Lab 1

Jason Separa
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Introduction:

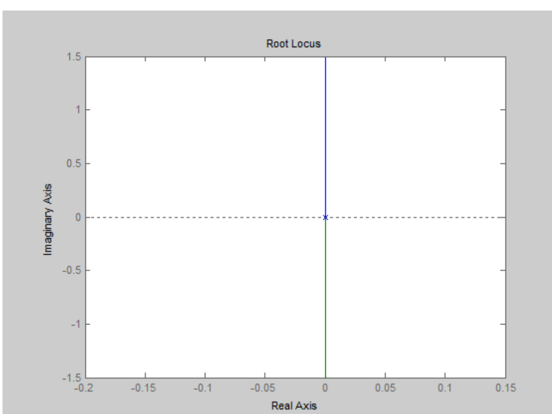
Before the digital revolution in the world, there was a time where analog was in control. Giant banks of operation amplifiers were used to simulate and control all types of systems. To understand control systems, a basis of analog control is necessary to fully grasp the concept. This project demonstrates how to control a marginally stable system, a double integrator, using the analog power of operational amplifiers. Using a feedback loop and a lead compensator, the system is transformed from marginal stability to stability. By altering the gain, the system will respond more efficiently to a given input signal.

Problem Statement:

The purpose of this project is to model spacecraft's using a double integrator circuit and control it using a lead compensator. The double integrator is in the form $G(s) = \frac{1}{s} * \frac{1}{s}$ and the compensator is in the form $T(s) = \frac{K(s+a)}{(s+b)}$. This compensator will help to control the system's instability by drawing the poles into the left half plane and force stability upon it.

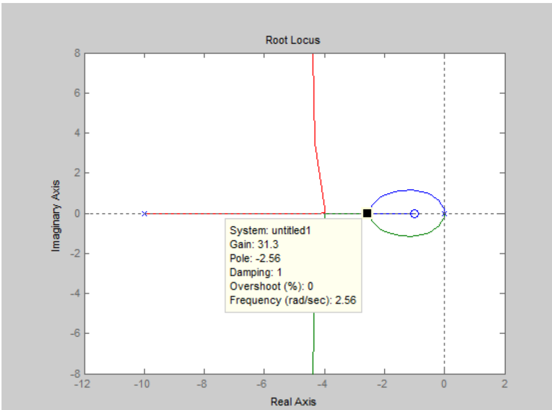
Root Locus Simulation:

$$G(s) = \frac{1}{s} * \frac{1}{s}$$



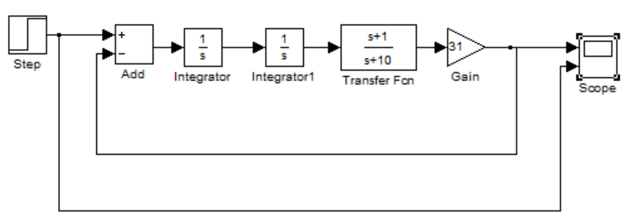
The root locus of a double integrating plant. The poles only exist on the imaginary axis, which means it is marginally stable. This system could either be stable or unstable, depending on the input. In order to make this system stable, a compensator must be added. The compensator to be added will have the transfer function $T(s) = \frac{K(s+1)}{(s+10)}$. Adding this transfer function into the system's loop will move the poles into the left half plane of the root locus plot.

$$G(s) = \frac{1}{s} * \frac{1}{s} * \frac{K(s+1)}{(s+10)}$$



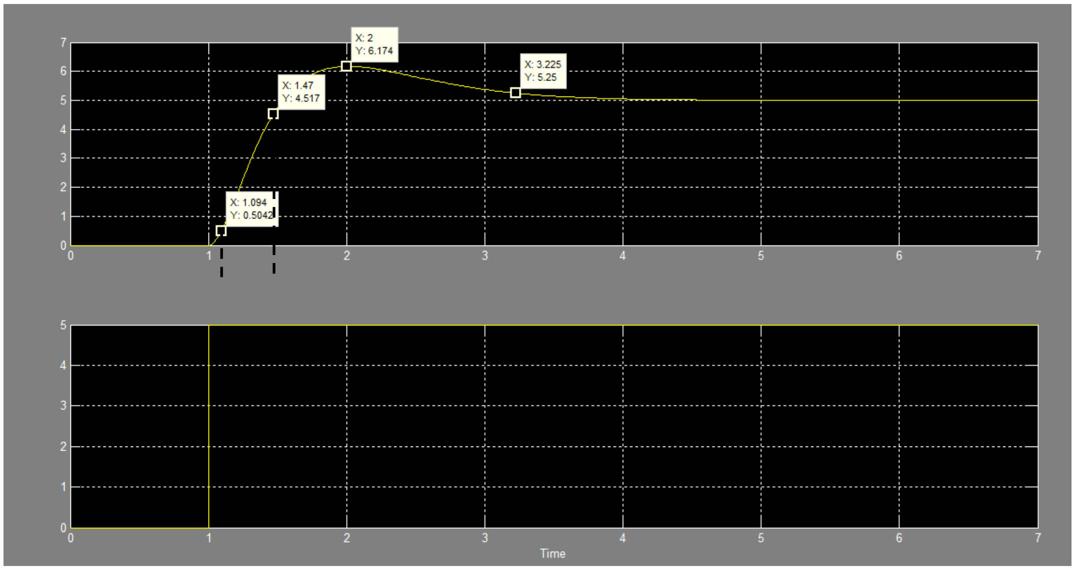
This is a root locus plot of the double integrating plant with an added lead compensator. This plot illustrates how changing the gain will alter the response of the system. With a gain of 31, the system seems to give the least overshoot. A system with quick rise time and the least amount of overshoot is desirable. Adding this lead compensator made the poles migrate to the left had plane, which in turn made the entire system stable by definition. Now the system must be given a step input in order to see how it will respond.

Matlab Model:



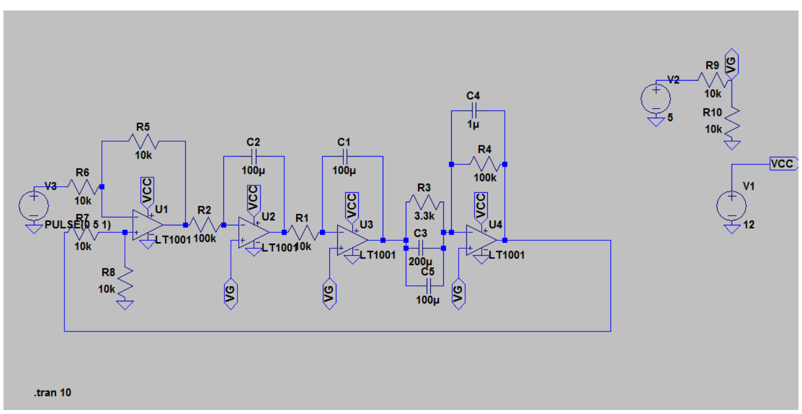
The model above is a simulink representation of the system. the model is a closed loop system with two integrators, a lead compensator, and a gain for improving system response. The scope added at the end will give a visual representation of the system response to a step input.

Matlab Results:



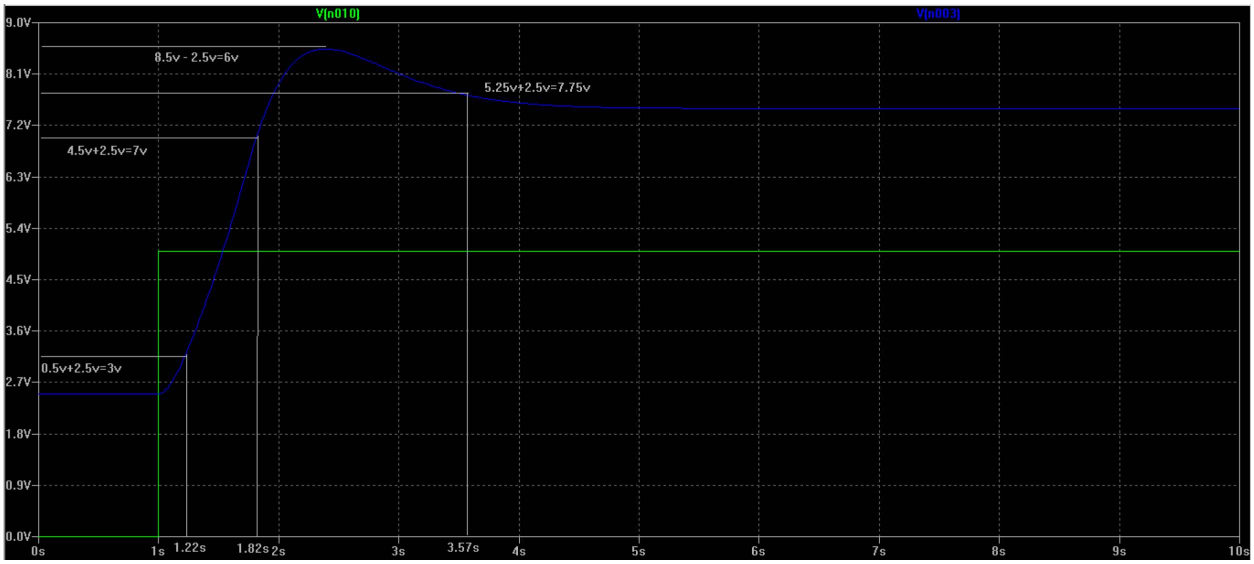
This response shows that there is a slight over shoot of 1.174v, or 23%. The overshoot is due to the gain not being fully past the point of no overshoot. The rise time is 1.47s-1.094s= .376s. The settling time is when the system gets below 1.05*5=5.25. This settling time turns out to be 2.25s. The system is now much more stable that it previously was. Now the system can be moved into the circuit design phase.

Schematic:



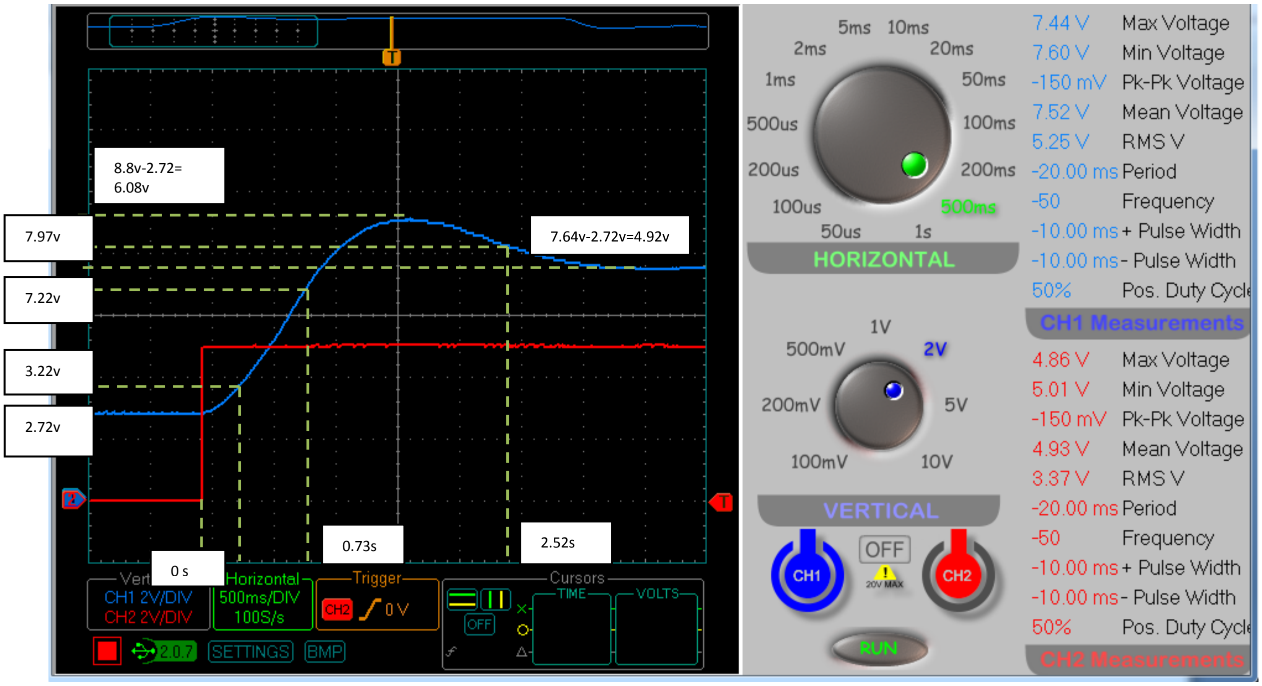
This is a schematic of the system which includes 2 integrators, the lead compensator, and a subtraction circuit for feedback. The subtraction circuit is very basic, with unity gain and a step input. The first integrator has a gain of 0.1, since the double integration of a 5 volt supply could create a large response. The loss of signal will be made up for in a later stage. The second integrator has unity gain, and is as simple an integrator as there is. The lead compensator has the transfer function $T(s) = \frac{K(s+a)}{(s+b)}$ with both a and b being the inverse of the RC circuits. K is the gain of the lead compensator, after doing the math it turns out to be $K = \frac{C1}{C2}$. Since this is an odd number of inverting circuits, the addition and subtraction terminals of the subtraction phase must be reversed. This gain will compensate for both the root locus measured response and the gain that was taken down in the first integrator.

Schematic Simulation:



This is the step response of the systems circuit, and it shows a very pleasing similarity to the simulink model. The rise time, overshoot, and settling time in this model have been calculated as 0.6s, 20%, and 2.57s. This means that the theory is even more solidified with another program to verify the results. The output is shifted up because the opamps have VEE wired to ground. This has lead to a need of a virtually ground, but has taken out the need for a negative supply.

Experiment Results:



This is the results from the real circuit, and it proves what all of the simulations have predicted. The rise time has come out to be 0.73s, the overshoot is 21.6%, and the settling time is 2.52s. The rise time, peak, and settling time are all very similar to the predicted models. The interesting thing is that the level shit did not work as predicted. The output should have been shifted up by 2.5v, but turned out the be 2.72v. The resistors could possibly have been off by that much, or some discrepancies with the opamp and its model. Any small discontinuities can be attributed to the resistor and capacitor tolerances. This result shows a successful design of a lead compensator to aid in a stable result from a marginally stable plant.

Conclusion:

This design turned out to have successful results, the system has been moved from marginally stable to fully stable. When a step input is applied to the plant, it takes approximately 500ms for it to stabilize an d reach the desired output. This stability could not be accomplished without the help of a lead compensator, which has dragged the poles into the left-half plane. Adding the virtual ground makes the system slightly more complex, but also takes out the massive defect of needing a negative supply to add the compensator. The only thing in the system that could not be compensated for was the tolerances of the resistors and capacitors, but it did not seem to have too much of a negative effect. The system response has been altered for the better, but the next step would be to add a PID controller with the help of a computer. This addition would further improve the systems design, and control ability.