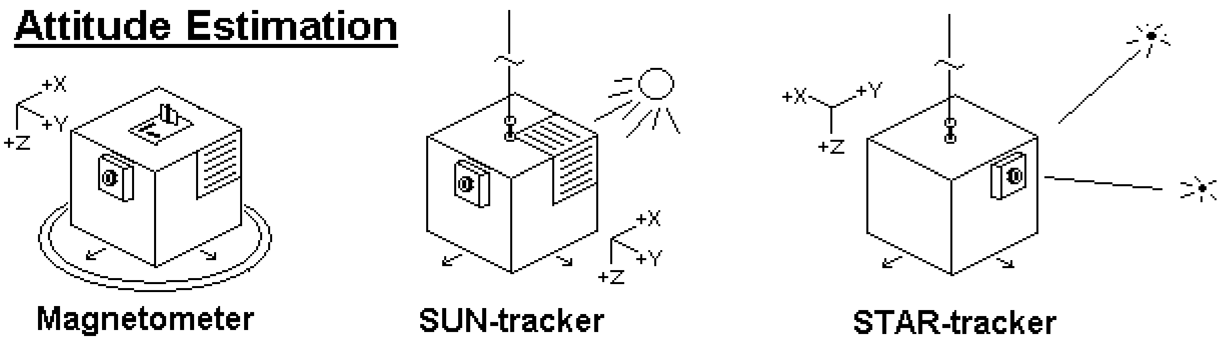
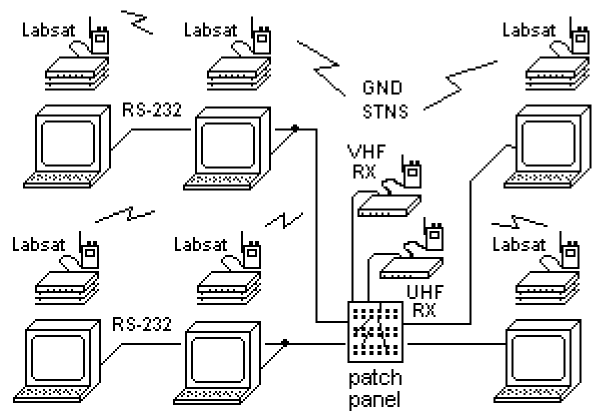
EA-467 ATTITUDE ESTIMATION LAB (rev e) Fall 2008

Introduction: To change the attitude of your spacecraft, first you need to know what it is. Several sensors are used for determining the attitude of a spacecraft. These include Earth and Sun sensors, magnetometers, star sensors and gyroscopes. In this lab you will explore three methods for attitude determination as shown below. First you will measure attitude by referencing the sun angles. Next you will measure angles relative to the Earth's magnetic field using a 3 axis magnetometer. And third, you will demonstrate a simple attitude estimation technique known as TRIAD using the SpySat cameras.



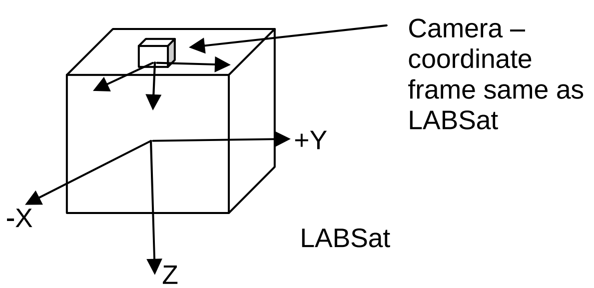
Laboratory Configuration:

As in other labs, the LABsat's transmit their telemetry and receive commands via the central VHF and UHF Ground Stations. To capture your LABsat's data, use Hyperterm on the PC and start a CAPTURE file with an appropriate file name. You can either cut-n-past your satellite data from the screen, or save the whole file and enter it into Excel for plotting.



Lab Coordinate Frame:

The LABSat coordinate frame is shown in Figure 1. For the purposes of this lab, we will use a coordinate frame designated as North-East-Down, and is shown in the Figure 2 below.



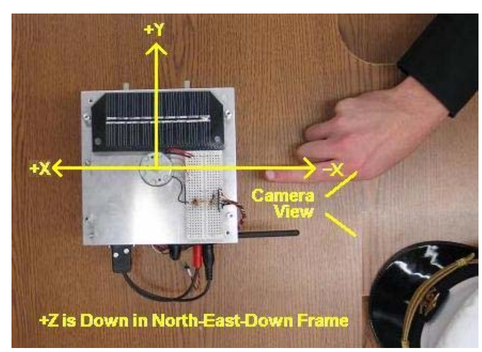


Figure 1. LABsat coordinate frame

The coordinates of the lab are 38 deg, 59.11 min North Latitude, 76 deg 29.11min West Longitude, and 30 feet above sea level. ***Check the Nautical Chart at the front of the class to determine the azimuth of the front of the room using the parallel ruler to the building/seawall.*** Is the NED coordinate frame inertial? If not, how can you find the transformation from the NED frame to the inertial frame? (Hint, we discussed this in EA364 and similar transformations in EA362.)

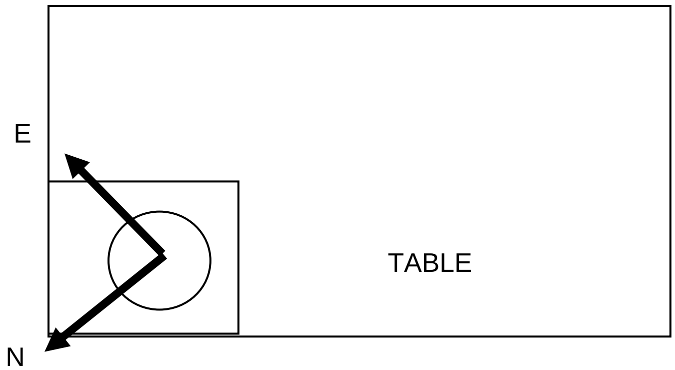
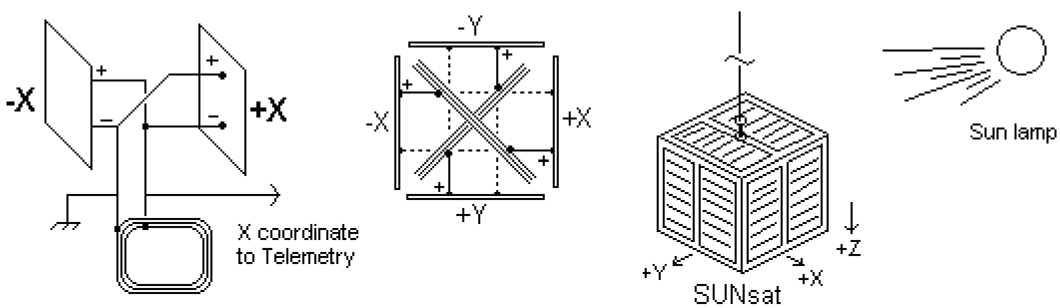


Figure 2. NED Coordinates (Down is into the paper). Example for a desk on the right side of the room. On the left side of the room the LABsat is aligned with the desk's right edge.

Part A. ADCS Sun Sensing and Attitude Control Demonstration:

One hanging LABsat has been configured with a combination of Solar panels for Sun sensing and magnetorquing coils for attitude control. To kick off this lab, the satellite has been configured to use the solar panels as Sun sensors and then to energize the magnetic coil that is orthogonal to the Earth's magnetic field based on the attitude estimation from the spotlight "Sun". As a result, the spacecraft should begin to turn when it is illuminated. . As each new panel is exposed to the sun, then the next coil is also energized in turn, and so on giving the spacecraft a "spin". But this spin is limited, because the string winds up and eventually provides a counter-torque to cancel the effect. At this point, we will reverse the sun's direction by 180 deg to cause a "spin" in the opposite direction. We will do this several times to build up the displacement to make it clearly visible that we are having an effect.



In this model, the currents from the X and Y solar panel pairs are connected to telemetry channels 1 and 2 and are being transmitted to the ground station receivers for capturing on your PCs using Hyperterm. We will illuminate this SUNsat at the start of the lab period and allow the ground stations to collect continuous data while you proceed with the remainder of the lab.

Post lab: Take the X,Y telemetry data into EXCEL and ***plot the Sun's X-Y currents with respect to time. Comment on the spacecraft's spin and attitude.*** Notice how the X and Y panels are connected to the "X" and "Y" coils but the coils are oriented 45 degrees to the X and Y arrays and the spacecraft's coordinate system. The coils are being pulsed with 7.2 volts, and with a coil resistance of 42 ohms, calculate the current in the coil. You will need the current again in the control lab.

Since the coils will exert the maximum torque when they are orthogonal to the Earths magnetic field, we have to orient the Sun lamp 45 degrees to the direction desired for the maximum coil current which is 90 degrees to North or South.

Part B: Magnetometer – Measuring the Earth's Magnetic Field: (Two set-ups at C1 and C3)

A spacecraft uses a magnetometer to measure the Earth's magnetic field vector. We have two magnetometers for our LABsats at work stations 3A and 3C. The magnetometer outputs a measurement of the Earth's magnetic field in X,Y, Z once a second. The magnetometer has been set (with an internal configuration of ps=1 (/64)) so that the units are approximately in microTesla.

Set the LABsat on the compass-rose base and be sure to align the base with the edge of the table so that the +X direction of the LABsat (and pointer) is pointing at 311 degrees when +X is pointing to the back of the room (or 131 if pointed at the front of the room).

Rotate the LABsat to see if you can null out the X and then the Y values. ***Note the angles on the compass rose.*** Next, rotate the LABsat to align the x direction with geographic north (0), the y direction with East, and the z direction with down (NED frame). The X,Y and Z values in this orientation should represent the Earth's magnetic field vector at that location. ***Record the Earth's magnetic field vector observed on the workstation.***

For reference, the magnetic field vector (in Tesla) in the North-East-Down (NED) frame has been calculated from a model of the Earth's magnetic field as shown to the right. The vector assumes the coordinates of the lab.

$$\underline{B}_{NED,model} = \begin{bmatrix} 2e-5 \\ -4e-6 \\ 4.7e-5 \end{bmatrix}$$

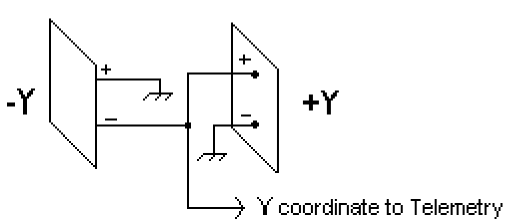
Compare the magnetometer reading to the above vector. Why is the actual vector in the lab different? (What corrupts the magnetic field in the lab?). Compare your reading with the other magnetometer LABsat reading from the other team. ***Borrow a magnet from the instructor and see its effect on the readings. (NOT TOO CLOSE). How far away does this magnet have to be to eliminate any effect on the readings? Try the LABsat Radio. Does it have an effect? How far?***

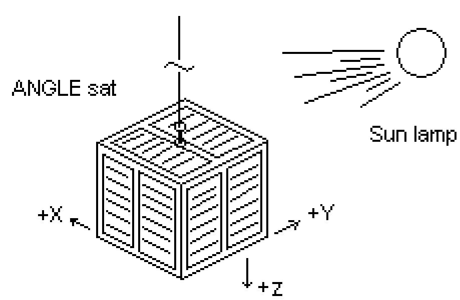
The Magnetometer LABsat has two transmitter simulators installed. When enabled they draw 500 mA each. One represents a satellite built by Midn Ace which is fed by a twisted pair of conductors (red and black) so the currents going to and from the load cancel. The other was assembled by Midn Bilger, who was asleep during the lecture on stray magnetic fields. He uses the black conductor on the left side and the red conductor on the right side to power his transmitter. Can you see an effect on the magnetometer when either transmitter is enabled? Explain.

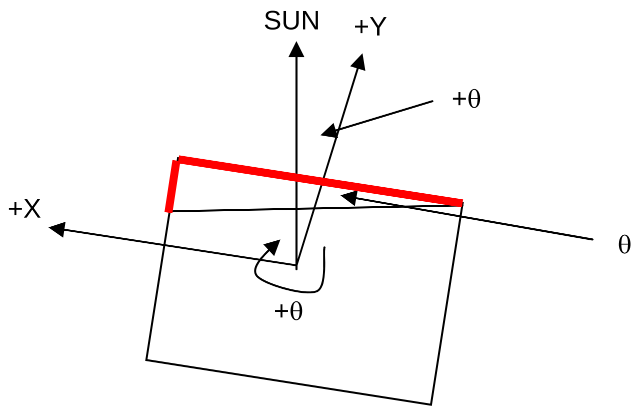
Next, find Magnetic North where the X value will maximize and the Y value will null. Rotate the magnetometer to find this angle and the x direction should then be pointed to the magnetic north. ***Approximately what is the angle between the geographic north and the magnetic north?*** Is magnetic north east or west of geographic north?

Part C: Satellite Attitude Estimation (Sun Sensing): (Two setups at B2 and B3)

In this experiment, as in part A, you will use 2 solar panels of your LABsat as a simple Sun sensor. By summing the currents from the pair of solar panels that constitute both ends of an axis, you will get a positive current when the sun is on the +X panel and a negative current when the sun is on the –X axis and in between, a magnitude of the cosine of rotation about the LABSat z direction as shown below.







But usually, we do not wire solar panels to give negative currents, but only positive so that they contribute to the spacecraft power bus. To get an angle from only positive solar currents, we use the tangent function instead of the cosine. In the example figure above, the +Y panel is illuminated and also part of the +X panel. If the telemetry count for current directly relates to the strength of the sun vector along each panel direction, the angle θ is simply the tangent of the ratio of the +X and +Y currents (both positive numbers). But since these solar panels might not be identical, these currents need to be normalized to their full sun value as shown in the equation below.

$$\tan\theta = \frac{\text{X panel current}}{\text{Y panel current}} = \frac{\text{X telemetry count/zero angle sun count}}{\text{Y telemetry count/zero angle sun count}}$$

A +X and +Y solar panel has been added to your LABsat and connected to a 100 ohm load and to telemetry channels 2 and 3. Channel 1 is your LABsat voltage x10). Connect your LABsat serial port to your PC for telemetry. Turn on your TNC.

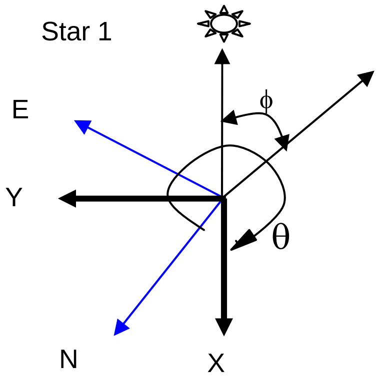
1) Place your LABsat in the Sun spot of the spot lamp and align it so that the +Y panel faces the lamp directly, note the zero angle current for ch3. Do the same for the +X panel and ch2. This establishes your maximum current for each panel at a sun angle of 0 for that panel and your benchmark for that 0 angle.

2) Now rotate LABsat back to where the +Y face is pointed at the sun lamp. Using your compass rose as a guide, rotate it through 90 degrees in 10 degree increments clockwise until the +X axis is fully illuminated, pausing at least 10 seconds on each angle to be sure your telemetry reports the X and Y. Keep a log of telemetry serial number versus angle setting so you can compare values later. Capture your LABsat telemetry data to a file (or jot down the 10 values for later use in Excel).

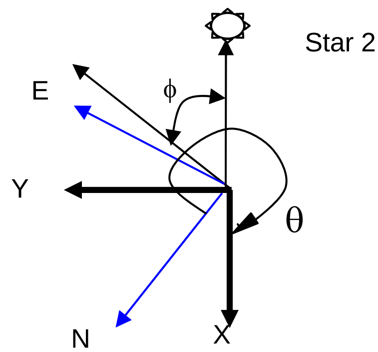
Post Lab: Enter your telemetry data into EXCEL and create an additional column so that you can enter the actual physical angles that match the telemetry serial T# you recorded above. Compute and plot the angles and compare against your measured angle to see how well this telemetry system is resolving the rotation angle. Do your computations match the actual angles you recorded? Can you completely resolve the attitude with only one vector source? Why or why not?

Part D: Satellite Attitude Estimation, Star Sensor: (Two setups at A2 and A3)

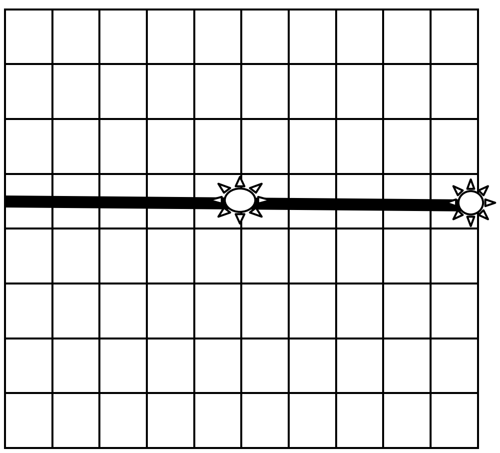
In this experiment you will further refine your attitude estimate using LABsats configured with SpySat image sensors to give two measured vectors to bright "stars" in the lab. Carefully align your LABsat compass-rose base with the edges of the workstation table. Turn on your camera with the LEDS OFF command. (Remember to turn it OFF when not in use to conserve the battery using the LEDS ON command!).



(LEFT SIDE OF ROOM)



(RIGHT SIDE OF ROOM)



(GRID FOR LEFT SIDE OF ROOM)

You will need to rotate the LABsat by an angle, θ, about the down direction so that Star 1 (or Star 2 if you are on the right side of the lab), is exactly in the center of your camera viewer. Record the angle θ from the compass rose. You will measure the angle, ϕ, from the horizontal scale on the viewer. Each square in the grid shown below measures 2.4 deg. Once you know ϕ, you need to form the two measured, unit vectors in the LABsat coordinate frame, $\hat{b}_1$ to star 1 and $\hat{b}_2$ to star 2. Make sure you compute the components for each vector in your LABsat frame, X-Y-Z. (The picture below is for LABsats on the left side of the room, for the right side of the room one star will be in the middle of the grid and the other will be to the left.)

For the left side of the classroom, the reference vectors for star 1 and star 2 are (NED frame):

$$\hat{r}_1 = \begin{bmatrix} -.75 \\ .66 \\ 0 \end{bmatrix} \quad \hat{r}_2 = \begin{bmatrix} -.94 \\ .34 \\ 0 \end{bmatrix}$$

For the right side of the classroom, the reference vectors for star 1 and star 2 are (NED frame):

$$\hat{r}_1 = \begin{bmatrix} -.45 \\ .89 \\ 0 \end{bmatrix} \quad \hat{r}_2 = \begin{bmatrix} -.76 \\ .65 \\ 0 \end{bmatrix}$$

Post Lab: Using the 2 measured vectors and the 2 corresponding reference vectors, compute the direction cosine matrix (DCM) from the NED frame to the LABSat body frame using the TRIAD method. Calculate the DCM from your measured angle, θ.

1. What is your DCM from TRIAD? What DCM did you calculate from your measured angle?
2. Calculate your rotation angle from the TRIAD DCM?
3. Does your calculated angle match with your measured angle?