Satellites are today taken for granted, as we daily use them for communications, cell phones, Internet, G.P.S., DSTV, weather imagery etc. It is but a few short years ago that this was only in the realm of science fiction and the dreams of visionaries. This paper covers Satellites for Beginners and will describe all the aspects needed to work some of the simplest satellites.

In order to work even the simplest of satellites some knowledge of satellite motion is required. Some understanding of Orbital Mechanics, Satellite tracking and Keplerian elements, Antennas: their gain and polar diagrams, Transmitters and Receivers is required.

Once a basic understanding of all these aspects of satellite operation has been gained it is them time to decide if satellite operation is for you or not. If it is you will now be armed with enough information to start putting together a satellite station. These can be very simple and in most cases radio amateurs already have the equipment that is used for VHF terrestrial communications in their shacks. It can also be very complex if directive gain antennas are used necessitating the use of azimuth and elevation controllers. It all depends on which satellites you choose to use.

At the end of the day it is the challenge and the fun of operating satellites that attracts some amateurs to use them. Armed with sufficient knowledge let the fun begin.
Types of Orbits

Polar Orbits

The more correct term would be near polar orbits. These orbits have an inclination near 90 degrees. This allows the satellite to see virtually every part of the Earth as the Earth rotates underneath it. It takes approximately 90 minutes for the satellite to complete one orbit. These satellites have many uses such as measuring ozone concentrations in the stratosphere or measuring temperatures in the atmosphere.

Sun Synchronous Orbits

These orbits allow a satellite to pass over a section of the Earth at the same time of day. Since there are 365 days in a year and 360 degrees in a circle, it means that the satellite has to shift its orbit by approximately one degree per day. These satellites orbit at an altitude between 700 to 800 km. These satellites use the fact since the Earth is not perfectly round (the Earth bulges in the center, the bulge near the equator will cause additional gravitational forces to act on the satellite. This causes the satellite's orbit to either proceed or recede. These orbits are used for satellites that need a constant amount of sunlight. Satellites that take pictures of the Earth would work best with bright sunlight, while satellites that measure longwave radiation would work best in complete darkness.

Geosynchronous Orbits

Also known as geostationary orbits, satellites in these orbits circle the Earth at the same rate as the Earth spins. The Earth actually takes 23 hours, 56 minutes, and 4.09 seconds to make one full revolution. So based on Kepler's Laws of Planetary Motion, this would put the satellite at approximately 35,790 km above the Earth. The satellites are located near the equator since at this latitude, there is a constant force of gravity from all directions. At other latitudes, the bulge at the center of the Earth would pull on the satellite. Geosynchronous orbits allow the satellite to observe almost a full hemisphere of the Earth. These satellites are used to study large scale phenomenon such as hurricanes, or cyclones. These orbits are also used for communication satellites. The disadvantage of this type of orbit is that since these satellites are very far away, they have poor resolution. The other disadvantage is that these satellites have trouble monitoring activities near the poles. See the picture below.
SATELLITE MOTION VIEWED FROM EARTH

Terrestrial Reference Frame

To describe a satellite’s movement as seen by an observer on the earth, we have to establish a terrestrial reference frame. Once again we simplify the situation by treating the earth as a sphere. The rotational axis of the earth (N-S axis) provides a unique line through the geocenter that intersects the surface of the earth at two points that are designated the north (N) and south (S) geographic poles. The intersection of the surface of the earth and any plane containing the geocenter is called a great circle. The great circle formed from the equatorial plane that plane containing the geocenter that also is perpendicular to the N-S axis, is called the equator. The set of great circles formed by planes containing the N-S axis are also of special interest. Each is divided into two meridians (half circles), connecting north and south poles.

Points on the surface of the earth are specified by two angular coordinates, latitude and longitude.

**Latitude.** Given any point on the surface of the earth, the latitude is determined by (i) drawing a line from the given point to the geocenter, (ii) dropping a perpendicular from the given point to the N-S axis and (iii) measuring the included angle. A more colloquial, but equivalent, definition for latitude is the angle between the line drawn from the given point to the geocenter and the equatorial plane. To prevent ambiguity, an N or S is appended to the latitude to indicate whether the given point lies in the northern or southern hemisphere. The set of all points having a given latitude lies on a plane perpendicular to the N-S axis. Although these latitude curves form circles on the surface of the earth, most are not great circles. The equator (latitude = 0°) is the only one to qualify as a great circle, since the equatorial plane contains the geocenter. Better models of the earth take the equatorial bulge and other asymmetries into account when latitude is defined. This leads to a distinction between geodetic, geocentric and astronomical latitude. We won’t bother with such refinements.

**Longitude.** All points on a given meridian are assigned the same longitude. To specify longitude one chooses a reference or “prime” meridian (the original site of the Royal Greenwich Observatory in England is used). The longitude of a given point is then obtained by measuring the angle between the lines joining the geocenter to (i) the point where the equator and prime meridian intersect and (II) the point where the equator and the meridian containing the given point intersect. For convenience, longitude is given a suffix, E or W, to designate whether one is measuring the angle east or west of the prime meridian.

**The Inclination**

As the earth rotates about its N-S axis and moves around the sun, the orientation of both the plane containing the equator (equatorial plane) and, to a first approximation, the plane containing the satellite (orbital plane) remain fixed in space relative to the fixed stars. (A) shows how the orbital plane and equatorial plane are related. The line of intersection of the two planes is called the line of nodes, since it joins the ascending and descending nodes. The relative orientation of these two planes is very important to satellite users. It is partially specified by giving the inclination. The inclination, i, is the angle between the line joining the geocenter and north pole and the line through the geocenter perpendicular to the orbital plane (to avoid ambiguity, the half-line in the direction of advance of a right-hand screw following satellite motion is used). An equivalent definition of the inclination, the angle between the equator and the sub-satellite path on a static (non-rotating) earth as the satellite enters the northern hemisphere, is shown in (B).

The inclination can vary from 0° to 180°. To first order, none of the perturbations to the simplified model we discussed earlier cause the inclination to change, but higher-order effects result in small oscillations about a mean value. A quick analysis of three cases yields the following information. When the inclination is 0°, the satellite will always be directly above the equator. When the inclination is non-zero the satellite passes over the equator twice each orbit, once heading north and once heading south. When the inclination is 90°, the satellite passes over the north pole and over the south pole during each orbit.

Orbits are sometimes classified as being polar (near polar) when their inclination is 90° (near 90°), or equatorial (near equatorial) when their inclination is 0° (near 0° or 180°). The maximum latitude north or south, that the sub-satellite point will reach equals (i) the inclination when the inclination is between 0° and 90° or (ii) 180° less the inclination when the inclination is between 90° and 180°.

**Argument of Perigee**

The angle between the line of nodes (the segment joining the geocenter to the ascending node) and the major axis of the ellipse (the segment joining the geocenter and perigee) is known as the argument of perigee (C) shows how the argument of perigee serves to locate the perigee in the orbital plane. In the simplified two-body model of satellite motion, the argument of perigee is constant. In reality however, it does vary with time, mainly as a result of the earth’s equatorial bulge.
(A) ORBITAL PLANE

PERPENDICULAR TO
ORBITAL PLANE

EQUATORIAL
PLANE

LINE OF
NODES

(B) I = INCLINATION ANGLE
OF ORBITAL PLANE

SUB-SATELLITE
PATH

W

EQUATOR

ASCENDING
NODE

(C) ORBITAL PLANE
W = ARGUMENT OF PERIGEE

APOGEE

LINE OF NODES

ASCENDING NODE

PERIGEE
**Keplerian Elements**

Keplerian elements are named after Johannes Kepler who was the first to describe the motion of planets in the universe.

**Johannes Kepler** is now chiefly remembered for discovering the three laws of planetary motion that bear his name published in 1609 and 1619. He also did important work in optics (1604, 1611), discovered two new regular polyhedra (1619), gave the first mathematical treatment of close packing of equal spheres (leading to an explanation of the shape of the cells of a honeycomb, 1611), gave the first proof of how logarithms worked (1624), and devised a method of finding the volumes of solids of revolution that (with hindsight!) can be seen as contributing to the development of calculus (1615, 1616). Moreover, he calculated the most exact astronomical tables hitherto known, whose continued accuracy did much to establish the truth of heliocentric astronomy (*Rudolphine Tables*, Ulm, 1627).

**CATALOG NUMBER:** A number assigned to a satellite by NASA.

**EPOCH TIME:** A reference time at which orbital elements are specified.

**DECAY RATE:** Short name for rate of change of mean motion. A parameter specifying how atmospheric drag affects a satellite's motion.

**ELEMENT SET NUMBER:** A number used to determine the latest set of Keplerian elements.

**INCLINATION:** The angle between the orbital plane of a satellite and the equatorial plane of the earth.

**RAAN:** (right ascension of ascending node): An angle that specifies the orientation of a satellite's orbital plane with respect to the fixed stars. The angular distance, measured eastward along the celestial equator, between the vernal equinox and the hour circle of the ascending node of the spacecraft.

**ECCENTRICITY:** A parameter used to describe the shape of the ellipse constituting a satellite orbit.

**ARGUMENT OF PERIGEE:** The polar angle locating the perigee point of a satellite in the orbital plane; drawn between the ascending node, geocenter and perigee; and measured from ascending node in direction of satellite motion.

**MEAN ANOMALY:** (MA) A number that increases uniformly with time, which is used to locate satellite position on orbital ellipse. For OSCAR satellites, MA varies from 0 to 256. When MA is 0 or 256, satellite is at perigee. When MA is 128, satellite is at apogee. When MA is between 0 and 128, satellite is headed up towards apogee. When MA is between 128 and 256, satellite is headed down towards perigee. Astronomers usually work with an MA that varies from 0 to 360.

**MEAN MOTION:** Number of revolutions (perigee to perigee) completed by satellite in a solar day (1440 minutes).

**ORBIT NUMBER:** The number of orbits or complete revolutions the satellite has completed since launch.

**CHECKSUM:** A checksum is used in two line Keplerian elements to check the integrity of the elements.
Kelperian Element Formats.

NASA 2 LINE FORMAT

DECODE 2-LINE ELSETS WITH THE FOLLOWING KEY:
1 AAAAAU 00 0 BBBBB.BBBBBBB .CCCCCCCC 00000-0 00000-0 0 DDDZ
2 AAAAA EEEE FFF.FFFF GGGGGG HH.HHHH III.IIII JJJJJJJJK KKKKZ
KEY: A-CATALOGNUM B-EPOCHTIME C-DECAY D-ELSETNUM E-INCLINATION F-RAAN
G-ECCENTRICITY H-ARGPERIGEE I-MNANOM J-MNMOTION K-ORBITNUM Z-CHECKSUM

TO ALL RADIO AMATEURS BT

AO-07
1 07530U 74089B 04197.68802813 -.00000029 00000-0 10000-3 0 2955
2 07530 101.6797 243.9770 0012017 165.7959 194.3449 12.53568878357487
AO-10
1 14129U 83058B 04196.81880124 0.00000036 00000-0 10000-3 0 00773
2 14129 026.4919 081.8353 6016526 107.2138 323.6870 02.05867142158587
UO-11
1 14781U 84021B 04197.78967637 0.00000036 00000-0 10000-3 0 00773
2 14781 026.4919 081.8353 6016526 107.2138 323.6870 02.05867142158587

SB KEPS @ AMSAT SORB04197.O
Orbital Elements 04197.OSCAR

AMSAT FORMAT

Satellite: AO-07
Catalog number: 07530
Epoch time: 04197.68802813
Element set: 295
Inclination: 101.6797 deg
RA of node: 243.9770 deg
Eccentricity: 0.0012017
Arg of perigee: 165.7959 deg
Mean anomaly: 194.3449 deg
Mean motion: 12.53568878 rev/day
Decay rate: -2.9e-07 rev/day^2
Epoch rev: 35748
Checksum: 348

Satellite: AO-10
Catalog number: 14129
Epoch time: 04196.81880124
Element set: 0077
Inclination: 026.4919 deg
RA of node: 081.8353 deg
Eccentricity: 0.6016526
Arg of perigee: 107.2138 deg
Mean anomaly: 323.6870 deg
Mean motion: 02.05867142 rev/day
Decay rate: 3.6e-07 rev/day^2
Epoch rev: 15858
Checksum: 302

SATELLITES FOR BEGINNERS

By
David Long ZS5FR
Part 2
Satellite Tracking

TRACKING: WHAT, WHY, HOW?
To a scientist, tracking a satellite means being able to specify its position in space. To a radio amateur, tracking more likely refers to practical concerns: When will a satellite be in range (accessible to you) and where should the antenna be pointed? Satellites generally are moving targets, so when a ground station uses directional antennas, aiming information must be available. The ability to predict access times is also important because most satellites are in range of a specific ground station for only a part of each day. (Geostationary satellites, which remain over a fixed location on the equator, are an exception.

A low-altitude satellite (such as Fuji-OSCAR 20, RS-10/11 or a MicroSat) will generally be in range for less than 25 minutes each time it passes nearby (satellite pass). A ground station will usually see four to six passes per day for each satellite. As a result, a satellite that’s operational 24 hours per day will be accessible only one to two hours each day at a specific ground station. Your average daily access time for a satellite is an important quantity in determining how useful the satellite will be to you.

A satellite in the high-altitude elliptical orbits used for Phase 3 spacecraft (such as OSCARs 13 and 40) behaves very differently. It will only provide one or two passes per day, but the total access time will be (very roughly) 12 hours for Northern Hemisphere stations. One way to look at this is to say that one Phase 3 satellite will provide you with as much daily operating time as roughly eight Phase 2 satellites.

Manual tracking of satellites would require charts onto which calculated information would have to be applied in order to determine when a satellite would be “visible” to a user. Charts would look like this:

Fortunately for amateurs the task of tracking satellites is made easy by the use of computer programs. There are many available on the web, some have to be registered but most are either freeware or shareware; they all do the same job. Some programs will even track your directional antennas automatically through an interface to the antenna azimuth and elevation rotators as the satellite moves from horizon to horizon. All that is needed is to enter the Keplerian Elements into the programs from time-to-time for them to be accurate. These are available on the web and some programs will even automatically download the latest Keplerian elements from the web and use them.

On the next page is a screen shot of one of the more popular tracking programs.
Globe view

Star View
Radar Map showing sky temperatures

Script tracking
It is not the intention to go into in-depth discussions of antenna design but to provide a working knowledge of the basic antenna’s for satellite communication.

Ground station performance is affected by many factors, but one stands out as being critically important: the antenna system. Although there are no intrinsic differences between antennas for satellite use and those for terrestrial applications, some designs are clearly better suited to satellite work than others. Properties that make a certain type of antenna desirable for HF operation may make it a poor performer on a satellite link, and vice versa. In this discussion we’ll consider the relation between basic antenna characteristics and satellite radio links. In the next discussion we’ll look at several types of practical antennas useful for satellite communications.

The antenna system characteristics we’ll focus on include:

1) Directional properties (gain and pattern)
2) Transmitting vs receiving properties
3) Efficiency
4) Polarization

One basic concept we’ll refer to time after time is the isotropic antenna: an array that radiates power equally in all directions. No one has ever been able to build a practical isotropic antenna but the concept is still very useful as a “measuring stick” against which other antennas...
can be compared. Closely related is the omnidirectional antenna, one that radiates equally well in all directions in a specific plane. Practical omnidirectional antennas are common; the ground plane is one example. Any antenna that tends to radiate best in a specific direction (or directions) may be called a beam antenna. Several beams (the Yagi, quad, loop Yagi and helix) are shown in the diagrams. Even the common dipole can be regarded as a beam since it has favored directions. The "first law" of antennas is: You don't get something for nothing. A beam can only increase the power radiated in one direction by borrowing that power from somewhere else. In other words, a beam acts by concentrating its radiated energy in a specific direction.

To quantify how well it accomplishes this task, we compare it to the isotropic antenna, our measuring stick.

We are however not going to consider these antenna's any further other than to use them for comparison purposes. These antenna's would require azimuth and elevation rotators.

The following are some of the antenna's that can be used to 'work' some of the simpler satellites with the simplest transceivers. The simplest being the dipole in it's various configurations.

This discussion focuses on several practical antennas that may be used at a satellite ground station. You'll no doubt recognize many, as they're also popular for terrestrial HF and VHF communication. We'll point out the advantages and disadvantages of each for accessing low- and high-altitude spacecraft, for construction difficulty, and for general utility as part of an overall antenna system.

THE DIPOLE AND ITS VARIANTS

The horizontal half-wave dipole (A) is a familiar antenna that can be used at satellite ground stations. Two offshoots of the dipole, the inverted V (B) and the somewhat less familiar V (C), have also been used. Be sure not to confuse the V antennas discussed here with the V-beam, which is radically different in construction and operation. Our discussion will focus on the inverted V since it has been investigated thoroughly. Nonetheless, it's safe to assume similar characteristics for the V.

The dipole and Vs are usually mounted fixed in the same configuration for both satellite and terrestrial applications (as in Fig). It therefore makes sense to label patterns as vertical and horizontal. Gain patterns in the horizontal plane for the dipole and inverted V are shown in Fig. Note how the horizontal dipole has higher gain broadside and deeper nulls off the ends. Their low gain renders the dipole and V suitable mainly for use with low-altitude satellites. Their broad beamwidth provides reasonably good coverage when the antennas are fixed mounted. Dipoles are most often used to receive the 29-MHz Mode A downlink. A few amateurs have tried them successfully on 146-MHz uplinks and downlinks in conjunction with low-altitude spacecraft on Modes A, B and J, but this has mainly been for experimental, not for general, communication.

Let's look at some practical applications of dipoles and Vs at 29 MHz. Given the patterns in the horizontal plane, most amateurs who are constrained to using a single fixed antenna choose the V to reduce the effects of the deep nulls associated with the dipole. Slightly better overall performance can be obtained by using two totally independent dipoles mounted at right angles to one another. If feed lines for both are brought into the operating position, switching between them to find the dipole that produces the best received signals is a simple matter. Another application, offering even better performance, consists of mounting a 10-rn dipole behind a small 2-rn beam, using a light-duty power from somewhere else.
Azimuth rotator to turn the whole perfectly conducting ground. The azimuth aiming requirements will be lax and, by inclining the 2-m beam at roughly 25° above the horizon, the elevation rotator can be eliminated. You’ll note that for all three examples just presented, improved performance seems to go hand-in-hand with increased complexity. The free-space gain pattern of the dipole in the vertical plane really isn’t of much interest to us because ground reflections change it drastically. As it turns out, the gain pattern depends on the height of the dipole. Look at the patterns in Fig for three specific heights: 1/4, 3/8 and 1 1/2 wavelengths above an infinite, pattern in (C) is very poor for satellite work since signals will fade sharply each time the satellite passes through one of the nulls. In reality, the nulls are not as severe as shown because the ground is not a perfect conductor and signals reflected off nearby objects often arrive at the ground station receiving antenna from several directions. The pattern in (B) is most desirable since gain variations tend to balance out changes in signal level as the distance between spacecraft and ground station varies. In other words, the gain pattern of (B) is high toward the horizon where signals are weak (large satellite to ground-station distances), and low in the overhead direction where signals are strong (small satellite to ground-station distances). The pattern in (A) is acceptable, though not as good as the one in (B). Gain patterns for the V antennas are similar when height is measured from the feed point to the conducting surface.

As the effective electrical ground does not generally coincide with the actual ground surface, you can’t simply measure height above ground to figure out which pattern applies to a given antenna. Many dipole users just orient the antenna with regard to the horizontal pattern and mount it as high and as clear of surrounding objects as possible. Although this does not always produce the best system performance, the results are usually adequate. Some users have tried to obtain the desired vertical patterns (A or B) by simulating a ground with a grid of wires placed beneath the dipole. Subjective reports suggest that even a single wire placed beneath a dipole or V antenna will improve 29-MHz Mode A reception. At 146-MHz and higher frequencies, a reflecting screen can be used for the ground so that a vertical pattern similar to the one of (B) can be achieved with the antenna mounted in a desirably high location. Because the ground screen is finite, gain at take-off angles below about 15° is reduced.

The basic half-wave dipole can also be mounted vertically. In this orientation the horizontal plane pattern is omnidirectional while the actual vertical plane pattern, which depends on mounting height, is likely to have one or more nulls at high radiation angles. Although the characteristics of this antenna appear suitable for work with low-altitude satellites, there is a hitch: the feed line must be routed at right angles to the antenna for at least a half wavelength if one hopes to obtain the patterns described. As a result, it’s usually easier to use a ground-plane antenna (see next discussion), which has similar characteristics. One novel configuration that has proved effective for working DX on Mode A consists of a vertical dipole for 29 MHz hung at the end of a tower-mounted 2-in beam. When the tower-to-dipole distance is set at roughly 6
feet, the tower will tend to act as a reflector and the resulting 29-MHz pattern will be similar to that obtained with a vertically mounted 2-element beam.

In truth, we’ve paid considerably more attention to the dipole and V than their actual use justifies. Nevertheless, they clearly illustrate many of the trade-offs between effective gain patterns and system complexity that a ground station operator is faced with.

THE GROUNDPLANE

The groundplane (GP) antenna, familiar to HF and VHF operators alike, is sometimes used at satellite ground stations. Physically, the GP consists of a 1/4- or 5/8-wavelength vertical element and three or four horizontal or drooping spokes that are roughly 0.3 wavelength or longer. At VHF and UHF, sheet metal or metal screening is often used in place of the horizontal spokes. The GP is a low-gain, linearly polarized antenna. The gain pattern in the horizontal plane is omnidirectional. Because of its low gain the GP is not generally suitable for operating with high-altitude satellites, though it may be used in special cases. We’ll focus on its possibilities with respect to low-altitude spacecraft.

Gain patterns in the vertical plane for 1/4-wavelength GP antennas are shown in Fig. Although the vertical plane patterns suggest that performance will be poor when the satellite is overhead, stations using the GP report satisfactory results. The reasons are most easily explained in terms of reception. Downlink signals usually arrive at the ground station antenna from several directions after being reflected off nearby objects. These reflected signals can either help (when the direct signal falls within a pattern null) or hinder (when interference between the main and reflected signals results in fading). In practice, the good effects appear to far outweigh the bad; the GP is a good all-around performer for working with all low-altitude OSCARs (heights under 1000 miles) and the ISS and US Space Shuttle.

A GP may be useful for receiving signals from high-altitude satellites in certain situations. For example, although the downlink S/N ratio using a GP generally will not be adequate for communication, it should be sufficient for spotting (determining if the spacecraft is in range). The omnidirectional (horizontal plane) pattern of the GP makes it especially suitable for this purpose. Also, the GP may be useful near perigee of elliptical-orbit missions if spin modulation is not excessive. We now turn to some practical GP antennas.

GP antennas designed for the 27-MHz CB market are inexpensive and widely available. For Mode A downlink operation the 1/4-wavelength GP usually out performs the “bigger is better” 5/8-wavelength model because its vertical plane radiation pattern is better suited to satellite operation. To modify a 1/4-wavelength CB antenna for 29.4-MHz the vertical element should be shortened about 9% - If a matching network is used it might also require a slight adjustment.

GP antennas designed for the 146-MHz and 435-MHz amateur bands are available commercially at moderate cost. Once again, the 1/4-wavelength models produce good results. Some users, however, prefer to use a 5/8 GP when the satellite is at low elevation angles, and a different type of antenna when the satellite is at higher elevation angles. A VHF or UHF 1/4-wavelength GP can be assembled at extremely low cost (see the illustration).
Tilting the vertical element of a 1/4-wavelength GP modifies the gain pattern in the vertical plane as shown in Fig (B). Note how the overhead null has been eliminated. The horizontal pattern is slightly skewed, but remains essentially omnidirectional. Tilting also tends to reduce the already low input impedance of the GP. One way to compensate for this reduction is to use a folded element as shown in (A). As in the folded dipole, the folded 1/4-wave element in a tilted GP steps up the input impedance and gives a broader-bandwidth antenna. The dimensions shown should give a good match to 50-ohm coax.

Low gain omnidirectional antennas like the GP are especially useful with low altitude satellites. How does one choose which particular antenna is most suitable? One important consideration is the antennas vertical plane radiation pattern. This pattern should be matched to the daily average time that the satellite will appear at specific elevation angles. To analyze the situation we'll divide elevation angles into three sectors: 0 to 30°, 30° to 60°, and 60° to 90°. We'll then compute the ratio of the access time in a given sector to the total access time and express the result as a percentage.

For a satellite in a circular orbit the desired information depends on the ground station latitude and on the satellite’s orbital inclination. However, a reasonably accurate estimate for mid-latitude ground stations and satellites in near polar orbits can be obtained by assuming that average daily access time in a given sector is proportional to the terrestrial area between the corresponding elevation circles.

Example, the average daily time that RS-10/11 will appear between 30 and 60° in elevation is proportional to the area between its 30 and 60° elevation circles, and the average time it will be in range is proportional to the area between its 0 and 90° elevation circles (area inside access circle). A more thorough analysis shows that, even for spacecraft like the US Space Shuttle where our assumptions are generally not valid, the results still hold.

SATIELITES FOR BEGINNERS

By

David Long ZS5FR

Part 4

Simple Transmitters/ Receivers

Have a 2m Radio?

Once you have acquainted yourself with the satellites by listening, it’s time to start making contacts. Perhaps you don’t have an HF rig, but are equipped for 2m FM. In that case, consider trying to work the ISS. If you also have a 1200 baud TNC, connect to the ISS BBS. Simple stuff, except that the other station is moving, not much different from your basic 2m operation. Just remember that, whether you’re working voice or packet, the passes don’t last long and there may be others wanting to do the same thing. Keep your contacts short, and if you’re on packet, send a “disconnect” before you loose contact or the digipeater will be unavailable until its TNC retry count is exceeded and the TNC resets. Don’t forget the effects of Doppler Shift; start listening high and tune down as the bird passes.

Have an HF Radio?

Maybe you have an HF receiver or transceiver. If so, you already have the ability to copy the 10m downlinks on several of the satellites. The antenna you use for the downlink will make some difference, but use whatever you have; you might be surprised at how well you can pull in those signals from space with what you have now. If you find that you are having some difficulty hearing the passes, consider a receive pre-amp. At 29 MHz you can use one inside the shack, but a good practice is to mount it close to the antenna where the signal is greatest. A word of caution is in order here: make absolutely sure you don’t transmit through your pre-amp unless it is designed for transceive operation; otherwise you end up with a very useless attenuator instead.

Have Both?

If you have a means of generating a CW or SSB signal on 2m as well as a 10m receiver, then you’re ready to get on the Mode A satellites. If you don’t yet have a 2m multimode transceiver, you may want to consider getting one. The reason I suggest the 2m multimode is obvious if you’re interested in satellite work; it will get you onto not only mode A, but there are other birds where 2m transmit is necessary. Many hams start out with handhelds and eventually find they...
want to get something more. The 2m multimode at home will allow them to remain on their favorite repeater or FM simplex frequency while trying something new.

If you can generate the RF, chances are you can hit the bird. Don’t sweat it if you can’t afford a big expensive new 2m base; there are used units to be found at swap shops. Some are mobiles, but what does that matter? Have you heard the old saying “It’s not the age or size of the car that counts, it’s how well you drive it”? Substitute “radio” and “operate” for “car” and “drive” and you’ll get the idea. You won’t need a lot of power to communicate through the satellites. In fact, you’ll need AT MOST 100W EIRP; it’s usually much less. Take into consideration the power out from your radio, feed line and connector loss, and antenna gain.

Note to the ZR’s: Don’t worry that you don’t have access to the HF bands. You aren’t transmitting on 10m, the satellite is, and the sponsoring group is responsible for meeting the licensing requirements for HF.

All We Need Now is 70cm

So far we’ve looked at the equipment needs for using ARISS. Access to the currently operational satellites requires only one more thing: a way to receive the 70cm downlink. This means you’ll need either a 435 MHz capable receiver/transceiver or a converter with your 10m receiver/transceiver. If you go the latter route, bear in mind that the satellite allocation on 70cm goes from 435 MHz to 438 MHz. This really isn’t a problem if your HF radio has general coverage capability, but if it doesn’t you will need a converter that has selectable local oscillators. That will allow you to have, for example, one position that converts 435 - 436.7MHz and the other 436 - 437.7 MHz to the standard 28 - 29.7 MHz 10m band. If you use a converter, you can save money by mounting the converter at the antenna instead of using a pre-amp because most converters have plenty of output gain to help overcome line loss at 10m. Finally, heed the warning I gave you previously: DON’T TRANSMIT THROUGH YOUR CONVERTER OR PRE-AMP! (That’s twice. Don’t say you weren’t warned.)

Simple Satellites for Beginners

There are several satellites available to amateurs for their use in many of the different modes. Most of the more exotic satellites require either some form of antenna tracking, hi gain antennas and/or high gain transmitters. The following satellites have been chosen for the beginner as they are LOE’s (Low Earth Orbit) satellites and do not need anything fancy by way of equipment and most can be worked with a hand held with about 2.5 watts of output. In may cases the “rubber ducky” will be good enough to establish communications with some limitations such as not being able to use the satellite until it is reasonably high in the sky, this also means loosing the signal sooner than when the satellite disappears over the horizon. By the addition of a simple antenna such as a ¼ wave ground plane most of these limitations can be overcome.

The addition of directional antennas with azimuth and elevation control, mast head pre-amps and multimode rigs will enable a greater variety of satellites to be used.

INTERNATIONAL SPACE STATION (ISS) - ARISS
Catalog number: 25544
Launch date: November 20, 1998

Status: Operational
Digipeater: Active

The current Expedition 9 crew is:
Commander Gennady Padalka, RN3DT
Flight Engineer Mike Fincke, KE5AIT

Worldwide packet uplink: 145.990 MHz FM
Region 1 voice uplink: 145.200 MHz FM
Region 2/3 voice uplink: 144.490 MHz FM
Worldwide downlink: 145.800 MHz FM

Russian callsigns: RS0ISS, RZ3DZR
USA callsign: NA1SS
Packet station mailbox callsign: RS0ISS-11
Packet station keyboard callsign: RS0ISS-3
Digipeater callsign: ARISS

O-29 JAS-2
Catalog number: 24278
Launch Date: August 17, 1996

Status: Operational

Voice/CW Mode JA
Uplink: 145.90 to 146.00 MHz CW/LSB
Downlink: 435.80 to 435.90 MHz CW/USB
Beacon: 435.795 MHz

Digital Mode JD
NO-45 SAPPHIRE
Catalog number: 26932
Launch Date: September 30, 2001

Status: Operational

Downlink: 437.095 MHz 1200 baud AX-25 AFSK
Uplink: 145.945 MHz UI Digipeater
Digi Callsign: KE6QMD

The NO-45 digipeater remains on. Users are requested NOT to use the Bulletin Board. When the Bulletin Board is used it effectively "locks out" ground access to the spacecraft CPU.

Everyone is welcome to use the digipeating/APRS features of Sapphire, callsign KE6QMD

AO-51 ECHO
Catalog number: 28375
Launch date: June 29, 2004

Status: Operational

Analog voice downlink: 435.225 MHz FM
Analog voice uplink: 145.920 MHz FM 67Hz PL tone

Digital 9600 bps AX25 PACSAT Protocol Mailbox

Digital downlink: 435.150 MHz FM
Digital uplink: 145.860 MHz FM

ECHO Experimenters Day Operation Wednesdays (UTC) 00:00 23:59
Default configuration will be:

Digital downlink: 2401.200 MHz 38.4 kbps FM
Digital uplink: 1268.700 MHz 9600 bps FM

AMSAT-OSCAR-51 is the newest satellite launched by AMSAT. It is the strongest satellite in the sky other than the ISS, and is one of the most complex satellites currently in operation. It has many subsystems and as some have said, “it has something for
everyone” including simultaneous voice and packet operations. In this article I’ll focus on making a voice contact.

Launch and Checkout

AO-51 was launched from the Baikonour Cosmodrome in Kazakhstan on June 29, 2004 and was inserted into a sun synchronous orbit which allows it to be over the same geographical location basically the same time every day. For us in North America, this happens in approximately 11am for the decending (north to south) pass, and late evening (11pm) for the ascending pass. It underwent testing for 30 days after launch, and was turned over to amateur access on July 30th.

When AO-51 was first turned on it’s first over the East Coast it was estimated that over 500 amateurs attempted to use the satellite. Three reported having QSOs, while the other 497 were left scratching their heads. When the satellite passed over central North America 80 minutes later, those 500 stations were joined by another 500 from the west coast. Two stations reported having QSOs. At 30 minutes past midnight AO-51 showed up out over the Pacific ocean. Estimates are that 200 people on the west coast stayed up, and about 8 QSOs took place. I was one of the lucky ones.

So what happened?

AO-51 is a low earth orbit satellite (LEO) mode J-FM (V/U) voice repeater, the same as launching your local repeater in orbit, except for one very significant difference. Instead of having a range of 50 or so miles, it can be accessible to the entire country at one time. While this may sound beneficial at first, the results can be disastrous. If you’ve ever heard a double on your local repeater when the net control calls for check-ins, think of the results when 500 stations suddenly try to check in to the same repeater at the same time. It’s a pileup.

Quite a lot of the pileup results from people who have never heard a satellite before but key up to “just to make sure it’s there”. There are also those who can hear it, but don’t have on the required 67Hz PL tone. Although AO-51 will not repeat those signals, they can jam weaker signals and prevent them from getting through. Lastly an FM repeater is not designed to handle that many simultaneous signals, so they double, triple and… well, you can see the results are predictable.

How Will I Ever Get In?

The good news is that in the weeks following activation of AO-51 the load has lightened and it’s easier to get it if you plan ahead and avoid the pileups. Many people are able to work Echo successfully and I have consistently been able to get in at 5 watts with both an Arrow antenna and a ½ wave whip. Aruni VE4WMK who is 10 years old uses an HT with an Arrow and is very successful following using very simple techniques that I posted in article on the AMSAT website entitled “12 Suggestions for Handheld Transceiver Users”. Here are some of the basics:

1) **Listen First.** If you can’t hear other stations, you can’t work them. AO-51 is very strong (only the ISS is stronger) so almost everyone can hear it on a good HT with a good whip antenna, the dual-band Arrow yagi or the dual band Elk log periodic that are sold at most flea markets in the area.

2) **Keep your squelch off.** Although Echo is strong, it’s not strong enough to break your squelch in most cases.

3) **Make sure you have your PL tone set to 67hz.** Like most repeaters, even if you get a chance to get in, you won’t without the
PL tone set. Don’t try to use tone squelch either, as Echo does not transmit a 67Hz PL tone back on it’s downlink.

4) **Don’t use a verticle antenna.** Whips and ground plane antennas should be tilted so that the verticle is 90 degrees off the elevation of the satellite.

5) **Know where the satellite is.** Keep a tracking program nearby where you can reference it. If you are handheld outside, use a handheld computer running PocketSat or PetiTrack to reference the satellite’s position.

6) **Use Dual Headphones!** I can’t stress this enough. Your brain is the best DSP there is, and if you only hear the signal through one ear, your brain can’t filter out the noise nor can it react quickly to call signs.

### How Should I Prepare?

When you decide to work AO-51 for the first time, some preparatory steps will help.

- Visit the AMSAT website and visit the Echo Project page to make sure you have the correct frequencies. The AMSAT website also has online pass predictions in the Tools section which will calculate the passes for your location.

- Try listening on one pass nearby (over 30 degrees of elevation) and see how well you are receiving. If you can’t hear the satellite, you may need to improve your receive antennas.

- Try to arrange a sked with another station. It’s easier to make a contact with someone who is experienced on the satellites than cold calling. That contact can also help you determine how well your signal is doing.

- Plan on working a pass away from populated areas (see the map - white spots are high density population areas.) If you can work to the north or west or over the ocean, your results will be better because statistically there are fewer people.

Most of all, don’t get discouraged. AO-51 is reprogrammable from the ground and they have made some improvements to it already. For example, initially the power was set to 330mw, then 500mw and now is set for 1W. AO-51 can operate up to 7 watts, but it is unlikely they will increase power over 2W since most stations now receive AO-51 full quieting.

### Echo Frequencies

The following are the announced frequencies for AO-51:

**Voice Uplink:** 145.920 MHz FM (PL - 67Hz)
1268.700 MHz FM (PL - 67Hz)

**Packet Uplink:** 145.860 MHz 9600 bps, AX.25

**Voice Downlink:**

**Voice 435.300 MHz FM**

**Packet Downlink:**

**Packet 435.150 MHz 9600 bps, AX.25**

**Downlink:**

2401.200 MHz 38,400 bps, AX.25
Website References

AMSAT – http://www.amsat.org
The Echo Project Page - http://www.amsat.org/amsat-new/echo/

So best of luck and CU on the Birds!

73,
Emily

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SATELLITES FOR BEGINNERS

By
David Long ZS5FR
Part 6

Keplerian Elements Tutorial

This tutorial is based on the documentation provided with InstantTrack, written by Franklin Antonio, N6NKF.

Satellite Orbital Elements are numbers that tell us the orbit of each satellite. Elements for common satellites are distributed through amateur radio bulletin boards, and other means.

Entering satellite elements is easy. Understanding them is a bit more difficult. I have tried to make this tutorial as easy to read as possible.

The Seven (or Eight) Keplerian Elements

Seven numbers are required to define a satellite orbit. This set of seven numbers is called the satellite orbital elements, or sometimes "Keplerian" elements (after Johann Kepler [1571-1630]), or just elements. These numbers define an ellipse, orient it about the earth, and place the satellite on the ellipse at a particular time. In the Keplerian model, satellites orbit in an ellipse of constant shape and orientation. The Earth is at one focus of the ellipse, not the center (unless the orbit ellipse is actually a perfect circle).
The real world is slightly more complex than the Keplerian model, and tracking programs compensate for this by introducing minor corrections to the Keplerian model. These corrections are known as perturbations. The perturbations that amateur tracking programs know about are due to the lumpiness of the earth's gravitational field (which luckily you don't have to specify), and the "drag" on the satellite due to atmosphere. Drag becomes an optional eighth orbital element.

Orbital elements remain a mystery to most people. This is due I think first to the aversion many people (including me) have to thinking in three dimensions, and second to the horrible names the ancient astronomers gave these seven simple numbers and a few related concepts. To make matters worse, sometimes several different names are used to specify the same number. Vocabulary is the hardest part of celestial mechanics!

The basic orbital elements are...

1. **Epoch**
2. **Orbital Inclination**
3. **Right Ascension of Ascending Node** (R.A.A.N.)
4. **Argument of Perigee**
5. **Eccentricity**
6. **Mean Motion**
7. **Mean Anomaly**
8. **Drag** (optional)

The following definitions are intended to be easy to understand. More rigorous definitions can be found in almost any book on the subject. I've used aka as an abbreviation for "also known as" in the following text.

**Epoch**

[aka "Epoch Time" or "T0"]

A set of orbital elements is a snapshot, at a particular time, of the orbit of a satellite. Epoch is simply a number which specifies the time at which the snapshot was taken.

**Orbital Inclination**

[aka "Inclination" or "I0"]

The orbit ellipse lies in a plane known as the orbital plane. The orbital plane always goes through the center of the earth, but may be tilted any angle relative to the equator. Inclination is the angle between the orbital plane and the equatorial plane. By convention, inclination is a number between 0 and 180 degrees.

Some vocabulary: Orbits with inclination near 0 degrees are called equatorial orbits (because the satellite stays nearly over the equator). Orbits with inclination near 90 degrees are called polar (because the satellite crosses over the north and south poles). The intersection of the equatorial plane and the orbital plane is a line which is called the line of nodes. More about that later.

**Right Ascension of Ascending Node**

[aka "RAAN" or "RA of Node" or "O0", and occasionally called "Longitude of Ascending Node"]

RAAN wins the prize for most horribly named orbital element. Two numbers orient the orbital plane in space. The first number was Inclination. This is the second. After we've specified inclination, there are still an infinite number of orbital planes possible. The line of nodes can poke out the anywhere along the equator. If we specify where along the equator the line of nodes pokes out, we will have the orbital plane fully specified. The line of nodes pokes out two places, of
course. We only need to specify one of them. One is called the ascending node (where the
satellite crosses the equator going from south to north). The other is called the descending node
(where the satellite crosses the equator going from north to south). By convention, we specify the
location of the ascending node.

Now, the earth is spinning. This means that we can't use the common latitude/longitude
coordinate system to specify where the line of nodes points. Instead, we use an astronomical
coordinate system, known as the right ascension / declination coordinate system, which does not
spin with the earth. Right ascension is another fancy word for an angle, in this case, an angle
measured in the equatorial plane from a reference point in the sky where right ascension is
defined to be zero. Astronomers call this point the vernal equinox.

Finally, "right ascension of ascending node" is an angle, measured at the center of the earth, from
the vernal equinox to the ascending node.

I know this is getting complicated. Here's an example. Draw a line from the center of the earth to
the point where our satellite crosses the equator (going from south to north). If this line points
directly at the vernal equinox, then RAAN = 0 degrees.

By convention, RAAN is a number in the range 0 to 360 degrees.

I used the term "vernal equinox" above without really defining it. If you can tolerate a minor
digression, I'll do that now. Teachers have told children for years that the vernal equinox is "the
place in the sky where the sun rises on the first day of Spring". This is a horrible definition. Most
teachers, and students, have no idea what the first day of spring is (except a date on a calendar),
and no idea why the sun should be in the same place in the sky on that date every year.

You now have enough astronomy vocabulary to get a better definition. Consider the orbit of the
sun around the earth. I know in school they told you the earth orbits around the sun, but the math
is equally valid either way, and it suits our needs at this instant to think of the sun orbiting the
earth. The orbit of the sun has an inclination of about 23.5 degrees. (Astronomers don't usually
call this 23.5 degree angle an 'inclination', by the way. They use an infinitely more obscure name:
The Obliquity of The Ecliptic.) The orbit of the sun is divided (by humans) into four equally sized
portions called seasons. The one called Spring begins when the sun pops up past the equator. In
other words, the first day of Spring is the day that the sun crosses through the equatorial plane
going from South to North. We have a name for that! It's the ascending node of the Sun's orbit. So
finally, the vernal equinox is nothing more than the ascending node of the Sun's orbit. The Sun's
orbit has RAAN = 0 simply because we've defined the Sun's ascending node as the place from
which all ascending nodes are measured. The RAAN of your satellite's orbit is just the angle
(measured at the center of the earth) between the place the Sun's orbit pops up past the equator,
and the place your satellite's orbit pops up past the equator.

**Argument of Perigee**

[aka "ARGP" or "W0"]

Argument is yet another fancy word for angle. Now that we've oriented the orbital plane in space,
we need to orient the orbit ellipse in the orbital plane. We do this by specifying a single angle
known as argument of perigee.

A few words about elliptical orbits... The point where the satellite is closest to the earth is called
perigee, although it's sometimes called periapsis or perifocus. We'll call it perigee. The point
where the satellite is farthest from earth is called apogee (aka apoapsis, or apifocus). If we draw a
line from perigee to apogee, this line is called the line-of-apsides. (Apsides is, of course, the plural
of apsis.) I know, this is getting complicated again. Sometimes the line-of-apsides is called the
major-axis of the ellipse. It's just a line drawn through the ellipse the "long way".

The line-of-apsides passes through the center of the earth. We've already identified another line
passing through the center of the earth: the line of nodes. The angle between these two lines is
called the argument of perigee. Where any two lines intersect, they form two supplementary
angles, so to be specific, we say that argument of perigee is the angle (measured at the center of
the earth) from the ascending node to perigee.
Example: When ARGP = 0, the perigee occurs at the same place as the ascending node. That means that the satellite would be closest to earth just as it rises up over the equator. When ARGP = 180 degrees, apogee would occur at the same place as the ascending node. That means that the satellite would be farthest from earth just as it rises up over the equator.

By convention, ARGP is an angle between 0 and 360 degrees.

**Eccentricity**

[aka "ecce" or "E0" or "e"]

This one is simple. In the Keplerian orbit model, the satellite orbit is an ellipse. Eccentricity tells us the "shape" of the ellipse. When e=0, the ellipse is a circle. When e is very near 1, the ellipse is very long and skinny.

(To be precise, the Keplerian orbit is a conic section, which can be either an ellipse, which includes circles, a parabola, a hyperbola, or a straight line! But here, we are only interested in elliptical orbits. The other kinds of orbits are not used for satellites, at least not on purpose, and tracking programs typically aren't programmed to handle them.) For our purposes, eccentricity must be in the range 0 <= e < 1.

**Mean Motion**

[aka "N0"] (related to "orbit period" and "semimajor-axis")

So far we've nailed down the orientation of the orbital plane, the orientation of the orbit ellipse in the orbital plane, and the shape of the orbit ellipse. Now we need to know the "size" of the orbit ellipse. In other words, how far away is the satellite?

Kepler's third law of orbital motion gives us a precise relationship between the speed of the satellite and its distance from the earth. Satellites that are close to the earth orbit very quickly. Satellites far away orbit slowly. This means that we could accomplish the same thing by specifying either the speed at which the satellite is moving, or its distance from the earth!

Satellites in circular orbits travel at a constant speed. Simple. We just specify that speed, and we're done. Satellites in non-circular (i.e., eccentricity > 0) orbits move faster when they are closer to the earth, and slower when they are farther away. The common practice is to average the speed. You could call this number "average speed", but astronomers call it the "Mean Motion". Mean Motion is usually given in units of revolutions per day.

In this context, a revolution or period is defined as the time from one perigee to the next.

Sometimes "orbit period" is specified as an orbital element instead of Mean Motion. Period is simply the reciprocal of Mean Motion. A satellite with a Mean Motion of 2 revs per day, for example, has a period of 12 hours.

Sometimes semi-major-axis (SMA) is specified instead of Mean Motion. SMA is one-half the length (measured the long way) of the orbit ellipse, and is directly related to mean motion by a simple equation.

Typically, satellites have Mean Motions in the range of 1 rev/day to about 16 rev/day.

**Mean Anomaly**

[aka "M0" or "MA" or "Phase"]

Now that we have the size, shape, and orientation of the orbit firmly established, the only thing left to do is specify where exactly the satellite is on this orbit ellipse at some particular time. Our very
first orbital element (Epoch) specified a particular time, so all we need to do now is specify where, on the ellipse, our satellite was exactly at the Epoch time.

Anomaly is yet another astronomer-word for angle. Mean anomaly is simply an angle that marches uniformly in time from 0 to 360 degrees during one revolution. It is defined to be 0 degrees at perigee, and therefore is 180 degrees at apogee.

If you had a satellite in a circular orbit (therefore moving at constant speed) and you stood in the center of the earth and measured this angle from perigee, you would point directly at the satellite. Satellites in non-circular orbits move at a non-constant speed, so this simple relation doesn't hold. This relation does hold for two important points on the orbit, however, no matter what the eccentricity. Perigee always occurs at MA = 0, and apogee always occurs at MA = 180 degrees.

It has become common practice with radio amateur satellites to use Mean Anomaly to schedule satellite operations. Satellites commonly change modes or turn on or off at specific places in their orbits, specified by Mean Anomaly. Unfortunately, when used this way, it is common to specify MA in units of 256ths of a circle instead of degrees! Some tracking programs use the term "phase" when they display MA in these units. It is still specified in degrees, between 0 and 360, when entered as an orbital element.

Example: Suppose Oscar-99 has a period of 12 hours, and is turned off from Phase 240 to 16. That means it's off for 32 ticks of phase. There are 256 of these ticks in the entire 12 hour orbit, so it's off for \((32/256)\times12\text{hrs} = 1.5\text{ hours}\). Note that the off time is centered on perigee. Satellites in highly eccentric orbits are often turned off near perigee when they're moving the fastest, and therefore difficult to use.

**Drag**

[aka "N1"]

Drag caused by the earth's atmosphere causes satellites to spiral downward. As they spiral downward, they speed up. The Drag orbital element simply tells us the rate at which Mean Motion is changing due to drag or other related effects. Precisely, Drag is one half the first time derivative of Mean Motion.

Its units are revolutions per day per day. It is typically a very small number. Common values for low-earth-orbiting satellites are on the order of \(10^{-4}\). Common values for high-orbiting satellites are on the order of \(10^{-7}\) or smaller.

Occasionally, published orbital elements for a high-orbiting satellite will show a negative Drag! At first, this may seem absurd. Drag due to friction with the earth's atmosphere can only make a satellite spiral downward, never upward.

There are several potential reasons for negative drag. First, the measurement which produced the orbital elements may have been in error. It is common to estimate orbital elements from a small number of observations made over a short period of time. With such measurements, it is extremely difficult to estimate Drag. Very ordinary small errors in measurement can produce a small negative drag.

The second potential cause for a negative drag in published elements is a little more complex. A satellite is subject to many forces besides the two we have discussed so far (earth's gravity, and atmospheric drag). Some of these forces (for example gravity of the sun and moon) may act together to cause a satellite to be pulled upward by a very slight amount. This can happen if the Sun and Moon are aligned with the satellite's orbit in a particular way. If the orbit is measured when this is happening, a small negative Drag term may actually provide the best possible 'fit' to the actual satellite motion over a "short" period of time.

You typically want a set of orbital elements to estimate the position of a satellite reasonably well for as long as possible, often several months. Negative Drag never accurately reflects what's happening over a long period of time. Some programs will accept negative values for Drag, but I don't approve of them. Feel free to substitute zero in place of any published negative Drag value.
Other Satellite Parameters

All the satellite parameters described below are optional. They allow tracking programs to provide more information that may be useful or fun.

Epoch Rev

[aka "Revolution Number at Epoch"]

This tells the tracking program how many times the satellite has orbited from the time it was launched until the time specified by "Epoch". Epoch Rev is used to calculate the revolution number displayed by the tracking program. Don't be surprised if you find that orbital element sets which come from NASA have incorrect values for Epoch Rev. The folks who compute satellite orbits don't tend to pay a great deal of attention to this number! At the time of this writing [1989], elements from NASA have an incorrect Epoch Rev for Oscar-10 and Oscar-13. Unless you use the revolution number for your own bookkeeping purposes, you needn't worry about the accuracy of Epoch Rev.

Attitude

[aka “Bahn Coordinates”]

The spacecraft attitude is a measure of how the satellite is oriented in space. Hopefully, it is oriented so that its antennas point toward you! There are several orientation schemes used in satellites. The Bahn coordinates apply only to spacecraft which are spin-stabilized. Spin-stabilized satellites maintain a constant inertial orientation, i.e., its antennas point a fixed direction in space (examples: Oscar-10, Oscar-13).

The Bahn coordinates consist of two angles, often called Bahn Latitude and Bahn Longitude. These are published from time to time for the elliptical-orbit amateur radio satellites in various amateur satellite publications. Ideally, these numbers remain constant except when the spacecraft controllers are re-orienting the spacecraft. In practice, they drift slowly.

For highly elliptical orbits (Oscar-10, Oscar-13, etc.) these numbers are usually in the vicinity of: 0,180. This means that the antennas point directly toward earth when the satellite is at apogee.

These two numbers describe a direction in a spherical coordinate system, just as geographic latitude and longitude describe a direction from the center of the earth. In this case, however, the primary axis is along the vector from the satellite to the center of the earth when the satellite is at perigee.

An excellent description of Bahn coordinates can be found in Phil Karn's "Bahn Coordinates Guide".