EA467 Communications Laboratory: Antennas (rev 0) Fall 2006

This is a new lab for Fall 2006 to integrate the LABsats and to further separate the material from the plaza antenna labs we do in EA204. In that sophomore lab, students were exposed to:

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

This lab and your lab report will cover three Lab sessions:
First session will be lecture and demo, including showing EZNEC.
Second session will be in the lobby and on the plaza with antennas (this write-up)
Third session will be in R122 with workstations and EZNEC (another handout)

Introduction: This is the first in a sequence of labs focusing on three main communications areas: antennas, receivers and digital communications (telemetry). This first 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.

Spacecraft: 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.

Ground Stations: 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.

Communications Subsystem: The comm 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.

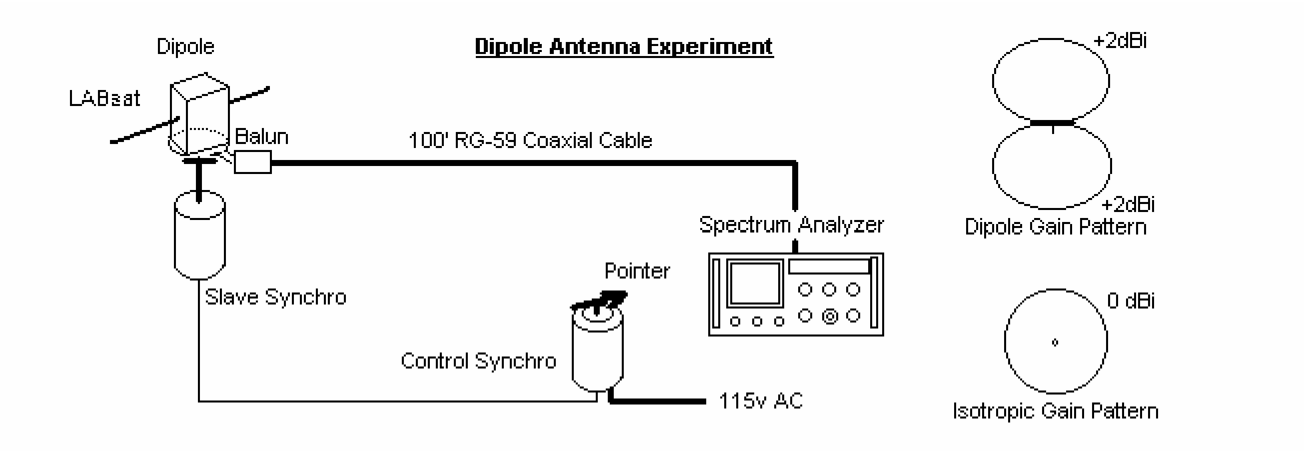
Laboratory Procedure:

There are numerous experiments in Rickover 122 and in the lobby or plaza. Form 6 or 7 teams and move to an unused station to perform the steps in each Lab Part. Each group should sketch a diagram of the lab setup, record observations and data as required. This lab will examine the practical aspects of different antenna systems and their effect on the link budget. You will make qualitative and quantitative observations concerning:

- Receive gain pattern of the fundamental antenna, a dipole.
- Gain and beam pattern of helix antennas and dipole with reflector.
- 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

Part A. UHF Dipole Antenna Pattern: This experiment uses a fundamental dipole antenna mounted on a LABsat to observe basic antenna gain patterns. It uses the MD Public TV stations on 530 MHz as the signal source and a dipole mounted on a LABsat model as the receiving antenna.



Lab Period:

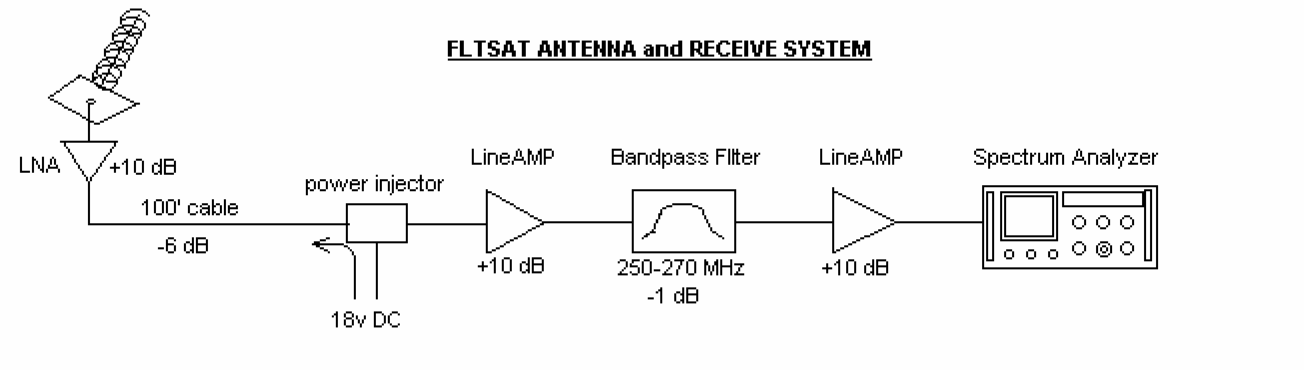
1. Tune the spectrum analyzer to 530 MHz with a bandwidth of 100 kHz and scan-width of 5 MHz per division. Set the Log Reference Level to –50 dBm and Linear Sensitivity to 0 dBm. Tune the spectrum analyzer to center the left hand signal (the Video carrier, the other is the audio carrier). Observe the signal power of the video carrier.
2. Slowly rotating the LABsat dipole using the linked synchro motor dial. Notice there is almost 20 dB of signal variation as the antenna is rotated. Rotate until you find the maximum and this is your 0 dB reference. Adjust the *linear sensitivity* if you like to bring this signal to one of the 10 dB graticule lines. Record the signal strength 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 signal strength versus azimuth on a piece of polar graph paper to make sure your data is meaningful before you leave the station.

Post-Lab: Your plot, which used only one signal as its reference, will show the antenna gain pattern of the dipole antenna mounted on the LABsat. Discuss the location and orientation of the antenna relative to the locations of this PBS station (about due west of Annapolis). How does this antenna pattern compare with the ideal dipole antenna pattern? (You will display this in EZNEC next week).

Part B. HELIX Antennas: You will repeat this experiment from EA204 to confirm you remember how to do a link calculation, but then you will take additional pointing data so you can make an antenna plot of the helix antenna pattern. This experiment uses live signals from the Navy's communications satellites as a signal source to observe the performance and antenna pattern of our helix receiving antenna.

Note: There are both an old FLEETSAT and new UFO in view of our antenna at the same time. Your display will show pairs of channels but offset slightly so that they operate independently without interference. Choose either the right or the left channel of each channel pair for your observations. Also *be sure the antenna is close to the Rickover building so that it cannot also see the Atlantic UFO when you swing the antenna.*

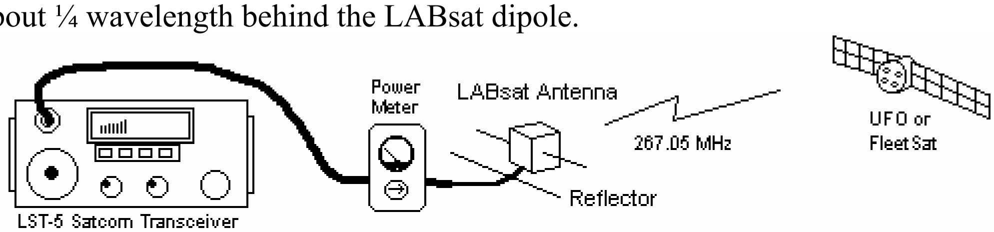
Lab Period:



1. Tune the spectrum analyzer to 260 MHz with a bandwidth of 100 kHz and scanwidth of 5 MHz per division to find the FLTSAT spectrum. Set the Log Reference Level to –50 dBm and Linear Sensitivity to 0 dBm. Notice that there are about 3 different "types" of signals representing the three types of transponders on these satellites.
2. Point the helix southwest and adjust Az/El for peak signals. Zoom in with a bandwidth of 30 KHz and scanwidth of 0.5 MHz and select the strongest, narrow signal for your measurements. Take this "peaking and tweaking" seriously or your data will be skewed. Record the azimuth, and elevation and signal strength of the peak signal.
3. Swing the antenna to the left 180 degrees in 15 degree increments while recording the signal strength on your selected signal. You will use this data to make a polar plot of the antenna pattern.
4. Using a ruler or tape measure, measure the approximate diameter, pitch and length of the Helix.

Post-Lab: Using the link equation and data from the Fleetsat handout that shows the EIRP of the strongest two channels as 26 dBW, calculate the received signal strength available from the satellite. Add to this, the gain of the antenna, the cable loss and the amplifier gains to see how close the observed signal strength compares to your calculations. Also calculate the gain of the helix from the dimensions you measured using the equation from Table 13-14 in *Space Mission Analysis and Design* and compare this value with the calculation above. Discuss possible reasons for the differences if any. Plot the helix antenna pattern on a polar plot (use the mirror image for the other 180 degree side).

Part C. UHF FLTSAT Reception: This experiment compares the gain of a LABsat antenna tuned to 250 MHz to the helix antenna used in part B. See if you can improve the gain by holding a reflector about ¼ wavelength behind the LABsat dipole.



Note 1: The bars on the signal strength LCD Display have been calibrated in dB using the spectrum analyzer. The resulting paper scale is attached to the radio for reference.

Note 2: You can often estimate the gain of simple antennas. In this case, a dipole is 2 dB gain relative to an isotropic antenna but adding the reflector should pick up another 3 dB; thus, about a 5 dBi gain antenna.

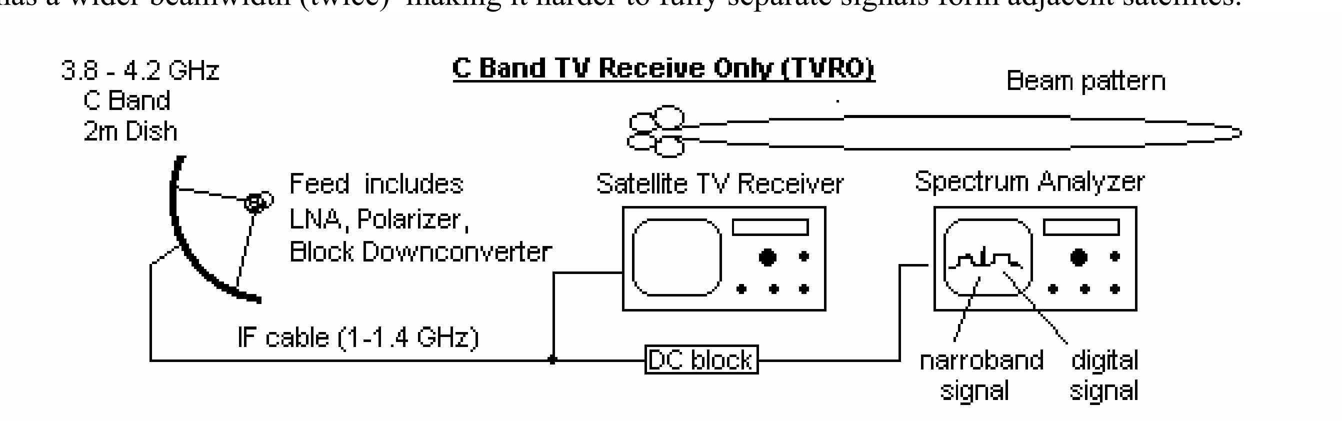
Lab Period:

1. Align the LABsat antenna with FLTSAT to maximize the received signal power on the LCD Display.
2. Next Measure the SWR of the antenna by comparing the forward and reflected power by briefly keying the Transmitter and record power on the watt-meter with the slug arrow pointed toward and then away from the antenna.

Post-Lab: Determine the Manpack antenna gain as the difference between your calculated signal power from FLTSAT (Part B) and the measured signal level. Compare this to the assumed 5 dB gain Discuss the directivity of this antenna compared to helix and dish antennas and its usefulness in satellite-to-satellite or satellite to ground communications. Compute the SWR values you measured using the equation:

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

Part D. Parabolic Antenna Gain: "C" band refers to the 3.8 to 4.2 GHz satellite band which became viable in the 80's but signal strengths required 3m (10') dishes to get high gain. But high gain also results in very narrow beamwidths to access the fixed satellites on the GEO arc. For this lab, to make it easier to handle, we will use a 5 foot dish which results in somewhat weaker signals (-6dB) but more significantly has a wider beamwidth (twice) making it harder to fully separate signals form adjacent satellites.



Lab Period:

Note: You will manually point the TVRO dish. It is heavy! Be careful and do not let it drop uncontrolled. There is an elevation nut that hopefully limits the elevation angle between about 15 and 25 degrees for this lab because we want everyone to use the same satellite.

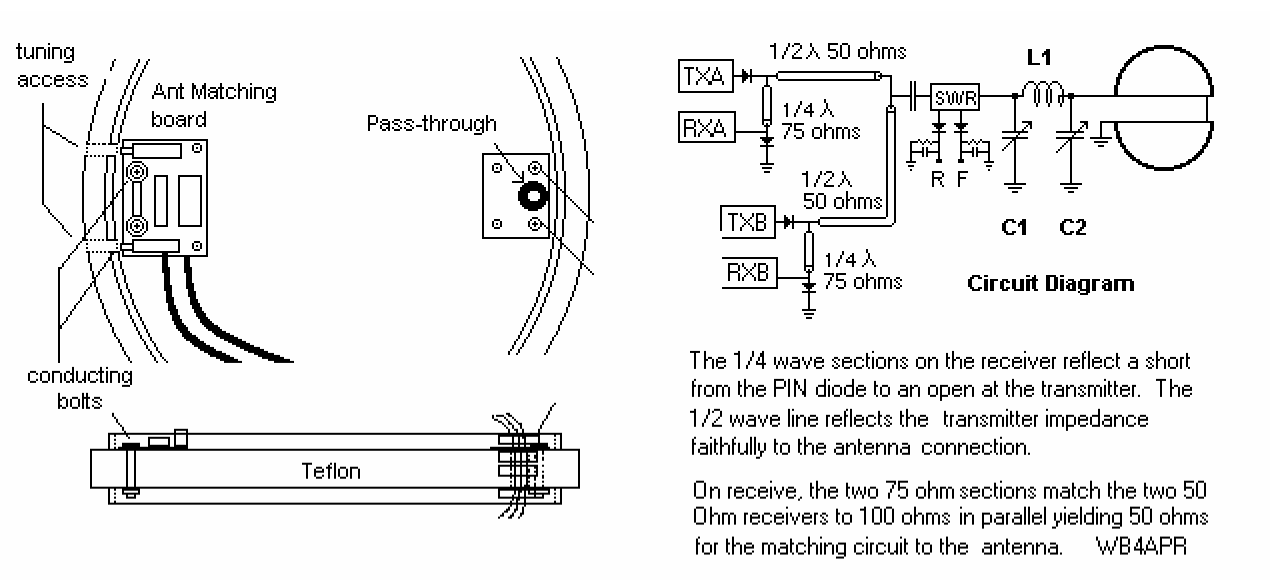
In Lab:

1. Observe the equipment block diagram and locate and verify all components.
2. Find a good strong satellite signal on the receiver and peak for maximum narrowband signal strength reading around 240 deg azimuth and 22 deg elevation. Tune both receiver and analyzer to 1130 MHz. (note, this is the IF frequency for the actual carrier which is at about 4 GHz.)
3. Swing the dish in 1 degree increments left and right 15 degrees or so, while taking signal strength measurements using the calibrated 10 dB/div spectrum analyzer. The friction in this mount will make this hard to do, but do the best you can to get good data. Also remember that adjacent to this satellite are other satellites with different signals, so do not get confused as your signal begins to disappear.

Post-Lab: Reference your signal strength measurements to 0 dB as the strongest signal and make a polar plot of the antenna pattern for this dish. Use the equation in SMAD to estimate the beamwidth of this antenna.

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 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) 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. 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 for comparison to other teams.

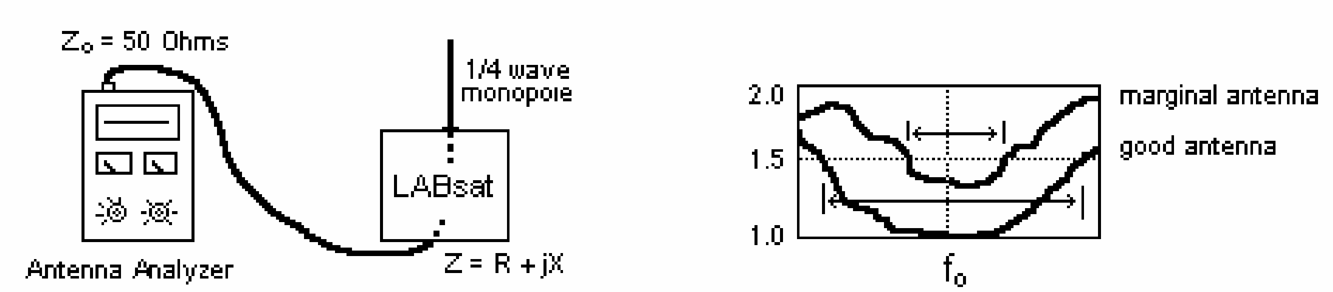
Part F. L-Band Quadrafiller GPS Antenna: The GPS constellation of 24 satellites gives us excellent signals for experiments since several satellites are always in view. Since the GPS unit must receive these multiple simultaneous signals, omnidirectional antennas are always used. Typical omnidirectional 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.

<u>Lab Period</u>:

1. Select the Horizon Plot page on the GPS unit, point the antenna straight up, and record the Az/El and signal strength of GPS satellites in view as calculated by the GPS based on the current almanac.
2. Choose the satellite that is the most directly overhead. Record signal strength as you rotate the antenna +/- 180 degrees in 30-degree steps. Assume each line on the GPS signal strength bar graph represents 5dB. At each angle, pause 5 seconds or more for the GPS to re-measure the signal strength before taking your readings.

<u>Post-Lab</u>: Discuss the reason for the differences in signal strength among all the satellites in view. (Hint: estimate their elevations based on the GPS' display). Here you might want to model the GPS constellation in STK for Annapolis at the same UTC time you conduct this part of the lab and look at the AER report/plot for some "in view" GPS. Plot the vertical antenna pattern on polar graph paper 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 to the transmitter and not radiated. The measure of the quality of this match is called the Standing Wave Ratio or SWR. 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 or transmitter driving it as shown in the equation in part E.



The complex impedance (R+jX) of an antenna is a function of its length, its breadth, its frequency, and all conducting and insulating materials within its near field (maybe including you). Thus, antennas have to have their final tuning completed in–place on the actual spacecraft. We will use an antenna analyzer to measure the SWR of two sample antennas. 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.

Lab Period:

1. Calculate the length of a ¼ wave resonant monopole for operation at 146.0 MHz. At resonance, the complex (reactive) component of the impedance goes to zero so that maximum power can be delivered to the remaining real resistive component, (usually designed to be 50 ohms). The exact length for resonance will be affected by the specific geometry of all the elements noted above. Perfect resonance may not be achievable.

2. Insert the thin antenna into the test fixture, extend it to your calculated length. Tune the analyzer to 146.0 MHz and notice the SWR. Tune for minimum SWR. This will tell you if your antenna is too short or long. Carefully extend or contract the antenna to minimize the SWR at 146.0 MHz. Remove your hands after each adjustment, and record the resonant antenna length.

3. Next, tune the analyzer up and down in frequency and record values so that you can make a reasonable SWR plot between the two frequencies that exhibit 2.0 SWR (at least 8 points).

3. 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 spaceframe is similar to the dimensions of a 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 thicker antenna into the test fixture. Repeat steps 2 and 3.

Post-Lab: Use the data from lab to plot the SWR for the two antennas on the same plot and you will notice that the usable bandwidth (frequencies between 1.5 SWR points) for the fatter antenna is broader than the thin one. This is an important consideration that can be used to broaden or narrow the response of an antenna design. Comment on the main learning points of this experiment.

Antenna Laboratory Report: Each group of 2-3 must produce a formal laboratory report in accordance with the report-writing guide. You should make sure to include the following in the body of the report as appropriate:

- ✓ Describe the purpose of this lab and provide a theoretical discussion of the link equation, antenna gain and beamwidth.

- ✓ Briefly describe the elements in each laboratory apparatus for every part of the lab using text and diagrams.

- ✓ Answer all "Post-Lab" questions. To get full credit you must answer the questions asked at the end of each lab section.

- ✓ Compare the measurements and theory (use a table of all the antenna systems as support). You should find a way to determine a theoretical gain and beamwidth for every combination of antenna used in the laboratory. Complete these calculations using SMAD, EA465 notes and 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 is the significance of other losses in the radiofrequency transmission such as atmospheric losses for the frequencies examined? How do these losses and line losses compare to free space loss?

  - ➢ 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?