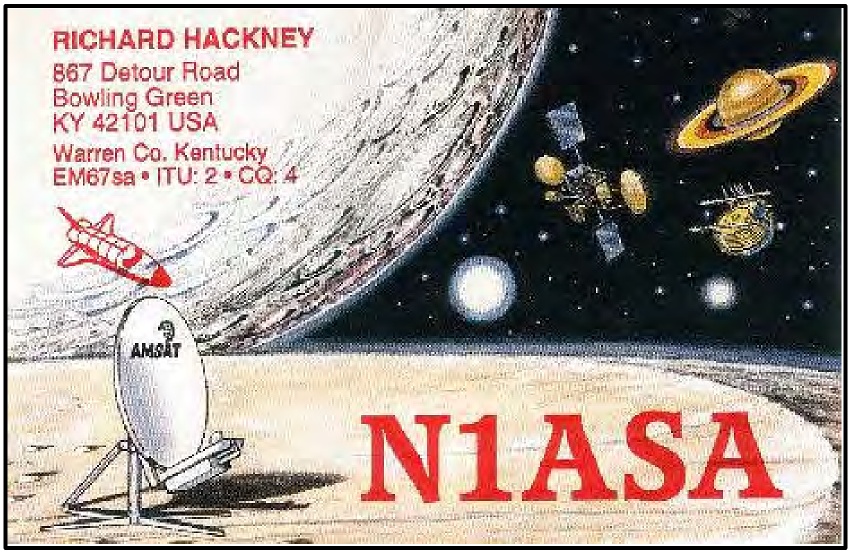

"Down-to-Earth" Satellite Communications

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Abstract

I describe some OSCAR basics, including what is needed to get on the air quickly using low-earth-orbit (LEO) satellites: AO-51, AO-27, SO-50, and the ISS crossband repeater. Stations up to about 4000 miles away can be worked with 5 watts on VHF/UHF by any amateur licensee, using FM repeaters orbiting at altitudes near 500 miles.

The discussion tells how to do it most simply, with minimal investment in equipment. The minimum equipment I will describe includes a dual-band HT and a handheld pair of yagis with elements mounted perpendicular to each other on the same boom (available from Arrow Antennas or homebrewed). Added conveniences (inexpensive) include an extension microphone, a small recorder (to catch the fast action for logging), a headlamp (if working at night), and a 440 MHz preamp.

I also discuss how to get predictions of usable satellite passes, how to easily track the satellites with the handheld yagis, and how to hear and possibly interact with the ISS through several ham radio modes.

You do NOT have to have long-boom circularly polarized yagis, expensive altazimuth rotors, computer tracking software, high-powered rigs, or rigs that work full duplex (hear on one band while transmitting on the other). If you like, you can eventually go that route, but you can easily and quickly get on the air with successful contacts with much less equipment and expense, as described here. In addition, it is portable and you can take it with you and use it anywhere. Some work from cruise ships. I think it's a lot more fun this way, and I'm not tied to one location. If you think you might be interested in working the satellites, **get just what you need to get started, practice by listening to a few passes, then jump in.** The absolute basics, distilled from the longer explanations, are summarized on the final page. You may want to read that first for an overview, and then look over the main text for explanations and details.

Technical Considerations and Set-up -- How to Get on Quickly and Easily

STEP 1 -- Ground-Station Antenna Selection - Polarizations and Patterns

A. Background Information

1. Satellite antennas are usually **linearly polarized** "whips"
2. **The satellite may slowly tumble**, changing the orientation of the antennas. If you happen to be "off the end" of its antenna, the signal may be too weak to work.
3. Signals are **linearly polarized** along the whip directions (and the satellite's xmt and rcv antennas may be oriented differently in space)
4. **"Faraday rotation" in the ionospheric plasma** rotates the plane of polarization depending on the distance of propagation, which is always changing because of the high speed of the satellite (about 18,000 mph, or 5 miles per second). It rotates the polarization of the uplink and downlink frequencies by different amounts (since they are on different frequency bands).

B. Resulting "Fade-outs"

1. Some "fade-outs" are unavoidable because the ground station may be temporarily in the end-on **null of the satellite antenna pattern**. Overcoming this problem (somewhat) requires very high-gain, long yagis, with corresponding narrow beam widths and need for expensive altazimuth rotators and accurate pointing controlled by a computer. However, this type of fade-out does not significantly affect most passes, so one can enjoy lots of satellite contacts without the expense and effort of building a major, fixed-location "super ground station."
2. **Severe "fade-outs" occur more frequently (several per pass) due to the ever-changing polarization** caused by "Faraday rotation" in the ionosphere. This problem can be easily solved by technique C-2, described below.

C. WHAT TO DO About Fade-outs

1. One option is to just live with it. One can successfully work satellites with a dual-band fixed J-pole, or dipoles, or separate fixed antennas (usually fairly omnidirectional) for the UHF and VHF bands. The number of contacts per pass will be reduced from other methods because there will likely be several periods of up to a couple of minutes each when the downlink can't be heard or the uplink is not making it into the repeater. Still, by transmitting 25-50 watts in this mode, you can expect to average one or two contacts per pass.
2. **A more reliable approach that I find much more satisfying (fewer fade-outs, and more contacts per pass) is to use a handheld directional antenna that allows you to control the receive polarization.** A widely-used solution is the Arrow Antenna Company's 146/437 pair of yagis, with a 3-element 2 meter yagi on the same boom with, and perpendicular to, a 7-element 440 MHz yagi. The overall dimensions are about a meter square. Holding the common boom in one hand by the padded handle at its back end, one rotates the antennas (about the boom as an axis) by twisting the wrist to keep the received signal at maximum strength throughout the pass. The other hand holds a 5-watt HT, or if an extension microphone is used, it is held directly and the HT hangs by a strap around the wrist. The most portable and complete version (see http://www.arrowantennas.com/146-437.html) is the $139 model **146/437-10WPB**, which includes a built-in duplexer (10-watt limit) combining to one feed line to the HT's single antenna connector. This "split boom" model disassembles into pieces no longer than about 20 inches for ease of transportation. It can be assembled in about 5 minutes. (For an additional $38, Arrow has a nice roll-up bag with inside pockets, which will actually hold two Arrow yagi split-boom sets, as well as whips such as the Pryme AL-800 (below) and knocked-down dual-band gain mobile whips such as those from Comet and Diamond, for mobile use.)

STEP 2 -- Programming Your Radio to Correct for Doppler-Shifted Frequencies

A. The "Doppler Effect"

- When a transmitter and receiver are **approaching each other**, the **received frequency is higher** than the frequency that was transmitted. If the transmitter and receiver are **receding from each other**, the **received frequency is lower** than the frequency that was transmitted. (If a car or train horn is coming toward you, then you hear the horn at a higher frequency that you would if it were not moving toward you. If it is moving away from you, then you hear it at a lower frequency than if it were not moving away from you. The amount of the shift increases with the speed of approach or recession.
- In the **middle of a satellite pass**, the repeater is moving **across** the line of sight (neither toward nor away from the ground station), so **the doppler shifts are zero** at that point. Otherwise, they range through the pass from some maxima (up or down), through zero at mid-pass, to the maxima in the reversed sense (down or up).
- The ground station needs to **allow for the changing doppler shifts during the pass**, by retuning the radio, either continously (via computer) or using memories, switched manually.
- In the table below, note that the **transmitter frequency (uplink) should start low and increase during the pass** (when the satellite is approaching, transmission below the nominal uplink frequency is doppler shifted (raised) to the nominal uplink frequency. The **received frequency (downlink) starts high and decreases during the pass.** It is initially doppler shifted (raised) above what is actually transmitted by the satellite.
- The doppler shift is proportional to the relative velocity and to the frequency. For a given speed, the **frequency shift at 435 MHz is three times the shift at 145 MHz**. At orbital speeds near **18,000 mph**, the full swing of the "doppler shift" is only about **4 KHz for a 145 MHz signal**, and about **12 KHz for a 435 MHz signal** (downlink). Consequently, **you don't actually need to adjust the 2 meter frequency**, and can be successful just adjusting the 435 MHz frequency in 5 kHz steps to correct for its doppler shift.

B. HOW TO Compensate for the Doppler Shift (depends on the radio(s) being used)

- The frequency shifts can be handled during the pass by **pre-programming memories** in the transceiver as shown in the table below. On a satellite-ready transceiver such as the Yaesu FT-847, there are **satellite memory pairs that tune together** using one memory-select knob.
- On a dual-band HT such as the Kenwood TH-F6A, **one can successfully work passes with the transmitter band (say, band A) left set at the nominal uplink frequency**. Several times during the pass, as the received signal (on band B) begins to sound ragged (slightly out of the passband), one uses the A/B key to change the active band to the receive band (435MHz), then drops the receive frequency by 5 KHz (pre-programmed memories), then changes the active (transmit) band back to the uplink band (2m). Other HTs may need a different approach. One "simply" needs to figure out how to achieve what is needed using whatever dual-band equipment one has (TH-F6A, TH-F7A, IC-W32A, FT-817, dual band mobile rigs such as TM-D700 at 10 watts, and many others), and then program the frequencies (and access tones for the uplink) into memories.

Time in Pass	**AO-51 (Echo)**		**AO-27 and SO-50 (Saudisat 1C)**		**ISS Crossband Repeater *Note differences from others**	
	Uplink Xmt	Downlink Rcv	Uplink Xmt	Downlink Rcv	Uplink Xmt	Downlink Rcv
Start (AOS)	**145.920** (67.0Hz)	435.310	**145.850** (67.0Hz)	436.805	437.790 @AOS	**145.800**
	145.920 (67.0Hz)	435.305	**145.850** (67.0Hz)	436.800	437.795 @2m	**145.800**
Mid-pass	**145.920** (67.0Hz)	**435.300**	**145.850** (67.0Hz)	**436.795**	**437.800 @4m**	**145.800**
	145.920 (67.0Hz)	435.295	**145.850** (67.0Hz)	436.790	437.805 @6m	**145.800**
End (LOS)	**145.920** (67.0Hz)	435.290	**145.850** (67.0Hz)	436.785	437.810 @8m	**145.800**

***Notes:** ISS operation and setup differs from the other LEO satellites, because ISS uses UHF for uplink and VHF for downlink. The LEOs operate in the V/U mode. However, the ISS crossband repeater (a Kenwood TM-D700) is operated in the U/V mode, because they want to downlink on the frequency 145.800 that they have established for all other downlinks (including direct voice contacts with astronauts and packet mode). There is the possibility that the astronauts could participate directly while operating in the crossband repeater mode. For ISS, one has to make the doppler adjustment on the 437 MHz uplink frequencies (transmitter), starting with the lower frequencies and increasing it throughout the pass. You can't hear the effects, as you do when it is the receive frequency you are adjusting. I have had success by planning in advance (on paper) -- dividing the 10 minute ISS pass into 5 (rounded-off) two-minute intervals and clicking one memory step of 5 kHz upward every two minutes according to the list. For a number of reasons, I find that contacts using ISS are usually not as easy as they are on the other LEOs. Just be patient and keep trying on several passes when it is active. Sometimes I get 1-3 contacts, and sometimes none.

STEP 3 -- Finding When the Satellites Pass Over and Where to Point Your Antenna

Use the NASA Marshall Space Flight Center's web-based program "**J-Pass**" to predict passes of ISS, AO-51, AO-27, and SO-50 (a.k.a. Saudisat 1C) -- all containing simple FM voice repeaters.

Most convenient is the J-Pass **email service**, which can regularly email pass information in the form of three-day predictions, sent every Monday, Wednesday, and Friday. To subscribe to the free service:

1. Go to: http://liftoff.msfc.nasa.gov/RealTime/JPass/20/
2. Select: J-Pass E-Mail
3. Give your email address, and proceed with the most advanced options, asking for ALL PASSES of ISS ("STATION"), AO-51, AO-27, and SO-50 (or Saudisat 1C.)
4. Choose M/W/F as the frequency of emails.

Below is a **sample** of emailed AO-51 pass predictions for Bowling Green, KY, for 9/30-10/03/2005:

```
>> AO-51 approx. vis. mag. 10
 Date                          Dur.   Lit Dur.   Max.
       mm/dd     Rise Set   mm:ss  mm:ss        Elev.
--------------------------------------------------
9/30 08:28:39pm ESE N 13:01 03:30 17 ENE
9/30 10:05:58pm S NNW 15:14 02:59 54 WSW
10/01 10:15:55am NNE S 15:15 15:15 61 E
10/01 11:55:30am N WSW 12:45 12:45 15 WNW
10/01 07:51:44pm E NNE 09:54 02:59 6 NE
10/01 09:26:47pm SSE N 15:24 03:30 62 E
10/01 11:07:19pm SW NNW 12:39 01:15 13 W
10/02 09:37:08am NNE SSE 14:15 14:15 25 E
10/02 11:15:46am N SW 14:45 14:45 35 WNW
10/02 08:48:20pm SE N 14:19 03:30 26 ENE
10/02 10:26:44pm S NNW 14:42 02:15 33 W
10/03 08:59:01am NE SE 11:15 11:15 9 E
10/03 10:36:24am N SSW 15:15 15:15 83 WNW
```

The first entry tells us that --

- On 9/30 at 8:28:39pm CDT,
- AO-51 rises in the ESE.
- It will set in the N after 13m01s.
- (It is sun-lit for 3m30s, which doesn't matter because it's too faint to see)
- Its maximum elevation is 17 degrees, looking in the ENE direction.

In preparation for the pass, I carry a small note card that simply reads:

AO-51 9/30 8:28pm ESE (17ENE) N

(Max altitude 17^{o} will be reached after about 6-7minutes)

So, at the given start time, I point my antenna to the ESE horizon and listen, rotating about the boom as an axis to match the polarization. When I acquire the signal, I follow it across the sky, maintaining the strongest received signal by adjusting the pointing direction and rotating the boom to match the polarization. It reaches its maximum elevation of 17^{o} in the ENE direction halfway (about 6-7 minutes) into the pass. I continue following it until it sets on the horizon in the N. All along, I am calling and listening, to make contacts (see later suggestions on techniques). In preparation for the pass, it helps me to imagine the path before the pass, and to practice sweeping the antenna from the rising point, to the maximum elevation point, to the setting point.

In the list from J-Pass, plan ahead which passes you want to try. That depends on your schedule, and to some extent, the maximum altitude of the passes. Passes above about 10^{o} usually work with the Arrow yagis, and higher passes will probably yield more contacts. When I've selected the passes, it helps me to set a timer or alarm clock to remind me, because it is easy to work on other projects and forget to work a pass.

Important: There are other constraints that determine which passes you can work. For example, AO-27 is only operated on its passes from generally S to N ("called ascending"). It is also only active for 10 minutes on those passes, and it might not be turned on by the control operator until it is already well above your horizon (or get turned off while still above it). AO-51 is sometimes operated in modes other than V/U (packet, L-band, S-band), so you periodically need to go the **AMSAT website** to see the planned schedule to know which passes will be useful.

Some Very Useful Websites for Planning and Scheduling:

AMSAT -- Main Page: http://www.amsat.org/amsat-new/index.php

AMSAT -- Satellite Status Page: http://www.amsat.org/amsat-new/satellites/status.php

AO-51 (Echo) Scheduled Ops: http://www.amsat.org/amsat-new/echo/ControlTeam.php

AMSAT NEWS: http://www.amsat.org/amsat-new/news/

ARISS -- News of **A**mateur **R**adio on the **I**nternational **S**pace **S**tation and **School Contacts**.

(If the ISS is above your horizon when the contact is made, you can hear the astronaut's comments from NA1SS to the school using an HT (freq: 145.800) and a good whip such as the AL-800, even if ISS is 1,500 miles from you.)

ARISS News at: http://www.amsat.org/amsat/ariss/news/arissnews.txt

Helpful announcements and news can be emailed to you by subscribing to: sarex@amsat.org as directed in instructions at: http://www.amsat.org/amsat/listserv/lists.html

ISS Astronaut Contacts: Sometimes, the astronauts get on the radio in their spare time (not predictable) and make **direct contacts** with amateurs on the ground. No doppler corrections are needed (both up and down links are on 2 meters). The AL-800 whip might work, but your chances are better for standing out if you use the 2-meter Arrow yagi. Frequencies are: **Uplink (xmt): 144.490*** and **Downlink (rcv) 145.800**. **(*Uplink 144.490** in ITU Regions 2 and 3 --US, Canada -- **Uplink 145.200** in ITU Region 1)

ISS Packet: Mostly, the ISS radio is operated in **packet mode** using the following frequencies: **Uplink (xmt): 145.990** and **Downlink (rcv) 145.800.** An AL-800 whip is sufficent to send and receive packets with a packet-ready HT such as the Kenwood TH-D7A (built-in TNC). Anyone can "hear" the packet downlink on 145.800. **To send packets** with an appropriate rig, set your packet parameters as described on the website: http://web.usna.navy.mil/~bruninga/iss-aprs/issicons.html

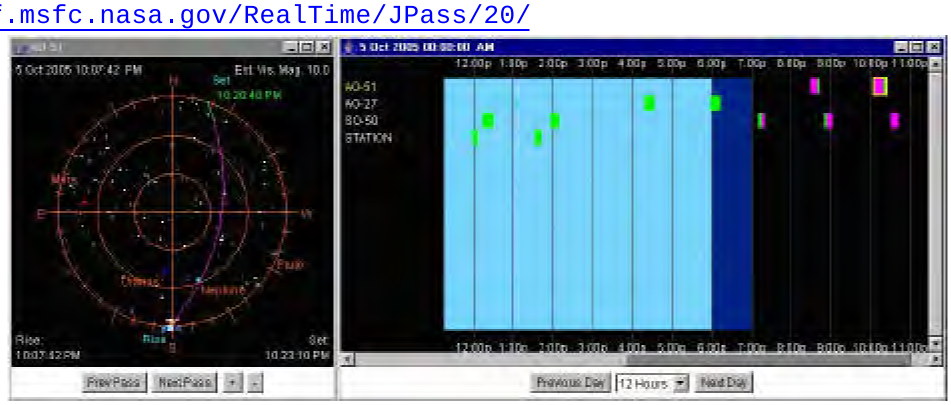
Packets received by the ISS are mapped and displayed at: http://www.ariss.net/ For example:

20040711034402 : N1ASA/RS0ISS-3*,WIDE,qAo,N0AN:'r6Zl /Western Ky U. Bowling Green

J-PASS 2.0: http://liftoff.msfc.nasa.gov/RealTime/JPass/20/

Emailed predictions, or **immediate predictions** (if you have Java enabled in your browser):

The sky chart on the left describes the 10:37pm pass of AO-51 that is selected on the day's chart to the right.



STEP 4 -- LEO and ISS Repeater Protocol and Technique

- **Call only when signals have been heard!**
- **Never call "CQ Satellite"**
- **Simply repeat your call, often, and wait for someone to return to it**.
- Call **during gaps** or anticipated gaps in received activity.
- Give your **callsign**, and perhaps **grid-square** (mine is EM67), as exchanged information.
- You will have better luck just **calling repeatedly**, with others coming back to you.
- It is not very productive to respond to a specific call (possible fades) - let them call you
- For LEOs, change the 440 MHz receiver frequency (downward) as signals slide out of the passband.
- For ISS crossband repeater, change the 440 MHz transmitter frequency (upward) during the pass.
- Many signals received from the “moving hot spot in the sky” are from 5 watt, handheld stations.

STEP 5 -- Optional Enhancements for Convenience or Better Reception

The following aids are not absolutely essential, but they can add to the convenience and pleasure of operating handheld, as described below. Don't wait until you have them all to get on the air. Begin operating and you will see how each can help in its own way.

1. **Alternate Antenna Usable with ISS.** The antenna shown on the HT is a Pryme (or Premier) AL-800 Telescoping Dual Band Whip. This antenna sells for about $35 and features operation as a ground-independent half-wave antenna on 2m. That means it needs no ground plane or counterpoise ("rat-tail"), which is a performance limitation of other whips (1/4, 5/8 wave) commonly used on HT's. It is also unusual in having adequate gain on 440 to hear some satellite downlink signals. It is shown in its collapsed state in the picture. In use, fully extended atop the HT, the **antenna must be slowly "waved about" in orientation** to find the orientation that matches the instantaneous polarization and keeps the downlink signal at maximum. This antenna is useful with the **stronger repeater on the ISS**, and is not as likely to make contacts on the other LEO's. However, anyone with an HT should own one -- it has gain on both 2 meters and 440 MHz, it is ground independent (a balanced dipole), and it will bring up repeaters when other "whip" antennas won't
2. **External microphone** , to get the 5 watt transmitter away from your head, if using the whip antenna.
3. **Recorder**, either tape or digital, and earphones. Satellite work is continuous and fast-paced. In handheld mode, **logging contacts** is impractical (both hands are occupied), and one will not likely remember the calls (and times) of the contacts. After the pass, one replays the tape to log the contacts. A direct audio signal for the recorder can be taken from the earphone jack (or some external microphones have an earphone jack on the microphone.) If using either jack for the recorder signal, then **earphones** must also be used (via a splitter) in order to hear the downlink while recording. After the pass, one replays the tape to log the contacts. Some small tape recorders work well enough just using their built-in microphone to catch the audio output of the HT. I currently use a tiny MP3 player that features a high-quality voice recorder mode, and I just hang it around my neck by its lanyard. It makes excellent quality recordings with its microphone picking up the HT's audio.
4. **Headlamp** – a small light held on a headband is helpful at night for checking things visually during the pass, including the band-switching/downlink doppler-frequency adjustment maneuver several times during the pass.
5. **440 MHz Pre-Amp** (not pictured). It may be helpful with the Arrow yagis to add a low-noise, GASFET 440MHz preamplifier for better reception of the LEO signals (AO-51 usually transmits with less than 1 watt, AO-27 with less, and SO-50 with even less). If you use a downlink preamplifier, you need to mount it on the boom, connecting the feedline from the 440 MHz yagi to its input, and its output to the duplexer. You don't want to fry it with the 2m transmitted signal, and the duplexer between it and the transmitter provides adequate attenuation of the 2 meter transmitted signal for the 440 MHz side. You don't want (or need) the preamp in the system if working the ISS crossband repeater, because the 440MHz transmitter is used for the uplink, and the downlink is 25 watts on 2 meters. Suitable models that I (or hams I know) have used are the MIRAGE KP-1/440, 70 CM IN SHACK PREAMP ($124.95 from HRO) and the Advanced Receiver Research (ARR) SP432VDG ($109 from ARR, see http://www.advancedreceiver.com/page7.html). Either can be powered from a small battery pack (not supplied) that you can put together and mount on the Arrow boom.

Overall, everything you need can be taken wherever you go, in a relatively small bag, briefcase, or suitcase!

In conclusion, don't wait until you can build a "super-station" for satellite work. Get on the air quickly and give it a try, using the given practical information and simple equipment. You may find that you don't need to make a major investment to have fun with amateur radio via satellites in a variety of ways.

To the Heart of the Matter -- Distilled Basics Summarized and Reviewed

1. **Antenna:** Get an Arrow Antenna Company 146/437-10WPB (dual-band portable yagis on one boom) or home-brew equivalent. Hand-hold it and follow the (invisible) track across the sky, pointing and rotating the polarization as needed to keep the received signal as strong as possible. The track is found in step 3.

2. **Transceiver:** Try to adapt what you have, if it has dual-band capability (duplex operation is not required). (Also, two radios could be used.) Keep power to 10 watts or less if holding the antenna by hand. Program modes and memories to correct for doppler effects on the 440 MHz band. Each model of rig is different in how to transmit on one band and receive on the other (and not necessarily at the same time). Read the manual and program the following frequencies (and tones) into memories once and for all:

Time in Pass	**AO-51 (Echo)**		**AO-27 and SO-50 (Saudisat 1C)**		**ISS Crossband Repeater *Note differences from others**	
	Uplink Xmt	Downlink Rcv	Uplink Xmt	Downlink Rcv	Uplink Xmt	Downlink Rcv
Start (AOS)	**145.920** (67.0Hz)	435.310	**145.850** (67.0Hz)	436.805	437.790 @AOS	**145.800**
	145.920 (67.0Hz)	435.305	**145.850** (67.0Hz)	436.800	437.795 @2^{m}	**145.800**
Mid-pass	**145.920** (67.0Hz)	**435.300**	**145.850** (67.0Hz)	**436.795**	**437.800 @4^{m}**	**145.800**
	145.920 (67.0Hz)	435.295	**145.850** (67.0Hz)	436.790	437.805 @6^{m}	**145.800**
End (LOS)	**145.920** (67.0Hz)	435.290	**145.850** (67.0Hz)	436.785	437.810 @8^{m}	**145.800**

3. **Pass Predictions -- Schedules and Directions:** Use NASA's J-PASS 2.0 for emailed or immediate pass information for ISS, AO-51, AO-27, and SO-50. Verify current operation modes from the given web references. Carry a note giving the pass information in a convenient form such as: **AO-51 9/30 8:28pm ESE (17ENE) N .** Set up a few minutes before the pass, and briefly practice the path by moving the antenna back and forth a few times between the rising and setting points on the horizon, passing approximately through the maximum altitude point. Remember, there are 90 degrees between the horizon and the point directly overhead.

4. **LEO and ISS Repeater Protocol and Technique**
   - **Call only when signals have been heard!**
   - **Never call "CQ Satellite"**
   - **Simply repeat your call, often, and wait for someone to return to it**.
   - Call **during gaps** or anticipated gaps in received activity.
   - Give your **callsign**, and perhaps **grid-square,** as exchanged information.
   - You will have better luck just **calling repeatedly**, with others coming back to you.
   - It is not very productive to respond to a specific call (possible fades) - let them call you
   - For LEOs, change the 440 MHz receive frequency downward as signals slide out of the passband.
   - For ISS crossband repeater, change the 440 MHz transmit frequency upward during the pass; start at 437.790 MHz and click upward 5 KHz every two minutes through the ~10 minute pass.

5. As needed, add enhancements such as extension microphone, small voice recorder (for logging), earphones, headlamp for night passes, and 440 MHz preamp for improved reception.

That's about all there is to it. After the initial setup and a few contacts, it becomes easier and easier. This document is meant to get you started quickly. After that, there are other satellites and more challenging modes that you may wish to explore, with corresponding enhancements of equipment.

Best wishes, and good V/U DX'ing on the LEOs!