Why Can't I Hear AO-51?

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Operating the low earth orbit satellites (LEO), particularly AO-51 (AMSAT Echo) can be a very fun and satisfying activity. The LEO FM birds are relatively easy to access with simple and common ham radio equipment. However, authors have a tendency to over simplify the ease of access to the LEOs. There is a huge difference in the probability of success between the operating conditions depicted in the figures labeled 23.8 and 23.9 (from the *2006 ARRL Handbook*).

Photo 1: W2RS shows another popular LEO FM antenna for handheld operations.

Also, if taken out of context, this statement from the AMSAT Web site could give the impression that an HT with rubber duck is all that is needed to access Echo.

The bottom line is that it is far easier to get your signal into the satellites than it is to hear the satellites. If you don't do your homework and try to access the satellites without the required equipment to hear the satellites, you will become frustrated because "no one is on the birds" or "no one is answering my CQ calls." The other users of the satellites in turn will become frustrated because their QSOs are being disrupted by your un-answerable transmissions that tie up valuable satellite access time. You need to hear the birds before you can use the birds and the simple vertical or rubber duck antenna that you use for repeater operations may not be good enough to hear the satellites. In addition to the HT or other quality receiver, you need to consider an antenna with some directional gain, good quality low loss coax feed line and maybe even a receiver pre-amp.

The following treatise is an attempt to quantify, explain and help you understand the science of radio that is required to access satellites. I hope it will convince you to explore equipment alternatives that will allow you to reliably access the satellites and maximize your enjoyment of this operating activity.

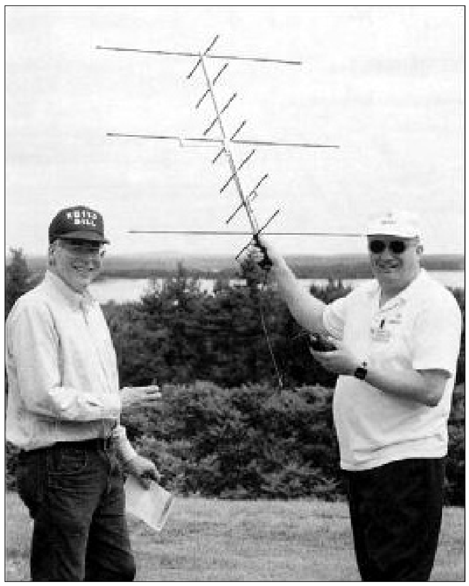

Photo 2: The handheld "Arrow gain antenna is popular for FM LEO operations. (Photo courtesy of* The AMSAT Journal*, Sep/Oct 1998.)

Satellite Path Power Budget

Some level of understanding of radio and mathematics fundamentals is assumed during the following discussion of power budget. If you need more detail, there are expanded explanations contained in the sidebars and also more information can be found in various ham radio publications.

To evaluate the kinds of equipment needed to make a successful satellite contact, we need to look at the gains and losses that occur along the path up to and down from the satellite. These gains and losses comprise what is called a power budget. If you think of the factors that impact a signal as it traverses between the satellite and your station, you will probably come up with a list something like this:

Gain/Loss factors in a satellite link path

- Transmitter power
- Feed line loss
- Transmitting antenna gain
- Path loss due to distance and frequency
- Path loss due to travel through ionosphere
- Polarization miss-match
- Receiving antenna gain
- Feed line loss
- Receiver sensitivity

These are just some of the factors that either add to (gains) or subtract from (losses) to the signal between the satellite and your station. To make comparisons between gains and losses, we need to use a common set of units, and that unit is the decibel (dB). So let's take a look at each factor in the power budget in dB from the satellite down.

Transmitter Power: The Echo transmitter has a power output of 1 watt (high power mode, normal mode is 500 mw). This is actually a pretty hefty satellite signal. One watt equates to a power of +30 dB_m (+27 dB_m low power). Since this is our starting power level, it is considered a gain (+ sign).

Feed Line Loss: The satellite antenna and the satellite transmitter are very close together so we can assume that there are negligible losses in the feed line.

Transmitting Antenna Gain: Satellite antennas are generally small in size to accommodate the physical space constraints of the launch vehicle. Because of the size constraints and the need to cover a large surface area below the satellite, high gain is not the norm for satellite antennas. The Echo antenna is rated at +2 dB_i of gain.

Path Loss: A radio signal loses apparent strength as it travels out away from the transmitting antenna into space. The Friis equation is a way to quantify the signal strength at some distance of travel. To simplify the signal strength generated by a moving target (the satellite), let's calculate the path loss at the furthest point when the satellite just becomes visible over the horizon, and at the closest point. The path loss for 3,000 km of travel is -154 dB and the path loss for 800 km of travel is -143 dB.

Loss Due to Travel Through the Ionosphere: The path loss calculated above is just due to the spreading out of the available power over and expanding area away from the transmitter in a vacuum, What are logarithms?

A logarithm, or log, is a mathematical technique to represent and manipulate incredibly large and/or incredibly small numbers. Any number can be replaced or represented by some base number raised to a power. For instance 10 raised to the power of 2 equals 100:

$$10^2 = 100$$

In the vocabulary of logs, the exponent 2 is the log, base 10, of 100. The number 10 in this example is called the base, or $\log_{10}$. There are two common base values used in mathematics, 10 and e. ("e" is the natural logarithm and has a value of 2.718281…) Using the vocabulary of logs, 100 would be represented this way:

$$2 = \log_{10}(100)$$

The log does not have to be a whole or integer number, nor does it have to be positive. For instance, .015 represented as a logarithm would be -1.82390….:

$$-1.82390 = \log_{10}(0.015) \text{ or } 10^{-1.82390} = 0.015$$

We would say the $\log_{10}$ of .015 is -1.82390 (the actual value goes on for an infinite number of decimal places so for practical reasons the number is rounded off). Negative logs represent numbers less than 1. There is one important $\log_{10}$ value to remember. The $\log_{10}$ of 1 is 0 (zero):

$$10^0 = 1 \text{ or } 1 = \log_{10}(0)$$

So why use logarithms other than a short hand way to represent very large or very small numbers? If we have a series of numbers, for instance gains and losses in a transmitting/receiving system, each successive gain or loss multiplies or divides the preceding numbers within the series to end up with the final gain of the system. If we use logs of the same base values to represent the numbers in the series, then because of the laws of exponents (logs are really just exponents), we can simply add the log values to accomplish the multiplication and division.

there are additional losses whenever the signal comes in contact with obstacles, like electrically charged particles that make up the earth's ionosphere. It is assumed that there will be a -1 dB loss as the signal travels through the ionosphere.

Polarization Mismatch: Satellite signals are generally right-hand circularly polarized. This is due in part to the stabilizing rotation of the satellite and Faraday rotation that occurs as the signals interact with the earth's magnetosphere. The signal polarization is not constant throughout the satellite passes so it will be assumed that there will be some polarization mismatch even if the receiving antenna is also right-hand circularly polarized. There is a -3 dB loss between a circularly polarized transmitting antenna and a linearly polarized receiving antenna.

The following table summaries the power budget from the satellite down to the receiving antenna. This portion of the power budget is out of your control and is a function of the satellite design and the physics of signal propagation.

Satellite TX Power	+ 30 dB
Feed line loss	0 dB
TX antenna gain	+2 dB
Path loss (3,000 km)	-154 dB
Ionosphere	-1 dB
Polarization mismatch	-3 dB
Total	-126 dB

The signal at the receiver antenna is – 126 dB.

Receiver Sensitivity: Most receivers specify the minimum signal required at the antenna jack to produce a minimally usable signal in the speaker. By convention, a 12 dB SINAD signal is considered minimally usable. This signal strength is probably not strong enough to break the squelch in your HT, therefore to hear a minimally usable signal you would have to manually open the squelch to hear the signal. A receiver sensitivity of .18µV is typical. This signal level equates to -122 dB_m.

Receiver Antenna Gain: Now we will discuss some of the station components that you have some control over. Let's assume that you are going to use a fixed station vertical antenna. The gain of this antenna is based on a lot of factors not to mention that the antenna is probably designed to work terrestrial repeaters located on the horizon and therefore the gain is optimized at the horizon. The typical gain of a simple ground plane antenna is around +3 dB.

Feedline Loss: Antenna feed line loss probably does not receive the attention it deserves. You would be amazed at the amount of signal that is lost in the antenna feed line. The following table summarizes the approximate loss of common coax types.

Approximate Loss in Coax at 430MHz		
Coax Type	dB loss/100 ft.	dB loss/50 ft.
RG8	3.08	1.54
RG58	10.7	5.35
RG213	4.6	2.3
LMR400	8.0	4.0
½ inch Hardline	1.4	0.7

What is a decibel?

The decibel (dB) is widely used in electronics to compare power levels to quantify if there are relative gains or losses within a circuit. The dB is a logarithmic unit used to describe a ratio between the power level of interest to some baseline power level. It is convenient to use a baseline power level of one milli-watt or 0.001 watt in radio and satellite work.

The difference in dB between two power levels is expressed as:

$$dB_m = 10\log\left(\frac{P_{watts}}{P_{reference_{milliwatts}}}\right)$$

or

$$dB_m = 10\log\left(\frac{P_{watts}}{.001watt}\right)$$

Both power levels need to be in the same units. Positive dB_m would mean relative gain, negative dB_m would mean relative loss.

Because there can be different baseline references depending on the application, it is sometimes important to indicate what the reference units are. In this case, the reference is one milli-watt so the "m" subscript is added to dB_m. Another baseline reference you will see in this paper is dB_i. dB_i will be used when antenna gains are compared to the mathematically ideal antenna which is called the isotropic antenna.

Let's assume that you are using 50 feet of RG58 for your coax run, the loss would be -5.35 dB.

Putting it All Together

The following table summarizes the power budget we have using a standard VHF/UHF ham station.

Satellite TX Power	+ 30 dB
Feed line loss	0 dB
TX antenna gain	+2 dB
Path loss (3,000 km)	-154 dB
Ionosphere	-1 dB
Polarization miss-match	-3 dB
RX antenna gain	+3 dB
Feed line loss	-5.35 dB
Total	-128.35 dB

The net result is that you need -122 dB to hear the signal, but you only have -128.38 dB available. You will never hear the satellite!

Now with the information in the basic power budget table, let's play with some of the entries to see what happens. First, will you be able to hear the satellite when it is overhead? Enter -143 for the pass loss, which adjusts the total to -119. So, yes, the received signal is a few dB above the minimum … if

Determining path loss with Friis equation

The available transmitted power is dispersed as if on the surface of an expanding sphere as it moves away from the transmitting antenna. Since there is a set amount of power being transmitted, as the wave travels further away from the antenna, this set amount of power is distributed over a wider and wider area. The Friis equation expresses the power level, in dB, as a function of the wavelength and the distance away from the signal source:

$$Loss_{dB} = 20\log\left(\frac{4\pi d}{\lambda}\right)$$

We can use the Friss equation to predict the satellite signal power at the receive antenna, in other words, the loss in signal strength in dB as the signal travels through space. The units for wavelength and distance must be the same.

For example, when a LEO comes over the horizon, the distance between your station and the satellite is approximately 3000 km. If the downlink frequency is in the 70 cm band, the wavelength is .7 m. Plugging these values into the Friis equation:

$$154dB = 20\log\left(\frac{4\pi * 3\times10^{6}}{.7}\right)$$

It is intuitive that there would be signal loss during the trip through space, the loss would therefore be -154 dB (rounded off).

For a second example, when a LEO is directly overhead, the distance between your station and the satellite is approximately 800 km. Using the same downlink frequency:

$$143dB = 20\log\left(\frac{4\pi * 8\times10^{5}}{.7}\right)$$

The loss is -143 dB.

we assume that the antenna gain is still 3 dB directly above, which is doubtful. But you might be able to hear the satellite for a few minutes of the pass.

Now try improving the coax from RG58 to RG8. Enter the loss of -1.54 dB and the total is -124 db (at the horizon), still not quite good enough though there will be more reception time as the satellite gets closer.

Many satellite users are using a handheld Yagi antenna (like the one pictured above) with good success. I have modeled this antenna and estimate the gain is approximately 10 dB_i. Considering that you manually point the antenna at the satellite, this gain should be relatively stable. So let's see what happens when using a handheld Yagi. Enter +10 dB for the receiver antenna gain and let's assume no feed line loss since the antenna will be handheld with an HT. The resulting signal at the radio is -113 dB, well above the signal required for the minimum! If we enter the path loss for the closest point of the satellite's approach, the signal is -102 dB, approaching full quieting.

If you want to receive the satellites with the same quality as you experience with repeaters, you would have to boost the signal at the receiver to approximately -94 dB. This would require the addition of a receiver pre-amp at the antenna. Most pre-amps will produce gains of between 12 and 15 dB. If you add the gain of the pre-amp to the power budget, the received signal is now -101 dB at the horizon and -90 dB overhead.

So from this discussion you should conclude that some antenna with gain, quality low loss coax and perhaps an antenna mounted pre-amp will help you at least hear the birds, if not being down right essential.

Why is it easier to hit the birds than receive the birds? To answer this question, let's take a look at the power budget for the uplink for the typical HT with rubber duck antenna using 2 meters for the uplink frequency.

Transmitter Power: Let's assume the typical 5 watt HT output power. That equates to +37 dB_m.

Feedline Loss: Zero, the antenna is mounted on the HT.

Antenna Gain: For a rubber duck antenna is actually a loss at typically -2 dB.

Path Loss: At 2 meters and 3,000 km path loss is -145 dB and at 800 km it is -134 dB.

We will use the same losses for polarization (-3 dB) and travel through the ionosphere (-1 dB).

Echo Antenna Gain: The same at +2 dB.

Echo Receiver Sensitivity: The satellite receiver is slightly less sensitive than your receiver at -125 dB for 12 dB SINAD.

Now doing the math, the signal at the Echo receiver is -112 dB, more than enough signal strength to be almost full quieting! So that statement about using an HT with rubber duck in the introduction is true, but only to transmit into the satellite, not receive the satellite. There also would be more than enough signal produced by the typical 50 watt mobile rig to hit the satellite with a simple vertical antenna, but you would not be able to hear the satellite.

Conclusion

I hope that you have found the discussion informative and I hope it will cause you to think about how you can improve your satellite receiving situation. I would recommend that you consider at least a modest gain antenna as a minimum, upgrading your feed line and adding a receiver pre-amp as your financial situation will allow. Don't automatically assume that you can fully access the LEO FM birds with the same station you use to access your local repeaters. Your HT and vertical antenna may allow you to transmit into the satellite but will not be good enough, except in the most extra ordinary conditions, to hear the satellites. A little thought, planning and understanding of the science of radio will go a long way into opening the satellites to you.

Converting receiver sensitivity into equivalent power levels

Receiver sensitivity is expressed by the manufacturer as the number of micro-volts of signal at the receiver input to produce 12 dB of SINAD. (SINAD stands for signal plus noise plus distortion and is a measure of signal quality produced by the receiver's speaker.)

$$SINAD_{dB} = 10\log\left(\frac{SND}{ND}\right)$$

Where SND is signal+noise+distortion and ND is noise+distortion

By definition, 12 dB SINAD is the minimally useful signal. An excellent signal would be 40 dB SINAD. We cannot use SINAD values directly in our signal path evaluation so we will need to convert the micro-volt specification to produce a 12 dB SINAD signal into dBm. My receiver specifies that .18μV will produce 12 dB SINAD. The standard input impedance of a modern receiver is 52Ω. Using Ohms law:

$$I = \frac{E}{R}$$

or

$$3.462\times10^{-9}\ amps = \frac{1.8\times10^{-7}\ volts}{52ohms}$$

and

$$P = EI$$

or

$$6.23\times10^{-16}\ watts = 1.8\times10^{-7}\ volts * 3.462\times10^{-9}\ amp$$

Converting this power into dBm:

$$-122dB_m = 10\log\left(\frac{6.23\times10^{-16}\ watts}{.001watt}\right)$$

The power at the receiver input to produce the minimally useful signal at the speaker would be -122 dBm. To produce full quieting (FM), an excellent signal would require a power level of approximately -94dbm.