You need only to use the orbital increment to estimate the sequence of RAs after the Epoch Time. Use the orbital period to determine when the RAs happen. Any RA which falls within either the green range or the red range should interest you.

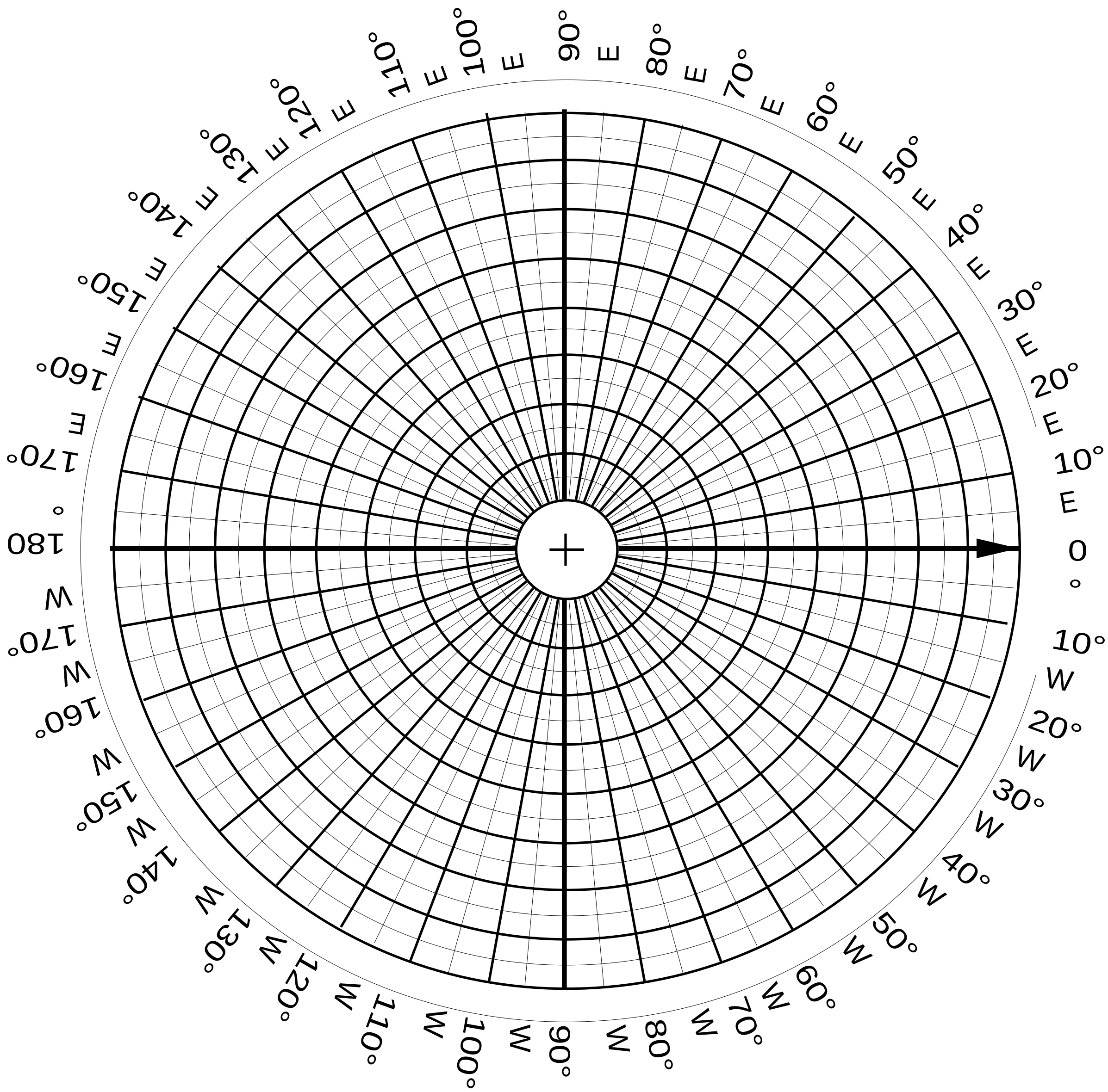

FIGURE 13-3, ORBITRACK CHART

A Worked-out Example: The author's location is about 122°W and 45° N. From Step B, Q_{LON} is about 80km per degree and Q_{LAT} is a 111.2km per degree. Since the viewing circle for the example satellite has a radius of 2200km, the east-west extent of the viewing circle is 27.5 degrees and the north-south extent is 19.8 degrees. Thus, the viewing circle at the author's location extends from [64.8°N, 122°W] to [45°N, 94.5°W] to [25.2N, 122°W] to [45°N, 149.5°W]. The oval which links these four points is cut out of the first copy as described. The second copy is marked with the orbit exactly as outlined in Step E.

The first thing which might be discovered is that the orbit barely shows above the lower edge of the viewing circle. This should tell us that the satellite, when it is visible, will always be low on the southern horizon. In fact, the orbit is so low that it is quite difficult to discern precisely when it is visible.

Rotate the two disks as described; mark the upper disk (opposite the 0° line of the lower disk) when the green orbit first appears in the viewing circle. Turn the upper disk further until equal amounts of green and red orbit show in the circle; put both a red and a green mark on the upper disk opposite the 0° line of the lower disk. Finally, continue turning until the red orbit just disappears from the circle and mark the upper disk with a red mark (again, opposite the 0° line of the lower disk). Now color with a red marker on the upper disk between the two red marks and with a green marker between the two green marks. To determine the corresponding RAs, rotate the upper disk until the arrowhead on the upper disk which denotes its 0° longitude lines up with the 0° latitude on the lower disk. We can now read off the range of RAs which result in visible satellite passes. It should come out green between 170°E and 148°E and red between 148°E and 120°E. Any RA in this range will result in a visible satellite. The following brief table shows a number of RAs after the Epoch Time. These are also marked with orbit number. Note from the original Keplerian Elements that the orbit for the given Epoch Time is orbit 70.

Orbit number	RA	Time, GMT
70	27.156°W	17:08:53
71	50.382°W	18:40:28
72	73.608°W	20:12:03
73	96.834°W	21:43:38
74	120.060°W	23:15:13
75	143.286°W	00:46:48
76	166.612°W	02:18:23
77	170.262°E	03:49:58
78	147.036°E	05:21:33

Orbit 77 might be visible for a very short time. Orbit 78 falls near the middle of the visible range. Note that the times shown are equatorial crossing. The satellite will become visible, when it does, a short time after the time shown.

Note, particularly, how the RA value is handled after the crossing of the International Date Line at 180°.

13.C MORE INFORMATION

This chapter has been very sketchy. There are several books which can provide more information. These are listed in the Bibliography (Volume 2). Your national amateur satellite organization can also provide a lot of information. In the United States, contact AMSAT-NA at 850 Sligo Ave, Silver Spring, MD, 20910-4704. Include a self-addressed and stamped envelope when requesting information.

Software and Keplerian Elements are available on a number of telephone bulletin boards. These include the AMSAT BBS (201) 261-2780, the SPACELINK BBS (205) 895-0028, the Dallas Remote Imaging BBS (214) 394-7438, and CompuServe.