introducing satellite communications

Basic information to get you started

Do you want to access a new Amateur band that's always open when it's supposed to be? A band that doesn't fade away without warning, that makes DX contacts sound like locals, and has no skip zones?

Listening to, or working through Amateur communications spacecraft isn't difficult, but most newcomers simply don't know how to go about it properly. Not sure of what they're doing, they usually achieve disappointing results; deciding that the amount of effort invested must be so much more than the results achieved, they give up and go back to their regular haunts, where they can usually at least find someone to talk to. This is a shame, because satellites have come of age and commercial equipment is as readily available for the satellite bands as for the regular HF or VHF bands. You can buy or roll your own, but in either case — just like on 20 meters or the other HF bands — you have to have some knowledge of what's going on if you're going to get the maximum enjoyment out of the equipment.

terminology

A communications satellite is basically a repeater in the sky. It receives signals transmitted up from the ground on one Amateur band and retransmits the same signals down to the earth on a second Amateur band. It's part of a communications link between two Amateur stations on the ground as shown in **fig. 1**; signals on their way up to the satellite are said to be *uplinked* by stations on the ground while the corresponding signals coming down from the satellite are being *downlinked*. As the satellite orbits the earth it passes over different locations; the point immediately beneath the satellite at any time is called the *subsatellite point*.

The area of the earth's surface that the satellite can "see" depends on its altitude; the higher it is, the more it can see. A commercial communications satellite in a high altitude over the equator can see about one third of the earth's surface. A satellite at a low altitude sees much less.

Any station that the spacecraft can see, can see the spacecraft. When a station can see the spacecraft, it is said to be *in range*. Thus any two stations in range of the satellite at the same time are said to have a *window* into the satellite and can communicate through it.

Most orbits are elliptical rather than circular. The highest point above the surface of the earth in the orbit is called the *apogee*; the lowest point of that same orbit is the *perigee*.

Even though the orbit of the satellite is fixed, the earth rotates beneath it. The time it takes for the satellite to travel once around its orbit from the place where the sub-satellite point crosses the equator to the next time the sub-satellite point crosses the equator going in the same direction is called the *period* of the orbit. When the sub-satellite point has returned to the equator, the point on earth that was previously below it will have moved away because of the rotation of the earth; consequently, a new location will be beneath it. The number of degrees of longitude that have passed by during this time is known as the *orbital increment* (see **fig. 2**). The first orbit of the day is known as the *reference orbit*.

Earth stations will see different parts of different orbits as shown in **fig. 3**. The azimuth, or horizontal bearing and elevation angle to the spacecraft, will change with the orbit. The spacecraft will appear to rise above the horizon when it enters the range of the ground station. The time at which the spacecraft rises above the horizon is called *Acquisition Of Signals*, or

By Joe Kasser, G3ZCZ, P.O. Box 3419, Silver Spring, Maryland 20901

AOS. The position of the satellite in the sky as seen by the ground observer will change as it passes along its orbit, rising higher and passing across the sky, getting lower, and then finally setting on the horizon. The time at which it sets beneath the horizon of the ground station is known as *Loss of Signals*, or *LOS*.

The path traced by a satellite in the sky as seen by a particular ground station will vary according to the type of orbit. The path traced by a satellite in a circular orbit will usually approximate a section, or chord, of a circle. The path traced by a satellite in an elliptical orbit will depend on the apogee and perigee of the orbit and how close the observer is to the subsatellite point.

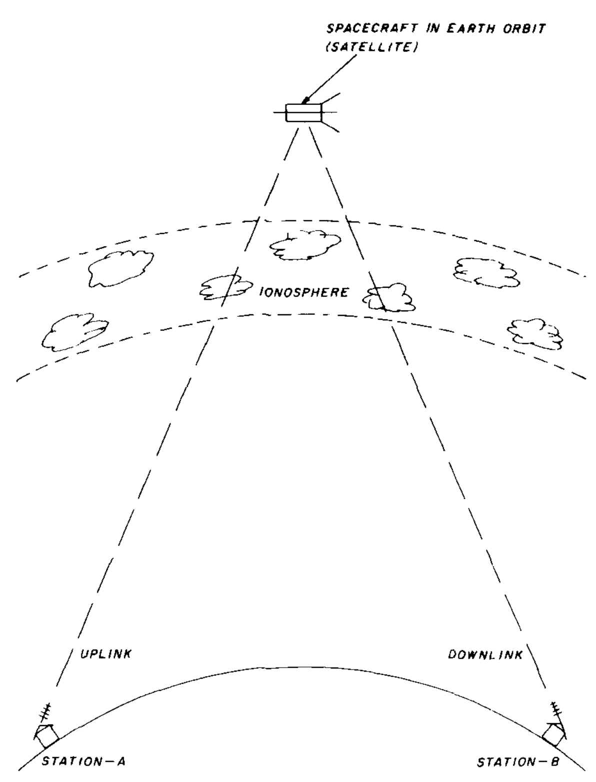
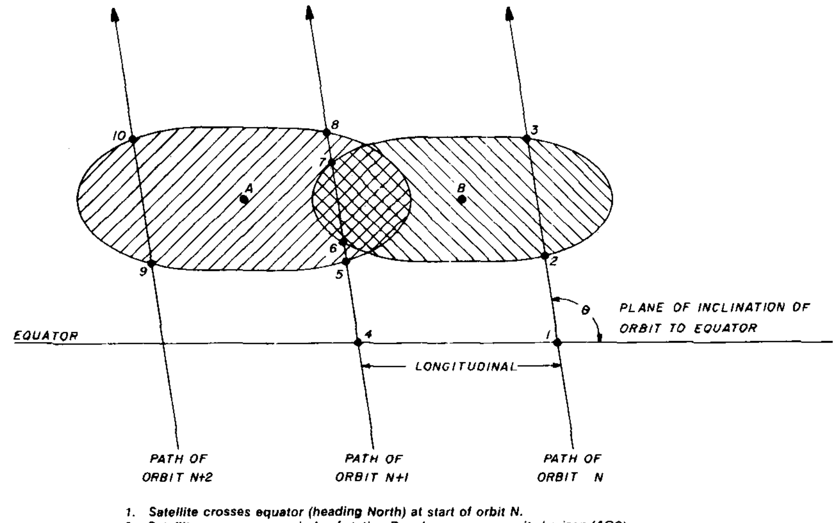


fig. 1. Satellite communications path. Station A is transmitting (uplink). Signals are received by the satellite and re-transmitted down to station B (downlink).

characteristics of satellite signals

In order to copy signals from satellites, we first need to know a little about the types of signals we're trying to receive. At any particular time, an observer on the ground may see the satellite in any direction with respect to the horizon (*azimuth*) and at any altitude between the horizon and a point directly overhead (*elevation*). This means that signals from various satellites arrive at a receiving station from any angle in any direction.

Radio waves are generated in a polarized manner. Conventional Amateur station antennas may generate vertically or horizontally polarized signals, depending on the position of the antenna with respect to the



1. *Satellite crosses equator (heading North) at start of orbit N.*
2. *Satellite crosses range circle of station B and comes up over its horizon (AOS).*
3. *Satellite crosses range circle of station B and sets on its horizon (LOS).*
4. *Satellite crosses equator at start of orbit N + 1.*
5. *Satellite crosses range circle of station A (AOS).*
6. *Satellite crosses range circle of station B (mutual access window opens).*
7. *Satellite crosses range circle of station B (mutual access window closes).*
8. *Satellite crosses range circle of station A (LOS).*
9. *Satellite crosses range circle of station A on orbit N + 2 (AOS).*
10. *Satellite crosses range circle of station A on orbit N + 2 (LOS).*

fig. 2. Looking down on the earth from the satellite showing track of spacecraft on surface (subsatellite point). Range circles are drawn as ellipses on rectangular (map) projection. Circles overlap to give mutual access window on orbit N + 1 between points 6 and 7.

TYPICAL SATELLITE ANGLES FOR ONE GROUND LOCATION ON ONE DAY

OSCAR-9

U.T.C. HHMM:SS	AZIMUTH DEGREES	ELEVATION DEGREES
1330:00	102	10
1332:00	68	14
1334:00	35	9
1336:00	16	2
1500:00	194	1
1502:00	207	10

OSCAR-11

U.T.C. HHMM:SS	AZIMUTH DEGREES	ELEVATION DEGREES
0824:00	359	5
0826:00	350	15
0828:00	327	31
0830:00	269	38
0832:00	231	21
0834:00	218	9

OSCAR-10

U.T.C. HHMM:SS	AZIMUTH DEGREES	ELEVATION DEGREES
1600:00	256	7
1700:00	240	12
1800:00	236	10
1900:00	235	6
2000:00	236	1

RS-7

U.T.C. HHMM:SS	AZIMUTH DEGREES	ELEVATION DEGREES
1856:00	347	5
1858:00	344	12
1900:00	340	21
1902:00	333	32
1904:00	318	45
1906:00	286	56
1908:00	242	54
1910:00	217	41
1912:00	205	28
1914:00	199	18
1916:00	195	10
1918:00	192	3

RS-5

U.T.C. HHMM:SS	AZIMUTH DEGREES	ELEVATION DEGREES
1748:00	4	3
1750:00	8	9
1752:00	15	17
1754:00	24	25
1756:00	39	34
1758:00	62	41
1800:00	91	42
1802:00	115	35
1804:00	131	26
1806:00	140	17
1808:00	147	10
1810:00	151	3

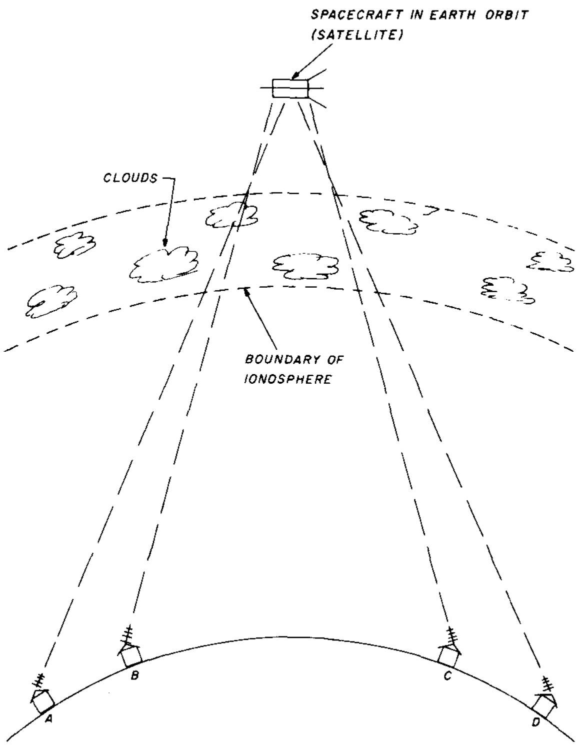
Space shuttle Challenger

U.T.C. HHMM:SS	AZIMUTH DEGREES	ELEVATION DEGREES
0625:00	328	0
0626:00	330	5
0627:00	334	10
0628:00	343	20
0629:00	7	37
0630:00	77	43
0631:00	113	24
0632:00	124	13

Shown are azimuth and elevation angles from the ground station to the different spacecraft at different times of the day. It can be seen that in order to adequately copy signals from the spacecraft, the ground station must be able to receive signals coming from any azimuth or elevation. This figure only lists data for one of the daily passes for each satellite. As a rule they will be audible at other times of the day with signals coming from other directions.

fig. 3. Typical satellite azimuth and elevation angles for various passes as seen by a representative ground station.

ground. If the radiating elements are horizontal, the antenna is said to be generating horizontally polarized signals; conversely, if the elements are vertical, the antenna is vertically polarized. The same polarization also holds for reception. Thus, vertical antennas receive vertically polarized signals best and horizontal antennas receive horizontally polarized signals best. True vertically polarized antennas will copy little or no horizontally polarized signals. Two-meter and other VHF/UHF FM antennas are vertically polarized, while base stations working SSB/CW use horizontal antennas. This is because automobile antennas are vertically polarized, and the mobile stations put weak signals into horizontal antennas. (In the early days of mobile radio communications, Amateurs fitted "halo" antennas on their cars to send and receive horizontally polarized signals in order to be compatible with the base stations. When the mobiles using FM began to outnumber



1. "Clouds" move around and change shape.
2. Effects are different at different frequencies.
3. Satellite itself may shield on-board antenna from one or more ground station(s). Such shielding was first noted on OSCAR 6.
4. Clouds attenuate or (polarization) rotate signals.

fig. 4. Some factors affecting satellite communications.

the fixed stations, there was no further need to use horizontal polarization and verticals became the rule. Nowadays, any base station that wants to use FM has to use vertical polarization.

On the HF bands both types of antennas are used interchangeably and everyone manages to work everybody. This is because the polarization of the radio waves changes as the signals pass through the ionosphere. A process known as *Faraday rotation* rotates the polarization of the signals. The signal as received on the ground is not entirely vertically or horizontally polarized and as such may be copied at somewhat lower signal strength on any antenna. Perhaps the good performance of quad antennas is due to their having both vertical and horizontal elements. When conditions in the ionosphere are changing, the received signals may appear to fade — i.e., get weaker and stronger as the plane of polarization is rotated by the ionosphere.

Satellite orbits are outside the ionosphere, which means that signals from the spacecraft are affected by the ionosphere in a manner similar to that which affects conventional terrestrial signals: the polarization of their signals changes. Conventional contacts tend to use the same part of the ionosphere. The ionosphere is not a constant layer above the earth, of course, but is instead made up of patches, or clouds. Since the satellite is moving, its uplink and downlink signals will pass through different parts of the ionosphere at different times, and the effects of the ionosphere on the signals will differ as time passes, as shown in **fig. 4**.

Not only does the ionosphere refract radio waves and change their polarization, it may also attenuate signals or even absorb them. As the spacecraft travels along its orbit, it may be spinning or tumbling, or the satellite itself may shield the on-board antenna from the receiving station. Because of the limitations of its equipment, the transmitter on the space vehicle is transmitting at a relatively low power — less than 10 watts output. Consequently, signals from satellites may arrive at the ground from any direction in azimuth or elevation, with any polarization, and at any signal strength (usually very weak). All these may, and usually do, vary as a function of time.

an ideal satellite receiving antenna

The ideal antenna for copying satellite signals should be rotatable in azimuth and elevation in order to cope with all the possible directions from which signals may arrive. It must be immune to changes in polarization if it is to cope with horizontal, vertical, and in-between polarization caused by Faraday rotation in the ionosphere. It must also have a reasonable amount of gain in order to cope with the fading in the already weak signals generated at the satellite.

Vertical and horizontal polarization are two kinds of linear polarization. Radio signals can also be circularly polarized. A circularly polarized antenna will respond equally to horizontally or vertically polarized signals — that is, changes in the plane of polarization will not be detected. Circular polarization also comes in two kinds, left-hand and right-hand (clockwise and counter-clockwise). To compound the problem, lefthand circularly polarized signals are not well received on righthand circularly polarized antennas and vice-versa.

antennas in common use on 10 meters

Figure 5 lists the commonly used bands in the Amateur Satellite Service. The most commonly used downlink bands are 10 meters, 2 meters and 70 cm. The first band combination that most people try is the 10-meter downlink and the 2-meter uplink commonly known as *Mode A*. This is because they usually have 10-meter capability in their stations and can thus attempt to copy the satellite without adding too much equipment.

1. ASSIGNMENTS

10 METERS	29.3	-	29.55 MHz
2 METERS	145.8	-	146.00 MHz
70 CENTIMETES	435.0	-	438.00 MHz

2. SATELLITE TRANSPONDERS

SPACECRAFT	MODE	UPLINK	DOWNLINK
AMSAT - OSCAR 6	A	145.85 - 145.95MHz	29.45 - 29.55MHz
AMSAT - OSCAR 7	A	145.85 - 145.95MHz	29.40 - 29.50MHz
AMSAT - OSCAR 7	B	432.125 - 432.175MHz	145.975 - 145.925MHz
AMSAT - OSCAR 8	A	145.85 - 145.95MHz	29.40 - 29.50MHz
AMSAT - OSCAR 8	J	145.90 - 146.00MHz	435.10 - 435.20MHz

The data supplied on AMSAT - OSCARs 6 - 8 is for historic purposes as the spacecraft are no longer operational.

CURRENTLY ACTIVE

SPACECRAFT	MODE	UPLINK	DOWNLINK
AMSAT - OSCAR 10	B	435.05 - 435.15MHz	145.95 - 145.85MHz
AMSAT - OSCAR 10	L	1269.05 - 1269.85MHz	436.95 - 436.15MHz
RS - 5	A	145.91 - 145.95MHz	29.41 - 29.45MHz
RS - 7	A	145.96 - 146.00MHz	29.46 - 29.50MHz

FUTURE (PROPOSED) SPACECRAFT

For launch in early 1986

SPACECRAFT	MODE	UPLINK	DOWNLINK
RS - 9/10	A	145.96 - 146.00MHz	29.46 - 29.50MHz
RS - 9/10	K	21.26 - 21.30MHz	29.46 - 29.50MHz
RS - 9/10	?	21.26 - 21.30MHz	145.96 - 146.00MHz

The RS spacecraft have been ground tested and are due for launch in 1986.

SPACECRAFT	MODE	UPLINK	DOWNLINK
FUJI - 1	A	145.85 - 145.95MHz	29.40 - 29.50MHz
FUJI - 1	M	1267.55 - 1267.75MHz	436.00 - 435.80MHz

The FUJI spacecraft is being built in Japan under the control of JAMSAT, a group of Japanese Radio Amateurs.

ARSENE

The ARSENE spacecraft built by a group of French Radio Amateurs is supposed to be launched in the demonstration flight of the ARIANE 4 rocket in 1986. It will contain a Mode B transponder.

AMSAT -PHASE 3C

The AMSAT Phase 3C spacecraft is also scheduled for launch in mid 1986. It will contain a Mode B transponder as well as other transponders having either uplink or downlink capability on the higher frequency bands.

AMSAT has a policy of not obsoleting user equipment, so mode B will be around for a long time. As mode A is an excellent introductory mode, it can be expected on any further general purpose Phase 2 type spacecraft. The Russians also tend to favour hf so mode A and possibly mode K will also be around for a while.

fig. 5. Commonly used satellite communications bands.

Once you're hooked on receiving, the price of a transmitter usually becomes a justifiable expense. Although putting together a minimal receiving and transmitting station isn't difficult, steerable antennas for the 10-meter band are relatively large. Therefore relatively few Amateurs can steer their 10-meter antennas in both azimuth and elevation. Steerable antennas for 2-meters and 70 cm are much smaller and as a result, more manageable.

Antennas in common use on the 10-meter band include verticals and multi-element beams optimized for working DX. As such, they have very good responses to signals arriving from low angles but are not at all suited for signals arriving at high angles. Vertical antennas respond to low-angle radiation from all directions, while beams respond to low-angle signals from the direction in

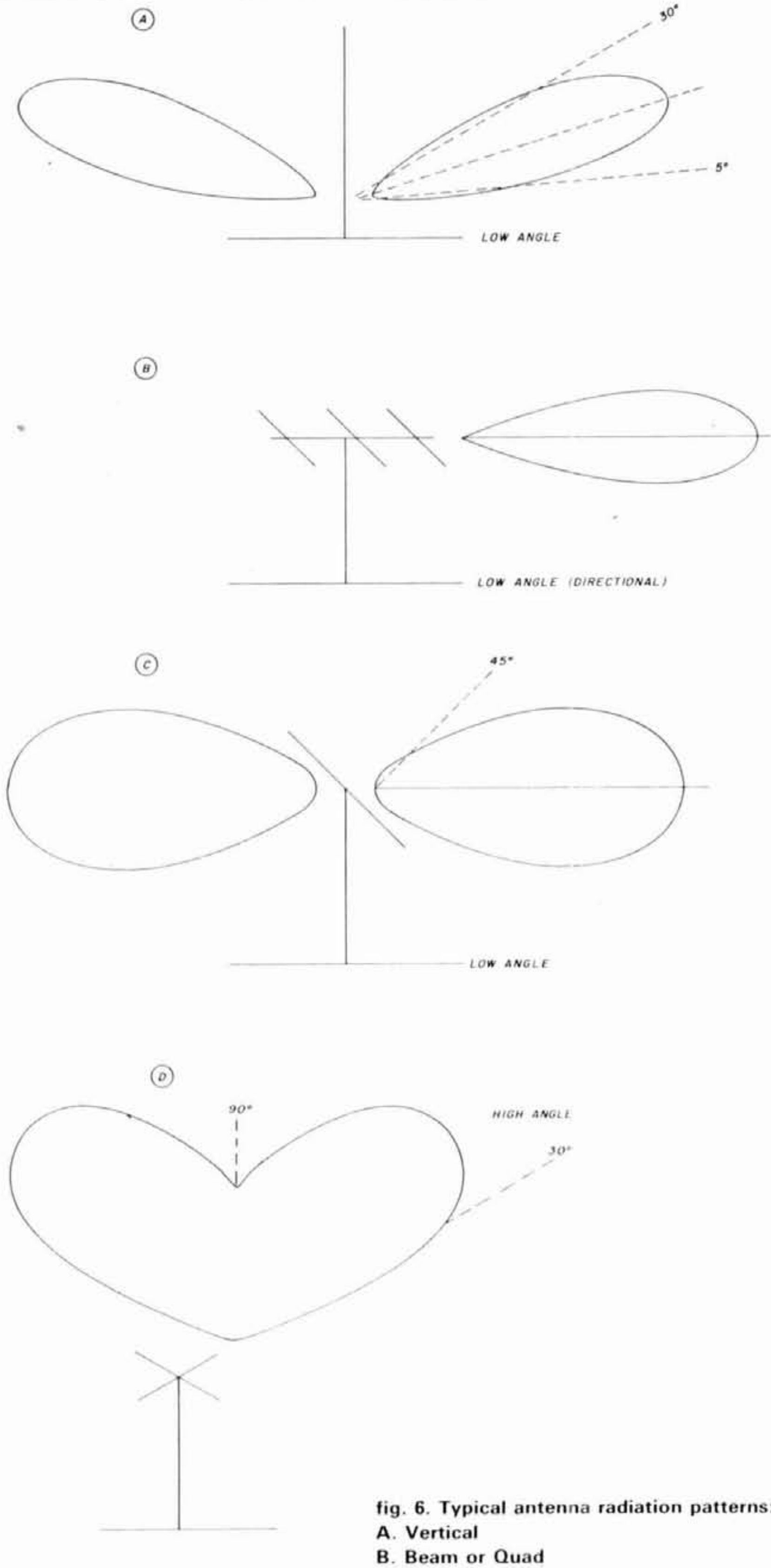


fig. 6. Typical antenna radiation patterns:
A. Vertical
B. Beam or Quad
C. Horizontal dipole
D. Turnstile.

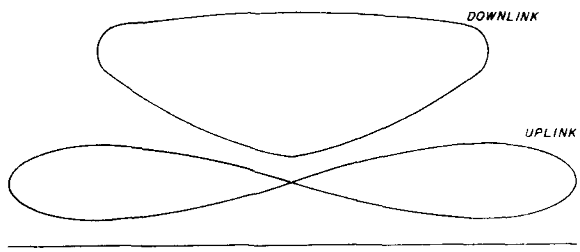


fig. 7. Typical VHF/UHF operator antenna characteristics. Hears well when satellite is high in sky. Talks well when satellite is low in sky.

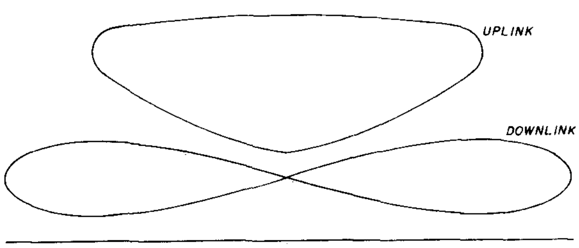


fig. 8. Typical HF operator antenna characteristics. Hears well when satellite is low in sky. Talks well when it is high in sky.

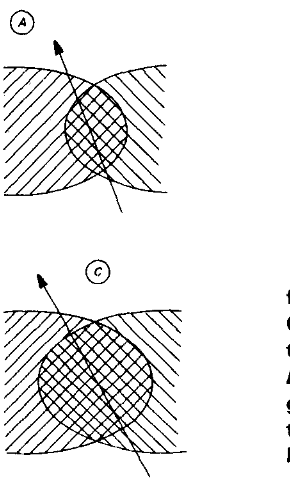


fig. 9. Contact possiblilities. Overlap of range circles: *A*) typical contact possibility; *B*) Range circles are tangents. Best DX minimum time; *C*) Large window, longer time.

which they happen to be pointed. Stations using these antennas have trouble hearing signals arriving from higher angles.

Conventional literature has touted the turnstile, or crossed dipole antenna, as the answer to the problems of satellite reception at 10 meters. It has circular polarization and a high-angle response pattern. It does very well when the satellite is located at elevations greater than about 30 degrees as seen by the observer, but has a poor response to signals arriving at low angles (close to the horizon). Typical radiation patterns for these antennas are shown in **fig. 6**.

Most Amateurs who have problems working Mode A fall into one of two categories. The first category includes the VHF/UHF operator who decides that satellites offer both a technical challenge and increased opportunity for some exciting DX. This operator usually has excellent linear (horizontal or vertical) polarized antennas for the 2-meter uplink bands but has nothing for 10 meters. Reading that a turnstile can be a simple, effective device for reception, he builds one and finds that, sure enough, he can hear something. It may be weak, but, by golly, those signals are coming from outer space!

Step back for a minute and analyze this situation as sketched in **fig. 7**. The uplink antennas on 2 meters can put a powerful signal into the satellite when it's at low angles of elevation as seen by this operator. His downlink antenna, however, receives best when the satellite is at a high angle. In other words, when he can hear it, he can't access it . . . and when he can access it, he can't hear it — meaning, he cannot hear himself.

The second type of Amateur who decides to have a go at satellite operation is the HF operator, who usually has a good beam antenna for 10 meters. Reading that a turnstile antenna is a good choice for satellite operation, he builds one and uses it. Now analyze this situation as sketched in **fig. 8**. The uplink antenna on 2 meters puts a weak signal into the satellite when it is at low angles of elevation as seen by this operator. His downlink antenna, however, receives best when the satellite is at low angles. In other words, when he can hear it, he cannot access it . . . and when he can access it, he cannot hear it — meaning that he cannot hear himself. Although this is the inverse situation to that of the VHF/UHF operator it has the same characteristics: both are "alligator operators" — all mouth and no ears.

There is a third category: the apartment dweller who cannot put up HF antennas at all. This type of operator can usually install some kind of VHF/UHF array on a balcony and work Mode B quite well. But when he tries Mode A, he has problems because of the size of his 10-meter receiving antenna.

It's no surprise, then, that the vast majority of Radio Amateurs who decide to become active in satellites have trouble working them at first.

matching uplink and downlink antennas

In order to get the most enjoyment out of satellite operation, it's necessary to match the uplink and downlink antennas. Before doing this, however, it's necessary to consider other aspects of the satellite communications path.

The Earth-Satellite-Earth ccommunications link is a line-of-sight path. Each ground station has a range circle for which a window allows communications into the satellite. In order to work any other station, the range circles of the two stations must overlap as shown in **fig. 9**. The duration of any contact is governed by the time that the spacecraft spends in that window. Thus, the higher the elevation of the satellite as seen by the ground station, the shorter its communications range along the surface of the Earth. The best DX contact between any two stations occurs when the sub-satellite point of the orbit of the spacecraft passes over the ground where their range circles just touch — that is, at a tangent to both range circles. They will, however, also have very little time to make that contact.

antenna characteristics

The usual three-element Quad or Yagi-type antenna puts out a good directional low-angle signal. The turnstile antenna puts out a good omnidirectional high-angle signal. Vertical antennas put out good omnidirectinal low-angle signals. The 3/8 and 5/8 wave antennas used on 2-meters have good omnidirectional low-angle radiation characteristics. Somewhat directional high-angle radiation may be obtained from sloping dipoles attached between the top of a mast and the ground in the manner of guy wires (but don't ever use them as such), as shown in **fig. 10**. If you want to work the satellites successfully, you must match the characteristics of your uplink (transmitting) and downlink (receiving) antennas so that they have similiar radiation patterns.

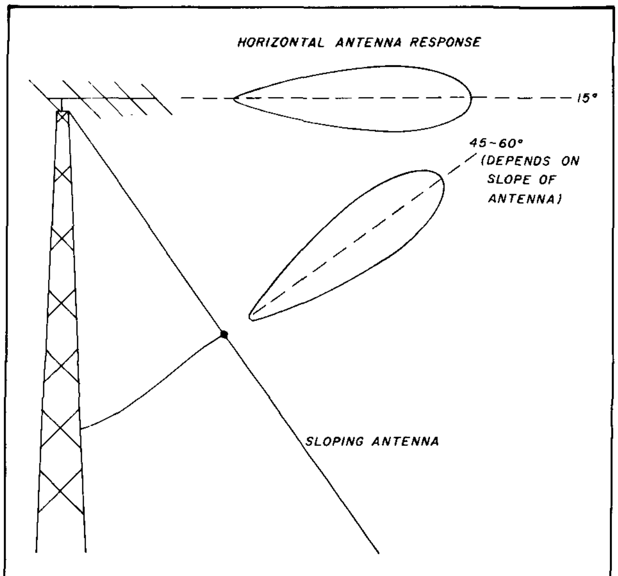


fig. 10. Sloping antennas for 10 meters. Optimally, put slopers on four sides of tower. These will work well for regular 10 meter contacts. Put dipole or beam on tower.

receiving signals

The satellite downlink is usually marginal because the spacecraft is using low power and is far away. Every ESE (earth-satellite-earth) contact practically qualifies the spacecraft for yet another 1000-mile-per-watt award for QRP communications.

Most modern receivers (and others not so modern) suffer from a loss of sensitivity at the top end of the 10-meter band so that using a preamplifier to increase the strength of the received signals is a good idea. Most Amateurs feel that to communicate with DX stations they need the biggest antenna they can put up and the maximum power they can put out. But there's a fallacy at work in this kind of thinking; if the minimum amount of transmitted power to put an S-9 signal into a DX location is, for example, 100 watts, then for that transmitter to use 1000 watts would be a waste of power . . . or would it? For the moment, ignore the QRM factor in which the more power you use, the louder you are and the more likely you are to be heard over the rest of the pack. If the signal is made weaker or attenuated by the ionosphere for one reason or another, what happens? In our example, we are receiving signals from a transmitter having the calculated 100 watts. If a fade equal to 5 S-units takes place, the received signal will drop down to S-4. This isn't too serious; S-4 signals can be copied, but what happens if the station is using the QRP and was S-4 to begin with? The same fade would take it down to S minus 1 or below the noise level, and no signals could be copied. The communications link should contain enough gain to minimize or avoid loss of reception due to extreme fading. In other words, some kind of margin should be built into the link.

the communications link

The communications link in a satellite contact can readily be split into two parts, the uplink and the downlink. Consider each of these in turn.

In the downlink, the transmitter output power is not under the control of the Radio Amateur, but is instead fixed by the satellite. The attenuation of the signals radiated by the satellite is a function of the distance between the spacecraft and the receiving station. The actual strength of the received signal at the ground station antenna will vary because of the attenuation due to fading and polarization changes in the ionosphere. Thus all the ground station operator can do is make sure that he has the best and most sensitive receiving capability that he can have. Ideally, the receiver should be such that the beacons on the downlink are receivable at good signal strength. In most cases, this means that a receiving preamplifier should be used ahead of the receiver.

In the uplink, the receiving antenna and on-board receiver sensitivity are governed by the design of the satellite. The attenuation of the signals from the ground as received by the satellite is a function of the distance from the spacecraft to the transmitting station. The actual strength of the received signal from the ground station antenna will vary because of the attenuation due to fading and polarization changes in the ionosphere. The effects of the ionosphere on the uplink may differ from those on the downlink. In the past, AMSAT has performed the link calculations before the launch of the spacecraft and released a recommended value in radiated uplink power (EIRP) for Amateurs to use with the satellite. This number has usually been conservative, and most satellite users have no trouble working through the transponder with much less power. The common solution to this problem is to boost the transmitter power until a good return signal is heard. This is not the optimal solution, because stations that have problems hearing themselves will tend to use too much power, not because they can't get into the satellite, but because they cannot hear themselves getting into it. The ionosphere may also behave differently in different places at any time, so that although the sending station may be having trouble hearing his own downlink, other stations further away may be copying him with ease. There's no easy solution to this situation. The compromise is to attempt to make your own signal as received on the downlink equal in strength to that of the transponder beacon. This means that you adjust your transmitter power to keep your own signal as strong as the beacon on your receiver. You can do this either by reducing the transmitter power gain or by aiming the antenna away from the spacecraft.

Gain in the communications link can be obtained by using amplifiers or directional antennas. Directional antennas are at a disadvantage in that they must be moved to track the satellite during the pass, while omnidirectional ones do not. On the other hand, they're usually cheaper than amplifiers, particularly high power UHF transmitting types. Thus, to obtain a certain power output level on the uplink, the Amateur has the choice of a directional antenna and low power or an omnidirectional antenna and high power, or something in between. Similarly, on the downlink, if the directional antennas are used, a receiving preamplifier may not be an absolute necessity. In any event, for reasonable results, make sure that the characteristics of your uplink and downlink antennas are matched.

locating the satellite

The common adage, "If you can't hear them, you can't work them" must be modified for satellite users to read, "If you can't locate them, you won't hear them . . . and if you can't hear them, you can't work them."

In order to work satellites, an Amateur has to know not only when a satellite is in range, but also where to aim his antenna in order to put a signal into it. A number of different techniques have been developed over the past few years: graphical "circular slide rules" were first used very successfully for Phase 2 low-orbit satellites. As the personal computer found its way into ham stations, computer programs were developed to locate the satellites and the graphical plotters could be used to augment computer-generated data.

Fortunately, the first OSCAR satellites used by large numbers of Amateurs (AMSAT's OSCAR 6, 7, and 8 and the early RADIO spacecraft) were in circular orbits, which made locating them easy. All you had to do was pick a "reference orbit" as published in the Amateur Radio press and add the orbital increment to determine the position of the next equator crossing (start of the next orbit) and then add the period of the orbit to find the time of the following orbit.

When the first Phase 3 satellite (AMSAT's OSCAR 10) was put into service, it was placed into an elliptical orbit with a high apogee and a low perigee — definitely a non-circular orbit. AMSAT's Tom Clark, W3IWI, an astronomer by profession, wrote a program that utilized Keplerian elements for keeping track of the position of any satellite in the Amateur Satellite Service. This and many other programs have been widely disseminated and there should be at least one member of each radio club who knows how to get hold of them. (AMSAT can supply copies of such software through its Software Exchange.) Locating the satellite, therefore, should not be a problem.

reference

1. Tom Clark, W3IWI, "Basic Orbits," *Orbit*, March/April, 1981.

ham radio