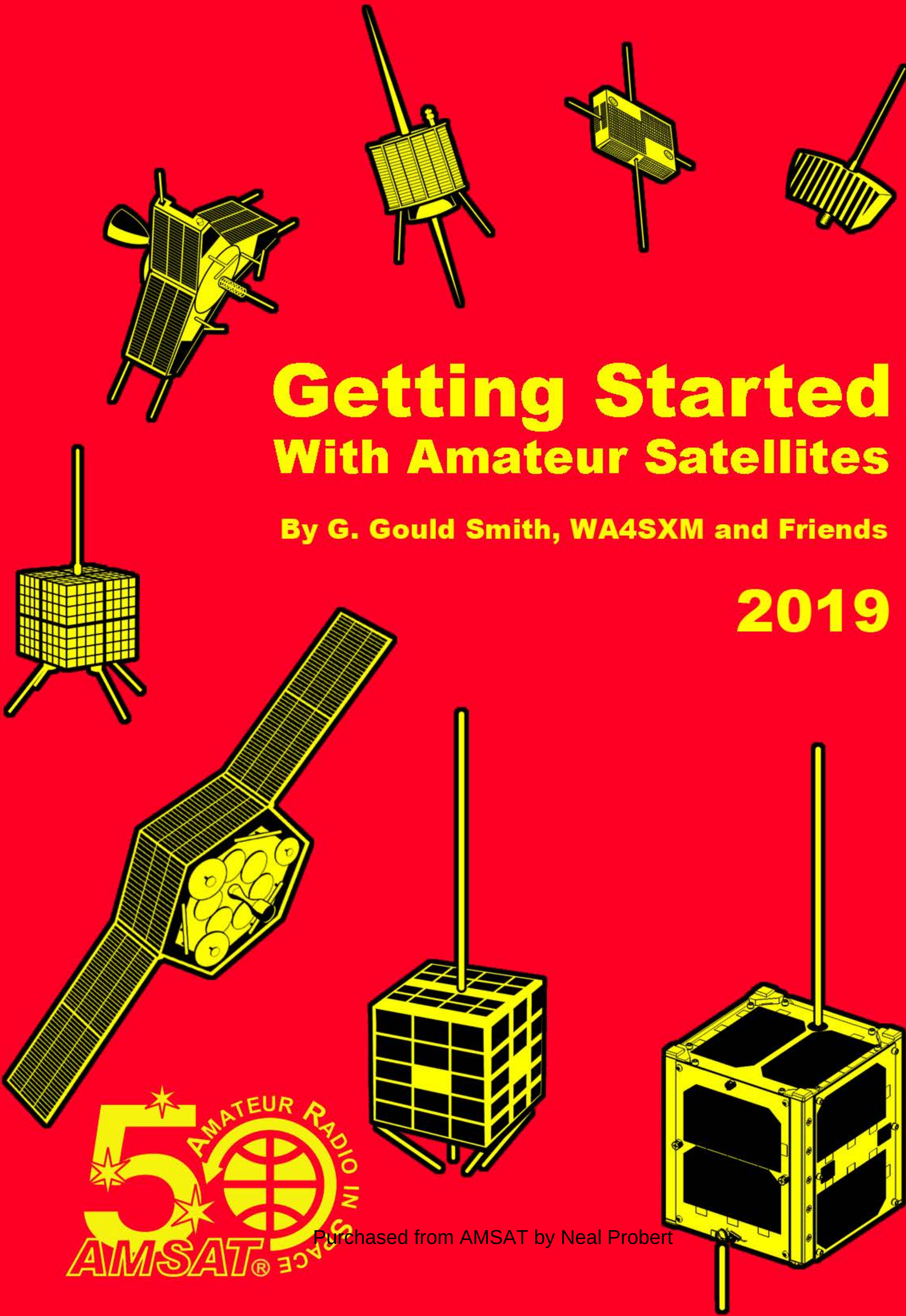
Getting Started
With Amateur Satellites

By G. Gould Smith, WA4SXM and Friends

2019



Hector, CO6CBF/W5CBF; Paul, N8HM; Michael, KD8QBA; Clayton, W5PFG; and Wyatt, AC0RA pose outside the 2014 AMSAT Symposium in Baltimore, Maryland.

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Gould Smith's

Getting Started With Amateur Satellites 2019

Including These Amateur Satellites:

AO-7, AO-73, AO-85, AO-91, AO-92, AO-95, CAS-4A, CAS-4B, EO-88, FalconSAT-3, FO-29, FO-99, Fox-1E (RadFxSat-2), FUNcube-4 (ESEO), International Space Station (ISS), JO-97, LilacSat-2, SO-50, XW-2A, XW-2B, XW-2C, XW-2D and XW-2F

G. Gould Smith, WA4SXM
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Revisions contributed by
Alan Biddle, WA4SCA
Patrick Stoddard, WD9EWK / VA7EWK
Frank Bauer, KA3HDO
JoAnne Maenpaa, K9JKM
Jim Wilson, K5ND
Sean Kutzko, KX9X
Steve Belter, N9IP

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-NA.** The authors do not receive royalties from this guide.

AMSAT-NA
10605 Concord St, Suite 304
Kensington, MD 20895
(888) 322-6728 US toll free
(301) 822-4376
martha@amsat.org

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 each year. 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!

Alan Biddle, WA4SCA
Jim Wilson, K5ND
Steve Belter, N9IP
n9ip@amsat.org

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 FM satellites SO-50, AO-91, and AO-92.

In addition to the "legacy" amateur satellites like AO-7, FO-29, SO-50, and the International Space Station (ISS), there are many new satellites. Many of these are telemetry-only (transmit only, no transponder) and have a lifetime of only a few weeks to a few months. But some, like AO-73, CAS-4A, CAS-4B, EO-88, Fox-1E, JO-97, XW-2A, XW-2B, XW-2C, XW-2D, and XW-2F have general-purpose transponders that support SSB phone and CW.

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. The examples will use long-duration satellites, but the same techniques will work on satellites with shorter lifetimes. 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 "EasySats" – SO-50, AO-91, and AO-92. 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 – AO-7, CAS-4A, CAS-4B, FO-29, Fox-1E (expected launch summer 2019), XW-2A, XW-2B, XW-2C, XW-2D, and XW-2F.

We have included 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, so we have omitted coverage of some exotic satellites in the interests of clarity and brevity.

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.

Here is Tom, KA6SIP, operating a satellite from the tailgate of his pickup truck.

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?

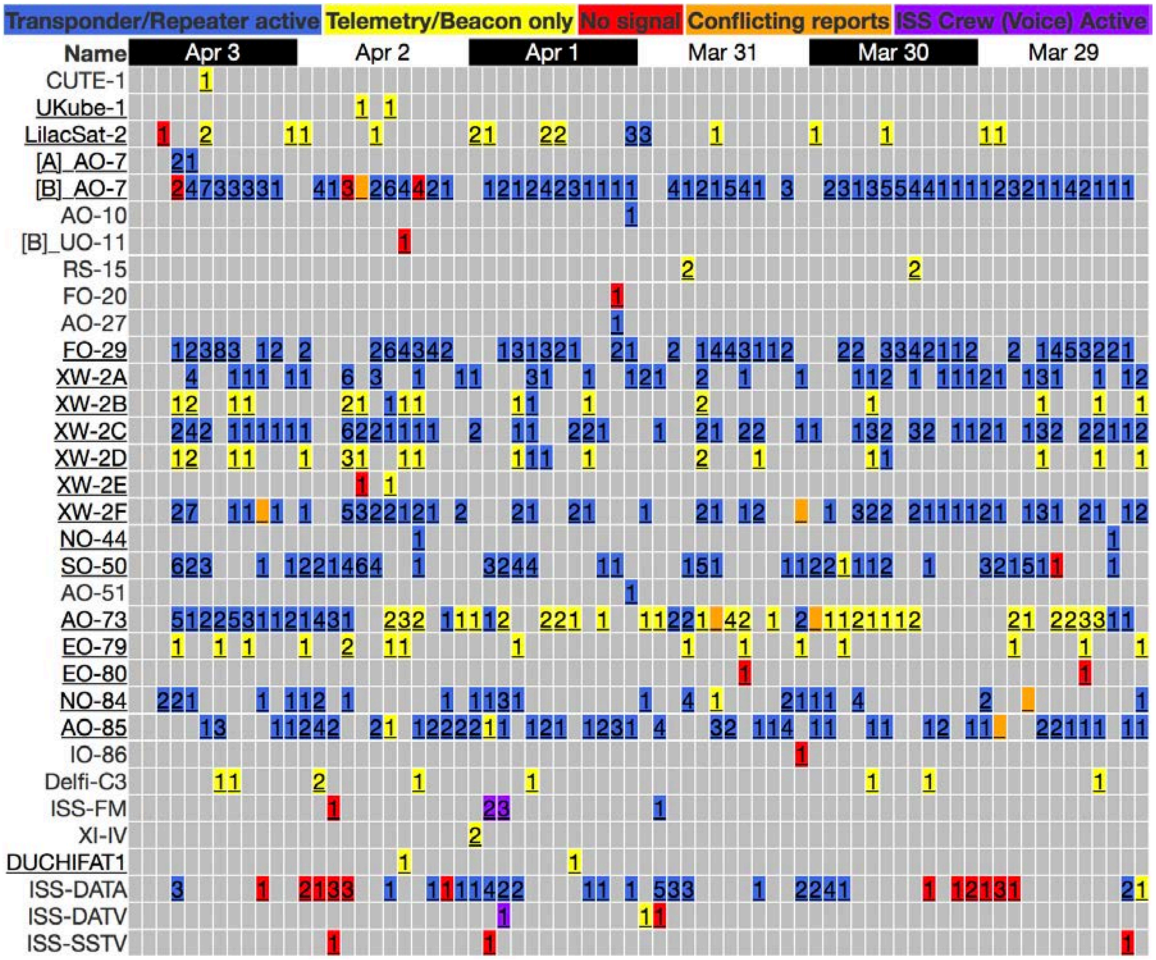
- Finish reading this *Introduction to Satellites* chapter so that you can identify which amateur satellites are currently operational.
- Read the next chapter, *Satellite Basics*, to gain an appreciation for types of satellite orbits and the Doppler effect. (In a hurry? Skim or skip this chapter.)
- Pick a tracking application or website from the *Locating Amateur Satellites* chapter so that you can determine when the satellites will be over your location.
- Use the *Your Antenna System* chapter to select an antenna for working the satellites, then build, borrow, or buy one.
- A number of equipment options are in the *Your Radio System* chapter. If you don't already own radios that will work, you'll need to borrow or buy one.
- Read the *Operating the FM Satellites* chapter, then pick a satellite and read its chapter too.
- 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 "Mailing Lists and Services".

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

If you use Twitter, follow @AMSAT, @AMSAT-UK, @ARISS_status, and @rs0iss for more real-time satellite information.

AMSAT issues weekly news and satellite status. You can sign-up for the AMSAT News Service (ANS) bulletins on the AMSAT website, or send a message to majordomo@amsat.org with 'subscribe ANS' in the text body, no subject needed.

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.

Note: In an attempt to make this guide as useful as possible, we have included information on a number of satellites that should be available for amateur use "soon". You can get up-to-the-minute status at https://www.amsat.org/status and progress reports at https://www.amsat.org .

Here is a summary of the status of the satellites mentioned above as of April 2019:
ISS: Intermittent schedule, FM packet, FM voice and SSTV
AO-91 (RadFxSat, Fox-1B): Working, FM voice
AO-92 (Fox-1D): Working, FM voice
ESEO: Undergoing commissioning, FM voice
LilacSat-2: Intermittent schedule, FM voice
PO-101: Undergoing commissioning, FM voice
SO-50: Working, FM voice
AO-7: Working, SSB/CW
AO-73: Working, SSB/CW
CAS-4A: Working, SSB/CW
CAS-4B: Working, SSB/CW
EO-88: Working, SSB/CW
FO-29: Working, SSB/CW
FO-99: Working, SSB/CW
Fox-1E (RadFxSat-2): Launch NET Summer 2019, SSB/CW*
JO-97: Undergoing commissioning, SSB/CW
XW-2A: Working, SSB/CW
XW-2B: Working, SSB/CW
XW-2C: Working, SSB/CW
XW-2D: Working, SSB/CW
XW-2F: Working, SSB/CW
FalconSAT-3: Working, FM packet
** NET is an acronym for No Earlier Than.*

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

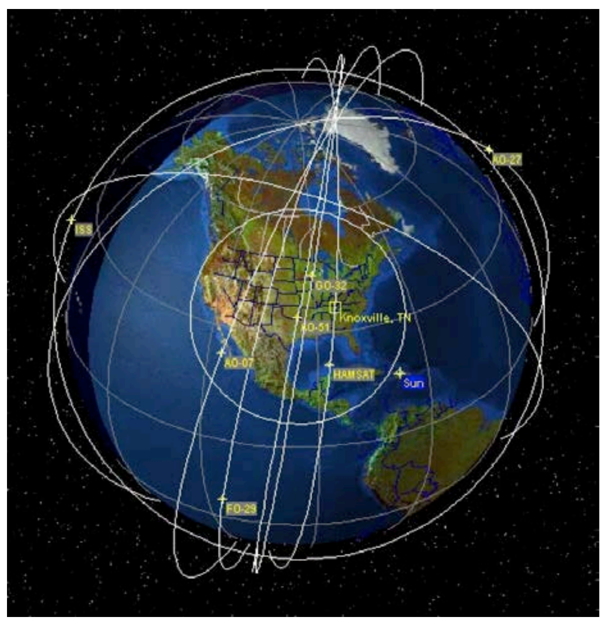
Before we jump into tracking, antennas, radios and operating, we'll cover some background information that should give you a basic understanding of the environment in which you'll be working: satellite orbits, Doppler shift, and satellite names.

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 the FM "EasySats" is about 90 to 110 minutes, depending on the altitude of the "bird".

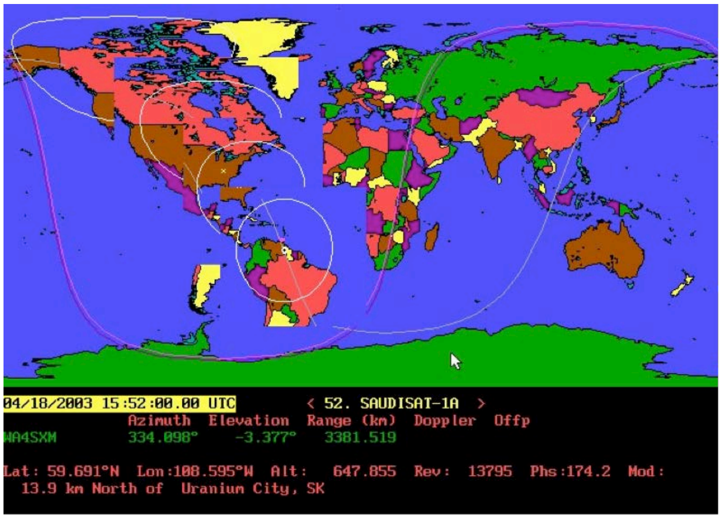
Some of the LEO satellites are in polar orbits that go over both the North and South Poles, crossing the equator at nearly 90°. Polar orbit amateur satellites include AO-7, AO-73, AO-91, AO-92, and FO-29, and make passes over the entire earth. If in addition the inclination is 98 degrees, the orbit is called a Sun Synchronous Orbit (SSO) and passes over a location at the same times daily. Other satellites are inclined to more of a diagonal as they cross the equator, like SO-50, AO-85, and the ISS. These satellites don't cover the polar areas of the earth.



This photo from the satellite-tracking program Nova shows the orbits of a number of amateur LEO satellites.

The earth spins to the east under the satellites as they orbit. For example, during the time it takes AO-73 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.

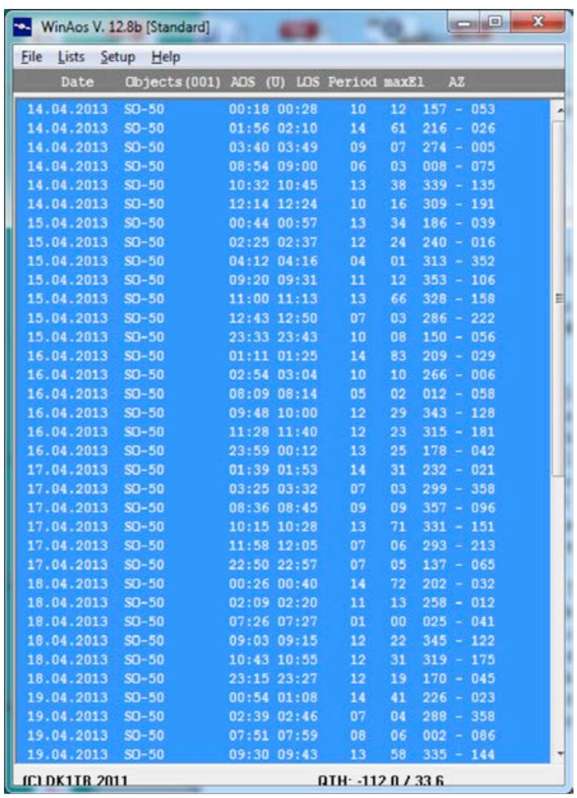
A satellite's footprint is the area of the earth that can be seen from the satellite, which is important as nearly all amateur satellite communication is line-of-sight.



The screen on the left is a collage that shows the footprint of the satellite as it moves across North America; it also shows the path of the next orbit. The path that the satellite footprint follows on the earth's surface is known as the **ground track.**

As you can see in the WinAOS list of SO-50 passes below, most passes are 10 to 15 minutes each. This is the value listed under Period. 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 SO-50 each day. The values listed under AZ show the beginning and ending azimuth of the pass. So with this information and the elevation data you should be able to print this sheet and use it to track the satellite outside without any other help.

WinAOS is part of the SatPC32 software package described in Appendix B, *Upgrading Your Amateur Satellite Station*. Other satellite tracking options are covered in Chapter 3, *Locating Amateur Satellites*.

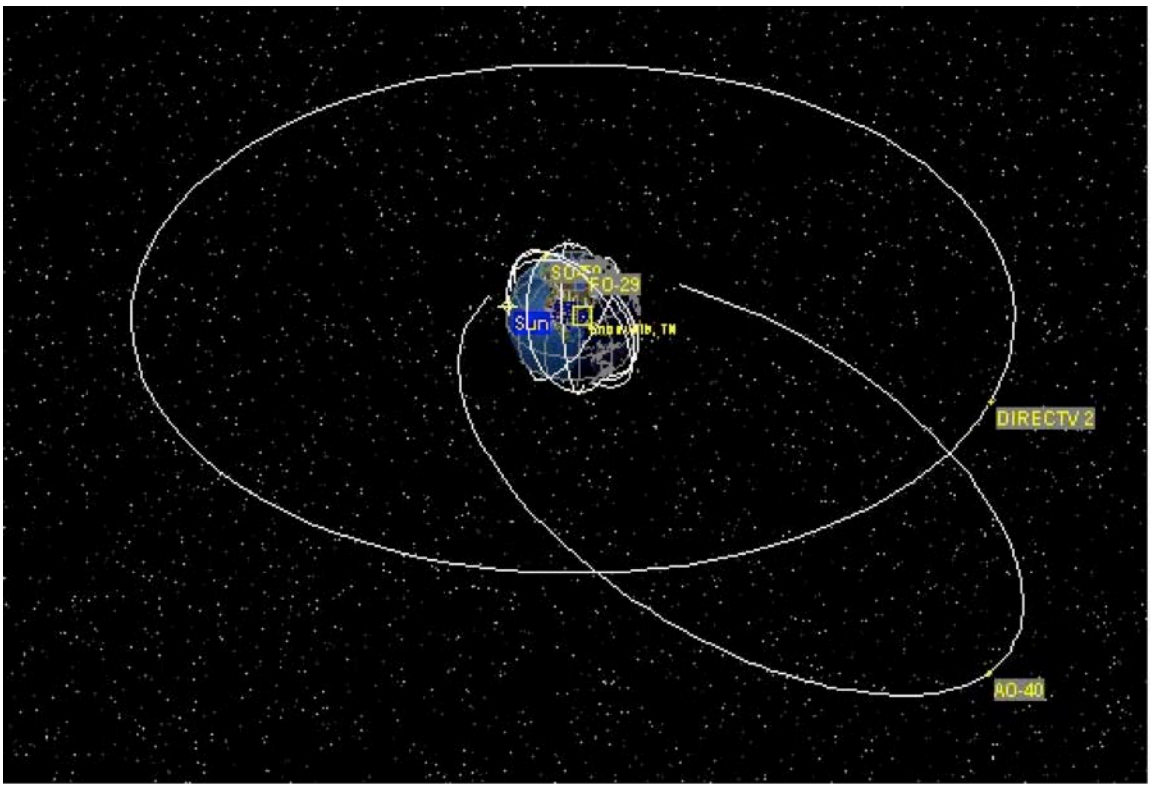


Date	Objects(001)	AOS	(U) LOS	Period	maxEl	AZ
14.04.2013	SO-50	00:18	00:28	10	12	157 - 053
14.04.2013	SO-50	01:56	02:10	14	61	216 - 026
14.04.2013	SO-50	03:40	03:49	09	07	274 - 005
14.04.2013	SO-50	08:54	09:00	06	03	008 - 075
14.04.2013	SO-50	10:32	10:45	13	38	339 - 135
14.04.2013	SO-50	12:14	12:24	10	16	309 - 191
15.04.2013	SO-50	00:44	00:57	13	34	186 - 039
15.04.2013	SO-50	02:25	02:37	12	24	240 - 016
15.04.2013	SO-50	04:12	04:16	04	01	313 - 352
15.04.2013	SO-50	09:20	09:31	11	12	353 - 106
15.04.2013	SO-50	11:00	11:13	13	66	328 - 158
15.04.2013	SO-50	12:43	12:50	07	03	286 - 222
15.04.2013	SO-50	23:33	23:43	10	08	150 - 056
16.04.2013	SO-50	01:11	01:25	14	83	209 - 029
16.04.2013	SO-50	02:54	03:04	10	10	266 - 006
16.04.2013	SO-50	08:09	08:14	05	02	012 - 058
16.04.2013	SO-50	09:48	10:00	12	29	343 - 128
16.04.2013	SO-50	11:28	11:40	12	23	315 - 181
16.04.2013	SO-50	23:59	00:12	13	25	178 - 042
17.04.2013	SO-50	01:39	01:53	14	31	232 - 021
17.04.2013	SO-50	03:25	03:32	07	03	299 - 358
17.04.2013	SO-50	08:36	08:45	09	09	357 - 096
17.04.2013	SO-50	10:15	10:28	13	71	331 - 151
17.04.2013	SO-50	11:58	12:05	07	06	293 - 213
17.04.2013	SO-50	22:50	22:57	07	05	137 - 065
18.04.2013	SO-50	00:26	00:40	14	72	202 - 032
18.04.2013	SO-50	02:09	02:20	11	13	258 - 012
18.04.2013	SO-50	07:26	07:27	01	00	025 - 041
18.04.2013	SO-50	09:03	09:15	12	22	345 - 122
18.04.2013	SO-50	10:43	10:55	12	31	319 - 175
18.04.2013	SO-50	23:15	23:27	12	19	170 - 045
19.04.2013	SO-50	00:54	01:08	14	41	226 - 023
19.04.2013	SO-50	02:39	02:46	07	04	288 - 358
19.04.2013	SO-50	07:51	07:59	08	06	002 - 086
19.04.2013	SO-50	09:30	09:43	13	58	335 - 144

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. The Phase 4A (P4A) QO-100 / ES'HailSat-2 satellite has a geosynchronous orbits (GSO). The screen shot below shows LEO orbits clustered around the earth, a GSO circular orbit labeled DIRECTV2, and a HEO Molniya orbit labeled AO-40.



High Earth Orbit (HEO)

HEO orbits are what the Phase 3 amateur satellites use (AO-10, AO-13, AO-40 and the proposed P3E). Many of these are also Molniya orbits because they favor the Northern Hemisphere. 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. Notice that these HEO orbits are much further out than the geo-synchronous orbits. The Phase 3 satellites 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 AO-73 and EO-88 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. EO-79 is a good example that does not operate in the “penguins and polar bear” regions to conserve power for use over populous areas.

Finally, modes may be selected by the command stations for many other reasons. For instance, AO-92 has a camera that will downlink pictures of the earth. However, since the voice repeater and the camera cannot be operated at the same time, the camera will need to be scheduled to maximize the probability of capturing useful pictures while minimizing the impact on communications. Satellites with these types of features are normally operated on a published schedule. For instance, AO-73 normally operates autonomously as described above, but is typically 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 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, the amateur satellite SO-50 is in a LEO orbit. During an SO-50 pass you will experience a 20 kHz shift in the received 436.8 MHz frequency. If you are listening on the standard 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 standard frequency at mid-pass and go about 10 kHz lower. This isn’t a linear change either. The Doppler changes fastest during the middle part of the pass.

AO-92 has both 70 cm and 23 cm uplinks. It is a LEO satellite, too, so the 70 cm uplink will have a 20 kHz total Doppler shift. However, when the 23 cm uplink is active, it will have 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-80), 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-14).

Ernie Bauer, N1AEW demonstrates satellite operation using an Arrow antenna and a handheld transceiver.

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 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

In order 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 a number of Apple iOS and Android operating system applications for locating satellites. Here are three of them that you might consider. See the respective app stores for a current selection.

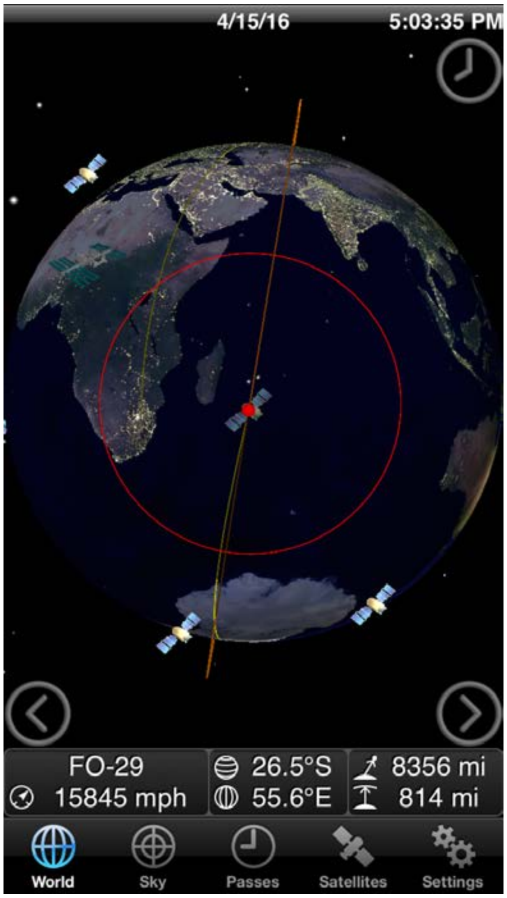
GoSatWatch (Apple iOS)

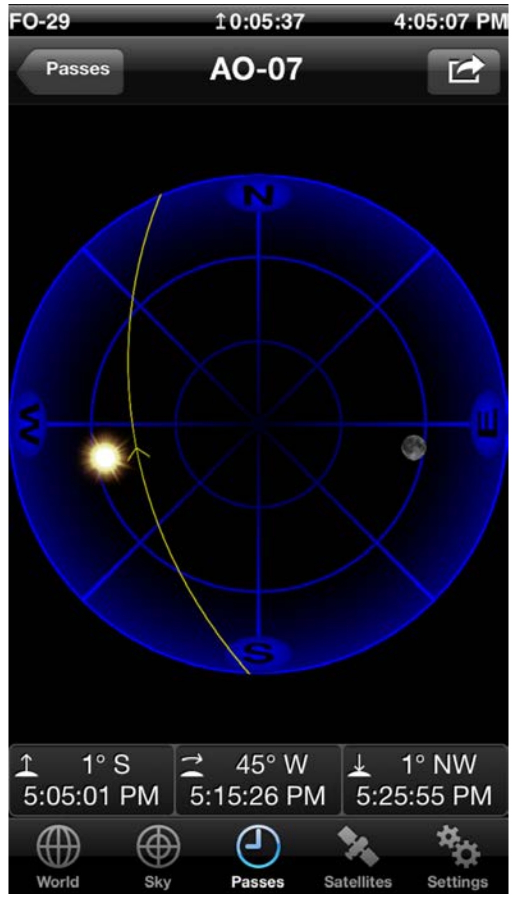
This $9.99 application works on both iPhones and iPads. The screen shot to the right shows upcoming passes for a series of amateur satellites.

Along the very top of the screen, you can see the next pass is FO-29, which will rise in 6 minutes and 13 seconds, and the current local time (4:04:31 PM).

The middle of the screen shows the next nine satellites that will be visible from your location. Second on that list is the ISS (International Space Station), which will rise at 4:34:20 PM local time, set at 4:42:17 PM, and have a maximum elevation of 10 degrees when it passes to the north of you.

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.





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).

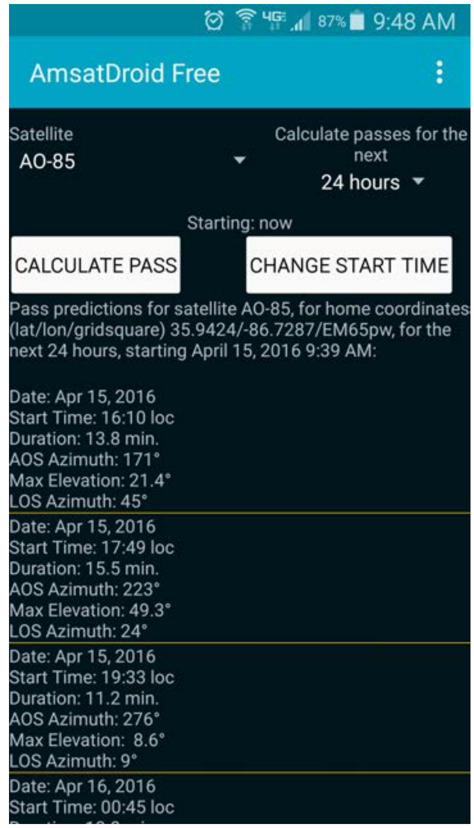
AmsatDroid FREE (Android OS)

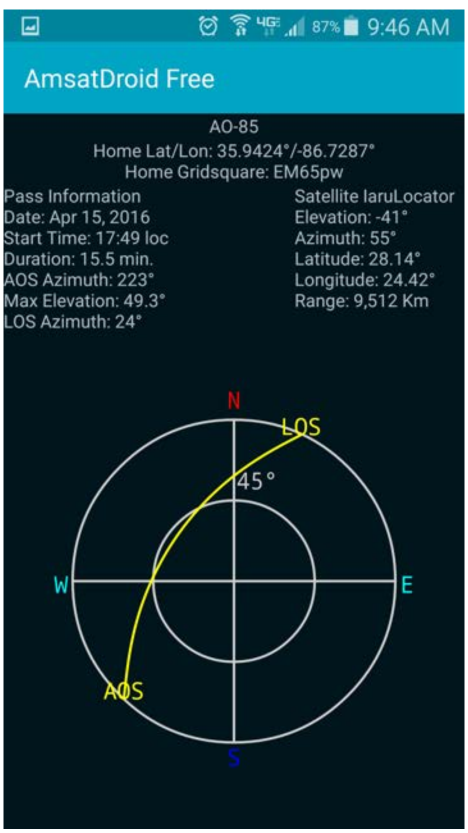
As the name suggests, this is a free app for smartphones or tablets running the Android OS. Dave Johnson, G4DPZ, one of the members of the AO-73 team, created this application.

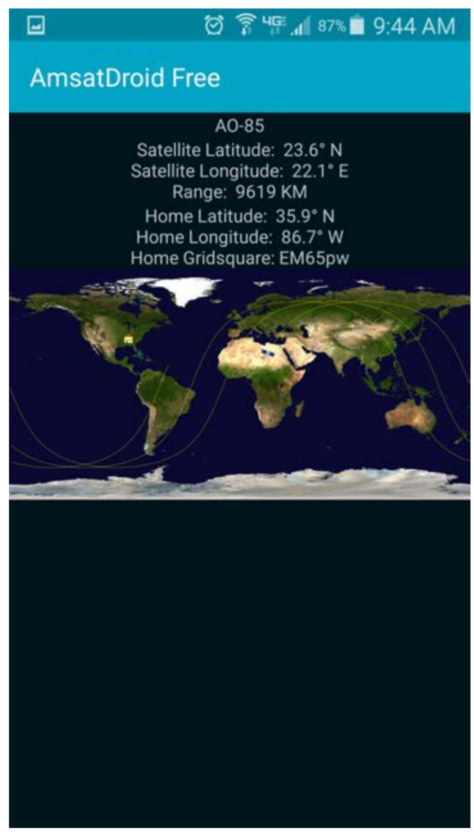
It is a basic, but popular program that will give you a 24-hour schedule of a single satellite, a nice radar display of its position as it passes, and a world map with the next three orbits shown.

The screen capture on the right lists pass predictions for AO-85, giving AOS times, maximum elevations, and AOS/LOS azimuths.

Shown below are the path AO-85 will take across the sky and the path over the earth for the next three orbits.





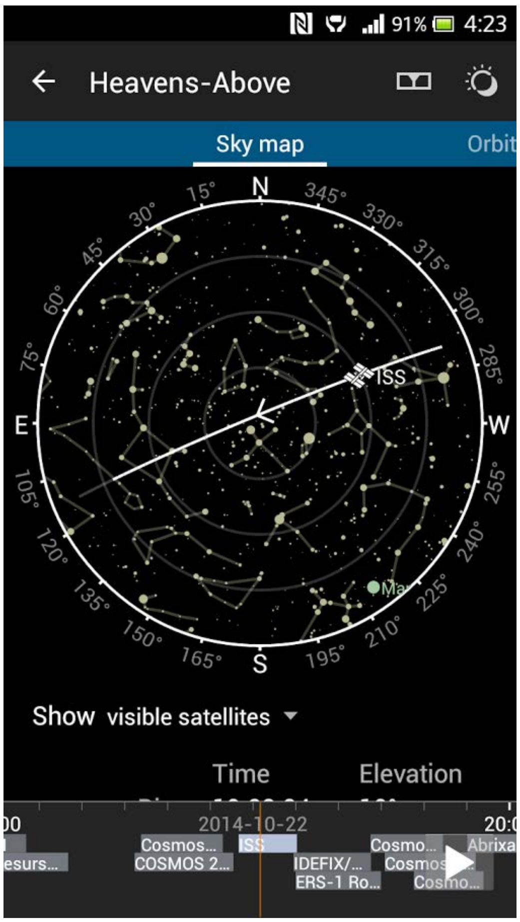


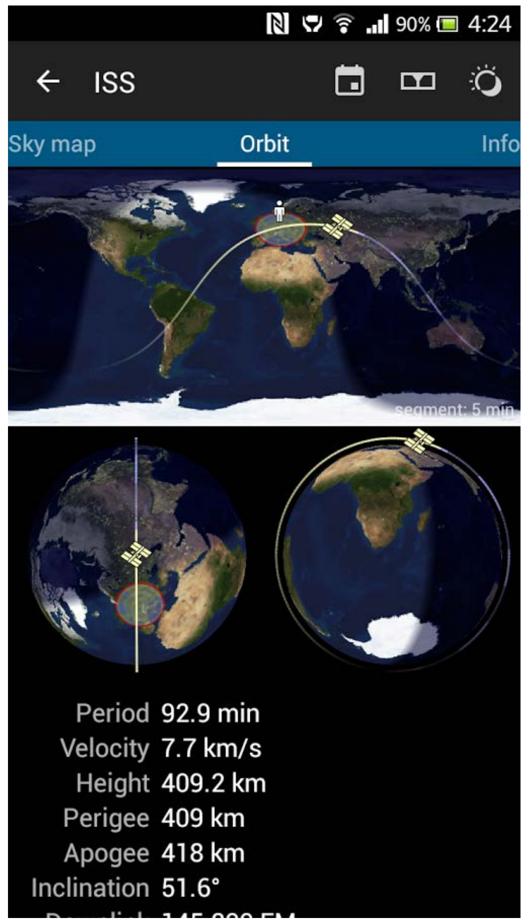
Heavens-Above (Android OS)

The Heavens-Above application for Android OS devices is free if you'll live with the advertising, or $5 for an ad-free version.

The screen capture on the right show three views of the satellite (in this case, the ISS) above the earth.

The screen capture on the left shows the path the satellite will take across the sky superimposed on the constellations. Please note that East and West are oriented correctly if you are holding the screen over your head.





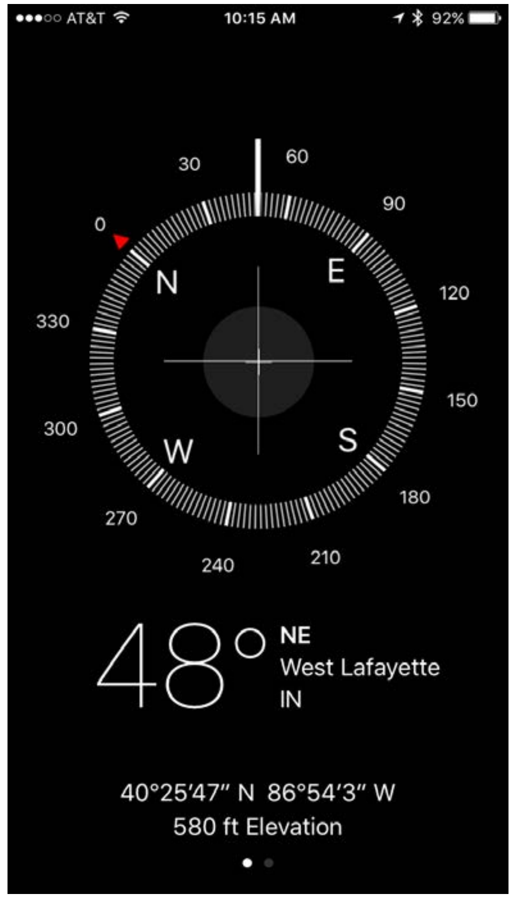
Satellite Tracking Websites

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.

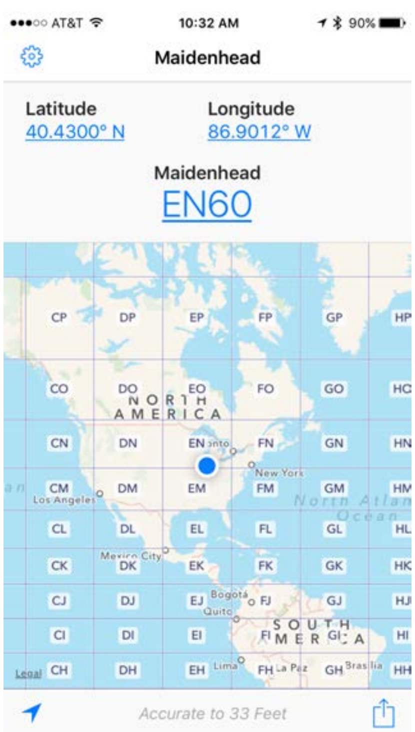
Where Are You?



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.

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".

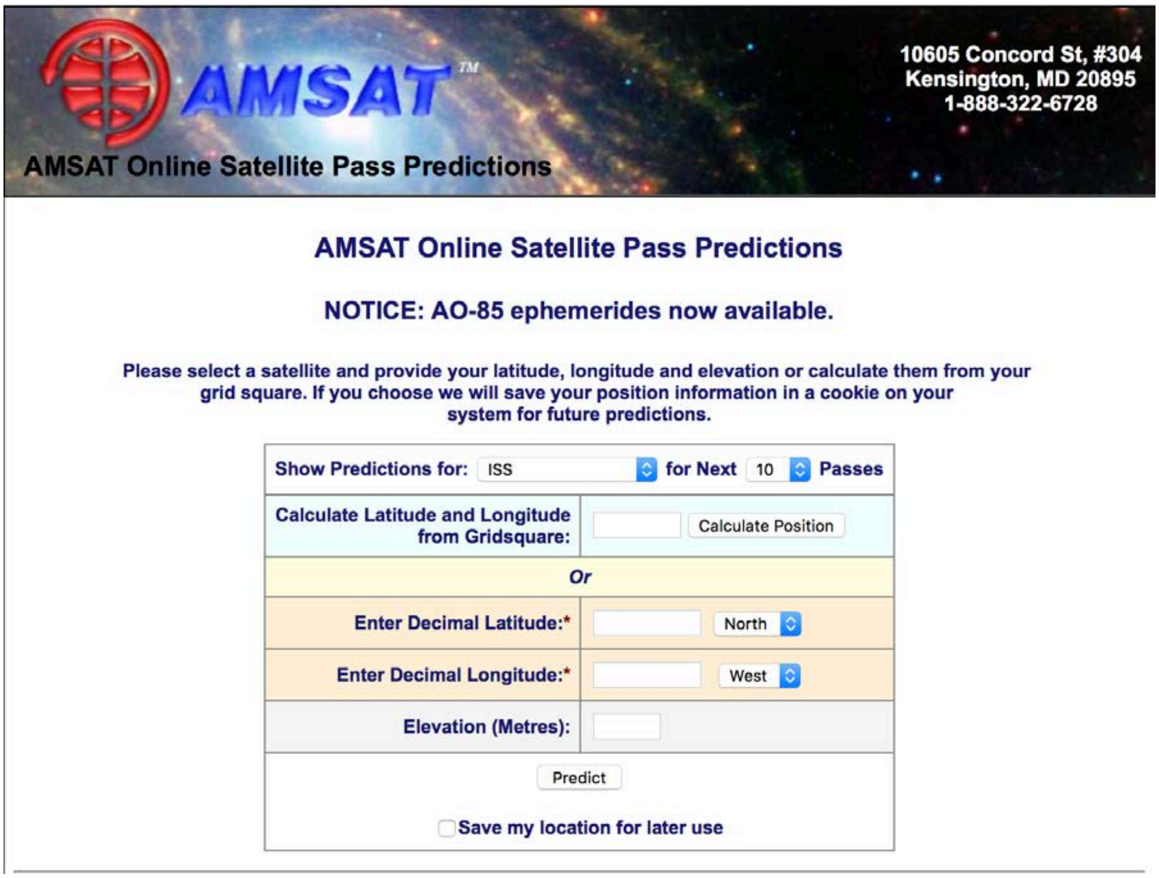


You can determine your grid square using the calculator on the AMSAT website at https://www.amsat.org/amsat-new/tools/grids.php or by using a smartphone app like Maidenhead Converter by Donald Hays (for iOS), shown in this screen capture on the left. For Android, look for HamGPS.

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)
16 Apr 16	18:03:54	00:09:46	199	20	140	66	18:13:40
16 Apr 16	19:39:47	00:10:33	248	43	343	50	19:50:20
16 Apr 16	21:17:30	00:09:13	287	14	347	48	21:26:43
16 Apr 16	22:55:08	00:09:15	309	13	10	68	23:04:23
17 Apr 16	00:31:45	00:10:24	311	31	44	105	00:42:09
17 Apr 16	02:08:16	00:10:15	298	28	245	151	02:18:31
17 Apr 16	17:12:25	00:08:31	182	10	142	75	17:20:56
17 Apr 16	18:47:20	00:10:46	234	81	323	53	18:58:06
17 Apr 16	20:24:42	00:09:44	276	17	336	48	20:34:26
17 Apr 16	22:02:33	00:09:00	305	12	5	60	22:11:33

Your results are shown above

Use the form below to request more pass predictions

Show Predictions for: ISS **for Next** 10 **Passes**	
Calculate Latitude and Longitude from Gridsquare:	EN60nk Calculate Position
Or	
Enter Decimal Latitude:*	40.4375 North
Enter Decimal Longitude:*	86.875 West
Elevation (Metres):	180
Predict	
Save my location for later use	

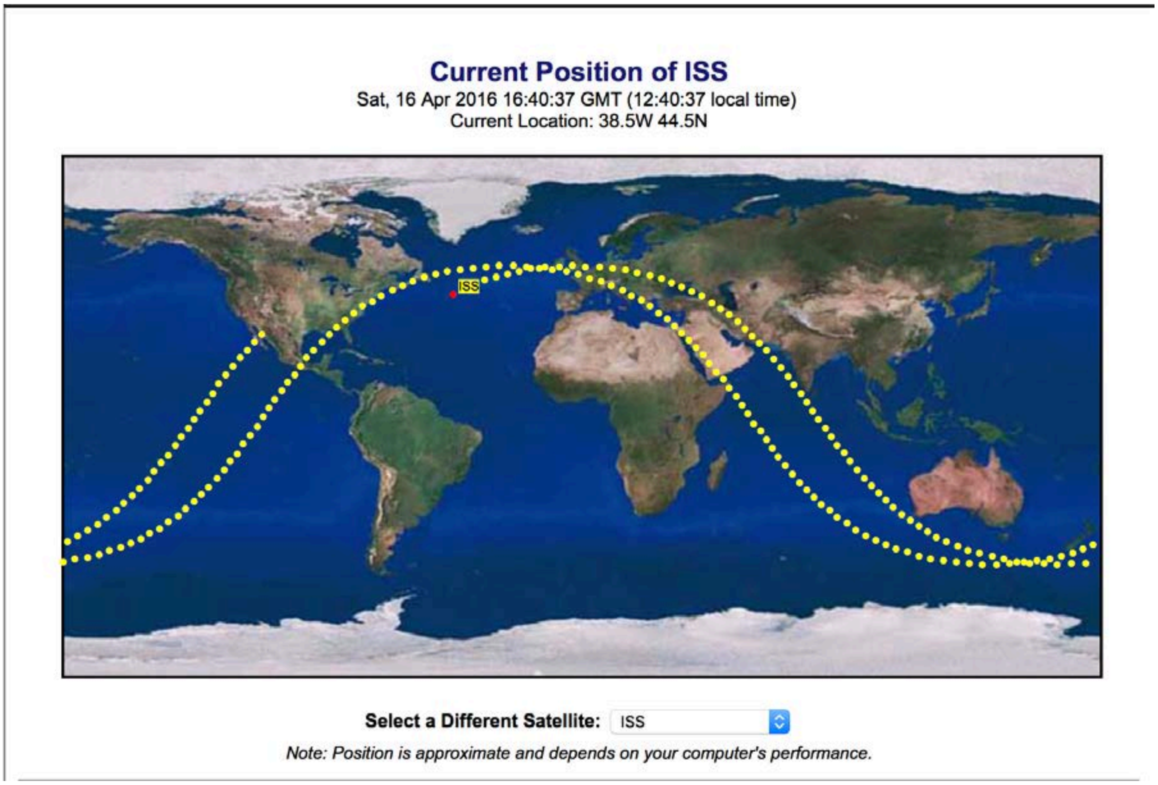
The date and time of the pass predictions are in UTC, so you'll probably need to convert them into your local time, adjusting if necessary, for daylight savings time.

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?

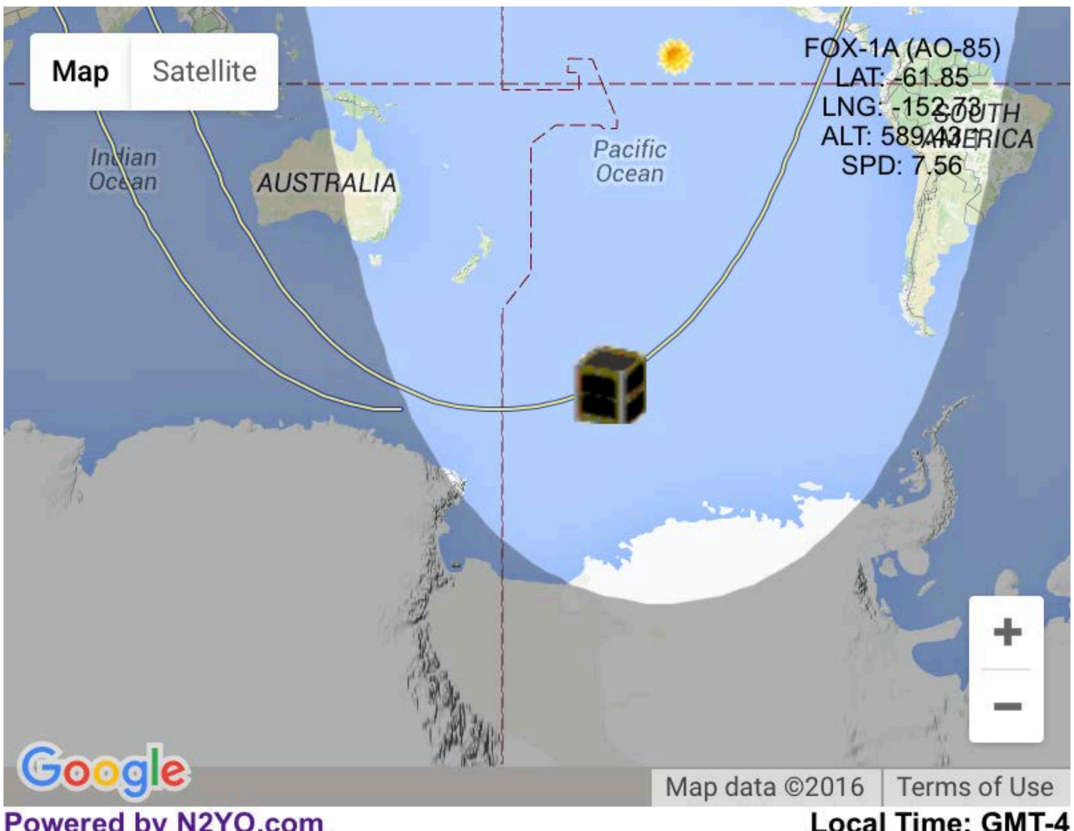
If the satellite isn’t close to you on the map, have you converted UTC to local time correctly? Did you enter your location correctly, including the hemisphere (north/south, east/west)?

N2YO's Satellite Predictions Website

Ciprian Sufitchi's live, real-time satellite tracking and predictions website has a wealth of information. In addition to amateur satellites, he also covers weather, commercial, and military satellites, and satellite news. You can find the website at: https://www.n2yo.com.

The website guesses at your location based on your IP address, which may or may not be a good approximation. You can set your location to a more precise location. It is also determining your local time by some technique that might involve the setting on your PC, so check the time carefully.

Here's a picture of part of the AO-85 page, including a prediction of the next pass:

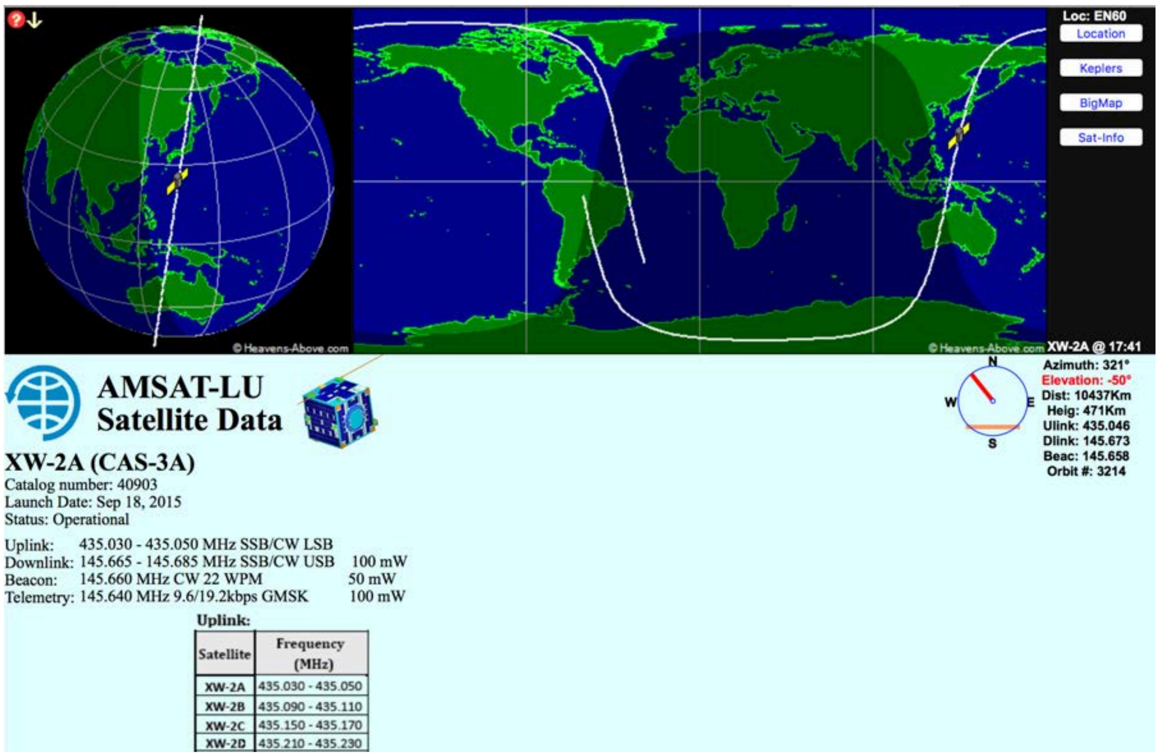


NEXT PASS OF FOX-1A (AO-85) OVER YOUR CURRENT LOCATION						
START AZIMUTH		MAX ELEVATION		END AZIMUTH		TOTAL DURATION
Apr 16 17:36	189° S	17:44	40°	17:51	40° NE	14m 55s

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:

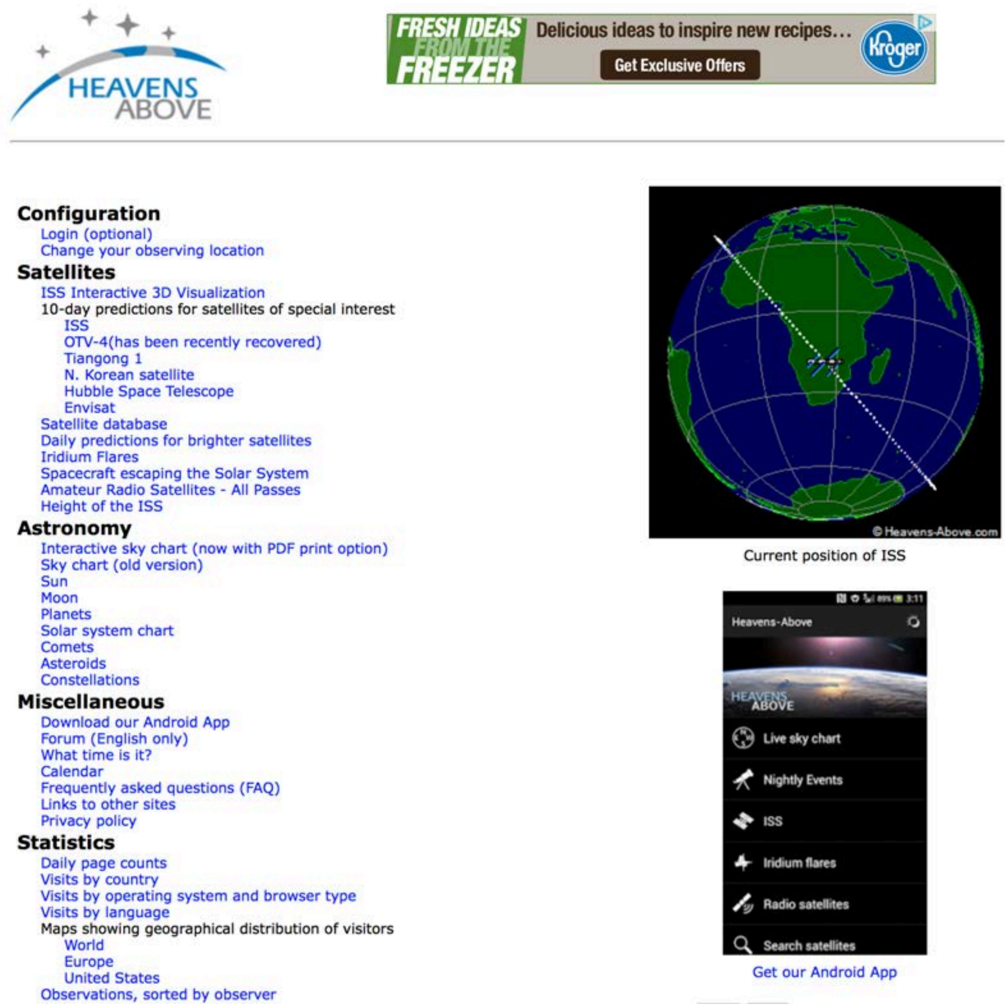


Heavens Above Website

In addition to the Heavens-Above smartphone application for Android OS discussed above, there is an extensive website devoted to astronomy and man-made satellites (the website predates the application by many years). You can find the Heavens-Above site here: https://www.heavens-above.com.

The links on the home page (shown below with advertising for a grocery store named Kroger) gives you a hint of the breadth of information that is available here. Note the link for Amateur Radio Satellites – All Passes, which takes you to a list of all amateur satellite passes over your QTH for the next 24 hours.

Click on a satellite name and the site displays information about that individual satellite.



Configuration
- Login (optional)
- Change your observing location

Satellites
- ISS Interactive 3D Visualization
- 10-day predictions for satellites of special interest
  - ISS
  - OTV-4(has been recently recovered)
  - Tiangong 1
  - N. Korean satellite
  - Hubble Space Telescope
  - Envisat
- Satellite database
- Daily predictions for brighter satellites
- Iridium Flares
- Spacecraft escaping the Solar System
- Amateur Radio Satellites - All Passes
- Height of the ISS

Astronomy
- Interactive sky chart (now with PDF print option)
- Sky chart (old version)
- Sun
- Moon
- Planets
- Solar system chart
- Comets
- Asteroids
- Constellations

Miscellaneous
- Download our Android App
- Forum (English only)
- What time is it?
- Calendar
- Frequently asked questions (FAQ)
- Links to other sites
- Privacy policy

Statistics
- Daily page counts
- Visits by country
- Visits by operating system and browser type
- Visits by language
- Maps showing geographical distribution of visitors
  - World
  - Europe
  - United States
- Observations, sorted by observer

Current position of ISS

Get our Android App

Click on the Amateur Radio Satellites – All Passes link and you'll get a long chart of all the passes for the next 24 hours that starts like this:

Amateur Radio Satellites - All Passes

Search period start: 16 April 2016 21:36 < >
Search period end: 17 April 2016 21:36
Location: Unspecified, 0.0000°N, 0.0000°E

Satellite	Date	Start	Highest point			End	Downlink Frequencies (MHz)
			Time	Altitude	Azimuth		
ZACube-1	16 Apr	21:38:11	21:42:13	33°	259° (WSW)	21:46:18	437.345
SRMSAT	16 Apr	21:38:48	21:44:35	50°	159° (SSE)	21:50:20	437.500
ISS	16 Apr	21:44:17	21:46:27	17°	54° (NE)	21:48:38	145.825
UNISAT 6	16 Apr	21:44:24	21:48:32	44°	102° (ESE)	21:52:37	437.425
SO-50	16 Apr	21:52:38	21:56:47	38°	248° (WSW)	22:00:52	436.795

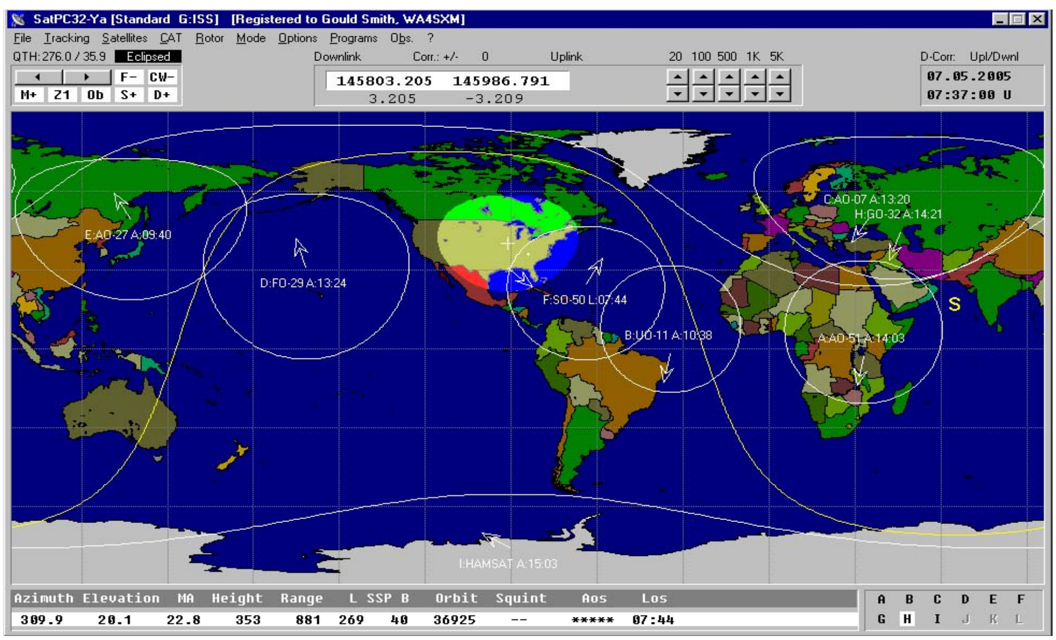
Satellite Footprint

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*.

Pete, AI4QY, and Mark, N8MH, operate AO-51 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. Fort Jefferson is in the background.

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 not often 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.*

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

Nearly all of the amateur satellites use the VHF (or 2 m) band and the UHF (or 70 cm) band simultaneously. For example, AO-91 receives on 70 cm while it simultaneously transmits on 2 m. Conversely, SO-50 receives on 2 m while it transmits on 70 cm.

As will be explained in Chapter 6, *Operating the FM Satellites* chapter, you want to be listening to your signal coming back from the satellite while you are transmitting. This is called full-duplex operation.

Most of 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 (like SO-50), 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?

The technically correct term for 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 is 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. 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 a number of 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 on the previous page shows this antenna. It is lightweight, 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. Both 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.

They also have 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 to hold for more than a couple of minutes.

Clayton, W5PFG, sometimes chooses not to install all of 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 of 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

CJU and IOio Satellite Antennas

Juan Antonio Fernández Montaña, EA4CYQ, has designed two satellite antennas that perform very well.

The CJU antenna is a 70-cm only antenna that connects directly to the BNC connector on top of an HT; you point the HT and its antenna towards a satellite that is transmitting on UHF. A picture of Juan using the CJU is shown in the next section.

Juan's IOio antenna is a dual-band version of the CJU with both a 2 m and 70 cm antenna on the same PVC pipe.

You can find instructions for building these antennas at: http://www.ea4cax.com/paginaea4cyq/cju/cjuingles.pdf and http://www.ea4cax.com/paginaea4cyq/Antenaioio/ioioingles.pdf

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, try to avoid generic or "equivalent" low-loss coax.

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. A dual-band FM transceiver can be used for QSOs through the FM satellites, if it is one of the few transceivers capable of simultaneous transmit on one band and receive on the other. A pair of almost any FM transceivers will also work.

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

As mentioned in Chapter 4, *Your Antenna System*, nearly all of 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 FM satellite AO-91 receives on 70 cm while it simultaneously transmits on 2 m. Conversely, SO-50, also an FM bird, receives on 2 m while it transmits on 70 cm. The discussion here will concentrate on radios that can be used for these two bands.

Your radio system will likely fall into one of two 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

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.

The FM satellites only allow a single conversation at a time. The SSB/CW satellites, depending on the frequency width of the transponder, allow three to 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.

Full-Duplex Operation

If you are looking for a transceiver to use for amateur satellite operation, make sure that it has full-duplex capability. That is, you can listen on one band and transmit on another at the same time. Some radios offer 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.

With the FM satellites, you want to be able to hear your audio coming back from the satellite so that you know what everyone else is hearing when you transmit. 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 becoming increasingly 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.

Transmitter Power

For voice LEO satellites, 5-10 watts uplink power is the maximum that should be used. Many people use excessive transmit power because their receive system is inadequate. 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.*

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. Many times AO-7, which only runs directly off the solar panels, shuts down because of excessive uplink signals requiring too much power from the solar panels to re-transmit.

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, or a Cheap Yagi, 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!

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.

Full-Duplex FM Handhelds 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. We don't recommend buying one of these radios just for operating the FM satellites. Only the Kenwood TH-D72A is currently in production. The TH-D72A is expensive, but it does have APRS features that make it useful for applications in addition to FM satellite operation. Kenwood now makes a TH-D74A, but it is not full duplex.

- Icom IC-W2A
- Icom IC-W32 (early versions with 5-digit serial numbers only)
- Kenwood TH-D7 (in photo to the right)
- Kenwood TH-D72A (only radio in current production)
- Yaesu FT-470
- Yaesu FT-530
- Yaesu FT-51R

Full-Duplex FM Handhelds for U/v only

Some handheld radios claim to be full duplex but will only work for the U/v satellites like AO-91 and AO-92. When configured for V/u operation for SO-50 or LilacSat-2, 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.

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

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

A number of 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 have APRS features that are useful for situations in addition to FM satellite operation.

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

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

Full-Duplex FM and SSB/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 chose to buy a radio specifically for your satellite operation. (You do have other options using two radios; see below.) Only the IC-9100 and IC-9700 are 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
- Icom IC-821H
- Icom IC-910H
- Icom IC-970
- Icom IC-9700 (currently in production)
- Icom IC-9100 (currently in production)
- Kenwood TS-790
- Kenwood TS-2000 (has birdie that interferes with SO-50 receive)
- Yaesu FT-726 (needs satellite module and tone module)
- Yaesu FT-736 (needs tone module)
- Yaesu FT-847

The photo below is of the front panel of an Icom IC-821H.

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)
- Yaesu FT-817
- Yaesu FT-818 (currently in production)
- Yaesu FT-857 (currently in production)
- Yaesu FT-897
- Yaesu FT-991
- Yaesu FT-991A (currently in production)

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.

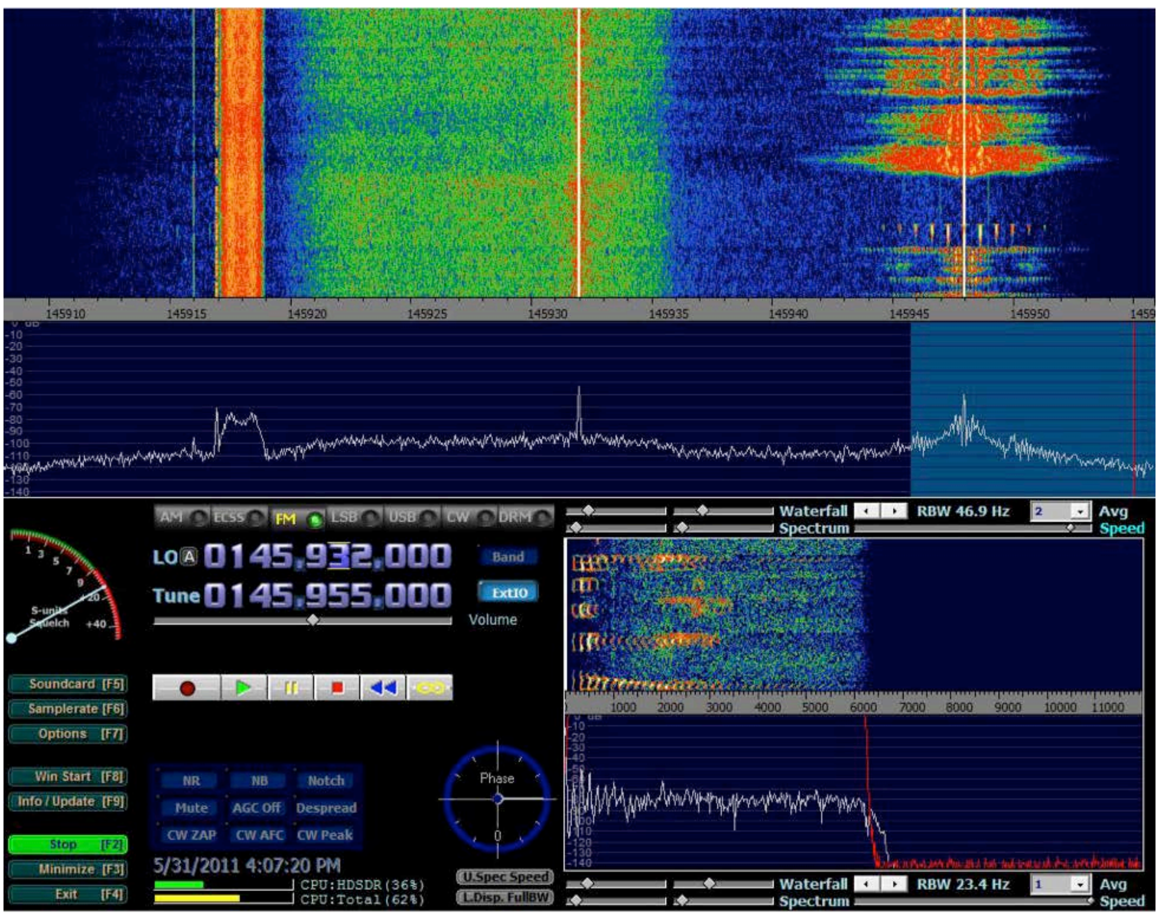
Some hams use a pair of FT-817 radios (one for transmit and one for receive), calling the combination an FT-1634.

Software Defined Receiver

A Software Defined Receiver (SDR) combines an RF interface for a computer and some very sophisticated software. The computer runs software that acts as a multiband, multimode receiver with 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 of 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 rapidly growing in popularity.

The computer screen shot below shows the entire ARISSat-1 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. The ARISSat-1 satellite burned up during re-entry into the atmosphere on 4 Jan 2012.



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 SDR receivers are listed below.

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-Radio, and HDSDR, the FCD will show you the signals from the satellite as you listen to FM, CW, and SSB through your headphones connected to the computer audio output. 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 on FO-29 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 (for AO-85, AO-91, AO-92, AO-95, and Fox-1E), and the AMSAT-UK FUNcube Dashboard (for AO-73 and EO-88). The FCD Pro+ works well with HDSDR, SDR-Radio, and SDR#.

A portion of the profits from the sale of the FCD Pro+ goes to support 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 RSP 1A, 2 and 2pro

The SDRplay RSP (Radio Spectrum Processor) 1A tunes from 1 kHz to 2 GHz, contains a 14-bit ADC and has 11 switchable front-end filters. The RSP 1A is usable with HDSDR, SDR-Radio, and their SDRUNO software, but is currently not supported by SDR#.

Additional information on the RSP 1A, RSP 2, RSP 2pro, and purchase details are located at https://www.sdrplay.com.

Airspy R2 and Airspy Mini

Benjamin Vernoux and Youssef Touil designed the Airspy SDR Receiver. Youssef is the author of SDR#, one of the three most popular SDR Windows-based software applications (see below). Revision 2 of the Airspy covers 24 MHz to 1.8 GHz, has a 12 bit ADC and samples at 10 MHz (9 MHz usable bandwidth). It includes a front-end tracking filter.

Look here for more information on the Airspy and Mini: https://v3.airspy.us.

DVB-T Dongle

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.

If your budget is limited and you're skilled with computers, the DVB-T dongles using the RTL2832U and R820T2 chipsets 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 have to replace the standard Windows device drivers with custom drivers for this application, a somewhat challenging operation. Windows updates can replace your hard work with newer television drivers, giving you the opportunity to try to replace the drivers again.

For current information and articles on installing and using a DVB-T SDR dongle for amateur radio, use Google to search for “RTL SDR Dongle” and “Zadig” (device drivers). One of the sites Google will take you to is https://www.rtl-sdr.com.

SDR Receiver Software

There are a lot of software packages for processing the data stream from an SDR receiver, which can convert your PC or tablet computer into an amazing radio. The three programs listed below are the most popular for the Windows operating system, and are free. There are also programs for Apple’s OS X (e.g., CuteSDR and GQRX) and Linux (e.g., Linrad, GQRX, and GNUradio).

HDSDR

The HDSDR package was written by Mario Taeubel, and is an advanced version of Winrad written by Alberto di Bene, I2PHD. Many people find that it is a great program with which to begin. 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-Radio

Simon Brown is the author of SDR-Radio and Ham Radio Deluxe. One of the interesting features of Simon’s software is the ability to have up to six 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.

You can download the current operational software, version 3.0.7, at https://www.sdr-radio.com which includes some satellite tracking features.

SDR#

Pronounced “S-D-R sharp”, this software is the product of Youssef Touil. There are many fans of SDR#, and it might work for you if it supports your SDR hardware: it works with the Airspy (obviously) and FUNcube Dongle Pro+, but not with the SDRplay RSP. SDR# includes some very advanced filtering, squelch, and other features.

Go to https://airspy.com/download/ to download the current version of SDR#.

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, low uplink power, minimum antenna satellites. The FM repeater mode is outstanding for satellite demonstrations, general use, and a low-cost entry into satellite operations.

Step 1: Pick one or more FM satellites

There are five FM amateur satellites that are working, have been available in the past, are waiting to be commissioned, or are scheduled to launch: AO-85, AO-91, AO-92, LilacSat-2, and SO-50.

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 status page shows that it is working, AO-91 is a good choice for your first contact. It hears well and has a strong signal, but it is a U/v satellite, so a little harder to operate.

SO-50 is also a good satellite for your first QSO. It has an excellent receiver, but a weak downlink. If you can hear SO-50, since it 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- and six-character Maidenhead grid square (for example, EN60 and 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 great deal of 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'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 of 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 4: Program your radio

If your radios have frequency memories, 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 SO-50. There are some not obvious differences for a U/v satellite (like AO-91) 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, SO-50 is a V/u satellite and the nominal frequencies are:

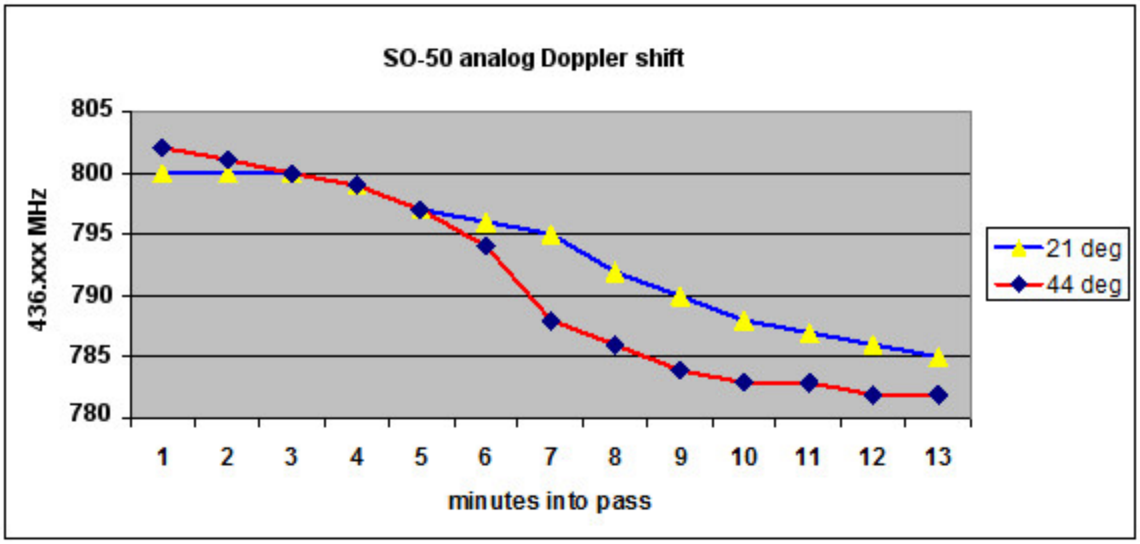
Uplink: 145.850 MHz FM *[with 67.0 Hz CTCSS tone]*
Downlink: 436.795 MHz FM *[±10 kHz for Doppler]*

During an SO-50 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. Use your memory channels to tune the receiver during the pass to keep the signal strong and to minimize off-frequency distortion.

For SO-50, 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.

SO-50	Downlink	Uplink
Beginning of pass	436.805 MHz	145.850 MHz + 67.0 Hz tone
Early pass	436.800 MHz	145.850 MHz + 67.0 Hz tone
Mid pass	436.795 MHz	145.850 MHz + 67.0 Hz tone
Late pass	436.790 MHz	145.850 MHz + 67.0 Hz tone
End of pass	436.785 MHz	145.850 MHz + 67.0 Hz tone

The graph below shows the received frequency of SO-50's 70 cm analog signal during a 21° maximum elevation pass, and a 44° pass. On the higher elevation pass, the received frequency starts higher and ends lower, that is, more Doppler effect than on the low elevation (21°) 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 and the Tune frequency to the Doppler-adjusted AOS frequency. Turn on the AFC (Automatic Frequency Control).

SO-50 needs an operator (another ham) to turn the satellite's transponder on. **This is done using a 74.4 Hz CTCSS tone to activate the satellite.** When the satellite hears the 74.4 Hz CTCSS, it will operate for the next ten minutes. Once the transponder is on, transmit to SO-50 with a 67.0 Hz CTCSS tone. When you're getting started, don't worry about sending the 74.4 Hz CTCSS; an experienced operator with a fixed base station will activate SO-50 for everyone.

Some FM satellites are U/v, including AO-91 and AO-92. 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.

Program the five memory channels on your radio(s) to the frequencies and CTCSS tone in the table below for AO-91. AO-91 and AO-92 also require 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 the same.

AO-91	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

If you're operating a satellite other than the examples above for SO-50 and AO-91, check the appropriate chapter 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, mobile phone, 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 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.

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 ("W4ABC grid EM83", for example).

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, "K9XYZ, W4ABC, EM83. QSL?" Use the standard phonetic alphabet when conditions are less than ideal, or when attempting to contact an operator who may not speak your language. For W9YB, use Whiskey Nine Yankee Bravo, not Wooly 9 Yogi Bear. A list of the standard phonetic alphabet is in Appendix A.

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

Don't be discouraged by other hams using excessive power or bad technique. Go about your business and ignore them.

The passes are relatively short, and hundreds 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.

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., AO-91), 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 the 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.

A friend you haven't met may have recorded the pass for you. John Papay, K8YSE, in northern Ohio records some of the satellite passes and posts them on his website. Go to https://www.papays.com/sat/general.html.

John is one of the most active hams on the satellites with over 1,800 confirmed grid squares, including all 488 grids in the continental United States. John's website is a good place to go just to hear typical satellite traffic.

Patrick Stoddard, WD9EWK, also records many satellite passes and posts them on Dropbox for others to hear.

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

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

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 – among others.

Some operators 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 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)

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 operate using full-duplex capabilities if at all possible, meaning you can transmit and receive at the same time.

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 made contact with 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) 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!

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.

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. AMSAT's website 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. Twitter is used frequently to announce grid expeditions; start by following @AMSAT.

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.

Chapter 7

Operating SSB and CW Satellites

Once you're comfortable operating the FM satellites, you'll be fully familiar with the biggest frustration of operating the FM satellites. You're competing to use a single-channel with dozens (in the evening and on weekends), if not hundreds (Field Day) of other hams, scattered over half a continent. If you're talking through an FM satellite, no one else is.

That's the primary advantage of the linear transponder satellites that support SSB and CW communication. Several, if not a dozen or more conversations can occur at the same time.

In this chapter, we take you through operating an SSB/CW satellite using SSB in a step-by-step fashion. There are lots of similarities to operating an FM satellite, but a number of important differences, too.

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**. So what does that mean?

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 move up in frequency on the uplink, 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, such as RS-10/11, RS-12/13 and RS-15.

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. Here 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 LSB	145.850	.860	.870	.880	.890	.900	.910	.920	.930	.940	145.950

Step 1: Pick an SSB satellite

There are fourteen SSB amateur satellites that are working, have been available in the past, or are waiting to be commissioned: AO-7, AO-73, CAS-4A, CAS-4B, EO-88, FO-29, FO-99, Fox-1E (RadFxSat-2), JO-97, XW-2A, XW-2B, XW-2C, XW-2D, and XW-2F.

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 it is working, the V/u satellite FO-29 is a good choice for your first contact. If FO-29 isn't operating, the U/v satellites CAS-4A, CAS-4B or one of the XW satellites may also be good first choice if they are operating: XW-2A, XW-2B, XW-2C, XW-2D, and XW-2F.

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 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). And 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 and EN60nk) and write it down on a piece of paper. For satellite QSOs in the US and Canada, we normally use four-character grid squares, 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 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.

Using a compass, a street map, or a smartphone compass application, determine which direction is north, and determine the 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'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 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 all of the LEO satellites.

Clayton, W5PFG, operates from a picnic table next to his fifth-wheel travel trailer using an Icom IC-821H. He is holding 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) handled 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'll need to do that by ear.

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).

For example, FO-29 is a V/u satellite with an inverting linear transponder. Ignoring the Doppler shift and any errors in the oscillator frequencies on the satellite, here are the passband and beacon frequencies:

Uplink (LSB)	*Downlink (USB)*	
145.900 MHz	435.900 MHz	
145.910	435.890	
145.920	435.880	
145.930	435.870	
145.940	435.860	
145.950	435.850 (passband center)	
145.960	435.840	
145.970	435.830	
145.980	435.820	
145.990	435.810	
146.000 MHz	435.800 MHz	
	435.795 MHz	CW Beacon

If you've chosen to operate a satellite other than FO-29, refer to its chapter to lookup the passband and beacon frequencies, whether the satellite is V/u or U/v, and if the transponder is inverting or non-inverting.

As explained in Chapter 2, *Satellite Basics*, 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. For example, FO-29 has a CW beacon sending HI HI (dit-dit-dit-dit dit-dit) followed by a series of hexadecimal values. This information is useful to the satellite's operators as it gives an insight to the health of the batteries and electronics.

The beacon is helpful to you because you can use it to 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.

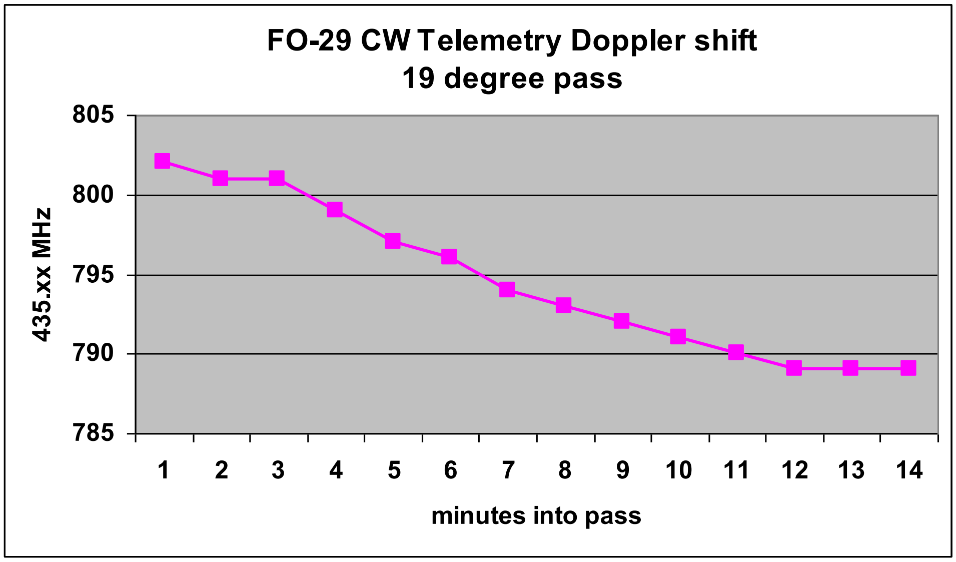
- If your receiver allows you to set the minimum tuning step when operating SSB, pick a small value (about 10 Hz).
- Choose the correct receive downlink band, for example, UHF for FO-29 because it is a V/u satellite.
- Always select USB for satellite downlinks.
- Put the receive frequency in the general vicinity of the satellite beacon.

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.

For FO-29, the beacon is on 435.795 MHz. Depending on the maximum elevation of the pass, you will experience about 15-20 kHz of Doppler shift from AOS to LOS. The Doppler shift will be most rapid during the middle part (TCA) of the pass.

The graph below shows the beacon frequency for a relatively low pass (19° maximum elevation) of FO-29. At AOS, the frequency is about 435.802 MHz. It drifts downward during the 14-minute pass until LOS when the frequency is about 435.788.



Listening on an SDR receiver

Tracking the beacon on an SDR receiver is pretty easy. You'll see it slowly drift across the waterfall display. Using the 19° pass in the example above, the beacon will drift from 435.802 through 435.788. To listen to 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 FO-29's beacon. You'll also be able to easily see the active QSOs on the waterfall, and if you change the Tune frequency, listen in on the conversation.

Listening on a conventional receiver or transceiver

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

For example, for FO-29, add 7-10 kHz (the same as 0.007-0.010 MHz) to the beacon frequency of 435.795. So, for a low pass you have, 435.795 + 0.007 = 435.802 MHz. If you don't find the beacon immediately, remember that it will be slowly dropping 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 be pointing the antenna toward the satellite and twisting 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 a little more challenging. Unless an operator is using 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? 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 you're first learning to operate SSB on the V/u satellites, leave the VHF frequency fixed and adjust the UHF frequency. For FO-29, that means to 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, if you increase the VHF transmit frequency, you'll need to decrease the UHF receive frequency.

Manual tuning when using a U/v satellite

If you're operating a U/v satellite like CAS-4A when you're learning, 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 tune the downlink VHF frequency slightly to understand the other station, depending on many factors. When you are 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, for example, VHF for FO-29 because it is a V/u satellite. Transmit on UHF for U/v satellites like CAS-4A.
- Does the satellite have an inverting transponder or a non-inverting transponder? Most, including FO-29, are inverting. For an inverting linear transponder, set your transmitter to lower sideband (LSB). For a non-inverting linear transponder, transmit using USB. If you're not using FO-29, check the chapter for your chosen bird.
- Pick a frequency pair in the transponder away from the center of the passband. For example, from the FO-29 table of uplink and downlink frequencies above, you might choose 145.910 MHz for transmit and 435.890 MHz for receive. If you're using a different satellite, check its chapter for an appropriate frequency pair.
- Tune both the transmitter and the receiver to the frequency pair you've chosen. If the downlink for your satellite is UHF like it is on FO-29, add two-thirds of the AOS Doppler shift to the receive 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 5-7 kHz shift (or 0.005 to 0.007 MHz) on UHF at AOS, so add the appropriate number to your chosen downlink frequency. If the uplink band for your satellite is UHF, you'll need to subtract the AOS Doppler shift from the transmit 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 automatically when you change your position in the passband. 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.

Step 7: Find yourself on the satellite

Now for your next challenge: Finding your signal in the satellite's passband. You are running 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 above for FO-29 (and for the other satellites in their respective chapters) 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 temperature of the satellite. The satellite temperature goes up in the sunlight and down during an eclipse (when they're in the shadow of the earth). The temperature also goes up when the transponder is being used and down when the transponder is off.
- Most amateur radios (including your radios) 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. FO-29 is pretty stable, drifting only slightly during a pass and from pass-to-pass. The error is typically 2-to-3 kHz on the UHF downlink.

In contrast, the FUNcube designers were forced to use a low-power oscillator design that isn't stable because of their limited power budget. A 1U CubeSat has very little room for solar cells and batteries. As a result, the early FUNcube satellites (e.g., AO-73) 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 that was away from the center of the passband. (The center of the passband is usually 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".

Regardless of the technique that works for you, remember that you are <u>legally required</u> to 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: It is a really good idea to have your current e-mail address in your https://www.qrz.com listing. 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. This approach of 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 amount of delay depends on the distance between you and the satellite, which is called the range. The greater the range, then 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 is bad 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 all of the active downlinks.
- You may cause the satellite to shutoff, depriving everyone of its use until the satellite next resets and restarts. (AO-7 is particularly sensitive to this.)

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

SDR receiver

This is the easiest 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 simply 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 like FO-29, 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 (for FO-29). 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.

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.

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, on the SSB birds, calling CQ is the norm. A relatively long CQ, giving your call several times (sometimes with standard phonetics instead of just letters) and your grid square will give the other station the time to find you and tune you in.

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

QSOs on the SSB birds are longer than on the FM satellites. Some people are still primarily interested in exchanging grid squares, but other operators will be interested in exchanging more information like first names, and details about your antenna and radios. Since these satellites allow multiple simultaneous contacts, the pace is more leisurely.

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 next pass of this satellite.

Record your contact by writing down the local date, local time, the satellite name (e.g., FO-29), 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 properly, 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 <u>transmitter</u> 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, then tune your <u>receiver</u> instead of changing the transmitter frequency. Software such as MacDoppler, Predict, 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.

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 all of the other QSOs by reducing the transmitted power of everyone else on the satellite. You can even modulate the whole passband or cause the entire passband to warble with your transmissions. AO-7 is particularly susceptible to this problem because of its age (old solar cells and no batteries), so don’t use CW on AO-7.

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 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.

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 considered 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 moving 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

Digital Modes

Digital communication, the electronic transmission of information that has been encoded digitally, is as old as amateur radio itself. We know the very first such mode as CW (Continuous Wave Morse Code). More recent techniques include radio teletype (RTTY), fast and slow scan TV (FSTV, SSTV), JT65, FT8, and packet radio.

Historically it required a person to do the encoding and decoding (CW) or equipment of varying size, complexity, and cost. Fortunately, by the 1980s, it became possible to send and receive these modes using cheap, simple interfaces between the rig and a "dumb terminal," or a personal computer. With the availability of fast personal computers and high-quality sound cards, the number of modes expanded rapidly to fill various needs and interests since "it is only software."

A very similar path was followed in amateur satellites. Early satellites used voice and CW for communicating. However, information on the health of spacecraft systems was needed. This was usually sent on the beacon in CW, RTTY, or in some cases a combination. OSCAR 1 (1964) sent a series of "HI HI HI HI" in CW, and the speed could be converted to the spacecraft temperature. AO-7 (1975) sent extensive information in both CW and RTTY. Today, while there are a wide range of modes in use, all those which will be 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.

Digital Telemetry

Satellite use of digital modes can be divided into two basic categories. The first is telemetry including camera images originated on the spacecraft. It is by far the most common and popular. The ISS periodically sends high quality SSTV images, as do some other spacecraft, for example AO-92. Many communications satellites, as well as research ones, 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 frequently is also forwarded to the spacecraft operators via the Internet.

Spacecraft based on the AMSAT-UK FUNcube series (AO-73 and EO-88) as well as the AMSAT-NA Fox series of spacecraft (AO-85, AO-91, AO-92, AO-95, and Fox-1E) are good examples. They 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).

Digital Communications

The second category of digital modes is communications. By far the most popular is the use of packet, and particular the Amateur Packet Reporting System (APRS) repeated through the digipeater on the International Space Station (ISS) or through dedicated packet satellites such as NO-84 and FalconSAT-3. Some other modes such as 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 and CW, and not modes which have high duty cycles such as PSK31, SSTV, or packet. The considerate operator will respect these limitations.

Telemetry Using Conventional Radio and Sound Card

The current generation of satellites is primarily of interest for their communications capabilities. For those with a technical bent, they also offer the opportunity to be a part of "Mission Control." A good example is the Dashboard, or telemetry display, of EO-88 (NAYIF-1).

For example, here is a screen capture from the FUNcube Dashboard showing the system status of EO-88 (NAYIF-1) during eclipse.

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.

Gathering telemetry has few counterparts in traditional amateur radio, except perhaps propagation studies. However, it allows someone to be a "Do It Yourself Rocket Scientist" and study the behavior of spacecraft in orbit, as well as providing information for the satellite's operators. A significant number of satellites transmit data that can be received using standard equipment suitable for voice transmissions. For instance, AO-73 sends telemetry in a Phase Shift Keying (PSK) format which can be received by an SSB receiver and decoded by the Dashboard program. Numerous commercial and homemade interfaces are available for SSTV, PSK31, packet, etc. and will work perfectly for this type of telemetry and are discussed briefly in the section on working the ISS using packet.

As is discussed in the chapter on the Fox satellites, there are exceptions to the use of standard hardware interfaces that use isolation transformers and other components that limit the range of audio passed. Both the very low speed Data Under Voice (DUV) and the high-speed telemetry, 9600 baud and higher, require the full range of audio from nearly DC to 15-20 KHz. The typical ham interface passes only a portion of this range. The same occurs in many rigs, which limit the audio to the normal voice range, 300-3000 Hz.

The solution to this technical challenge is to use a sound card directly connected to what is normally called the "9600 baud" output on the rig. Note that in some cases additional menu options or settings may need to be adjusted in the rig's menu. The 9600 output provides unfiltered audio, though the performance of radios varies somewhat. Typical radios such at the FT-847, IC-910, IC-9100, and TS-2000 are all known to perform well, but many less expensive radios have been used. In practice there are usually no issues with feedback in the typical station, but if so, the interface can be disconnected for normal voice operations.

The ideal sound card has a flat response from DC to 15-20 KHz. Fortunately, due to the level and sophistication of error correction in the data encoding, less than ideal cards have proven to be completely adequate. USB sound interfaces (dongles) available from $5-$10 give excellent results, though it is not always easy to determine their suitability from the specifications. For instance, many give the input as a microphone rather than line input. This normally means a limited frequency response. However, whether by design or cost cutting, the actual response is more like a line input with fair to good extended frequency response. Try what you have or get a recommendation for a device which is known to work. Equipment can be found in the $25-$50 range which is intended for near-professional sound recording which comes close to the ideal response.

Telemetry Using Software Defined Radios

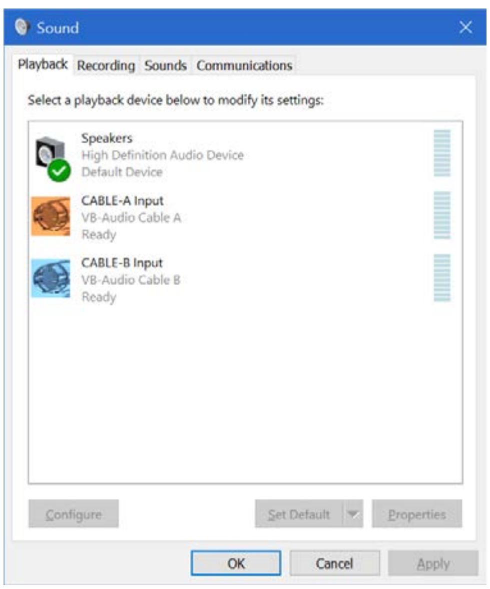
Using conventional equipment for telemetry is an excellent way to get started but does entail trial and error along with some compromises. Fortunately, a new generation of Software Defined Radios (SDRs) has become available in recent years. The mode and response of the radio can be tailored to precisely meet the signal and conditions. The most prominent ones are discussed in the *Software Defined Receiver* section of Chapter 5, *Your Radio System*.

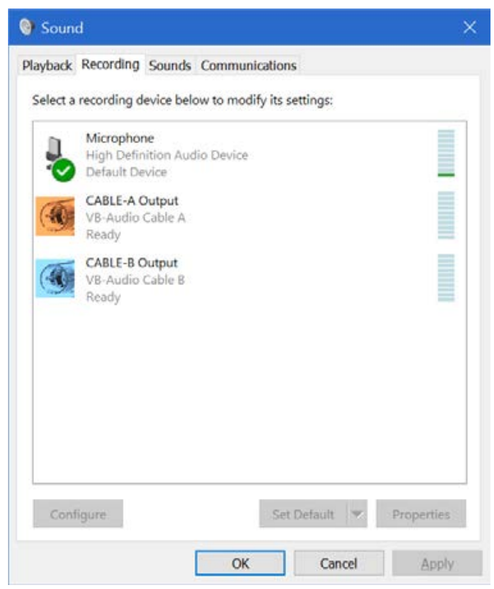
Some telemetry programs such as the FoxTelem (for AO-85, AO-91, AO-92, AO-95, and Fox-1E), and the FUNcube Dashboard (for AO-73 and EO-88) directly access the FUNcube Pro+ SDR dongle, which makes the process as simple as installing the software, plugging the radio dongle into a USB port, and providing the signal from your antenna. However, it may be desirable to use a separate program as a "front end" between the dongle and the telemetry software.

The use of an intermediary program adds significant flexibility in exchange for a slight increase in complexity. First, the direct telemetry program support for dongles is very limited, while the general programs support a wide range of devices, with support being added as new ones appear. Second, they often have better processing algorithms and can be tuned by many tracking programs. Third, this combination has the flexibility to accommodate new telemetry systems by simply starting a different program for each unique satellite.

Using this approach, there is one additional component needed for telemetry that is not required when using an SDR as a voice receiver. You must have a way to connect the audio from the SDR to the telemetry program. Fortunately, Virtual Audio Cables (VACs) are available which allow the internal routing of sound in much the same way as Virtual Serial Ports (VSPs) allow control signals such as frequency control and keying. VB-Audio Software makes available a free VAC on their web site: www.vb-cable.com. This is all that is needed to receive telemetry. They make additional devices available for a donation. After following the installation instructions, one "end" will appear among your recording devices, and the other "end" will appear as a playback device. Note than unlike some software, the VB-Audio Software is bidirectional, so a single cable can be used for both reception and transmission.

The windows below show Virtual Audio Cables as audio devices in addition to speakers and microphones.





Your receiver program (SDR#, HDSDR, SDR-Console, etc.) will have a menu section where you can choose the audio output. Choose the VAC from among the various other devices such as speakers. Likewise, the telemetry program will allow you to choose a VAC input. Using the VAC software is the equivalent of placing a jumper between the output and input of a conventional sound card, but without the accompanying loss of fidelity.

Selecting a Satellite to Monitor

If you are generally interested in learning about satellite telemetry, the most currently accessible satellites are AO-73 and EO-88 in terms of equipment and signal strength. They operate the telemetry beacon at high power when the spacecraft is in daylight, and at lower power with the communications transponder available in darkness. At present, each satellite has an individual Dashboard to display telemetry and forward it to a central repository. However, a common program that will automatically switch format depending on the spacecraft being received is expected in the near future. Please see the chapters on these satellites, and the included links.

For a slightly more demanding project, consider the Fox series of satellites. The chapter on AO-85 (Fox-1A) gives the basic details on both software and hardware, with the slight differences located in the chapters on AO-91, AO-92, and AO-95. Fox-1E will have a linear transponder, using Phase Shift Keying (PSK) similar to AO-73 and EO-88.

If you have interests in a specific satellite, consult their web site for information on the frequencies and modes in use. Normally they will make available specific software with instructions for its use on that satellite. Finally, DK3WN maintains a site where software decoders may be found for nearly any satellite of interest:

http://www.dk3wn.info/software.shtml

The page may be translated by the Google Translate page. The software itself is in English.

SSTV and other pictures from space

The ARISS station aboard the ISS has a Kenwood VC-H1 to take and transmit SSTV images. There is also an SSTV system using a computer interface (SpaceCam or MMSSTV) that supports multiple SSTV operating modes. In 2008 Richard Garriott, W5KWQ took many pictures with these devices. The Russians are also doing SSTV experimentation, using some of the higher resolution SSTV modes available through the MMSSTV program. Pictures typically show life aboard the ISS or celebrate the anniversary of Cosmonaut Yuri Gagarin's mission.

Many SSTV images can be found at http://ariss-sstv.blogspot.com/ and https://www.spaceflightsoftware.com/ARISS_SSTV/index.php

While the ISS SSTV operations are the most widely known, periods of operation are limited to a few times a year. Other satellites often have the ability to downlink pictures of the earth. For instance, AO-92 supports images, though the format is different from conventional SSTV and will require the FoxTelem ground station software.

Digital Communication Through Spacecraft

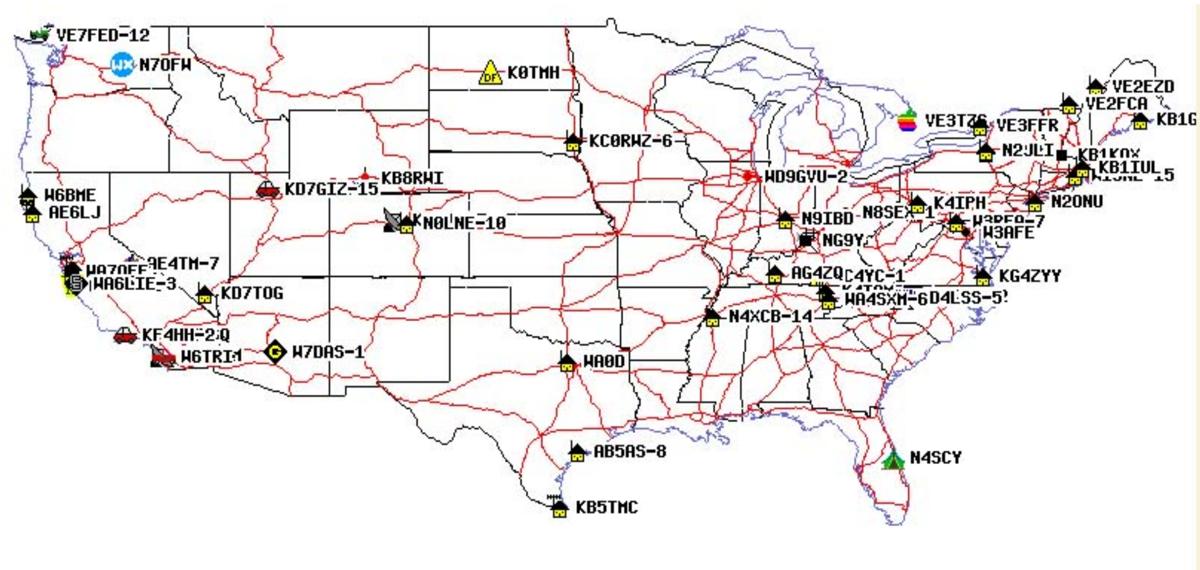
The ISS holds a special fascination for anyone interested in satellites. It is also by far the easiest to communicate through since is uses basic AX.25 1200 baud packet. The ISS orbit is relatively low, 350-400 km, and has a high-power transmitter. The digipeater functions much like a terrestrial unit,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

The most common 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

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



Bob Bruninga, WB4APR has a good write up on operating APRS via the ISS on his web site:

http://aprs.org/iss-faq.html

Packet activity from the ISS is often noted on **145.825 MHz.** Since the crew members <u>rarely</u> engage in keyboard contacts, most of the packet activity you hear is 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.

The good news is once you have equipped your station for ARISS packet and learned the ropes for ARISS packet operation your station will be ready for those rare voice contacts with the ISS crew. You will just need to swap the packet gear for a microphone and start calling.

A note about a packet “Hard-Connect” to RS0ISS-11 BBS: In a word … **don’t**! The ISS PBBS with the ID RS0ISS-11 operates in the same manner as a terrestrial Packet BBS operates. A "hard-connection" (C RS0ISS-11) establishes a full AX.25 connection which brings the entire messaging handshaking protocol into operation. The handshake messages will faithfully repeat, and repeat, and repeat per protocol until they are properly acknowledged. The usual case is that there are many stations sending packets to the ISS resulting in data collisions when RS0ISS-11 is expecting its handshake. Everyone tuned into the pass will see the endlessly repeating AX.25 handshake bytes until the sequence times out. You may have been out of range for several minutes already, but the ISS is still listening for you. This approach is not used for obvious reasons. The generally accepted procedure is to send your UI packet via ARISS (or RS0ISS if you wish to use the callsign).

Ground station requirements

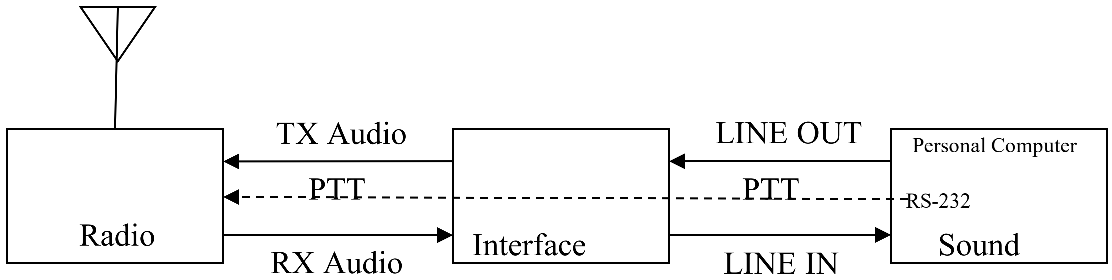
For your packet ground station, a standard 2 m FM transceiver with 10-30 watts into a Yagi antenna that can be pointed in both azimuth and elevation is best. Many operators use the Kenwood TH-D72A or TH-D74A with a handheld Arrow or Elk antenna. The downlink signal from the ISS is generally easily heard 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, software for sending and receiving an AFSK packet signal has been created for the sound card in your personal computer. Your computer with sound card interface and packet software will perform the functions previously provided by a TNC hardware box.

In addition to the sound card software 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. You have a few options to this approach also.

- Build a sound card interface from plans found on the Internet.
- RIGblasters by West Mountain Radio $100-$300 (http://www.westmountainradio.com)

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



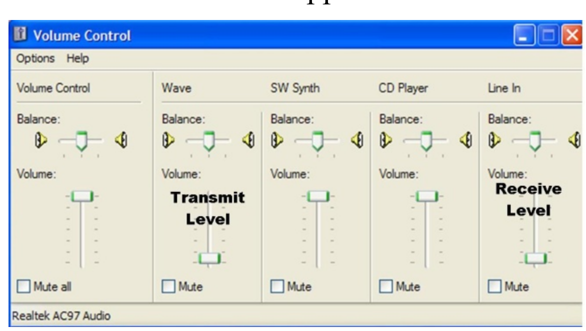
Overview Sound Card and Radio Connection

- 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. Or 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 ARISS packet operation with the ISS – 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 PSK31, etc., usually the same settings can be used for packet. If needed use the "Wave" slider control to set the transmit level; use the "Line In" slide control to set the receive level.



Install the Software You Need

The software for ARISS packet operation is available for free download. The items you will need include:

- **AGWPE** - Written by George Rossopoulos, SV2AGW, and is an acronym for "SV2AGW's Packet Engine". It was originally created as a TNC management utility and has many super features of value to TNC users, plus it has the ability to encode and decode packet tones using your computer's sound card. Download from: https://www.sv2agw.com/downloads/default.htm
- **UISS** – Written by Guy Roels, ON6MU designed for UI packet communication (unproto) packet with ISS. This will be your user interface for packet communications with the ISS. This software is free for amateur and non-commercial use. A PRO version is available and donations are welcome. Download from: http://users.belgacom.net/hamradio/uiss.htm

Installation and user guides for the software packages are included on their websites. Here are a few links to websites that will give you the information needed to get on the air quickly:

- The "golden" reference for sound-card packet configuration and operation is the "Sound Card Packet" site by Ralph Milnes, NM5RM: https://www.soundcardpacket.org
- Mineo Wakita, JE9PEL has published several on-line references for the installation and use of UISS:
  http://www.ne.jp/asahi/hamradio/je9pel/ui32uiss.htm
  UISS setting up APRS satellite:
  http://www.ne.jp/asahi/hamradio/je9pel/uissagwp.htm

  The UISS site has a reference page: http://users.belgacom.net/hamradio/uisslinks.htm

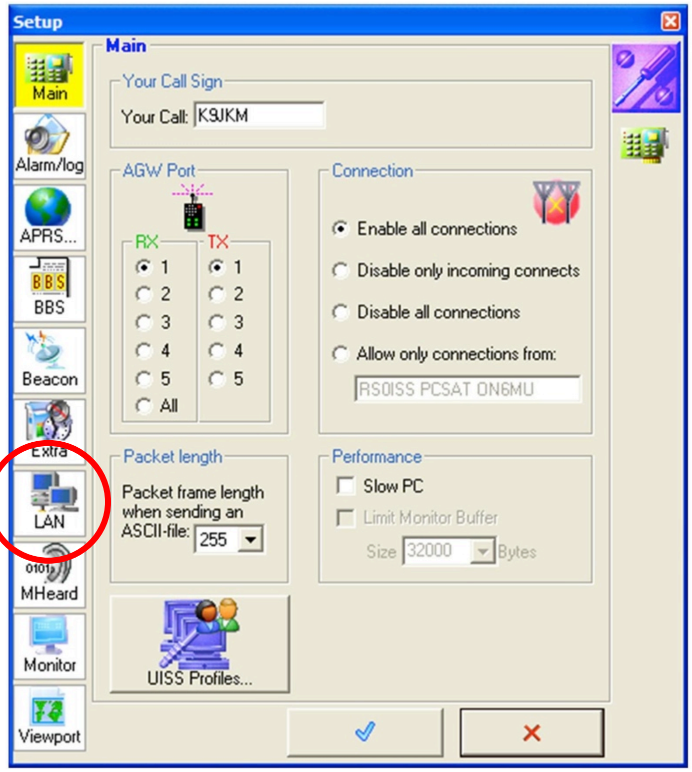
Swapping the UZ7HO Soundmodem packet program in place of AGWPE

Many operators note that often a strong sounding downlink is heard from the ISS but the AGWPE and UISS combination of software will not decode and display the packet message. This is because the checksum was not correct. Losing only a bit or two of the digital packet due to noise or fading will result in that packet's checksum not being correct. AGWPE only passes the received packets that have a correct checksum. Often the packets with errors contain enough useful data for a human to still understand them. In addition, the UZ7Soundmodem supports an increasing number of PSK and BPSK modes which are used by other satellites.

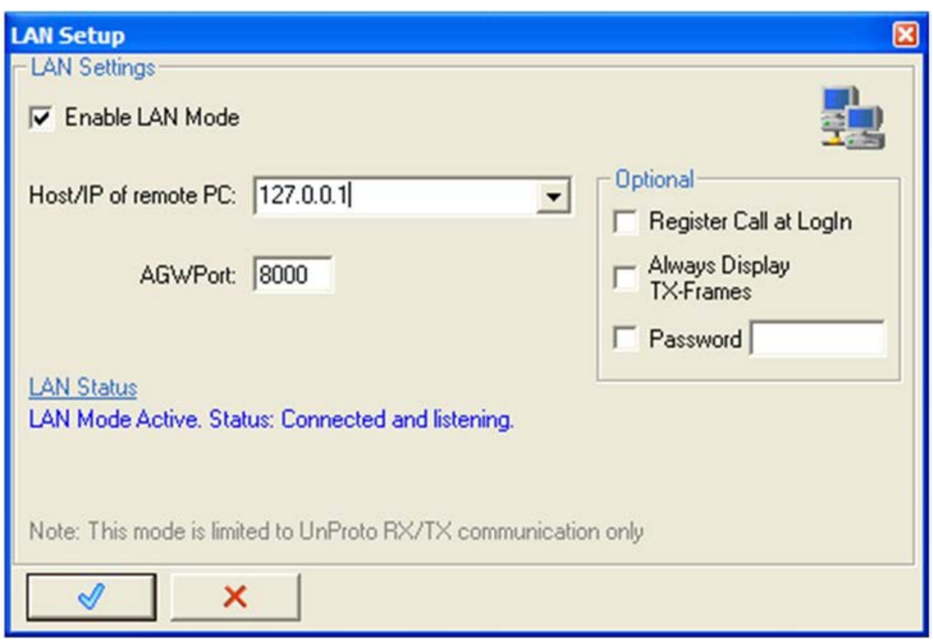
To get started using this optional approach get the UZ7HO Soundmodem from: http://uz7.ho.ua/packetradio.htm

The UISS program will require settings to be changed to operate with UZ7HO Soundmodem:

1. In UISS top menu select Setup -> UISS -> LAN and you will see this screen:

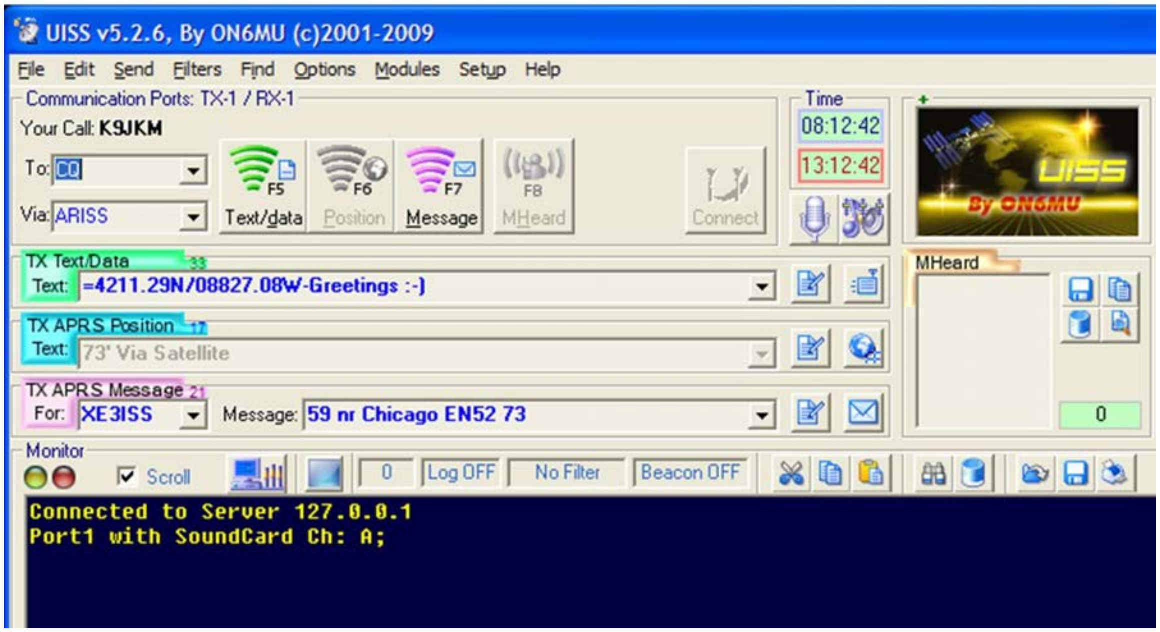


2. In LAN setup click on 'Enable LAN Mode' Host 127.0.0.1 Port 8000

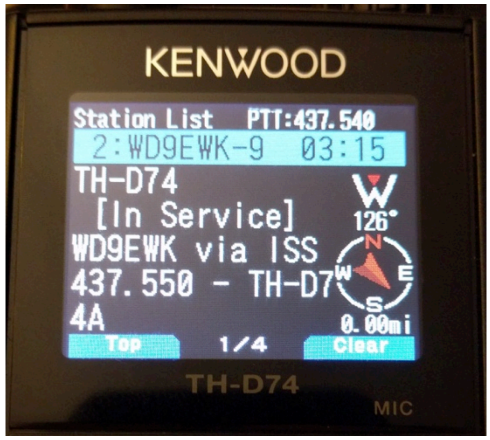


3. UISS may ask you to restart, go ahead and restart UISS. To return back to operation with the AGWPE software unclick the 'Enable LAN Mode' option and restart UISS.

For normal operation start the UZ7HO Soundmodem first. Then start UISS. When both programs are running UISS will show it has connected with the Soundmodem:



If you use a Kenwood HT as your radio, it has the packet modem 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. Examples are the Kenwood HTs TH-D72A and TH-D74A, and mobile units such as the Kenwood TM-D710E and Yaesu FTM-400. They only require changing the operating frequency and path to those given above. While convenient for portable operations, they are somewhat less flexible than previous techniques, which are more suitable for home operation.

Resources:

https://www.ariss.org
https://www.nasa.gov/mission_pages/station/main/index.html (great ISS photos)
https://spaceflight.nasa.gov/station/reference/radio/index.html
http://www.arrl.org/amateur-radio-on-the-international-space-station
https://www.amsat.org
https://funcube.org.uk/working-documents/funcube-telemetry-dashboard/

Thanks to JoAnne Maenpaa, K9JKM for graciously allowing her AMSAT Journal article, Getting on the Air with ARRIS Packet, to be adapted for use here.

Fernando, NP4JV, 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.

AO-7

Name(s):	AMSAT-OSCAR 7 (Phase-IIB)
NASA catalog number:	7530
Launch:	November 15, 1974 Vandenberg AFB, CA
Orbit:	Polar LEO
Inclination:	101.8°
Period:	104.7 minutes
Altitude:	1450 km
Size:	360 mm height x 424 mm diameter
Shape:	Octahedral shaped
Weight:	28.6 kg (63 pounds)
Transmit power:	200-8000 mW

AO-7 was launched in 1974 and was operational for 6.5 years until a battery failure ceased operation in mid-1981. Then on June 21, 2002, Pat Gowen, G3IOR, posted an email message on AMSAT-BB that he copied some CW telemetry that obviously was an OSCAR, but he couldn't quite figure out which one. AO-7 arose like a Phoenix in the summer of 2002.

This OSCAR was similar to AO-6, built by a multi-national (Germany, Canada, United States, and Australia) team of radio amateurs under the direction of AMSAT-NA. The satellite has four antenna masts mounted at 90-degree intervals on the base.

AO-7 currently operates as a CW/SSB "bent-pipe" transponder in Mode A or Mode B. Mode C is a low-power Mode B, and observers have noticed that AO-7 is particularly weak at times, leading to speculation that it occasionally switches to Mode C.

Transponders:

AO-7 has both a non-inverting transponder and an inverting transponder.

Mode A: 145.850 – .950 MHz uplink and 29.400 – .500 MHz downlink [SSB/CW], non-inverting

Mode B: *432.175 – .125 MHz uplink and 145.925 – .975 MHz downlink [SSB/CW], inverting

***Note**: The uplink frequency at 432.150 MHz predates the WARC '79 allocation of 435-438 MHz by the ITU for the Amateur Satellite Service and places the uplink in 70cm weak signal segment. On April 19, 1974, the Federal Communications Commission in Report No. 907 waived the provisions of Section 2.106 of the rules regarding the frequency allocations of the Amateur Satellite Service to the extent that AO-7 is allowed to use 432.125 through 432.175 as uplink frequencies. The same order prohibits the use of the AO-7 S-band downlink at 2304.1 MHz. As a result of this FCC waiver, licensed amateur radio operators may transmit to AO-7 while operating in the United States. Amateur radio transmissions to AO-7 outside of the U.S. are obviously governed by the rules and regulations of the country where the transmitter is located.

AO-7 is only running on solar cell power, whichever way the mode bit powers up determines which transponder AO-7 will activate when it leaves eclipse and encounters the sun. **Observations note that AO-7 tends to favor Mode B over Mode A**. When AO-7 is in a period of continuous sunlight, it changes modes every 24 hours.

A good source of real-time information on the status of most amateur satellites, and the current operational mode of AO-7 in particular, can be found here:

https://www.amsat.org/status/

Beacons:

Unfortunately, AO-7's beacons are weak and unreliable. The best way to determine if AO-7 is in Mode B is to listen for the noise peaks around 145.940 and 145.955 MHz. These are especially apparent on an SDR spectrum display.

29.502 MHz (200 mw) Used in conjunction with Mode A

145.972 MHz (200 mw) Used in conjunction with Mode B and Mode C [low power Mode B].

Non-inverting Transponder — Mode A (V/a)

Uplink	Downlink
145.850 MHz USB	29.400 MHz USB
145.860	29.410
145.870	29.420
145.880	29.430
145.890	29.440
145.900	29.450
145.910	29.460
145.920	29.470
145.930	29.480
145.940	29.490
145.950 MHz USB	29.500 MHz USB

Mode A (Mode V/a) operation uses a non-inverting transponder. Here you use USB on both the uplink and the downlink. And as you tune your transmitter frequency higher, you also tune your receiver frequency higher. Doppler is also present here, but with a much-reduced effect because of the lower frequencies involved.

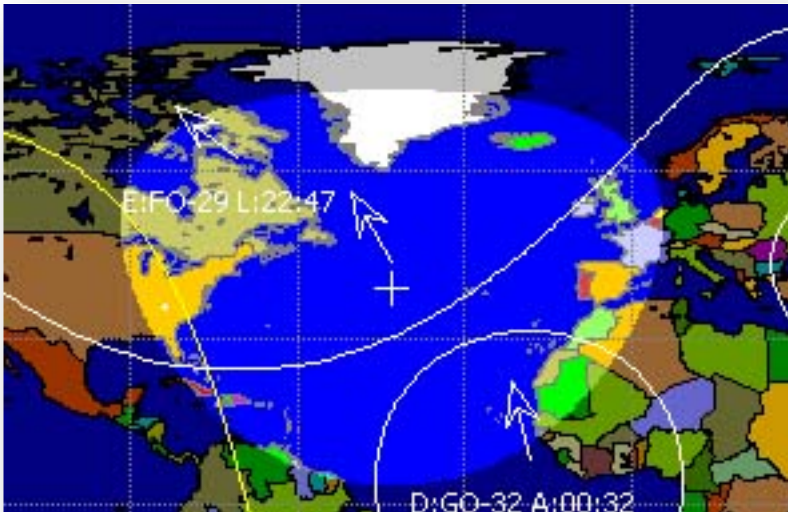
Inverting Transponder — Mode B (U/v)

Uplink	Downlink
432.125 MHz LSB	145.975 MHz USB
432.130	145.970
432.135	145.965
432.140	145.960
432.145	145.955
432.150	145.950
432.155	145.945
432.160	145.940
432.165	145.935
432.170	145.930
432.175 MHz LSB	145.925 MHz USB

Mode B (Mode U/v) is 70cm up and 2m down and is the inverting transponder. This means that you should use LSB on the 70cm uplink, USB on the 2m downlink. As you tune your receiver higher in frequency your uplink will go down in frequency and vice versa. This does not take into account the Doppler shift, which makes the tuning non-linear. Since the uplink is on 70cm it will be necessary to change the uplink frequency more than the downlink frequency.

Operating AO-7

Jan King, W3GEY notes that AO-7 has a very sensitive receiver and a good uplink antenna. Five watts EIRP up should provide a good downlink. The use of amplifiers for the uplink are strongly discouraged. Excessive uplink power will cause FMing of the transponder, interference to other users, frequent change of modes or shutdown, and will create errors in the telemetry data. Excessively strong CW signals, sometimes derisively called “The Mad Ditter,” are especially disruptive. They can use all the power in the downlink and “bounce” the entire passband. AO-7 is running only off the solar panels; it



will only be on only when in the sun and off in eclipse. Since it is resetting each orbit it may not come on every time. However, since the orbit of AO-7 is higher than most LEO satellites, some good DX is possible – eastern US to Europe and Africa.

SatPC32 can control the tuning and Doppler correction of your satellite transceiver quite well. Follow the ‘One True Rule’ (see Appendix A) and maintain the same receive frequency by adjusting both your transmit frequency and receiver.

- **Keep your power low.** Generally you can work AO-7 on 5 watts or less.
- **Use tracking (manual or automated) Yagi antennas with receive pre-amp**
- **An FMing signal means lower your power.**
- **Adjust for Doppler**. See ‘One True Rule for Doppler Tuning’ in Appendix A.
- **Use voice if possible.** Voice operation taxes the satellite power less than CW.

Commanding AO-7

Mike Seguin, N1JEZ, AMSAT Principal Satellite Investigator has successfully commanded the satellite after 21 years. He was first able to change the CW speed of the telemetry in July of 2002 and since then he has had the satellite respond to seven different commands. Not bad for an old bird.

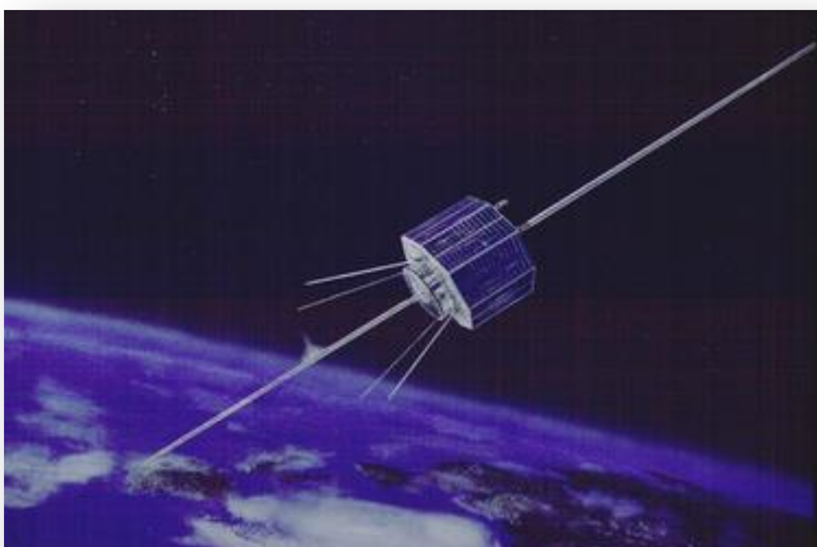
Jan King, W3GEY, the AMSAT-OSCAR-7 Project Manager commented:

> “AO-7 is almost certainly running only off the solar panels. It is very likely to be on only when in the sun and off in eclipse. Therefore, AO-7 will reset each orbit and may not turn on each time.
>
> [AO-7] has a good set of arrays and the first BCR (battery charge regulator) we ever flew. It's the first spacecraft we ever had that was capable of overcharging

> the battery. When the battery failed the [battery] cells began to fail short. One cell after another failed and the voltage measured on telemetry began to drop. So, the cells were clearly failing SHORT. Now, after all these years, what happens if any one of the cells loses the short and becomes open? Then, the entire power bus becomes unclamped from ground and the spacecraft loads begin to again be powered but, this time only from the arrays. Now you have a daytime-only satellite but, each time the sun rises at the spacecraft you have a random generator that either turns on Mode A or Mode B or whatever it wants. So, occasionally that 70cm/2m transponder transmitter and beacon must least work. From what you have told me (and without going back and decoding the old telemetry equations) I can tell you that the following things work in that spacecraft: The arrays, the BCR, the ISR (instrumentation switching regulator), the Mode B transmitter and beacon injection circuitry, the Morse Code telemetry encoder, and the voltage reference circuitry. The latter I know is working because the last telemetry value is 651. The "6" is just the row number of the telemetry value but the 51 means that the 1/2 volt reference is measuring 0.51 volts. I know that telemetry equation by heart since it was used as the calibration value for the rest of the telemetry system. So the telemetry has a fair chance of being decoded and making some sense!!!“

Tom Clark, K3IO, has a slightly different take. He has described AO-7 as the only known case where two catastrophic satellite failures canceled each other out.

Note that the telemetry beacons, like many features of this grand old satellite, have become intermittent and may be silent, even when the transponder is active.



AO-7 telemetry format

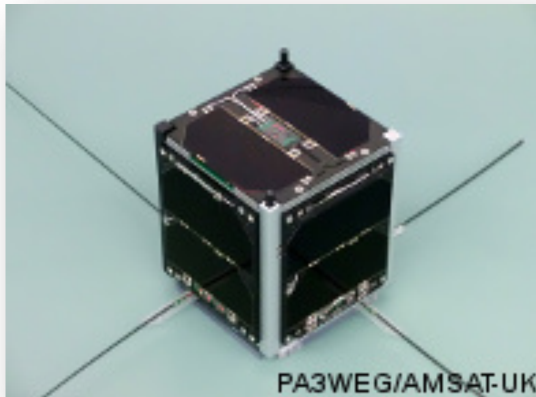
Format	Sample Data
HI HI	HI HI
1aa 1bb 1cc 1dd	100 176 164 178
2aa 2bb 2cc 2dd	280 262 200 254
3aa 3bb 3cc 3dd	375 358 331 354
4aa 4bb 4cc 4dd	453 454 461 459
5aa 5bb 5cc 5dd	541 501 552 529
6aa 6bb 6cc 6dd	600 600 601 **651**
HI HI	HI HI

These data are valid when 6D has a value of 649, 650 and 651. The telemetry data is sent as CW at approximately 10 wpm.

AO-7 Telemetry Channel and Decoding information

Channel Measured Parameter	Measurement Range	Calibration Equation (Preliminary)
1A Total Solar Array Current	0 to 3000 ma	I = 29.5 N (ma)
1B +X Solar Panel Current	0 to 2000 ma	I = 1970 - 20N (ma)
1C -X Solar Panel Current	0 to 2000 ma	I = 1970 - 20N (ma)
1D +Y Solar Panel Current	0 to 2000 ma	I = 1970 - 20N (ma)
2A -Y Solar Panel Current	0 to 2000 ma	I = 1970 - 20N (ma)
2B RF Power Out 70cm/2m	0 to 8 watts	P = 8(1 - 0.01N)^2 (watts)
2C 24 Hour Clock Time	0 to 1440 min.	t = 15.16N (min)
2D Battery Charge/Discharge	-2000 to 2000 ma	I = 40(N - 50) (ma)
3A Battery Voltage	6.4 to 16.4 V	V = 0.1N + 6.4 (volts)
3B Half-Battery Voltage	0 to 10 V	V = 0.10N (volts)
3C Bat. Chg. Reg. #1	0 to 15 V	V = 0.15N (volts)
3D Battery Temperature	-30 to +50 deg. C	T = 95.8 - 1.48N (deg. C)
4A Baseplate Temperature	-30 to +50 deg. C	T = 95.8 - 1.48N (deg. C)
4B PA Temp. 2m/10m	-30 to +50 deg. C	T = 95.8 - 1.48N (deg. C)
4C +X Facet Temp.	-30 to +50 deg. C	T = 95.8 - 1.48N (deg. C)
4D +Z Facet Temp.	-30 to +50 deg. C	T = 95.8 - 1.48N (deg. C)
5A PA Temp. 70cm/2m	-30 to +50 deg. C	T = 95.8 - 1.48N (deg. C)
5B PA Emit. Current 2m/10m	0 to 1167 ma	I = 11.67N (ma)
5C Module Temp. 70cm/2m	-30 to +50 deg. C	T = 95.8 - 1.48N (deg. C)
5D Instrument Sw. Regulator Input Current	0 to 93 ma	I = 11 + 0.82N (ma)
6A RF Power Out 2m/10m	0 to 10,000 mw	P = (N^2)/1.56 (mw)
6B RF Power Out 70cm	0 to 1,000 mw	P = 0.1(N^2) + 35 (mw)
6C RF Power Out 13cm	0 to 100 mw	P = 0.041(N^2) (mw)
6D Midrange Telemetry Calibration	0.500 V	V = 0.01N(0.50 +/- 0.01) (V)

AO-73



Name(s)	**AO-73, FUNcube-1**
NASA catalog number	39444
Launch	November 21, 2013
Orbit	Polar LEO
Inclination	97.8°
Period	101.7 minutes
Altitude	682 x 595 km
Size	10cm x 10cm x 10cm
Shape	CubeSat
Weight	1 kg (2.2 pounds)
Transponder	Linear Inverting
Beacon	145.935 MHz BPSK
Uplink	435.150 - 435.130 MHz (See discussion below.)
Downlink	145.950 - 145.970 MHz USB
Transmit power	300mW for transponder, 35 or 300mW for telemetry

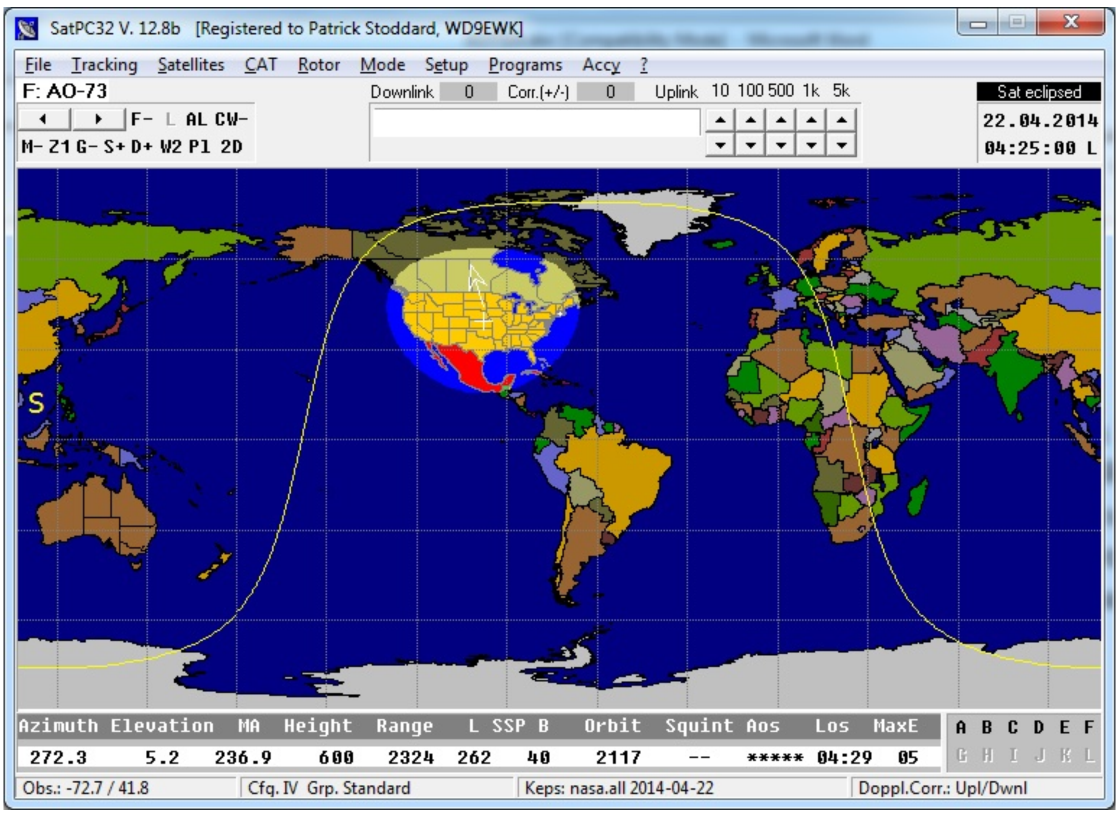
AO-73 was launched in 2013, the result of a project started by AMSAT-UK with a grant from the UK-based Radio Communications Foundation in 2009. As the satellite was prepared for launch, AMSAT-UK partnered with AMSAT-NL and ISIS BV in the Netherlands to avoid the restrictions with registering the satellite in the UK. In keeping with the terms of the grant, this satellite was designed to have an educational mission, in addition to a transponder for use by radio amateurs around the world.

On one end of the satellite, there are two dipoles used for 2m and 70cm. These dipoles were deployed after the satellite was ejected from the launch vehicle.

AO-73 has a 20 kHz linear transponder and a BPSK-1200 telemetry beacon operating at 145.935 MHz +/- for Doppler. This beacon can be received by a receiver or transceiver capable of receiving SSB on the 2m band.

AO-73 typically operates autonomously, alternating between Educational and Amateur modes. When in sunlight (Educational mode), the satellite transmits telemetry on 145.935 MHz at 300mW. When in eclipse (Amateur mode), AO-73 operates its 20-kHz wide inverting linear transponder with a 300mW downlink along with the telemetry on 145.935 MHz at only 30mW. AMSAT-UK has commanded the satellite to use the transponder and lower-power telemetry downlink on weekends for five years following its launch. AO-73 has entered a period of nearly continuous illumination which seems to be causing problems. Please consult the FUNcube project web site for more information about the satellite's operating configuration: https://funcube.org.uk

This view from SatPC32 shows the AO-73 footprint on a pass covering the continental USA, along with parts of Canada and Mexico:



AO-73 is in a polar sun-synchronous orbit, meaning it will usually have the same types of passes in the mornings and evenings – southbound passes in mornings, northbound passes in evenings.

Transponder

AO-73's 20 kHz transponder may be smaller than other satellites with linear transponders, but this has not diminished the interest in working this satellite. Observations indicate that the transponder uplink may be 5 to 10 kHz higher than the nominal frequencies, depending on the time of day. (The oscillator design emphasized low power consumption which had the unfortunate side effect of reduced frequency stability.) The table that follows shows observed frequencies, not the nominal frequencies.

AO-73 Mode B (U/v) Transponder Band Plan (Observed)

Uplink	Downlink
435.170 MHz	145.950 MHz CW/SSB
435.165 MHz	145.955 MHz CW/SSB
435.160 MHz	145.960 MHz CW/SSB - Passband center
435.155 MHz	145.965 MHz CW/SSB
435.150 MHz	145.970 MHz CW/SSB

Because of the uplink drift, it is not recommended that computer frequency control be used on this satellite since this relies on a fixed relationship between uplink and downlink. Most operators find manual control to be easy, and this prevents having to constantly recalibrate your tracking program. The transponder can handle multiple signals simultaneously, as long as the signals are not using excessive power. Stations transmitting with no more than 5W have been successfully working this satellite, including WD9EWK's station (Yaesu FT-817ND transmitter, Kenwood TH-F6A receiver, Elk Antennas handheld 2 m/70 cm log periodic):

AMSAT-UK has recommended that stations use no more than 5W into a 7 dBi antenna when working the AO-73 transponder. This would cover those using FT-817 transceivers into antennas like the Arrow Yagi, Elk log periodic, or other similar antennas.

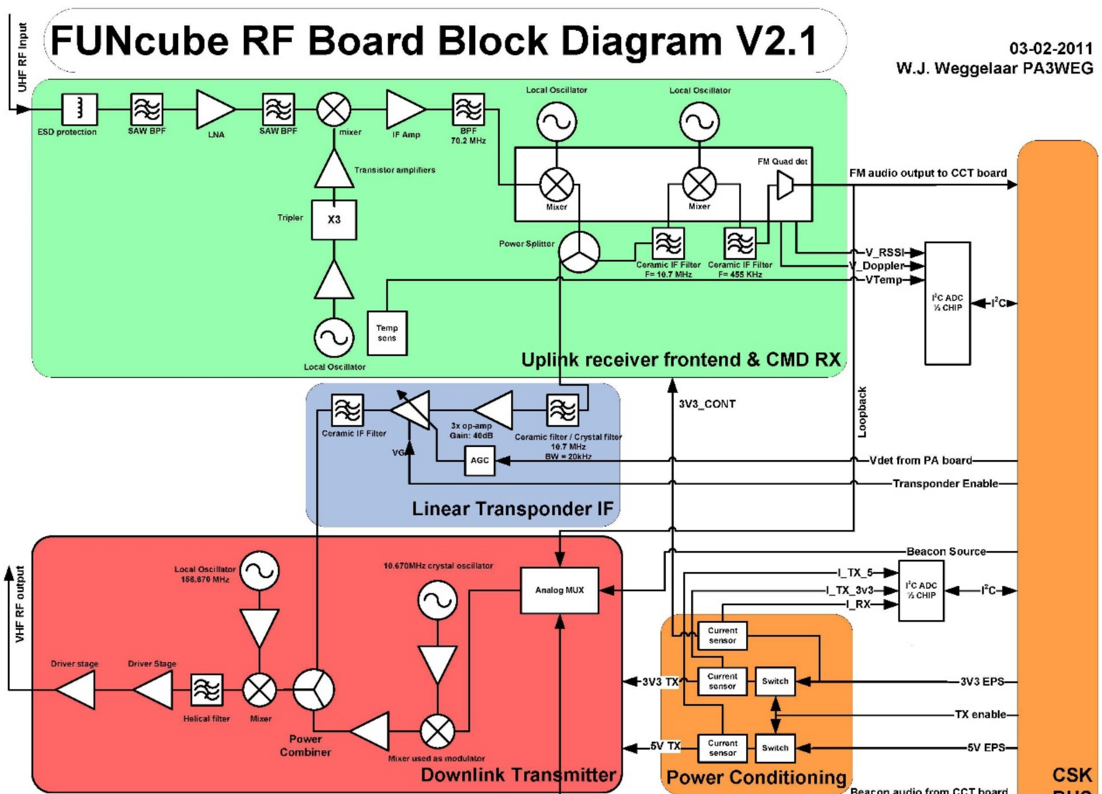
Telemetry

AO-73 has a BPSK-1200 beacon operating on 145.935 MHz, +/- for Doppler. When the transponder is off, the beacon operates at 300mW. When the transponder is on, the beacon operates at only 30mW. The FUNcube group has developed a Dashboard program, capable of decoding the telemetry, presenting the data on the screen, and – with an Internet connection – uploading the telemetry to the FUNcube project's data warehouse server. The Dashboard program is capable of controlling the FUNcube Dongles, setting the center frequency and finding the BPSK signal automatically.

For other receivers, the operator or other software (like SatPC32) needs to make the periodic tuning adjustments to compensate for the Doppler effect.

This is an example of the Dashboard program copying the AO-73 telemetry, using a FUNcube Dongle Pro+. Data is presented across the top of the window, and the bottom of the window shows where the program is decoding the signal. This is near the end of a pass, and the Dashboard is listening around 145.9325 MHz at this point in the pass:

This is the RF block diagram for AO-73, showing how the satellite processes the signals it receives from ground stations, and then transmits back to the ground stations:



Source: PA3WEG/AMSAT-UK

Resources

FUNcube project: https://funcube.org.uk

FUNcube project Dashboards: https://funcube.org.uk/working-documents/funcube-telemetry-dashboard/

FUNcube data warehouse: http://warehouse.funcube.org.uk

FUNcube discussion forums: http://forum.funcube.org.uk

AMSAT-UK: https://amsat-uk.org

AMSAT-NL: http://amsat-nl.org

ISIS BV: https://www.isispace.nl

Operator Insights from Steve Belter, N9IP

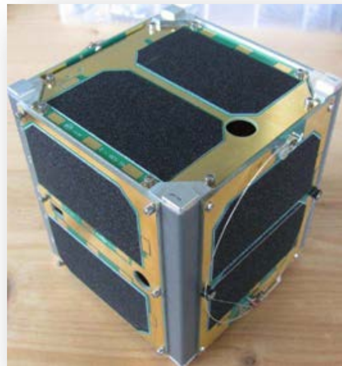
Before attempting to operate, make sure AO-73 is in transponder mode by checking https://amsat.org/status and https://funcube.org.uk. When healthy, the normal practice has been to have AO-73 in transponder mode on weekends and when in eclipse (at night when no part of the footprint is in daylight). Recent constant illumination seems to be causing high internal temperatures and the transponder has been turned off to avoid adding additional heat which has the potential to damage the batteries.

If the satellite is in transponder mode, most regular operators of AO-73 recommend using manual tuning instead of computer control because of the frequency drift. Follow the instructions for operating a U/v SSB satellite in Chapter 7, Operating SSB and CW Satellites.

Start by using the observed frequencies in the table above, as the uplink frequency is often 5-to-10 kHz above the nominal frequencies, and drift with the internal temperature of the satellite.

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.

AO-85



Name(s)	AO-85, *Fox-1A*
NASA catalog number	40967
Launch	1249 UTC, 8 October 2015, Atlas 5, NROL-55, Vandenberg AFB, CA
Orbit	LEO (Low Earth Orbit)
Inclination	64.8°
Eccentricity	0. 0212
Period	97.6 minutes
Estimated orbital lifetime	5+ years
Altitude	520-810 km
Size	10 x 10 x 10 cm (4 inch cube)
Weight	1.3 kg (~3 pounds)
Transmit power	400-800 mW
Downlink (Limited Schedule)	145.979 MHz FM voice, FSK digital data up to 9600 bps
Uplink	435.172 MHz FM voice (67.0 Hz CTCSS)

By early 2019, due to the unexpectedly high temperatures encountered, the batteries have deteriorated sufficiently that they can not maintain even Safe Mode during normal eclipses. A decision was made to place AO-85 in Storage Mode, with only the receiver and basic electronics powered, except when the satellite is continuously illuminated. At those times, approximately 45 days a year, it will be returned to general use if possible. The first such test period in January 2019 was successful with normal operations reported.

AO-85 is the first of the new generation of AMSAT-NA Fox-1 CubeSats. CubeSats take advantage of the ability to provide functionality in a satellite you can hold in your hand comparable to one which would take up most of a desktop 10-20 years ago. Despite their small size, CubeSats have launch prices commensurate with their capabilities and are currently running about $125,000 for the smallest "one unit" (1U) versions. Fortunately, NASA and other agencies see the educational value of these satellites and are willing to provide free launches to satellites that have a significant educational purpose. Since AMSAT-NA has always included a strong educational component, we have paired with universities who provide experiments while we provide the basic spacecraft and communications.

The voice portion of the satellite operates as a cross-band or "bent pipe" FM repeater. The 2 m downlink and the 70 cm uplink, known as Mode-B or U/v, both use FM voice modulation and can be worked using the **recommended** equipment used for SO-50, and other FM satellites. As with some earlier FM satellites, to conserve battery power for use over populated areas, the transmitter turns on when the receiver detects a 67. 0 Hz CTCSS tone. Once the satellite detects the 67.0 Hz tone, the transmitter "hang time" stays on for at least 1 minute, or as long as it continues to detect the tone.

AO-85 is an "Easier-Sat" for two reasons: The use of a 2 m downlink makes the satellite approximately 9 dB stronger than the usual 70 cm downlink with the same transmitter power, and the satellite receiver has Automatic Frequency Control (AFC) to assist in Doppler correction on the uplink. That makes it possible to access the satellite even if the ground station uplink is a bit off-frequency. As with other FM satellites, stronger stations have an advantage.

Please use the **minimum** power possible as a courtesy to allow stations with lower power to access the satellite. These are often portable stations activating rare grid squares or new satellite operators who need encouragement and consideration. Because of an antenna issue, corrected in the later *Fox-1* series of satellites, the receiver is not as sensitive as planned, and the AFC works somewhat less effectively.

In addition to the amateur operation, there are two scientific experiments on board the spacecraft. Vanderbilt University is providing a Low Energy Proton (LEP) radiation experiment. This measures the effect of radiation on selected memory devices, leading to more accurate radiation effects modeling. The Penn State University–Erie Attitude Determination Experiment (ADE) is a 3-axis Micro-Electro-Mechanical Systems (MEMS) gyroscope experiment. This gyroscope experiment will fly on all versions of the Fox-1 spacecraft and will provide detailed information on the spacecraft spin and stabilization.

Experiment and spacecraft status telemetry are normally transmitted in the subaudible 0-200 Hz range usually used for CTCSS tones in terrestrial repeaters (called Data Under Voice or DUV), allowing simultaneous voice and 200 bps data operation. The high-speed (up to 9600 bps) mode downlink has been tested for engineering purposes but is not normally active in AO-85. Later Fox-1 series spacecraft use high speed telemetry for a camera and other experiments requiring higher data rates.

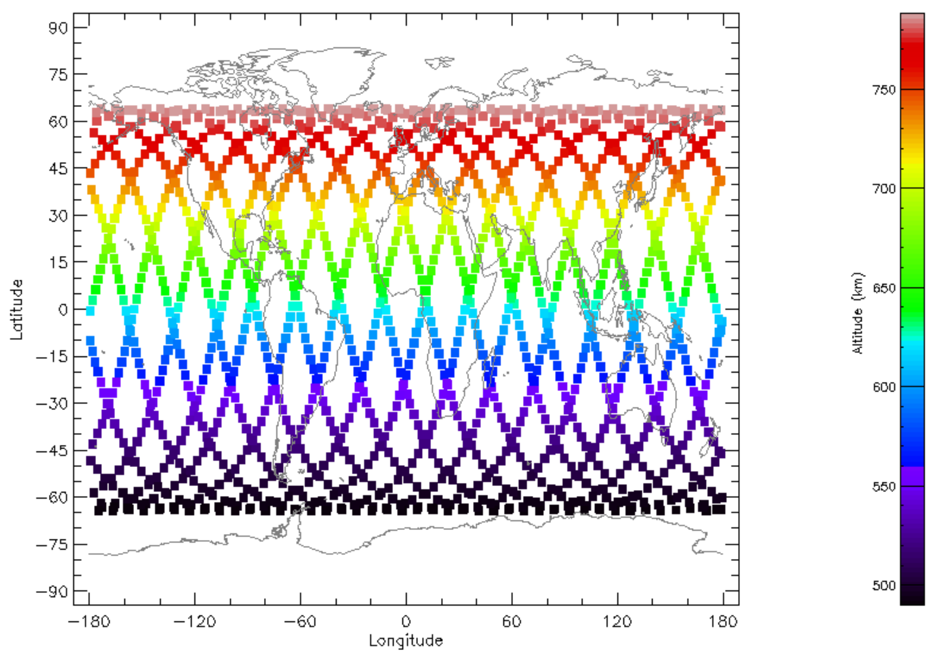
Satellite characteristics

AO-85 is a 10 cm (4 inch) cube, a 1U CubeSat. Both the antennas are linearly polarized, each consisting of a quarter wave whip. The satellite is locked to the earth's magnetic field using an internal permanent magnet in the Z axis. The magnet is offset from the Z axis, causing a small amount of wobble. The satellite uses conventional dark and light strips to impart a rotation about the Z axis for thermal stability, and to help stabilize the spacecraft orientation. Since the antennas extend in the +Z and –Z directions, they are approximately parallel to the Earth's magnetic field. However, the combination of spin and wobble result in periodic fades on both uplink and downlink. This is especially noticeable during periods where the satellite is in full illumination for periods of about 10 days, and the spin rate is increased. There are nine circuit boards within the aluminum frame containing the transmitters, receivers, power systems, computer, experiments, memory storage electronics, and radiation shielding.

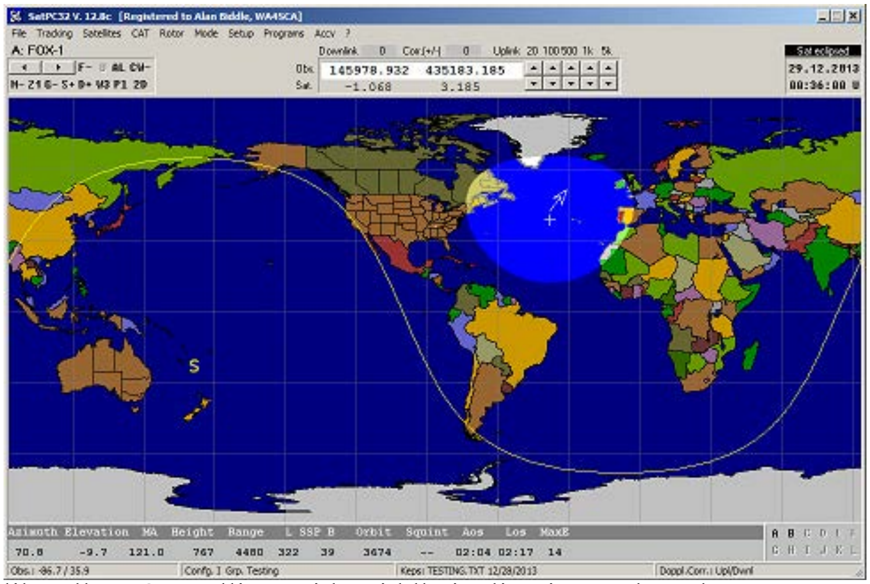
AO-85 Orbit

The orbit defines how the satellite communication behaves. AO-85 is in an orbit with an inclination of 65º. This places all of its coverage over regions with hams or people interested in its scientific and educational functions. The map below shows the typical global coverage in a 24-hour period:

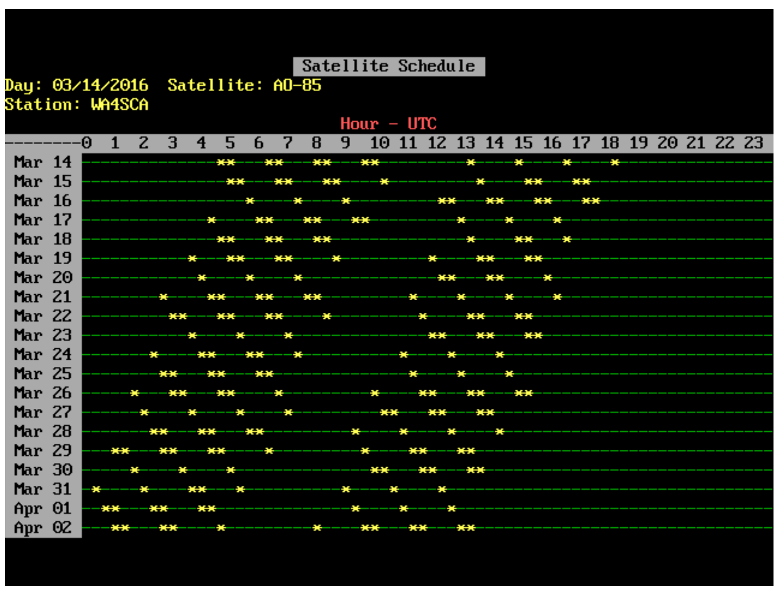
Because the orbit is elliptical, the size of the reception footprint varies throughout the orbit. At apogee, stations appropriately located are often be able to make intercontinental contacts, with full coverage of a continent being typical. The latitude of the apogee was at



the northernmost point of the orbit which optimized communication opportunities in the northern hemisphere but has slowly moved to the southern hemisphere.



AO-85, like all LEO satellites with middle inclination and moderate eccentricity, has a group of approximately 3 passes, lasting 3-13 minutes each, approximately 100 minutes apart, with a gap of one or two passes in the middle, followed by another 3 passes. This is followed by a period of 10-12 hours of no passes, with this general pattern repeating daily. The groups of passes will alternate between arriving from the north and south.



Doppler Shift Correction for AO-85

The U/v frequency plan used by AO-85 makes tuning for Doppler shifts no harder than the V/u configuration, but it does require some change of technique to decide when to tune. With earlier V/u satellites, when the signal reception became scratchy or was lost, you knew you needed to retune the received frequency. This applied to everybody's signal, so you could tune properly while listening to another QSO. With U/v, each station needs to tune his or her **uplink** based on their specific location with respect to the satellite. How do you do this?

While the satellite receiver AFC will help minimize the needed transmission Doppler correction, you must be prepared to make adjustments when using an HT or similar equipment. Some HTs may be set for 2.5 KHz channel spacing, but 5 KHz spacing with the satellite AFC should be adequate. Experience after launch with multiple users with different power levels has shown that tuning is not needed under all circumstances, but recommended, especially for low power stations.

For a typical HT with 5 KHz spacing, the following memory frequencies are suggested:

Receive Frequency*	Transmit Frequency with 67.0 Hz Tone	Satellite Position
145.980 MHz	435.160 MHz (Mem #1)	AOS
145.980 MHz	435.165 MHz (Mem #2)	Approaching
145.980 MHz	435.170 MHz (Mem #3)	Passing
145.980/145.975 MHz	435.175 MHz (Mem #4)	Departing
145.980/145.975 MHz	435.170 MHz (Mem #5)	LOS

* 145.977.5 MHz may be useful for HTs with 2.5 KHz tuning steps.

Note that you start with a frequency **lower** than the nominal transmit frequency and increase it during the pass.

AO-85 Telemetry

AO-85 has an amateur communications package, plus other features and experiments, which will send continuous telemetry whenever the transmitter is on. Because of the strong downlink signal and extremely sophisticated error correction encoding of the data, very modest receiving equipment is needed to receive it.

Subaudible Telemetry

In order to allow simultaneous operation of both the voice repeater and the housekeeping and experiment telemetry, an innovative system has been developed for low speed telemetry that will not be noticeable during normal communications. Normally amateur FM radios use the CTCSS tones for access and control of repeaters. These frequencies are in the range of 67.0 to 254.1 Hz. The *Fox-1* series uses this frequency range for 200 bps low speed telemetry.

While any HT or other amateur FM equipment may be used for voice communications, not all will be satisfactory for receiving telemetry since the normal speaker and headphone output is blocked below 300 Hz to prevent what would be an annoying PL hum. Some HTs and communications receivers will be satisfactory as long as they have a "9600 baud packet" or other unprocessed FM output.

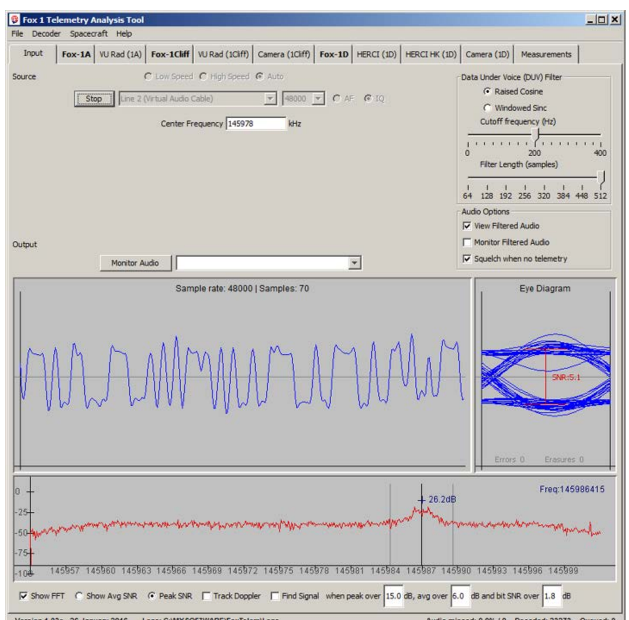
Recently a new type of extremely inexpensive receiver such as the FUNcube Dongle or other similar units have become available. When combined with readily available software, the response can be tailored to the exact needs of the application. For instance, the same equipment could be used to receive only the voice transmissions or only the telemetry. If your radio does pass these low frequencies, even if attenuated, you will hear a very characteristic “rumble” at low amplitude under the normal voice.

High Speed AFSK telemetry

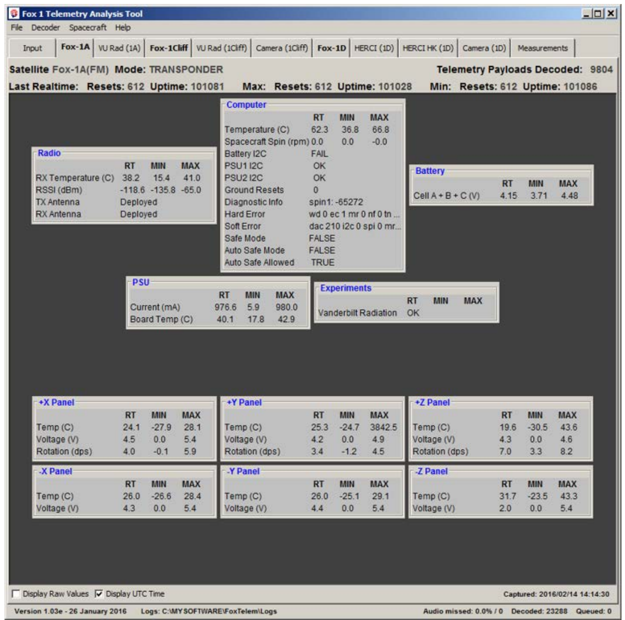
The subaudible telemetry is normally used because it allows simultaneous operation of the voice transponder. Other members of the Fox-1 family are have experiments such as a camera, which will require a faster downlink. When in use, telemetry and experiment data will be multiplexed with the pictures, but since it uses the same downlink frequency as the voice transponder, the repeater function will be unavailable. When listening with normal equipment, the high speed mode can be easily recognized by tone with a periodic beep, similar to old phone modems.

Radio equipment which will allow the reception of 9600 baud packet should be usable with the ground software. The FUNcube dongle will work very well for this mode as well. Note that the format is not standard AX.25 packet, so a hardware TNC or software equivalent will not work. The FoxTelem application will automatically select the telemetry speed being sent.

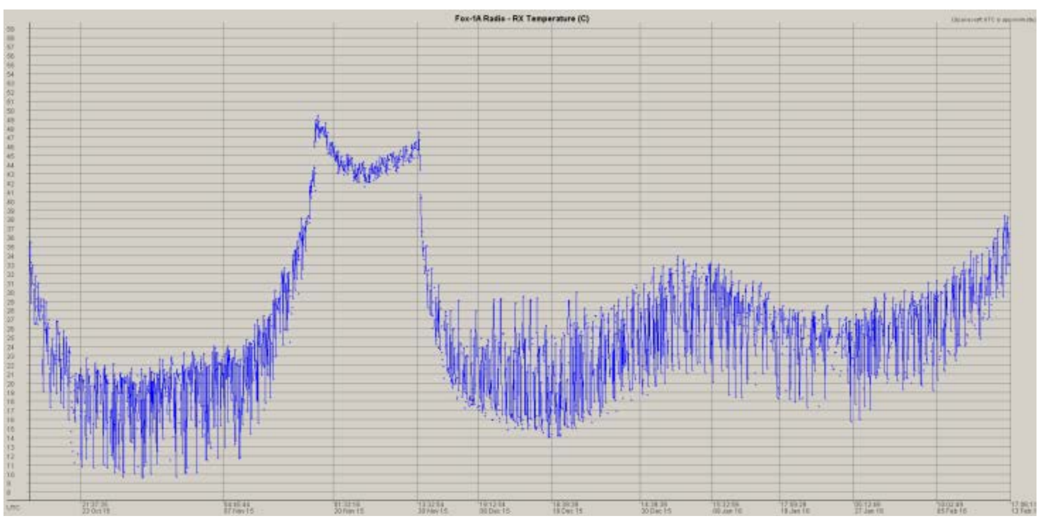
For those interested in spacecraft performance and experiments, software is available to display the data in real time, and to forward it to a server for later study and analysis. The display shows the FoxTelem console, which is available for Windows, MacOS, and Linux platforms. See Chapter 8, *Digital Modes*.



Low Speed Telemetry Signal



Available Telemetry Channels



Display of Spacecraft Temperature vs Time

More information including detailed software and hardware configurations are available to download free at www.amsat.org. This software will support all of the planned Fox-1 series of spacecraft, including the ability to download data for their cameras and other experiments.

Dozens of amateur radio operators and non-hams who are interest in satellites regularly download spacecraft and experiment information which is automatically forwarded to a central server. The most recent information is always available at:

http://www.amsat.org/tlm/health.php?id=1

Operator Insights from Steve Belter, N9IP

Before attempting to operate, make sure AO-85 is in transponder mode by checking https://amsat.org/status. The batteries are weak and the satellite may be shut off to preserve them.

AO-85 has a relatively strong transmitter, but seems deaf on receive. This is likely due to issues with the antenna which required last-minute repairs prior to delivery. As a result of the insensitive receiver, I normally use an Elk antenna because the Elk's elements are co-linear, as are AO-85's antennas, instead of the 90-degree separation on the Arrow's UHF/VHF elements.

If you can operate full-duplex, twist and point your antenna to get the best received signal, then adjust the twist (polarity) to get the best signal when you are transmitting. If you can hear yourself cleanly, everyone else (with a decent receiver) will be able to hear you too.

If you're operating half-duplex with an Arrow, point and twist the antenna for the best received signal, then twist the Arrow 90 degrees when you transmit. If you're half-duplex with an Elk, don't twist the antenna when transmitting.

You can leave the receive frequency fixed (145.980 MHz). Tune the transmitter for Doppler correction, starting at 435.160 MHz. As AO-85 rises, tune up to 435.165, then 435.170 when it is highest in the sky. As AO-85 starts to come down, tune up to 435.175 and finally to 435.180. If you're operating full-duplex, you should do the Doppler correction by ear, tuning for the clearest sounding signal when you're transmitting.

AO-85 also needs to hear a CTCSS tone of 67.0 Hz. The satellite only needs to hear this CTCSS tone every 60 seconds, so it is possible to transmit through AO-85 without the tone as long as someone else gets in with the tone every 60 seconds. (Think of AO-85 as a repeater with a really long hang-time.)

Speak in a normal voice! It is possible to over deviate the AO-85 receiver, resulting in a distorted signal being retransmitted. If you notice this happening, speak more softly and/or retune the uplink frequency.

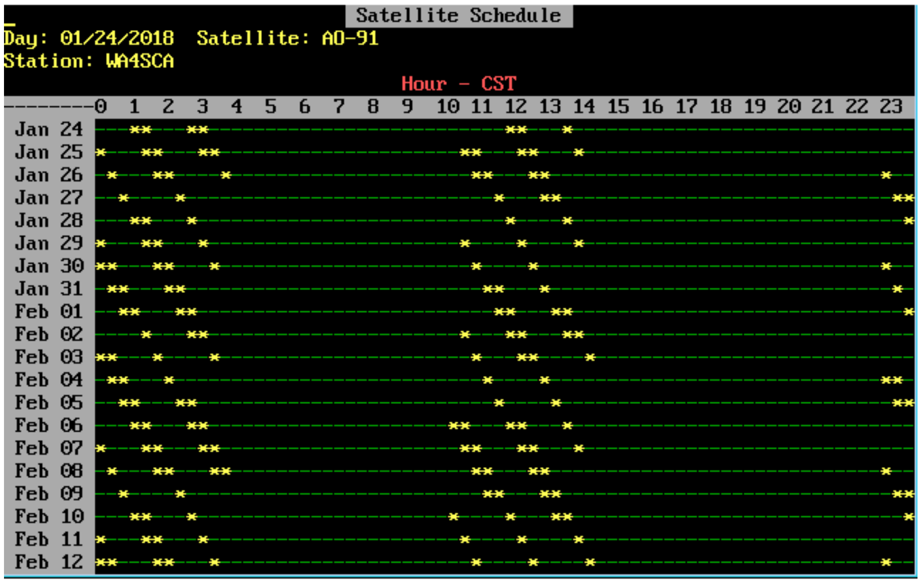
Some hams have a lot of trouble operating AO-85. If you can master the antenna polarity tricks outlined above, you may find that you like AO-85 because it is less crowded than the more popular FM satellites.

AO-91

Name(s):	**AO-91, *Fox-1B,* RadFxSat**
NASA catalog number:	43017
Launch:	0947 UTC, 14 Nov 2017 -- NASA ELaNa XIV Mission JPSS-1 Delta II Vandenberg AFB, CA
Orbit:	LEO (Low Earth Orbit)
Inclination:	98 degrees
Eccentricity:	.0258
Period:	Approx. 97 minutes
Estimated orbital lifetime:	5+ years
Altitude:	455-815 km
Size:	10 x 10 x 10 cm (4 inch cube)
Weight:	1.3 kg (~3 pounds)
Transmit power:	500 mW
Downlink:	145.960 MHz FM voice AFSK digital data up to 9600 bps
Uplink:	435.250 MHz FM voice (67.0 Hz CTCSS tone)

AO-91 is the second of the new *Fox-1* generation of AMSAT-NA CubeSats, and is nearly identical to AO-85, especially from an amateur communication standpoint. Please see the chapter on AO-85 for general *Fox-1* information. Only the significant differences will be covered here.

AO-91 is in a Sun Synchronous Orbit (SSO). The orbit is close to polar and all stations will see passes daily. Unlike some satellites, the passes will occur at a station, any station, at approximately the same local time of day, with a pattern which repeats every few days. The passes will center on 0030 and 1230 Local Time (LT)



From a communications standpoint AO-91 has three major changes from AO-85. First, it has a more sophisticated power control system which utilizes a Maximum Power Point Tracker to insure optimum charging of the batteries under all illuminations. This is largely transparent to the typical user but significantly increases the available battery life. Second, the detection of the 67.0 Hz tone has been enhanced, which helps accommodate ground stations whose CTCSS tones may be slightly off frequency. This combination makes accessing the satellite easier and also decreases the likelihood of dropouts. Finally, it “hears” significantly better than AO-85 with a more effective AFC, making it much easier to access using modest equipment.

AO-91 has an advanced version of the AO-85 Vanderbilt University Low Energy Proton (LEP) radiation experiment and the standard *Fox-1* Penn State University–Erie Attitude Determination Experiment (ADE). Subaudible telemetry is normally used, allowing simultaneous voice and 200 bps data operation.

Doppler Shift Correction for AO-91

Because of the increased sensitivity of the AO-91 receiver, stations with solid uplinks are finding that the AFC allows using a fixed uplink as well as downlink for all or most of the pass. If you do wish to adjust the uplink, correcting for Doppler shift involves the same techniques as for AO-85, with slightly different frequencies to prevent mutual spacecraft interference:

Receive Frequency	Transmit Frequency (67.0 Hz Tone)	Satellite Position
145.960 MHz	435.240 MHz (Mem #1)	AOS
145.960 MHz	435.245 MHz (Mem #2)	Approaching
145.960 MHz	435.250 MHz (Mem #3)	Passing
145.960 MHz	435.255 MHz (Mem #4)	Departing
145.960 MHz	435.260 MHz (Mem #5)	LOS

Table 1. Approximate AO-91 Doppler Correction Frequencies.

AO-91 Telemetry

Subaudible Telemetry

Except for a different downlink frequency, the low speed subaudible telemetry is the same as for AO-85. It is supported by the same FoxTelem software released for AO-85. Existing FoxTelem users will receive an update notice when a new version is available.

High Speed AFSK telemetry

There are no experiments on AO-91 which require the use of high-speed telemetry, though the mode may be occasionally used when a higher data is required for Command Station activities. These will normally be announced in advance.

Operator Insights from Steve Belter, N9IP

AO-91 has a strong transmitter and a sensitive receiver. It has a relatively high orbit, so at apogee, the footprint is larger than most FM CubeSats.

If you can operate full-duplex, twist and point your antenna to get the best received signal, then adjust the twist (polarity) to get the best signal when you are transmitting. If you can hear yourself cleanly, everyone else (with a decent receiver) will be able to hear you too.

If you're operating half-duplex with an Arrow, point and twist the antenna for the best received signal, then twist the Arrow 90 degrees when you transmit. If you're half-duplex with an Elk, don't twist the antenna when transmitting.

You can leave the receive frequency fixed (145.960 MHz). Tune the transmitter for Doppler correction, starting at 435.240 MHz. As AO-91 rises, tune up to 435.245, then 435.250 when it is highest in the sky. As AO-91 starts to come down, tune up to 435.255 and finally to 435.260. If you're operating full-duplex, you should do the Doppler correction by ear, tuning for the clearest sounding signal when you're transmitting.

AO-91 also needs to hear a CTCSS tone of 67.0 Hz. The satellite only needs to hear this CTCSS tone every 60 seconds, so it is possible to transmit through AO-91 without the tone as long as someone else gets in with the tone every 60 seconds. (Think of AO-91 as a repeater with a really long hang-time.)

Speak in a normal voice! It is possible to over deviate the AO-91 receiver, resulting in a distorted signal being retransmitted. If you notice this happening, speak more softly and/or retune the uplink frequency.

The biggest challenge with AO-91 is its popularity. Use the Best Practices listed in Chapter 6, Operating the FM Satellites.

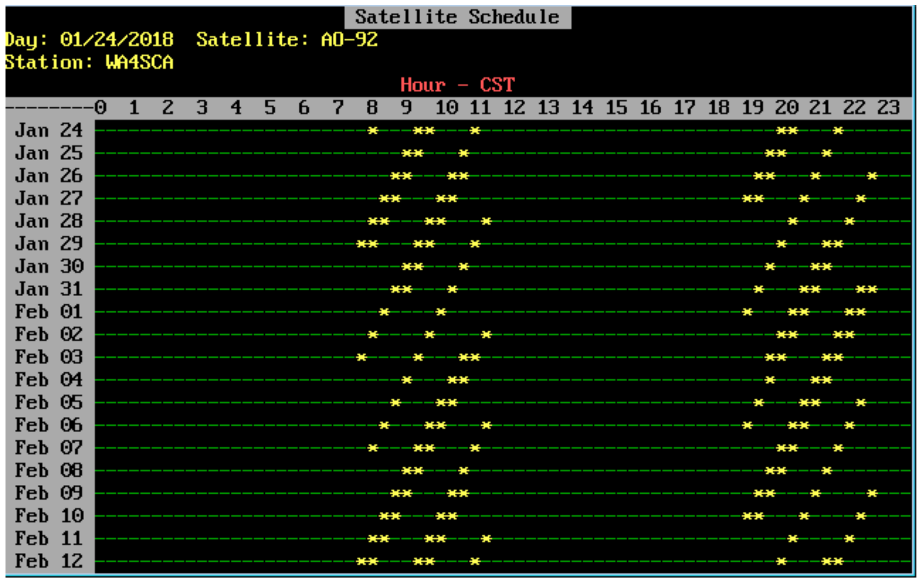
For details about *AO-91* please see https://www.amsat.org, subscribe to the AMSAT News Service, and the AMSAT Journal. To receive the AMSAT Journal you must be an AMSAT-NA member. You may join via the link to the AMSAT Store on our web site.

AO-92

Name(s):	**AO-92, *FOX-1D***
NASA catalog number:	43137
Launch:	0359 UTC, 12 Jan 2018 Polar Satellite Launch Vehicle (PSLV), Satish Dhawan Space Centre Sriharikota India
Orbit:	SSO (Sun Synchronous Orbit)
Inclination:	97.1°
Eccentricity:	.000080
Period:	Approx. 95 minutes
Est. orbital lifetime:	5+ years
Altitude:	505 km
Size:	10 x 10 x 10 cm (4 inch cube)
Weight:	1.36 kg (~3 pounds)
Transmit power:	400 mW (Minimum)
Downlink:	145.880 MHz FM voice AFSK digital data up to 9600 bps
Uplinks:	435.350 MHz FM voice (67.0 Hz CTCSS) 1267.360 MHz FM voice (67.0 Hz CTCSS)

AO-92*,* the third of the new generation of AMSAT-NA CubeSats launched, flew on a commercial launch purchased by AMSAT-NA. It includes the University of Iowa's High Energy Radiation CubeSat Instrument (HERCI) radiation mapping experiment. HERCI is intended to provide a mapping of radiation in low earth orbit. This is of scientific interest for planning CubeSat test flights for low energy X-Ray detectors. The instrument consists of a digital processing unit (DPU) derived from processors currently in orbit around Saturn on Cassini and on the way to Jupiter on the Juno spacecraft. It also carries the Virginia Tech JPEG Camera Experiment.

Like AO-91, AO-92 is in a Sun Synchronous Orbit (SSO). Its passes will appear at approximately the same local times daily for all stations. In comparison with AO-91, its passes are 3 hours earlier, allowing them to be used in sequence. Passes are centered on 0930 and 2130 Local Time.



It is nearly identical to AO-85, especially from an amateur communication standpoint.

Please see the chapter on AO-85 for general information on the *Fox-1* series. Only significant differences from AO-85 will be covered here. The receiver sensitivity and AFC performance are comparable to AO-91.

From a communications standpoint AO-92 has three major changes from AO-85. First, it has a more sophisticated power control system which utilizes a Maximum Power Point Tracker (MPPT) to insure optimum charging of the batteries under all illuminations. This will be largely transparent to the typical user but will significantly increase the available battery life.

Second, the detection of the 67.0 Hz tone has been enhanced, which helps accommodate ground stations whose CTCSS tones may be slightly off frequency. The combination will make accessing the satellite easier and also decrease the likelihood of dropouts.

Most obvious is that in addition to the normal the 70 cm (Mode-U) uplink found on AO-85, AO-92 has a 23 cm (Mode-L) receiver fed by the 70 cm antenna, which is used on experimenter days. It can be commanded on for up to 24 hours before automatically reverting to the 70 cm (Mode-U) uplink. Because much of the same receiver circuitry is used for both uplinks, only one can be active at a time. Tests show that it can be accessed using a 1 watt HT and standard antenna under ideal conditions, though the use of a directional antenna is strongly recommended for normal operations. Approximately 100 watts EIRP (radio power plus antenna gain) is needed for solid communications through a pass.

Doppler Shift Correction for AO-92

Correcting for Doppler shift involves the same techniques as for AO-91, with slightly different frequencies to prevent mutual spacecraft interference. The AFC greatly reduces the need to tune the uplink. However doing so may be advisable for several reasons such as low power, poor antennas, and extreme range.

Receive Frequency	Transmit Frequency (67.0 Hz Tone)	Satellite Position
145.880 MHz	435.340 MHz (Mem #1)	AOS
145.880 MHz	435.345 MHz (Mem #2)	Approaching
145.880 MHz	435.350 MHz (Mem #3)	Passing
145.880 MHz	435.355 MHz (Mem #4)	Departing
145.880 MHz	435.360 MHz (Mem #5)	LOS

Table 1. Approximate AO-92 Doppler Correction Frequencies.

The Mode-L Doppler shift is significantly larger than on 70 cm, ±30 KHz. Experience has shown that the use of a tracking program giving instantaneous uplink frequencies rather than a table is preferable, but not required. The receiver is very sensitive, and as little as a watt into a 10 element beam works well with practice. There are occasional nulls, dead times, due to the antenna patterns and the spacecraft rotation. Because only one uplink frequency can be active at a time, the use of the Mode-L uplink is limited to experimental periods announced in advance. Currently this is a 24 hour period beginning early Sundays UTC.

AO-92 Telemetry

Subaudible Telemetry

Except for a different downlink frequency, the low speed subaudible telemetry is the same as for AO-85 and AO-91 and is supported by the FoxTelem program.

High Speed AFSK telemetry

AO-92 has a Virginia Tech JPEG camera experiment. It operates in a small 320 X 240 mode. Note that this is not SSTV, but will be decoded in the FoxTelem program. By design and licensing requirements, all pictures will include at least a portion of the earth. In addition, the University of Iowa HERCI experiment also requires the use of the high speed AFSK telemetry.

There are two separate high-speed AFSK modes. When the camera high-speed mode is in use, telemetry and experiment data will be multiplexed with the pictures. When the HERCI high-speed mode is in use, telemetry and HERCI data will be multiplexed. In both cases, since the high speed AFSK uses the same downlink frequency, the voice transponder will be unavailable. Both modes can be commanded on for 45 minutes by command stations. In the case of the camera experiment, not all areas of the earth will be covered. In both cases, AO-92 will revert to the normal mode U/v transponder at the end of the high speed data runs.

Receiving equipment that will allow the reception of 9600-baud packet, combined with appropriate audio software, will be usable with the FoxTelem software. This is not 9600 baud packet, so TNC hardware is not needed or usable. The FUNcube dongle will work very well for this mode as well. Because of the higher data rate, the high-speed mode normally requires somewhat stronger signals to properly decode. Periods when the high-speed telemetry will normally be in use will be announced in advance.

The FoxTelem software package has an option that will automatically switch between high speed and low speed telemetry modes, allowing unattended operation. In addition to the normal spacecraft and telemetry, the pictures will be downlinked and stored for later viewing. Parts of pictures received at individual stations will be uploaded to the server, and stitched into complete images for viewing.

HERCI information courtesy of the University of Iowa.

Operator Insights from Steve Belter, N9IP

Before attempting to operate an AO-92 pass, check the https://www.amsat.org website for the current operating schedule. You won't be successful operating U/v if the satellite is in L/v or if high-speed data or camera images are being sent.

AO-92 has a strong transmitter and a sensitive receiver.

If you can operate full-duplex, twist and point your antenna to get the best received signal, then adjust the twist (polarity) to get the best signal when you are transmitting. If you can hear yourself cleanly, everyone else (with a decent receiver) will be able to hear you too.

You can leave the receive frequency fixed (145.880 MHz). Tune your transmitter for Doppler correction, starting at 435.340 MHz. As AO-92 rises, tune up to 435.345, then 435.350 when it is highest in the sky. As AO-92 starts to come down, tune up to 435.355 and finally to 435.360.

The biggest challenges with AO-92 are its schedule and its popularity. Use the Best Practices listed in Chapter 6, Operating the FM Satellites.

AO-95

Name(s):	**AO-95,*Fox-1Cliff**, *Fox-1C***
NASA catalog number:	43770
Launch:	1834 UTC 3 December 2018 SpaceX Falcon 9, SSO-A Vandenberg AFB, CA
Orbit:	SSO LEO (Low Earth Orbit)
Inclination:	97.8°
Eccentricity:	.0016
Period:	Approx. 96 minutes
Estimated orbital lifetime:	5+ years
Altitude:	575-595 km
Size:	10 x 10 x 10 cm (4 inch cube)
Weight:	1.1 kg (~2.5 pounds)
Transmit power:	400 mW (Minimum)
Downlink:	145.920 MHz FM voice AFSK digital data up to 9600 bps
Uplinks (Inoperative):	435.300 MHz FM voice (67.0 Hz CTCSS tone) 1267.300 MHz FM voice (67.0 Hz CTCSS tone)

AO-95 is the fourth of the new generation of AMSAT-NA CubeSats and flew on a commercial launch purchased by AMSAT-NA. It is nearly identical to AO-85, especially from an amateur communication standpoint. Please see the chapter on AO-85 for the general *Fox-1* information, AO-91 for information on the high-speed telemetry, and AO-92 for the 24 cm Mode-L uplink.

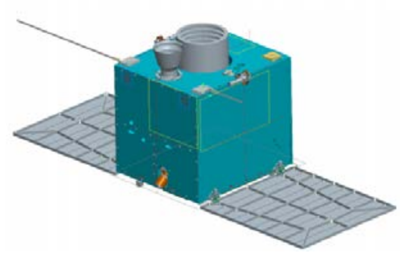
**Fox-1C was renamed Fox-1Cliff as a memorial to Cliff Buttschardt, K7RR, longtime AMSAT member, contributor, and benefactor.*

AO-95 has a new version of the AO-85 Vanderbilt University Low Energy Proton (LEP) radiation experiment, and the standard *Fox-1* Penn State University–Erie gyroscope experiment. In addition, Virginia Tech provided a VGA (640 X 480) resolution JPEG camera experiment for pictures of the Earth.

Unfortunately, while AO-95 was successfully launched and telemetry indicates the systems are healthy, due to an anomaly in the receiver system the satellite can neither be commanded nor used for its intended purposes. It is in Safe Mode and sends two telemetry packets every 2 minutes. Signals are strong, and telemetry is solicited.

Joe Werth, KE9AJ, gets his feet wet operating an FM satellite from the shore. He's using an Arrow dual-band Yagi and a Yaesu FT-60R.

CAS-4A & CAS-4B

The OVS-1A & 1B satellites carrying the CAS-4A and CAS-4B payloads.

Names:	**CAS-4A and CAS-4B**
Object #s:	CAS-4A 42761 CAS-4B 42759
Launch:	03:00 UTC, June 15, 2017, CZ-4B, Jiuquan Satellite Launch Center
Period:	95.4 minutes
Orbit:	Nearly Circular
Altitude:	538 km (approx.)
Inclination	43.0 °
Height:	63 cm
Width:	50 cm
Length	50 cm
Mass:	55 kg
Transponder:	SSB/CW Inverting
Lifetimes:	5+ years
Sponsor:	CAMSAT (AMSAT-CN)

Background

The CAMSAT CAS-4A and CAS-4B transponders are not independent satellites. Both are hosted on larger primary satellites, OVS-1A and OVS-1B respectively. The primary payload is a hard X-ray Modulation Telescope (HXMT), as well as optical sensing instruments. This has advantages in that many functions such as stability and power are being provided by the primary payload, but availability of the secondary amateur payloads depends on the primary payload mission requirements.

To determine whether the transponders are active, go to AMSAT Live OSCAR Satellite Status Page at https://www.amsat.org/status/. Users regularly report the status of active satellites in near-real time; in particular, whether the transponder is active, or only telemetry. You are encouraged to submit your own reports so that others may benefit from your experience. Operating techniques are similar to other mode U/v analog satellites such as AO-73.

Satellite Descriptions

CAS-4A and CAS4B use quarter wavelength monopole antennas for both uplinks and downlinks. The satellite is stabilized with the +Y direction pointing upward.

CAS-4A

Call Sign:	**BJ1SK**
Object #	42751
Transponder:	Mode (U/v) 100 mW, Inverting
Downlink:	145.860 MHz – 145.880 MHz
Uplink:	435.230 MHz – 435.210 MHz
CW Beacon	145.855 MHz (50 mW)
Digital Beacon:	145.835 MHz, AX.25 4.8k Baud GMSK (100 mw)

CAS-4B

Call Sign:	**BJ1SL**
Object #	42759
Transponder:	Mode (U/v) 100 mW, inverting
Downlink:	145.915 MHz – 145.935 MHz
Uplink:	435.290 MHz – 435.270 MHz
CW Beacon	145.910 MHz (50 mW)
Digital Beacon:	145.890 MHz, AX.25 4.8k Baud GMSK

Information courtesy of CAMSAT, AMSAT-UK, and AMSAT-NA

Operator Insights from Steve Belter, N9IP

CAS-4A and CAS-4B have strong transmitters and sensitive receivers. Most operators agree that both are great SSB/CW satellites, easy to hit and easy to hear.

First, listen for the CW beacon at 145.855-145.858 (CAS-4A) or 145.910-145.913 (CAS-4B) as the bird approaches you. Once you can hear the beacon, pick a transmit frequency in the passband, not in the center, but close to 435.210 (CAS-4A) or 435.270 (CAS-4B). While you transmit, tune the receiver to find yourself, probably near 145.880 (CAS-4A) or 145.935 (CAS-4B). As the satellite rises, you'll need to increase the transmitter frequency so that you can continue to hear yourself on the downlink.

Use the steps for operating a U/v satellite listed in Chapter 7, Operating the SSB/CW Satellites.

EO-88

Name(s):	**EO-88, Nayif-1, FUNcube-5**
NASA catalog number:	42017
Launch:	February 15, 2017, PSLV-C37 ISRO Satish Dhawan Space Centre Sriharikota, Andhra, Pradesh India
Orbit:	LEO (Low Earth Orbit)
Inclination:	97.5
Eccentricity:	.00002482
Period:	95.6 minutes
Estimated orbital lifetime:	5+ years
Altitude:	498-528 km
Size:	10 x 10 x 10 cm (4 inch cube)
Weight:	1.3 kg (~3 pounds)
Transmit power:	400 mW
Bandwidth:	30 kHz
Transponder:	Mode B (U/v) analog inverting
Beacon:	145.940 MHz 1200 baud BPSK
Uplink:	435.045 MHz – 435.015 MHz LSB/CW
Downlink:	145.960 MHz – 145.990 MHz USB/CW

EO-88 (Emirates-OSCAR 88) has been developed by the Mohammed bin Rashid Space Centre (MBRSC) and American University of Sharjah (AUS). The United Arab Emirates' first Nanosatellite was developed by Emirati engineering students from AUS under the supervision of a team of engineers and specialists from MBRSC within the framework of a partnership between the two entities, aiming to provide hands-on experience to engineering students on satellite manufacturing. It employs enhanced oscillator circuitry and includes an active attitude determination and control system. It was one of a record 104 satellites deployed on the same mission.

EO-88 shares many similarities with AO-73, differing primarily in slightly higher available power, and better frequency stability. In order to support its dual mission of education and communications, the satellite functions in a telemetry-only high power mode (420 mW) when in daylight, and switches to low power telemetry beacon transponder mode (42 mW) in darkness, the remaining approximately 400 mW allocated to the transponder. This autonomous mode may be overridden by command stations, but unlike AO-73 this is not expected to be a normal procedure. At present a separate Telemetry Dashboard is available to display the various system parameters, and also upload them to a central data warehouse. Plans exist to release a combined Dashboard which will support AO-73 and EO-88. The current EO-88 Dashboard may be found at: https://funcube.org.uk/working-documents/funcube-telemetry-dashboard/

In order to utilize the transponder and telemetry beacon, equipment suitable for other linear transponder satellites such as AO-73 will be needed. Initial reports are that the receiver is very sensitive. Please do not attempt to transmit using FM, which will render the satellite unusable for other users. It is recommended that you listen for other users and/or the beacon to insure that the satellite is available, and your receiving equipment is working correctly. Please use only enough power to be heard at the same general level as the other users. In general the recommendations for operating FO-29 and AO-73 are applicable.

As with other linear transponders, a separate telemetry beacon at 145.940 MHz is used for satellite identification as well as spacecraft and experiment health information. It can be received using any SSB capable radio, with the audio being decoded using the latest version of the EO-88 Dashboard program. The latest version, along with detailed instructions, can be found at:

https://funcube.org.uk/working-documents/funcube-telemetry-dashboard/

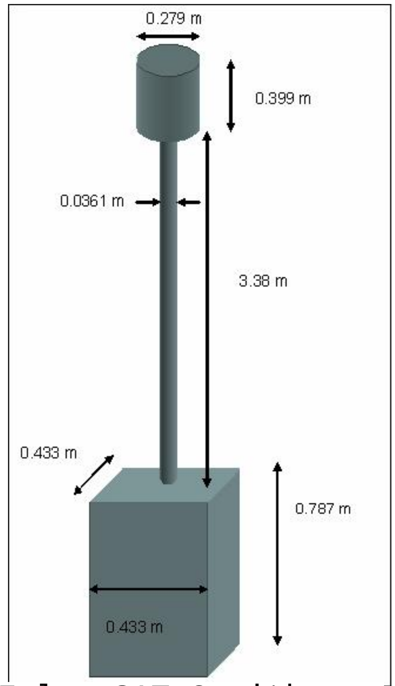
Information courtesy of AMSAT-UK and AMSAT-NL

FalconSAT-3

Name(s):	**FalconSAT-3, FS-3**
NASA catalog number:	30776
Launch:	March 9, 2007, Atlas-5, Cape Canaveral Air Force Station, Florida
Orbit:	LEO
Inclination:	35.4°
Period:	93.7 minutes
Altitude:	458 km x 456 km
Size:	43.3 cm x 43.3cm x 78.7 cm with 334 cm gravity stabilization boom
Shape:	Rectangular
Weight:	54.3 kg (120 pounds)
Transponder:	9600 baud digital
Digipeater Callsign	PFS3-1
Broadcast Callsign	PFS3-11
BBS Callsign	PFS3-12
Uplink	145.840 MHz
Downlink	435.103 MHz
Transmit power:	1.25 watts continuous (5 watts intermittent)

FalconSAT-3 is the 3rd in a series of United States Air Force Academy (USAFA) student-built microsatellites. Its primary mission was to test a gravity gradient boom for stabilization of the spacecraft in the Z direction, with magnetorquers control the rotation about the Z axis. Primary and secondary payloads include Micro Propulsion Attitude Control System (MPACS), Flat Plasma Spectrometer (FLAPS), and Plasma Local Anomalous Noise Environment (PLANE). The basic spacecraft bus is Commercial off the Shelf (COTS) manufactured by SpaceQuest Ltd, thus allowing primary attention to be directed at the individual experiments and equipment.

In addition to the experiments themselves, FalconSAT-3 has functioned as a practical training platform to allow USAFA cadets to familiarize themselves with the operation of a functioning spacecraft, including the need to resolve hardware and software issues detected or developed after deployment. The spacecraft has finished its USAFA mission and been released to AMSAT-NA for the remainder of its estimated 4-to-5 year remaining lifetime as a digital communications satellite. Because of the low inclination of 35 degrees, coverage is limited to approximately between 58 degrees North and South latitudes. For a typical station around 35-to-40 degree latitude, there will be approximately 5 passes a day. The footprint will be slightly larger than the ISS.

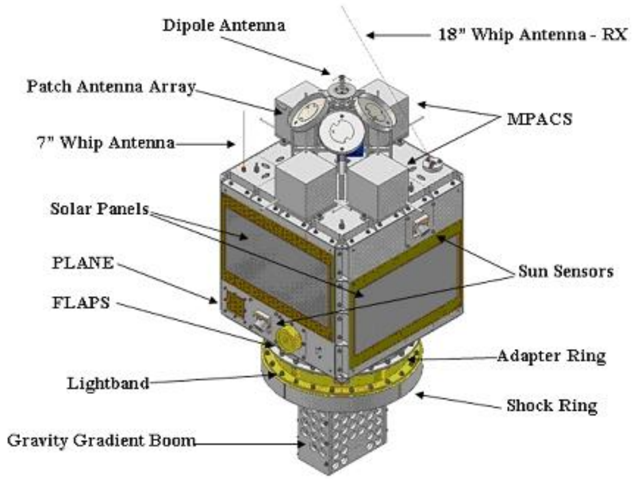


FalconSAT-3 with Gravity Gradient Boom (Image Courtesy USAFA)

The primary features of the satellite for amateurs are the digipeater, and the PACSAT Broadcast Protocol (PBP). The digipeater is similar in function to that used on the ISS and other satellites but has some significant differences in implementation. It differs in four primary ways. First, it uses different uplink and downlink bands. The 2 m uplink will not need to be adjusted for Doppler, but the 70 cm downlink will. In a sense, it is a cross between the 2 m and 70 cm ISS operations.

Second, it is full duplex. The satellite transmitter is on constantly to support the PBP, much like the typical FM voice repeater, and unlike the ISS and other packet satellites which only key the transmitter when it has a packet to repeat. This means that in order to transmit, you must be able to disable the APRS squelch in order to transmit at all. To hear your echoed packets, you will need to be able to hear the downlink while transmitting. Otherwise, your digipeated packed may be sent while your rig is switching from transmit to receive.

Note that the APRS squelch is usually not the same as the normal voice squelch settings. Depending on the manufacturer, it may be referred to as APRS Squelch, or Data Carrier Detect (DCD). It must be set to Off or Ignore. Otherwise, your transmitted packets will be held until LOS. As a practical matter, a standard dual band rig should be adequate **so long as the transmit squelch can be disabled** since you are only concerned with hearing packets from other stations. Full duplex however is highly recommended to reduce the need for repeats due to packet collisions.



FalconSAT-3 Antenna Locations

The third difference is that unlike the ISS and most other digipeater satellites, it operates at 9600 baud rather than 1200 baud. Modern software such as MixW, HS_Soundmodem, and AGW all support this standard. Many newer rigs which support packet, such as the Kenwood TH-D72, have the ability to use the higher speed by menu selection. However, some rigs do not. So, insure that your rig explicitly supports 9600 baud. Please see the Chapter 5: *Your Radio System* and Chapter 8: *Digital Modes* for more detailed discussions. As with other high-speed modes, a relatively strong signal is required for good decodes.

Finally, it does not use the standard ARISS as the spacecraft address. Instead, it uses PFS3-1, which was the standard adopted when the original software was written. Like other satellite digipeaters, it only supports UNPROTO packets, so you cannot connect to yourself or another station directly. Use a path of CQ VIA PFS3-1 for a conventional TNC, or the equivalent for your software package.

For use with a typical HT, it will not be necessary to tune the uplink, but the downlink will need to be adjusted through the pass. Depending on your equipment, there may well be brief periods where the standard 5 KHz spacing will be outside the usable range. This situation will be brief as the satellite orbit shifts. These are the recommended frequency selections.

	Downlink	**Uplink**
Beginning of pass	435.115 MHz	145.840 MHz*
Early pass	435.110 MHz	145.840 MHz*
Mid pass	435.105 MHz	145.840 MHz*
Late pass	435.100 MHz	145.840 MHz*
End of pass	435.095 MHz	145.840 MHz*

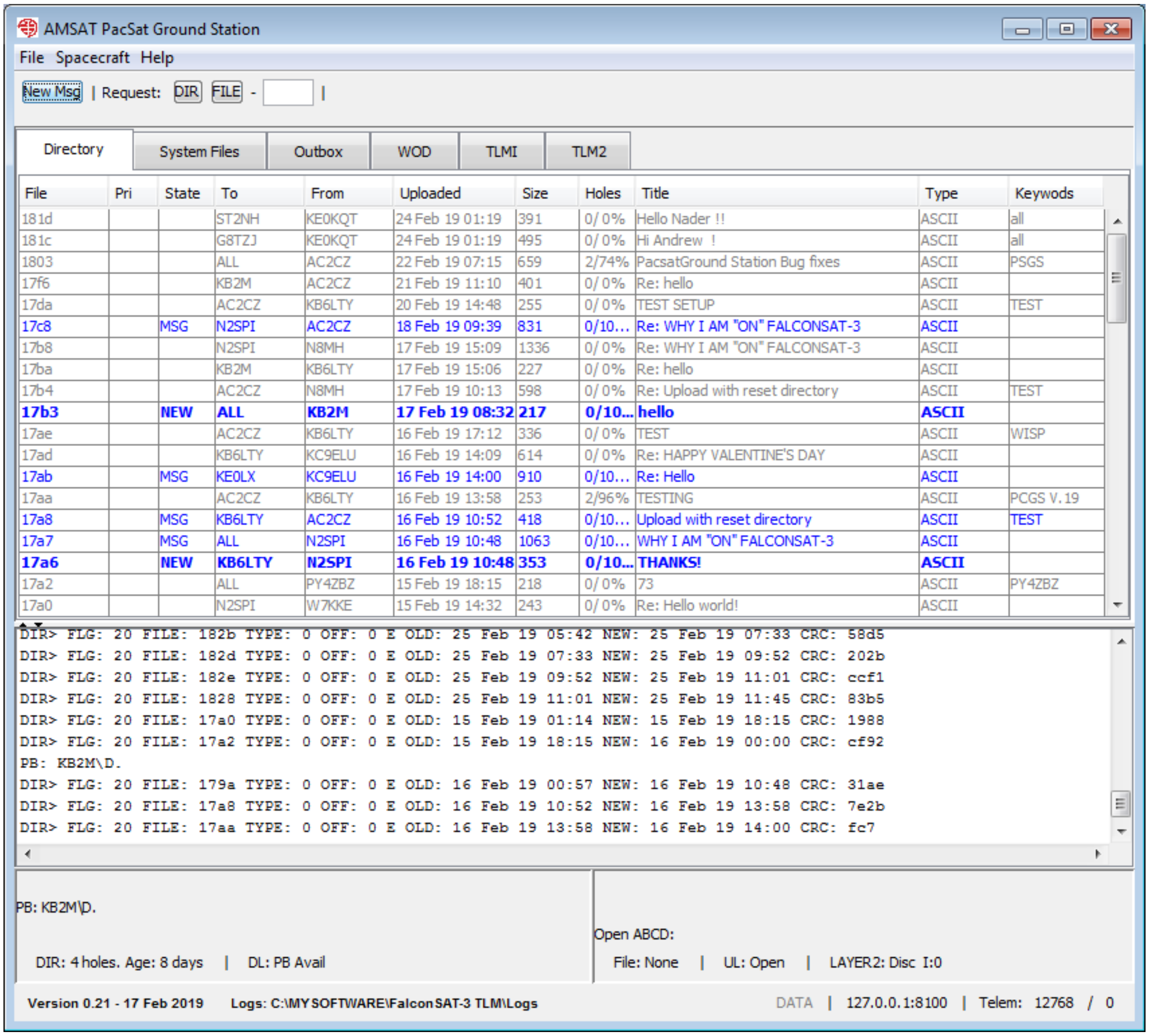
*Some rigs may work better using 145.845 MHz during the later parts of the pass.

In the standard Packet BBS (PBBS), a single user connects and then interacts via keyboard in real time. These used to be common for terrestrial packet but is unusable for space operations such as the ISS due to multiple interfering packets, the short periods of visibility, and the requirement to download a directory or file repeatedly, even if the previous user did so. In contrast, the PBP is designed to support a number of users at a time. It was extensively used by PacSats in the early 1990s and continues to be used for special purposes today. Even when not interacting directly, a ground station can gather information requested by other stations such as directory, messages, and telemetry information. The ground station prepares any uplinked messages off line, and then uplinks them automatically during a pass. Since **all** stations will receive the downloaded packets, it is only necessary to request, if needed, any existing "holes" and the software assembles the completed messages for reading off line. Along with message traffic, information such as telemetry is also broadcast. Note that unlike the digipeater, full duplex capability is necessary since you will be interacting directly with the satellite. While half duplex capability may work, it will result in unnecessary interference with other stations. As with the digipeater, the transmit squelch **must** be disabled.

The software that supports this is called WiSP and is available from AMSAT-NA. Though written 25 years ago, it can be used with the latest version of Windows. As with other old software, do not install it in the default \PROGRAM FILES\ directories since it does not comply with User Account Controls requirements. While fully functional, a registration number is necessary to remove a small nag. This will be provided at no cost by AMSAT-NA to encourage operation.

See the FalconSAT-3 page on the AMSAT website (https://www.amsat.org/FalconSAT-3/) for software and operating guide download links. Software for Linux machines, PacSatTools and PB/PG, is also available from AMSAT-NA. As with WiSP, these software packages were also written many years ago but have been compiled and installed on modern Linux distributions.

Fortunately, AMSAT PacSat Ground Station (APGS), a modern JAVA version of WiSP which supports Windows, macOS, and Linux, is being developed. While still in development, it currently supports the transfer of both text and JPG files, as well as spacecraft engineering data which can be viewed locally, and also forwarded to AMSAT to assist in spacecraft management. APGS supports hardware TNCs and software such as MixW which can emulate one, but it also can use modern software modems such as HS_Soundmodem so long as they have the required Full Duplex mode.



The upper portion of the screen closely resembles a simple forum page. You can see who has posted, the topic, and the status of the download. Remember, the program will capture all downloads your station can hear, so you may already have a complete file. If not, you can request a "fill." The lower pane is shows things such as the files being uploaded and downloaded, status messages, etc. Not strictly necessary for communications, but interesting to see what is normally behind the scenes.

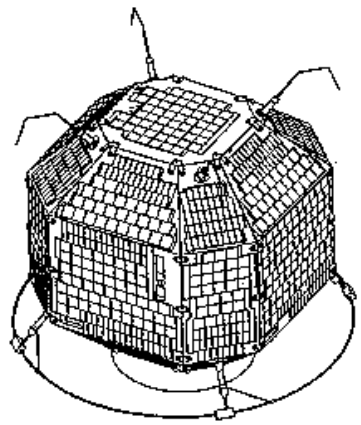
Software support is provided through the AMSAT-BB mailing list.

Resources

Earth Observation Portal: https://directory.eoportal.org/web/eoportal/satellite-missions

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.

FO-29



Names:	**Fuji-OSCAR 29, JAS-2.** **(JAS - Japan Amateur Satellite)**
Object #:	24278
Launch:	17 Aug 1996
Period:	106 minutes
Orbit:	Polar LEO
Altitude:	Average 1080 km, perigee 801 km, apogee 1350 km
Shape:	Multisided
Height:	0.47 m (18.5 in)
Diameter:	0.44 m (15.75 in)
Weight:	50 kg (110 lb.)
Bandwidth:	100 kHz
Transponder:	Mode JA or V/u (analog) Inverting, Mode JD or V/u (digital – not currently used)
Modes:	Analog - CW, SSB voice, previously Digi-Talker
Telemetry:	JA - CW , 100 mW
Uplink:	146.000 MHz – 145.900MHz LSB/CW
Downlink:	435.800 MHz – 435.900 MHz USB/CW
Sponsor:	JAMSAT, JARL

Background

Launched in 1996, FO-29 is the second of the basketball sized, 26-sided, multimode satellites that JAMSAT placed into orbit. Like its predecessor FO-20, this satellite provided both digital and analog operation. Only the analog transponder is currently activated.

FO-29 Analog Mode V/u Frequency Plan

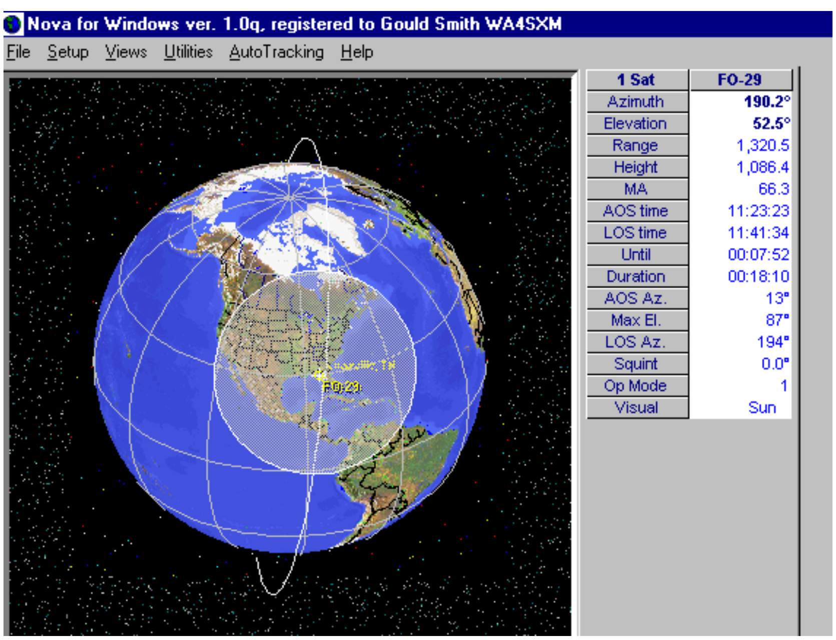
Downlink (USB)	Uplink (LSB)
435.900 MHz	145.900 MHz
435.890	145.910 phone
435.880	145.920 phone
435.870	145.930 phone
435.860	145.940 phone
435.850	145.950 Passband center
435.840	145.960 CW
435.830	145.970 CW
435.820	145.980 CW
435.810	145.990CW
435.800 MHz	146.000 MHz
435.795	Beacon

FO-29 hears well, but does not have a great deal of transmit power. It is up to the ground stations to prepare the best downlink stations they can. Very modest uplink stations will perform very well. **Do not compensate for weak reception by increasing the uplink power, especially on CW.**

Directional antennas such as Yagis or log periodics will provide the best reception and transmit efficiency. Adding an inexpensive preamp is a quick method of improving your satellite downlink station. If added at the antenna, you will hear even more improvement.

FO-29 Coverage

As you can see below, the coverage area of FO-29 is quite good, all of North America, the Caribbean, and Northern South America. Since this satellite's average altitude is around 1080 km, the pass will last nearly 20 minutes. FO-29's apogee is about 1350 km, so if the satellite is near its apogee, you can use this satellite for serious DX.



FO-29 CW Telemetry

The CW telemetry signal from FO-29 is transmitted on 435.795 MHz using 100 mW of power at a frame rate of one frame per minute. Each frame begins and ends with the historical 'HI'. The characters are sent at a rate of about 100 characters per minute.

The frame is sent in six groups of four data channels 1A - 1D, 2A - 2D, ... , 6A - 6D. Each channel is made up of two digits hexadecimal digits. FO-29 has three digits per channel.

The first digit of each channel is the group number (1-5). The next digit of the analog data is the hexadecimal data value. This data must be calibrated to give the actual value monitored in the spacecraft. So the transmitted value (N) is placed into a calibration equation for each channel. The hexadecimal status values use the binary equivalents to determine the status.

Example FO-29 CW telemetry

HI HI A6 07 81 77 00 9C FD CD 0C 42 79 5D 7B 47 91 8E 9C 69 C5 C3 C4 C4 BF

Hexadecimal to binary conversion table

Hexadecimal	Binary	Hexadecimal	Binary
0	0000	8	1000
1	0001	9	1001
2	0010	A	1010
3	0011	B	1011
4	0100	C	1100
5	0101	D	1101
6	0110	E	1110
7	0111	F	1111

Example FO-29 CW Telemetry Data Frame Format (left) and Actual Data (right)

```
HI   HI      1A   1B   1C   1D          HI HI       A6 07 81 77
             2A   2B   2C   2D                      00 9C FD CD
             3A   3B   3C   3D                      0C 42 79 5D
             4A   4B   4C   4D                      7B 47 91 8E
             5A   5B   5C   5D                      9C 69 C5 C3
             6A   6B   6C   6D                      C4 C4 BF
```

FO-29 Telemetry channel values

System Status:

```
   bit  contents          1    0
--------------------------------
1A  0  Main Relay       OFF   ON
    1  DCM              ON   OFF
    2  SRAM             ON   OFF
    3  Packet         1200  9600 or OFF
    4  Packet         9600  1200 or OFF
    5  JTA              ON   OFF
    6  JTD              ON   OFF
    7  GAS              ON   OFF
1B  0  SAS              ON   OFF
    1  UVC              ON   OFF
    2  UVC Level         2     1
    3  PCU Mode       MANU  AUTO
    4  PCU Level         2     1 or 3
    5  PCU Level         3     1 or 2
    6  Battery Mode   TLIC  FULL
    7  Battery Logic  TLIC  FULL
1C  0  Engineering Data  ----
    1  Engineering Data  ----
    2  Engineering Data  ----
    3  Engineering Data  ----
    4  Digitalker Mode  ON   OFF
    5  Engineering Data  ----
    6  UVC ACT/PAS     ACT   PAS
    7  CPU RUN/RESET   RUN RESET
1D  Engineering Data
```

Analog Data and Equations:

```
2A  Engineering Data
2B  Engineering Data
2C  Spin Period
2D  Spin Period
3A  Attitude Status
3B  Sun Angle
3C  GAS-Z                    nT=N*490.196           [nT]
3D  GAS-X                    nT=N*490.196           [nT]
4A  Solar Current             I=N*9.804             [mA]
4B  Battery Current           I=-(2000-N*19.6)      [mA]
4C  Battery Voltage           V=N*0.10761           [V]
4D  Battery Middle Voltage    V=N*0.04817           [V]
5A  Bus Voltage               V=N*0.09804           [V]
5B  JTA Tx Power             mW=N*6.4997-98.0863    [mW]
5C  Structure Temp. 1         T=-N*0.388375+81.883 [C]
5D  Structure Temp. 2         T=-N*0.388375+81.883 [C]
6A  Structure Temp. 3         T=-N*0.388375+81.883 [C]
6B  Structure Temp. 4         T=-N*0.388375+81.883 [C]
6C  Battery Cell Temp.        T=-N*0.388375+81.883 [C]
```

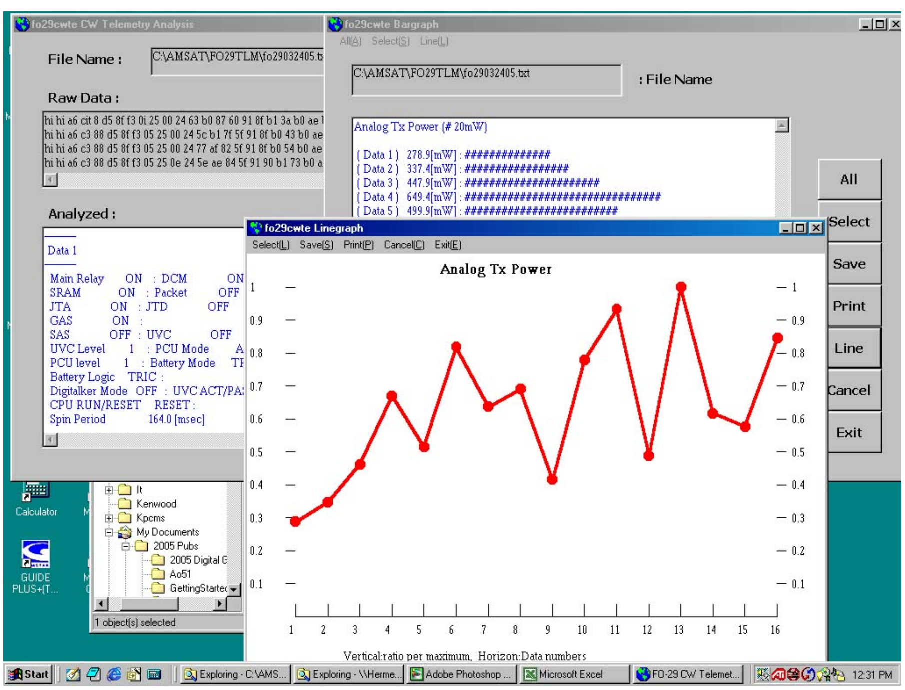
Spin Period:

	bit	
2C	0	----
	1	----
	2	8192 [msec]
	3	4096 [msec]
	4	2048 [msec]
	5	1024 [msec]
	6	512 [msec]
	7	256 [msec]
2D	0	128 [msec]
	1	64 [msec]
	2	32 [msec]
	3	16 [msec]
	4	8 [msec]
	5	4 [msec]
	6	2 [msec]
	7	1 [msec]

Mineo Wakita JE9PEL offers a nice FO-29 Satellite CW Telemetry Analysis Program for free on his web site. The program is called “fo29cwte”. Mineo’s web site is:

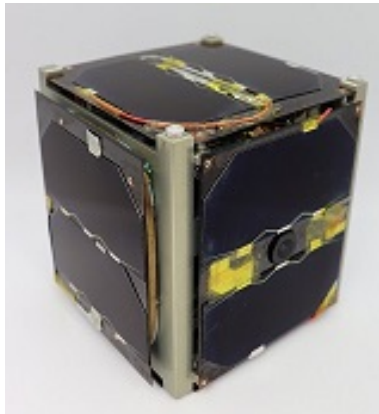
http://www.ne.jp/asahi/hamradio/je9pel/

The screen capture below shows the FO29CWTE program display.



Paul, N8HM, operated FO-29 from the National Mall in Washington, DC, during the National Parks on the Air (NPOTA) event. He used an Elk log periodic and two Yaesu FT-817 radios.

FO-99



Name(s):	**FO-99, NEXUS**
NASA catalog number:	43937
Launch:	00:50 UTC, 18 January -- JAXA Epsilon CLPS Uchinoura Space Center Kagoshima Prefecture, Japan
Orbit:	LEO (Low Earth Orbit)
Inclination:	97.3°
Eccentricity:	.00266
Period:	Approx. 96 minutes
Estimated orbital lifetime:	5+ years
Altitude:	480-515 km
Size:	10 x 10 x 11.3 cm (4 inch cube)
Weight:	1.24 kg (~3 pounds)
Transmit power:	500 mW Maximum
Transponder	Linear Inverting
Downlink:	435.880-435.910 MHz SSB/CW
Uplink:	145.900-145.930 MHz SSB/CW
CW Beacon:	437.075 MHz 100 mW
Data:	437.075 MHz 500 mW AFSK, GMSK 435.900 MHz FSK AX.25 / π/4 shift QPSK

NEXUS (NExt generation X Unique Satellite) is a satellite developed jointly by Miyazaki Yamazaki Laboratory of Nihon University College of Science and Technology and the Japan Amateur Satellite Association (JAMSAT).

The NEXUS mission includes several goals and objectives:

- Provide amateur radio communications via the 145/435 MHz transponder and SSTV.
- Download pictures from the 640×480 pixel camera.
- Operate the data downlink at 38400 bps QPSK.
- Compare the performance of the data downlink when using AFSK, GMSK and QPSK modes.

As of this writing, April 2019, FO-99 is currently undergoing system verification and validation with most transmissions limited to periods within sight of the Japanese ground station. It is planned to be released for general use in the near future.

NEXUS website in Google English: http://tinyurl.com/NEXUS-Satellite

For details about FO-99 please see https://www.amsat.org.

Information courtesy of NEXUS team and JARL.

Fox-1E

Name(s):	***Fox-1E*** **(RadFxSat-2)**
NASA catalog number:	TBD
Launch:	Possible Summer 2019 NASA ELANA XX mission Virgin Orbit LauncherOne Mojave Air & Space Port Mojave, CA
Orbit:	LEO (Low Earth Orbit)
Inclination:	TBA
Eccentricity:	TBA
Period:	Approx. 95 minutes
Estimated orbital lifetime:	5+ years
Altitude:	TBA
Size:	10 x 10 x 10 cm (4 inch cube)
Weight:	1.3 kg (~3 pounds)
Transmit power:	400 mW (Minimum)
Bandwidth:	30 kHz
Transponder:	Mode JA (V/u) analog inverting
Beacon:	435.750 MHz 1200 baud BPSK (100 mW Beacon)
Downlink:	435.760 MHz – 435.790 MHz USB/CW
Uplink:	145.890 MHz – 145.860 MHz LSB/CW

Please see the chapter on AO-85 for general *Fox-1* spacecraft information. Only the significant differences will be covered here.

Fox-1E will be the fifth of the new generation of AMSAT-NA CubeSats and will be built using the proven *Fox-1* platform. However, instead of a single FM channel it will be have a 30 KHz wide analog inverting transponder with a separate 1200 baud BPSK telemetry downlink.

Fox-1E will be similar to AO-73, except that *Fox-1E* has a V/u transponder and AO-73 uses a U/v transponder.

Fox-1E will have the advanced Maximum Power Point Tracker which will optimize battery charging under all conditions of illumination, prolonging battery life and allowing optimum availability of the linear transponder.

Fox-1E will carry a radiation effects experiment similar to RadFxSat (*Fox-1B*) but will study the new FinFET technology, along with the standard *Fox-1* Penn State University–Erie Attitude Determination Experiment (ADE). It will not include any experiments requiring high speed telemetry since that will not be supported.

In order to utilize the transponder and telemetry beacon, equipment suitable for other linear transponder satellites such as FO-29 and AO-73 will be needed. Estimates are that a few watts into a small beam should be adequate, along with a small beam with a low noise preamp serving for reception.

Please do not attempt to transmit using FM, which will render the satellite unusable for other users. It is recommended that you listen for other users and/or the beacon to insure that the satellite is available and your receiving equipment is working correctly. Please use only enough power to be heard at the same general level as the other users. In general the recommendations for operating FO-29 and AO-73 are applicable.

As with other linear transponders, a separate telemetry beacon at 435.750 MHz will be used for satellite identification as well as spacecraft and experiment health information. It can be received using any SSB capable radio, with the audio being decoded using the latest version of the FoxTelem program. The latest version, along with detailed instructions, can be found at:

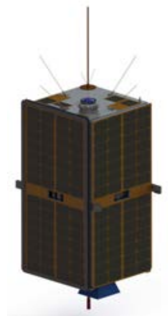
https://www.amsat.org/foxtelem-software-for-windows-mac-linux/

For details about *Fox-1E* please see https://www.amsat.org,

You can also subscribe to the AMSAT News Service https://www.amsat.org/mailman/listinfo/ans

The AMSAT Journal is also an excellent source of information. To receive the AMSAT Journal you must be an AMSAT-NA member. You can find information on joining at https://www.amsat.org/join-amsat/

FUNcube-4



ESEO (FUNcube-4) Spacecraft

Name(s):	**FUNcube-4, ESEO**
NASA catalog number:	43792
Launch:	1834 UTC 3 December 2018 SpaceX Falcon 9, SSO-A Vandenberg AFB, CA
Orbit:	Sun Synchronous
Inclination:	97.8°
Period:	Approx. 96 minutes
Altitude:	575-595 km
Size:	33 cm x 33 cm x 63 cm
Shape:	Microsat
Weight:	45 kg
Transponder:	FM
Transmit power:	More than 500 mW
Downlink:	145.895 MHz
Uplink:	1263.5 MHz (67 Hz CTCSS)
Beacon:	145.895 1200 bps BPSK (Shared with FM downlink.)

FUNcube-4 is not an independent satellite. Instead, it is hosted on a larger satellite, the European Student Earth Orbiter (ESEO) of the European Space Agency (ESA) Education Office project. The purpose of this mission, the third in the series, is to give students hands-on experience with the design, development, and operation of a space project. The other payloads include a camera to take pictures of the Earth, radiation measurements and other equipment to characterize the space environment, and a drag sail from Cranfield University to deorbit the spacecraft after mission completion. It also has an S-band (13 cm) communication system from Wroclaw University, though this will not be available to the amateur community. The FUNcube-4 communications system will serve as a backup, as it has on other such missions.

As with other satellites in which the amateur payload is not primary, availability will be dependent on the requirement of the other hosted experiments. The primary mission is expected to last approximately 6 months. When the primary goals have been met, it will switch to extended mission status which will likely result in greater availability of the FUNcube-4 amateur mission. As with earlier satellites in this series, a Dashboard has been released by AMSAT-UK to decode and forward telemetry to a central archive. The latest version may be downloaded here: https://funcube.org.uk/working-documents/funcube-telemetry-dashboard/

Information courtesy of Gunter's Space Page, ESA Education Office, AMSAT-UK, and AMSAT-NL

Information on release for amateur service will be though AMSAT-BB, AMSAT News Service, and other media.

Kevin Manzer, N4UFO, goes portable in Roswell, New Mexico, using his "short Arrow" and a pair of Yaesu FT-817's.

ISS (International Space Station)

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:	2m Voice, packet, SSTV, DATV

Frequencies

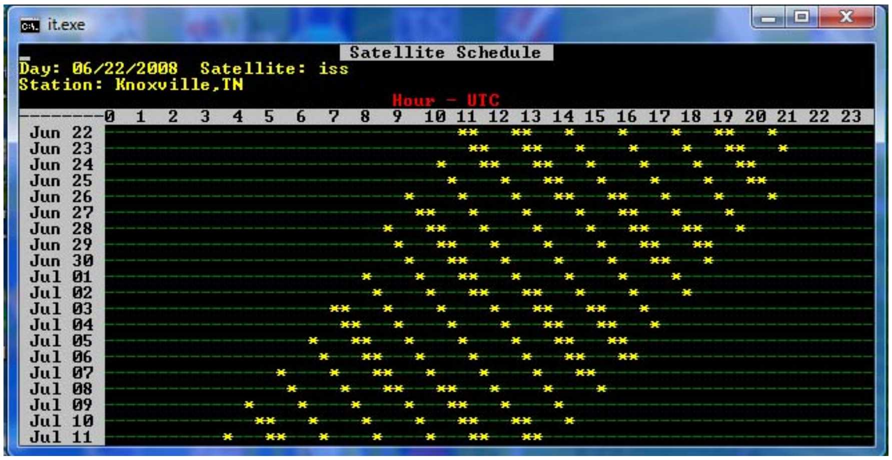
Voice Downlink	145.800 MHz FM (Worldwide)
Voice Uplink	144.490 MHz FM (Regions 2&3 - the Americas, Pacific) 145.200 MHz FM (Region 1 - Europe, Central Asia, Africa)
VHF Packet	145.825 MHz FM simplex (Worldwide)
UHF Packet	437.550 MHz FM simplex (Worldwide)
Cross-band repeater [1]	145.990 MHz FM (CTCSS 67Hz) uplink (Worldwide) 437.800 MHz FM downlink (Worldwide)
HamTV (DATV) [2]	2.395 GHz, 2.422 GHz, 2.437 GHz, 2.369 GHz downlink (Worldwide)

[1] Voice repeater not available until InterOperable Radio System is launched
[2] HamTV has been returned to Earth for repair

Amateur radio operation aboard the ISS has been operational since the year 2000. Please check the AMSAT BBS, www.issfanclub.com, or www.ariss.org for the most current information and operating modes.

Schedule

The ISS orbits the earth every 92 minutes. Most locations in the mid-latitudes get about 7 passes per day. The *InstantTrack* pass schedule below shows the ISS pass pattern for about two weeks. Notice how the seven passes occur back to back over a ten-hour period; this is different from other amateur satellite schedules.



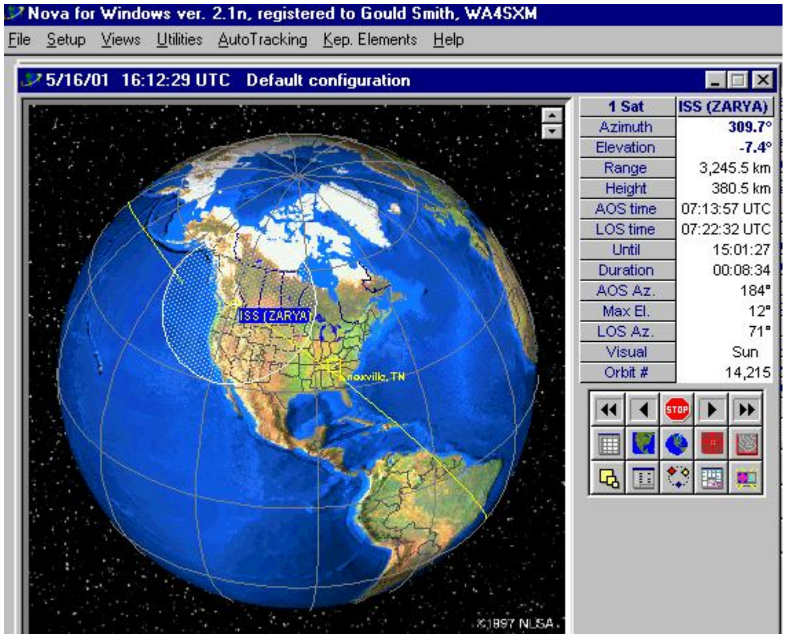
It is important to update your Keplerian elements for the ISS often. While every three to four weeks is fine for the other amateur satellites, weekly is a minimum for the ISS. Daily is recommended. There are two related reasons the ISS requires special attention.

First, it is in a relatively low orbit, and has a very large surface area. While the atmospheric pressure at the ISS altitude is a good vacuum by ordinary standards, at 17,500 mph there is significant drag, causing the ISS orbit altitude to decrease rapidly compared with more compact satellites in higher orbits. By itself, this requires more frequent updates since the mathematical models used to predict the satellite position assume that the drag effects will be fairly small.

Second, this drag means that the ISS must periodically have its orbit raised. This is done using its own thrusters, but is also done using thrusters on supply vehicles when they dock with the station. Usually the orbit is raised a few km, though in the past there have been significantly larger boosts. For every km change in altitude, there is a 19-20 second change in AOS per day compared with the previous orbit, or calculations using the old Keplerian elements. After an orbital adjustment, it takes a few hours to establish the new information, and have it publically available.

If you want to communicate with the ISS, you should get the latest set of elements to plan the correct pass windows. Daily Keps are available on the AMSAT website in nasabare.txt. (Note that the NASA.ALL lists are only updated once a week, usually on Fridays. Daily/hourly updates are available through most modern tracking programs, or via manual download from sources such as www.celestrak.com.) If you are especially lucky, some super-active crew members are known to listen on the voice channels for a quick voice QSO after a school event.

Footprint and Orbit



The ISS orbits between 377 km and 410 km (about 248 miles) above the Earth. This altitude provides a circular footprint about 2700 miles in diameter. A large number of hams are constantly attempting to make contact with the ISS on each pass.

The Nova for Windows screenshot to the right shows the ISS footprint and a typical orbit track. Note that this orbit is inclined 51.6° and is not a polar orbit as with many of the LEO amateur satellites.

ARISS

Amateur Radio on the International Space Station (ARISS) inspires students, worldwide, to pursue careers in science, technology, engineering and math through amateur radio communications opportunities with the crew on-board the International Space Station (ISS). Students learn about life on board the ISS and explore Earth from space through science and math activities. ARISS provides opportunities for the school community (students, teachers, families and community members) to become more aware of the substantial benefits of human spaceflight and the exploration and discovery that occur on spaceflight journeys. Students have the opportunity to learn about space technologies and the technologies involved with space communications through exploration of amateur radio.

ARISS was created and is managed by an international working group, including several countries in Europe as well as Japan, Russia, Canada, and the USA. Volunteers run the organization from the national amateur radio organizations and the international AMSAT (Radio Amateur Satellite Corporation) organizations from each country. Hundreds of Amateur Radio operators around the world provide thousands of hours of volunteer support each year to make these educational experiences possible. Since ARISS is international in scope, the team coordinates locally with their respective space agency and as an international team through ARISS working group meetings, teleconferences and webinars.

AMSAT-NA team members leading many of the ARISS efforts include Frank H. Bauer, KA3HDO, Dave Taylor, W8AAS, and Lou McFadin, W5DID.

The primary goals of the ARISS program are:

1) Educational outreach—Through school contacts, ten or more students at each school ask the orbiting ISS crews questions and hundreds of students and family members participate. The nature of these contacts embodies the primary goal of the ARISS program -- to inspire students' interest in science, engineering, mathematics, technology and amateur radio.
2) Crew psychological factors—Contacts can be scheduled with the astronauts' friends and families. Random contacts with the amateur radio public provide a unique opportunity for casual conversations with non-project related individuals. These boost the crew's morale by reducing the sense of isolation.
3) ISS-based Communications Experimentation—ISS provides a test bed for development of new communications techniques that can be used to develop new educational projects.
4) International Good Will—Astronaut contacts to schools and the amateur community fosters international good will. Joint hardware development provides a forum to enable international technical partnerships.
5) Emergency Communications Backup— Serves as an emergency communications backup, in case the US or Russian communication links go down.

Callsigns used aboard the ISS

Russian callsigns:	**RS0ISS, RZ3DZR**
USA callsign:	**NA1SS**
European:	**DP0ISS, OR4ISS, IR0ISS**

All of the ISS Expeditions have had licensed amateur radio operators aboard.

Check out this web site for information about the current ISS Expedition crews: https://www.nasa.gov/mission_pages/station/expeditions/index.html. The astronauts and cosmonauts may also use their own call signs. Bill McArthur, KC5ACR of Expedition 12 set many amateur radio space operating milestones. Bill made 35 school contacts and 1755 casual contracts during his six months in space. Thank you Bill!

ISS Amateur Equipment

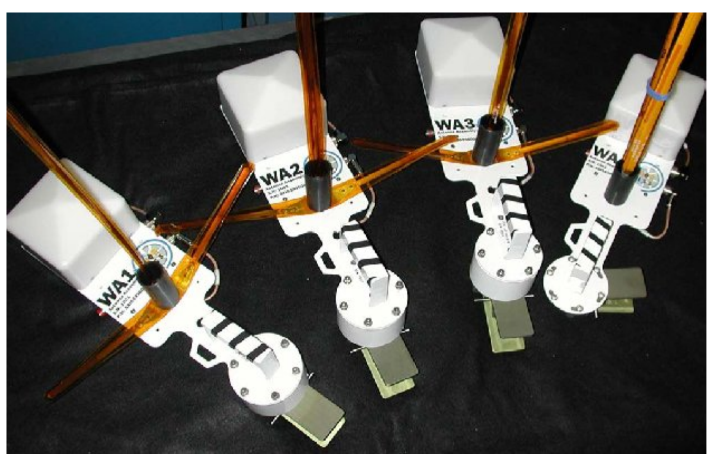
The ARISS amateur radio system consists of several stations in different modules of the ISS. ARISS has been installed in three different locations—the Zarya (FGB), the Russian Service Module (Zvezda) and the Columbus Module. Stations in the Service Module and Columbus Module are currently operational. Two equipment developments have occurred thus far—Phase one, employing handheld equipment, and Phase two, employing higher power mobile-class equipment. Other hardware, such as SSTV equipment and Digital Amateur Television (DATV) downlink capabilities, have also been installed as additional modes to augment the Phase 1 and Phase 2 hardware.

The Phase One amateur radio equipment includes: an Ericsson MX-P 2 m radio and a 70 cm radio, an enhanced packet system and multi-band antennas. The 2 m hardware is currently set up in the Columbus Module in what is described as the US segment. Note that as the position of the space station changes, transmission signal strength can change dramatically. A good quality radio system with a gained, preferably circularly polarized, antenna is recommended for casual listening. The photo below shows the Phase One ISS amateur radio equipment during ground testing.

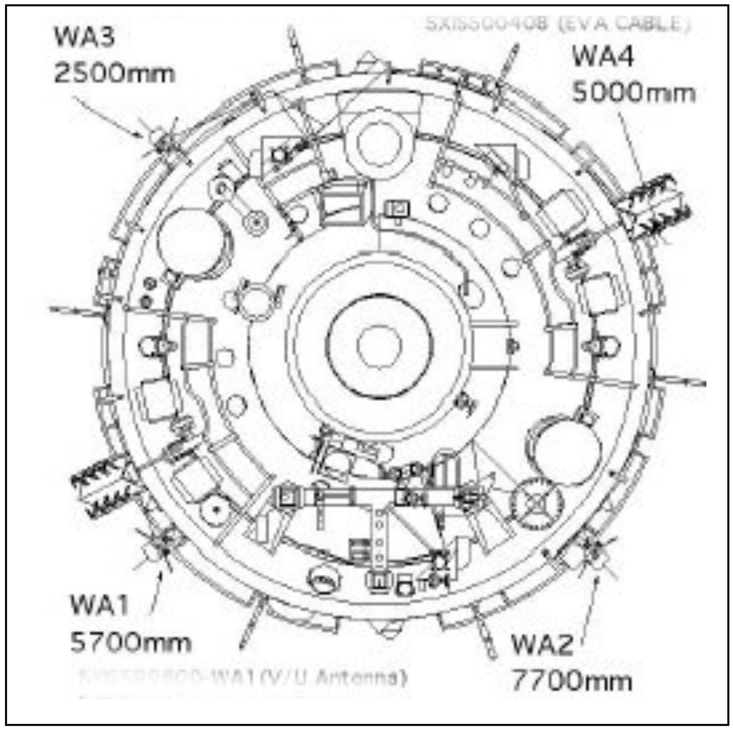
The original amateur radio equipment for ISS

The phase one hardware was initially installed in the Zarya module (FGB) and used a 150 MHz antenna that was already installed on the module to support ISS docking. With ISS docking complete, this antenna was given to the ARISS team by the Russians for permanent use.

In preparation for the Phase 2 hardware implementation, four antennas—WA1, WA2, WA3 & WA4—were developed by an ARISS international team and installed by the ISS crew. These antennas encircle the Russian Service Module. They permit operation on both the VHF (2 m) and UHF (70 cm) bands. Operation on HF (20, 15 and 10 meters) and microwave (L & S band) is also supported.



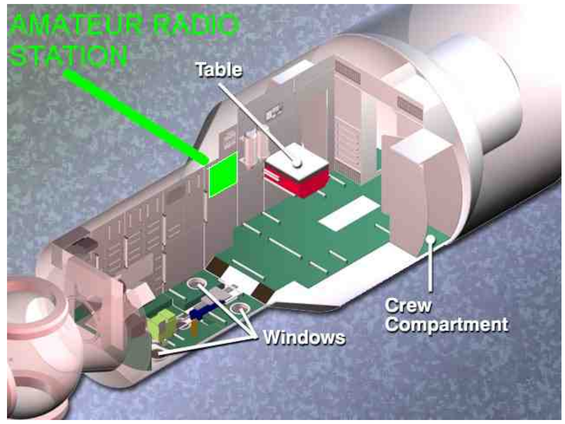
The WA3 and WA4 were installed externally in January 2002; the other two antennas, WA1 and WA2, were installed in August 2002. Three of the four antennas, WA1-WA3, are identical. These can support both transmit and receive operation on 2m, 70cm, L band and S band. These are also used during space walks to receive TV signals using the Russian Glisser TV system. The WA4 antenna is a 2.5m (8 foot) vertical to be used for HF, especially 10 meters. See Figure 5 for the location of the antennas on the Zvezda module. These antennas connect to the module via clamps that work like clothespins (the green clamps in the antenna photo). They are attached to EVA handholds on the side of the module.



The Zvezda (Service Module) and the Zarya (Control Module, FCB)

Phase Two Amateur Radio Equipment

The Zvezda Service Module, drawing to the right, is the living quarters, a popular location. Right next to the dining table there is a green Velcro table on the bulkhead that has the Kenwood D710E and a laptop attached to it. Here the crew can make voice contacts. The Kenwood D710E was initially set up to support only SSTV. Thus, the Kenwood radio in the Service Module is semi-operational.



Future Amateur Radio Equipment

The ARISS team is currently developing an interoperable radio system (IORS) that includes a JVC Kenwood D710GA 25-watt radio and a custom power supply system that can support operations in both the Service Module (Russian Segment) and the Columbus Module (US segment). This system will be common across all ISS and will be more robust than the previously flown systems (higher power in the Columbus module and protected from accidental frequency erasures). It also offers additional capabilities, such as a cross-band voice repeater. The hardware is planned to be delivered to NASA for launch in late 2019, pending successful fundraising.

2010 NASA photo of Doug Wheelock, KF5BOC using the TM-D700A in the Russian Service Module

Voice Operation with the ISS

Luck is the name of the game here. Since the crew is on Greenwich Mean Time, UTC +0, they are five hours ahead of those on the US east coast and eight hours ahead of those on the Pacific coast (four and seven hours during DST). Several people have happened upon the crew giving a CQ during the afternoon or morning commute, so monitor 145.800 MHz FM.

For your voice ground station, a standard 2 m FM transceiver with 10-30 watts into a Yagi antenna that can be pointed in both azimuth and elevation is best. Communication can be accomplished with hand-held and mobile radios if conditions are good. Many people have made contacts using mobile and fixed vertical or ground-plane antennas. As with all LEO satellite operations, small beams are best. Note that voice operation and packet operation require different frequencies.

Voice uses non-standard splits, so adjust your radio appropriately.

All the analog modes use the same 145.800 MHz downlink frequency.

The ISS crews are kept very busy, so there is little time to use the amateur radio. You can most often catch them right after they get up and before they sleep. (The ISS crew follows GMT.) So, be patient and keep trying.

SSTV

The ARISS station aboard the ISS has a Kenwood VC-H1 to take and transmit SSTV images. There is also an SSTV system using a computer interface (SpaceCam or MMSSTV) that supports multiple SSTV operating modes. In 2008 Richard Garriott, W5KWQ took many pictures with these devices. The Russians are also doing SSTV experimentation, using some of the higher resolution SSTV modes available through MMSSTV. Many SSTV images can be found at http://ariss-sstv.blogspot.com/ and https://www.spaceflightsoftware.com/ARISS_SSTV/index.php.

Special SSTV events are announced by ARISS and picked up by many ham radio news, usually about 1-2 weeks beforehand (when scheduling becomes certain).

DATV/Ham TV/Ham Video

The Ham Video DATV transmitter, developed for installation in the Columbus module, features the following characteristics:

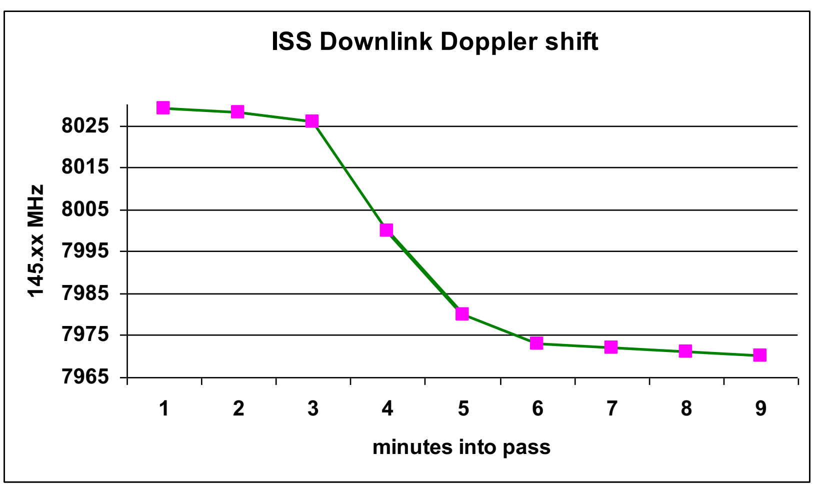
- Downlink frequencies: 2.395 GHz, 2.422 GHz, 2.437 GHz & 2.369 GHz
- DVB-S standard (QPSK modulation)
- Symbol rates: 1.3 Ms/s and 2.0 Ms/s
- FEC: ½
- SIF: 352x240 or D1: 720x480
- RF radiated power: approximately 10 W EIRP

Ham Video operates with a video camera provided by NASA. Ham Video is downlink only. To date, the ARISS team has conducted many school contacts using VHF or UHF uplink and Ham TV video and audio downlink, beginning with the Tim Peake Principia mission. Ham TV generally uses a set of 3 or more ground stations that are linked together using the BATC streaming video portal https://batc.org.uk/live/. Information on Ham TV and details on setting up a Ham TV ground station is available at https://www.amsat-on.be/hamtv-summary/.

Note: The HamTV transmitter failed and was returned to Earth for troubleshooting and repair in early 2019.

ISS Doppler

Since the downlink from the ISS is on 2 m, very little Doppler shift is encountered, but just enough to make your experience difficult. If you cannot tune finer than 5 kHz, you can't do much about the Doppler shift. Note how the shift changes fastest during mid-pass or TCA (Time Closest Approach).



ISS Operating Hints:

- **Listen before transmitting**. The most prevalent mode is digipeat mode on 145.825. If you want to make a voice contact, listen to 145.800. Do not call until you hear voices; then make sure they are not from confused ground-based operators.
- Keep your Keplerian elements up to date. The ISS repositions itself quite often. Check the AMSAT website or other sources for current ISS Keps every few days.
- Be patient, a large number of hams are just as anxious as you to communicate with the ISS.
- Keep your calls short and pass along your name, call sign and grid square.
- Up to date QSL information can be found on the ARISS web sites.
- The ISS is in process of upgrading the station, so check the web sites listed in the Information section for current status.
- Information about packet operation can be found in the AMSAT-NA publication "Digital Satellite & Telemetry Guide" and on the web sites listed below.

Resources:

https://www.ariss.org

https://www.nasa.gov/mission_pages/station/main/index.html (great ISS photos)

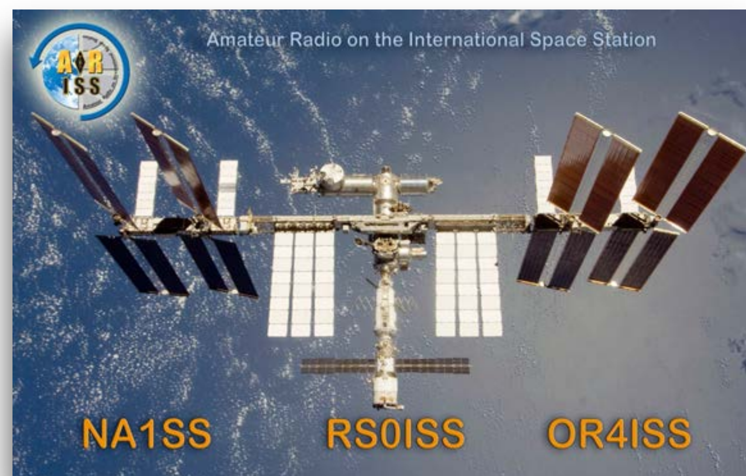
https://spaceflight.nasa.gov/station/reference/radio/index.html

http://www.arrl.org/amateur-radio-on-the-international-space-station

https://www.amsat.org

For general information on how the ISS is operated:

> https://blogs.nasa.gov/spacestation/2018/04/13/new-book-offers-inside-look-at-station-flight-controllers/



JO-97

Name(s):	JO-97, JY1SAT, FUNcube-6
NASA catalog number:	43803
Launch:	1834 UTC 3 December 2018 SpaceX Falcon 9, SSO-A Vandenberg AFB, CA
Orbit:	SSO LEO (Low Earth Orbit)
Inclination:	97.8°
Eccentricity	.0016
Period:	Approx. 96 minutes
Altitude:	575-595 km
Size:	10cm x 10cm x 10cm
Shape:	CubeSat
Weight:	1 kg (2.2 pounds)
Transponder:	Linear Inverting
Transmit power:	400 mW
Downlink	145.855 - 145.875 MHz USB
Uplink	435.120 - 435.100 MHz
Beacon	145.840 MHz BPSK

JO-97 is very similar to AO-73 and EO-88, and those chapters should be read for basic details and operating information.

JO-97 is Jordan's first satellite, under the Masar Initiative at the Jordan University of Science and Technology under the Crown Prince Foundation. Support has been provided by ISIS – Innovative Solutions In Space, AMSAT-UK, AMSAT Netherlands, and the Royal Jordanian Radio Amateurs Society. It is named in memory of His Majesty the late King Hussein whose call sign was JY1.

It functions in a similar manner to AO-73, with the addition of the ability to broadcast stored Slow Scan Digital Video (SSDV) images of Jordanian life and culture and a recorded audio message by His Royal Highness Crown Prince Al Hussein bin Abdullah

II. The images will are not standard Slow Scan TV. Both the images and audio message are decoded by Dashboard software.

Below is an example.

The most recent dashboard version for JO-97 and all FUNcube spacecraft can be found at: https://funcube.org.uk/working-documents/funcube-telemetry-dashboard/

As of April 2019. the transponder has been tested, however an operating schedule for the transponder has not yet been determined. Check the AMSAT-UK website and other AMSAT resources for updates.

Resources

AMSAT-UK: https://amsat-uk.org
AMSAT-NL: http://amsat-nl.org/
ISIS BV: https://www.isispace.nl

Information courtesy of Jordan Times, AMSAT-UK, and AMSAT-NL

SO-50

Name(s):	**SO-50, SaudiSat-1C, Saudi-OSCAR-50**
NASA catalog number:	27607
Launch:	20 December 2002
Orbit:	LEO (Low Earth Orbit)
Inclination:	65°
Period:	97.6 minutes
Altitude:	700 km (~434 miles)
Size:	35 x 35 x 35 cm (13.7" inch cube)
Weight:	11 kg (~24 pounds)
Transmit power:	250mW
Uplink:	145.850 MHz FM voice + 67.0 Hz CTCSS tone
Downlink:	436.790-436.800 MHz FM voice

SO-50 is the third amateur radio satellite built by KACST (King Abdulaziz City for Science and Technology) in Riyadh, Saudi Arabia. SaudiSat-1C was also launched aboard a modified Russian SS-18 ICBM (Inter-Continental Ballistic Missile) with five other satellites. The rocket was launched from the Baikonur Cosmodrome in Kazakhstan, as were the first two SaudiSats two years earlier. After a short commissioning period, Turki Al-Saud announced in January 2003 that SO-50 was available to all amateur operators worldwide. Operate this satellite as you would other FM satellites except this satellite does require a 67.0 Hz tone on the uplink to activate the transmitter.

The analog portion of the satellite operates as a "cross-band, FM repeater" or "bent pipe". The 2m uplink and the 70cm downlink both use FM voice modulation. As the satellite has aged, some slight shifts, apparently seasonal, have been noticed in the downlink frequency. While the nominal downlink frequency is given as 436.800 MHz, 436.795 MHz has been found to be more typical, with 436.790 MHz sometimes being observed. You may need to tune slightly lower in frequency for the best received signal. No significant change has been found in the uplink frequency.

In addition to the amateur operations there are a number of scientific experiments on board the spacecraft. According to the *Arab News* “the satellite is equipped with capabilities to provide vital data concerning weather conditions and oil exploration as well as to monitor the movement of vehicles in remote regions of Saudi Arabia.”

Satellite characteristics

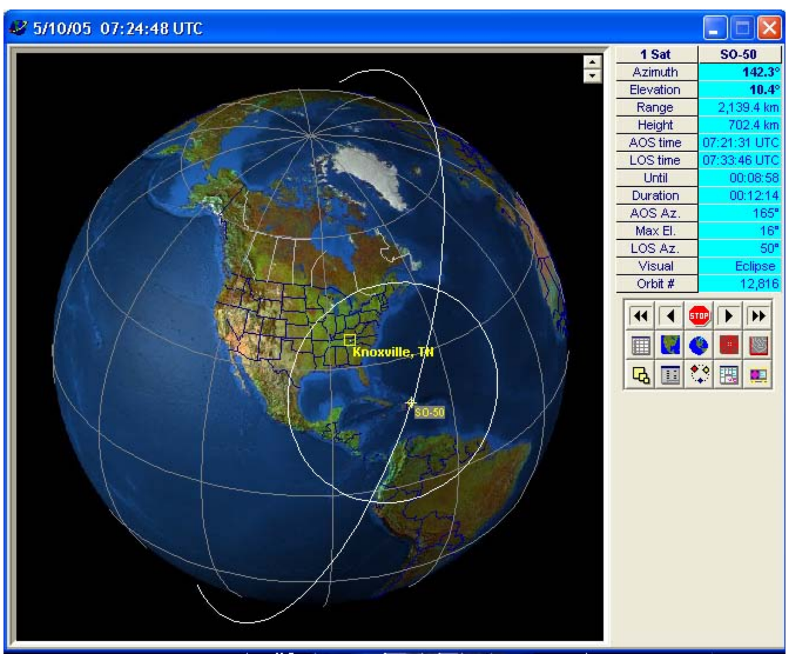
SaudiSat-1C is a 23cm (9 inch) cube built on the Microsat model. The -Z (‘bottom’) of the satellite has four gold 400 MHz antennas in a turnstile array with the 436 MHz downlink antenna in the center. The satellite uses left-hand circular polarization on the downlink. The long gold blade on the +Z (‘top’) of the satellite is the 145-150 MHz receiving antenna. There are the standard five compartments within the aluminum frame contain the transmitters, receivers, modems, batteries, charging system, computer and memory storage electronics.

SO-50 is a good, reliable FM satellite and performs well for the daily user as well as demonstrations to radio clubs and other interested parties. The problem with demonstrating SO-50 is that the pass schedule is constantly changing.

SO-50 orbit

This satellite is not in the standard ‘EasySat’ polar orbit. The inclination is 64º and the altitude is only 700 km. This will cause the passes to be at a different time each day and night. Every month it will have passes during all the daytime hours and nighttime hours. So you may have to burn the midnight oil a number of times if you want to communicate through SO-50.

Figure 1. SO-51 orbit with a 64º inclination



Since the orbit is closer to the earth, the signals will be stronger, but SO-50 is only running 250mW on the transmitter. Using your handheld with a vertical will be very difficult. Using an Arrow or similar antenna for this bird is an excellent choice.

Figure 2. SO-50 pass pattern from *Instant*Track

The orbit again defines how the satellite communication will behave. Since the satellite is only 700 km above the earth it will travel faster than the other satellites at 800 km altitude.

Suggested memory channel frequencies for SO-50

SO-50 is another FM Mode V/u (Mode J) satellite. So the downlink will experience quite a bit of Doppler shift, about 20 kHz. The uplink Doppler shift is generally not enough to worry about, keep the transmit frequency set on 145.850 MHz + 67.0 Hz CTCSS tone.

	Downlink	Uplink
Beginning of pass	436.805 MHz	145.850 MHz + 67.0 Hz tone
Early pass	436.800 MHz	145.850 MHz + 67.0 Hz tone
Mid pass	436.795 MHz	145.850 MHz + 67.0 Hz tone
Late pass	436.790 MHz	145.850 MHz + 67.0 Hz tone
End of pass	436.785 MHz	145.850 MHz + 67.0 Hz tone

Turn on tone

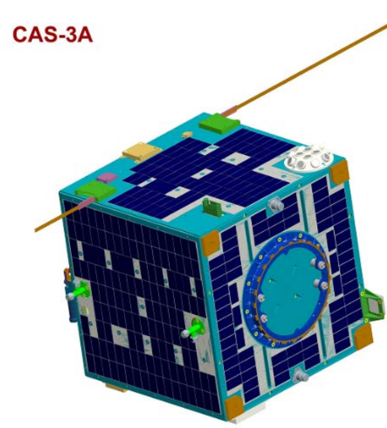
To save energy and not transmit all night or over the oceans when no one is listening SO-50 requires a turn-on tone to active the satellite in addition to the standard 67.0 Hz tone to activate the transmitter.

During each pass over an area, someone must activate SO-50 by sending it a tone of **74.4 Hz** on the 145.850 MHz uplink for 1-2 seconds which will activate the satellite for 10 minutes.

Subsequent transmissions to converse must use a 67.0 Hz tone to activate the transmitter.

> ***Operator Insights from Steve Belter, N9IP***
>
> *SO-50 has a very sensitive receiver but a weak transmitter. You can usually depend on other stations to send the 74.4 CTCSS tone to activate the satellite, but make sure you have your radio configured to send 67.0 CTCSS anytime you transmit.*
>
> *If you can operate full-duplex, twist and point your antenna to get the best received signal, then adjust the twist (polarity) to get the best signal when you are transmitting. If you can hear yourself cleanly, everyone else (with a decent receiver) will be able to hear you too.*
>
> *You can leave the transmitter frequency fixed (145.850 MHz). Tune the receiver for Doppler correction, starting at 436.805 MHz. As SO-50 rises, tune down to 436.800, then 436.795 when it is highest in the sky. As SO-50 starts to come down, tune down to 436.790 and finally to 436.785.*
>
> *As long as you can hear the satellite, the biggest challenge with SO-50 is its popularity. Use the Best Practices listed in Chapter 6, Operating the FM Satellites.*

XW-2 (CAS-3)



The other XW-2(CAS-3) satellites are similar but not identical in configuration to CAS-3A.

Names:	**XW-2A thru XW-2F, CAS-3A thru CAS-3I, LilacSat-2**
Object #s:	Various
Launch:	Long March 6, Taiyuan Launch Complex, 18 Sep 2015
Period:	95 minutes
Orbit:	Polar SSO (Inclination = 98 degrees)
Altitude:	Perigee 528 km, apogee 551 km (approx.)
Height:	Various (11 cm – 40 cm)
Width:	Various (10 cm – 40 cm)
Mass:	Various (1.5 kg – 22 kg)
Bandwidth:	See below
Transponder:	See below (100 mw – 250 mw)
Modes:	See below
Telemetry:	See below (25 mw – 50 mw)
Lifetimes:	8.5 yrs – 18 yrs
Sponsor:	CAMSAT (AMSAT-CN)

Background

The CAMSAT XW-2 (CAS-3) launch was unusual (but becoming more common) in that it included several satellites at the same time. In fact, this launch came close to doubling the number of amateur satellites available! Some were dedicated amateur satellites and others amateur payloads on other platforms whose primary mission was non-amateur in nature. Because of this, detailed information on the individual spacecraft is not available. In addition, not all spacecraft are available to amateurs 24/7. Some are, others are turned on for periods of a few days at a time, and others work on published schedules such as Monday, Wednesday, and Friday.

To determine whether the transponders are active, see the Communications Satellites Current Status https://www.amsat.org/status/. This will provide general information on an individual satellite and whether it is currently active.

Users regularly report the status of active satellites in near-real time; in particular, whether the transponder is active, or only telemetry. Not all of the satellites listed below have activated their amateur payloads or kept them active, so they may not be listed at all. The telemetry beacons may be active, but this is not guaranteed. You are encouraged to submit your own reports so that others may benefit from your experience.

Satellite Descriptions

XW-2A thru XW-2F all use quarter wavelength monopole antennas for both UHF and VHF. LilacSat-2 (CAS-3H) is known to use circularly polarized antennas which helps reduce signal fading.

Note that many of this flight of satellites use frequencies that while in the frequency range allowed for satellite downlinks, are outside the normally coordinated range of 145.800 MHz to 146.000 MHz. As a result, they may conflict with existing repeater and simplex allocations already in use. Please listen for local activity on both the uplink and downlink frequencies before attempting to use uncoordinated satellites.

As of this writing (May 2019) the following satellites are known to be active at least semi-regularly:

XW-2A (CAS-3A)

Object #	40903
Digital Beacon:	145.640 MHz, AX.25 telemetry: 100 mW, 19.2k/9.6 kbps GMSK
CW Beacon:	145.660 MHz, 50 mW, 22 wpm
Transponder:	Mode B (U/v) 100 mW, inverting
Downlink:	145.665 MHz – 145.685 MHz
Uplink:	435.050 MHz – 435.030 MHz

XW-2B (CAS-3B)

Object #	40911
Digital Beacon:	145.795 MHz, AX.25 telemetry: 100 mW, 19.2k/9.6 kbps GMSK
CW Beacon:	145.725 MHz, 50 mW, 22 wpm
Transponder:	Mode B (U/v) 100 mW, inverting
Downlink:	145.730 MHz – 145.750 MHz
Uplink:	435.110 MHz – 435.090 MHz

XW-2C (CAS-3C)

Object #	40906
Digital Beacon:	145.705 MHz, AX.25 telemetry: 100 mW, 19.2k/9.6 kbps GMSK
CW Beacon:	145.790 MHz, 50 mW, 22 wpm
Transponder:	Mode B (U/v) 100 mW, inverting
Downlink:	145.795 MHz – 145.815 MHz
Uplink:	435.170 MHz – 435.150 MHz

XW-2D (CAS-3D)

Object #	40907
Digital Beacon:	145.835 MHz, AX.25 telemetry: 100 mW, 19.2k/9.6 kbps GMSK
CW Beacon:	145.855 MHz, 50 mW, 22 wpm
Transponder:	Mode B (U/v) 100 mW, inverting
Downlink:	145.860 MHz – 145.880 MHz
Uplink:	435.230 MHz – 435.210 MHz

XW-2E (CAS-3E)

As of this writing (May 2019) XW-2E (CAS-3E) only telemetry is operational.

Object #	40909
Digital Beacon:	145.890 MHz, AX.25 telemetry: 100 mW, 19.2k/9.6 kbps GMSK
CW Beacon:	145.910 MHz, 50 mW, 22 wpm
Transponder:	Mode B (U/v) 100 mW, inverting
Downlink:	145.915 MHz – 145.935 MHz
Uplink:	435.290 MHz – 435.270 MHz

XW-2F (CAS-3F)

Object #	40910
Digital Beacon:	145.955 MHz, AX.25 telemetry: 100 mW, 19.2k/9.6 kbps GMSK
CW Beacon:	145.975 MHz, 50 mW, 22 wpm
Transponder:	Mode B (U/v) 100 mW, inverting
Downlink:	145.980 MHz – 146.000 MHz
Uplink:	435.350 MHz – 435.330 MHz

LilacSat-2 (CAS-3H)

Object #	40908
Beacon:	437.225 MHz CW
Transponder:	Mode J (V/u) FM
Downlink:	437.200 MHz FM
Uplink:	144.350 MHz FM
Digipeater paths:	BJ1SI-1 as first digipeater for immediate mode BJ1SI-2 and delay in minutes for first and second digipeaters in path
Transponder:	Mode J (V/u) Linear, non-inverting
Downlink:	437.180 MHz - 437.220 MHz
Uplink:	144.3825 MHz – 144.3425 MHz

Information courtesy of CAMSAT, AMSAT-UK, and AMSAT-NA

Appendix A

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, you transmit to FO-29 on VHF (2 m) and receive on UHF (70 cm), so FO-29 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 and QRM, 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	**Queen**
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	**Zebra**

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. There have been several cases of contacts being made with mutual availability windows of less than a minute using this technique which would otherwise be difficult or impossible using traditional techniques.

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.

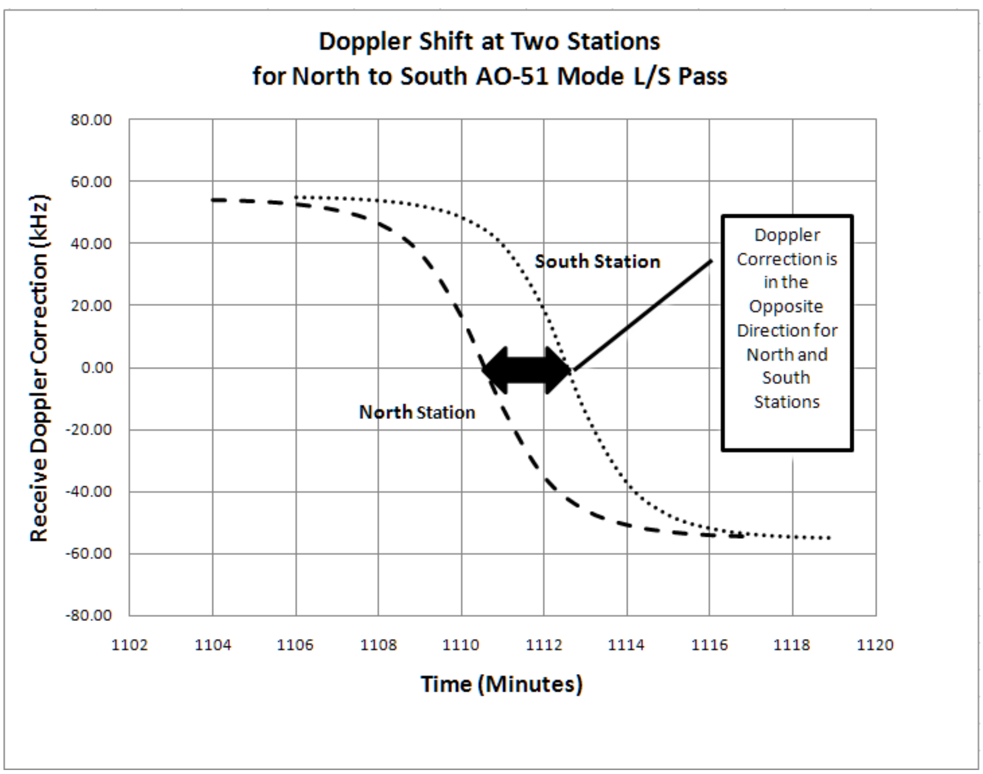


Figure 1: Doppler Shift at Two Stations in a North to South AO-51 Mode L/s Pass

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 Weekly Satellite Report. 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 program displays 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*!

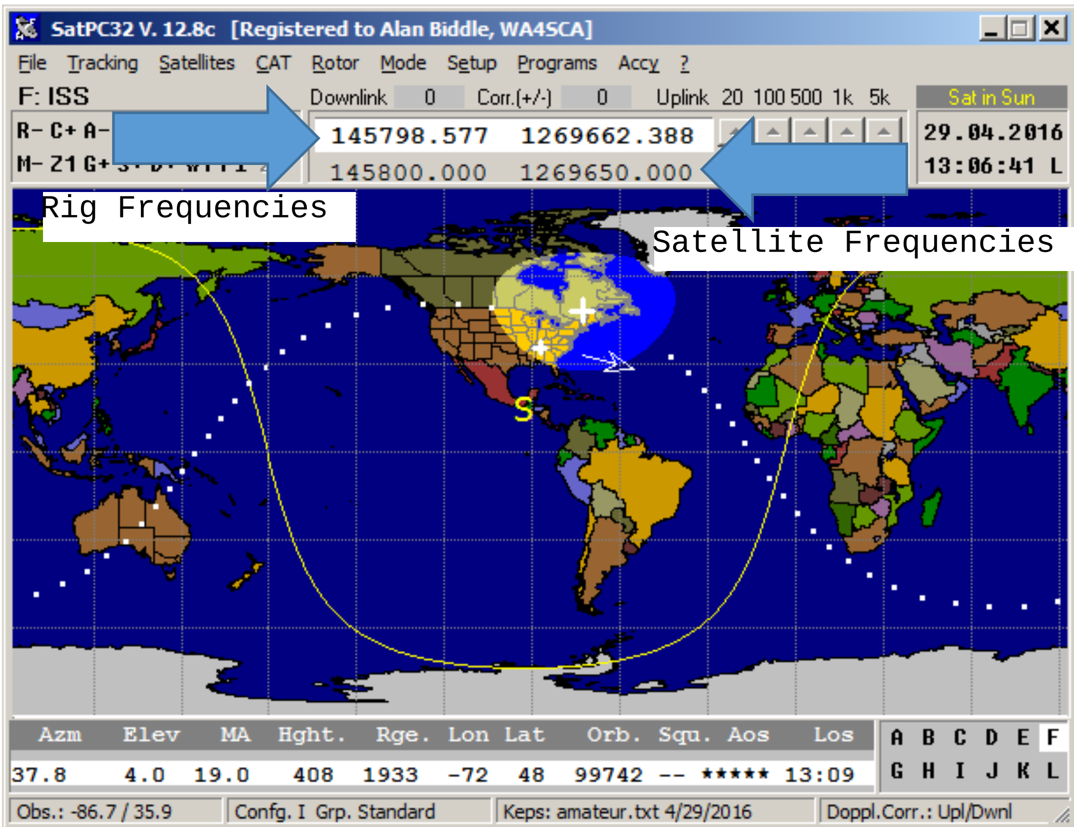


Figure 2: SatPC32 Program Display for Spacecraft Frequency Tuning

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. 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 the first half of this book, we 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.*

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 an FO-29 pass in Patagonia, Argentina.

Improving Your Tracking Software

In Chapter 3, *Locating Amateur Satellites*, we surveyed a number of 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.

Computers continue to shrink while becoming more powerful. In recent years, basic but fully functional Windows PCs have become available in small tablet form, some for less than $100! They are capable of running some of the tracking programs described below as well as logging and even operating the new generation of Software Defined Radios. Excellent insight on using a tablet computer for portable operations can be found in the article "Pairing SDR dongles with smaller Windows 8.1 tablets" by Patrick Stoddard, WD9EWK in the March/April 2015 edition of The AMSAT Journal.

Which tracking program is best? All tracking programs will give you the two necessary pieces of information: **Where is the satellite?** and **When is it visible?** There are also a number of additional features or utilities in each of the packages.

Satellite Tracking Programs for Windows PCs

There are several tracking programs that run on the Windows operating system. Pick one that seems to best fit your needs, then try the others as you have the time and motivation. There are a number of screen shots from most of the tracking programs shown throughout this book. Look through it and see which features appeal to you.

SatPC32 is a great program that runs under Windows, has a number of 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, 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 enhance the program. Updates are free. The demo version is free and completely functional. If you purchase the registration key or buy the software on CD, your entire purchase price goes to AMSAT.

***Instant*Track** has been around since 1989 and underwent a major upgrade in 2000. It is a DOS-based program but runs fine under Windows. It is quick to start, gives you the information you need for tracking and also performs rotor control. Franklin Antonio, N6NKF, and Paul Williamson, KB5MU provided *Instant*Track. For beginners and for day-in and day-out operation this is a good choice. Input your call sign, city, set the time zone in the configuration file, load new Keps and you are good to go. You can use Tony Monteiro AA2TX's InstantTune software (provided free to the amateur community) to tune your radio and adjust for Doppler if your transceiver is computer controllable.

Nova for Windows is a very powerful, visually stunning Windows tracking program that provides outstanding graphics of the satellite's orbit, as well as the earth's features beneath. There is a fairly involved setup for this program, but it's worth the effort. You can even set this up to automatically update your Keps in the background. Nova allows you to visualize exactly where the satellite is in relation to your QTH, what polar orbits look like, how large the orbit of the Phase 3 satellites are, and even see a map of sky noise behind the satellite. Michael Owen, W9IP, is a Geology professor and has done an incredible job with this program. It has rotor control for many controllers and will even talk through your computer to alert you that a satellite pass is imminent.

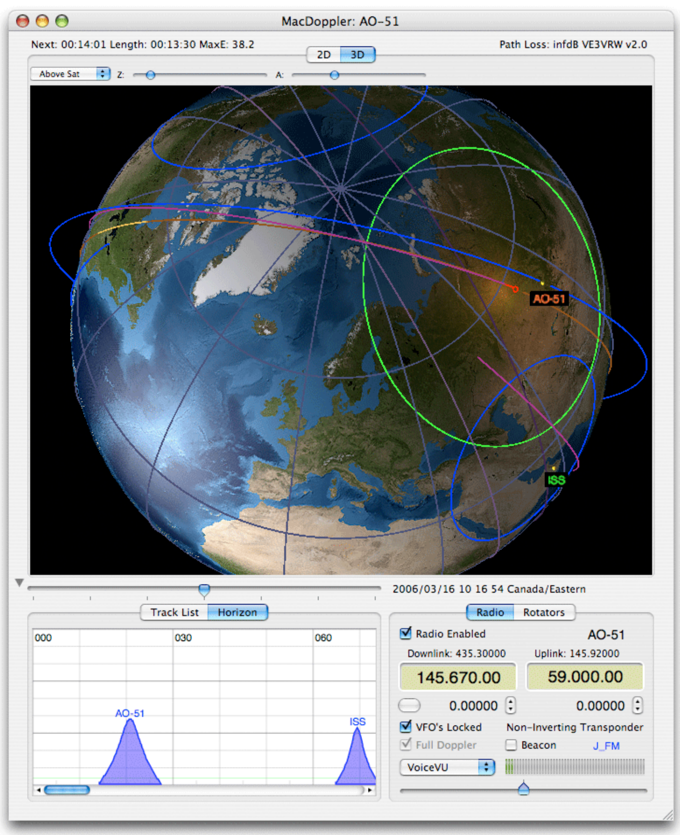
WiSP does tracking and antenna control as well as decoding and encoding of the PACSAT Protocol. Written by Chris Jackson, ZL2TPO/G7UPN during the 1990's and updated in 1997, it is geared toward digital satellite operation. It is not the best choice for your first tracking program. WiSP is covered in depth in the *Digital Satellite and Telemetry Guide*.

Tracking Programs Apple's OS X

MacDoppler is an excellent program for the Mac user running OS X. 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.

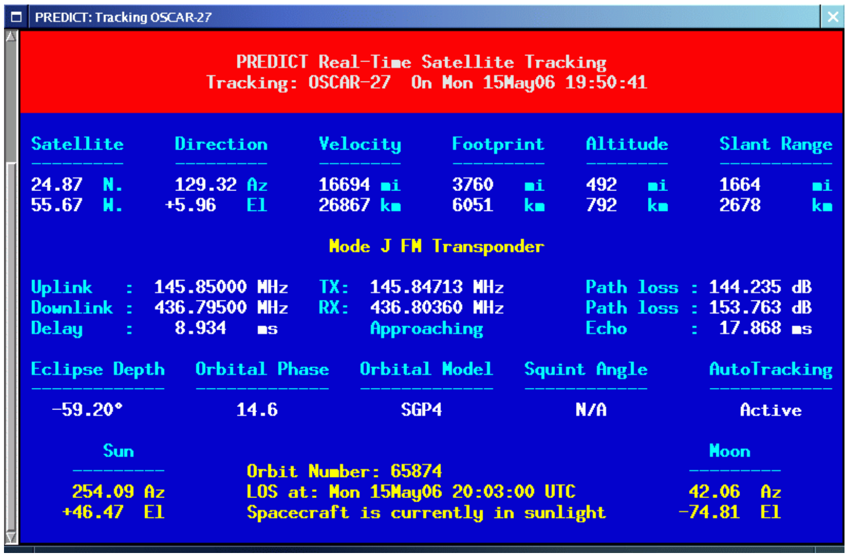
Doppler display and control is standard as well as rig and rotor control. You can purchase MacDoppler online at the AMSAT Store at https://www.amsat.org/shop/.



Tracking Programs for Linux

Linux users have not been left out. John Magliacane, KD2BD provides the excellent **Predict** software for Linux. This is included in many Linux distributions

Predict also has a version that runs under DOS with many orbital features.



Also, for Linux, look for the **GPredict** package.

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! The more features the tracking program provides the more setup parameters are required.

UTC and DST

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

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 a number of 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 good.

Why is it now called UTC?

According to National Institute of Standards and Technology, "In 1970 the Coordinated Universal Time system was devised by an international advisory group of technical experts within the International Telecommunication Union (ITU). In order to minimize confusion, the ITU felt it was best to designate a single abbreviation for use in all languages. Since unanimous agreement could not be achieved on using the English word order, CUT, or the French word order, TUC, the acronym UTC was chosen as a compromise."

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 "EasySats" 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.

Keplerian Elements or "Keps"

The tracking programs compute the satellite's location and future locations/schedules from information known as Keplerian elements. 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. Don't miss the Keplerian element tutorial in *Instant*Track if you are interested.

You only need 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 the ISS chapter for additional information about 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. Nova for Windows will allow you to set up the program to go out and automatically capture the Keplerian data and update the program automatically.

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/, the Heavens Above web site, https://www.heavens-above.com/main.aspx, 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 of 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 <u>system</u> 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

With the exception of one specific application (described below), omnidirectional antennas 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.

The one amateur satellite application that is well suited to an omnidirectional antenna is the building of an internet gateway (IGate) for APRS satellites. These stations work best when operating 24 hours per day, 7 days per week. An unattended 24/7 rotor operation is prone to failure, and one goal of the IGate networks is to have lots of stations that cover small geographic areas. Any of these omnidirectional antennas will work: quarter-wave vertical, three-quarter-wave vertical, eggbeater, J-pole, Lindenblad or quadrifilar.

For more information on antennas for IGates, see the Bob Bruninga, WB4APR, discussion at http://www.aprs.org/aprs-satellite-igate-antennas.html.

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, and then adjust where you're pointing and adjust the polarity by listening for the best signal.

Higher Gain Antennas

Larger antennas with higher gain are available from a number of 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.

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.

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. Your PC, using an LVB Tracker and tracking software like SatPC32 and MacDoppler, can control the Yaesu rotor and automatically track a satellite across the sky. See the AMSAT store to see if assembled LVB Trackers are available: https://www.amsat.org/shop/.

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, MFJ, and others) and the EME-class rotors from M^2.

The photo below 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.

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.

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 everyone claims his or her 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 actually 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.

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 result frequently results in 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 of the 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 or MacDoppler 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.

Upgrade to SDR

While some operators prefer radios with tuning knobs, if you're comfortable with installing software and using computers, changing to a good Software Defined Radio (SDR) for your receiver will be a significant improvement to your satellite operating experience. In this context, a good SDR does not include a $20 DVB-T dongle. This is because it has no useful front-end filtering.

For example, the software HDSDR is a powerful tool when combined with SDR hardware like the FUNcube Dongle Pro+ (FCDPP), SDRplay RSP, or AirSpy SDR Receiver. When used with SatPC32 and a conventional radio for a transmitter, you get an amazing station for satellite communication.

You can view the entire satellite passband at once, see when the satellite has risen above the local horizon, recognize CW, SSB, and FM signals, and view 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, HDSDR is being used as the receiver. A separate Icom, Yaesu, or Kenwood 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.

HDSDR emulates a Kenwood TS-2000 and is used as a receiver for SatPC32's "Radio 1". Your transceiver is used as a transmitter for SatPC32's "Radio 2".

SatPC32 polls the Rx VFO frequency of Radio 1 (HDSDR emulating a Kenwood TS-2000), so clicking in the waterfall or spectrum display, or otherwise changing the Tune frequency of HDSDR changes the receive frequency of SatPC32, which in turn changes the TX frequency of your transceiver. Using the SatPC32 controls will change the tuning on both HDSDR and the transceiver.

Appendix C

Future Major Satellites

AMSAT-NA's GOLF Program

Expected launches: TBD. GOLF-TEE NET 1Q 2020. GOLF-1 NET 1Q 2021

Originally, The *FOX* program consisted of two basic components. *Fox-1* was conceived as a "starter" project consisting of a series of 1U spacecraft with capabilities similar to the popular AO-51, to be launched as quickly and cheaply as possible. This was to be followed by *Fox-2* spacecraft which would have been larger and with significantly greater flexibility and capabilities. However, as experience was gained and new technologies and launches became available, it seemed more appropriate that the next generation be given its own designation. Traditionally AMSAT-NA has called spacecraft before launch by a letter, to be replaced by an AMSAT OSCAR number after launch. Just as Foxtrot, shortened to Fox, is the phonetic for the letter F, Golf was adopted for the G series. Conveniently, *GOLF* is an acronym for: "Greater Orbit, Larger Footprint."

The goal of the *GOLF* program is to work by steps through a series of increasingly capable spacecraft. The first is to be one or more Low Earth Orbit (LEO) satellites similar to the existing AO-85, AO-91, AO-92, and AO-95, but with technologies needed for higher orbits. With proven technologies, an interim high LEO or Medium Earth Orbit (MEO) satellite would follow on. The eventual goal is a High Earth Orbit (HEO) similar to AO-10, AO-13, and AO-40, but at a currently affordable cost combined with significantly enhanced capabilities which in turn will allow the use of much less complex ground stations.

The first element has been given the designation *GOLF-TEE*, with TEE standing for "Technology Exploration Environment." While a fully functional LEO V/u amateur satellite with conventional backup systems, essentially those of *Fox-1E*, two primary systems needed for higher orbits will be developed and tested. First, an Attitude Determination and Control (ADAC) system will be tested to allow active pointing of the satellite's antennas which will have significant gain. Second, a deployable solar array which will allow significantly greater power to be generated than is possible with arrays attached to the sides of a small spacecraft. While not technically necessary or primary, a Software Defined Radio (SDR) is the only way to obtain high flexibility in a constrained package. A commercial SDR, the Ettus E310, is planned as an experimental package to allow a 1 Mbps downlink in the 10 GHz band.

NASA approved *GOLF-TEE* in February 2018, but this does not include a commitment to a specific launch. The requested orbit will be for a 650 km altitude, with an inclination between 63 degrees (AO-85) and 98 degrees (AO-91 and AO-92.) While this orbit easily complies with the FCC requirement that a satellite reenter (or be boosted to a higher "disposal orbit") within 25 years of the final mission, a test device will be included to prepare for later, higher missions which will require active measures to comply with debris mitigation constraints.

The second element, *GOLF-1*, also approved by NASA without a specific launch, will build on technology and lessons learned from the *GOLF-TEE* mission. However, it will be a return to the primarily educational mission, including a Vanderbilt University radiation experiment and an imaging experiment from the Albuquerque Public Schools in collaboration with Virginia Tech. While not yet fully defined, the primary radio will be SDR, and should have a range of uplink and downlink frequencies, including microwave bands. Since the orbit will be significantly higher than *GOLF-TEE* in order to obtain coverage similar to AO-7 and FO-29, a method of disposal acceptable to the FCC, the controlling agency will be required.

AMSAT-DL P3 Express

Expected launch: TBD

The spacecraft is well developed and has been undergoing updates to some systems to take advantage of newer technologies.

The primary obstacle to launch has been the cost of relatively large spacecraft to Molniya and other high-altitude orbits. Recently, Virginia Tech approached the US Government to fly the Phase 3E space frame into High Earth Orbit (HEO) in order to support scientific payloads as well as serve as an amateur radio satellite. During the AMSAT-DL Annual Meeting on 4 JUL 2015, the AMSAT-DL membership approved the concept, agreeing to allow the Phase 3E space frame that is currently stored in Germany to be shipped to Virginia Tech in the USA for further construction, testing and preparation for eventual launch to HEO should the US Government formally agree to fund such a mission.

Should the project move forward, AMSAT-NA will apply for frequency coordination from the IARU Satellite Advisor and satellite licensing from the FCC as the satellite's initial operator.

At present it is not possible to show in detail the frequencies and modes which be available, though both traditional transponders and digital systems are under consideration and development. Unlike earlier Phase 3 satellites, AMSAT transponders will not be the primary payloads. Internal space and antenna arrays will be subject to the requirements of the primary payload, launch vehicle, and mission. This will have both advantages and disadvantages, but the eventual spacecraft, if approved and funded, will provide exceptional coverage and flexibility to the amateur community.

AMSAT-NA Phase 4B

Expected Launch: TBD

Throughout the long history of amateur satellites, the ultimate goal for many has been a geosynchronous satellite for amateur use. Such a satellite would be available 24 hours a day and be nearly stationary so that antennas could be pointed once. Coverage would be approximately a third of the earth's surface. Unfortunately, the cost and complexity of such a satellite has placed this beyond the reach of the satellite community until recently.

Several events have made this a realistic, though far from certain goal. Some are technical such as the advance of inexpensive microwave systems, and others are finding the opportunity to work with a major contractor. AMSAT-NA accepted an opportunity to participate in a potential rideshare as a hosted payload on a geosynchronous satellite to be constructed by Millennium Space Systems (MSS) of El Segundo, CA. This was an opportunity to go forward with "AMSAT-Eagle" which, in the 2006-2008 timeframe, evolved into a microwave payload. The transponder was expected to support a wide range of voice, digital, and experimental advanced communications technologies.

As with the Phase 3E satellite, the amateur component was subject to constraints of funding and operation imposed by the primary payload and mission. Because of constraints imposed by the primary mission, it will not be possible to use the traditional VHF and UHF frequencies used on other spacecraft. Nevertheless, the availability of new digital modes to the general operator will usher in a new age of amateur operation and innovation.

For numerous reasons, including frequency allocation and propagation, ground equipment using 5 GHz uplinks and 10 GHz downlinks is being developed. Dubbed "Five and Dime," it is being designed for ease of use by amateurs using readily available components at costs typical of middle range commercial equipment.

Unfortunately, the primary mission, and hence any AMSAT-NA participation, has been put on hold indefinitely. However, the work on ground station and other components will carry over to future projects.

For details about these and other satellites please see https://www.amsat.org.

You can also subscribe to the AMSAT News Service
https://www.amsat.org/mailman/listinfo/ans

The AMSAT Journal is also an excellent source of information. To receive the AMSAT Journal you must be an AMSAT-NA member. You can find information on joining at https://www.amsat.org/join-amsat/

Marissa, W4AQT is ready for SSB contacts on the linear satellites with a pair of Yaesu FT-817 radios (sometimes called an FT-1634). Her Arrow antenna has been modified to lessen its weight by perforating the boom with multiple holes. Marissa obtained her amateur license and made her first satellite contact when she was 10 years old.

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.

Get Involved in AMSAT!

AMSAT is Amateur Radio in Space, and you are AMSAT! 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 (AO-85, AO-91, AO-92 and AO-95) and FUNcube Dashboard (for AO-73, ESEO, EO-88 and JO-97)

Contribute Satellite Status Information – Hear an amateur satellite or make a contact? Help other hams by adding your information to the AMSAT Live OSCAR Satellite Status Page at https://www.amsat.org/status

AMSAT Ambassador – AMSAT is looking for satellite operators to promote amateur radio in space with hamfest satellite demonstrations, making presentations at club meetings, answering e-mail and Facebook questions, and being an Elmer for new operators. For more information see https://www.amsat.org/ambassador/

AMSAT News and Communications – This involves a wide range of activities from authors and editors for the AMSAT Journal and the weekly New Service to working with our website and social media channels. Contact our Communications Volunteer Coordinator at https://www.amsat.org/contact-amsat-communications/ for more information.

General AMSAT Support – There are an entire range of activities that could use your experience, expertise, and enthusiasm. Contact AMSAT General Volunteers at https://www.amsat.org/contact-amsat-general-volunteers/

ARISS Development and Support – AMSAT's Human Space Flight Team is looking for volunteers to help with development and support of Amateur Radio on the International Space Station (ARISS). Learn more at http://www.arrl.org/ariss-volunteers

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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