Propagation Segment

Contents

Introduction

Hi, welcome to the Aerospace Maker channel. I'm Aaron Harper. This channel is all about the nuts and bolts of aerospace. This week is the propagation segment of a link budget in preparation for a satellite reception project. At the end of these videos, we will have made a satellite ground station receiver and received images from space.

This week we'll cover the communication link from the spacecraft antenna all the way to the ground station antenna. If you have not seen this series' previous videos, I encourage you to view them to see how we arrived at these figures rather than take our word for it.

There will be a fair bit of math in this video, so have a decent scientific calculator available. I use RealCalc, a free app for android phones which is similar to the Casio I started out using in college. Should you get lost, don't panic. Feel free to go over the video a couple of times. All of the material, including the math step by step, is available on our website, aerospacemaker.org.

A Bit of a Review

Let's review what we know so far. Our scenario is to receive the images from the NOAA-19 weather satellite, assuming our satellite is 60 degrees above the horizon, and at an altitude of 870 km above the surface of the earth transmitting at a frequency of 137.1 MHz. We also know that the satellite's output power is 12.45dB estimate isotropic radiated power, or EIRP.

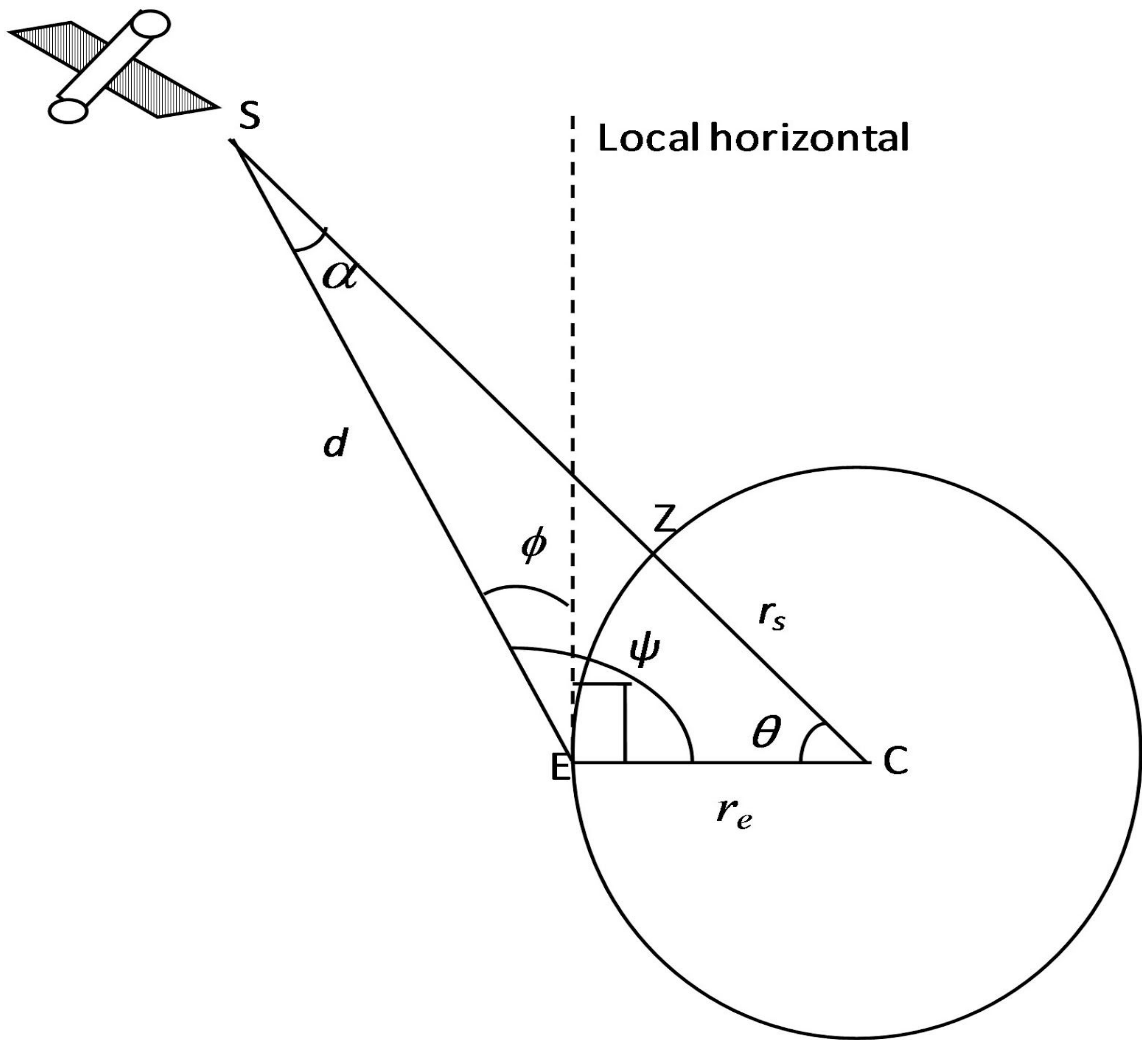
Breaking it Down Further

There are several calculations we need to do to figure out the signal we will receive at the ground station antenna.

1. Figure out the distance between the satellite and ground station, called the slant range. This will require some trigonometry, but we'll step through this bit by bit. Don't panic.
2. With the slant range we can figure out the free space propagation loss. This is the loss caused by distance, similar to the way a light may be bright up close, but nearly invisible a few kilometers away.
3. Next, we need to figure out how much of the slant range is in the atmosphere and calculate the reduction of the signal caused by the various gasses in the air.
4. Finally, we add all of these to the power output (EIRP) of the satellite to get the signal level at the ground station.

The Problem

To understand the issue, let's look at the illustration and review what we know and what we need to figure out. The satellite, the ground station, and the center of the earth make a triangle which we can solve for all angles and sides using a bit of trigonometry. We need to know the distance between the satellite and ground station, labeled *d* in the illustration. We know the observation angle is 60 degrees elevation above the local horizon, and the altitude of NOAA-19 is 870 km above sea level.



Let's start with the ground station elevation angle, labeled with the greek letter Phi (Φ) in the illustration. We know that this angle is 60 degrees above the local horizon, and that the horizon is at a right angle to the center of the earth. This puts angle E at 60 + 90, or 150 degrees.

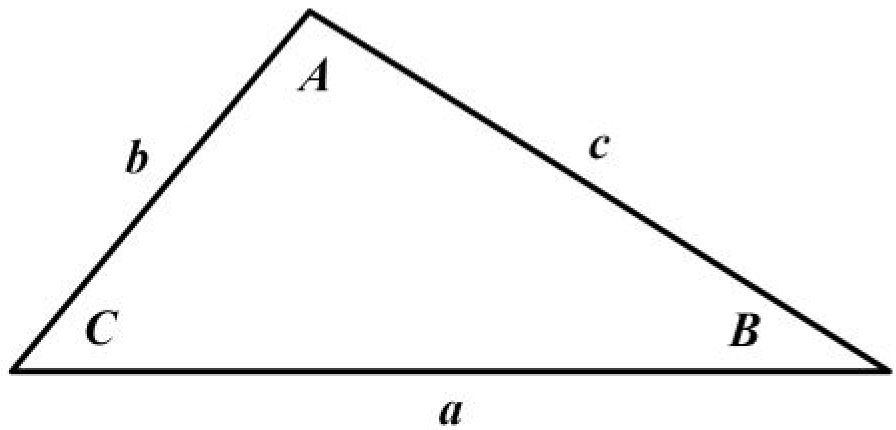
We also know that distance to the center of the earth from sea level, r_e and r_s in the illustration, is 6378 km. NOAA-19 is at an altitude of 870 km above this, therefore the distance from the satellite to the center of the earth, Z in the illustration, is 870 + 6378, or 7248 kilometers.

For simplicity, let's just say that the ground station is at sea level using r_e = 6378 km, but if it were not, we would simply add the altitude to the radius of the earth just as we did with the satellite altitude.

At present, we can't quite get the slant range with the data we have, but we can calculate the rest since we have one angle (E), the opposite side (Z), and at least one other side or angle (r_e).

Law of Sines

The law of sines states that the sine of an angle over the length of the opposite side is equal to the sine of any other angle over its opposite side. Given this triangle:



$$sin(A)/a = sin(B)/b = sin(C)/c$$

With this handy equation, we can solve most triangles broken down to segments and angles, where an angle and the opposing side is known, which establishes a ratio. With this, any additional side will yield an angle, and any angle will yield a side.

Lookdown

Since we know both the values of angle E (150 degrees) and segment Z (7248 kilometers), we have the ratio. We also have the length of side r_e (6378 kilometers), and with the ratio of sin(E) over Z, and r_e, we can figure out the angle S, the lookdown angle of the satellite.

Substituting some values and moving terms around we get:

$$sin(S)/6378 = sin(150)/7248$$

The sine of 150 is 0.5, therefore:

$$sin(S)/6378 = 0.5/7248$$

$$sin(S)/6378 = 1/14496$$

$$sin(S) = 6378/14496$$

$$S = Sin^{-1}(6378\ 14496)$$

$$S = Sin^{-1}(0.44)$$

$$S = 26.103$$

Our lookdown angle is 26.103 degrees.

Finding C

This part is easy. We know that the sum of all angles of triangles equal 180 degrees. Therefore,

$$C = 180 - 150 - 26.103$$

$$C = 3.897$$

The angle at the center of the earth between the ground station and the satellite and opposite of the segment between the satellite and ground station is 3.897 degrees. Now all we have to do is solve for that side for our slant range.

Slant Range

From the first law of sines equation, we already have the ratio of 0.5 over 7248, which equals 1 over 14496. Therefore:

$$sin(3.897)/d = 1/14496$$

$$d = sin(3.897) * 14496$$

$$d = 985.192$$

Our slant range is 985.192 kilometers.

Calculating Free Space Propagation Loss

The formula for the signal lost over distance where distance is in kilometers, the frequency is in MHz, and the output is in decibels (dB) is:

$$FSPL = 20Log_{10}(d) + 20Log_{10}(f) + 32.45$$

Substituting real values, we get:

$$FSPL = 20Log_{10}(985.192) + 20Log_{10}(135.1) + 32.45$$

$$FSPL = 59.87 \; + \; 42.74 \; + \; 32.45$$

$$FSPL = 135.06$$

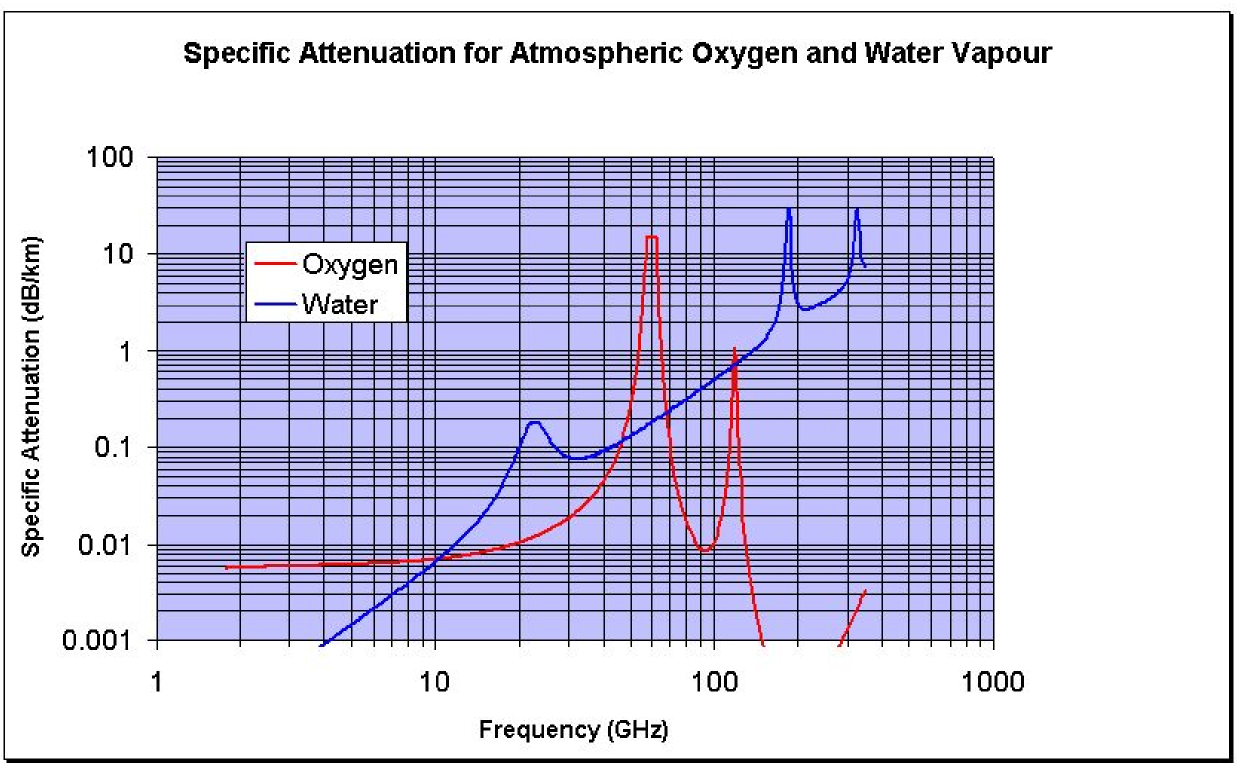
We lose 135.06 dB of our signal before it gets to the ground station. The only thing left to calculate is the signal blocked by our atmosphere.

Atmospheric Losses

There are a lot of models for how the atmosphere absorbs signals, and to an extent they are all right... ...and all wrong. The complex real world does not follow a simple math function. Weather and other less visible atmospheric phenomenon can and will change this variable. A simple model is better for our uses because it will be an approximation, so we should consider these figures as a guideline.

In this chart, we can see the signal attenuation of the primary factors in our atmosphere, oxygen and water vapor. In our chart, the X-axis is the frequency in GHz, and the Y-axis is the attenuation in dB per kilometer.

Looking for at 137 MHz which is off the chart to the left, we find that the effect of water vapor is below measurable limits. The effect of oxygen may be projected at 0.005 dB per kilometer.



So, how many kilometers of atmosphere does the signal pass through before it is in a vacuum? The correct answer is that our atmosphere extends well beyond the Karman line at 100 km, but the real world answer is that beyond the Karman line, the atmosphere is so thin that it has no real effect in any way.

Since we know that NOAA-19 is at an altitude of 870 km, and we know the slant range is 985.192 km we can use this as a ratio to determine the amount that the slant range is below 100 km:

$$985.192/870 * 100$$

$$113.24$$

113.24 kilometers of atmosphere is in the signal path. Multiplied by our atmospheric attenuation from the chart of 0.005dB/km we get:

$$113.24 * 0.005$$

$$0.566$$

We lose another 0.566dB of signal to atmospheric loss.

The Big Finale

Bringing it all together, the signal level at the ground station antenna is:

$$+ 12.45 - 135.06 - 0.566$$

$$- 123.176$$

Our signal strength is predicted to be -123.176dBW at the ground station antenna. We have a fair bit of signal to make up, but fortunately, we should have the equipment to pull it off.

Conclusion

That's it for the transmit section. Next week we will go through the receiver segment for NOAA-19. The equipment we hope to use is the inexpensive RTL-2832u software defined radio receiver. These radio receivers can be had for around $10 USD from a number of online vendors and connect to any modern computer via the USB port.

If you want to get a jump on things, go ahead and order one online. The software to run this device is generally free and easy to get online for any operating system, and it will become a core component of the ground station receiver we will build. If you do pick one up, make sure it has the R820T tuner, as this combination yields great results. There are also models with a R820T2 tuner which is superior in every way for the same price. Given the opportunity, get the R820T2 model which usually comes in a blue case.

Let's go!