EA-467 ATTITUDE CONTROL LAB (draft) Fall 2006

Introduction: This lab uses our LABsats to demonstrate as much about attitude control as we can achieve in the lab, in air and in a 1 G environment. Magnetic stabilization both passive and active will be demonstrated as well as torquing via momentum wheels and a small chemical thruster. The forces needed to change the attitude of a spacecraft are extremely small in space, but are effective because all other forces acting on the spacecraft in the vacuum and microgravity of space are even smaller. Although it is difficult to achieve these minute forces in the lab, we can get close enough in one dimension by hanging our models on a thin string to see the principles involved in 4 out of 5 of the attitude control methods.

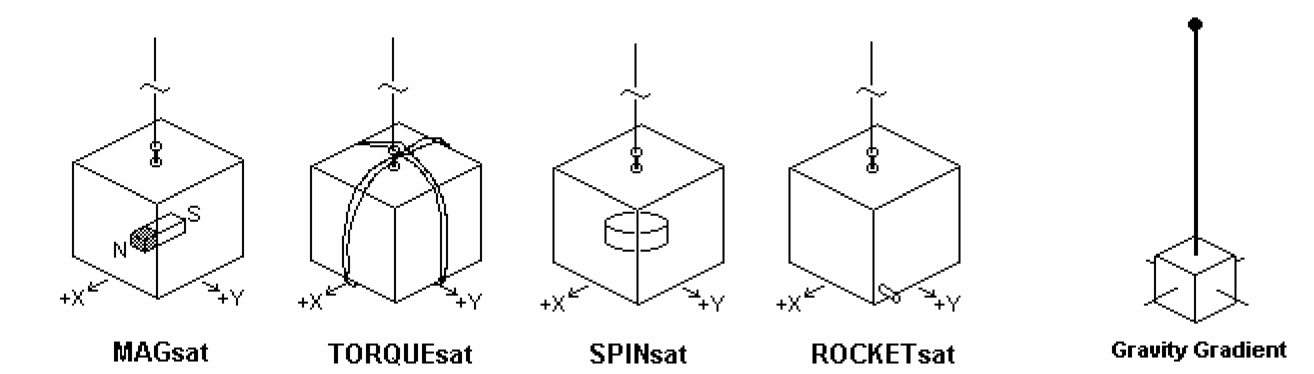
The lab will use four of our LABsat models, configured as follows:

MAGsat - Passive magnetic stabilization

TORQUEsat - Active Magentorquing

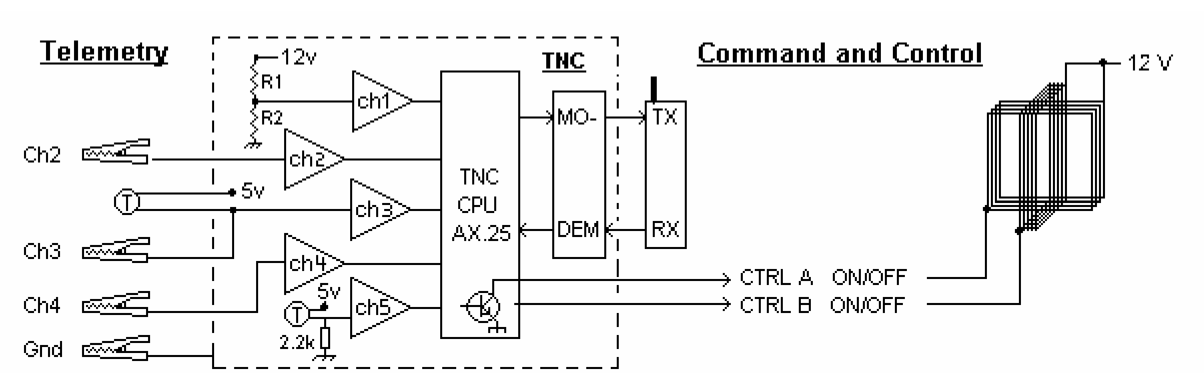
SPINsat - Momentum wheel

ROCKETsat - Hot Gas rocket Thruster



Cannot do in lab

Background: The LABsats we used for the earlier telemetry labs also have a command and control capability. They have three ON/OFF circuits that can be initiated under control from the ground as shown in the figure below :



The CTRL A and CTRL B circuits are open-drain FET transistors that can close a circuit of up to 500 mA to ground. The LEDS command gives an output at 0 and 5v TTL voltage levels but can neither source nor sink any appreciable current. The operator commands are simply CTRL A ON or CTRL A OFF or LEDS ON or LEDS OFF, etc. To open the command link to the spacecraft you must first logon via the password protected command link. To do this. from your ground station “cmd:” prompt issue the C

TORQUE-3 or C SPIN-3 connect commands to connect to the remote command callsign.

You will be challenged with three sets of 6 password numbers that your must match from your "secret" password string (this year it is "GoNavy"). You must respond with the matching character for the given byte number. In other words, G is for 1, o is for 2, N is for 3, etc… Thus, you simply type back one of the strings as received and if successful, you will get the spacecraft's command "prompt:". From the prompt you can send the CTRL A/B ON/OFF commands.

You will use these commands to command the momentum wheel in SPINsat and the torqueing coils in TORQUEsat. But note, that there are significant delays in the exchange of data and acknowledgments like the internet or any other packet-switched network, so precise timing is not possible with this command system. Anticipate a second or more delays.

Laboratory Configuration:

The LabSat's telemetry and command system are connected to a small radio transceiver to link it to the central ground station on the single TDMA shared channel as we used in the Telemetry Lab. Each workstation monitors the RS-232 serial port telemetry data received by the central ground station and distributed by the patch panel. This way, each work station can see the telemetry from any other LABsats on the channel.

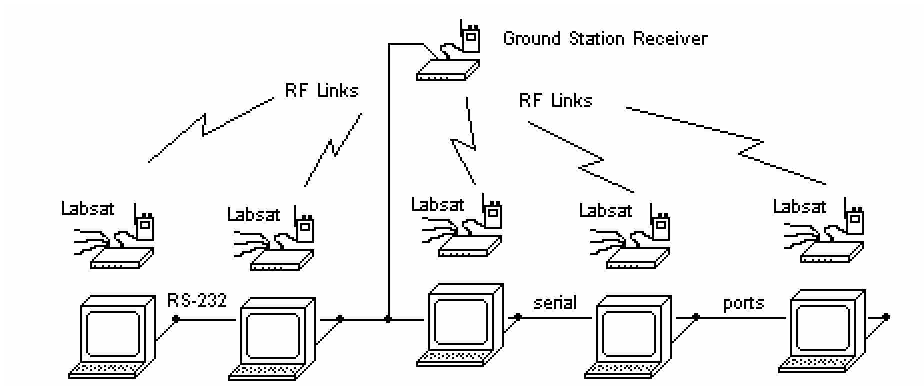
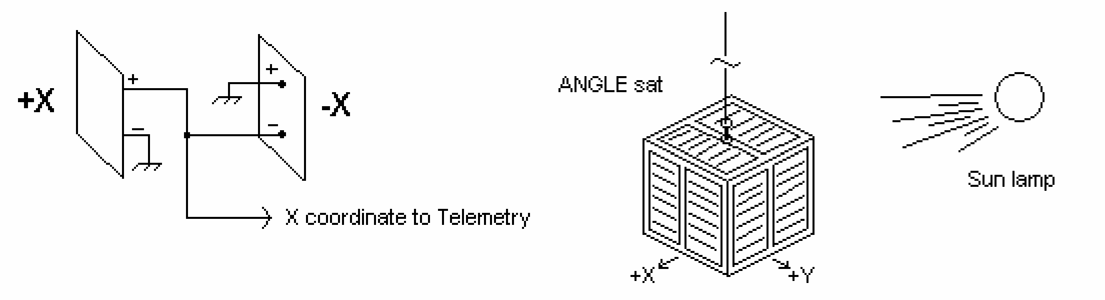


Figure 1 LabSat Network

Part A: Preliminaries – Measuring the Earth's Magnetic Field Lines:

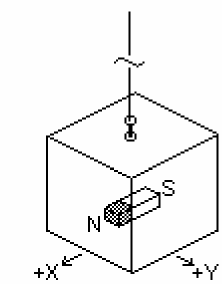
A spacecraft uses a magnetometer to measure the Earth's magenetic field vector. In our low-cost lab, we will simply use a compass. Measure the direction of the Earths Magnetic Field vector (horizontal component) at your labstation with respect to the front edge of your desk. Transfer these vectors to the lab-room layout so that we can see the summation of the magnetic field lines and infer the lines in the vicinity of your lab station and of the center of the room where TORQUEsat is located. Also use one of the "dip needles" to measure the dip in the magnetic field at your location and write it on the chart.

Part B: Measuring the Satellite's Attitude: Several methods are used for determining the attitude of a spacecraft. These include Earth and Sun sensors, magnetometers, star sensors and gyroscopes. In this lab, we will use the 6 sides of the spacecraft as a simple Sun sensor. If we take the +X and –X solar panels and take the difference in their currents, we will get a magnitude of the attitude vector in the X direction. Similarly by taking the X, Y and Z magnitudes we get the result of a vector A(x,y,z) giving the instantaneous attitude of the spacecraft.



Lab Procedures: Our ANGLE satellite has its solar panels configured for Sun sensing as described above. Take the SUN lamp from several different locations in the room (holding for at least 10 seconds in each location, and shine it on the satellite, making careful note of the angles to the satellite. Capture the concurrent telemetry data. **Post Lab:** From the telemetry data, compute the attitude vector with regard to the sun. Compare the results with your original angles.

Part C: Moment of Inertia: To do anything with spacecraft dynamics, we must first compute the moment of inertia of the spacecraft. This is simply the sum of the moments of inertia of all the component parts of a spacecraft about the center axis. Remember to also apply the parallel axis theorem to any masses that are off-center. As a collective effort, compute the moment of inertia about the Z axis of SPINsat. Also of the FOAMsat. For SPINsat, we will accumulate the total on the blackboard.



MAGsat

Part C: MAGsat Passive Magnetic Stabilization:

Passive magnetic stabilization is one of the easiest stabilization methods for spacecraft. It will keep one axis of the satellite always aligned with the Earth's magnetic field. Hang your foam satellite on a 15" string over your lab table to allow it to rotate with one degree of freedom with nearly zero countertorques. Also, tape a piece of paper to the lab table under the satellite for making notes about the satellite orientation. Gently assist your satellite to achieve equilibrium that results in zero torque from the string.

1) Mark the stable alignment of the X and Y axis on the paper under the satellite for future reference. Compare these with the Earth's magnetic field that you measured with your compass (Magnetometer). Choose the axis that is the most orthogonal to the Earth's magnetic field lines for step 2.

2) To activate your MAGsat, take one of the permanent magnets (two sizes, BIG and little and insert it into the hole in the face of your FOAMsat that is the most orthogonal to the field lines. The North Seeking Pole is painted white. Choose the orientation that will give the best torque. Insert the magnet, and very carefully release the satellite in exactly the original steady-state orientation it had before.

3) Observe the movement of the spacecraft towards the north or south pole. Estimate the velocity after the first 45 degrees of movement. Knowing this terminal velocity, and the moment of inertia, you should be able to estimate the initial magnetic force imparted to the spacecraft by this magnet.

4) Help the spacecraft stabilize with the magnet still in place. This orientation has the force of the magnet

times the cosine of the angle-off-north (or south) balancing the spring torque of the string. Calculate this string torque. Now move the magnet to the +Y face and again help the satellite to equilibrium. Compare this new orientation with the original Y axis orientation and again make an assessment of the string torque based on the magnetic force times the cosine of the angle with the field line. These two measurements should be rather consistent?

Other things to ponder:

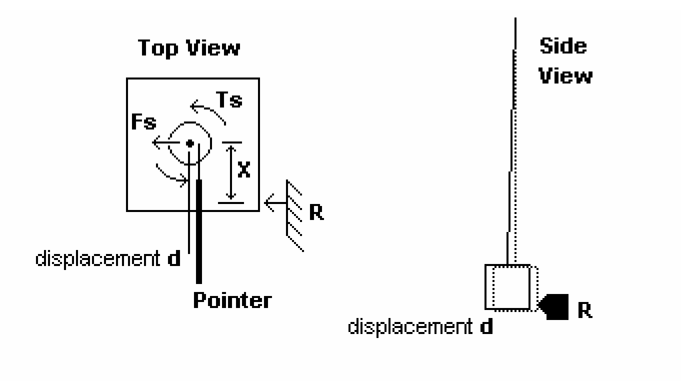
a) If your satellite is in a polar orbit, and your magnet is along the Z axis, how many rotations in attitude will occur for each orbit of the spacecraft?

b) If your Z axis magnetically stabilized satellite is in equatorial orbit, what attitude will an observer on the ground at the equator see?

c) PCsat is magnetically stabilized in a high inclination orbit with the –Z axis being its North Seeking pole. Also on PCsat is an array of 80 red LEDs that we can turn on to see if we can see the satellite. Although we have no control over the X and Y axies, we do know that PCsat spins at ½ RPM from the differential solar radiation pressure of the black/white antennas. Thus during any 2 minute period, the LED's mounted on the –X face will have pointed towards us. Why did we orient the LED's at about 45 deg to the Z axis so that they are optimally pointed at most of the USA when the –X face is directly overhead our location?

Part E: Preliminaries - Measuring the String Torque:

The FOAMsats used in this lab are hanging from a 15 inch piece of monofilament fishing line to minimize the amount of torque applied to the spacecraft. The torque of the string is extremely small, but we can still measure it using the technique described in the figure below.



1) Tape a scrap paper on the table under the satellite and let the satellite achieve equilibrium.

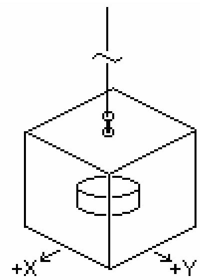
2) Place a fixed block as close to as possible (without touching) one corner of the satellite and then adjust a pointer to point perfectly at the string from an orthogonal direction as shown.

3) Now carefully trace the exact location of the block and pointer block on the paper and then remove them temporarily.

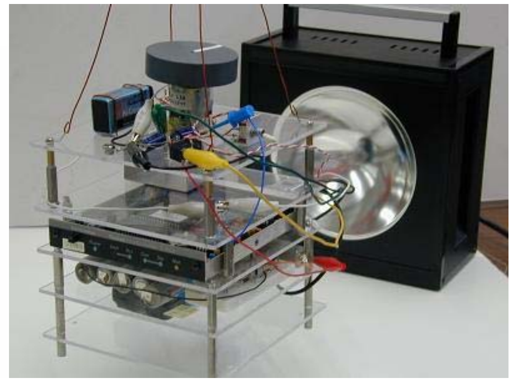
4) Now, without changing the location of the pivot point in any way, wind up the satellite 50 times in a clockwise direction.

5) Holding the satellite, return the block and the pointer to their previous position and gently place the corner of the satellite against the block. The reaction force R operating over the moment arm X will result in a counter torque equal to the string torque. This torque will result in a Force Fs and a displacement in the direction shown. For small displacements, this Force is related to the weight of your satellite by the sine of the angle of the displaced string.

6) From your measured displacement, length of the string. calculated force Fs, and 50 turns, calculate the spring constant of the string in grams per degree of rotation. Compare this to the spring constant you estimated in Part B.



SPINsat



Part F: SPINsat Momentum Wheel:

SPINsat weighs 1.62 kg and has a small 0.65” by 2.5” diameter disk (momentum wheel made of PVC with a density of 22.7g/cuin) connected to a motor which can be spun up under ground command. From rest, you will send commands to start the motor and observe the speed of rotation of both the momentum wheel and opposite reaction spin of the spacecraft. The motor is rated at 24,000 RPM (no load) but about 18,000 RPM drawing 2 amps at 18 volts optimum load. At 9 volts, it should run at something around 9,000 RPM.

Lab Procedure:

1) Let the spacecraft achieve equilibrium at rest. It weighs 1.62 kg.

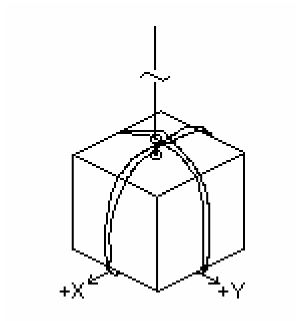
2) Prepare to take data on the spin rate of the reaction spin of the spacecraft with time. The spin-up will be over in 15 seconds. We want to estimate the angular velocity of the satellite at that time. We will do that as follows:

3) Command station sends CTRL A ON to spin the motor. One observer begins counting revolutions continuously until the spacecraft stops spinning and begins to reverse. Then he begins to separately count revolutions in the opposite direction as the spacecraft spins back down. This will let us know when it gets back to the original equilibrium point.

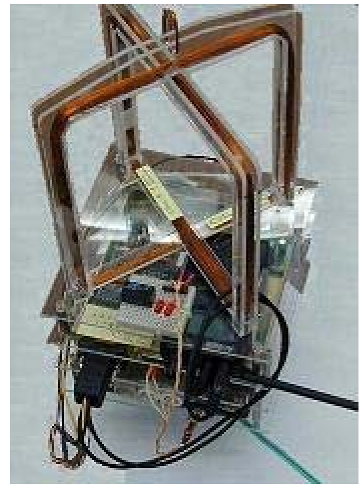
4) After 15 seconds, then for the next 15 seconds a second observer counts the number of rotations of the spacecraft so that we can make a good estimate of its angular velocity at momentum wheel steady state.

5) After 30 seconds, the command station will send CTRL A OFF. This will de-spin the wheel and at the same time, begin to despin the spacecraft. The spacecraft will continue forward for several more seconds but slowing down rapidly. The timing clerk will note the instant the motor stops turning, and the #1 counter will reverse his count when he sees the spacecraft momentarily stop.

6) In space, we would observe the spacecraft and momentum wheel both returning to zero at the same time. But in our experiment, the string was winding up and producing a counter torque. That is why we have counter #1 keeping track of the revolutions.   When the slowing down count equals the forward count, then the string will be at zero torque and except for some overshoot, the spacecraft should again be stable at that point.



TORQUEsat



Part G: TORQUEsat Torquing Coils:

TORQUEsat is hanging from a 6 foot piece of the same string as your FOAMsats. TORQUEsat has two orthogonal coils wound from 205 turns of #30 wire operated from 7.2 volt bus. These two coils may be individually activated using the commands CTRL A ON or CTRL B ON. The North seeking pole of the coils is marked on the satellite. Maximum torque is achieved when the coil is pulsed or energized when its vector is perpendicular to the magnetic field. To help keep the batteries charged, TORQUEsat has a –Z solar panel that can be illuminated from below. TORQUEsat has a mass of 1.39 kg.

<u>Lab Period as a group:</u>

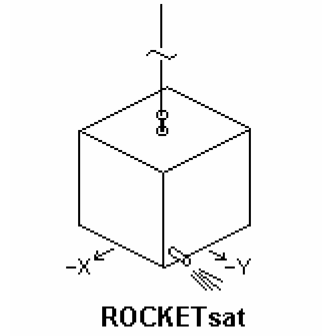
1) Let the satellite stabilize. Note the orientation of the +X and +Y axis of the satellite

2) Choose the axis that is closer to being orthogonal to the Earth's field and note closely its exact orientation. Send the CTRL A ON or CTRL B ON command to energize the coil. Observe the maximum change in orientation.

3) At his point, observe the orientation of the other coil with respect to the Earths magnetic field. If it can be used to further torque the spacecraft in the same direction, send the commands to turn it on and the other coil off. OR if the other coil is not optimally oriented, then simply turn off the first coil and let the counter torque of the string carry it back past its original orientation to a point where the other coil can be effective.

4) After you have measured the maximum orientation change you can make, you are welcome to try to spin up the spacecraft by alternating the pulsing of the coils.

5) Knowing the voltage, and resistance (42 ohms), calculate the current in the coil. Then with 200 turns and the earths magnetic field compute the torque of the 6" coil (T = D x B where D = n*I*A). By observing the time it took to move 45 degrees, we can estimate an acceleration. Using the moment of inertia we calculated for SPIN sat, how well does our measurements match our observations (T = I* a).



Part H: ROCKETsat Thrusters:

Each lab station has a ROCKETsat which has a small chemical rocket thruster. You will assemble your thruster from a single match wrapped in a small piece of Aluminum foil. Assemble your rocket thruster and lightly stick it into the thruster holder provided. This is very fragile. Be careful not to over stress this holder in the foam holding it. And DON'T BURN THE SATELLITE!

Lab Procedure:

1) Weigh your ROCKETsat. It is a homogeneous block of material so you can easily calculate the moment of inertia about the Z axis. For a cube, it is 2/3rds $M r^2$. Assemble your thruster by wrapping the head of a match in Aluminum foil and twisting the end to a point. Insert the point into the mounting hole on the side of your ROCKETsat. Help the satellite reach equilibrium with no spin. Mark its alignment on the paper.

2) Put on safety goggles in case the thruster emits any particulates or pieces of foil. Using a second match, heat your thruster to ignition.

3) Observe the initial reaction spin rate of your spacecraft (how many seconds to say, go 90 degrees?). This gives you angular velocity (ω). Neglecting the string spring constant, because the actual rotation is small, calculate the thrust of your engine. Remember Torque is the change in angular momentum over time. $T = I * d(\omega) / dt$. How long did your thruster fire? (t).

Convert Torque to Force and you have your thrust.