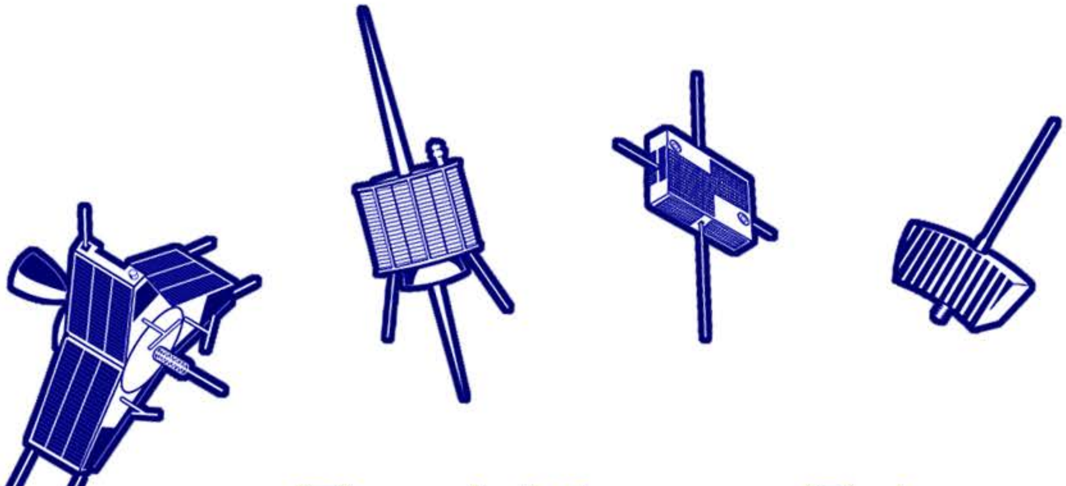
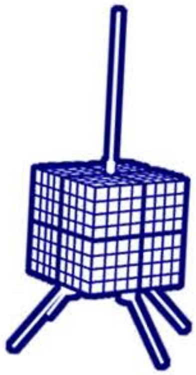
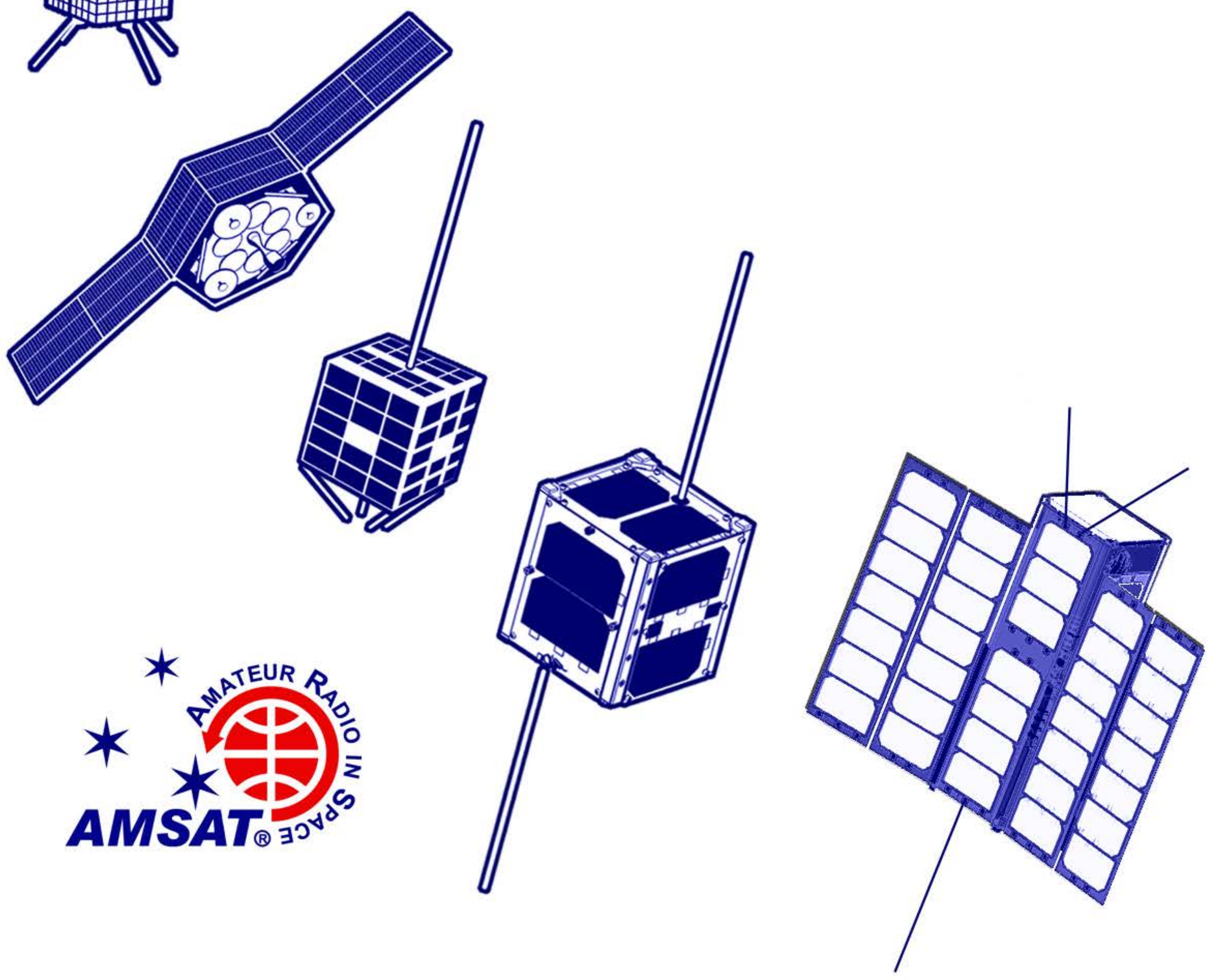


Getting Started
With Amateur Satellites

By G. Gould Smith, WA4SXM and Friends





Hector, CO6CBF/W5CBF; Paul, N8HM; Michael, KD8QBA; Clayton, W5PFG; and Wyatt, AC0RA pose outside the AMSAT Symposium in Baltimore, Maryland.

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When you join AMSAT, you receive six issues of the AMSAT Journal each year. You're also joining over 3,500 amateur radio satellite enthusiasts around the world who are Keeping Amateur Radio in Space. Your dues help fund the AMSAT website, AMSAT publicity and educational materials, publication and mailing of the AMSAT Journal, AMSAT IT infrastructure, and AMSAT operations. Already a member? Invite a friend or get your club to join.

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The AMSAT President's Club members give monthly or annually to AMSAT in addition to their dues because they believe in AMSAT's mission and enjoy satellite operation. See https://www.amsat.org/product-category/amsat-presidents-club-donations/ .

Front cover (not to scale) counter-clockwise from the top: OSCAR I, AO-6, AO-7, AO-13, AO-16, AO-40, AO-51, AO-85, and GOLF-TEE (preliminary design).

Gould Smith's

Getting Started With Amateur Satellites

G. Gould Smith, WA4SXM
Version 6.0
May 2025

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This guide was written to (1) aid amateur operators in becoming active on the amateur satellites and (2) to raise funds to support both current and future amateur satellite programs. **All donations for this document go directly to AMSAT.** The authors do not receive royalties from this guide.

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The author, G. Gould Smith, WA4SXM, has been an AMSAT member since 1989 and a life member since 1998. An Advanced Class license holder, Gould became immediately involved with AMSAT once he joined, first as an Area Coordinator, then as a prolific writer of various "Guides" that have been donated by Gould to AMSAT for publication.

Among the books written by Gould is "Decoding Telemetry" first published in 1990, which later became the AMSAT-NA "Digital Satellite Guide" in 1994 and published until 2008. "The RS Satellite Operating Guide" published from 1993-1997, became the "Analog Satellites Operating Guide" in 1998, which in turn became the "Getting Started With Amateur Satellites" in 2003. "Getting Started With Amateur Satellites" has been updated many times since then. Beginning in 2013, several of Gould's friends assumed the responsibility of updating and expanding the content of this book.

Adding to his considerable body of work for AMSAT, Gould became a member of the AO-51 command team in 2006 after he wrote a book on the satellite in 2005. "AO-51 Development, Operation and Specifications" described the satellite's construction, launch, experiments and hardware specifications. Gould also stepped forward to serve as Project Manager of SuitSat-2 in 2008 after it became clear that the program, started in 2006, needed additional management direction.

Gould's writing has graced the pages of the AMSAT Journal over the years covering a variety of topics as well as numerous papers presented at AMSAT's Annual Space Symposiums. Gould saw needs within the organization and filled them, such as writing books that were useful to both newcomer and old hand alike.

Gould was first elected by the membership to the AMSAT Board of Directors in 2008 and served until 2014. As a BoD member he was actively engaged in the strategic direction of the organization, developing recommendations on improving communication with the membership and educational outreach. Gould remains an enthusiastic supporter of AMSAT, but due to health issues, he has scaled back his participation in AMSAT activities.

-- Barry Baines, AMSAT President (2008-2017)

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Suggestions for improvements to this book are welcome. See you on the satellites!

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Chapter 1
Introduction to Satellites

Many hams who contemplate amateur satellite operation assume it is a very expensive and highly technical undertaking. This is *not* the case. *Building* amateur satellites is rocket science; *operating* amateur satellites is not. However, the thrill of making your first satellite contact is hard to beat!

There are a number of amateur satellites that the "average" ham can easily operate, some with equipment you probably have in the shack. For example, a basic two-meter handheld or mobile radio is all that is necessary to talk with the International Space Station (ISS). Some dual-band FM (2 m and 70 cm) radios or a pair of inexpensive FM radios will allow you to operate the FM satellites.

The purpose of this guide is to give you enough basic information to understand, to plan, and to make a QSO on any of the analog amateur satellites, both FM and SSB/CW. In many cases, the station you build for analog satellites will also work for the digital modes, both for receiving telemetry and for two-way packet exchanges.

The best place to "get your feet wet" without investing much time or money is the FM satellites. As you become more interested in and experienced with satellite operation, simply acquire a little more equipment, knowledge and experience and move to the SSB/CW satellites.

Alex Free, N7AGF, operates portable with his Arrow dual-band Yagi antenna from Washington State. The snow-covered mountain in the background is Mount Baker.

We will focus on working satellites that are of general interest to those getting started. However, there are many other satellites that require somewhat unusual equipment, may be of limited interest to the traditional ham, have short operational lifetimes, or are infrequently available. As with other parts of amateur radio, operators normally find specialized areas of interest after becoming comfortable with general operations.

Appendix B, *Upgrading Your Amateur Satellite Station* will help you plan your progress in satellite operation. None of this is difficult; you just have to learn some new information and techniques.

This introductory satellite guide should answer most of your questions about operating the LEO (Low Earth Orbit) satellites. It takes you step-by-step through the process of finding the satellites, equipping your station, listening to a satellite, and finally making a QSO.

Getting Started

Since each satellite is unique, it can be somewhat overwhelming to determine where to begin. In addition, some of these satellites require specialized equipment and some technical knowledge. So, where do you start?

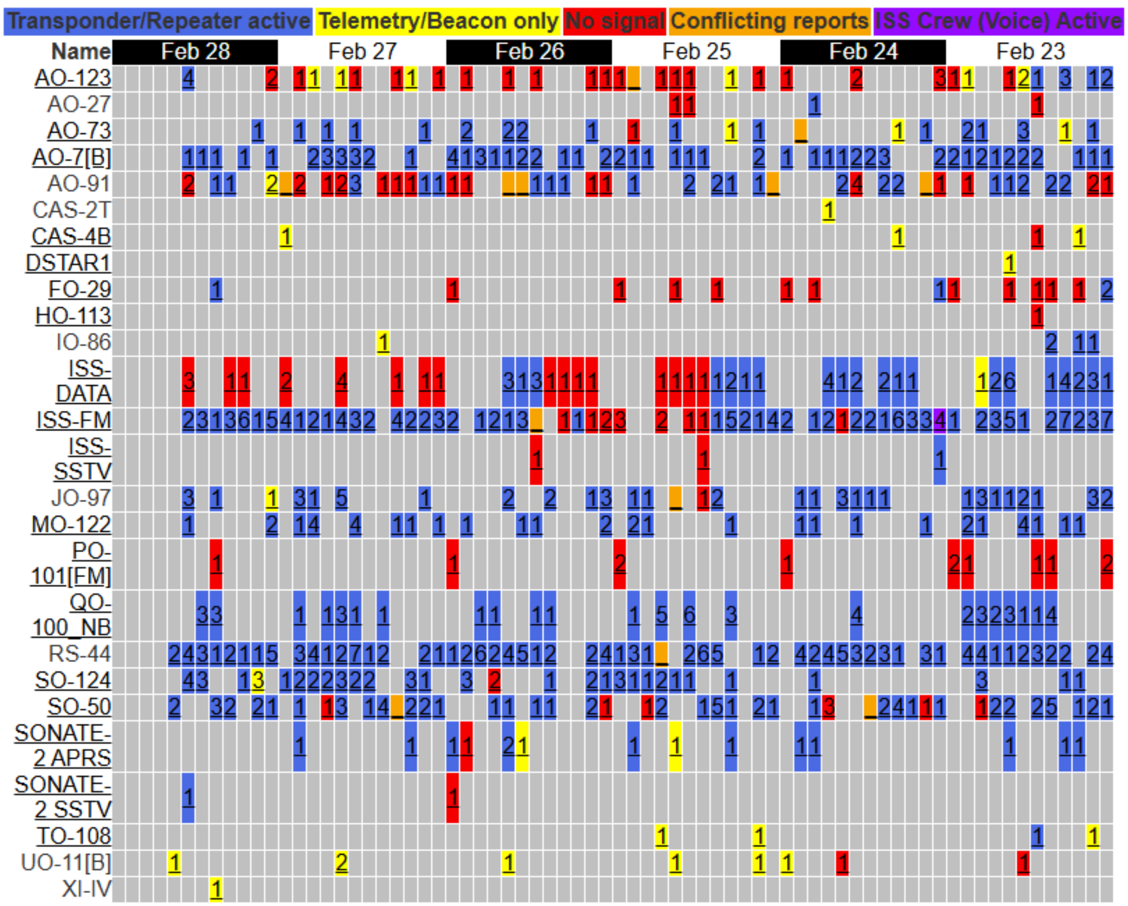
- Finish reading this *Introduction to Satellites* chapter.
- Read the next chapter, *Satellite Basics*, to gain an appreciation for types of satellite orbits and the Doppler effect. (In a hurry? Skim or skip this chapter.)
- Pick a tracking application or website from Chapter 3, *Locating Amateur Satellites,* so that you can determine when the satellites will be over your location.
- Use Chapter 4, *Your Antenna System,* to select an antenna for working the satellites, then build, borrow, or buy one.
- Several equipment options are in Chapter 5, *Your Radio System*. If you don't already own radios that will work, you'll need to borrow or buy one.
- Don't have your ham license yet? Skip to Chapter 8, *Receiving Satellite Digital Data*.
- If you have your license, read Chapter 6, *Operating the FM Satellites*, then pick a satellite.
- Listen to a few passes of the satellite to get a feel for what to expect and the operating practices. If you can't hear it reliably, fix your receive setup now.
- Now do it – Make your first satellite contact!

The authors of this book have enjoyed satellite operation more than most of the other things that we have done in amateur radio. We want to share this enjoyment. As your interest grows, investigate some of the other satellites and modes. We think you will find amateur satellite operation fun, interesting, challenging and rewarding.

What satellites are operational?

Just like any other mechanical device, amateur satellites have down times. Sometimes these are planned, sometimes not.

Your best source for which satellites are operational in near real-time is to visit the AMSAT Live OSCAR Satellite Status Page at https://www.amsat.org/status. Here satellite operators post their observations of the current condition and time they observe or operate various satellites. They also post if they tried but didn't succeed trying to receive the satellite.



AMSAT Live OSCAR Satellite Status Page

Current Information and Assistance

There is a wealth of information on operating amateur satellites and on AMSAT on the https://www.amsat.org/ website.

The AMSAT-BB mail list is usually a good source of information. Information about how to sign up for the AMSAT-BB mail list can be found on the AMSAT website at https://www.amsat.org/ under the "Services" tab. Select "AMSAT e-Mail Lists".

If you use Facebook, join the AMSAT group at
https://www.facebook.com/groups/AMSATNA/

If you use X (Twitter), follow @AMSAT, @AMSAT-UK, and @ARISS_Intl for more real-time satellite information. Also, while on X, look for callsigns of operators that you hear on the satellites; there is a robust group of satellite operators on X from which to learn.

AMSAT issues weekly news and satellite status. You can sign-up for the AMSAT News Service (ANS) bulletins on the AMSAT website at https://www.amsat.org/ under the "Services" tab. Select "AMSAT News Service".

AMSAT has a network of volunteer Ambassadors available to assist anyone interested in amateur satellite activities. Check on the AMSAT web site or call AMSAT to find the nearest AMSAT Ambassador.

Ruth, KM4LAO, holds her Arrow Antenna and the Kenwood TH-D74A handheld transceiver (HT) that she uses for transmit. An Icom IC-51A that she uses for receive is inside the shoulder bag.

Chapter 2

Satellite Basics

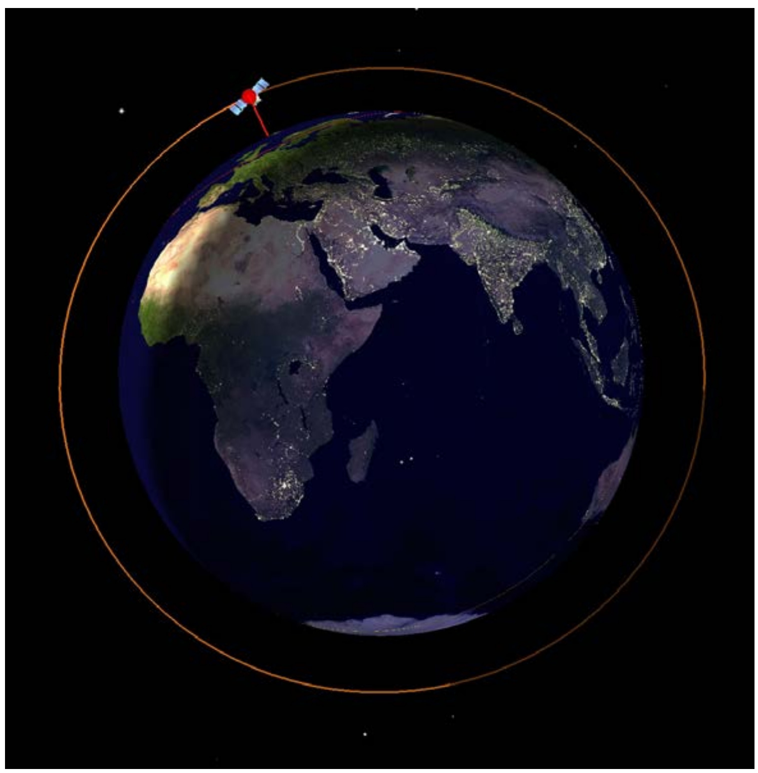
Before we jump into tracking, antennas, radios and operating, we'll cover some background information that should give you a basic understanding of the environment in which you'll be working: satellite orbits, Doppler shift, and satellite names.

The easiest way to visualize communicating with a satellite is to envision it as a normal FM repeater, but with an antenna several hundred miles or more in the air. Just like a terrestrial repeater, satellite communications are line of sight. If you envision standing where the satellite is and looking down on the earth, the part of the earth you can see will transcribe a circle on the earth. The higher up you are, the larger the circle. We call this circle on the earth the satellite's "footprint". Anyone within the footprint can talk to the satellite and therefore each other.

Satellite Orbits

Low Earth Orbit (LEO)

Most of the amateur satellites are in Low Earth Orbit (LEO), so we call them LEO satellites. The period or the time it takes for a single orbit around the earth of most of the FM satellites is about 90 to 110 minutes, depending on the altitude of the "bird."



What constitutes a "Low" orbit? Normally LEOs have a maximum altitude of 2,000 km, though the majority of new satellites are more likely to be below 800 km. The orbit of a LEO satellite viewed from above the orbital plane is in the illustration on the right.

Some of the LEO satellites are in polar orbits that go over both the North and South Poles, crossing the equator at nearly 90°. Polar orbit amateur satellites make passes over the entire earth. If a polar orbit satellite has an inclination of 98 degrees, the orbit is called a Sun Synchronous Orbit (SSO) and passes over the same location at the same time of day, several times per day. Other satellites are inclined to more of a diagonal as they cross the equator. These satellites don't cover the polar areas of the earth.

The earth spins to the east under the satellites as they orbit. For example, during the time it takes a typical LEO satellite to make one revolution around the earth, the earth rotates about 24º in longitude to the east. Depending on the altitude of the satellite and its inclination, stations in the mid-latitudes will typically get four-to-six passes per day, half of them as the satellite heads from south-to-north. A half-day later, more or less, the other half of the passes will head from north-to-south.

Most satellite passes are 10 to 15 minutes each. There will basically be four good passes per day for much of the world. This means you can have about an hour of operation on this satellite each day.

Medium Earth Orbit (MEO)

A Medium Earth Orbit (MEO), also called Intermediate Circular Orbit (ICO), is a region of space between Low Earth Orbit (LEO) and Geostationary Orbit (GEO), typically ranging from 2,000 to 36,000 kilometers (1,243 to 22,300 miles) above Earth, and is commonly used for global navigation systems like GPS. A MEO satellite completes between 2 to 14 full orbits per day.

Satellites in MEO have the advantage over LEO satellites because of much longer passes (hours per pass) and much bigger footprints. Often, a MEO footprint will be about half the earth at a time.

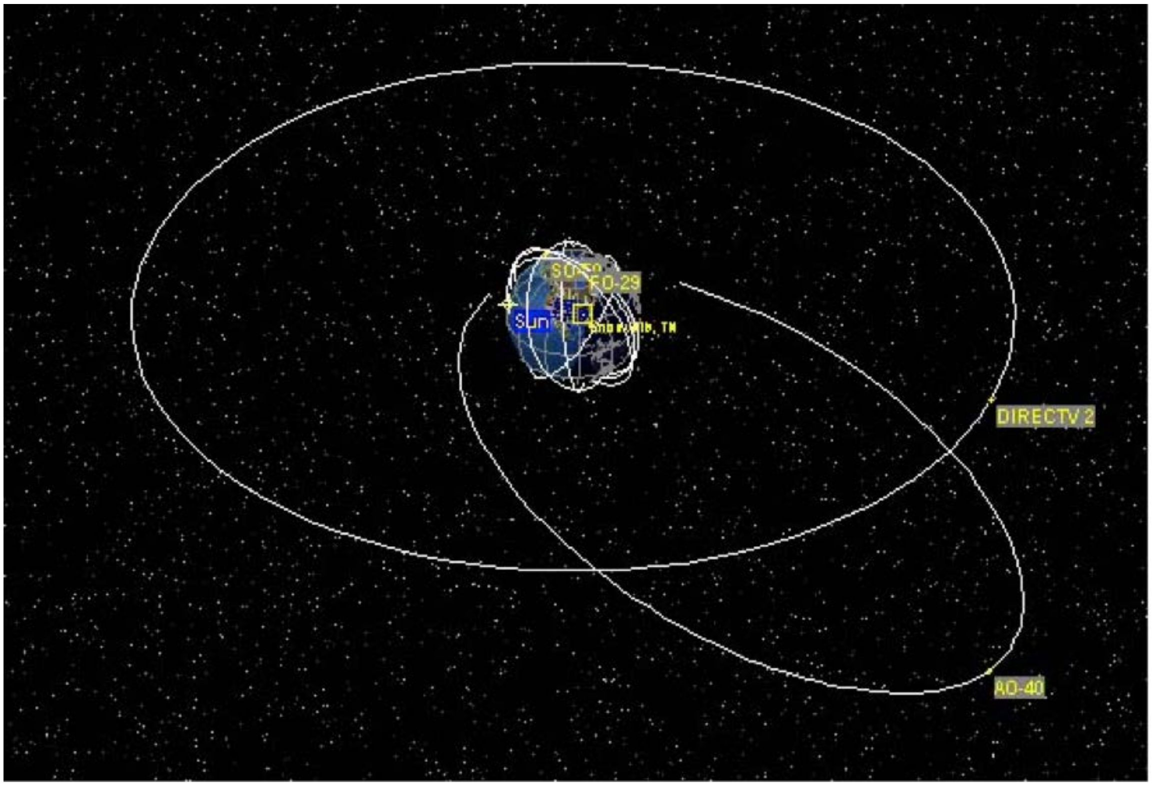
Unfortunately, both the launch costs of a MEO satellite as well as the build cost is much higher than a LEO satellite, because the satellites must be equipped with radiation-hardened components due to space weather.

Geosynchronous Orbit (GSO)

Most people are familiar with the geostationary satellites (like DIRECTV) that provide TV and communication signals to fixed antennas. Their circular orbit matches the rotation rate of the earth and stays exactly above the equator, so the antennas to receive their signals must be aimed at a fixed point in the sky. Their orbit is at 22,236 miles or 35,800 km above the earth. Geostationary orbits are a special case of geosynchronous orbits.

A satellite in a geosynchronous orbit stays at about the same longitude, but wobbles above and below the equator by a small distance, tracing out a figure-8 pattern and returning to the same point 24 hours later. A satellite in a geostationary orbit doesn’t have the figure-8 wobble and holds at a fixed location above the equator.

The screen shot below shows LEO orbits clustered around the earth, a GSO circular orbit labeled DIRECTV2, and a High Earth Orbit Molniya orbit labeled AO-40.



High Earth Orbit (HEO)

HEO orbits may be circular or elliptical in shape. Some elliptical orbits are Molniya orbits because they favor the Northern Hemisphere. (While technically High Elliptical Orbits, the amateur community tends to use the High Earth Orbit terminology interchangeably because our interest is the greatest height where the longest-range communication occurs.) This orbit provides about 13 continuous hours per day of coverage to nearly half the earth. In addition, they move much slower across the sky than the LEOs. Note in the image above that HEO orbits (AO-40 in the image) are much further out than the geosynchronous orbit (DIRECTV 2). In an elliptical orbit, satellites can go out as far as 50,000 to 60,000 km at apogee (the furthest point in the orbit from the earth). While there are lots of challenges building a functional HEO satellite, the biggest impediment is the launch cost of approximately $10,000,000!

Satellite Scheduling

While being in the footprint of a satellite is necessary for communications, it may not always be sufficient. This is because satellites, or a particular operating mode, may not be available continuously. The most common reason is that the satellite may be in one mode in daylight, and a different mode in darkness. In this case, “daylight” or “darkness” status is determined by whether the satellite solar panels are producing power. Good examples are satellites with certain “education” missions whose transponders are normally switched off in daylight to maximize the strength of the telemetry beacon for educational purposes.

Often the satellite will be illuminated while the ground stations are in darkness, so it is necessary to use a tracking program to determine its illumination status. Most of the full featured programs will indicate this by displaying "Satellite in Sun" or "Satellite in Eclipse" along with the other information. If this is not annunciated explicitly, but the "terminator" (line showing sunrise or sunset) is shown, when the satellite footprint touches the terminator or extends into the daylight side, then the satellite is illuminated and is "in daylight."

Another, related reason for changes in availability is the spacecraft "power budget." Because of the small size of modern satellites, there is relatively little surface space to mount solar cells. Some satellites switch off power hungry functions during periods of low illumination because there is insufficient power to support them continuously. A satellite may not operate in the arctic regions to conserve power for use over populous areas.

Finally, operating modes may be selected by the command stations for many other reasons. For example, a satellite that switches between telemetry and transponder modes autonomously as described above, may be commanded to continuous repeater operation over weekends and holidays with prior announcements.

Exceptions to regular operations are minimized but are sometimes unavoidable due to the requirement to reset a satellite or gather specialized telemetry.

Doppler Shift

Most of us remember the high school science explanation of the change in frequency of a train horn as it passes by you as an example of Doppler shift. Satellite operation offers another example, and you'll need to adjust the tuning of your radios to compensate for the Doppler. The amount of Doppler shift observed depends upon the transmitted frequency and speed of the satellite relative to the user. The higher the frequency is, the more the Doppler shift.

For example, take an amateur satellite in a LEO orbit that transmits in the UHF band. During a satellite pass you will experience a 20 kHz shift in the received 436 MHz frequency. If you are listening on the published frequency, you won't hear the signal until it is nearing mid-pass.

The downlink signal will start about 10 kHz higher than the published downlink, move through the published frequency at mid-pass and go about 10 kHz lower as the satellite reaches the horizon. This isn't a linear change either. The Doppler changes fastest during the middle part of the pass.

AO-92 (now End of Mission) had both 70 cm and 23 cm uplinks. It was a LEO satellite, too, so the 70 cm uplink had a 20 kHz total Doppler shift. However, when the 23 cm uplink was active, it had a 57 kHz total Doppler shift! Some past and future satellites use the X band at 10.250 GHz that has a total Doppler shift of 460 kHz!

Wavelength	Frequency	Doppler shift
2 m	145 MHz	± 3.25 kHz
70 cm	435 MHz	± 9.75 kHz
23 cm	1.269 GHz	± 28.5 kHz
13 cm	2.401 GHz	± 53.8 kHz
3 cm	10.250 GHz	± 230.0 kHz

Satellite Names

OSCAR is an acronym for Orbiting Satellite Carrying Amateur Radio. It was first coined in 1961 with the first amateur satellite OSCAR 1. Most amateur satellites have OSCAR as part of their name. To receive an OSCAR number the satellite must (1) achieve orbit and (2) one or more transmitters must operate successfully in the amateur bands. The owners/builders of the satellite must formally apply for an OSCAR number that is issued by AMSAT.

Most of the OSCAR satellites are a combination name of the owner/country/builder plus the OSCAR designation. Some of the more common ones are: AMSAT-OSCAR (AO-7, AO-73, AO-91), European-OSCAR (EO-79, EO-88), UoSAT for the University of Surrey (UO-14), Fuji-OSCAR (Japan's FO-29), KITSAT-OSCAR (South Korea's KO-23), and SaudiSat-OSCAR (Saudi Arabia's SO-50). The Russian satellites use their own designation RS for Radio-Sport (RS-44).

Unique Satellite Operating Considerations

Satellite operations are in many ways similar to terrestrial operations, but with some important differences. Later chapters will discuss the specifics of operation techniques, but in all cases the guiding principle is being a Considerate Operator. Make certain you can hear the satellite before making a long transmission. If you are tuned to the wrong downlink frequency or have other receiving problems, it is easy for you to wipe out an entire pass for other users.

Likewise, use the minimum power. This is particularly important for "linear" satellites which support SSB and CW. Unlike the ionosphere where any number can operate, these operate as an "artificial ionosphere" where the strongest signal grabs most of the downlink power. Technically, this is a "Zero Sum Game." In some cases, using too much power can even flip the spacecraft operating mode!

The most important switch for the new operator is the "Release to Listen Button." Hearing the other stations is necessary; hearing them well is the mark of an experienced and Considerate Operator!

Fernando, KF7R, is operating SO-50 from the rim of the Grand Canyon during the National Parks on the Air (NPOTA) event. He is holding an Elk log periodic antenna and an HT.

Chapter 3

Locating Amateur Satellites

The first thing that distinguishes amateur satellite operation from other amateur radio modes of operation is that **the satellite must be visible from your location for you to operate through it.** Nearly all amateur satellite operation is line-of-sight. If you follow a straight line from your antenna to the satellite, you won't be able to operate if that line passes through hills, mountains, or most buildings.

Wooden structures and trees attenuate radio signals at VHF frequencies and above. Whether or not you'll be able to talk through trees will depend on the gain of your antenna and the sensitivity of your receiver.

To determine when a particular satellite is visible, you'll use a tracking program. There are satellite tracking websites and programs for smartphones, tablets, and PCs. All will tell you two important pieces of information:

1) When the satellite is visible at your location; and
2) Where the satellite is located in the sky during the time it is visible.

To get you working as quickly as possible, we'll review several websites and smartphone applications that can answer these questions. Most of the Apple iOS and Android smartphone apps will also run on iOS and Android tablets.

In Appendix B, *Upgrading Your Amateur Satellite Station*, there is a review of tracking programs for personal computers and Windows tablets. Many of these PC-hosted programs will also automatically tune your radios and steer your antennas.

Here are a few terms and acronyms that will help you:

- **AOS** – Acquisition Of Signal, in this case, when the satellite rises above the horizon.
- **TCA** – Time of Closest Approach, when the satellite is closest to you and highest in the sky.
- **LOS** – Loss Of Signal, in this case, when the satellite sets below the horizon.
- **Azimuth** – The compass direction, usually in degrees, toward the satellite. 0 degrees is true north, not magnetic north. 90 degrees is due East.
- **Elevation** – The angle above the horizon to the satellite. 0 degrees is on the horizon and 90 degrees is directly overhead.
- **UTC** – Universal Time Coordinated, formerly known as GMT or Greenwich Mean Time or Zulu time. Most of the tracking programs and satellite schedules are done in UTC, so you need to be fluent in UTC and 24-hour format.

Smartphone Satellite Tracking Applications

To compute the location of a satellite orbiting the earth, a program or application needs two critical pieces of information: the correct time and the Keplerian Elements for the satellite (or "Keps"). The Keps are numerical values that describe the satellite's orbit. A more detailed description of Keps can be found in Appendix B, *Upgrading Your Amateur Satellite Station*.

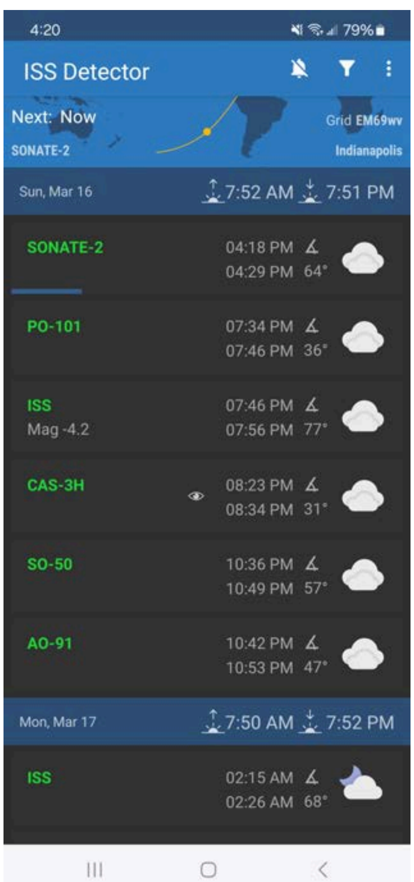
Using the time and Keps, an application can calculate a reasonably precise location for a satellite, including its latitude, longitude, and elevation above the earth's surface. Knowing your location, the application can compute the direction toward the satellite (the azimuth) from where you're located, along with the angle above the horizon (the elevation).

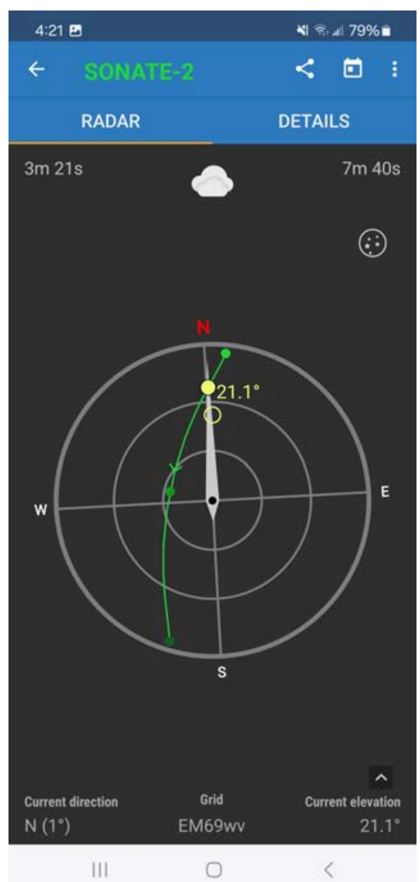
Using a smartphone application to find a satellite is very easy. The phone knows the correct time (from the cell phone tower), can download current Keps (from the Internet), and knows your location (from its GPS). In addition to being easy to use, using your smartphone to locate satellites is inherently portable.

There are several Apple iOS and Android applications for locating satellites. Here are three of them that you might consider.

ISS Detector (Apple iOS and Android)

Versions of this application are available for both Apple iOS devices and Android devices. Despite referring to the International Space Station (ISS) in the name of the application, it also works for amateur radio satellites. It is free for the ISS and $2.99 for all the amateur radio satellites.





On the main screen, the app shows you a list of the upcoming satellite passes with AOS times and maximum elevation in degrees at TCA. Tap on a pass, and the app will show a polar map of the pass to assist you with pointing your antenna. From this screen you can see where AOS occurs, as well as TCA and LOS. The arrow indicator shows what the azimuth for your antenna should be. The rings show 0º, 30º, and 60º elevation.

Using ISS Detector, you can set alarms and make calendar entries for passes. That's nice for remembering to operate a particularly high pass or your favorite satellite.

GoSatWatch (Apple iOS)

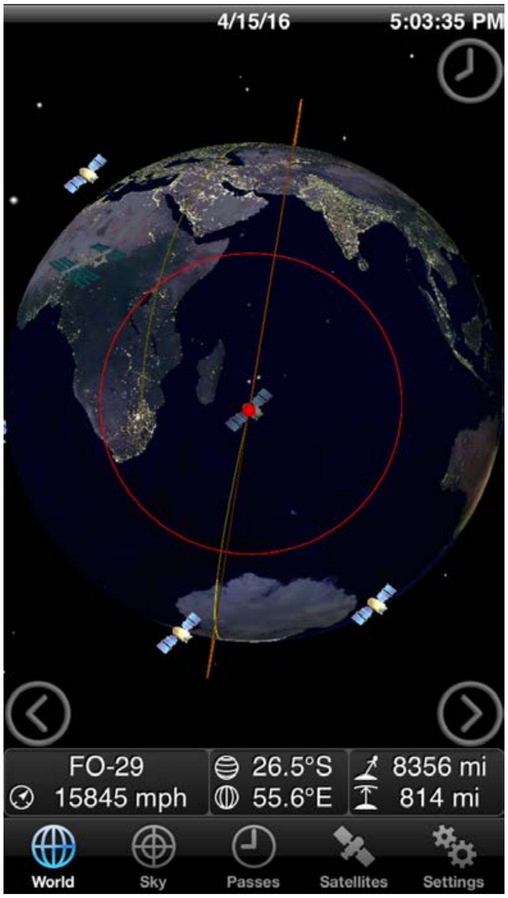
This $9.99 application works on both iPhones and iPads. The screen shot to the right shows upcoming passes for a series of amateur satellites.

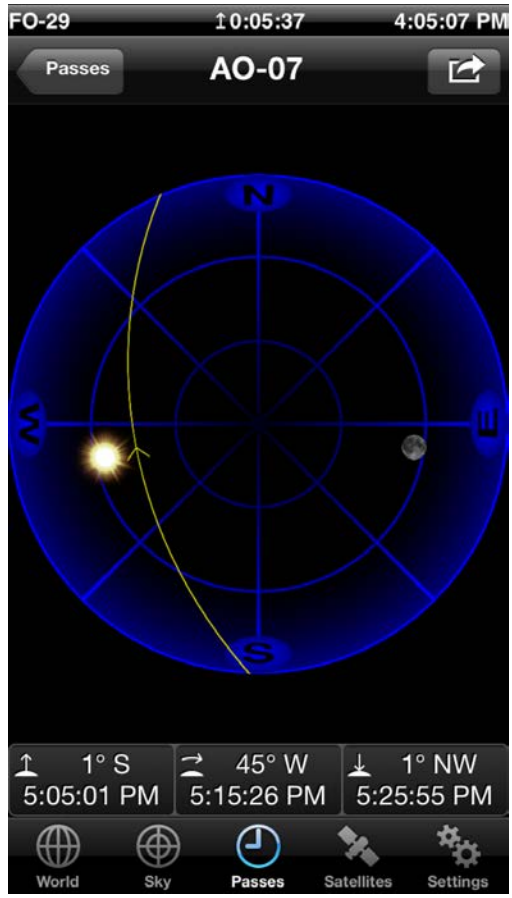
Along the very top of the screen, you can see the next pass is AO-07, which will rise in 5 minutes and 22 seconds, and the current local time (5:41:57 PM).

The middle of the screen shows the next nine satellites that will be visible from your location. Second on that list is the FO-29, which will rise at 5:03:07 PM local time, set at 5:14:50 PM, and have a maximum brightness of 12 degrees when it passes to the northwest of you. The maximum brightness almost always occurs at maximum elevation, but we have seen exceptions.

The buttons along the bottom bring up other screens. For example, the World button takes you to a picture of a satellite positioned over the earth, the path of the orbit, and a circle circumscribing the portion of the earth that is in the satellite's footprint. Using your finger, you can rotate the earth, or advance or reverse time to track the path of the satellite.

One nice feature is that you can easily edit the list of satellites to display only the ones you are interested in seeing.



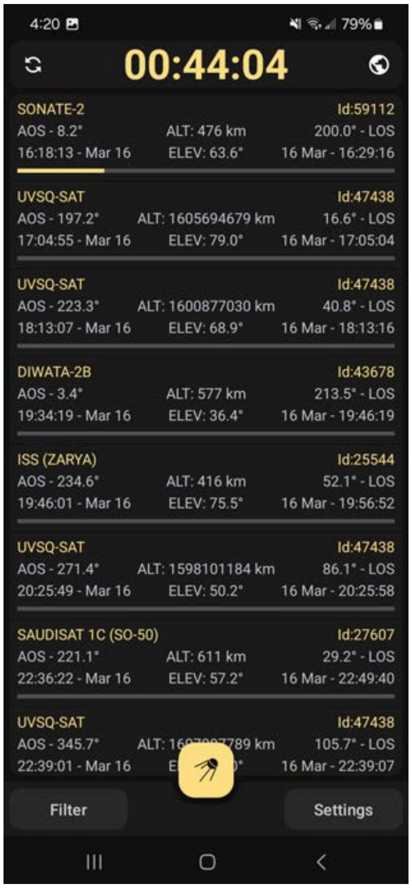


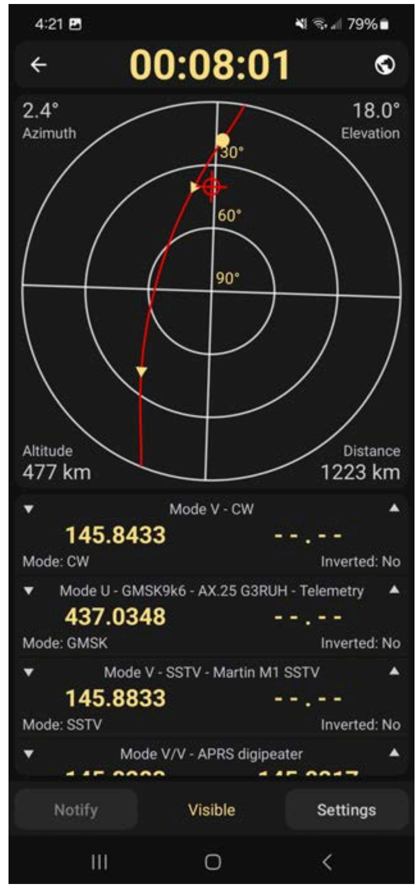
The screen capture on the left shows the footprint of FO-29, the portion of the surface of the earth that is seen by the satellite. Stations within this footprint should be able to communicate with FO-29 and with other stations that are within the footprint. At this time, the satellite is traveling 15,845 mph and is 814 miles above the earth.

The screen capture on the right shows the path AO-7 will take across the sky. It will rise above the horizon to the south of you, travel nearly across the face of the sun to a maximum elevation of 45 degrees, and set below the horizon just to the west of due north. It also shows that the moon will be to your back while you're facing the sun. This is a great tool when you're pointing your antenna by hand (the "Armstrong" method).

Look4Sat (Android)

This is a free application for Android devices. Like the two applications discussed above, it shows a list of upcoming satellite passes and a polar map of the path of each satellite.



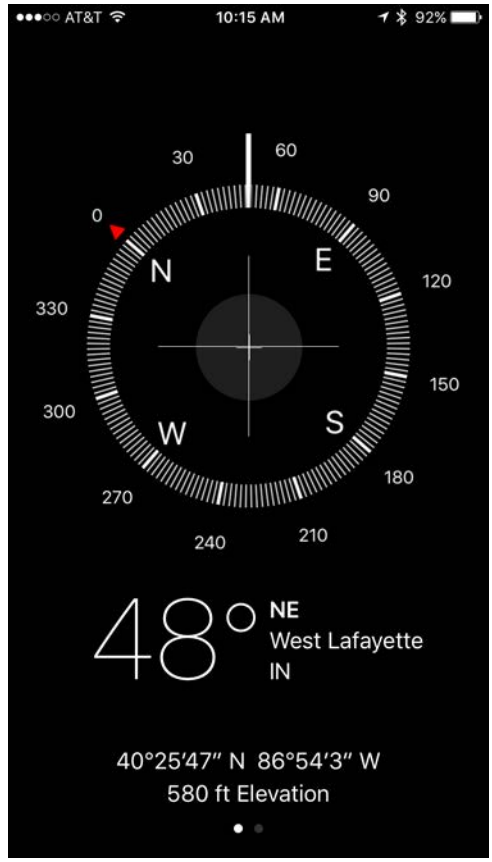


Satellite Tracking Websites

An easy alternative to using an application on your smartphone is to use a website for tracking satellites. A website needs the same three pieces of information that a smartphone app needs: the correct time, the Keplerian Elements for the satellite, and your location. In general, a website will know the correct time (in UTC) and has access to up-to-date Keps.

While your cell phone knows your location and your local time, in general, your web browser won't. You'll need to give your location to the website; the more accurately you describe your location, the more accurate the predicted satellite AOS and LOS will be. The website may ask for your latitude and longitude, or your Maidenhead Grid Square, or the name of the nearest town.

Where Are You?



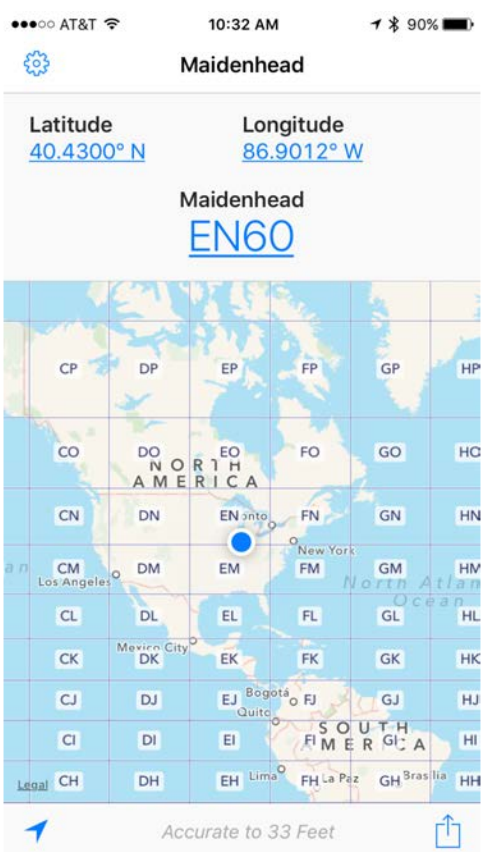
You can determine your latitude and longitude from a paper map, or from an online map, or using your call sign at https://qrz.com, or using a GPS. Since your smartphone has a GPS to assist with emergency 911 calls, your phone may be a convenient tool to determine your coordinates.

The screen capture on the right is from Apple's Compass application on an iPhone. In addition to showing north, south, east and west, it also gives the latitude (in degrees, minutes, and seconds), longitude and elevation.

If the website application wants your position in decimal degrees (e.g., 32.8080º), the iPhone Maps application will give it to you in that format.

The Maidenhead Converter, discussed below, will also give you your position in decimal degrees.

You should also determine your grid square, as it is used frequently when exchanging locations during a satellite QSO. Rather than saying "I'm in West Lafayette, Indiana", you could say "I'm in EN60" or better "I'm in Echo November Six Zero".

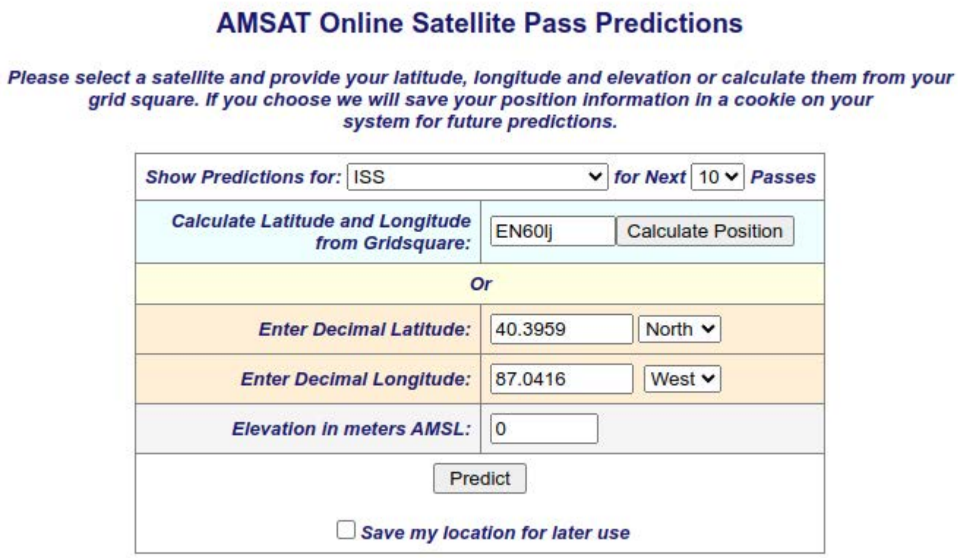


You can determine your grid square using the calculator on the AMSAT website at https://www.amsat.org/amsat-new/tools/grids.php or by using a smartphone app like "Maidenhead Converter" by Donald Hays (for iOS), shown in this screen capture on the left. For Android, look for the app "Grid Square".

In 1980, a group of European VHF Managers (hams) met in the town of Maidenhead outside of London and agreed on the Maidenhead Locator System. The system divides the earth's surface into grid squares, one-degree of latitude by two-degrees of longitude. (Yes, it isn't square, and because it is on the surface of a sphere, it isn't a rectangle either.) In the continental United States, a grid square is about 70 x 100 miles. You can learn more about grid squares on the ARRL web site at: http://www.arrl.org/grid-squares.

AMSAT Online Satellite Pass Predictions

The AMSAT website has a satellite orbit prediction tool at https://amsat.org/track, which presents the following form:



To use the tool, select a satellite from the dropdown box.

Next enter your location, either by typing your four- or six-character grid square and pressing the “Calculate Position” button, or by typing your decimal latitude and longitude. Make sure the latitude North/South and the longitude East/West selections are correct! Enter your elevation in meters.

If you just know you elevation in feet, Google will convert from feet to meters for you if you type “590 feet in meters” in a Google search box (at https://www.google.com). If you’ll be using the tool frequently from this location, check the box “Save my location for later use”.

Press the “Predict” button. You’ll get results that look like this:

AMSAT Online Satellite Pass Predictions - ISS

View the current location of ISS

Date (UTC)	AOS (UTC)	Duration	AOS Azimuth	Maximum Elevation	Max El Azimuth	LOS Azimuth	LOS (UTC)
07 Apr 25	14:09:29	00:09:58	200	20	141	65	14:19:27
07 Apr 25	15:45:41	00:10:46	247	44	342	50	15:56:27
07 Apr 25	17:23:43	00:09:34	286	15	346	50	17:33:17
07 Apr 25	19:01:41	00:09:23	309	13	9	68	19:11:04
07 Apr 25	20:38:38	00:10:37	311	32	44	105	20:49:15
07 Apr 25	22:15:28	00:10:27	299	29	207	151	22:25:55
07 Apr 25	23:55:21	00:02:22	252	1	239	226	23:57:43
08 Apr 25	13:22:25	00:08:57	185	12	125	73	13:31:22
08 Apr 25	14:57:50	00:10:52	236	74	325	52	15:08:42
08 Apr 25	16:35:34	00:09:52	278	17	337	48	16:45:26

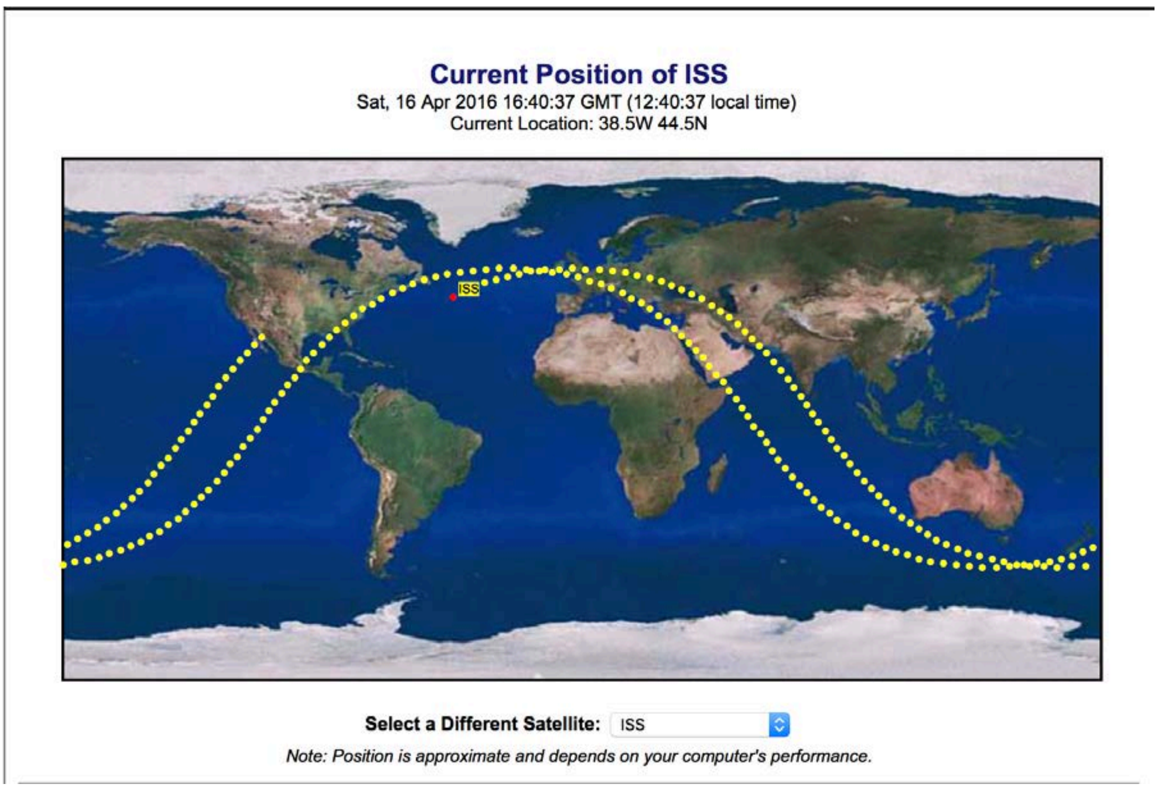
The date and time of the pass predictions are in UTC, so you'll probably need to convert them into your local time, adjusting if necessary, for daylight savings time.

For example, the first (and next) pass of the ISS begins at 18:03:54 in the AOS (UTC) column. If you're in the Eastern Time zone, you should subtract 4 hours in the summertime and 5 hours in the wintertime to get your local time. That's 14:03:54 or 2:03 pm in the summer and 1:03 pm in the winter.

After the times, the next important piece of information here is in the Maximum Elevation column. The higher the elevation, the closer the satellite is to you and the less likely nearby hills, buildings or trees will be blocking the signal. The 81-degree pass in the screen shot above is nearly overhead, so the satellite should be very strong.

The azimuth values give you the direction in which to "wave" your directional antenna when you're trying to find the satellite's beacon or active QSOs.

If you click on the "View the current location …" link, you'll get a map of the next two orbits that looks like this:



It makes very good sense to check your work when using a website to predict when you can work a particular satellite. It is very frustrating to point your antenna toward the satellite and hear nothing, especially when you eventually discover that the satellite is actually on the other side of the world! Most amateur satellite operators have experienced this problem, multiple times.

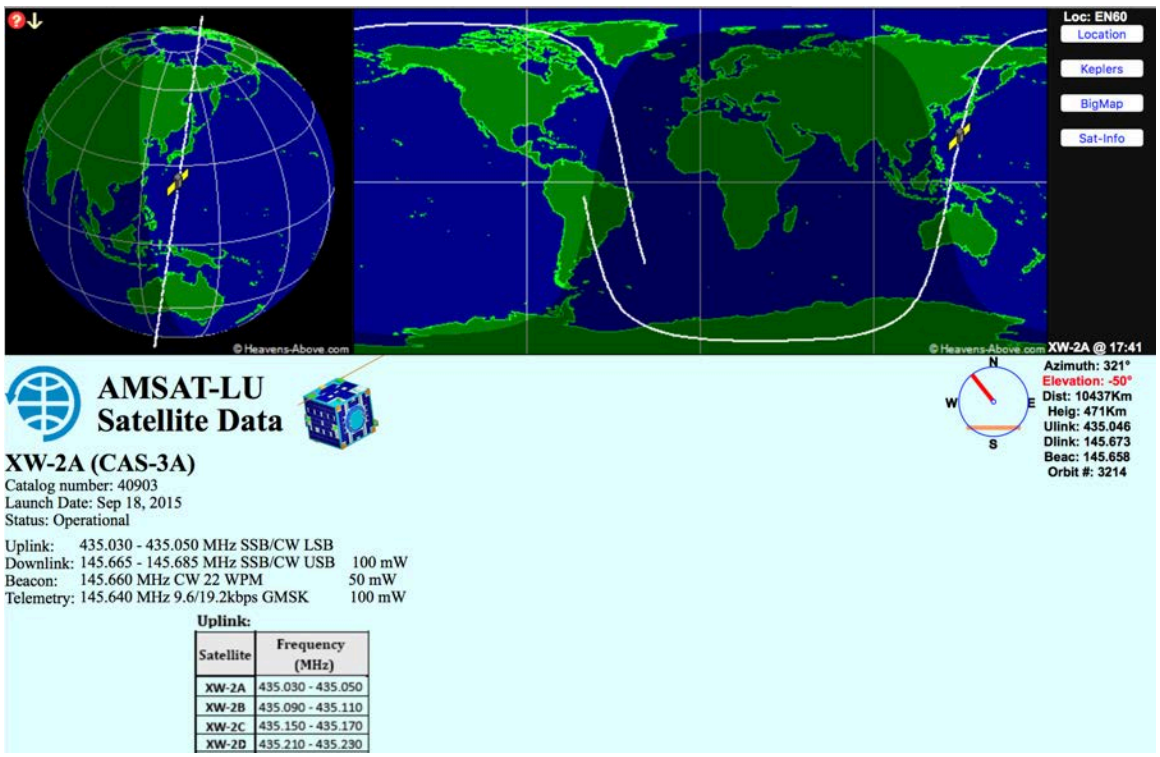
Click on the "View the current location …" link when the pass prediction table shows the satellite close you. Does the map agree that the satellite is close?

If the satellite isn't close to you on the map, have you converted UTC to local time correctly? Did you enter your location correctly, including the hemisphere (north/south, east/west)?

AMSAT Argentina Satellite Prediction Website

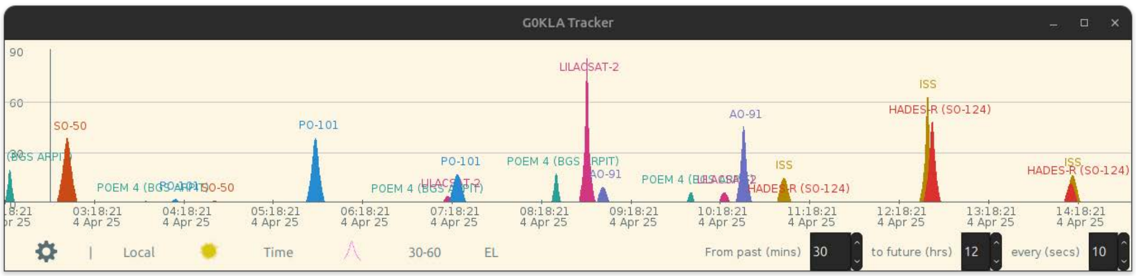
AMSAT-LU in Argentina has a very functional satellite prediction website (in English) at: http://amsat.org.ar/sat.htm

The complete tracking page includes links to bring up predictions for about 70 satellites, a list of passes, maps with the orbit, and information on the satellite chosen, including frequencies. As an example, here are the maps and a portion of the information shown for the Chinese amateur satellite XW-2A:



KlaTrack

KlaTrack (https://www.g0kla.com/klatrack/) is a cross-platform application that has a unique way of displaying future satellite passes. After selecting the satellites you are interested in, it plots the elevation of upcoming passes on an adjustable timeline (1-24 hours) while updating it in real time. There are many other options like dark mode, UTC or local time, filled or outline, or displaying minutes in the future versus the actual time on the timeline. David, N9KT, always has this running in his shack to show what satellites are coming up.



Kevin Manzer, *N4UFO*, goes portable in *Roswell, New Mexico*, using his “short Arrow” and a pair of Yaesu FT-817 radios.

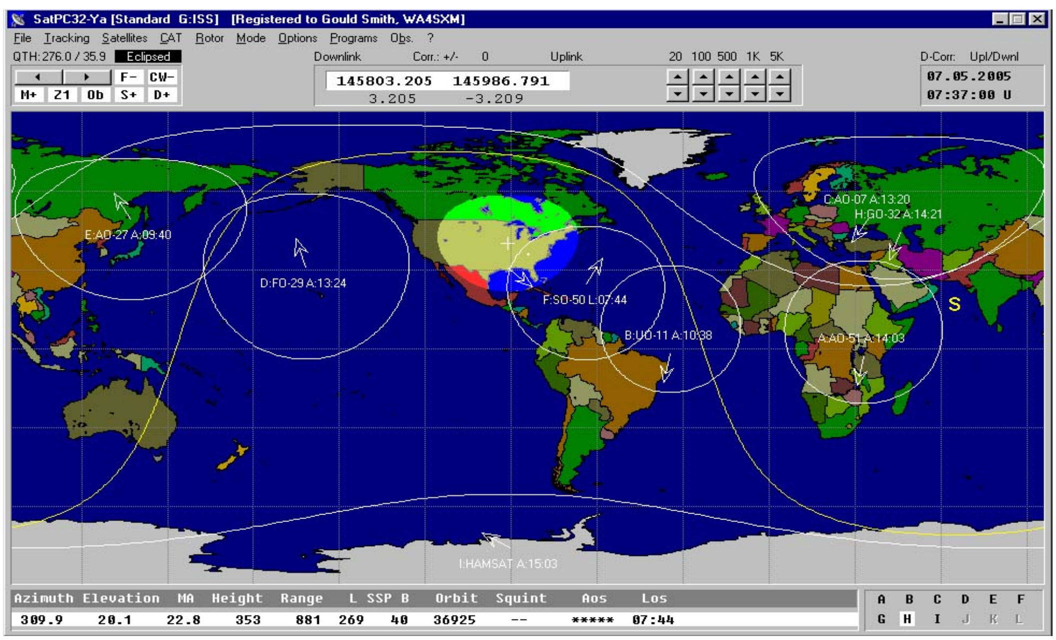
Satellite Footprint

Using one of the above smartphone applications or Internet websites, you can determine when a satellite will be visible from your location. Some of these programs will also show you the "footprint" of the satellite, that is, the area of the earth that is visible to the satellite, and vice versa. If you're in Georgia and you want to contact a ham in Alaska, both of you need to be in the footprint at the same time.

From the satellite's view, the footprint is how much of the earth it sees. This information is critical to you, as most satellite communication is line-of-sight. If you are at sea level and standing on the water, your horizon is about 3 miles; at 100 feet above the water your horizon is about 12 miles in all directions. As your altitude increases so does the distance to the horizon, which is why you want repeaters on top of mountains. In an airplane at 30,000 feet your horizon is about 213 miles or a circle about 426 miles in diameter.

The ISS at 200 miles (330 km) has a view of the earth covering a circle about 2,700 miles across. FO-29 orbits at about 750 miles (1,200 km) and has a footprint about 4,880 miles in diameter. That is why satellites are such great communication devices; they allow many hams to have equal access to the satellite at the same time. The screen shot below shows the footprint of several amateur satellites. The bright footprint over the eastern part of North America is the ISS, which is orbiting at 353 km above the earth. Notice how much smaller the ISS footprint is than that of FO-29 (over the Pacific).

You must have the satellite footprint over your location to operate the satellite.



The screen shot above is from the Windows PC satellite-tracking program SatPC32, which is described in Appendix B, *Upgrading Your Amateur Satellite Station*.

David, N9KT operates an FM satellite using an Arrow antenna and an FM HT running the OpenGD77 firmware. Photo by Jim Brown, W0RLD.

Chapter 4

Your Antenna System

It is occasionally possible to *receive* the amateur satellites with a handheld radio (an HT or Handheld Transceiver) and an attached flexible antenna (a "rubber duck"), but the satellite won't hear you transmit with that antenna. This is because these flexible antennas are designed for use with nearby repeaters that make up for the shortcomings of a tiny antenna.

We have observed satellite communications using a handheld and a 3-foot whip antenna, but this stresses the HT's antenna connector and is rarely successful. The best antenna for satellite work is a small beam that is pointed at the satellite.

> *The key to reliable satellite communication is to put together the best* ***receive*** *station you can. If you don't hear well, you will interfere (QRM) other users of the satellite when you transmit!*

In this chapter, we'll concentrate on simple antennas, including fixed omnidirectional antennas and small handheld beam antennas. Larger antenna systems with azimuth and elevation rotors are covered in Appendix B, *Upgrading Your Amateur Satellite Station*.

Diplexers and Dual-Band Operation

The antennas discussed below are dual band, both VHF and UHF. Some have a single connector for the antenna; the remaining antennas have separate connectors for VHF and UHF.

Depending on your choice of radio or radios, you may have:

- One dual-band radio with a single antenna connector.
- One dual-band radio with separate 2 m and 70 cm connectors.
- Separate transmit and receive radios, each with its own antenna connector.
- Separate 2 m and 70 cm transceivers, each with its own antenna connector.

If you have a dual-band radio with a single connector, and an antenna with a single connector, there's no problem connecting them with a single piece of coax.

If you have two radio connectors and separate 2 m and 70 cm connectors on your antenna, again there's no problem; use two pieces of coax for your connections. When receiving a satellite on 70 cm, using a preamp can make a noticeable difference. Split antenna feeds (two pieces of coax) make this easier to implement.

If your chosen antenna(s) and radio(s) don't have the same number of connectors, you can use a diplexer to combine separate 2 m and 70 cm signals into a single dual-band connector. A diplexer is bi-directional; it can be used both to combine and to split signals.

Pictured to the right is a Comet CF-416 diplexer with a common port at the top and a 1.3-170 MHz port and a 380-1400 MHz port at the bottom. The Arrow antenna (discussed below) is available with a smaller diplexer that slides inside the handle of the antenna. You can also build your own diplexer.

So, is it diplexer or duplexer, as labeled in the photo?

Technically, the correct term for a splitter and combiner for two widely separated frequency bands that uses filtering is a diplexer. When the frequencies in use are the same or nearly the same and the combiner is constructed using a circulator or high-speed switching, the correct term is duplexer.

Most hams use the terms diplexer and duplexer interchangeably. Here's a tip: don't correct someone who uses the wrong term. You understand what they mean, and that's what's important.

Omnidirectional Antennas

Transmitting to a satellite is generally not a problem; it is always line of sight. Unless you are trying to use a low-power HT with a rubber-duck antenna, you will be running much more power and have a more efficient antenna than the satellite. Most of the amateur satellites are only running 0.25 to 1 watt, so reception is the key.

You can transmit to the satellite using any of these omnidirectional antennas: vertical, eggbeater, J-pole, Lindenblad or quadrifilar helix (QFH). These antennas will also work for receiving the satellite, but not as well as a small directional beam. With an omnidirectional receive antenna you are picking up noise and signals from 360º. With a beam you are concentrating only on the signals within about 30º of where the antenna is pointing. Plus, you get increased gain from the antenna.

For receiving from the satellites, side-by-side comparisons always yield the same results: a small directional antenna works better than an omni, even if the omni has a preamp. Hams with favorable experiences with omnidirectional antennas are typically located in rural areas away from broadcast transmitters, radio towers, and other sources of man-made RFI.

It is counter-intuitive, but using a high-gain omni makes the situation worse, as the gain comes from the horizon and to the detriment of signals above the horizon where your satellite is located.

There are occasionally applications where an omnidirectional antenna may be the best choice but know that you're sacrificing the gain and signal-to-noise ratio of a beam antenna.

A hybrid approach of using a directional antenna for receive and an omni for transmit is sometimes a good choice. See the discussion and photo at the end of this chapter.

Directional Antennas

There are a lot of advantages to using a small, handheld, directional antenna. The antenna is lightweight, making it easier for you to hold and point towards the satellite. You can change the horizontal or vertical polarity of your antenna by twisting your wrist. Your antenna is inherently portable, avoiding issues of roof access, and fights with the homeowners' association, though you may attract the attention of local law enforcement who are curious about what you are doing. And you're saving a lot of money by avoiding buying rotors, preamps, coax and towers while you decide if you like operating satellites.

This photo shows Tim, N3TL, using an Elk log periodic antenna with an HT.

Small directional antennas have a lower gain than larger antennas with more elements. Even so, a very positive side effect of the lower gain is a broader beam width.

With a high-gain antenna you have a narrow beam width, which then requires precise aiming at the satellite. If you aren't pointed exactly at the satellite, you'll lose a lot of gain. If you're off by 15 degrees or more, you may not hear the satellite.

In contrast, with a small handheld directional antenna, you can sweep the sky in the general direction of the satellite and find it relatively easily. Once you've found it, it is easy to home in on the azimuth and elevation, and twist your wrist for the best polarity just by listening for the strongest signal. Tracking the movement of the satellite across the sky is easy too. There are several YouTube videos demonstrating this process, for example, search for WD9EWK. Patrick has literally made thousands of satellite contacts using handheld antennas.

Elk Log Periodic Dual-Band Antenna

The picture above shows this antenna. It disassembles easily and is a dual-band VHF/UHF satellite antenna. It has a single SO-239 connector (or optionally an N connector) that works well with a single dual-band radio.

Note that the connector is at the front of the antenna as shown in the picture. Most log periodic and Yagi antennas share the characteristic that the shorter elements are at the front of the antenna and that the rear elements are the longest elements.

For more information, visit https://elkantennas.com.

Arrow II LEO Satellite Yagi Antenna

The elements for Arrow antennas are aluminum archery arrow shafts, hence the name of the company. In the photo, Keith, KB1SF, who also uses the call signs VA3OB, and VA3KSF, is using his Arrow antenna with a dual-band HT.

The standard Arrow satellite antenna is a 3-element 2 m antenna with a 7-element 70 cm antenna at 90-degrees, each with a BNC connector. Options include a split boom for more compact packing and a diplexer if you have a dual-band radio with a single connector. Keith's diplexer is installed inside the handle of the antenna.

Arrow also has an Alaskan Arrow with 4 elements on VHF and 10 elements on UHF. This antenna has a higher gain (helpful when working near the horizon, say in Alaska) and narrower beam width. However, because of the additional length and weight, it is very difficult for most people to hold for more than a couple of minutes.

Clayton, W5PFG, sometimes chooses not to install all the elements on his Arrow, creating a "Short Arrow" antenna with 2 elements on 2 m and 4 elements on 70 cm. The gain is slightly less; but because of the reduced weight at the far end of the antenna, it is much easier to hold and point for multiple satellite passes.

You can find all the different Arrow antennas at http://www.arrowantennas.com.

WA5VJB Cheap Yagi Antenna

For a few dollars in parts, you can also build a portable antenna that performs as well as commercial products. Kent Britain, WA5VJB, has designed and documented an easy to build dual-band LEO antenna.

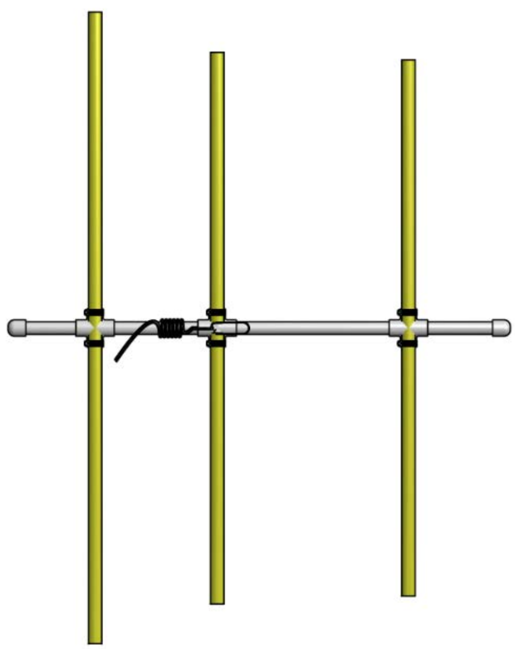
In the photo to the left, Drew, KO4MA, is holding a WA5VJB Cheap Yagi.

The unit shown here has 2 elements on VHF, 5 elements on UHF, and a diplexer. With the diplexer, it has a single cable and connector for use with a dual-band radio with single connector. Without the diplexer, each antenna will need a separate cable. Kent also includes instructions for adding additional elements if you want a design with higher gain and narrower beam width.

See pictures and detailed construction instructions at
http://www.wa5vjb.com/references/Cheap%20Antennas-LEOs.pdf

Tape Measure Yagi Satellite Antenna

A very inexpensive (about $15) but well performing satellite antenna can be made with a tape measure and some PVC pipe. Indeed, many amateur radio LEO satellites use tape measures as their antennas!



David, N9KT, has made contact with all 48 continental states, over 285 grids, eight countries, and two astronauts *from inside his house* using a tape measure antenna designed by NT1K and a five-watt HT: https://nt1k.com/vhf-3el-tape-measure-yagi/

Purists will note that this is a 2 m-only yagi. It turns out that it's broadband enough and the third harmonic is on 70 cm so it works just fine on all the FM LEO satellites.

A tape measure antenna is also great for roving! You can yank it in and out of your car quickly without worrying about bending the elements. David can pull his car over on a road and be talking on an FM satellite in under one minute.

Using both Omni and Directional Antennas

Occasionally it makes sense to use both omnidirectional and directional antennas at the same time. For example, if you're using a separate transmitter and receiver, you can employ an omnidirectional antenna with a transmitter and a small directional antenna with your receiver. This allows you to maximize your receiver performance and allows you to use higher power to overcome the deficiencies of the omni transmit antenna.

Here's a photo of Juan, EA4CYQ, and his mobile setup:

He has a 70 cm CJU antenna on his HT in his right hand with earphones. In his left hand is the microphone for his automobile mobile rig with a 2 m vertical antenna mounted on the fender in the lower right corner of the picture.

Coax

You will use coaxial cable (or coax) to connect your antenna to your radio. Your antenna may come with the coax, like the diplexer on an Arrow antenna, or you may have to supply the cable.

While any 50-ohm cable will work, you'll get the best performance from Times Microwave LMR-195, LMR-200, or LMR-240 Ultraflex coax for your antennas and jumpers. The most reliable connections will be correctly installed crimp connectors (instead of soldered connectors). For reliability and performance, avoid generic or "equivalent" low-loss coax, and avoid connector adapters (e.g., BNC to PL-259).

There is a more detailed discussion of coax and connectors in Appendix B, *Upgrading Your Amateur Satellite Station*.

Chapter 5
Your Radio System

With a little luck, you may already own the radio or radios you'll need to make your first amateur satellite contact.

If you do need to buy a radio for your satellite work, we'll point to multimode radios that can be used for FM contacts, but which will also work when you graduate to SSB contacts on satellites with linear transponders.

As mentioned in Chapter 4, *Your Antenna System*, nearly all the amateur satellites use the VHF (or 2 m) band and the UHF (or 70 cm) band simultaneously, much like a cross-band repeater. The discussion here will concentrate on radios that can be used for these two bands.

Your radio system will likely fall into one of three categories:

- A dual-band transceiver that can simultaneously transmit and receive on VHF and UHF
- A separate VHF and UHF transmitter and a multiband receiver
- A newer dual-band handheld transceiver with a satellite mode

Once you have conquered the FM satellites, you'll probably want to try the satellites with transponders. These SSB/CW transponders take an entire 20 kHz to 100 kHz slice of the band and retransmit it on another band, not just a single channel like the FM satellites.

FM satellites only allow a single conversation at a time. The SSB/CW satellites, depending on the bandwidth of the transponder, allow up to about twenty conversations to occur at the same time.

So, if you decide to buy a radio for your satellite work, consider a radio that covers the satellite frequencies and has both FM and SSB.

You can find some real bargains in used satellite gear, and some expensive antiques sold at a premium because the seller thinks you might be buying it for satellite work. Use some caution with old radios that don't have satellite mode and may have RoHS solder deteriorating that needs to be touched up with "real" solder. Also, some components in older rigs, especially capacitors, deteriorate over time. Rebuild kits (capacitors) are available for some rigs on eBay.

Radios mentioned in this chapter will be shown as **boldface** if they are in production as of the publication date of this guide.

Full-Duplex Operation

If you are buying a new modern radio for a base or mobile transceiver to use for FM, SSB, and CW amateur satellite operation, make sure that it has full-duplex capability. That is, you can listen to one band and transmit on another at the same time. Some radios offer dual receive, cross-band or split-frequency operation, but this is not the same thing. It is very important that you hear your own downlink while you are transmitting.

Using older full-duplex HTs with the FM satellites, you'll need to be able to hear your audio coming back from the satellite to know when to change memories. You won't get a call back if you aren't capturing the bird's receiver, or if your transmission is distorted, or if someone else grabs the satellite before you finish your call.

As you move up from the FM satellites to SSB or CW, it is necessary to be able to adjust your transmitter frequency so that it lands on the correct receive frequency.

You certainly can use two separate radios for satellite operation; this approach is very popular. Your receiver can be an HT, a scanner, or a Software Defined Radio (SDR). The point is that you need to be able to transmit and receive at the same time.

Half-Duplex Operation

A new class of handheld FM transceivers includes a satellite mode of operation. While you can't monitor your downlink signal, these are very easy to operate and have proven very successful for making contacts. These satellite mode HTs work better than older full-duplex HTs for the FM birds because they typically tune to within 10 Hertz of the satellites Doppler adjusted frequencies instead of the older FM HTs which are constrained to 5 kHz channel operation.

These satellite mode radios allow you to enter specific satellite information, predict passes and do *automatic Doppler shift* to keep you on frequency.

Several manufacturers are offering these radios at attractive prices. There is also an Open-Source radio project called OpenGD77 that allows you to convert some HTs to include a satellite mode: https://www.opengd77.com . There is more information on these radios below.

Transmitter Power

For voice LEO satellites, 5 watts uplink power is the maximum that should be used. Too many people use excessive transmit power because their receive system is inadequate. On X (Twitter), stations with poor receive systems are called CHS, because they Can't Hear Squat.

These excessive power users are known as **alligators - all mouth, no ears**. Be a responsible and legal satellite user; only use as much power as needed.

> *The key to reliable satellite communication is to put together the best* ***receive*** *station you can. If you don't hear well, you will interfere (QRM) other users of the satellite when you transmit!*

For the SSB transponder satellites where multiple QSOs can take place, running high power is especially harmful, since many people suffer. Unlike using the ionosphere to bounce HF signals, a linear satellite is a zero-sum game. Everybody needs to share the satellite's available downlink power.

Those using CW can operate well with a watt or less.

Many of the handheld radios listed below are only capable of 2-5 watts output. Coupled with a small beam like an Arrow, an Elk, an inexpensive Yagi, or a tape-measure antenna, this is more than adequate for making satellite contacts.

Tim Lilley, N3TL, earned the OSCAR Satellite Communications Achievement Award for making twenty satellite QSOs using only 50 milliwatts for all his contacts!

What we suggest you buy

In the sections below, we cover all the different combinations of potential satellite radios.

If you are buying a new base or mobile transceiver to use with FM, SSB, and CW satellites, we recommend you look in the "**Full-Duplex FM, SSB, and CW Base Station Radios for U/v and V/u**" or "**Dual-Band Half-Duplex Transceivers**" sections below.

If you are considering buying a new FM HT for satellite work, we recommend you look at the "**Dual-Band Half-Duplex HTs**" below.

The other sections below are for people with existing radios that might work for satellite operations.

Currently available radios will be listed in **boldface**.

Dual-Band Full-Duplex Transceivers

A few FM handheld transceivers (HTs), FM mobile radios, and multimode base stations are capable of transmitting and receiving simultaneously on different bands. Unfortunately, none of these radios are in production, but you may be able to find them online or at a hamfest.

Full-Duplex FM HTs for U/v and V/u

If you already have one of these rigs, it is certainly very convenient to operate the FM satellites with them. These were all good radios when they were first introduced; the (estimated) year when first shipped is noted in parentheses.

Despite their age, they frequently sell at a premium price. Because of their age and price, we don't recommend buying one of these radios just for operating the FM satellites. Currently, there are no fully capable full-duplex handhelds available.

- Icom IC-W2A (1993), IC-W32 (1998, early versions with 5-digit serial numbers only)
- Kenwood TH-D7 (2007, in photo to the right), TH-D72A (2010)
- Yaesu FT-470 (1990), FT-530 (1992), FT-51R (1996)

Full-Duplex FM HTs for U/v only

Some handheld radios claim to be full duplex but will only work for the U/v satellites. When configured for V/u operation, transmitting on 2 m either blocks the 70 cm receiver or dramatically reduces the 70 cm sensitivity (a condition called "desense") so that you can't hear the satellite. Because they are FM only and because they don't work on V/u, we don't recommend buying any of these handhelds for satellite operation.

- Alinco DJ-G7T
- AnyTone TERMN-8R
- Icom IC-W32 (late versions with 7-digit serial numbers desense in V/u operation)
- Wouxun KG-UV8D, KG-UV9D

Full-Duplex FM Mobile Radios for U/v and V/u

Several FM mobile radios are full duplex. We don't recommend buying one of these radios just for operating the FM satellites, because you can't use them to operate the SSB/CW satellites. If you already have one, by all means go ahead and use it. The TM-D700/710 series of radios and the FTM-350 and FTM-400 have APRS features that are useful for situations in addition to FM satellite operation. Unfortunately, none of these radios are in production, but you may be able to find them online or at a hamfest.

- Icom IC-2710, IC-2720, IC-2728H, IC-2800
- Kenwood TM-D700A, TM-D710A, TM-D710GA, TM-741, TM-742, TM-941, TM-942
- Yaesu FT-5100, FT-5200, FT-8800, FT-8900, FTM-350, FTM-400

The photo below shows the control head of a Kenwood TM-D710GA.

Full-Duplex FM, SSB, and CW Base Station Radios for U/v and V/u

These radios are normally promoted as "satellite" radios and generally work well for both the FM and the analog transponder satellites. Most also have the capability of being computer controlled (CAT), giving you the ability to implement full Doppler frequency correction.

The term CAT comes from Yaesu's acronym for Computer Aided Tuning, Computer Assisted Tuning, or Computer Aided Transceiver. The amateur community uses the term for any brand of radio that allows computer control.

Since these radios work on both FM and SSB/CW, you should consider these rigs if you choose to buy a radio specifically for your satellite operation. (You do have other options using two radios; see below.) Only the IC-9700 is currently in production. Use some care when buying older radios on this list; some had limited CAT commands or required upgrades to work correctly.

- Flex 5000 (with 2 m and 70 cm modules)
- Icom IC-820, IC-821H, IC-910H, IC-970, IC-9100
- **Icom IC-9700**
- Kenwood TS-790, TS-2000 (has birdie that may interfere with satellite receive)
- Yaesu FT-726 (needs satellite module and tone module), FT-736 (needs tone module), FT-847

With its Spectrum Scope (waterfall), the **Icom IC-9700** has become very popular:

Dual-Band Half-Duplex Transceivers

In addition to the full-duplex transceiver surveyed above, you have the option to use two radios, one for transmit and one for receive. Some operators prefer having two radios, so this isn't necessarily a compromise. The use of two radios may also mean you already own one or both of the radios you need.

For the FM satellites, two handheld radios, or a handheld and a mobile should work well. Or you can use an FM transmitter and either a scanner or an SDR receiver.

If you decide to buy a radio for satellite operation, the best choice is a multimode transceiver that will operate FM and SSB/CW on both 2 m and 70 cm, for example:

- Icom IC-706MKIIG (earlier versions do not have 70 cm), IC-7000
- **Icom IC-7100, IC-705, IC-905**
- Yaesu FT-817, FT-818ND, FT-857D, FT-897D, FT-991
- **Yaesu FT-991A, FTX-1F**

The photo on the left is a close-up of a Yaesu FT-817ND half-duplex multimode and multiband transceiver. It contains a rechargeable battery and is very portable with the included neck strap.

In the photo to the right, Clayton, W5PFG is using his FT-817 as a transmitter and an Icom IC-R20 scanner as his receiver.

Some hams use a pair of FT-817 radios (one for transmit and one for receive), calling the combination an FT-1634. Or a pair of FT-818 radios called an FT-1636.

Dual-Band Half-Duplex HTs

A new class of dual-band half-duplex HTs is now available for working the FM satellites. In addition to their FM and Digital modes of operation, these radios include an FM satellite mode of operation. By configuring the radio with location information, and specific satellite data they predict satellite passes and *automatically manage Doppler shift.* This simplifies operation considerably. The only disadvantage is that you can't monitor your signal on the downlink while transmitting. But, because the radio is always on frequency that compensates for the disadvantage of not being able to hear your signal.

Radios with this feature built from the factory include:

- **AnyTone AT-D168UV, AT-D878UVII Plus**
- **Radioddity GD-168**
- **BTECH DMR-6X2 and DMR-6X2 Pro**

There is also an Open-Source project that provides a firmware replacement for various radios https://www.opengd77.com/ . The manual is at: https://github.com/LibreDMR/OpenGD77_UserGuide/blob/master/OpenGD77_User_Guide.md

The OpenGD77 firmware includes a satellite mode that operates like the factory radios described above. It was introduced to the ham community more than 5 years ago and has an active development and user community.

OpenGD77 replaces the factory firmware with a new set of features. Note that the original analog and digital modes of the radio are preserved.

The OpenGD77 project has been ported to many radios including the following. Others may be supported but you should check the OpenGD77 forum for more information:

- Radioddity GD-77 (also known as TYT MD-760), GD-77S
- **Baofeng DM-1701/DM-1701B**, DM-1801 (Version 1 HW only - also known as DM-860), DM-1801A, DM-1802, RD-5R (also known as DM-5R Tier 2)
- **TYT MD-UV380/MD-UV390 (versions: Original, GPS, and Plus), MD-2017, MD-9600**
- **Retevis RT-3S**, RT-84, RT-90, RT-92

David Spoelstra, N9KT, has made hundreds of contacts using a tape measure antenna and an OpenGD77 converted radio.

The photo to the left shows an **AnyTone AT-D878UVII Plus** and a **TYT MD-UV380 using OpenGD77** side by side. Each radio is showing an ISS pass including countdown to AOS, the path of the ISS and when active the elevation and azimuth.

The AnyTone radio provides GPS for your location, although you can also manually specify the location if desired. Also, it will not allow you to transmit until the satellite is above the horizon.

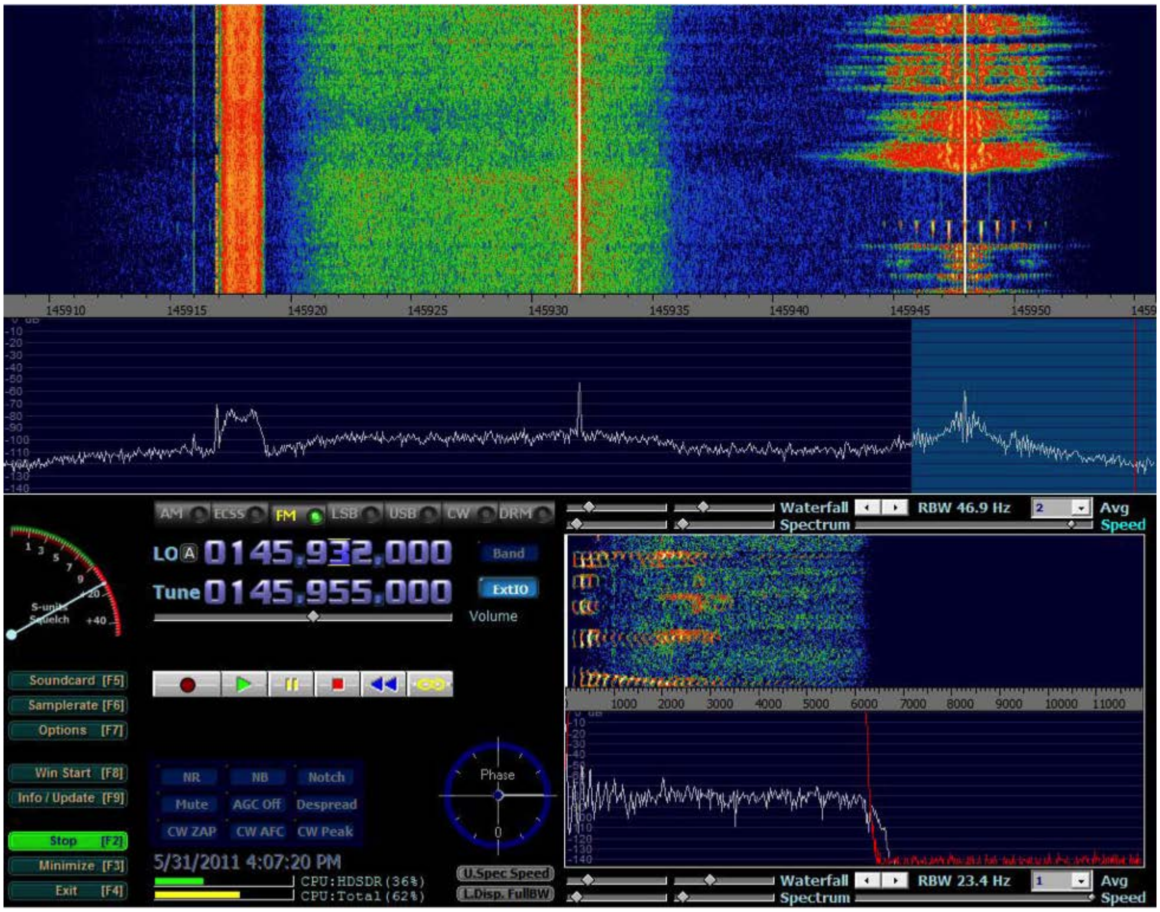
The TYT radio requires that you enter your location but has no limits on transmitting.

Software Defined Receiver

A Software Defined Receiver (SDR) combines an RF interface with a computer and some very sophisticated software. The computer runs software that acts as a multiband, multimode receiver with a panadapter. An SDR is ideally suited as a receiver for a satellite station as it allows you to see the entire passband of the satellite, including the beacon, telemetry, and all the stations operating through the satellite. With only a little practice, you'll be able to visually recognize FM, SSB, CW, SSTV and telemetry, and diagnose problems like desense.

A satellite station with an SDR as its receiver and a multimode transceiver used as the transmitter is a very powerful combination, and one that is growing in popularity.

The computer screen shot below shows an entire multimode downlink. In the waterfall display at the top, you can clearly see (from left to right) the CW message, the BPSK-1000 telemetry, the 16 kHz analog CW/SSB transponder passband, and the FM Voice/Slow-Scan TV signal. This picture is illustrative of the power of software defined radios when receiving satellite transmissions; the screen shot is from an older version of HDSDR (about v1.0) and the original version of the FUNcube Dongle.



SDR Receiver Hardware

There are a wide variety of SDR receivers at prices that start near $20. Many connect to a USB (Universal Serial Bus) port on a standard PC or a Windows tablet. As to be expected, there is a correlation between the purchase price and the quality of the product, but devices with excellent performance can be purchased for between $99 and $200.

When you are shopping for your SDR hardware, you'll likely want to compare certain features. The greater bit depth of the analog-to-digital converter (ADC) results in better dynamic range and ability to handle strong interference. The faster the sampling rate, the wider the bandwidth your SDR can see at one time. This isn't an issue for a single satellite passband but might be a consideration if you want to process the entire amateur 2 m band at once. Front-end filtering will have a major impact on issues you might have with nearby commercial transmitters. Whether or not your SDR requires special device drivers for your computer and operating system may impact which computer and applications you can use.

Four of the most popular low-cost SDR receivers are listed below. For an extensive list of SDR radios, see https://en.wikipedia.org/wiki/List_of_software-defined_radios

FUNcube Dongle (FCD) Pro+

Howard Long, G6LVB has developed an innovative, USB, multimode, software defined receiver that covers 150kHz to 240MHz and 420MHz to 1.9GHz. Using one of the many SDR programs like SDR#, SDR Console, and HDSDR, the FCD will show you the signals from the satellite as you listen to FM, CW, and SSB. Simply plug the FCD into a laptop, connect an antenna to the SMA connector, run the software, and you are in business.

The **FCD Pro+** has excellent switchable front-end filtering, especially for the 2 m and 70 cm ham bands. To a PC or Tablet, it looks like a standard sound card, so it does not require you to obtain or install special device drivers. The ADC depth is 16 bits (12 bits usable) and the sampling rate is 192 kHz, so the received bandwidth is limited to about 180 kHz. The widest amateur satellite transponder is currently about 90 kHz so you'll be able to see and tune the full satellite passband without changing the LO.

Several SDR programs support this SDR dongle directly, including the AMSAT FoxTelem, and the AMSAT-UK FUNcube Dashboard. The **FCD Pro+** works well with HDSDR, SDR Console, and SDR#.

A portion of the profits from the sale of the **FCD Pro+** supports the building and launching of the FUNcube series of satellites. You can find more information and order the FCD Pro+ at http://www.funcubedongle.com.

SDRplay

SDRplay has several models: **RSP1B**, **RSPdx**, **RSPduo**, and a networked **nRSP-ST**. The devices are usable with HDSDR, SDR Console, and their SDRuno and SDRconnect software, but are not supported by SDR#.

Additional information on the SDRs, software, and purchase details are located at https://www.sdrplay.com.

Airspy R2 and Mini

Benjamin Vernoux and Youssef Touil designed the Airspy SDR Receiver. Youssef is the author of SDR#, one of the most popular SDR Windows-based software applications (see below). The **Airspy R2** covers 24 MHz to 1.7 GHz, has a 12-bit ADC and samples at 20 MHz (9 MHz usable bandwidth). It includes a front-end tracking filter.

Look here for more information on the **Airspy R2** and **Mini**: https://airspy.com.

RTL-SDR (DVB-T) Dongles

In Europe and in many countries around the world (but not in the USA, Canada or Mexico), terrestrial broadcast television uses a standard called Digital Video Broadcasting – Terrestrial or DVB-T. This huge market has spawned a number of very low cost (about $20) SDR receivers for TV reception. With the right software and device drivers, these DVB-T dongles can be used for amateur radio reception. In the amateur radio community, DVB-T dongles are referred to as RTL-SDR dongles.

If your budget is limited and you're skilled with computers, then the RTL-SDR dongles may work for you. These are definitely lower performance than the SDRs described above, with 8-bit ADC and almost no filtering.

The device drivers included with Windows for the DVB-T dongles are for television reception, so you must replace the standard Windows device drivers with custom drivers for these applications. MacOS and recent Linux distributions have the drivers built-in.

Currently, the two most popular RTL-SDR dongles are the Nooelec series from https://www.nooelec.com/ and the RTL-SDR series from https://www.rtl-sdr.com (which is also a great place to keep up with the latest news in this area).

For current information and articles on installing and using a RLT-SDR dongle for amateur radio, search the internet for "RTL-SDR".

SDR Receiver Software

New software packages for processing the data stream from an SDR receiver, which can convert your PC or tablet computer into an amazing radio are constantly coming out. Many are free and cross platform. There are even applications for smartphones. We suggest you use internet searches to see what is currently popular. We describe some of the current popular ones below.

SDRangel

SDRangel is an extremely popular, sophisticated but easy to use, free, cross platform application supporting plugins that works on many SDR receivers *and* transmitters. https://www.sdrangel.org/

SDR++

SDR++ is another very popular, sophisticated but easy to use, free, cross platform application supporting plugins that works on many SDR receivers. https://www.sdrpp.org/

GQRX

GQRX is yet another very popular application supporting macOS and Linux only that works on many SDR receivers. https://www.gqrx.dk/

HDSDR

HDSDR is a Windows only application. When combined with SatPC32 (see Appendix B, *Upgrading Your Amateur Satellite Station*) and a CAT-capable transmitter (for example, one of the radios in *Dual-Band Half-Duplex Transceivers* above), you'll have a great radio system for your amateur satellite station.

Go to http://www.hdsdr.de to download the software and the drivers for your SDR hardware.

SDR Console

SDR Console is a Windows only application with the ability to have up to 24 VFOs demodulating different signals in the SDR passband. There is also client/server support for remote monitoring, and the ability to use the GPU in your graphics card to accelerate the digital signal processing of the data stream. https://www.sdr-radio.com

SDR#

Pronounced "S-D-R sharp", is a Windows only application. There are many fans of SDR#, and it might work for you if it supports your SDR hardware: it works with the Airspy and FUNcube Dongle Pro+, but not with the SDRplay receivers. SDR# includes some very advanced filtering, squelch, and other features. https://airspy.com/download/

Web-based applications

There are numerous web-based SDR applications including OpenWebRX https://www.openwebrx.de/ , WebSDR http://websdr.org/ , and WSDR https://wsdr.io/ .

Chapter 6

Operating the FM Satellites

The preceding chapters have all discussed information that will help you make contacts on amateur satellites. In this chapter, we take you through operating an FM satellite in a step-by-step fashion. With preparation, some attention to detail, and only a little luck, the result will be your first of many satellite contacts.

The FM satellites are fun, require low uplink power, need a simple antenna, and are outstanding for satellite demonstrations, general use, and a low-cost entry into satellite operations.

Step 1: Pick one or more FM satellites

There are multiple FM amateur satellites that are working, as of this writing.

In Chapter 1, *Introduction to Satellites*, we discussed how to determine if a satellite is currently operating by checking reports from other hams around the world using the AMSAT Live OSCAR Satellite Status Page: https://www.amsat.org/status/

If the ISS status page shows that the Columbus Module radio is scheduled to be in crossband repeater mode, the ISS is a good satellite for your first QSO: https://www.ariss.org/current-status-of-iss-stations.html. Since the ISS is a V/u satellite, it is a little easier to operate.

Step 2: When and where will your satellite be visible?

In Chapter 3, *Locating Amateur Satellites*, several smartphone applications and internet websites were discussed. Use one of them to determine when your chosen satellite will appear above the horizon at your location (QTH). Consider using a second app or website to check your results from the first one. It is frustrating trying to work a satellite that isn't where you think it should be.

If it won't be convenient to have a smartphone, tablet, or laptop screen with this information at your operating position during the passes, print it or write it down for easy access. You'll want to note the time and location (azimuth) when the satellite will rise above the horizon (AOS). Record when and where (azimuth and elevation) the satellite will be at its highest point in the sky (TCA). And write down the time and azimuth where the satellite will set at the horizon (LOS).

Identify your four- or six-character Maidenhead grid square (for example, EN60 or EN60nk) and write it down on a piece of paper. The standard satellite exchange in the USA is four-character, but six-character is common in Europe and parts of South America. You might forget it during the excitement of a contact!

Make sure you know the correct time. If you use your cell phone instead of a watch, it should have the correct time. If you use a watch or a laptop for your time, check it against WWV or a GPS receiver. Several seconds off can make a difference in where you think the satellite is and where it actually is when you're trying to follow a satellite you can't see across the sky. A few minutes off is the difference between hearing and not hearing that pass.

Finally, using a compass, a street map, or a smartphone compass application, determine landmarks for where the satellite will rise and set.

Step 3: Assemble your antenna

Chapter 4, *Your Antenna System,* and Chapter 5, *Your Radio System,* discussed some of your choices for antennas and radios.

> *The key to reliable satellite communication is to put together the best **receive** station you can. If you don't hear well, you will interfere (QRM) other users of the satellite when you transmit!*

If you're using a portable antenna like an Elk log periodic or an Arrow Yagi, assemble the antenna. The elements of the antenna are about the same length, but not identical. The shortest elements go closest to the satellite. The longest elements are closest to you.

Three- or four-element 2 m beams and seven- to eight-element 70 cm beams will give you horizon-to-horizon coverage on all the LEO satellites.

Paul Bousquet, N1PEB, is using a modified Elk log periodic antenna and a Kenwood TH-D72A from grid FN51 on Cape Cod, Massachusetts.

Step 4a: Setup your satellite-mode HT

If you are using a Dual-Band Half-Duplex Handheld Transceiver (HT) that has a Satellite mode with automatic Doppler shift, you still need to configure it for satellite operation. Examples of this type of radio are the AnyTone AT-D878UVII Plus and the TYT MD-UV380 (with OpenGD77 firmware). **If you aren't using this type of radio, skip to Step 4b.**

- Make sure your radio's location (automatic if GPS enabled) and accurate time (including UTC offset if needed) has been configured in the radio.
- Load the current Keps into the radio. If you're working the ISS, you should update your Keps frequently. Other satellites need Keps that have been updated in the past week or two.
- Put the radio in satellite mode and choose the satellite you want to operate.
- Make sure the radio's projection for the satellite pass agrees closely with the satellite projection on your smartphone or with the website projection. If not, update the Keps, correct your location, and set the clock. You won't work the satellite if they don't agree.
- Note that some radios will not let you transmit until the satellite is above the horizon.

Skip Step 4b and go to Step 5.

Step 4b: Program your standard radio

For older radios without automatic Doppler shift, preprogram five memory channels with the satellite frequencies, including the Doppler shift, and the CTCSS tone.

The first example shows how to program your radio's memories for a V/u satellite, using the ISS. There are some not obvious differences for a U/v satellite that we'll consider later.

As explained in Chapter 2, *Satellite Basics*, the Doppler effect is more pronounced with higher frequencies. VHF frequencies will vary ±3 kHz with LEO satellites. UHF is 3-times higher in frequency than VHF and has 3-times the Doppler shift. So, 70 cm frequencies will vary ±10 kHz with LEO satellites, for a total of 20 kHz from AOS to LOS.

If the smallest frequency steps on your radio on 2 m are 5 kHz (very common for handheld and mobile radios), you'll just use the nominal VHF frequency of the satellite for all five transmit memory channels. The AFC (Automatic Frequency Control) of the receiver at the (V/u) satellite should compensate for the off-frequency effects of Doppler. For the UHF transmitter of the (V/u) satellite, you'll use +10 kHz, +5 kHz, none, -5 kHz, and -10 kHz offsets from the nominal satellite frequency when you program the receiver memories of your radio.

For example, ISS is a V/u satellite, and the nominal frequencies are:

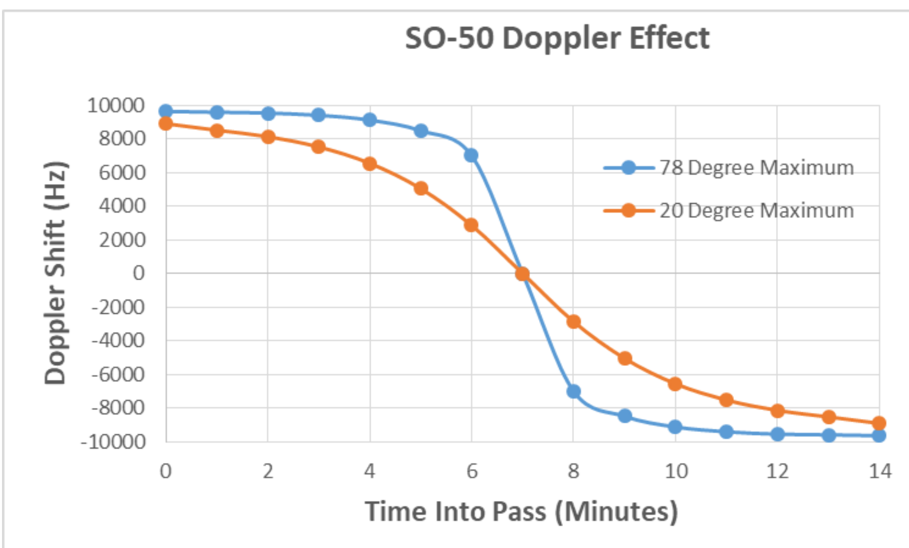
Uplink: 145.990 MHz FM *[with 67.0 Hz CTCSS tone]*
Downlink: 437.800 MHz FM *[±10 kHz for Doppler]*

During an ISS pass, you will experience a 20 kHz shift in the received 70 cm frequency. This means that if you don't tune your receiver, you will miss part of the pass if not most of the pass. Use your memory channels to tune the receiver during the pass to keep the signal strong and to minimize off-frequency distortion.

For ISS, program the five memory channels on your radio(s) to these frequencies and CTCSS tone. As explained above, notice that the downlink UHF frequency changes and the uplink VHF frequency stays the same.

ISS	Downlink	Uplink
Beginning of pass	437.810 MHz	145.990 MHz + 67.0 Hz tone
Early pass	437.805 MHz	145.990 MHz + 67.0 Hz tone
Mid pass	437.800 MHz	145.990 MHz + 67.0 Hz tone
Late pass	437.795 MHz	145.990 MHz + 67.0 Hz tone
End of pass	437.790 MHz	145.990 MHz + 67.0 Hz tone

The graph below shows the received frequency of SO-50's 70 cm analog downlink signal during a 20° maximum elevation pass, and a 78° pass. On the higher elevation pass, the received frequency starts higher and ends lower, that is, more Doppler effect than on the low elevation (20°) pass.



If you're using a Software Defined Radio (SDR) for your receiver, set the LO frequency to approximately 15 kHz below the satellite's nominal downlink frequency so that the signal from the satellite doesn't intersect with the LO frequency. Set the Tune frequency to the Doppler-adjusted AOS frequency. Turn on the AFC (Automatic Frequency Control).

Some FM satellites are U/v. Instead of adjusting the downlink VHF frequency to compensate for Doppler, the adjustments will be done on the UHF uplink frequencies. The Doppler shift correction for U/v satellite uplinks go from low-to-high, which is the opposite of the correction for downlinks that go from high-to-low. When using radios with large tuning steps (like 5 kHz), you adjust the UHF frequency and leave the VHF frequency alone.

As an example only, AO-91 (no longer in service) had a nominal uplink frequency of 435.250 MHz and a downlink frequency of 145.960 MHz, making it a U/v satellite. To operate AO-91, you could program the five memory channels on your radio(s) to the frequencies and CTCSS tone in the table below. Note that the transmit frequency at the beginning of the pass starts at 10 kHz below the published transmit frequency and then increases in frequency. AO-91 also required that users transmit the 67.0 Hz CTCSS tone. As explained above, notice that the downlink UHF frequency *changes* and the uplink VHF frequency *stays fixed*.

AO-91 (end of mission)	**Downlink**	**Uplink**
Beginning of pass	145.960 MHz	435.240 MHz + 67.0 Hz tone
Early pass	145.960 MHz	435.245 MHz + 67.0 Hz tone
Mid pass	145.960 MHz	435.250 MHz + 67.0 Hz tone
Late pass	145.960 MHz	435.255 MHz + 67.0 Hz tone
End of pass	145.960 MHz	435.260 MHz + 67.0 Hz tone

For any satellite you intend to operate, check online for the suggested memory-channel frequency pairs.

Make sure you have your radio batteries charged, and your smartphone, tablet, or laptop batteries too.

Step 5: Listen for your satellite

Use an audio recorder or an audio recording program/app on a computer, smartphone, or tablet during the pass. Recording is one way to capture the call sign and grid square of someone you worked during a pass. You can replay the recording after a pass to update your logbook. If the program/app doesn’t already do this, make a note of the date and UTC time of the start of the recording.

While you wait for your satellite pass to begin, practice aiming your antenna. Start at the point on the horizon where AOS will occur. Slowly trace an arc across the sky with the antenna, rising through the TCA point, then arcing downward to LOS. You want the aiming of the antenna to become second nature so that you can concentrate on your QSO.

A minute or two before the predicted AOS time, open the squelch on your radio. When you first hear the satellite, the signal won't be strong enough to open the squelch and fades during the middle of a pass are common. You'll likely find that headphones will help with the ambient noise and will minimize feedback.

Wave the antenna back and forth a little while twisting your wrist ±90° while you search for the signal from the satellite. Once you find the satellite, you can quickly adjust where you point the antenna and its twist for the strongest signal. Continue to follow your tracking data with the antenna but move the antenna in 1- to 2-foot circles to optimize the signal. It is difficult to accurately eyeball both azimuth and elevation, but once you've found the satellite, you keep tracking by ear, not by azimuth and elevation.

It is very rare for the FM satellites to be quiet over large population centers like the continental USA or Europe during the daylight and evening hours. There may be only one or two operators if it is early on a Sunday morning and the majority of the satellite's footprint is over an ocean or northern Canada. Otherwise, expect to hear lots of traffic.

So, you don't hear anything? Here are a few things to check:

- Check that you are listening to the downlink frequency, and not the uplink.
- Check that the right antenna is connected to the receiver
- Is the satellite really where you think? Check your location in the tracking software.
- Check to be sure your watch or time-keeping device is correct. Have you converted from UTC to local time correctly?
- Does the AMSAT Live OSCAR Satellite Status Page show that other hams are hearing this satellite?
- Does this combination of antenna, coax, and radio hear another FM radio or the local repeater?

Step 6: Make the call

After you've listened to a couple of passes, practiced pointing and tuning, and have a feel for the pace and content of FM satellite QSOs, you're ready for your first attempt.

Your audio recorder is running, right?

Listen for signals from the satellite before transmitting. As you know from listening to the traffic on a couple of passes, the FM satellites are busy. If you don't hear it, you've got a problem that won't be solved by transmitting and interfering with the other users of the satellite that you can't hear.

DO NOT CALL CQ ON AN FM SATELLITE! CQ calls, especially long CQ calls, unnecessarily tie up the satellite and annoy the other dozen hams waiting to make a call.

Listen to who is talking and whether they are talking with someone in particular. Note the call sign of a clear station that sounds confident in their operating ability.

Make a short call to this specific station when he/she ends a QSO. Don't just throw your call sign into the mix – it is unlikely that someone will answer you.

If you hear dead air when you call, or just part of the first word, did you remember to set the CTCSS tone when you programmed your memory channels?

If you are confident the satellite is operational, that your station is working, and you do not hear other stations, a brief announcement of your call sign and grid locator is acceptable, "Whiskey 4 Alpha Bravo Charlie, Echo Mike 83", for example. Use phonetics for both your call and your grid!

DO NOT CALL CQ ON AN FM SATELLITE! This is an important point, worth emphasizing a second time.

When the station you called comes back to you, start with their call sign, then your call sign, grid locator, and a short greeting or message. For example, "K8YSE, Whiskey 4 Alpha Bravo Charlie, Echo Mike 83. QSL?" ALWAYS use the standard phonetic alphabet for your call and grid square. For W9YB, use Whiskey Nine Yankee Bravo, not Wooly 9 Yogi Bear. A list of the standard phonetic alphabet is in Appendix A, *Reference Material*.

Once you have completed the exchange with another station, give your call sign to conclude the QSO. For example, "W4ABC QSL."

To summarize, a typical QSO with K8YSE on an FM satellite goes something like this. Satellite operators exchange grid squares (EN91 and EM83 in the example below), not signal strength (e.g., "59"). Assuming your call is W4ABC (remember to use the standard phonetic alphabet for your call and grid):

You: Listening to the satellite, you hear K8YSE with a strong, clear signal. In between QSOs, you transmit "K8YSE, Whiskey 4 Alpha Bravo Charlie, Echo Mike 83."

K8YSE: In response, you hear "W4ABC, K8YSE, Echo November 91. QSL?"

You: In reply, you transmit "W4ABC QSL.

The station you are calling knows his call, so you don't need phonetics for that. He doesn't know your call or grid, so use phonetics for those. If he responds with your call correctly, then you don't need to use your phonetics again. You don't know his grid, so he should respond with the phonetics for his grid. You won't always hear people using phonetics, but you'll hear a lot of people asking for a correction on call signs and grids because they didn't understand just the letters.

If you are using an older non-Doppler corrected HT and your signal that you hear back from the satellite is distorted, that means you didn't change your radio's memories as the satellite crossed the sky. Go back and review Step 4b above.

The passes are relatively short, and dozens of people may be trying to work the same pass. It may take a few passes until you make a contact. Continue to practice pointing your antenna and listening to the other stations.

Please do not use the FM satellites for long conversations with other stations, as many others may be listening and wanting to make QSOs. The Linear satellites have much more bandwidth and are great for making longer QSOs.

ENJOY the experience of operating through an amateur satellite!

Remember that many people are making their first satellite contact and may not know about good satellite operating practices. Give them the benefit of the doubt, complete your QSO with the new operator, and attempt to contact them via e-mail after the contact to offer friendly suggestions on how to work the satellite. Trying to do this on the air is not recommended as it ties up the satellite and embarrasses the new operator.

Step 7: Log the QSO using LoTW

Congratulations! You've made your first satellite contact. For many of us, that first contact is an incredible experience.

Once the adrenalin rush subsides, add your contact to your logbook. Write down the local date, local time, the satellite name (e.g., ISS), the call sign of your contact, and their grid square. Then convert the local date and time to UTC.

Were you were so engrossed in the contact, pointing the antenna, tuning the radio, pressing the PTT, trying to talk, that you forgot their call and their grid? Welcome to the club; it has happened to many of us.

No problem. Just listen to the recording you made. You forgot to start the recorder? That happens a lot, too. Use e-mail to ask another station on that pass if they have a recording they can share with you. Most satellite operators have their e-mail address in their QRZ.com listing.

While many satellite operators will reply to QSL cards, using the ARRL's Logbook of the World (LoTW) is very popular because a lot of operators are chasing satellite awards. You can sign-up for LoTW here: http://www.arrl.org/logbook-of-the-world.

The difference between a DX record and a satellite record in LoTW is that the satellite record includes two additional lines of data (obviously using different standardized satellite names for the different satellites: https://lotw.arrl.org/lotw-help/frequently-asked-questions/#sats):

- Propagation Mode: <PROP_MODE:3>SAT
- Satellite Name: <SAT_NAME:4>AO-7

Most logging programs easily allow you to log satellite contacts. However, if you find you are not getting credit in LoTW for your satellite contacts, make sure you have the above two lines in your ADIF data. Further information is available on the LoTW site at https://lotw.arrl.org/lotw-help/satellite-qsos

Please use LoTW to log your satellite contacts. You may provide yourself or someone else a state or grid square they don't have toward a satellite award.

Why would someone care if you confirm a grid square or a state? Glad you asked….

Operating Awards

Just like with other terrestrial operating, there are awards for satellite operators making confirmed contacts with other stations. Examples of these awards are the ARRL's Worked All States (WAS – confirming satellite contacts with all 50 US states) and VHF-

UHF Century Club (VUCC – confirming satellite contacts with at least 100 grid locators), along with a series of awards offered by AMSAT and others including AMSAT's prestigious GridMaster Award for working all 488 Maidenhead grids in the United States. For more information about awards, see https://www.amsat.org/awards-2/

Some operators, (called Rovers) will travel away from their home stations and operate from other states and/or grid locators, to help operators obtain contacts with these locations – some of which are rarely heard via satellite. Many satellite operators live within an hour or two from a grid locator different than the one for their home stations, and many of these grid locators are not heard regularly on the satellites. Since satellite stations can be very portable, this can add a unique aspect to working satellites. It also is one way to deal with Home Owner Association (HOA) restrictions on antennas mounted on houses – an unfortunate reality for many hams.

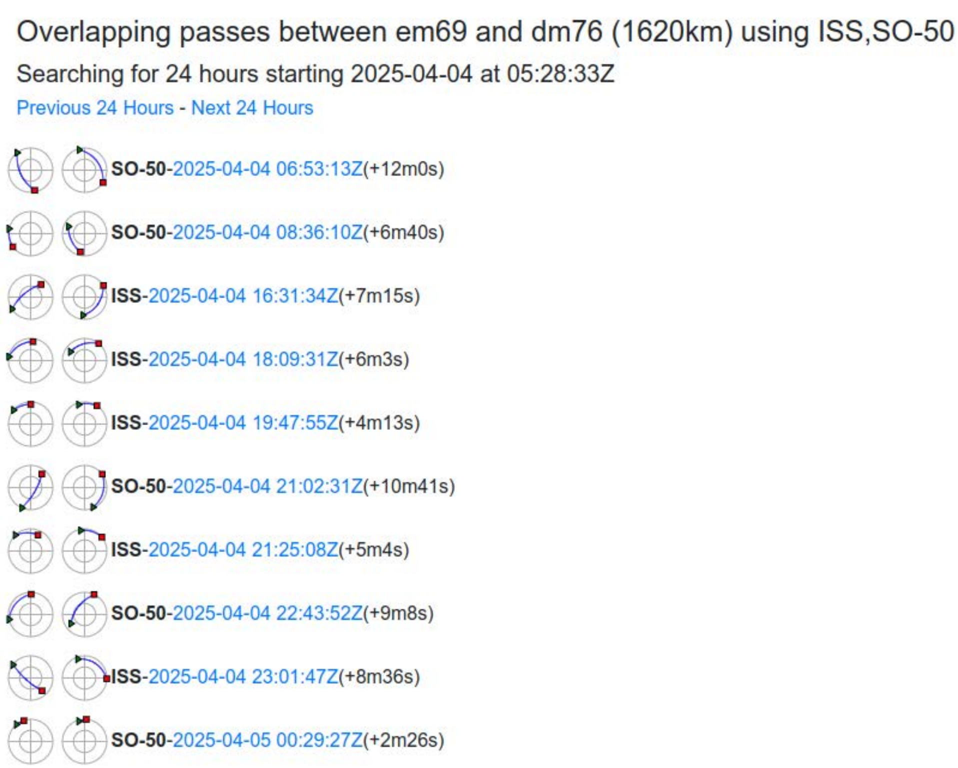
More information on satellite awards is available at the following web sites:

https://www.amsat.org/awards/ (AMSAT awards)

https://www.arrl.org/awards (ARRL awards, including WAS and VUCC)

SatMatch

SatMatch https://www.satmatch.com/ is an excellent resource if you are trying to get needed grid squares for an award. You fill in a list of satellites along with your grid, and the grid you want. SatMatch returns all the passes available with both grid squares in the satellite footprint along with polar images of the pass for both locations so you can choose the best ones.



Sean Kutzko, KX9X, is operating from grid DN74 in Wyoming, looking down on Devil's Tower. He's using an Arrow dual-band Yagi and a pair of Yaesu FT-817.

Best Practices

While working stations through an FM satellite is fairly easy, there are some operating practices that all operators should follow. Since FM satellites are a shared resource, all operators during a pass need to help keep the passes accessible for as many stations as possible.

Sean Kutzko, KX9X, has summarized these best practices. Many of these guidelines are based around two simple "Golden Rules" of satellite operating: Don't transmit if you can't hear the satellite, and if operating using full duplex, listen to the satellite while you transmit.

1) Share the Pass

FM satellites are just like a repeater: only one person may transmit at a time. Since a satellite is overhead for 15 minutes at most, each operator will want to make some contacts. Please don't monopolize a pass; let your other ham colleagues have some time on the pass as well. It takes a lot of self-discipline, but sometimes the best engagement is to make one single QSO and sit back to listen for the remainder of the pass.

2) Let Other QSOs Finish

Please let other stations complete their QSO before you call another station. It's very frustrating when you are calling a station to complete a QSO and another station starts a call before your QSO is completed. Calling someone who has just called another station is considered rude. It's the equivalent of being interrupted; nobody likes being interrupted. If you hear a QSO in progress, please let that QSO finish before you make your own call.

3) Minimize Repeat QSOs

There are often times where you will hear stations on a pass that you have already worked several times. If a pass has other callers, please refrain from calling a station you have already contacted numerous times. If you think about it, there are only so many QSOs that can be made during a given pass. Each QSO that is made between two stations that have already contacted each other prevents another QSO from happening, one that might be a new grid square or state for another station, or a station's first QSO.

4) Don't Call CQ

Please don't call "CQ Satellite" on an FM satellite. It's the same as calling CQ on a repeater; you just don't do it. Generally, it's better to pick out a station and call them directly. However, if you want to announce your presence on an FM satellite during a pass with low activity, simply give your call and grid (example: "W1ABC FN32"). If you have given your callsign several times and are not getting calls, there may be a problem with your station. Take a break and examine your station before transmitting again.

5) Use Phonetics

It can be very difficult during a busy pass to hear and understand a callsign correctly. Using standard phonetics (see Appendix A, *Reference Material*) will make initial copy of your callsign much easier, which reduces the need for repeated transmissions. This makes each QSO shorter, which makes more of the pass available for others. It is not a race. There is no need to give your callsign quickly.

6) Rare/Portable Stations Take Priority

It is common for satellite operators to take their equipment with them to portable locations, to transmit from rare grid squares or other DX countries. Courtesy should be extended to these stations; they are providing a rare location to all satellite operators and will be at that location for a limited time. If you hear a station on from a rare grid or DXCC entity, use good judgement before calling stations in more common grids. If the rarer station is working a lot of people on a pass, it may be best to let that station work as many people as possible. There will always be another pass to work more common stations.

7) Use Only the Minimum Power Required

Generally, 5 watts from an HT and a directional antenna is plenty of power to work an FM satellite from horizon to horizon.

8) Work the New Stations

Satellites are for everybody, and the satellite community LOVES hearing new calls on the FM birds. Regular satellite operators should pay close attention during a pass. If you hear a callsign that's new to you, take the time to call them. You may be that station's first satellite QSO; what an honor!

How to Get the Latest News on Satellite Activity

There are several ways satellite operators can stay abreast of operations from rare grids or DXCC entities. Many operators are now using the popular https://hams.at/ to post their roves and rare grid activations.

AMSAT's website also has an area for Upcoming Satellite Operations https://www.amsat.org/satellite-info/upcoming-satellite-operations/. Check this regularly for the latest info. If you're on Facebook, you can also join the AMSAT-NA Facebook group; many operators post their activity news in the group.

X (Twitter) is used frequently to announce grid expeditions; start by following @AMSAT, @AMSAT-UK, and @ARISS_Intl for more real-time satellite information. Also, while on X, look for callsigns of operators that you hear on the satellites; there is a robust group of satellite operators on X from which to learn.

Finally, you can always listen to a pass. If a lot of people are calling a specific station, that's a good indicator they are at a rare location. This is especially important at the beginning or ending of a pass, when the satellite's footprint is more likely to include DX stations.

We hope that these guidelines provide a way for all satellite users to cooperate and share each pass. We want you to work lots of stations and have fun, but not in a way that prevents others from having a good time on the satellites, too. Be neighborly and a good steward of the satellites, and we can all have fun for a long time.

Ron, AD0DX, operates from Vargas Island in grid CN69 using his Arrow antenna, dual Yaesu FT-818 for SSB, and a Yaesu VX-6R paired with a FT-70D for FM.

Chapter 7

Operating SSB and CW Satellites

Once you're comfortable operating the FM satellites, you'll become familiar with the main challenge of using them: competing for a single channel with dozens of other hams in the evenings and on weekends, and even hundreds during Field Day, spread across half a continent. No one else transmits through that satellite while you're using an FM satellite.

The primary advantage of the linear transponder satellites that support SSB and CW communication is ability to have multiple conversations. If you desire, you can have a longer conversation without preventing others from using the satellite.

In this chapter, we guide you step by step through operating an SSB/CW satellite using SSB. While operating an SSB satellite shares many similarities with operating an FM satellite, there are also some significant differences.

Inverting and Non-Inverting Linear Transponders

Satellites with linear transponders come in two versions – inverting linear transponders and non-inverting linear transponders. An inverting linear transponder (the most common) swaps the SSB sideband (LSB/USB) and the receive frequency decreases as the transmit frequency increases. A non-inverting linear transponder maintains the same sideband for uplink and downlink, and the receive and transmit frequency move up and down together.

The convention is to **use USB on the downlink**.

Inverting linear transponders

Inverting linear transponders have an uplink on one sideband and the downlink signal produces a signal with the opposite sideband. Linear transponders don't recognize transmission types (SSB, FM, CW, PSK, etc.); they just retransmit what they hear. Any signals the satellite receiver hears, e.g., radar, taxis or ham radio operators, are all retransmitted proportional to their received signal strength.

Since the convention is to use USB on the downlink, this means you should use LSB for the uplink. You may find this memory aid useful: The Lower station (on earth) uses LSB; the Upper station (on the satellite) uses USB.

As you increase the uplink frequency, the downlink will decrease in frequency and vice versa. A CW signal sent to an inverting linear transponder will not change sidebands, but the frequencies for the uplink and downlink will track in opposite directions.

One of the reasons that most satellites (especially the newer ones using higher frequencies) select inverting linear transponders is that it lessens, but doesn't eliminate, the effect of Doppler shift on the signal. Non-inverting linear transponders exaggerate the Doppler effect.

For example, AO-7 operates with Mode A and Mode B transponders. Mode B (U/v) is an inverting linear transponder, so as the uplink frequency increases the downlink frequency decreases.

Down	**USB**	145.975	.970	.965	.960	.955	.950	.945	.940	.935	.930	145.925
Up	**LSB**	432.125	.130	.135	.140	.145	.150	.155	.160	.165	.170	432.175

Non-Inverting linear transponders

Non-inverting linear transponders have an uplink on one sideband and the downlink signal uses the same sideband. Many of the Russian transponders have used non-inverting linear transponders.

USB is still the preferred downlink, but USB is also used for the uplink.

For example, AO-7 has an inverting Mode B transponder, but AO-7 also has a non-inverting Mode A (V/a) transponder. When AO-7 is in Mode A, both frequencies increase; as the uplink frequency increases so does the downlink frequency.

Down	**USB**	29.400	.410	.420	.430	.440	.450	.460	.470	.480	.490	29.500
Up	**USB**	145.850	.860	.870	.880	.890	.900	.910	.920	.930	.940	145.950

Step 1: Pick an SSB satellite

In Chapter 1, *Introduction to Satellites*, we discussed how to determine if a satellite is currently operating by checking reports from other hams around the world using the AMSAT Live OSCAR Satellite Status Page: https://www.amsat.org/status/

In the special case of AO-7, you can also determine if the satellite is in Mode A or Mode B.

If the status page shows that they are working, the U/v satellites are good choices for your first SSB satellite contact.

Step 2: When and where will your satellite be visible?

Chapter 3, *Locating Amateur Satellites*, discusses several smartphone applications and Internet websites. Use one of them to determine when your chosen satellite will appear above the horizon at your location (QTH). Consider using a second app or website to check your results from the first one. Trying to work a satellite that isn't where you think it should be is frustrating.

If it won't be convenient to have the smartphone, tablet, or laptop screen with this information at your operating position during the passes, print it or copy it down for easy access. You want to note the time and location (azimuth) when the satellite will rise above the horizon (Acquisition of Signal or AOS). Record when and where (azimuth and elevation) the satellite will be at its Time of Closest Approach (TCA). Write down the time and azimuth where the satellite will set at the horizon (Loss of Signal or LOS).

Identify your four- and six-character Maidenhead grid square (for example, EN60 or EN60nk) and write it down on a piece of paper. We normally use four-character grid squares for satellite QSOs in the US and Canada, but Europe and other locales sometimes use six-character grids.

Make sure you know the correct time. If you use your cell phone instead of a watch, it should have the correct time. If you use a watch or a laptop for your time, check it against WWV or a GPS receiver. Several seconds off can make a great deal of difference in where you think the satellite is and where it is when you're trying to follow a satellite you can't see across the sky. A few minutes off is the difference between hearing and not hearing that pass.

Using a map or smartphone compass application, determine which direction is north and pick landmarks for where the satellite will rise and set.

Step 3: Assemble your antenna

Chapter 4, *Your Antenna System* and Chapter 5, *Your Radio System* discussed some of your choices for antenna and radios.

> *The key to reliable satellite communication is to put together the best **receive** station you can. If you don't hear well, you will interfere (QRM) other users of the satellite when you transmit!*

If you're using a portable antenna like an Elk log periodic or an Arrow Yagi, assemble the antenna. The antenna elements are about the same length, but not identical in length. The shortest elements go closest to the satellite. The longest elements are closest to you.

Three- or four-element 2 m beams and seven- to eight-element 70 cm beams will give you horizon-to-horizon coverage on most LEO satellites.

An essential part of the antenna system is the feed line. Using a high-quality low-loss cable with as short a run as possible will yield the best results. If operating portable, using a cable such as Times Microwave LMR-240UF will provide the flexibility needed between a hand-held antenna and radio. A cable such as LMR-400 or LMR-600 would be suitable when operating from a fixed location. With longer cable runs, an at-the-antenna preamp with T/R switch might be necessary.

Clayton, W5PFG, operates from a picnic table next to his fifth-wheel travel trailer using an Icom IC-821H. He holds his "short Arrow" with two 2 m elements and four 70 cm elements. It has a little less gain than a standard Arrow Yagi but is a lot easier to hold.

Step 4: Setup your receiver

When you're operating an FM satellite, there is only a single uplink channel and a single downlink channel. At the satellite, these are at fixed frequencies. Your challenge is to compensate for the Doppler shift during the pass, normally by tuning only the UHF frequency using stored frequencies in your radio's memory channels. The FM capture effect and the VHF receiver AFC (on the satellite for V/u, or in your radio for U/v) handle any small VHF frequency errors.

For SSB, you'll obviously need radios capable of operating SSB. Tuning your transmitter and receiver is very different for sideband operation.

First, you can easily hear if you're off frequency by 25-100 Hz when receiving SSB, and worse, you may not be able to understand what is being said if you're off by a few hundred Hz. There is no AFC to correct the off-frequency problem; you must do that by ear. This is not as significant an issue when using CW, as the tone is copyable over a wide range of audio frequencies.

Second, the SSB satellites listen to a passband that can be 20 kHz to 100 kHz wide, and they retransmit that entire 20-100 kHz passband. Your transmitted SSB signal will likely be about 3 kHz wide, so you'll only occupy a 3%-15% portion of the passband, if you're not drifting through it because of Doppler. Other hams can use other portions of the passband simultaneously. If you're both being courteous and using proper technique, you won't interfere with each other.

If the satellite isn't crowded, it's common to find people clustered around the center.

By convention, the downlink is always Upper Sideband (USB).

Ignoring the Doppler shift and any errors in the oscillator frequencies on the satellite, here are the passband and beacon frequencies:

An example of a U/v 20-kHz-wide Transponder Band Plan

Uplink (LSB/CW)	Downlink (USB/CW)
435.235 MHz	145.855 MHz CW Beacon
435.230 MHz	145.860 MHz
435.225 MHz	145.865 MHz
435.220 MHz	145.870 MHz Passband center
435.215 MHz	145.875 MHz
435.210 MHz	145.880 MHz

Once you've chosen a satellite from the AMSAT Live OSCAR Satellite Status Page https://www.amsat.org/status/ , click the satellite name to look up the passband and beacon frequencies, whether the satellite is V/u or U/v, and if the transponder is inverting or non-inverting.

As Chapter 2, *Satellite Basics*, explains, the Doppler effect is greater with higher frequencies. VHF frequencies will vary ±3 kHz with LEO satellites because of Doppler. UHF frequencies are 3-times higher than VHF and have 3-times the Doppler shift. So, 70 cm frequencies will vary ±10 kHz with LEO satellites, for a total of 20 kHz from AOS to LOS.

A satellite's beacon may be a solid carrier or a steady stream of telemetry in CW or one of the digital data modes. Many linear satellites have a CW beacon.

The beacon is helpful because you can find the satellite in the sky and on your radio. The difference between the published beacon frequency and the frequency on your radio gives you a real-time indication of the size of the Doppler shift at that instant. In general, you also want your signal coming back from the satellite to be about the same strength as the beacon.

Setting up your SDR receiver

If you're using an SDR for your receiver, you need to set it to receive Upper Sideband (USB) and change the LO so that the entire downlink passband (with beacon) is displayed on the screen. If possible, set the LO frequency (which is usually associated with the center or DC spike) so that it is completely below the downlink passband. If the SDR bandwidth isn't wide enough to put the LO frequency below the passband, put the LO in the lower portion of the satellite downlink.

Remember that the Doppler shift causes the entire downlink passband to be higher in frequency at AOS, slowly drifting down in frequency as the satellite passes by and then moves away from you. So, if the downlink is in the 70 cm band, allow 10 kHz both above and below the downlink passband on the SDR receiver, or 3 kHz above and below for a 2 m downlink.

Setting up your conventional receiver or transceiver

If you're using a conventional receiver (half-duplex transceiver, full-duplex transceiver, or a receive-only radio), you'll want to check several settings.

- If your receiver allows you to set the minimum tuning step when operating SSB, pick a small value (about 10 Hz).
- Choose the correct receive downlink band. VHF for a U/v or UHF for a V/u satellite.
- Always select USB for satellite downlinks.
- Put the receive frequency above the published frequency of the satellite beacon. Add 2-3 kHz for U/v satellites and 7-10 kHz for V/u satellites.

Step 5: Listen for your satellite

Before we discuss transmitting to the satellite, you need to practice tracking the path of the satellite across the sky, finding the satellite's downlink on your radio, and tuning the radio to keep the beacon at a steady pitch despite the Doppler effect as the satellite goes from AOS, to TCA, to LOS.

Listen for the beacon at AOS. Depending on the maximum elevation of the pass, you can experience about 20 kHz of Doppler shift from AOS to LOS. The Doppler shift will be most rapid during the middle part (around TCA) of the pass.

Listening on an SDR receiver

Tracking the beacon on an SDR receiver is straightforward. You'll see it slowly drift across the waterfall display. To listen for the beacon, adjust the Tune frequency, not the LO frequency. Leave the LO frequency alone for the entire pass.

Depending on the speed of your waterfall display, you may be able to read the CW from the beacon. You'll also be able to see the active QSOs on the waterfall easily, and if you change the Tune frequency, listen to the conversation. Remember that you're listening in USB mode.

Listening on a conventional receiver or transceiver

If you're using a conventional receiver (half or full duplex), changing the tuning to compensate for the Doppler shift while listening to the beacon is relatively easy. While looking for the beacon near AOS, add the expected Doppler shift to the published frequency of the beacon.

If you don't find the beacon immediately, remember that it will slowly drop in frequency during the pass. Near TCA, the beacon will be close to the published beacon frequency. Of course, just like for the FM satellites, you'll need to point the antenna toward the satellite and twist it to adjust the polarity.

Once you have the technique for tracking the beacon after one or two passes, try finding satellite QSOs near the middle of the passband. These may be more challenging. Unless an operator uses computerized Doppler compensation on his transmitted signal, you'll be compensating for both your and his Doppler shift. This isn't impossible; it is just a little more challenging. Keep practicing manually tuning your receiver so that the conversation remains readable.

So, you don't hear the beacon? Here are a few things to check:

- Check that you are listening to the downlink band, and not the uplink
- Check that the correct antenna is connected to the receiver
- Is the satellite really where you think it is? Check your location in the tracking software.
- Check to be sure your watch or time-keeping device is correct. Have you converted from UTC to local time correctly?
- Does the AMSAT Live OSCAR Satellite Status Page show that other hams are hearing this satellite?
- Does this combination of antenna, coax, and radio hear when you switch to FM and listen to the local repeater?

Step 6: Setup your transmitter

When setting the initial estimate of the transmitter uplink frequency, you're going to need to subtract the Doppler shift as the satellite approaches you, especially if the satellite you're working uses the 70 cm band for its uplink.

The ultimate setup for Doppler compensation is to have a computer track the satellite and automatically tune the uplink and downlink frequencies to adjust for Doppler. This is called Full Doppler Tuning (FDT). The advantages of FDT are discussed in Appendix A in the section titled *The One True Rule for Doppler Tuning*. Using satellite tracking software and controlling your radios with your computer is discussed in Appendix B, *Upgrading Your Amateur Satellite Station*.

We'll assume here that you don't have FDT and suggest how you should tune for Doppler manually.

Manual tuning when using a V/u satellite

When first learning to operate SSB on the V/u satellites, set and leave the transmit frequency fixed (your VHF transmit) and adjust the UHF receiver for Doppler, slowly lowering the UHF received frequency to best hear yourself or the other station as the satellite progresses through the sky.

As you gain experience and you want to change the VHF transmit frequency, you'll need to decrease the UHF received frequency if you increase the VHF transmit frequency.

Manual tuning when using a U/v satellite

If you're operating a U/v satellite, you still leave the VHF frequency fixed and adjust the UHF frequency. The big change is to set and leave the VHF receive frequency fixed and adjust the UHF transmitter for Doppler, slowly raising the UHF transmit frequency to best hear yourself.

When listening to the other station, you may need to slightly tune the downlink VHF frequency to understand the other station, depending on many factors. When transmitting, you leave the downlink VHF frequency fixed, and raise the UHF transmit frequency to adjust for Doppler to best hear yourself.

One very important note: When adjusting for Doppler on the transmitter, you start low and slowly tune up. This is the opposite direction of Doppler correction for a receiver!

Troubleshooting your SSB operation

- If your transmitter allows you to set the minimum tuning step when operating SSB, pick a small value (about 10 Hz).
- Choose the correct uplink band. Transmit on UHF for U/v satellites. Transmit on VHF for V/u satellites.
- Does the satellite have an inverting transponder or a non-inverting transponder? Most are inverting. For an inverting linear transponder, set your transmitter to lower sideband (LSB). For a non-inverting linear transponder, transmit using USB.
- Pick a frequency pair in the transponder away from the center of the passband.
- Tune both the transmitter and the receiver to the frequency pair you've chosen. If the uplink for your satellite is UHF, subtract two-thirds of the AOS Doppler shift from the transmit frequency. (For an inverting transponder, the 2 m shift partially compensates for the 70 cm shift, hence the two-thirds factor.) For example, you should expect a 8-10 kHz shift (or 0.008 to 0.010 MHz) on UHF at AOS, so subtract the appropriate number from your chosen uplink frequency. If the downlink band for your satellite is UHF, you'll need to add the AOS Doppler shift to the receive frequency.

Satellite Mode on full-duplex radios

Some full-duplex transceivers have a "satellite mode" that couples the transmit and receive VFOs so that you can tune the receive frequency and the transmit frequency together when you change your position in the passband. This is useful if your satellite has a very high orbit and is located where the Doppler shift is very small. If your radio has this satellite mode feature, you'll need to know how to turn it on and off.

When you're adjusting for Doppler so that you can track and hear yourself, turn off satellite mode and only change the UHF frequency while you transmit.

When you're adjusting to best hear someone else, turn on satellite mode so that both the receive and transmit frequencies change. Then turn off satellite mode so that you can adjust for Doppler when you transmit again.

If the satellite has an inverting linear transponder (almost all do), use "Reverse Satellite Mode". If the satellite has a non-inverting linear transponder (e.g., AO-7 Mode A), use "Normal Satellite Mode". It is counter-intuitive, but "Normal" isn't normal.

Step 7: Find yourself on the satellite

For your next challenge: Find your signal in the satellite's passband. You are using full duplex, so you can hear your signal when you transmit. When other stations call you, they'll use your signal coming back from the satellite as the place they'll transmit. If you can't hear yourself, you won't hear them either.

If you're getting pretty good at aiming your antenna and pointing it at the satellite, and if you can reliably find the beacon and other QSOs in progress, there is a real good chance you'll hit the satellite when you transmit. Almost all of the SSB satellites have good receivers. Getting into the satellite is rarely a problem. Using too much power to get into a satellite is a much more common problem.

Finding where your signal is in the passband, so that you can listen to it, is the challenge.

The frequency pairs given are only approximate:

- Most amateur satellites don't have the physical space or the available power to operate highly accurate oscillators in their linear transponders, so they often drift with the satellite's temperature. The satellite temperature goes up in the sunlight and down during an eclipse (when they're in the earth's shadow). The temperature also goes up when the transponder is being used and down when the transponder is off.
- Most amateur radios (including yours) don't have perfectly accurate oscillators in their transmitters or receivers. They drift with temperature too. Some radios offer high-precision oscillators as an option, which suggests that the standard oscillators aren't perfect.

The amount of error between the published frequency pairs and the actual frequency depends on the satellite. As you become familiar with a satellite and your radios, you'll learn what frequency offsets work best.

In contrast, some designers were forced to use a low-power oscillator design that isn't stable because of a limited power budget. A 1U CubeSat has very little room for solar cells and batteries. As a result, some early satellites drift a lot, during a pass, and from pass-to-pass. The typical error between the published frequencies and actual use can be 10-12 kHz (on the UHF uplink). The 2 m telemetry beacon wanders 2-3 KHz. This isn't criticism; squeezing a linear transponder into a 1U CubeSat is an amazing engineering feat.

In Step 6 above, you picked an uplink/downlink frequency pair in the phone portion of the transponder passband away from the center of the passband. (The center of the passband is often crowded, and you're trying to find your transmitted signal where you are less likely to interfere with a conversation already in progress.)

To find yourself, you'll transmit on the uplink while you listen for your signal to come back on the downlink. Some operators send a series of CW dits. Others whistle into the microphone or say "testing, testing, 1-2-3-4". Legally identifying yourself and including a grid square can establish an early contact for you.

Remember that you must legally identify your transmission with your call sign. This may have the side benefit of getting you a little help (via e-mail) if you're having trouble. (Hint: Having your current e-mail address in your https://www.qrz.com listing is an excellent idea. You'd be surprised at the help you can get if someone can find your e-mail address.)

In general, it is best to leave your transmitter frequency fixed while you adjust the receive frequency while searching for your signal. You may be interfering with someone else's QSO (you picked a frequency away from the center of the passband for a reason), but at least you'll only be interfering with one QSO, instead of moving your interference through all of the satellite's passband. Using a fixed transmit frequency is easier for V/u satellites, but you can also do it for U/v satellites.

There should be a slight, but perceptible delay on your received signal. The delay depends on the distance between you and the satellite, which is called the range. The greater the range, the longer it takes the radio waves moving at the speed of light to traverse the distance.

If you can't detect any delay and if tuning the receiver doesn't make a difference, the signal you are hearing may be your transmitted signal bleeding into your receiver. Solutions to this problem might include:

- Reducing your transmitter power
- Separating the transmit and receive antennas
- Adding filtering to the input of the receiver. See the discussion of Receiver Desense in Appendix B, *Upgrading Your Amateur Satellite Station*.

If you hear a warble in your downlink signal, you're using too much power to transmit and causing the entire satellite passband to "FM"! This isn't good on many levels:

- You are interfering with everybody else using the satellite. Their signals are suffering from the same warbling that you are causing.
- You are stealing power from their downlink signals. The satellite's transmitter can only transmit up to its output limit, dividing that power between active downlinks.

- You may cause the satellite to shutoff, depriving every one of its use until the satellite next resets and restarts. (Old solar-power only AO-7 is particularly sensitive to this.)

The details of finding yourself in the satellite passband depend on your radio system.

SDR receiver

This is the most straightforward receiver with which to find yourself. You have the SDR waterfall and bandscope set to allow you to see the entire satellite passband. When you transmit, you should be able to see your signal in the passband, then adjust the Tune frequency to listen to it.

If the whole screen lights up when you transmit, you're overloading the receiver front end, and you need to fix that (see above).

Compare the power of your signal to that of the satellite's beacon using the bandscope. You should be at about the same power level. If you're much higher in strength, you're transmitting using too much power. Back it down.

Half-duplex transmitter and receiver pair and full-duplex transceiver

When using either a full-duplex transceiver or a receiver and transmitter pair, leave the transmitter frequency fixed and tune the receiver until you hear yourself. For a stable satellite, you shouldn't need to go too far away from your Doppler-adjusted calculated receive frequency. An adjustment of 2-3 kHz is typical.

Even with the Doppler shift, you shouldn't be (or can't be) more than ±15 kHz away from the published frequency pair. If you're searching the entire passband, or worse, frequencies outside of the passband, look for other problems. Check your calculations and listen more carefully in the vicinity of where your downlink signal should be. Check to make sure the tuning step is 10 Hz not 1 kHz; you could be jumping past your signal when you tune.

Step 8: Call CQ

Don't forget to start your audio recorder and make a note of the date and UTC time of the start of the recording. Note: some digital audio recorders create file names that are date/time stamped.

Once you've found yourself, try calling CQ from that frequency. Even though you're not in the busiest part of the passband, the hams that use an SDR receiver will see you on their display and will QSY to your signal to see who the new guy is and to check on your grid square.

Unlike the FM satellites where you should never call CQ, calling CQ on the SSB birds is the norm. A relatively long CQ, giving your call several times using standard phonetics instead of just letters, and your grid square will give the other station the time to find and tune you in.

Depending on the satellite, you'll need to adjust your UHF frequency, either the uplink or the downlink, to compensate for the Doppler shift.

QSOs on the SSB birds last longer than on the FM satellites. While some operators mainly focus on exchanging grid squares, others may prefer to share more details, such as first names, and information about their antennas and radios. Since these satellites allow for multiple simultaneous contacts, the pace is more relaxed unless you're speaking with a Rover who is trying to make many contacts during that pass.

Step 9: Complete the contact

When you're done, write down the transmit and receive frequencies where you found your signal. These will give you a better starting point for the satellite's next pass.

Record your contact by writing down the local date, local time, the satellite name, the call sign of your contact, and their grid square. Then convert the local date and time to UTC.

Use LoTW to confirm your contact. You may provide someone a state or grid square they don't have.

Best Practices

Best practices for SSB/CW satellites are mostly the same as for FM satellites, with a few important differences. Since SSB/CW satellites are a shared resource, all operators during a pass need to help keep the passes accessible for as many stations as possible.

Many of these guidelines are based around two simple "Golden Rules" of satellite operating: Don't transmit if you can't hear the satellite, and operate using full-duplex capabilities if at all possible, meaning you can transmit and receive at the same time. If you have your receiver setup correctly, you'll be able to hear the noise from the passband of the satellite even if nobody is talking.

1) Listen first

Do not transmit until you hear the beacon on SSB/CW satellites. If you transmit when the satellite is above your horizon but before you can hear it, you are likely to interfere with another QSO.

2) Don't QRM the Passband

Please don't "swish" your transmitter frequency back and forth across the band trying to find your downlink. Doing some simple calculations will provide an uplink frequency very close to the chosen one, and then you can tune your receiver instead of changing the transmitter frequency. Software such as MacDoppler, GPredict, and SatPC32 will do these calculations for you and make your operation more pleasant for both you and others.

3) Identify Your Transmissions

Give your call when locating your downlink, do not just whistle or send CW dits. Adding your grid location is also common and may encourage a contact. FCC regulation 47 CFR § 97.119 states the requirement that you identify your transmissions.

4) Use Only the Minimum Power Required

Use only the amount of power that is necessary for communication. SSB/CW satellite transponders are a "zero-sum game;" the power you use reduces the strength of everyone else's transmission. Adjust your transmitter power so that you get the same S-meter reading for your downlink as you are receiving from the beacon. Too much power on your signal disrupts the other QSOs by reducing everyone else's transmitted power on the satellite. You can even modulate the whole passband or cause the entire passband to warble with your transmissions.

5) Use Phonetics

It can be very difficult to hear and understand a callsign correctly. Using standard phonetics will make initial copy of your callsign much easier, which reduces the need for repeated transmissions. This makes each QSO shorter, which makes more of the pass available for others. It is not a race. There is no need to give your callsign quickly.

6) Rare/Portable Stations Take Priority

It is common for satellite operators to take their equipment with them to portable locations to transmit from rare grid squares, states, or DX countries. Courtesy should be extended to these stations, as they provide a rare location to all satellite operators and will be at that location for a limited time.

7) Let Other QSOs Finish

Please let other stations complete their QSO before you call. It's very frustrating when you are calling a station to complete a QSO and another station starts a call before your QSO is completed. Calling someone who has just called another station is rude. If you hear a QSO in progress, please let that QSO finish before you make your own call.

8) Work the New Stations

Satellites are for everybody, and the satellite community LOVES hearing new calls on the SSB birds. Regular satellite operators should pay close attention during a pass; if you hear a callsign that's new to you, take the time to call them. You may be that station's first linear satellite QSO; what an honor!

9) Use Full Doppler Control, or Adjust the Highest Frequency

If you can, use full computer-controlled Doppler correction of your uplink and downlink frequencies. If that isn't possible, compensate for the Doppler shift by tuning the higher frequency of the current mode, e.g., if you are using Mode V/u, change the receive frequency downlink on 435 MHz; if you are using Mode U/v, change the 70 cm transmit uplink frequency.

John, K8YSE, operates on his 2014 Western Grid DXpedition from a scenic spot. He is using an Icom IC-910H and a laptop running SatPC32 for Doppler control, all from a 17-ampere-hour battery. The Arrow antenna is mounted on a speaker stand with a counterweight.

Chapter 8

Receiving Satellite Digital Data

Many satellites use voice and CW for communicating between hams, but we recommend that new satellite operators listen to many satellites before actually transmitting. Remember that receive-only activity does not require a license so you can receive images and telemetry before you take an amateur exam!

In addition to listening to other amateurs talking or sending code, there are several digital receive-only operations.

One example is satellite telemetry: most amateur spacecraft have a method of sending information on the health of spacecraft systems. Receiving and decoding this data can be not only interesting to analyze for an individual ham, but of great help to the satellite's operators and creators. This data is generally called "telemetry" (measurement at a distance).

Telemetry can also be used to send the results of scientific experiments on satellites. For example, the Vanderbilt University radiation experiments carried on some of the AMSAT Fox satellites resulted in several PhD theses and scientific papers by Vanderbilt faculty and students; this would not have been possible without receive-only stations around the world.

In addition, some satellites occasionally send images, either pictures taken by the satellite itself or stored images of such things as QSL cards, astronauts and other people, rocket launches, or perhaps commemorative images for some special occasion. You can sometimes get an award or a QSL card for showing that you have received pictures from the International Space Station!

Of course, communication between amateurs can also be done digitally; we cover that in Chapter 9, *Operating the Digital Satellites*.

Today, while there are a wide range of modes in use for both telemetry and pictures, most of those encountered by the typical operator can be received by interface equipment and software they likely already have or can obtain free or at low cost. In this chapter, we'll discuss a few simple ways to receive images and decode telemetry.

Digital Images from Space

SSTV

To receive a digital image from space on the amateur bands, you normally just need an amateur receiver or HT (most commonly, the 2 M band is used), an antenna, and decoding software.

There are a set of standards for sending low-resolution images which are normally decoded using software on a smartphone or PC. These standards, known as Slow Scan Television (SSTV), transmit images consisting of several hundred pixels in each dimension, depending on the specific format variant. In contrast, current commercial television images can contain up to 4000 pixels in one dimension.

SSTV is sent using a series of tones and thus can be received using standard FM or SSB on nearly any radio capable of voice reception on the amateur bands. Some high-end receivers have a mode they call Digital-FM and Digital-Data which support a wider audio bandwidth, but that is generally not necessary for SSTV.

An easy connection between your radio's audio output and your computer's audio input will allow you to decode SSTV pictures. The easiest connection is holding your smartphone or a digital recorder next to your radio's speaker!

SSTV Step 1: Install SSTV Decoder Software

There are many software programs that can decode SSTV. Here is a list of some of the better programs you can try:

- iPhone: SSTV Slow Scan TV
  https://apps.apple.com/us/app/sstv-slow-scan-tv/id387910013
- Android: Robot36
  https://play.google.com/store/apps/details?id=xdsopl.robot36&hl=en_US
- Linux: QSSTV
  https://www.cqsstv.com/
- Mac: Multiscan 3B SSTV
  https://qsl.net/v/ve3elb/KD6CJI-MultiScan3B/
- Windows: RX-SSTV
  https://www.qsl.net/on6mu/rxsstv.htm
  or MMSSTV
  https://hamsoft.ca/pages/mmsstv.php
  or YONIQ
  https://hamsoft.ca/pages/mmsstv-yoniq.php

Test your software decoder using an audio recording of an SSTV image. Here's a test recording (in PD120 format) that you should be able to decode:
https://soundcloud.com/spacecomms/pd120-sstv-test-recording

Notice that we said SSTV is a "set" of standards. There are in fact multiple similar formats with names like Robot, Martin, Scottie, and PD120 which is used by the ISS. The programs listed above can identify and decode any of the common formats.

SSTV Step 2: Pick a satellite sending SSTV

Some amateur radio satellites include a camera and send SSTV pictures of Earth, either automatically or on command. However, the strongest and most reliable signal is the SSTV that ARISS sends from the International Space Station a few times a year.

If you're lucky and the ISS is sending pictures (typically for a few days several times per year), try receiving these pictures; the ISS has a strong transmitter that is easy to receive.

The status of the ISS radios can be found here. Look for the Service Module radio: https://www.ariss.org/current-status-of-iss-stations.html

Plans for special event transmission of SSTV from the ISS is usually announced here: ariss-sstv.blogspot.com . Also watch the AMSAT bulletin board and AMSAT Facebook group for additional satellites sending SSTV.

In Chapter 1, *Introduction to Satellites*, we discussed how to determine if a satellite currently operation by checking reports from hams around the world using the AMSAT Live OSCAR Satellite Status Page: https://www.amsat.org/status/

SSTV Step 3: When and where will find your satellite?

In Chapter 3, *Locating Amateur Satellites*, several smartphone applications and internet websites were discussed. Use one of them to determine when your chosen satellite will appear above the horizon at your location (QTH). Consider using a second app or website to check your results from the first one. It is frustrating trying to work a satellite that isn't where you think it should be.

SSTV Step 4: Choose your antenna

If you're using a portable antenna like an Elk log periodic or an Arrow Yagi, assemble the antenna. The elements of the antenna are about the same length, but not identical. The shortest elements go closest to the satellite. The longest elements are closest to you. Check the assembly instructions carefully.

Make sure you have your radio batteries charged, and your smartphone, tablet, or laptop batteries too. Consider finding a support for a handheld antenna to save your wrists (a forked stick works!)

SSTV Step 5a: Prepare your Satellite-Mode Radio

If your satellite sends images using FM, and if you are using a Dual-Band Half-Duplex Handheld Transceiver (HT) that has a Satellite mode with automatic Doppler shift, you still need to configure it for satellite operation. Examples of this type of radio are the AnyTone AT-D878UVII Plus and the TYT MD-UV380 (with OpenGD77 firmware). If you aren't using this type of radio, skip to Step 5b.

- Make sure your radio's location (automatic if GPS enabled) and accurate time (including UTC offset if needed) has been configured in the radio.
- Load the current Keps into the radio. If you're working the ISS, you should update your Keps frequently. Other satellites need Keps that have been updated in the past week or two.
- Put the radio in satellite mode and choose the satellite you want to operate.
- Make sure the radio's projection for the satellite pass agrees closely with the satellite projection on your smartphone or with the website projection. If not, update the Keps, correct your location, and set the clock. You won't hear the satellite if these don't agree.

Skip Step 5b and go to Step 6.

SSTV Step 5b: Tune your standard radio

For a satellite sending an image on 2 M using FM, just tune your radio to the nominal frequency of the transmitter. With luck, the Automatic Frequency Control (AFC) of the radio will compensate for the ± 3 kHz Doppler you'll see on the ground.

If you have a UHF satellite, compensating for the Doppler with 5 memory channels may work, like you would do for a V/u FM satellite, but each time you change channels you'll introduce a break in the picture received.

If you are looking at a satellite sending SSTV over sideband, you will require a computer to keep tuning the radio to the correct frequency.

SSTV Step 6: Listen for your satellite

Use an audio recorder or an audio recording program/app on a computer, mobile phone, or tablet during the pass. The recording will give you the opportunity to decode the image multiple times, as you may need to adjust the decode software parameters.

If you're experienced and confident, you can try decoding as the satellite passes overhead. Otherwise, you should record that signal and decode it after the pass.

While you wait for your satellite pass to begin, practice aiming your antenna. Start at the point on the horizon where AOS will occur. Slowly trace an arc across the sky with the antenna, rising through the TCA point, then arcing downward to LOS. You want the aiming of the antenna to become second nature so that you can concentrate on recording the pass.

A minute or two before the predicted AOS time, open the squelch on your radio. When you first hear the satellite, the signal won't be strong enough to open the squelch and fades during the middle of a pass are common.

Wave the antenna back and forth a little while you search for the signal and twist your wrist ±90° until you find the satellite. Once you find the satellite, you can quickly adjust where you point the antenna and its twist for the strongest signal. Continue to follow your tracking data with the antenna but move the antenna in 1- to 2-foot circles to optimize the signal. It is difficult to accurately eyeball both azimuth and elevation, but once you've found the satellite, you keep tracking by ear, not by azimuth and elevation.

SSTV Step 7: Decode your recording

Feed your recording to your decoding software. The audio quality will be better if you make a direct connection from the recorder to the device with the decoding software if possible, or take an mp3 file from the recorder and use that as input.

An example of an SSTV pictures sent from the International Space Station is shown below.

Weather Satellites

The most common and easiest-to-receive pictures are SSTV pictures from the ISS, but those are only sent a few times per year. Weather satellites, while not amateur satellites, transmit higher resolution pictures regularly. You may be able to decode using similar techniques and different software.

If your radio will tune down to 137 MHz, you should be able to receive and decode the NOAA weather satellites like these:

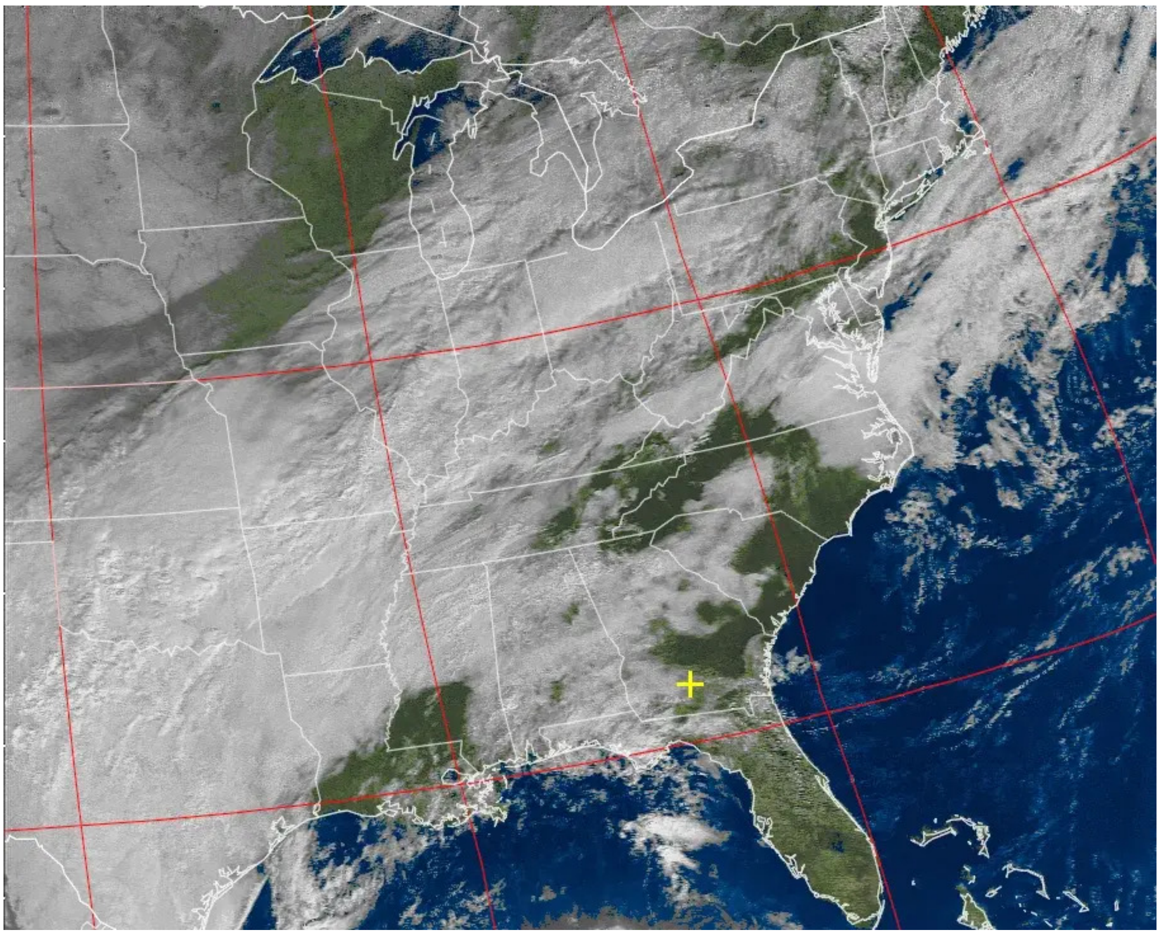
- NOAA 15 – 137.62 MHz ± Doppler
- NOAA 18 – 137.9125 MHz ± Doppler
- NOAA 19 – 137.1 MHz ± Doppler

Software to decode weather satellites can be found here:

- Open-Weather APT: Web-browser-based decode software that takes an audio recording:
  https://open-weather.community/decode/

- SatDump: Windows, Linux, and macOS software that expects an SDR receiver and can decode 90 different satellites. This software is both versatile and very complicated.
  https://docs.satdump.org

The raw weather image is in black & white, but the software packages mentioned above allow you to colorize the image and add a mapping overlay. After processing, here's an image from NOAA-18:



Digital Telemetry

Many amateur satellites send telemetry giving information on the spacecraft health such as temperature, battery status, spin rates, etc. This information can be analyzed by the individual amateur but is also commonly forwarded to the spacecraft operators via the internet.

Telemetry can be sent by the satellite using many different techniques. Initially it was sent on a transmitted signal in CW, RTTY, or in some cases a combination. OSCAR 1 (1964) sent a series of "HI HI HI HI" messages in CW, and the CW speed could be converted to the spacecraft temperature. However now it is most common to send data via tones or carrier phase-shifts representing digital ones and zeros.

Spacecraft based on the AMSAT-UK FUNcube series, as well as the future AMSAT Golf series of spacecraft are good examples. Both have amateur communications packages, but also science experiments of interest to students ranging from elementary school though college and beyond.

By copying and automatically forwarding the information to the central data repositories, you aid the command stations in managing the spacecraft for optimum use and lifetime, and provide information to both the sponsors of the science experiments and students worldwide interested in the core curricula of Science, Technology, Engineering, and Mathematics (STEM). Receive stations widely scattered around the world allow the operators and sponsors to get data from a larger part of the satellite's orbit, which can be crucial to understanding the satellite or the experiment behavior.

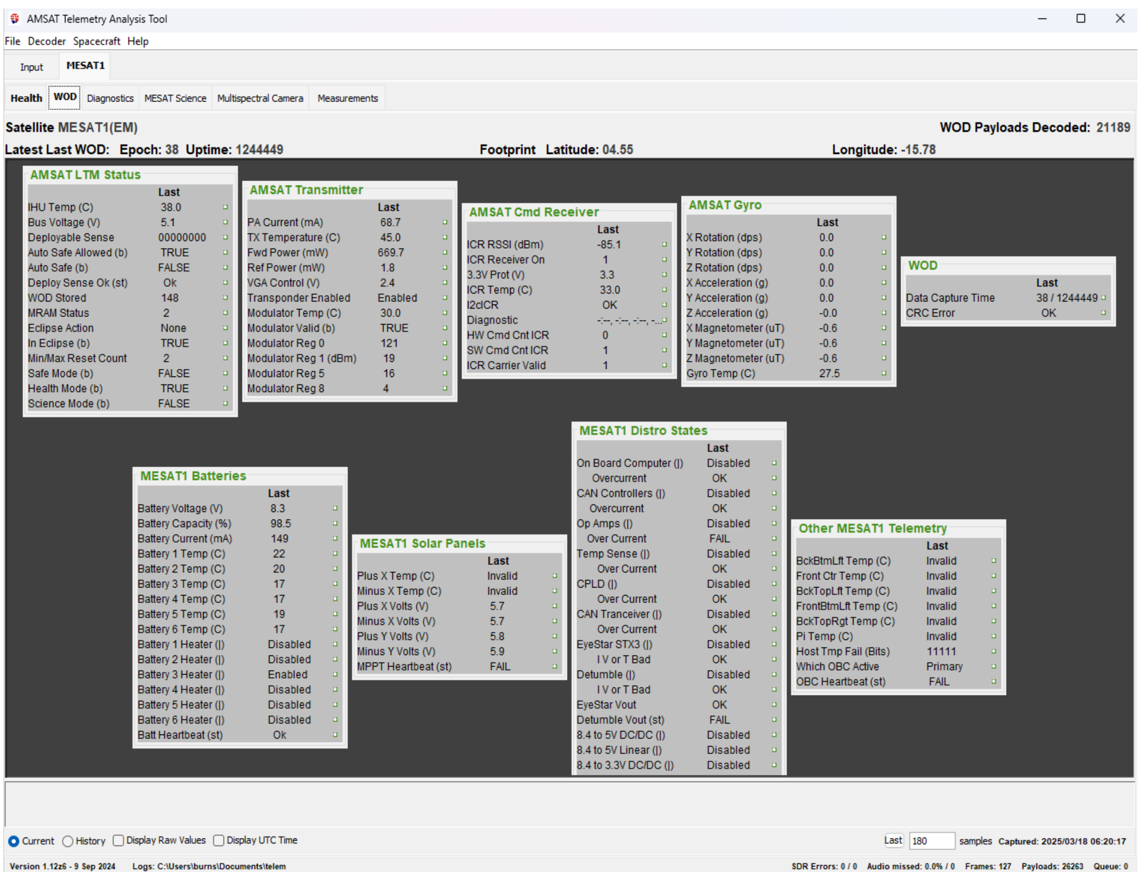
There is little standardization in the amateur satellite world for exactly what telemetry data is transmitted in what order and what modulation format. Thus, if you want to receive telemetry from a particular satellite, you will have to find out what software is required to decode the telemetry. Examples of the software that you might use are "FoxTelem" for satellites using AMSAT radios and a variant of the FunCube Dashboard for AMSAT-UK FunCube-based satellites

Let's take a look at the telemetry programs mentioned above. These are largely examples, although they are often modified to work with new satellites and thus are likely to be in use for some time.

Here is one example: a screen capture from the FUNcube Dashboard showing the system status of EO-88 (NAYIF-1) during eclipse. EO-88 has re-entered, but AO-73 was still available as of this writing.

Interested users can watch how the systems behave over time and use either their own or the plotting capability of the Dashboard software to analyze the trends. Several academic papers and presentations have already resulted from the work of Citizen Scientists. The FunCube-1 Dashboard is available, along with many other documents about the satellite at https://funcube.org.uk/working-documents/ .

Below is a screenshot of AMSAT's FoxTelem displaying data from the University of Maine's MESAT1, which uses an AMSAT radio set called LTM. This program was also used for the Fox satellites and HuskySat-1 and will be used in the future for the Golf series and possibly other university satellites. Like Dashboard, FoxTelem has many graphing and other analysis capabilities. As FoxTelem supports new satellites, new versions are released.



Only fairly simple hardware is required to decode telemetry: A computer, a sound card, and a connection between the sound card and your radio are what you will need. We will discuss that in Chapter 9, but it is even easier to use programs that can decode the RF themselves using software defined radio hardware. This is the method that we describe below as a step-by-step list of setting up FoxTelem with an SDR dongle.

FoxTelem Step 1: Install the software

The latest released version, along with installation and running documentation is available at https://www.amsat.org/foxtelem-software-for-windows-mac-linux/ . FoxTelem will run on a Windows PC or Linux (either a desktop/laptop or a Raspberry Pi). It should also work on a Mac, although many fewer people use the Mac. FoxTelem can work on multiple operating systems because it is written in the Java language. However, this means you need the Java JRE (Java Runtime Environment). The JRE is often already installed on Windows, but it is available here for any OS: https://www.java.com/en/download/manual.jsp.

You can look at https://burnsfisher.com/AMSAT/FoxInABox/ for more info about using FoxTelem on a Raspberry Pi, but from here on in this book, we will talk about the Windows version.

FoxTelem Step 2: Install the Software Defined Radio (SDR) hardware.

FoxTelem supports two kinds of SDR hardware: The FunCube Dongle (FCD) and the RTL-SDR. The FCD is more sensitive and selective, and has better noise characteristics, but is also much more expensive. It can be ordered here: https://www.funcubedongle.com. The RTL-SDR has many imitators. We recommend the "real" one. There are also two versions. As of this writing, FoxTelem only supports Version 3. See https://www.rtl-sdr.com/buy-rtl-sdr-dvb-t-dongles/ where you can buy the RTL-SDR; it also has an Amazon link.

We recommend using a small USB "extension cord" with a USB-A male connector on one end and a USB-A female on the other. It does not have to be long; just enough to take the strain off the USB plug on the computer.

FoxTelem Step 3: Attach an antenna

Similar to the SSTV section above, you can use an Elk or Arrow antenna, but you do not need the radio because FoxTelem will not only receive the RF, but it will also compensate for Doppler shifting. Like many HTs, the FCD and RTL-SDR both use a common SMA connector.

FoxTelem Step 4: Test the FoxTelem Setup

The Windows version of FoxTelem comes with a Windows application that you can run to get FoxTelem started. Starting works differently on other operating systems. Start FoxTelem by running FoxTelem.exe; if there is a problem you may not have the JRE installed. Select the "Input" tab, then select the SDR device that you are using. Click the start button and you should see a red line in the bottom panel, and black, red, and green lines in the middle panel. The bottom "graph" shows the signal strength vs the frequency, and the top shows various forms of the demodulated output. If you have an HT or other radio and can legally transmit, set the radio to the lowest possible RF power and to a frequency within the bottom graph of FoxTelem (for example a bit above or below the value in the text box that says “Center Frequency”. Briefly send a carrier (don’t forget to ID). You should see a strong signal on the bottom graph.

FoxTelem Step 5: Choose a Satellite and Set FoxTelem to Receive It

Looking at the AMSAT server here https://www.amsat.org/tlm/leaderboard.php?id=0&db=FOXDB is the best way to find out which satellites that use FoxTelem are currently operating. This page is the “leaderboard” showing the top 10 telemetry receivers. However, on the right side of this page is also a list of satellites and how much telemetry has been received from each of them in the last 24 hours.

Ideally, choose a satellite that has had a number of “frames” received recently and which will be passing over your location at a time when you can watch the screen (check the timing on https://www.amsat.org/track/index.php). If there is not a tab on FoxTelem showing the satellite you chose, look in the menu “Spacecraft” and select “Add” and choose the satellite you want. For example, for MESAT1, the name you will see is MESAT1.MASTER. If the spacecraft name you want is not there, you may need a newer version of FoxTelem.

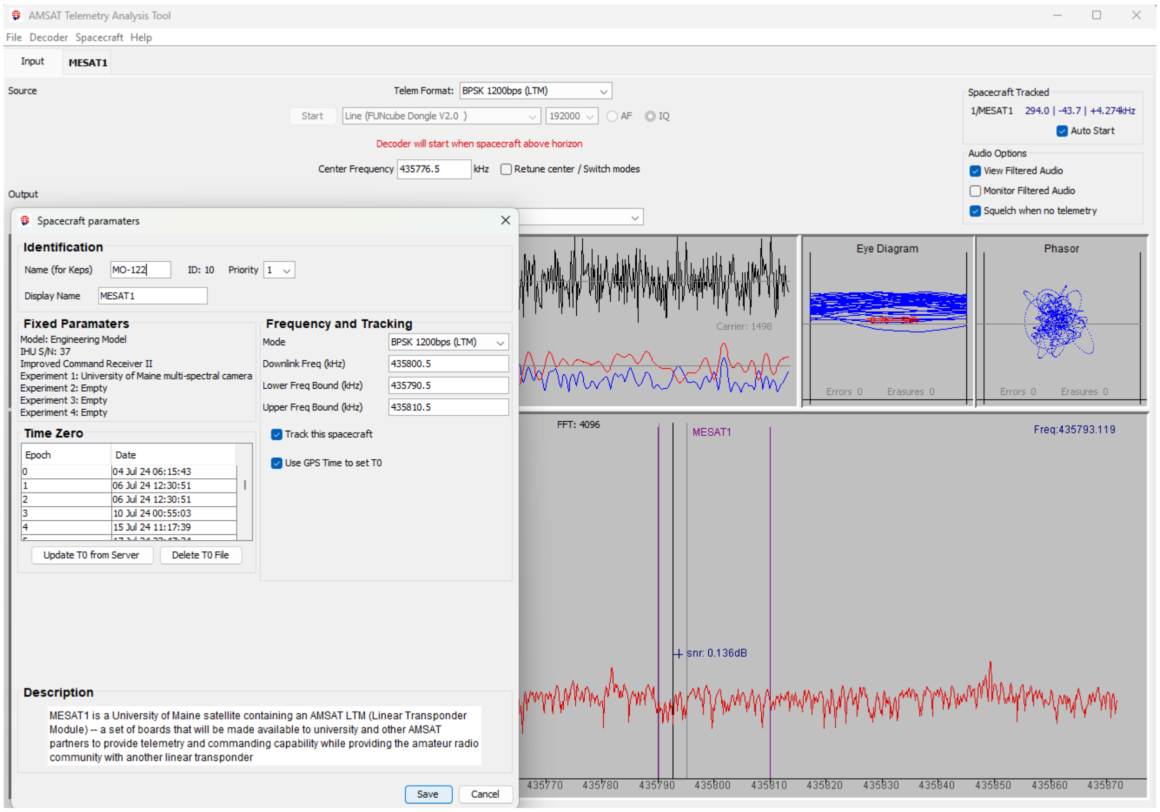
You should be aware that many amateur satellite names change a few weeks after they are launched. Essentially all satellites have a name that is used while they are being built and first launched. After they have been shown to be transmitting amateur radio signals, the owners often request an “OSCAR number” and a first letter. For example, the University of Maine developed MESAT1 and when it was operational, they requested the letter M for Maine, and were given the number 122, so it can be referred to as MO-122.

This is important because FoxTelem tracks the orbit of satellites, and the set of numbers it uses to track the satellite (called TLEs or Keps) are named with the Oscar number. Thus, FoxTelem must have the name as listed in the TLE list. For older satellites, this will be setup already in FoxTelem, but it is worth checking. Under the Satellites menu, select the name of the satellite which causes a Spacecraft Parameters dialog box to appear. Look under “Identification”. If it has an Oscar number, that name should appear in the text box labelled “Name (for Keps)”. For the Display Name you can put whatever you want, but it is often the original name.

When you have the satellite that you want set up, the display name should appear on the right of the main “Input Window” with “Not Tracked” to the right of the name. If you click on “Not Tracked” it should change to show the current attitude, azimuth, and Doppler correction (even if it is below the horizon). If it shows something else, try closing FoxTelem and restarting it. If it still does not seem to work, look at the website https://www.amsat.org/tle/dailytle.txt and compare the name in that dialog box above with the names in the Keps list. You may have typed it wrong (caps and dashes count!)

On the FoxTelem screenshot below, you can see the Spacecraft Parameters dialog box as well as part of the signal strength and demodulation graphs and the section to the right showing the azimuth, elevation, and Doppler correction. Of course, MESAT1/MO-122 is just an example that was current at the time of this writing.

Next choose “Retune Center/Switch Modes” in the center near the frequency, and select “Auto Start” under the spacecraft name on the right. FoxTelem will now stop when there is no satellite in view. Be doubly sure that “Retune Center/Switch Modes” is selected to ensure that FoxTelem switches to the correct frequency and mode when a satellite is visible.



FoxTelem Step 6: Wait, Check, and Adjust

You should try to watch the first few passes of the satellite you chose. As the time arrives for the satellite to be visible, FoxTelem should start and the frequency of the satellite should be visible in the frequency graph. As the satellite rises higher, you should see a signal appear in the frequency graph (it will not be as strong as your HT test above). The eye diagram should display what appears to be an open eye, and the phasor will show a more-or-less straight line. Eventually, you should see “Frames” at the bottom counting upward. Not all frames are the same, but after a while you will see more and more data on the tab specifying your satellite. If you have set up to send your data to the central server (see the installation instructions), you will usually see “Queue” go up and down as frames are received and sent.

If this works, fine. Otherwise, adjusting the gain of the SDR radio may help. The SDR gain looks different depending on whether you have an FCD or an RTL-SDR. When FoxTelem is running with the FCD, you will see checkboxes that say Mixer Gain and LNA gain. Try different combinations of these to attempt to get a signal at around 40 dBm. There are more adjustments on the RTL-SDR, but there is an “automatic” setting with different gain numbers to choose. That is the best thing to adjust.

Telemetry and SSTV Using Conventional Radio and Sound Card

Essentially any SSTV and Telemetry program will have a way to choose different inputs. For example, MMSSTV, under the option menu and "setup" selection has a box to specify the sound card. Most telemetry programs have similar choices. However, using a computer sound card and a conventional radio requires connecting the radio and the computer together. For receive-only operations, the sound card could be the output from a generic software defined radio program like SDR# or HDSDR. These connections are essentially the same for digital communication, so we will cover it in Chapter 9, *Operating the Digital Satellites*.

gr-satellites

gr-satellites (https://gr-satellites.readthedocs.io/en/latest/introduction.html) is a free, cross platform, GNU Radio module encompassing a collection of telemetry decoders that support a massive number of satellites including amateur radio satellites (https://gr-satellites.readthedocs.io/en/latest/supported_satellites.html). This open-source project started in 2015 with the goal of providing telemetry decoders for all the satellites that transmit on the Amateur Radio bands and is constantly updated.

gr-satellites supports most popular protocols, such as AX.25, the GOMspace NanoCom U482C and AX100 modems, an important part of the CCSDS stack, the AO-40 protocol used in the FUNcube satellites, and several ad-hoc protocols used in other satellites.

Because gr-satellites is a GNU Radio module (https://www.gnuradio.org/), it can be used as a building block to implement decoders for other satellites or other ground station solutions.

SatNOGS

A discussion of satellite telemetry would not be complete without mentioning SatNOGS, an open-source global network of ground stations. SatNOGS allows anyone to build a simple SDR-based ground station to include in their network, and to request telemetry from any satellite via any of its ground stations.

SatNOGS is not only for amateur satellites; for example, they also can receive NOAA weather satellites. SatNOGS has decoders for some but not all satellite telemetry. However, it is possible to download what a SatNOGS network station has received and decode it using a satellite-specific decoder. If you are interested in telemetry, it is worth looking a https://satnogs.org to see what they have to offer and what you can contribute.

Chapter 9
Operating the Digital Satellites

In Chapter 8, *Receiving Satellite Digital Data*, we concentrated on receiving pictures and telemetry. In this chapter, we'll look at two-way digital communications via satellite.

By far the most popular 2-way digital communication is the use of packet - particularly the Amateur Packet Reporting System (APRS) repeated through the digipeater on the International Space Station (ISS) or through dedicated packet satellites.

Other modes such as FT8/4 and PSK31 are also used, but only on satellites dedicated to their use. FM repeaters are single channel and kept busy with voice contacts. Linear satellites are intended for use by relatively efficient (RF power) modes such as SSB, CW, and very low power FT4 at the low end of the passband. Linear satellites are not made for modes which have high duty cycles such as FT8, PSK31, SSTV, or packet. The considerate operator will respect these limitations.

Digital Communication Through Satellites

The ISS holds a special fascination for anyone interested in satellites. It is also by far the easiest to communicate through since it uses basic AX.25 1200-baud packet. The ISS orbit is relatively low, 350-400 km, and has a high-power transmitter. The digipeater functions much like a terrestrial unit, though it uses **145.825** MHz.

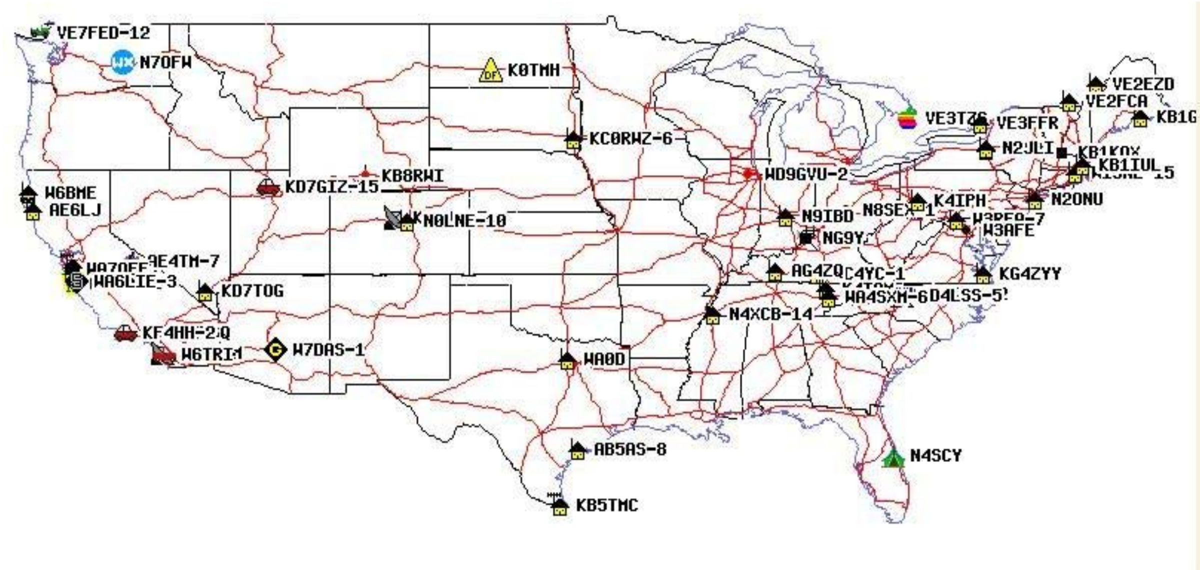
The normal Packet/APRS frequency of 144.390 MHz typical in the US is **NOT** used since other regions have different allocations.

Even if you are only interested in receiving signals, decoding the ISS Packet/APRS radio is a good way to learn your way around such topics as interfacing to your rig, antenna tracking, Doppler shift, software decoding, and satellite availability. In general, the basic equipment will be useful for most other digital techniques. If you can hear and decode the packet signals from the ISS, you are well on your way to deciphering satellite digital communications!

Packet Operation with the ISS

A most popular operating mode for the ISS is the packet digipeat mode. Here you send an APRS type UI frame with ARISS in the path while the ISS is overhead. If one of the ground based SatGates receives your digipeated packet from the ISS, it will be posted on the ARISS net. To see stations all over the world digipeating through the ISS, go to http://www.ariss.net

This an ARISS Digipeat Map Display of stations in the continental US:



AMSAT_UK has a web page with links to lots of info about working the ISS using APRS Packet Radio:
https://amsat-uk.org/beginners/how-to-work-the-iss-on-aprs-packet-radio/

Packet activity from the ISS is on **145.825 MHz.** Aside from a beacon every three minutes, the packet activity you hear originated from earth stations using the ARISS digipeater. Lacking packet gear, you will only hear the brzzzzz-brap sound of the 1200-baud audio frequency-shift keyed (AFSK) signal.

Getting on the air with the ARISS packet digipeater can likely be accomplished with amateur radio gear you already own. No special amateur radio equipment beyond that used for terrestrial packet contacts is needed to begin taking your first steps toward amateur radio in space. This means if you do not own certain items they can likely be acquired inexpensively. Think of ARISS packet radio as regular ham radio (including packet) aimed skyward.

Ground station requirements

For your packet ground station, a standard 2 m FM transceiver Yagi antenna that can be pointed in both azimuth and elevation is best. Many operators use a radio described in “Chapter 5 *Your Radio System*” with a handheld Arrow or Elk antenna described in “Chapter 4 *Your Antenna System*”.

The downlink signal from the ISS is generally easily heard but you will not have much luck trying to get your packets through the digipeater with an indoor antenna or with the flexible antenna on your HT. The good news is that your external antenna does not require full OSCAR-class tracking and control. Many enjoy success with a VHF vertical antenna on the roof of the house. Or you can use a simple beam antenna. A 3-element VHF beam at a fixed elevation of 15-20 degrees on a small TV rotor is all that is necessary.

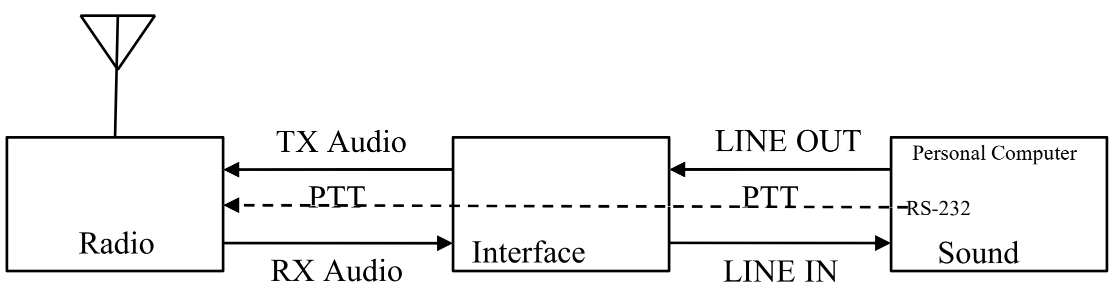
In the years since the peak of the hardware TNC based activity, sound card based TNC software has now replaced all the functions of a hardware based TNC for sending and receiving an AFSK packet signal. Indeed, testing of sound card based TNCs has shown that they decode *better* than hardware TNCs.

In addition to the sound card TNC software, you will need a way to connect the audio of your radio to the computer. If you have a newer radio like the Icom IC-9700, they will often have sound cards built-in and you will only need a single USB cable to accomplish the task and can skip to the Packet/APRS software section below.

If your radio does not have a built-in sound card, then you will need to install a sound card interface between your radio and your computer to adapt the signal levels to be compatible with the digital signal processing done by the sound card. Here are a few options to this approach:

- Tigertronics SignaLink USB https://tigertronics.com/
- RIGblasters by West Mountain Radio http://www.westmountainradio.com
- Digirig interfaces https://digirig.net/
- Build a sound card interface from plans found on the Internet.

Here is a sketch of the connections for operating the ISS Digipeater using your computer's sound card and software:



Overview Sound Card and Radio Connection

- Software will generate and decode the AX.25 packet signal using the digital signal processing capabilities of the sound card in your computer.
- A sound card interface box is needed to set the proper sound levels between the computer and the radio.
- Push-to-talk (PTT) rig control is often generated by the software by setting the selected pin(s) of the RS-232 serial interface. Some radios such as a Yaesu FT-857D will reliably switch between TX and RX function if the VOX levels are set in the radio's operating menus.
- If you already have interfaced your radio to the sound card for other amateur radio applications such as RTTY, PSK31, WSJT, SSTV, you are already set for AX.25 packet operation with the ISS or another satellite – all you need is to download, install, and configure some free software.

Since the connections between your radio and the sound card interface of your choice are specific to your situation, we will defer discussion. You'll instead need to consult your radio operator's manual and the instruction book of the sound card interface. Careful research before buying an interface box will reveal that many of the leading brands will also sell you an interface cable kit specific to your radio.

Setting Your Sound Card Levels

If you are already using your sound card for other amateur radio applications such as FT8, usually the same settings can be used for Packet/APRS. Getting the input and output levels set correctly can be tricky. We suggest you search the internet for articles about setting your interface levels correctly for FT8.

Install the Software You Need

The software for satellite packet operation is available for free download. Depending on your setup, you will typically need two pieces of software:

- Sound card TNC software - this replaces the hardware TNC
- Packet/APRS software - this sends and receives the Packet/APRS messages

Sound card software TNCs

There are three main sound card TNCs that people use:

- UZ7HO Soundmodem (soundmodem114.zip on http://uz7.ho.ua/packetradio.htm) - it can also run on Linux under Wine.
- Dire Wolf Software TNC (https://github.com/wb2osz/direwolf/releases) - great for Mac and Linux.
- AGWPE (AGWPE.zip on https://www.sv2agw.com/downloads/)

We recommend UZ7HO Soundmodem because it has an easy to use waterfall display to help you setup and verify your interface levels. It will also show partial packets to help you debug issues. Lastly, UZ7HO has other sound card TNCs on his web page for some of the new esoteric high-speed digital satellites.

Packet/APRS software

There are two main Packet/APRS satellite applications used today:

- Greencube/CUBEBEL-2/LEDSAT/ISS Terminal (https://moonbounce.dk/hamradio/greencube-terminal-program.html)
- UISS (https://www.qsl.net/on6mu/uiss.htm)

We recommend Greencube/CUBEBEL-2/LEDSAT/ISS Terminal because it covers more than just the ISS, has extensive features and documentation, and is regularly updated.

However, if you only use the ISS for satellite Packet/APRS, then UISS is a viable option. If you do use UISS, please read "Sidebar: Swapping the UZ7HO Soundmodem packet

program in place of AGWPE" on
https://www.ariss.org/uploads/1/9/6/8/19681527/k9jkm_2012_symposium_ver2.pdf

Fun things to do with Packet/APRS satellites

Once your satellite packet has been picked up by a terrestrial internet gateway, you can route it to many different services on the internet. You can get a weather report, send a text message, or even an email! David, N9KT, has sent texts and emails through satellites when he was in wilderness areas with no cellular service.

Packet/APRS routing and gateways are an extensive subject and will not be discussed in detail here. We suggest you look at:

- http://www.ui-view.net/files/APRS101.pdf to learn about APRS and routing
- https://www.aprs-is.net/Email.aspx to learn about email gateways
- https://aprs.wiki/ to learn about SMS gateways

Gateways come and go, so search the internet to see which ones are working. Please support the gateways you use to keep them working.

Using HTs and mobiles with built-in packet modems

Some HTs have packet modems built-in! For example, here is the screen showing a WD9EWK packet digipeated through the ISS 70 cm digipeater.

There are a few rigs that include suitable packet capability in an integrated unit. "Dual-Band Half-Duplex HTs" in "Chapter 5 *Your Radio System*" lists examples that can also do FM voice with the satellites.

Packet only examples are the Kenwood HTs TH-D72A and TH-D74A, and mobile units such as the Kenwood TM-D710G and Yaesu FTM-400.

Be aware that packet operations using HTs and mobiles is much less flexible than using base stations running full-fledged packet software on computers. Nonetheless, they are convenient for portable operations and a lot of fun.

Pete, AI4QY, and Mark, N8MH, operate using an Elk log periodic antenna and a Yaesu FT-817 from the north beach at Garden Key in the Dry Tortugas National Park, about 70 miles west of Key West, Florida in grid EL84. Fort Jefferson is in the background.

Chapter 10

International Space Station (ISS)

Amateur radio in human spaceflight began in 1983, when Owen Garriott, W5LFL took a hand-held ham radio and window-mounted antenna aboard Space Shuttle Columbia. He spoke with students in scheduled contacts and made random contacts with earth-bound hams. This activity was so popular that ham radios flew on more space shuttle missions than any other single payload, and NASA expressed interest in having us aboard ISS.

In 1996, the ham radio world responded by forming an international working group called Amateur Radio on the International Space Station. ARISS coordinates all amateur radio activity on the ISS. It is managed by hams from five regions of the world, corresponding to the five space agencies that support the ISS. The United States delegates are appointed by ARRL and AMSAT.

ARISS continues Owen's efforts by promoting science, technology, engineering, and mathematics (STEM) education through 80-100 educational contacts (students talking to ISS crew) each year. In addition, ARISS radios give hams multiple ways to communicate among themselves and occasionally with the ISS crew. ARISS also provides backup communications for ISS.

You can learn more about ARISS at https://www.ariss.org/.

ISS Technical Specifications

Names:	**Space Station, ARISS**
Object#:	25544
Launch:	Sep 2000 (first amateur equipment)
Period:	92 minutes
Orbit:	Circular
Inclination:	51.6 degrees
Altitude:	Approx. 400 km (248 miles)
Modes:	Voice, packet, SSTV, DATV

Frequencies

Voice and SSTV	145.800 MHz FM downlink only
VHF Packet	145.825 MHz FM simplex
UHF Packet	437.550 MHz FM simplex
Cross-band repeater	145.990 MHz FM (CTCSS 67Hz) uplink 437.800 MHz FM downlink
HamTV (DATV)	2.395 GHz, 2.422 GHz, 2.437 GHz, 2.369 GHz downlink

See the *ISS Operating Modes* section, below, to learn which frequencies are used and when. In addition, ARISS posts equipment status and expected operating schedules at https://www.ariss.org/current-status-of-iss-stations. For reports on recent activity seen by other hams, go to https://www.amsat.org/status.

ISS Amateur Radio Stations

There are two active amateur radio stations aboard ISS. One is in the Columbus Module, at the forward end of the station as it moves in orbit. The other is in the Russian Service Module (Zvezda), at the aft end.

Columbus Module Station

The Columbus Module, in the United States operating segment (USOS), houses an Interoperable Radio System and has three ham antennas – two L/S-band patch antennas and one VHF/UHF whip antenna. Columbus will also be home to the DATV Ham Video transmitter when it returns to service.

The Columbus ham radio station operates as a voice repeater most of the time, with scheduled interruptions for educational and other contacts performed by USOS crew members.

InterOperable Radio System (IORS)

This ham equipment aboard the ISS consists of a customized Kenwood TM-D710GA radio and an ARISS-designed and built multi-voltage power supply. The power supply can operate from either of the two power systems aboard ISS (120 VDC and 28 VDC). ARISS thanks JVC Kenwood for donating the radios and their substantial work to customize the radio hardware and firmware for our needs.

The IORS radio, used in both amateur stations on the ISS, has higher power than the earlier Ericsson HT, easier operation for the crew, and improved fault recovery.

ARISS uses the program mode capability of the TM-D710GA to hold configurations for different operating modes. The PMs are used as follows:

PM	Primary Use	Output Power
PM 1	Voice contacts, SSTV	25 watts
PM 2	Voice repeater	5 watts
PM 3	Data (packet digipeater)	10 watts
PM 4	Experimental	10 watts
PM 5	ISS backup communications	25 watts

Service Module Station

The Service Module, known as Zvezda in Russia, houses a second IORS radio and has four multi-band ham antennas mounted outside. The four antennas were developed by an international ARISS team and installed by the ISS crew. These antennas encircle the aft end of the Service Module. Three of the antennas permit operation on 2 m, 70 cm, and the L and S microwave bands. The fourth replaces the VHF/UHF section with an experimental HF (10 m) whip.

The Service Module ham radio station normally operates as a digipeater, with occasional interruptions for SSTV events or educational and other contacts by cosmonauts.

Call Signs Used Aboard the ISS

Russian callsign: RS0ISS

USA callsign: NA1SS

European callsigns: OR4ISS, IR0ISS, GB1SS, DP0ISS, FX0ISS

NA1SS and RS0ISS are the callsigns of the ISS amateur radio stations when operating in automatic mode (such as repeater and digipeater operation). On educational and unscheduled voice contacts, you might hear any of these call signs, or even a crew member's personal call. Different call signs are needed to meet third-party traffic rules.

All USOS astronauts who use the amateur radios are licensed and volunteer their personal time to participate in ARISS events. Cosmonauts have similar authorization.

NASA has information about the current ISS Expedition crews at https://www.nasa.gov/international-space-station/expedition-missions/.

Availability and Schedules

ARISS radios generally operate around the clock. However, crew safety rules require that the amateur radios be shut off during EVAs, dockings, and undockings. The radios might be off up to a day before and after such events. In addition, voice repeater or digipeater operation will occasionally be interrupted for an educational contact or special event such as SSTV. ARISS posts scheduled down times and mode changes on its website at https://www.ariss.org/current-status-of-iss-stations. You should also remember that ISS schedules can change unexpectedly due to launch slips and unplanned events.

ISS Operating Modes

The amateur radio stations on ISS provide opportunities for hams to listen to an astronaut talk with students on Earth, to talk with other hams via the voice repeater, and to talk directly with an astronaut making unscheduled contacts.

Cross-band Voice Repeater

The voice repeater is the default mode of the Columbus Module ham radio (NA1SS). When it is active, you can talk to other hams on the ground via the ISS. For your radio station, anything that will work with an FM V/u satellite will work. The uplink requirements are about the same as a satellite, but the downlink will be easier to receive due to the higher output power of the ISS.

Astronaut Voice Operations

Many astronauts get an amateur radio license and volunteer part of their free time to talk with students. Some also get on the repeater to chat with the ham community.

Educational Contacts

An astronaut talks with students somewhere in the world about once or twice a week. You can hear the astronaut's answers to student questions on the voice downlink frequency (145.800 MHz) from anywhere within several hundred miles of the contact site. The questions to be asked are posted on the ARISS website and social media, as are the location and time of each scheduled contact.

Using the ISS repeater is fun, but the main reason NASA allows ham radio on ISS is the work hams do to interest students in space, radio technology, and STEM (Science, Technology, Engineering, and Math).

In addition to listening, you could participate in an educational contact if a local school or other educational group is hosting one. Local volunteers help erect antennas, operate the radios, and often teach the students about ham radio.

Crew Contacts

Astronauts in the USOS can talk on the voice repeater just by picking up the mike and turning up the volume. However, just as most people on Earth aren't hams, only a few astronauts are avid operators who make such unscheduled contacts. Word spreads quickly when one of them is aboard. Be patient and keep listening. The crew's usual workday is

0800-1930 UTC. Although they could be on the radio at any time, it's a bit more likely to hear them in the hour before and after work, when they have more personal time.

Packet/APRS Digipeater

The digipeater is the default mode of the Service Module ham radio (RS0ISS). It works with any AX.25-formatted packet. The most popular use is making QSOs with APRS messages, but anything you might do with terrestrial APRS, or packet is possible.

For the ISS digipeater, use 1200 bps and the path ARISS, APRSAT, or RS0ISS. The digipeater is normally on VHF. Any use of UHF will be announced beforehand.

For details on using packet or APRS through spacecraft, see Chapter 9, *Operating the Digital Satellites*.

Telemetry - Decoding ISS Beacon Packets

Both IORS radios transmit digital beacon messages in repeater mode (about every 5 minutes, 9600 bps) and digipeater mode (every 3 minutes, 1200 bps). In addition to the usual information contained in a Kenwood beacon packet, you can also find the internal temperature of the radio and an indication of the current Program Mode.

Temperature

The radio's internal temperature in degrees Celsius is indicated by the fractional minutes of the latitude. (A GPS signal is not available inside ISS, so the rest of the position information in the beacon is meaningless.) Because the TM-D710GA uses Mic-E format for beacons, the latitude is encoded in the destination address of the AX.25 packet. For example, consider this example packet:

```
NA1SS>0P0PS4,APRSAT:`v&<0x1c>l <0x1c>SI]ARISS-ISS PM2=<0x0d>
```

The destination address is 0P0PS4, which represents the latitude combined with some other information. In ISS beacons, the destination address always begins with 0P0P and the final two characters represent the radio temperature, encoded as in the following table. Thus, S4 represents 34°C.

Character	P, 0	Q, 1	R, 2	S, 3	T, 4	U, 5	V, 6	W, 7	X, 8	Y, 9
Represents	0	1	2	3	4	5	6	7	8	9

When viewed on radios that decode the latitude into degrees and fractional minutes, you can read the temperature directly, as follows:

```
N  00° 00.34′
```

On radios that display seconds rather than fractional minutes, you must divide the seconds by 0.6 to obtain the temperature. For example, if you see

```
N  00° 00′ 20.4″
```

the temperature is 20.4 ÷ 0.6 = 34°C.

Program Mode

The status message corresponds to the current Program Mode of the radio, as follows.

Status Message	Used in
ARISS-ISS	PM OFF
ARISS-ISS	PM 1 (voice)
ARISS-ISS PM2	PM 2 (repeater)
ARISS-International Space Station	PM 3 (digipeater)
ARISS-ISS PM4	PM 4 (experimental)
ARISS-ISS PM5	PM 5 (backup communications)

Slow-Scan Television (SSTV)

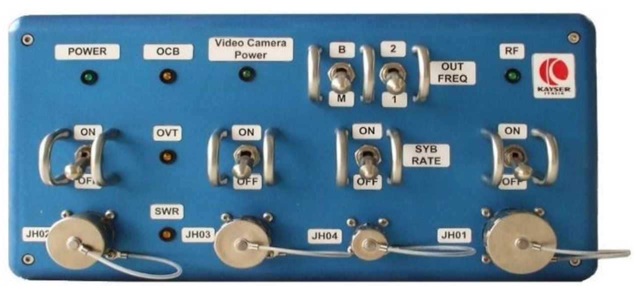
Slow-scan television images are transmitted several times a year as special events. SSTV operations use a computer to send images over the Service Module radio on the voice downlink frequency. The format to be used (usually PD120) is announced prior to the event, along with operating hours and other details. Most events run for 2-3 days, although some are longer. You can submit images you receive and view those submitted by other hams in the ARISS SSTV Gallery (https://ariss-usa.org/ARISS_SSTV).

In addition to ARISS events, the Moscow Aviation Institute (MAI) has occasionally transmitted similar image sets as part of their MAI-75 experiment. These events run for a few days, but usually only during orbits that pass over Moscow on that day.

SSTV transmissions, both ARISS and MAI, are announced on the ARISS website and social media.

Digital Amateur Television (DATV)

As of this writing, the Ham Video DATV transmitter is aboard ISS and awaiting installation in the Columbus Module. This is the same transmitter that operated from 2014 to 2018 before experiencing a problem and being returned to Earth for repair.



The Ham Video transmitter operates with a video camera provided by NASA and one of the L/S-band antennas on the Columbus Module. The operating mode, known as HamTV, is downlink only. When HamTV resumes operation, it is expected to transmit a test signal interrupted occasionally by video during an educational contact. When HamTV is transmitting, the British Amateur Television Club will operate a merger system that combines video streams from several ground stations along the ISS path into a single, higher quality video stream for educational use.

You can find detailed information about the Ham Video transmitter, how to receive DATV signals from ISS, and how to contribute to the merger system at https://wiki.batc.org.uk/HAMTV_from_the_ISS.

ISS Operating Hints

Although ISS is technically a satellite, it differs in some ways from other amateur satellites. You need to keep these differences in mind when using the ISS radios.

Tracking

Unlike other satellites, ISS compensates for altitude changes due to drag by boosting its altitude 1-2 times a month (and as needed to avoid orbital debris), thus changing its orbital elements. For accurate tracking, always use the latest set of Keplerian elements. Daily Keps are available on the AMSAT website at https://www.amsat.org/tle/dailytle.txt (these are updated in the first hour of each UTC day). Daily/hourly updates are available through most tracking programs and via download from sources such as https://celestrak.org.

ISS Voice Repeater Hints

- Keep your transmitter power under 100 watts EIRP (including the antenna gain, see Appendix B under *Transmitter Power and Antenna Gain* for EIRP explanation).
- As always in ham radio, **listen before transmitting**.
- Keep your calls short and send your call sign and grid location. Do not call CQ.
- If the voice repeater goes quiet, stop transmitting and give the time-out timer a chance to reset.
- When possible, pick times that are less busy, such as late night/early morning or (if you are near a coast) when ISS is offshore and fewer hams are in range.
- Be patient. There are many hams just as eager as you to contact the ISS.

QSL information for contact with an astronaut is on the ARISS website.

Resources

Here are some sources of information about amateur radio on the ISS and ISS activities:

- https://www.ariss.org (ARISS information)
- https://www.ariss.org/current-status-of-iss-stations
- https://www.ariss-usa.org (information on hosting a US educational contact)
- http://www.ariss.net (amateur radio stations heard via ISS digipeater)
- https://ariss-usa.org/ARISS_SSTV (SSTV image gallery)
- https://www.nasa.gov/international-space-station/ (crew activities and more)
- https://www.amsat.org/status

ARISS Social Media

Information on ARISS can be found on several social media sites, including X, Facebook, YouTube, Instagram, Mastodon, BlueSky, Threads, LinkedIn, and Reddit.

Follow @ARISS_Intl (or similar names) for current info on equipment status, upcoming events, and related "hams in space" news.

Steve, N9IP points his Arrow Antenna over Lake Irwin, Colorado. Note the use of red and blue tape on the boom and the coax to indicate VHF and UHF connections. He is wearing a Heil Pro Micro Dual iC headset and is using a Heil PTT Handswitch in his left hand. The radio was an Icom IC-821H, now replaced with an IC-9700.

Appendix A
Reference Material

Amateur Satellite Modes

The current convention for describing the bands used by a satellite is to specify the uplink band followed by the downlink band, separated by a slash. For example, if you transmit to a satellite on VHF (2 m) and receive on UHF (70 cm), this bird is a mode V/u satellite. Here is a list of the frequency band designator letters.

Frequency	Wavelength	Designator
21 MHz	15 m	**H**
29 MHz	10 m	**T or A**
145 MHz	2 m	**V**
435 MHz	70 cm	**U**
1.2 GHz	23 cm	**L**
2.4 GHz	13 cm	**S**
5.7 GHz	6 cm	**C**
10.5 GHz	3 cm	**X**
24.0 GHz	1.5 cm	**K**

The original scheme for specifying the bands used by a satellite were named with a single letter. For example, AO-7 had both Mode A (now called mode V/a) and Mode B (now called mode U/v). Mode J (now called mode V/u) was first used by a Japanese satellite. As some amateur satellites became more sophisticated (e.g., AO-40), supporting a dozen or more band pairs, the single-letter mode designations became unwieldy and impossible to memorize.

Old Mode Name	New Mode Name	Uplink	Downlink
Mode A	Mode V/a	145.8 – 146.0 MHz	29.3 – 29.5 MHz
Mode B	Mode U/v	435 – 438 MHz	145.8 – 146.0 MHz
Mode J	Mode V/u	145.8 – 146.0 MHz	435 – 438 MHz
Mode K	Mode H/a	21.26 – 21.30 MHz	29.40 – 29.50 MHz
Mode L	Mode L/u	1260 –1270 MHz	435 – 438 MHz
Mode S	Mode U/s	435 – 438 MHz	2400 – 2450 MHz
Mode T	Mode H/v	21.26 – 21.30 MHz	145.8 – 146.0 MHz

Standard Phonetics

With weak signals, QRM and fading, it can be very hard to understand call signs and grid squares. The used of standard phonetics speeds up exchanges and allows more contacts on a given pass. Since there are several "standard" phonetic alphabets, here is the standard most likely to be understood by English-speakers in North America.

A	**Alpha**	N	**November**
B	**Bravo**	O	**Oscar**
C	**Charlie**	P	**Papa**
D	**Delta**	Q	**Quebec**
E	**Echo**	R	**Romeo**
F	**Foxtrot**	S	**Sierra**
G	**Golf**	T	**Tango**
H	**Hotel**	U	**Uniform**
I	**India**	V	**Victor**
J	**Juliet**	W	**Whiskey**
K	**Kilo**	X	**X-Ray**
L	**Lima**	Y	**Yankee**
M	**Mike**	Z	**Zulu**

When giving numbers, say each digit separately. For example, say 60 as six-zero, not sixty.

The One True Rule for Doppler Tuning

In January 1994 Paul Williamson, KB5MU wrote a seminal paper discussing the merits and deficiencies of the basic rule then and now in effect for manual tuning to compensate for changing Doppler shift: **Tune the higher of the two frequencies**. Paul showed that while this was the best manual approach, the optimum strategy would be to tune both your transmit and receive signal so that they were at a **constant frequency at the satellite**. At the time neither the software nor hardware to implement this was readily available. Over the past two decades, both have become common, though not as widely used as is desirable. One of the most powerful motivators to adopt the One True Rule is the many contacts made at the extremes of the satellite footprint with mutual availability windows of less than a minute. With traditional manual methods, these record breaking contacts would be difficult or impossible.

In the July/August 2010 issue of The AMSAT Journal, Alan Biddle, WA4SCA presented an updated article, based firmly on Paul's original work. It showed that the traditional manual techniques were still useful but fail badly under several situations that are encountered in daily operations. The following is a lightly edited version of Alan's original article.

Bringing the One True Rule of Doppler Tuning into the 21st Century

(Or, "What frequency is the DX on?!)

By Alan Biddle, WA4SCA

wa4sca@amsat.org

Abstract

In 1994, Paul Williamson, KB5MU discussed extending the existing conventional wisdom on Doppler correction to what is known as the One True Rule. [1] This describes a method where each operator tunes his transmit frequency, corrected for Doppler, so that it arrives at the same frequency *at the spacecraft* as every other operator. Likewise, each operator tunes the receive frequency, adjusted for Doppler, to the same downlink frequency *at the spacecraft*. This optimizes the use of the linear transponder passband, and if fully automated, greatly reduces operator workload. Due to limitations in existing software, it could only be approximated at the time. Only 5 years later, software existed to support this in a basic form. Today, all the major tracking and tuning software supports this in a largely transparent fashion. It is time to review the benefits of this approach as currently implemented, and to extend this to a new, unambiguous method of specifying operating frequencies.

Introduction

One of the most significant differences between terrestrial and satellite operations is the need to track not only the satellite, but also the uplink and downlink frequencies. The closest we have come to date to "normal" terrestrial operations is a Phase 3 satellite near apogee. It appears to be nearly stationary in the sky for several hours, and once the matching uplink and downlink frequencies are found, you can tune around as you do on HF. When you tune the receive frequency a certain amount, you tune the transmit frequency an equal and opposite amount for most transponders. Some rigs such as the Yaesu FT-847 have a hardware method of locking this in. Away from this approximation of a stationary repeater in the sky, and particularly as the operating frequencies move into the microwave region, things become more complicated.

Historically, the manual method of tuning has been to adjust the highest frequency, whether the uplink or downlink. Since Doppler shift is proportional to the frequency, if you only tune one knob, this is the one. A refinement used by some is to do a quick "touchup" of the transmit frequency at the start of each station's transmission. This is simple, in principle easily understood, and is usable with old equipment. It requires no additional equipment, which can substantially simplify operations in remote locations. It has served us for decades and is widely used to this day. However, it has major deficiencies, over and above the workload, particularly when applied to Low Earth Orbit (LEO) and Middle Earth Orbit (MEO) satellites.

It is easy to think that the other station is doing essentially the same correction you are, with only slight differences. In the Phase 3 example above, that is essentially true. For LEO or MEO satellites, this similarity is the exception rather than the rule due to the much shorter windows and rapidly changing velocities. Each satellite pass is unique to each station except for special geometries. If the stations are very near each other geographically, then they will tune the same way. For another case, consider two stations on the same latitude but different longitudes. If a satellite in a North-South orbit passes exactly between them, then they will in fact make exactly the same tuning corrections. While possible, these are configurations rarely seen.

A much more realistic scenario would result in one station seeing the satellite pass close to overhead, and the other station seeing it much closer to the horizon. Whatever tuning method is used, these stations would make corrections at different times and amounts. For instance, the Time of Closest Approach (TCA) is the time in any pass where the rate of **change** in Doppler correction is most rapid, and changes from a positive to a negative correction of the receive frequency. Most importantly, the TCA (and rapid frequency change) occurs at different times for each station except for the sort of artificial situations discussed above. Figure 1 shows the difference in Doppler correction at my station and another station approximately 600 miles to the north. For the indicated period, about 2 minutes, the northern station is applying a large, negative Doppler correction while I am still applying a large positive one.

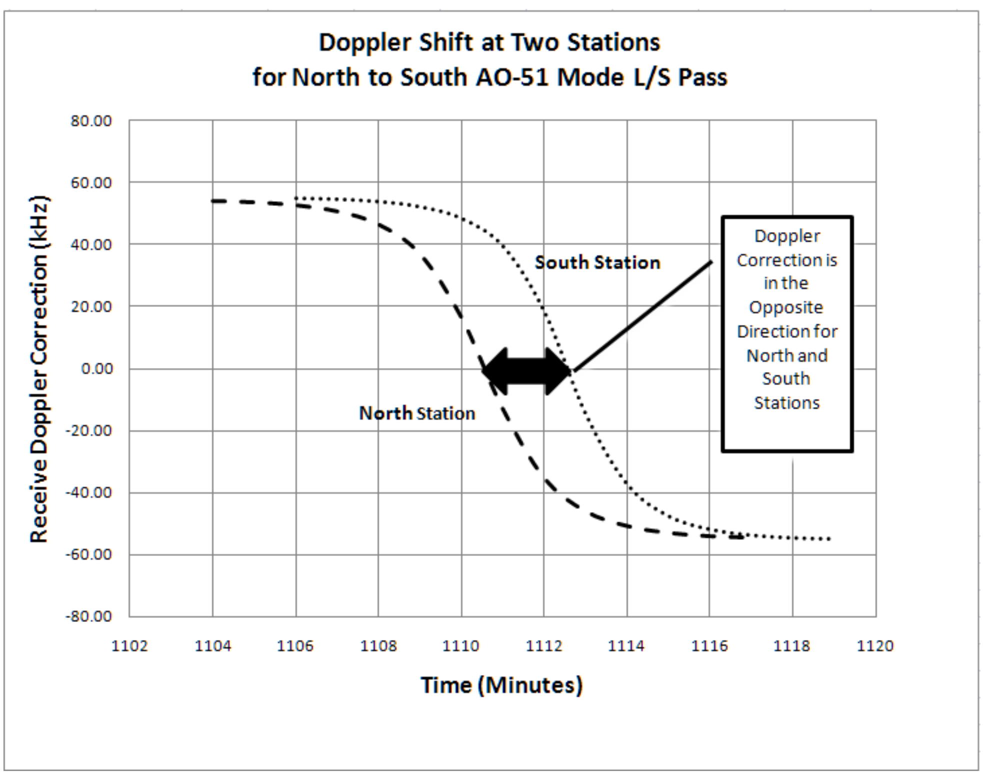


Figure 1: Doppler Shift at Two Stations in a North to South AO-51 Mode L/s Pass

KB5MU discussed these factors in an abbreviated manner in the original article. [1] He also discussed in detail optimizing the use of traditional tuning methods. Tony Langdon, VE3JED has an extended discussion [2] of the differences in Doppler shift, with excellent graphics, of high and low elevation passes. Both are highly recommended for those desiring more detail and a better feel for the subtle aspects of Doppler shift and correction. Since it really does depend on how you look at the satellite, the brief following discussion of the limitations of traditional manual tuning is necessarily simplified. Hopefully it gives a good qualitative feel without covering all the unique ways problems can arise.

First, if we use the traditional manual tuning methods, there will be at least some drift through the satellite passband. Ideally, if everybody is using the same technique, most of the QSOs will drift roughly in parallel, most of the time. Again, around TCA, a particular station may jump in the opposite direction, or “over” an adjacent QSO. Still, as long as nobody starts near the edge of the passband, all is reasonably well. New stations just find an unused frequency pair and go with the flow. Even this idealized situation is complicated by the fact that everybody has their own way to implement a given technique. The real-world result is that you have QSOs colliding with each other in a crowded passband.

Second, you have the situation of round table QSOs. On some satellites such as AO-7 and FO-29, they are still found, though sometimes it is hard to find a QSO consisting of more than signal, grid square, and name even if the pass is otherwise empty. There is a more natural flow of conversations, rather than a series of monologs. The result is that if you wish to tweak your uplink on each transmission, you are doing this more often. (Since most tracking programs call their implementation of the One True Rule something like Full Doppler Tuning (FDT), I will use that term for simplicity.) By comparison, I have worked multiple stations in a round table on AO-7 and FO-29, all using FDT, from AOS to LOS, without significant manual tuning. A recent listening survey on AO-7 and FO-29 showed about half were using FDT. In general, portable stations do not because of the extra equipment required, while home stations do. Are there circumstances where it should not be used? Yes. There are a few satellites in which the difference between the received and transmitted signals drifts due to poor thermal stability. AO-73 is one example where the basic assumption breaks down. In this case, users are strongly urged to use purely manual tuning.

Finally, techniques that work well in practice on modes V and U are challenging at mode L and higher frequencies, even for the relatively less critical FM modes. Table 1 shows the typical maximum Doppler shift found in selected orbits. The three altitudes shown are roughly those of AO-51 and other LEO satellites, AO-7, and a higher MEO orbit which is currently being considered. Except around TCA, even mode U Doppler shift changes slowly enough for normal human intervention. At mode S, 2.45 GHz, the shift is 5-6 times as large. More importantly, so is the rate of change. Lacking an ideal stationary satellite, the change in the Doppler shift is too rapid for all but those with the skills of a virtuoso pianist. For even MEO satellites, the uplink can drift so far from the previous frequency that the tuning required for a new transmission resembles more closely the initial hunt at the beginning of the QSO.

Satellite Mode	V	U	L	S
Frequency (MHz)	145.9	436.0	1280.0	2401.0
800 Km	± 3.0	± 9.0	± 26.2	± 49.6
1500 Km	± 2.9	± 8.6	± 25.0	± 47.3
8000 Km	± 2.1	± 6.4	± 18.5	± 35.0

Table 1: Maximum Doppler Shift (kHz) at Selected Altitudes for Circular Orbits

Using what we have

How does FDT really work? Imagine a satellite transponder on a very tall tower, or equivalently on a spacecraft in geosynchronous orbit such as the fabled Phase 4 satellite. It is stationary with respect to all stations. In this case, there is no Doppler shift. All stations transmitting on the same frequency will listen on the paired downlink frequency. Should another FTD station wish to use the transponder, they simply find an unused downlink frequency and call on the matching uplink frequency. The operation is very similar in concept to terrestrial repeaters, though most are FM and only accommodate a single channel.

FDT uses modern computing power and rig control to work the problem backwards, making the Doppler shift nearly invisible to the operator. The program actually "thinks" in terms of the frequencies *at the satellite* and constantly computes the matching rig frequencies. While both the uplink and downlink *on the rig* may be changing rapidly, the frequencies *at the satellite* do not. In a practical sense, the satellite appears *from an operator tuning standpoint* to be stationary.

Making this happen requires only a simple setup for each satellite transponder. You need to specify the relationship between the uplink and downlink frequencies. The nominal values are given for the transponder in various places including the AMSAT website under "Communications Satellites":

https://www.amsat.org/two-way-satellites/

All of the major tracking programs have this capability and explain its usage. Think of this as equivalent to "locking in" the frequency offset of a Phase 3 satellite discussed in the introduction. However, there is an important difference. Once this is done, it is good for all parts of the orbit, every orbit! [3]

Once this is achieved, you can tune around the passband. The matching uplink frequency will follow. Whatever your receive frequency, when you key the transmitter, you will hear your voice or CW come back to you. No tuning around, no "aaaaaahhhhhh" dragged across a QSO in process, and better, no one doing so to you. In practice this makes satellite tuning very much like terrestrial HF. You can largely forget about what the transmitter is doing, since the computer takes care of that for you.

Now assume someone answers who is also using FDT. You will hear the reply on the frequency you are currently listening. More importantly, over time the satellite position and hence relative velocity will change, and both station's uplinks and downlinks will be changed, but the signal will remain in tune at both stations. Should another FDT station join the QSO, all three will be able to concentrate on talking, not tuning. That is because each station will always put his uplink on the same frequency *at the satellite*, and so each station knows on a second by second basis where to look for the downlink. By contrast, the traditional methods place the uplinks scattered over a few hundred Hz to a few kHz of the satellite passband as the QSO progresses.

Is this useful with other stations still using manual tuning? Yes and no. Most programs have a way to select whether you wish to tune the uplink, downlink, or both. By selecting the one which corresponds to the higher frequency, you can decrease your workload a bit and receive most of the benefits of FDT. As a practical matter, it works better if you use either full automatic or full manual methods. People are used to using one method or the other, but not a combination. The few times I have tried a mixed mode, it generated both interest and confusion in equal parts. In some geometries, it can actually increase the rate of walking through the passband.

Another practical application is in working stations that have a very limited window of mutual visibility. The topic has come up on the AMSAT bulletin board with regard to AO-7 and other satellites with linear transponders. In a window which may be measured in a minute or less, you do not want to waste time in netting in the uplink and downlink frequencies. With FDT if you hear someone calling CQ, you already have his downlink, and your uplink will already be zeroed in for you. The only unknown is where he is listening. If he is also using FDT, you don't care! Key the rig and you should have a QSO. What happens if he is not using FDT? He will be listening to his downlink, so at that instant he will in effect be doing FDT. Depending on how closely he matches his tuning, he will hear you exactly on frequency, or at least close enough that you will get his attention. In either case, you have your QSO.

So what is missing? FDT allows us to work a station easily that we hear while tuning around. What about a scheduled contact? A terrestrial traffic net, or a scheduled QSO with old friends, is easily specified as a frequency, ± QRM. Everybody starts there, and then tunes around slightly. Even with FDT, we still lack a way to do the equivalent. For instance, two stations planning to meet "on 435.000 MHz" can tune their rigs to that frequency, but because Doppler shift is different for each station, they may not even be close enough to hear each other. We would like to have a frequency which each station can use in the same unambiguous way as terrestrial stations. Such a frequency exists, as we shall see, though neither the rig nor most current tracking programs display it.

Where do we go from here?

With full implementation of the One True Rule, we have largely taken the busy work out of satellite communications. There is one question we have not made it easy to answer yet: "What frequency are we on?" Unless you are talking with a station across the street, each station will have his rig tuned to different receive and transmit frequencies. As we can see from Table 1, in the case of microwave frequencies, these can be significantly different frequencies. However, in the case of FDT, every station will be listening to the **same** frequency *at the satellite*. No matter how many are in the QSO, this will be an invariant **all** operators can agree upon.

This seemingly privileged frequency is not really a new idea. Modern tracking programs actually use this idea in two ways. For channelized FM satellites, you specify the repeater input and output. The program does the rest. We just say that the uplink is 145.920 MHz and the downlink is 435.300 MHz for short. The "± Doppler" is simply assumed, but we don't put it on a QSL card.

The other way is when configuring the reference frequency pairs for a linear transponder. For AO-7, I find that an uplink of 432.14768 MHz and a downlink of 145.950 MHz is a good match for the "Hello Test" calibration. The tracking program will start here, just as it would for the FM case. The difference is that as you tune around the downlink, the transmit frequency will change appropriately. While clumsy, we could specify our SSB/CW frequencies *at the satellite* here and achieve the goal.

As we have seen, we work daily with satellite-centric frequencies, even though they are not normally visible in tracking programs. How can we make them visible? A tracking program will normally display the rig frequency, and the Doppler shift being corrected. If you add those two numbers, including the sign, the sum will not change, even though both of the components may be changing rapidly. Why? This sum is what we are looking for; the frequency *at the spacecraft*!

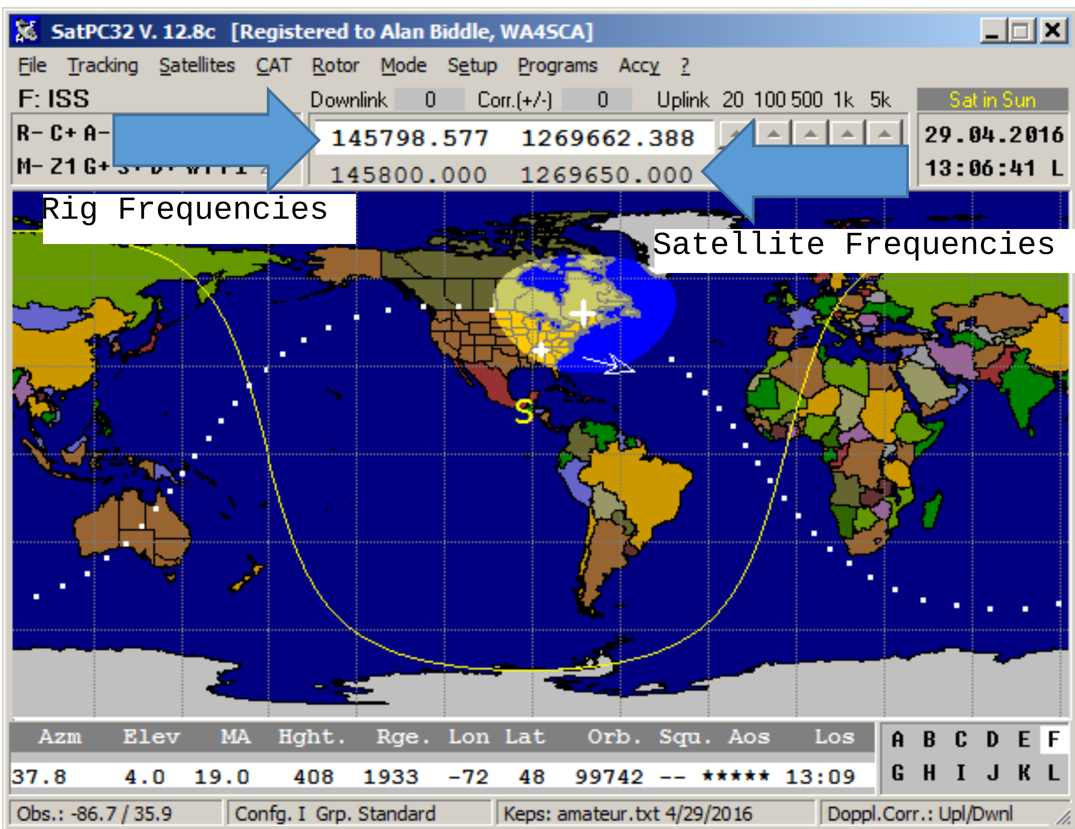


Figure 2: SatPC32 Program Display for Spacecraft Frequency Tuning

The author of SatPC32, Erich Eichmann, DK1TB has implemented this capability. See Figure 2 for a typical display. How do we use it, and how does it change our operating techniques? First, we change the way we think about and specify the QSO frequency. The full version would be "ISS, 145.800 MHz, Spacecraft." This gives the spacecraft, and the ground receive frequency *at the spacecraft*. No questions or ambiguities, no matter your QTH. (This is also the frequency to which your rig would be tuned near TCA.) Do we need to specify the full mode, such as L/u or V/u? No! Both AO-13 and AO-40 had modes in which more than one uplink was translated to the same downlink simultaneously. While knowing which uplink the other operator is coming in on is interesting and appropriate for a QSL card, it is redundant so far as making a QSO is concerned. Any uplink which gives the same downlink frequency *at the spacecraft* is equivalent.

Second, the primary tuning reference moves by necessity to the computer screen rather than the rig. One could tune the rig dial but watch the "Spacecraft Frequency" on the screen, or presumably enter it manually. With the steady progress toward software defined radios, or at least control software, this will soon seem natural, and already is for many.

Implementation

How do we get from here to there, and should we? The many existing tracking programs make this relatively easy to approximate, even if they do not implement it explicitly. With your tracking software's version of FDT engaged, one can look at the rig frequency and Doppler shift, and mentally combine them to get the needed frequency. If you have a schedule with another station using this technique, it will get you much closer than just tuning the rig to the schedule frequency, and then having to hunt around. Usually you will get close enough to hear the other station. A quick tune of your receive frequency, and you are done, except for the QSO. When this option is added into existing and future programs, it will become a true "HF mode" in terms of simplicity, both hypothetical and practical. Manual tuning, while still viable, especially for portable stations, may eventually be considered in the same way we consider Straight Key Night.

Considering that the basic One True Rule is not yet universally used 15+ years after the software to use it became readily available, it is to be expected that such a radical paradigm shift in how we specify "the frequency" will require another generation to fully assimilate and implement. Still, this extension can be tested, verified, and refined with minimal to no impact on more traditional users as operating frequencies continue to expand. But is it useful? You be the judge. There are often cases where the window of opportunity to work stations at the extreme ends of the footprint may be measured in seconds. Using this technique, several stations have reported intercontinental DX contacts which required perfect coordination without spending time for locating the other station by traditional means.

My thanks to KB5MU for valuable suggestions and insights for this article. Any mistakes and omissions are my own contribution.

Footnotes

1. "The One True Rule for Doppler Tuning," Paul Williamson, KB5MU. OSCAR Satellite Report #284, Jan 1, 1994. https://www.amsat.org/category/archive/

2. “A Close Up of Doppler Shift” Antony Langdon, VK3JED https://vkradio.com/doppler.html

3. For FM operations, the nominal values are usually accurate enough. For CW and SSB, it is necessary to specify the values closer than the nearest kHz. For natural sounding reception, 25 Hz or better is desirable. This is nominally a onetime calibration, though in practice it needs to be touched up due to aging and temperature shifts in the spacecraft a few times a year. This compares well with updates for every QSO with traditional methods.

Jim Wilson, K5ND, uses his Arrow dual-band Yagi to operate from Benton Harbor, Michigan in grid EN62.

Appendix B

Upgrading Your Amateur Satellite Station

In this book, we have concentrated on getting you on the air as quickly as possible and with a minimal investment. In this Appendix, we outline how you can upgrade each part of your station, to extend your capabilities, and to increase your opportunities to enjoy the hobby.

> *The key to reliable satellite communication is to put together the best **receive** station you can. If you don't hear well, you will interfere (QRM) other users of the satellite when you transmit!*

Getting your signal to a satellite is surprisingly easy. Taxi cabs using ham gear (not legally) are heard on the FM satellites frequently. The most common problem is hitting an SSB/CW satellite with too much power, frequently causing harmful interference to others, and sometimes causing the satellite to reset or change modes.

Hearing a satellite well is your best ticket to having many pleasurable contacts and receiving compliments for your station and your operating technique.

This photo suggests another reason you might want to upgrade your station. Miguel, LU3EMB, took this picture while waiting for a satellite pass in Patagonia, Argentina.

Improving Your Tracking Software

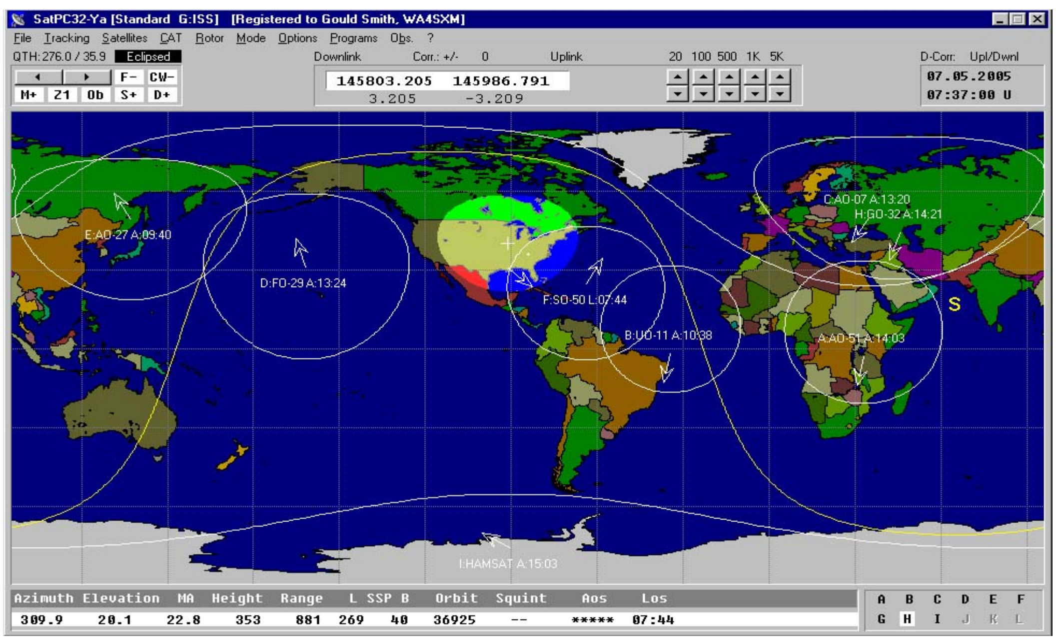
In Chapter 3, *Locating Amateur Satellites*, we surveyed several smartphone/tablet applications and website tools for locating and tracking amateur satellites. These are very useful when you're first getting started with amateur satellites or when you're operating away from your home station.

When you're operating from a fixed station at home, you'll want to upgrade to one or more of the software packages that will run on personal computers using Windows, macOS, or Linux. In addition to predicting satellite orbits, these packages will automatically point your antennas and tune your radios.

In addition to the personal-computer-based software packages, CSN Technologies has their S.A.T. (Self-contained Antenna Tracker) which will predict orbits and control your rotors and radios. It is also described below.

Satellite Tracking Programs for Windows PCs

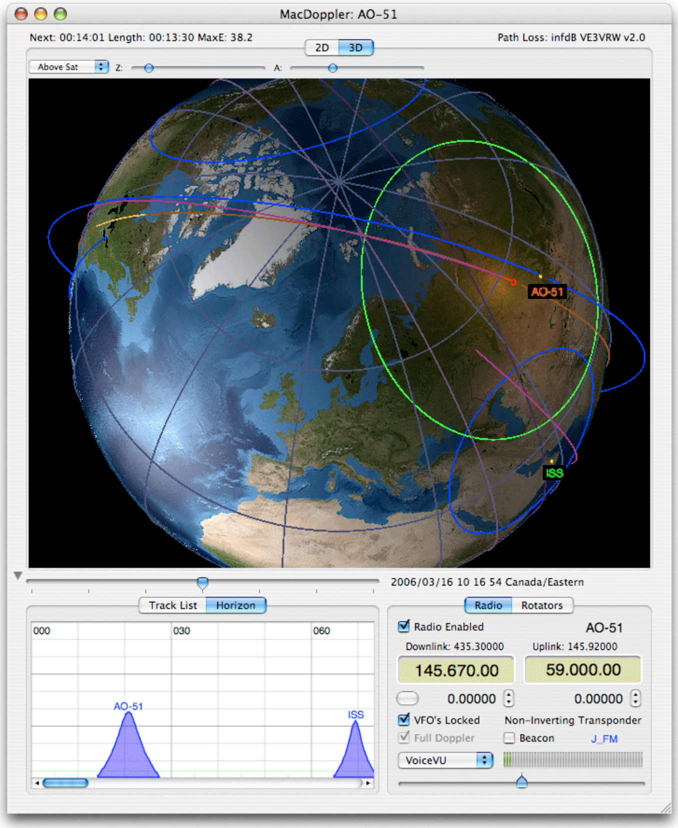
SatPC32 is a great program that runs under Windows, has several powerful features, and is the most popular among AMSAT members. It has everything available at your fingertips (or mouse cursor). It has a multi-satellite map with satellite direction arrows and also does rotor control and radio control. There is a great deal of information available on the main screen, including your frequency at the satellite (compensating for the Doppler shift). The setup is straight forward, and the results are outstanding.



Erich Eichmann, DK1TB, wrote SatPC32 and continues to support the program. Most new users post their questions and get answers from other AMSAT members or Erich on the AMSAT-BB. Updates are free. The demo version is free and completely functional. If you purchase the registration key, your entire purchase price goes to AMSAT https://www.amsat.org/product/satpc32-by-electronic-download/ .

SatPC32 is used by most of AMSAT's control stations to track and control our satellites.

Tracking Programs for macOS

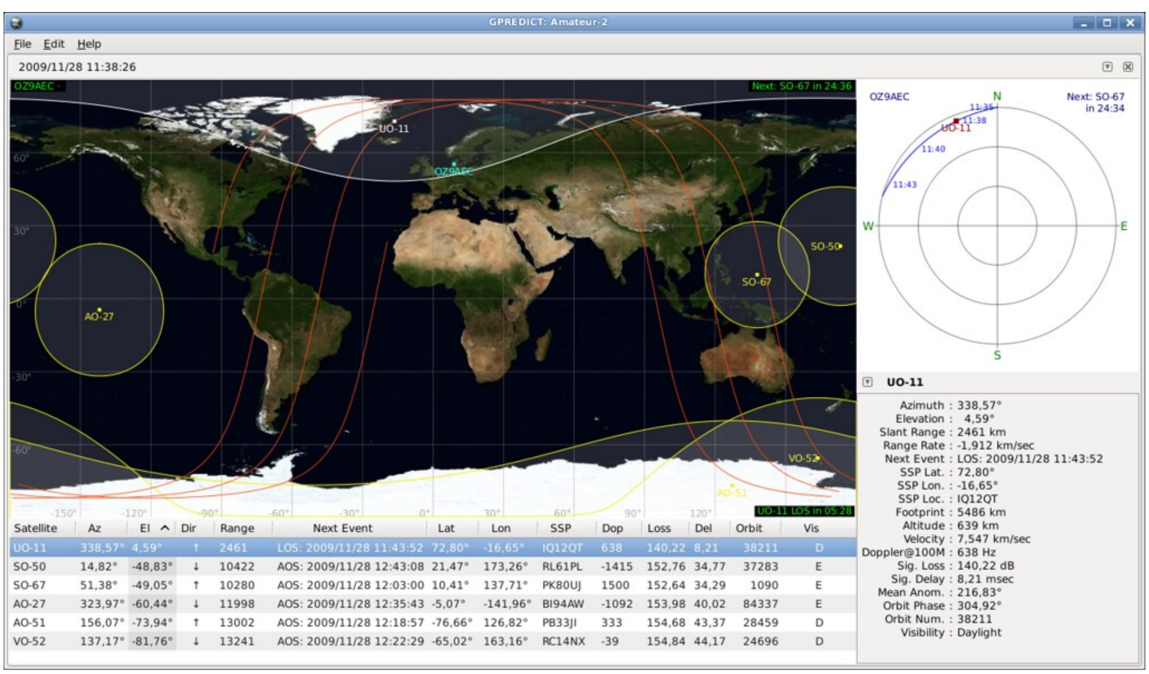


MacDoppler is an excellent program for the Mac user running macOS. It provides all the basics, plus many, many useful features and views – typical Mac quality program.

The program was written by Don Agro, VE3VRW. It provides beautiful screen displays of the earth, satellite orbits and even 3-D Squint angle graphics. It includes an easy-to-read text list of upcoming passes and a graphical display of the satellite maximum elevation over your QTH along the horizon.

Doppler display and control are standard as well as rig and rotor control. You can purchase MacDoppler online at the AMSAT Store at https://www.amsat.org/shop/.

GPredict (Linux, macOS, and Windows)



GPredict (https://oz9aec.dk/gpredict/) is an excellent free, cross platform, full-featured tracking and control program. It can control any radio (https://github.com/Hamlib/Hamlib/wiki/Supported-Radios) and rotator (https://github.com/Hamlib/Hamlib/wiki/Supported-Rotators) that HamLib can control.

One very nice feature are the exhaustive configuration options allowing advanced users to customize both the functionality and look & feel of the program. Look through the screenshots to get an idea (https://oz9aec.dk/gpredict/screenshots.php).

The S.A.T. Controller

The CSN Technologies S.A.T. Controller is a completely self-contained device used to predict and track satellite passes while simultaneously controlling a Yaesu rotator and tuning an Icom satellite transceiver. It can also control any SDR that uses a HamLib-based application such as SDRangel or GQRX.

Additionally, the unit interfaces with PstRotator to control a wide range of non-Yaesu rotators. It also includes a built-in GPS so that you don't have to determine and enter your latitude and longitude or time.

While the unit has a small LCD status display, the primary User Interface is through a web browser on any device connected to the unit via its built-in WiFi.

This description just scratches its extensive capabilities. For full information and to purchase one, visit http://www.csntechnologies.net/ .

Setting up your tracking program

Each of the programs has a different setup. Some require more information than others. Generally, what you need is your call sign or name (not too difficult), your station location (longitude, latitude, and elevation), your time zone, and whether or not you observe Daylight Savings Time. Another very important consideration is your computer clock. Make sure it is correct!

Computer clock

Your computer clock is close enough for general work, but NOT for real time satellite operation. You need to correct your computer clock "regularly". What "regularly" means depends upon how quickly your computer deviates from the correct time. Check your computer time against a standard and reset it often. Just two minutes off can cause you to be looking 100° away from the satellite's actual location. Many of the LEO satellites have at most a 12–15-minute window, so you can miss a great deal of the pass, not to mention being unable to find the satellite by pointing in the wrong direction. Some of the tracking programs have a feature to connect to the National Institute of Standards and Technology and correct your system clock, but you have to remember to do it.

A more sophisticated approach to keeping your computer clock highly accurate is to use a local NTP client, such as Meinberg NTP or NetTime. Once installed as a service on your Windows computer, regular updates keep your clock accurate, in the milliseconds range. You can read more about Meinberg NTP and NetTime at these links: https://www.meinbergglobal.com/english/sw/ntp.htm and https://www.timesynctool.com/ .

UTC and DST

You need to know how many hours you are different from UTC (Universal Time, Coordinated – Universal Coordinated Time, formerly known as GMT or Greenwich Mean Time or Zulu time). Most of the tracking programs and satellite schedules are done in UTC, so you need to be fluent in UTC and 24-hour format. There are many clocks available today that automatically synchronize themselves to UTC via WWV for less than $30. Make sure you find a location in your station where the reception of WWV is reliable.

North American UTC offset		
Standard Time	**Daylight Time**	**Time Zone**
AST -4	ADT -3	Atlantic
EST -5	EDT -4	Eastern
CST -6	CDT -5	Central
MST -7	MDT -6	Mountain
PST -8	PDT -7	Pacific
YST -9	YDT -8	Yukon
HST -10	not observed	Hawaiian
NT -11		Nome, AK

Keplerian Elements or "Keps"

The tracking programs compute the satellite's location and future locations/schedules from information known as Keplerian elements, or Keps for short. These are named after Johannes Kepler who formulated many of the orbital laws. The Keplerian elements are numerical values that describe the satellite's orbit as it crosses the equator going South to North.

You only need to update the Keplerian elements every three to four weeks for the amateur satellites, though weekly is preferred. *The ISS is an exception*; it changes its orbit quite often, so daily orbit information is necessary. Check Chapter 10, *International Space Station*, for additional information and sources.

The elements are available from numerous sources; here are two that should work for you:

(1) The AMSAT website (https://www.amsat.org), select the "Satellite Info" tab and scroll down to "TLE/Keplerian Elements Resources"

(2) https://www.celestrak.com, maintained by Dr. T. S. Kelso

Capturing the Keplerian data

Some satellite tracking programs will fetch and load current Keplerian data directly from the Internet. For example, SatPC32 has a one click "Update your satellite elements" button.

For other tracking programs, get the NASA or 2-line data from the AMSAT website under the "Satellite Info" tab and scroll down to "TLE/Keplerian Elements Resources".

Check the Results!

After you have configured the tracking program and updated the Keplerian elements you have tracking data, *but is it correct?* The most common problems setting up the tracking programs are:

- Time – set the computer's clock, time zone, and daylight-saving time
- Station Location – check your latitude, longitude, and elevation
- Keplerian Data – make sure the information is up to date

Check your data against a known source! It is time well spent; you will waste a great deal of time and become very frustrated trying to work a satellite that is not there.

Good tracking sources are the AMSAT website, https://www.amsat.org/track/, and smartphone applications. Note that your smartphone has the correct time via the cell phone towers, the correct location from its internal GPS, and Keps automatically updated from the Internet. In this way it avoids all of the typical errors people make configuring a tracking program.

Upgrading Your Antenna System

There are few topics about satellite station equipment that generate more opinions than antennas and antenna systems. While we think all the following is good advice, you can easily find people with different opinions.

Optimizing your receiving station means getting or building the best antenna you can. Using a preamp **at the antenna** will help a great deal. A good antenna and a preamp at the antenna will provide a good signal to your receiver and make your satellite experience much better. If you scrimp on the receive antenna you will cause yourself a great deal of frustration.

Your antenna system includes the antennas, rotors, preamps, and coax. Each will have a significant impact on your ability to work the satellites. Also included here is a description of receiver desense and how to fight it.

Omnidirectional Antennas

Apart from unattended telemetry collection (described below), omnidirectional antennas (verticals, discones, eggbeaters, J-poles, Lindenblads or QFHs) are not well suited to satellite operation. They don't provide enough gain in the direction of the satellite and they pick up too much noise from every other direction. Using a high-gain omni makes the situation worse, as the gain comes from the horizon and to the detriment of signals above the horizon where your satellite is located.

For receiving satellites, side-by-side comparisons always yield the same results: a small directional antenna works better than an omni, even if the omni has a preamp. Hams that have good experiences with omni antennas are typically located in rural areas away from broadcast transmitters, radio towers, and other sources of man-made RFI.

An unattended telemetry collection station is one good application for an omnidirectional antenna for satellite reception. An unattended 24/7 rotor operation is prone to failure necessitating a repair visit, not always an easy task. For example, Burns, WB1FJ lives in New Hampshire, but has an unattended telemetry collection station in Hawaii. He uses a J-Pole antenna, a Raspberry Pi running FoxTelem, and an SDR receiver. See the AMSAT store for the Fox-In-A-Box software installed on an SD card.

Directional Antennas

After eliminating omnidirectional antennas, you're left with choosing a directional antenna. Basically, beams are the best performing antennas, but require azimuth and (usually) elevation rotors.

Antenna Polarity

You're probably familiar with vertically and horizontally (linearly) polarized antennas. An Elk log periodic antenna mounted with the elements pointed up and down is vertically polarized. Twist the antenna 90° so the elements are level and the antenna is now horizontally polarized.

The picture to the right shows an Elk antenna mounted on a mast so that it is vertically polarized.

An Arrow satellite antenna has the 2 m elements mounted at 90° with respect to the 70 cm elements, which improves the isolation between the two antennas. So, if you're holding the antenna so that the 2 m elements are horizontal (and thus horizontally polarized), the 70 cm elements will be vertically polarized.

Some satellite antennas are circularly polarized, either right-hand circularly polarized (RHCP) or left-hand circularly polarized (LHCP). A relay, usually mounted at the antenna, will allow you to switch between RHCP and LHCP. Typically, circularly polarized antennas are built using both horizontal and vertical elements with a phased coax feed that splits the RF in a precise relationship to achieve RHCP or LHCP. Helix antennas are another example of a circularly polarized antenna.

You'll find lots of disagreement about which type of polarity antenna works best. Some operators are happy with linearly polarized antennas, more often vertical than horizontal, but both work. Other operators prefer circularly polarized antennas.

Both linear and circular proponents will normally say that switchable polarity, either horizontal/vertical or RHCP/LHCP, improves their results. A few hams that enjoy building and experimenting with antennas will build a switching system that gives them all four choices: horizontal, vertical, RHCP, and LHCP.

Transmitter Power and Antenna Gain

In HF operation, the antenna gain is basically limited by the physical size of the antenna. Stations compensate by increasing power. Since satellite work is done on higher frequencies, antennas are the best place to increase gain. You can get a good signal to the satellites with 5 watts and a decent transmit antenna. You will often hear stations with signal levels well above the beacon because they use more power than necessary so they can hear on a less than adequate receiving system.

On SSB/CW satellites, the total amount of power transmitted by the satellite is fixed and divided among all the users, so hitting the satellite with more power than necessary decreases everyone's downlink signal. A strong enough uplink signal will literally turn off the transponder for other users! Also, by optimizing your receive system you will be able to hear and work stations easier. This is especially true for those that are unable to use much uplink power or unable to point at the satellite.

Keep your downlink signals at or below the beacon level. Share the satellites responsibly.

The EIRP (Effective, or Equivalent, Isotropic Radiated Power) is calculated using the formula EIRP = 10^(dB/10) x PWR, where the ^ symbol means 'raised to the power'. An antenna with 12 dBi (dBi = dBd + 2.15) and fed with 10 watts gives 10^(12/10) x 10 or 10^(1.2) x 10 = 158.5 watts EIRP.

Antenna Gain vs. Pointing Accuracy

In general, the longer the antenna boom and the more elements your antenna has, the higher its gain. As the gain of an antenna increases, its beam width decreases. If you use a very high-gain antenna, the beam width gets much narrower. That means you'll need to point your antenna with high accuracy to get any benefit from the high gain of the antenna.

It is counter-intuitive, but if you can't point both antennas with great precision, you're better off with smaller, lower-gain antennas. This is part of the reason why Elk, Arrow, and WA5VJB handheld antennas work so well. You can wave the antennas in approximately the right direction, then adjust where you're pointing and adjust the polarity by twisting your wrist and listening for the best signal.

Higher Gain Antennas

Larger antennas with higher gain are available from several sources. For linearly polarized antennas, visit Arrow, Elk, Diamond, Cushcraft, and M^2 Antenna Systems, among others. For circularly polarized antennas, look at the M^2 antennas, or maybe old KLM antennas. The KLMs haven't been made for years, but they were very popular.

The M2 LEO-Pack is a very popular antenna system used by many hams. If you decide to buy one, please support AMSAT by purchasing it from the AMSAT store (https://www.amsat.org/shop/) and you will receive free shipping if you are in the US!

While AO-40 is no longer working, you'll frequently see mention of an "AO-40 Class" station on the AMSAT-BB or in the AMSAT Journal. AO-40 was in an elliptical orbit where the satellite spent most of its time 50,000 km or more above the earth, where the ISS is only 370 km, and most LEO satellites are 600 to 1200 km. As a result of the path loss, reliable operation with AO-40 required high-gain, circularly polarized antennas with switchable polarity and low-noise preamps along with azimuth and elevation rotors.

Antenna systems of this type can work the LEO satellites from horizon to horizon. If you get hooked on amateur satellites, you may eventually build an antenna system like this. The satellite control operators may have this type of elaborate setup, but you sure don't need one to get started or to enjoy satellite operations!

Since satellites rarely pass directly over your head, and you're using small antennas with a wide beamwidth, you can do quite well without an elevation rotor. You should get excellent reception of the weak digital signals from about 8º to 45º (about a 30º beam width) with this fixed elevation setup. This covers about 97% of the satellite passes that you could work; even the overhead passes are only overhead for a brief period of time.

Rotors

For a fixed (not portable) station, the normal method for pointing an antenna is to use an azimuth rotor to aim the antenna north, east, south, and west, and at points in between. Usually, but not always, an elevation rotor is used to aim the antenna above the horizon to track the path of the satellite.

This photo shows an Elk log periodic satellite antenna at a fixed elevation of 22.5° on a simple AZ rotor. Harry, K4BAD, reports that he's happy with the performance.

For fixed station operation of the LEO satellites, a small boom with separate uplink and downlink antennas works well. For the LEO satellites a small 8 element, 70 cm yagi is fine when paired with a 4 or 5 element 2 m Yagi. These antennas are inexpensive and provide enough gain and background noise reduction to work very well. Add an inexpensive TV rotor for azimuth pointing, fix the antenna's elevation between 15 and 23 degrees above the horizon, and you will have a very capable LEO antenna system.

The most popular satellite azimuth and elevation (or az-el) rotor is the Yaesu G-5500. It isn't the cheapest and it isn't heavy duty, but it is a reasonable compromise. It does require an interface between your computer and the rotor control panel. Your PC, using tracking software like SatPC32 and MacDoppler, can control the Yaesu rotor and automatically track a satellite across the sky. To connect your Yaesu controller to your PC, you'll need an interface like the Fox Delta ST2, the Vibroflex ERC-M, or the Yaesu GS-232 which is expensive but often found second hand. For several years, AMSAT sold assembled LVB Trackers. Used ones appear for sale from time to time. For the builder, designs exist for the Arduino. The CSN Technologies S.A.T. has the Yaesu rotor interface built in.

If you have a larger satellite antenna array and you want something stronger than the Yaesu az-el rotors, you can look at the AlfaSpid rotator made by Spid Electronik in Poland (sold by Alfa Radio, Green Heron, and others) and the EME-class rotors from M^2. The Green Heron controller is recommended by many users instead of the AlfaSpid controller.

Preamps

A preamp may not be necessary for portable operation, when using a small directional antenna like an Arrow yagi or Elk log periodic (or homebrew equivalents) and a 3-foot (1 meter) piece of coax. Some portable operators add a relatively inexpensive wideband preamp for 70 cm receive that uses a 9V battery for power.

Preamps make a great deal of difference with fixed station operation because of the losses in longer coax runs. A good quality preamp will give you a great deal of added signal without adding a lot of noise (look for a smaller noise figure). This is a less expensive option than adding higher-gain larger antennas, heavy-duty rotors, and installing large-diameter lower-loss coax. Preamps with low noise figures (< 1 dB) are best.

Install your preamps at the antenna, not in your shack. Look for models that are weatherproof and which will automatically switch from receive to transmit.

Some commercial units have RF sensing, automatically bypassing the preamp when you transmit. While the price is higher, it provides significant protection against a momentary expensive lapse of attention. Another alternative is to use a preamp that is powered via the coax from the radio and use a radio that provides that power when receiving, but removes the power when transmitting. The Icom IC-9700 is a current production satellite radio that includes this feature.

When the budget is tight, you may be able to use an indoor preamp but mounted at the antenna and sheltered under a plastic food container. Simply replace the container each year. Those built for outdoor use work well but are more expensive.

If you are using 30 or more feet of coax, a preamp is really recommended, even if you are using a small beam and good coax. The primary purpose of a preamp is to compensate for the signal loss in the coax. If your receiver has poor sensitivity (is "deaf"), the preamp can help compensate.

Coax

The old standby RG8 coax is fine for HF use, but not for VHF, UHF, or higher-frequency weak-signal work. 70 cm signals have a lot of loss in RG-8 coax: 5 dB per 100 feet; even low-loss coax at 435 MHz has a 2 dB per 100 feet loss factor. If you have a long run, a preamp is a less expensive way to improve your situation when compared to the cost of large diameter, low-loss coax.

Use low-loss coax when setting up your receive system. The first problem is that many manufacturers and suppliers claim that their coax is "low loss". Restrict your choices to either the 9913-type coax or the Times Microwave LMR series.

Standard 9913 coax has good loss numbers when new but is very stiff and has a hollow core. There are lots of stories about puddles of water appearing in the shack when someone pointed the connectors down. Some of this is condensation in the hollow core, some is water seepage. Newer 9913F is much more flexible and less subject to water leaks.

Our advice is to use genuine Times Microwave Systems LMR cable. The TMS LMR cables are not only better-quality cables to start with, but they maintain their properties with age (i.e., 20+ years), extreme weather, and mechanical stresses (coiling and uncoiling, rotator movement). Unless you're building a permanent installation where the coax will never be moved, choose the Ultraflex version of the LMR coax.

Most non-LMR coax uses an insulator of poly-foam with air pockets, or an air dielectric with a spiral poly strand (9913) to maintain the spacing between the inner conductor and shield. This works well until age, stress, and weather extremes allow moisture to enter the air cavities. The foil shield on non-LMR coax is usually loosely wrapped around the insulator, and can be stretched, ripped, or separated as the coax is moved, coiled, uncoiled, or bent around corners, introducing holes and leakage in the shielding.

Consider Times Microwave LMR-400 Ultraflex for use at your home, and LMR-240 Ultraflex for your portable setup. Flexibility is important around the antenna and rotor. Other users report good long-term results with Messi & Paoloni (https://messi.it/en/home.htm) and with the CXP1318FX coax made by Cable X-perts.

Connectors

Everyone who terminates coax has an opinion on which type of connector is better: crimped or soldered.

Soldered connectors are difficult, but not impossible, to solder correctly. The common results are poor mechanical connections, cold solder joints, and melted cables. You need a high-wattage gun for the connector body, and a low-heat pencil for a BNC or N connector pin. They are also prone to shorts or failures because the connectors can be twisted with respect to the cable.

Crimped connectors will pull apart if not installed correctly. With the correct crimping tool and dies (buy or borrow), and the correct connectors for your coax, you'll get a solid mechanical and electrical connection that won't twist or pull apart.

Using heat-shrink tubing over the coax and the ferrule that is crimped over the coax helps keep moisture out of the coax braid and makes for a better-looking job. Colors other than black can be used to help identify the cable.

The standard thin-wall heat shrink tubing will contract by a ratio of 2:1. The dual-wall adhesive-lined heat shrink tubing will contract by a ratio of 3:1 and is a better choice for outdoor installations.

Pieces of tubing approximately 1.25” in length seem to work well for covering the ferrule on a crimp connector.

The ferrule on an LMR-240 connector is approximately 0.27” in diameter, so 0.375” (3/8”) tubing is probably the right choice. Quarter-inch diameter tubing is too tight. Half-inch (1/2”) tubing is the right choice for LMR-400 connectors.

The type of connector you use may be dictated by the equipment to which you’re connecting. For example, if a radio or antenna has an SO-239 UHF-style connector, you’re going to use a PL-259 on your cable.

However, if you have a choice, choose N and BNC connectors, as they are constant impedance connectors. This reduces the loss and SWR due to your cables and connectors impedance “bumps”.

When you’re buying crimp connectors, ask for the specification sheet that gives the recommended stripping dimensions. If you can’t get them, buy a few extra pins so that you can experiment, or just buy the Amphenol connectors and get the stripping dimensions from the mechanical drawings on the Amphenol website.

Also, try to avoid using adapters to mate your coax jumper to the antenna or the radio. As a rule-of-thumb, each adapter reduces the signal (but not the noise) by 0.1 to 0.3 dB.

Receiver Desense

A common problem with all Mode V/u satellites is that sometimes you can’t hear your downlink because of interference from your uplink. This occurs when your transmitted signal overloads your receiver.

If you are new to satellite work, this probably is a new phenomenon. Analog mode on the amateur satellites is full-duplex operation; you talk and listen at the same time, just like a telephone. You want to hear yourself on FM satellites so that you know that you’ve captured the receiver on the satellite. For SSB/CW birds, it is important to locate your downlink signal and position it in a clear spot before calling CQ.

Your downlink is your own voice or CW signal being retransmitted by the satellite, with a slight delay. When looking for your downlink, if the signal you hear is distorted and real time, you probably are not hearing a downlink signal, but your uplink signal desensing your receiver. If you cannot correctly find your downlink signal from the satellite due to desensing of your receiver, you may well be transmitting on top of someone else and not realize it. It is very important to solve this problem before actively trying to operate on the Mode V/u satellites.

Solutions to cure desense issues include:

1) Separating your transmit and receive antennas by 8-10 feet (2-3 meters)
2) Decreasing your transmit power
3) Checking your SWR and fixing the problems if it is high (i.e., greater than 1.5:1)
4) The problem can be too strong 2 m signal getting to your 70 cm receiver. Try adding a diplexer or other high-pass or bandpass 435 MHz filter to your downlink coax line to attenuate the 2 m signal before the receiver.
5) The problem can also be the 2 m transmitter's third harmonic which can be a strong 70 cm signal near the downlink signal. Add a diplexer or low-pass filter to your uplink coax line to attenuate your transmitter's third harmonic.

Attenuation from Trees

You don't need a great deal of height for the antennas, unless you are in the middle of an apartment / condominium complex or the middle of a forest.

Of course, trees and buildings will attenuate the received signal quite a bit. The attenuation increases as the signal wavelength decreases. If you are interested in signal attenuation, see *Environmental Factors Effecting AO-40 Reception* in the 2002 AMSAT Symposium Proceedings. Essentially, the type of trees and the thickness of the trees that the signal must go through determine the attenuation.

A reasonable rule of thumb is to expect attenuation of 1-2 dB/M of tree(s).

M is the thickness of the tree(s) in meters. Many times it is not just one tree the signal must go through. So be sure to calculate the total distance in meters for all the trees in line with the satellite. Studies have shown that 2/3 of the attenuation is from the non-leafy part of the tree. So, you will see some improvement in winter with deciduous trees when the leaves drop.

Signal Attenuation due to a medium deciduous tree:

Received signal	Attenuation
UHF	10.5 dB
L-Band	11 dB
S-Band	18 dB
K-band	23 dB

To improve this situation: (1) Move up in elevation and (2) back from the obstacle.

A Better Radio System

In Chapter 5, *Your Radio System*, we surveyed most of your choices for radios for amateur satellite operation.

Upgrade to CAT control and FDT

Most likely, the best way to improve your radio system is to buy a radio that includes CAT control, giving you the ability to implement Full Doppler Tuning (FDT). These are more expensive radios and will generally have better receivers and transmitters, too.

The term CAT comes from Yaesu's acronym for Computer Aided Tuning, Computer Assisted Tuning, or Computer Aided Transceiver. They've used all three names. The amateur community uses the term for any brand of radio that allows computer control.

Using tracking software like SatPC32, MacDoppler, or GPredict to control the tuning of your radio for FDT should be your primary goal when upgrading your radios. These programs will tune one radio (a full-duplex transceiver) or two radios (transmitter and receiver) to compensate for the Doppler shift and allow effortless tuning up and down the passband.

If your radio is an Icom IC-9700, you should consider using the CSN Technologies S.A.T. Controller discussed earlier in this chapter.

Upgrade to SDR

If you have an older non-SDR based transceiver, or a transceiver that has limitations in satellite work like the Kenwood's TS-2000 birdies or Icom's IC-9700 4800 baud limit, changing to a good Software Defined Radio (SDR) for your receiver may bring a significant improvement to your satellite operating experience. In this context, a "good" SDR does not include a $20 RTL-SDR dongle - you need better front-end filtering and more bits of digitization than the RTL-SDR supplies.

Using a conventional radio transceiver and an SDR along with one of the SDR applications in "Chapter 5 Your Radio System" and a satellite tracking and control program described in "Improving Your Tracking Software" above, you will get an amazing station for satellite communication.

Some of the benefits of using an SDR over a conventional receiver include being able to view the entire satellite passband at once, seeing when the satellite has risen above the local horizon, recognizing CW, SSB, and FM signals by sight, and viewing your own signal's frequency and modulation. You can find yourself in the passband almost instantly, and you can quickly move to an active frequency rather than slowly tuning up and down the passband looking for someone calling CQ.

In this setup, your SDR will be used as the receiver and your transceiver is used as the transmitter. The result is a full-duplex setup, allowing you to receive while you transmit. The transceiver can be a full-duplex satellite radio or a half-duplex radio, as it is only used as the transmitter.

Organization

Our Vision

Our Vision is to deploy satellite systems with the goal of providing wide-area and continuous coverage communications, to continue active participation in human space missions, and support a stream of Low Earth Orbit (LEO) satellites developed in cooperation with the educational community and other Amateur Radio satellite groups.

Our Mission

AMSAT is a non-profit volunteer organization which designs, builds, and operates experimental satellites and promotes space education. We work in partnership with government, industry, educational institutions, and fellow Amateur Radio societies. We encourage technical and scientific innovation and promote the training and development of skilled satellite and ground system designers and operators.

Our Core Values

We lead by example.

We respect the individual.

We work collaboratively towards a common purpose and shared goals.

We embrace change and innovation to help our members, our partners, and ourselves.

We are committed to the Amateur Radio satellite community.

We are open and honest in our communication.

Above all, we act with integrity.

Strategic Satellite Objectives and Organization Goals

Highly Elliptical Orbit

1. Upward to HEO. Develop and deploy a series of spacecraft capable of providing wide-area and continuous coverage from high-Earth and geostationary transfer orbits.

Greater Orbit, Larger Footprint

2 GOLF. Develop and deploy a series of increasingly capable spacecraft through a program to learn skills and systems for which we do not yet have the necessary low-risk experience, including active attitude control, deployable/steerable solar panels, radiation tolerance for Commercial off the Shelf (COTS) components in higher orbits, and propulsion.

Amateur Radio on the International Space Station

3. AREx-A. Partner with ARISS and ARISS-USA to advance Amateur Radio's presence aboard NASA's International Space Stations, Deep Space Gateway and Artemis missions and provide opportunities to engage with astronauts in lunar and deep space operations.

Low Earth Orbit

4. LEO. Support a stream of LEO satellites developed in cooperation with the educational community and other Amateur Radio satellite groups.

- **4.1 FM Operations.** Develop, deploy, and support a series of 1u spacecraft to support continued FM amateur satellite operations in low Earth orbit.
- **4.2 Partnerships.** Develop a plug-and-play communications solution for educational and other Amateur Radio CubeSat programs, providing a VHF/UHF telemetry beacon, command receiver, and linear transponder or FM repeater communications module.

AMSAT STEM Initiatives

5. AMSAT Education. Support science, technology, engineering, and mathematics (STEM) initiatives and training programs for satellite and ground system designers and operators.

- **5.1 CubeSat Simulator.** Continue development of AMSAT's CubeSat Simulator Program.
- **5.2 High Altitude Ballooning.** Develop program to support and sponsor the use of amateur radio in high-altitude balloon (HAB) launches.
- **5.3 Youth Initiative.** Develop an educational outreach program that encourages youth to pursue STEM interests in space science and communication technology.

There's No Better Time to Join AMSAT than Right Now!

For over 50 years the Radio Amateur Satellite Corporation (as AMSAT is officially known) has played a key role in significantly advancing the state of the art in space science, space education, and space technology. By becoming a member, you can help propel AMSAT into the next 50 years of discovery, adventure and excitement.

Your membership helps support AMSAT activities such as:

- Working in partnership with government, industry, educational institutions, and fellow amateur radio societies to foster Amateur Radio's participation in space research and communication,
- Designing and building communication satellites to operate in the harsh environment of space,
- managing those satellites, once they are in orbit, and ensure they are available for public use,
- Promoting space education and bringing space-based STEM initiatives to life,
- Providing opportunities for students to speak with astronauts aboard the International Space Station (ISS), and
- Collecting, compiling, and sharing what is learned with not only AMSAT members, but, with the world!
- Resources open to all Radio Amateurs such as the
  - Voice and digital communications via AMSAT-built satellites
  - AMSAT Website
  - AMSAT Bulletin Board
  - AMSAT News Service
  - Satellite status and orbital elements
  - And much, much more!

Plus, your annual or lifetime membership includes the following exclusive benefits:

- One-year subscription to *The AMSAT Journal*
- Access to past issues of *The AMSAT Journal* and Symposium Proceedings
- Discounted price on certain items in the AMSAT Store
- Opportunity to serve on committees and gain valuable professional experience
- Be nominated for awards
- Voting rights in elections
- Opportunity to run for office

Your membership in AMSAT is more important than ever and it takes only a few moments to join.

Do it *right now* while you're thinking about it! Go to **launch.amsat.org** and click on "JOIN US NOW." Your membership lasts for one year from the date of purchase.

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Join the 2025 AMSAT President's Club

And Help Keep Amateur Radio in Space!

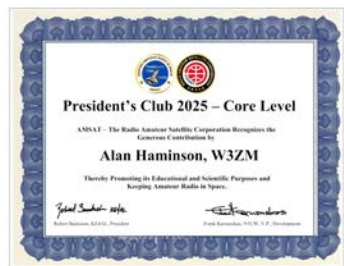
Since its inception four years ago, President's Club members raised over $200,000 to help move AMSAT programs forward:

The **GOLF** program to return Amateur Radio satellites to HEO has taken great strides with the development of entirely new 3U spaceframe with deployable solar panels; software defined radios; housekeeping circuits, power generation and management; attitude detection and control capabilities.

The **FOX-PLUS** program continues to build on the original and wildly popular FOX satellites. This new generation of LEO satellites will continue to provide affordable access to space communications to entry-level users as well as to provide payload capabilities for advanced educational programs and scientific experiments.

With your membership, AMSAT is pleased to recognize your generosity. All members receive:

Commemorative Coin 2" with 4-color enamel accents and polished gold finish.



Full-Color Membership Certificate

Higher tier members receive even more benefits! You can join with a single payment or with twelve affordable monthly payments with your credit card. For payment by check or electronic transfer, contact Frank Karnauskas, VP-Development at f.karnauskas@amsat.org.

Learn More - Go to amsat.org/donate and Join Today!

Tier	Core	Bronze	Silver	Gold	Platinum	Titanium
Annual Donation	**$120 +**	**$300 +**	**$600 +**	**$1,200 +**	**$2,400 +**	**$4,800 +**
Journal Listing	X	X	X	X	X	X
Certificate	X	X	X	X	X	X
Coin	X	X	X	X	X	X
Desk Plaque			X	X	X	X
TAPR/AMSAT Dinner @ Dayton				X	X	X
Symposium Admission					X	X
President's Symposium Lunch					X	X
Symposium VIP Recognition						X

Important:

- President's Club membership is separate from AMSAT Annual Membership.
- Recognition items available for U.S. addresses only. For contributions from elsewhere please contact Frank Karnauskas, VP-Development at f.karnauskas@amsat.org.
- AMSAT is a 501(c)(3) corporation. Donations may be tax deductible. Check with your tax advisor.

Hope, KM4IPF, really enjoys getting out and activating grids on the FM satellites! In this photo, she was activating FM26 from the Wright Brothers Monument in Kill Devil Hills, NC. She was first licensed at age 8 and received her Extra Class license at age 9.

AMSAT Needs YOU!

We couldn't keep amateur radio in space without a large team of dedicated volunteers. AMSAT needs volunteers in several areas, and you don't need to have a technical or science background to be of service.

Here are several opportunities to launch your amateur radio experience to new heights and help your fellow satellite operators and AMSAT members along the way:

Copy and Upload Telemetry – Monitor the health of our satellites using FoxTelem and FUNcube Dashboard. The telemetry reports we receive provide critical, real-time information on satellite health.

Contribute Satellite Status Information – If you use, hear or *don't hear* a satellite, tell the community! File a report on the AMSAT Live OSCAR Satellite Status Page at https://www.amsat.org/status

AMSAT Ambassador – Be the face and the voice of AMSAT! Make hamfest satellite demos, present at club meetings, answer e-mail and Facebook questions, and be an Elmer for new ops. For more information see https://www.amsat.org/ambassador/

AMSAT News and Communications – Help with writing and editing the *AMSAT Journal* and the weekly AMSAT News Service Bulletins.

Website Support – We're always looking for web developers with experience in WordPress, database management, and Wild Apricot.

Satellite Development – If you have hardware or software technical skills, and proven experience directly applicable to satellite design, you might have what it takes to help the engineering team specify, design, build, test, and launch our amateur satellites.

Educational Activities – AMSAT needs volunteers with a background in education and classroom lesson development.

For more information about volunteering to help AMSAT, go to
https://www.amsat.org/volunteer-for-amsat/

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