EA467 Antenna and Link Equation Lab (rev b) Fall 2008

This antenna lab is combined with the EZNEC lab and will take three periods to give practical comparisons of the EZNEC antenna models to real antenna measurements. In the 2nd class year EA-204 Labs, students were previously exposed to:

Antenna types, frequency, and wavelength. ½ wave dipole and ¼ wave monopole
Fleetsat measurement of Signal-to- Noise and simple link budget
Manpack satellite Antenna and simple link budget
C-band Parabolic Dish Beamwidth
Signals Bandwidth (TV, radio, cell phones, data)
GPS familiarization

Introduction: Antennas are the first topic in a sequence of labs focusing on three main communications areas: antennas, receivers and digital communications (telemetry). This antenna laboratory will provide hands-on experience with antenna performance and patterns and how antennas affect the link budget equation. Space loss due to the distance between transmitter and receiver is the largest signal loss in spacecraft communications. The main trade-off in system design is where to add the power and gain required for successful communications (ground or satellite), while allowing some margin for variations in the terrestrial and space environment and equipment.

The LINK Equation (in dB) PR = PT + GT + GR – LI – LS

<u>Spacecraft</u>: A powerful satellite transmitter can be used with a low gain antenna, but this will add weight and expense to the spacecraft. Or a higher gain antenna can be used with a lower power transmitter, but this will decrease the antenna beamwidth and require greater pointing accuracy as well as increased spacecraft volume and a complex deployment strategy that may fail on orbit.

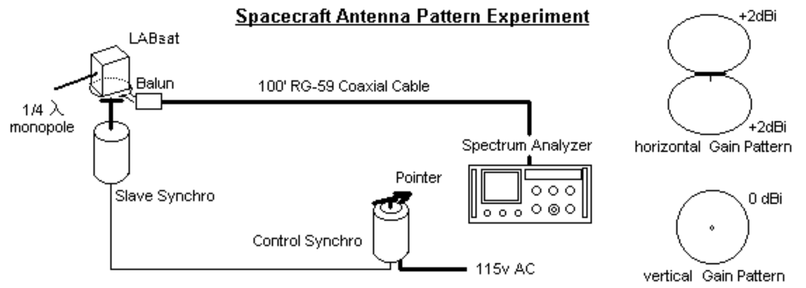
<u>Ground Stations</u>: Ground Stations contend with similar issues. Smaller antennas require higher power transmitters and produce weaker received signals. Each receiver has performance limits. Mobile platforms have antenna size and transmitter power limits. Reducing electromagnetic interference with more highly directional antennas also plays a part in ground station design.

<u>Communications Subsystem</u>: The communications subsystem consists of both the spacecraft and ground system design which must meet end-user requirements while conforming with all the other spacecraft subsystem constraints as well frequency management concerns. The overall design is dependent on the link budget of both the up and down link.

Laboratory Procedure: The antenna experiments are in R122 and in the lobby or plaza. Form new teams of 2 and move to an unused station to perform the required steps. Sketch a diagram of the lab setup, record observations and data as required. You will make qualitative and quantitative observations concerning:

- Antenna gain patterns of a dipole and a LABsat model at 520 MHz
- Link calculations for SPYsats at .17 and .88 miles and extrapolate to LEO orbit.
- Beam pattern and relative performance of parabolic dish antennas.
- Received power from a spacecraft and antenna Standing Wave Ratio (SWR).
- Antenna matching and minimizing SWR on the ANDE spacecraft
- Antenna summing (Phasing) for increased gain.

Part A. Spacecraft Antenna Pattern: This experiment uses a simple monopole antenna mounted on a LABsat to observe basic antenna gain patterns. It uses the MD Public TV station west of Annapolis on UHF at 520 MHz as the signal source. The LABsat is mounted on a horizontal platform so it can be rrotated horizontally. Although the monopole antenna on one face of the satellite would appear to give an unbalanced radiation pattern when rotated horizontally, in fact, the pattern will not be that much different from the ½ wave dipole pattern observed in the EA-204 lab. This is because the ground plane of the spacecraft is small relative to wavelength and simply acts as a counterpoise to reflect the missing half of the dipole.

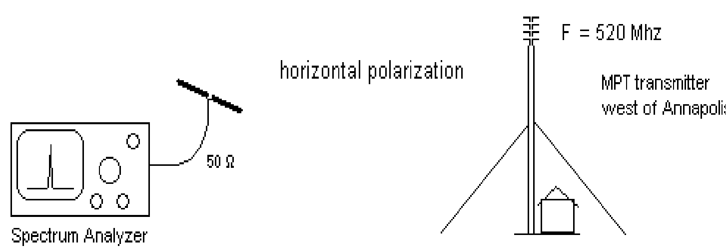


1. Tune the spectrum analyzer to 520 MHz with a bandwidth of 100 kHz and scan-width of 0.5 MHz per division. Set the Log Ref Level to –50 dBm and Linear Sensitivity to 0 dBm. Tune the analyzer to center the Video carrier signal (the stronger one on the left. The right one is the audio carrier). Observe the signal power of the video carrier.

2. Slowly rotate the LABsat dipole using the linked synchro motor dial. Notice there is almost 20 dB or more of signal variation as the antenna is rotated. Rotate until you find the maximum and this is your 0 dB reference. Adjust the Log Ref Level and *linear sensitivity,* to bring this signal to the top reference line for easier reference as 0 dB. Rotate the compass rose on the syncro to make this azimuth be 0 also. Record the signal strength below that as the dipole antenna is rotated through 360^o in 20^o increments. Smaller increments *are necessary* in the vicinity of the narrow nulls. Sketch the your data on a polar plot to make sure your data is meaningful before you leave the station.

Post-Lab: Your plot will show the antenna gain pattern in azimuth of this monopole antenna mounted on the top of a LABsat (set horizontally). How does this antenna pattern compare with the EZNEC model from the last Lab?).

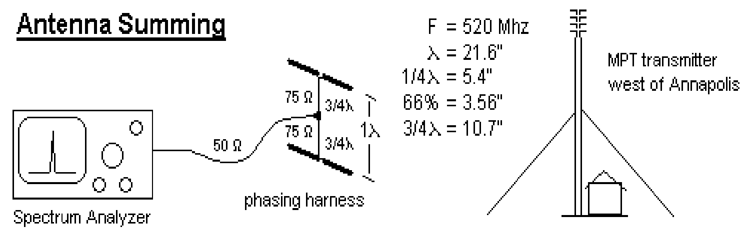
Part B. Antenna Combining for Gain: This experiment will verify the gain pattern of a dipole and the 3 dB gain of two dipoles combined in phase by the ¼ wave transmission line transformer technique you demonstrated in the Transmission-Lines-Lab. You will also observe that this gain is only in the favored directions where they add in phase, with commensurate reductions in gain in other directions. That is, you can sum antenna elements to achieve gain in one direction, but this is always at the expense of gain in other directions and more nulls.



1. Connect the single dipole antenna to the spectrum analyzer tuned to MPTV west of Annapolis at 520 MHz. Hold it horizontally to match the horizontal polarity of the TV station. Move it around several feet to get a feel for the variability in its performance due to polarization, directivity and multipath. Find the optimum location for this measurement and record the best signal strength.

2. Now change to the two dipoles with the phasing harness as shown below. This is the same ¼ wave harness, as you learned in the earlier lab, but uses two ¾ wave lengths of 75 ohm coax to reach the antenna spacing we need. Being an odd number of ¼ waves will transfer the 50 ohm antenna

impedance to 100 ohms so that they can be paralleled with a “T” connector to give a matched 50 ohm impedance to the 50 ohm line.

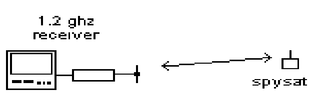


3. Place the stacked dipoles where the best signal was found in step 1 and again move it to find the best signal. These dipoles are spaced vertically about 1 wavelength for optimum gain. In the absence of any degrading reflections, the gain from this two-antenna system should be about 3 dB compared to the single dipole. Multipath nulls from the ground should also be reduced. Record your results and observations.

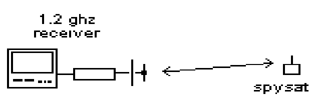
4. Now lean the stack backward so that the top antenna is about ½ wavelength farther from the TV station than the bottom one (10 inches). Look for a minimum signal. Notice that just as the second antenna can add signal (+3dB by doubling the signal available), it can also subtract and significantly cancel out the original signal. This shows how simply changing phase of antenna elements can re-direct the main lobe of an antenna (as in Phased arrays) Record the depth of the best null and any other observations. Hold the big aluminum about ¼ wave behind the dipoles (dipoles facing west). How much more gain should be obtained with this reflector?

Part C. 1.2 GHz Parabolic Antenna Gain and Link Margin:

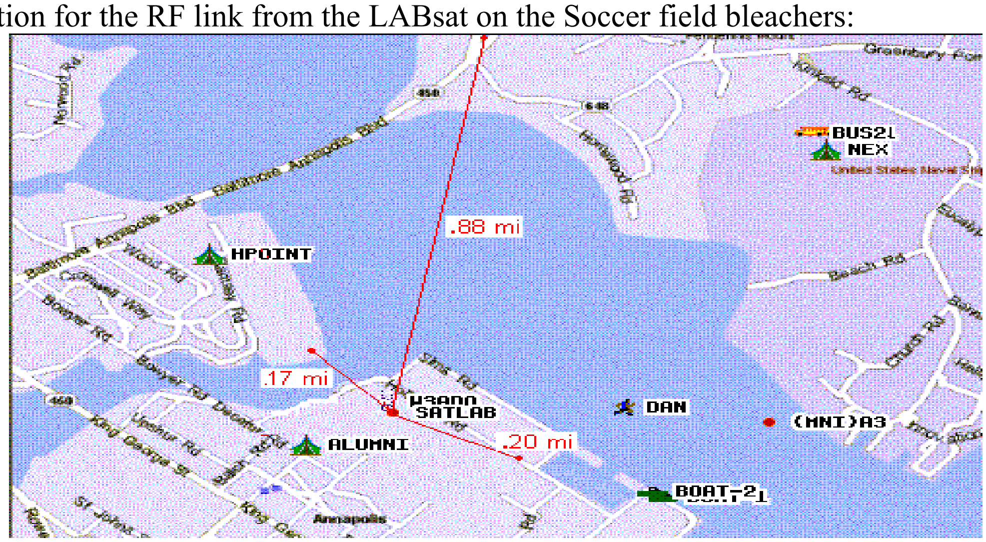
The figure below shows how we have placed three LABsat’s configured with image sensors and microwave transmitters at several points within line-of-sight of the Rickover Plaza. Out the door to the left is the receiving work station for the RF link from the LABsat on the Soccer field bleachers:



Basic link with fundamental dipole antenna but very susceptible to multipath fades and cancellations.



Adding a reflector off the back of the dipole gives 3 dB gain and possibly better viewing by eliminating half of the multi-path reflections.



1. Connect the simple dipole to the receiver. Move it around the worktable area to find the best signal from the LABsat on the Soccer field bleachers. Notice how the pattern is very broad at any given location /orientation. To measure the link margin, see how much attenuation you can add and still see a useable signal. This attenuation equals the link margin available for this link.

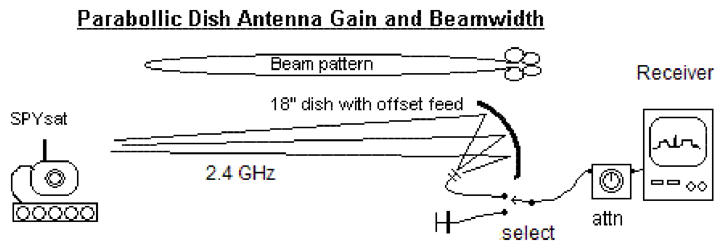
2. Next connect the dipole with the reflector at the same location and repeat the procedures of step 1. More attenuation should be required for the same useable signal, with the difference being the relative gain of this configuration. Also, by eliminating waves from the back of the dipole, you should see some directivity and less cancelling effects of multi-path from surrounding buildings.

Post-Lab: Calculate the power received for the .20 mile link to the Soccer field bleachers on 1.2 GHz using the link equation:

PR = PT + GT + GR –Li – LS (in dB) (assume incidental losses (Li) total to 3 dB)

Where Transmit power, PT is 5 milliwatts, gain, Gt, of the omni transmit antenna is 0 dB, and gain of the receiver antenna, Gr is a simple dipole (2.1 dBi). Then re-compute the link received power using the gain of the dipole with rear reflector as indicated in the steps listed in the figure.

Part D. 2.4 GHz Parabolic Antenna Gain and Link Budget: This exercise uses a small 18" dish with a 2.4 GHz "S" band offset feed to explore the antenna pattern and gain of a parabolic dish antenna. With a simple dipole at the focal point of a dish, the aperture of the dipole is drastically increased to the full size of the parabolic reflector. The increase in aperture area yields a corresponding antenna "gain". As discussed in class, placing a small reflector behind the dipole at the focal point doubles the energy into the dish and minimizes sidelobes, thus adding to the overall gain by about 3 dB.



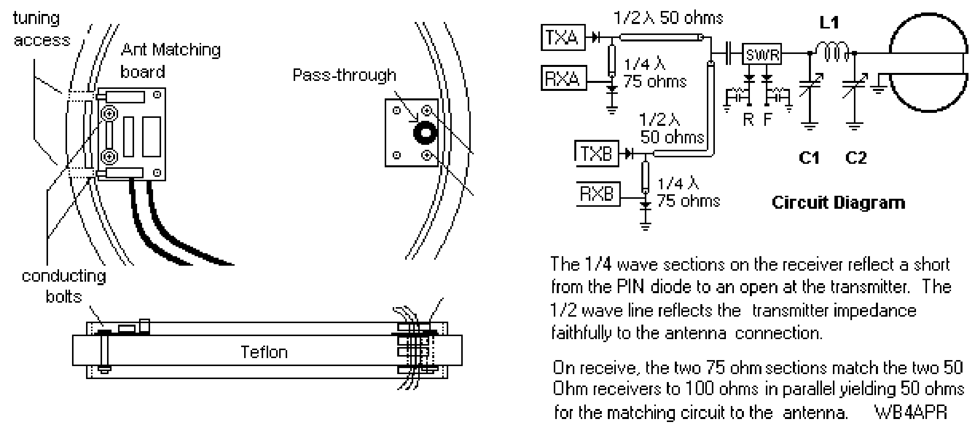
1. **Dipole Baseline:** Connect the 2.4 GHz receiver and attenuator to the dipole/ reflector feed and hold it generally facing the small SPYsat that is operating on the corner of Hospital point field. Set to channel 4 and orient it to get the best signal at your location. Also see if you can see the SPYsat across the Severn (near the War memorial) on channel 2 (you probably can't). Now pointing back to the Hospital point SPYsat, increase the attenuation to find out how much link margin you have before the signal becomes un-useable. This attenuation establishes your baseline for this path.
2. **Dish Gain:** Now move the dipole feed to the focal point of the dish and point it at the Hospital Point SPYsat to maximize the signal. Next add more attenuation until just before the signal becomes un-useable again, making sure to optimize the dish pointing as the signal gets weaker. This additional attenuation is the measure of the added gain of the parabolic dish compared to the dipole.
3. **Path Loss:** Set the variable attenuator back to 0 and point the dish across the river to the War Memorial and see if you can now see the channel-2 SPYsat. It is at the top of the hill facing this way with a similar omni antenna as the one on Hospital point. See how much attenuation you can add and still keep a minimum signal. This difference in attenuation from the Hospital Point measurement is now the added path-loss due to the increased distance (.17 to .88 mi).
4. **Antenna Beamwidth:** Now peak the antenna on the signal and then adjust the attenuator to minimum useable signal. From that value, reduce the attenuation (improve the signal) by 3 dB. Now carefully swing the dish left and right to where the signal is again minimum. This is the angle where the signal drops by 3 dB. The angle difference between these two – 3dB points is called the 3 dB beamwidth of the antenna.

Post Lab: Calculate the gain of this dish from its dimensions using the equation in SMAD. How does the gain compare to the gain you measured as link margin (attenuation) in step 2? Use the link equation to compute the minimum receive power for this 2.4 GHz receiver to give a decent image, assuming a TX power of 5 milliwatts. How does the link margin (attenuation) of the two links of .17 and .88 miles compare in dB to the difference in distance?

As an exercise, now calculate how much power would it take on a satellite to make this image sensor system work from LEO (say 1000 km) to a 10' dish on receive to give you the same minimum useable signal received as you calculated in this lab? Hint: Keep the Pr the same, but increase the Gr of the dish to 10 feet, keeping Gt the same and then solve the link equation for Pt.

Part E. ANDE Antenna Matching:

Although antennas are simple to design and construct just like assembling a guitar out of wood, wire and glue, they do not perform until tuned to resonance or to the frequency of use. Tuning is the process of adjusting the complex (real & reactive) impedance of the antenna to get the best impedance match (lowest SWR) to the 50 ohm transmission line and transmitter. For ANDE, which actually uses both halves of the satellite as the dipole antenna, we used a network consisting of two variable capacitors and one inductor (called a PI network) C1, C2, and L1 in the diagram below which can usually match a wide range of impedances.



LAB Procedure: ***WARNING: BE CAREFUL NOT TO BREAK THE TUNING CAPS & TOOL***

1) Turn on the SWR analyzer and tune it to the ANDE operating frequency of 145.8 MHz. Notice the SWR. Tune up and down by +/- 30 MHz and note if the SWR changes significantly.
2) Now go back to 145.8 and use the tuning tool to *CAREFULLY* adjust the multi-turn C1 and C2 capacitors to improve the SWR. These adjustments are interactive and need to go back and forth to find the best match. These caps are at least 10-turn devices so it takes many turns to find the optimum setting. You are lucky that the size of the inductor has already been determined, or you would then have three variables to balance.
3) Record your best SWR at 145.8 MHz and R + jX impedance.
4) Now tune the SWR analyzer up and down in frequency in 1 MHz increments recording the SWR values between the frequencies showing less than 3.0 values. You will use this to make an SWR plot to show the *bandwidth* of this antenna system
5) When finished, turn both capacitors *GENTLY* back to fully CCW so that the next team does not benefit from your hard work.

Post Lab: Plot the SWR from your data and mark the useable bandwidth between the 2.0 SWR points. Report your best SWR and impedance at 145.825 MHz for comparison to other teams.

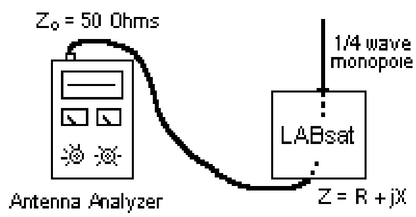
Part F. L-Band Quadrafiller GPS Antenna: The GPS constellation of 24 satellites gives us excellent signals for experiments from the satellites that are always in view. Since the GPS unit must receive these multiple simultaneous signals, omni-directional antennas are always used. Typical omnidirectional GPS antennas are either a patch antenna or a short quadrifilar helix. In this experiment, we will plot the antenna pattern for the GARMIN GPS-III unit that uses a quadrafiller helix antenna.

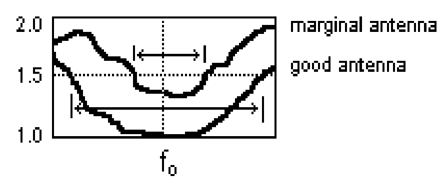
1. Select the Horizon Plot page on the GPS unit which shows graphically the approximate azimuth and elevation of each satellite. Point the antenna straight up and record the Az/El and signal strength of the GPS satellites in view as shown.
2. Choose the satellite that is closest to directly overhead. Tilt the antenna (and rotate the stand) as needed to point directly to that satellite. Hold the antenna still and align the dial to (0/360). Now record signal strength for that satellite as you rotate the antenna +/- 180 degrees in 30-degree steps away from that satellite. Assume each line on the GPS signal strength bar graph represents 5dB. At each angle, pause 15 seconds or more for the GPS to re-measure the signal strength before taking your readings. You will use these readings to make a polar plot of the antenna pattern.

Post-Lab: Discuss the reason for the differences in signal strength among all the satellites in view. (Hint: estimate their elevations based on the GPS' display). Plot the vertical antenna pattern on a polar plot based on your recorded values. Comment on the antenna gain pattern.

Part G. LABsat Antennas Matching and Tuning: As in part E, every antenna must be precisely tuned to resonance for the frequency of operation and to match the output impedance of the transmitter. Any mismatch will result in power being reflected back from the antenna and not radiated. The SWR gives us a good measure of the quality of this match. Numerically, SWR represents the ratio between the forward wave voltage and the reflected wave voltage or the ratio between the impedance of the antenna to the impedance of the line. When measured as forward and reflected power, SWR is given by:

$$SWR = \frac{1+\left(P_{ref}/P_{fwd}\right)^{1/2}}{1-\left(P_{ref}/P_{fwd}\right)^{1/2}}$$





The complex impedance (R+jX) of an antenna is a function of its length, its breadth, its frequency, and all conducting materials within its near field (maybe including you). Thus, antennas have to have their final tuning completed in–place on the actual spacecraft. You will use an antenna analyzer to measure the SWR of a VHF and UHF antenna for your LABsat. An SWR of 1.0 is perfect, an SWR of 1.5 delivers 96% power, 2.0 delivers 89% and 3.0 delivers only 75% of power. Most designs strive for 1.5 or better.

1. Calculate the length of a ¼ wave resonant monopole at 145.8 MHz. At resonance, the reactance component (jX) goes to zero so that maximum power can be delivered to the real resistive component (R), (usually designed to be 50 ohms). The exact resonance length will be affected by the specific geometry of all metal in the vicinity. Perfect resonance is often not achievable, but the minimum SWR is desired.

2. Place the longer antenna onto your LABsat model, extend it to your calculated length. Tune the analyzer to 145.8MHz and notice the SWR. Tune the meter to find the minimum SWR. The best SWR frequency will tell you if your antenna is too short or long (c=f*λ). Carefully extend or contract the

antenna to minimize the SWR at 145.8 MHz. You can add clips to the antenna to simulate a fatter element if needed. Remove your hands after each adjustment, and record the lowest SWR antenna length.

3. Next, tune the analyzer up and down in frequency and record values (at least 8 points) so that you can make an SWR bandwidth plot between the two frequencies that exhibit 3.0 SWR. Move in the vicinity of the antenna. Notice the effect on the impedance and SWR (you will comment on this in the lab report).

4. Since this LABsat is on-the-order of the dimensions of the resonant monopole, you may find another resonant frequency where the spaceframe itself may combine with the whip to also form a resonance. What other resonant frequencies do you find (if any)?

5. Insert the shorter antenna into the test fixture. Repeat steps 2 and 3 for UHF (436 MHz). Press the UHF button on the Antenna Analyzer to read UHF. Again use clips to help find a good match. Un-push this button when you finish.

<u>Post-Lab</u>: Use the data from lab to plot the SWR for the two antennas over the frequency range between the 3.0 SWR points. How good was your SWR? How does it compare to your EZNEC model? Comment on the main learning points of this experiment.

Antenna Laboratory Report: Each group of 2 must produce a formal laboratory report in accordance with the report-writing guide.

- ✓ Describe the purpose of this lab and discuss wavelength, the link equation, antenna gain, antenna beamwidth and SWR in your introduction. Briefly describe the elements in each laboratory experiment using text and diagrams.

- ✓ Answer all questions in your results section. Also address any comments and do not overlook some of the rhetorical questions sometimes asked within the lab descriptions.

- ✓ Compare the measurements, EZnec plots and theory (use a summary table of the gains, beamwidths and directivity of each of the antenna systems covered). You should find a way to determine a theoretical gain and beamwidth for each antenna system using SMAD, EA465 notes and/or EZNEC.

- ✓ Summarize your conclusions regarding the different antennas and discuss how well the theory supports your observations?

    - ➢ What are the implications of antenna gain to the link equation for spacecraft, a ground terminal/station?

    - ➢ What are the differences in the various antenna types? What drives the designer to choose one over another?

    - ➢ Did EZNEC model these antennas adequately? How would you use EZNEC in a design environment? Would you still need to test the antenna if you have a tool like EZNEC?