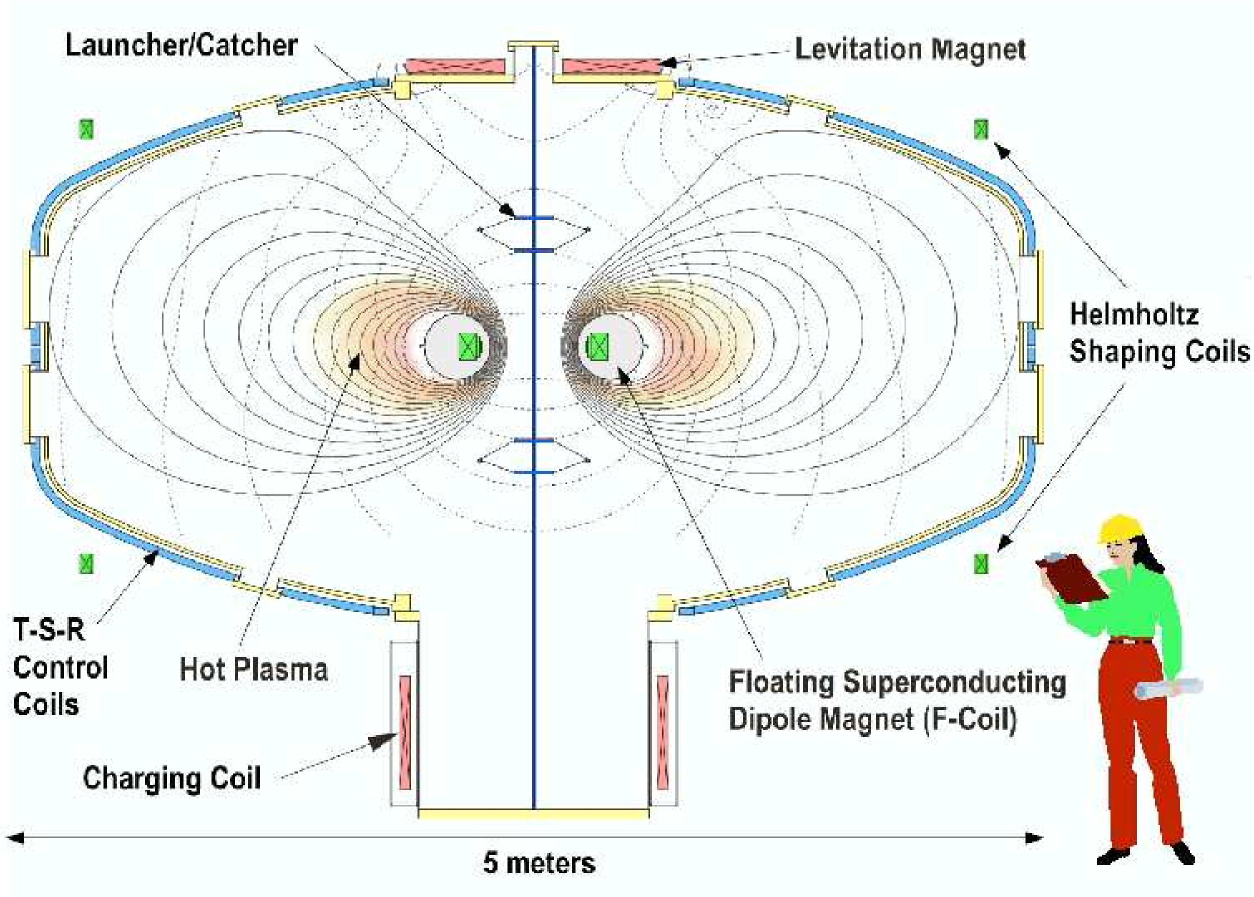
Levitation Control System in the Levitated Dipole Experiment (LDX)

Abstract

The design, installation, and calibration of the levitation control system in LDX is presented. A number of laser beams will pass tangentially to the surface of the floating coil in the center of the LDX vacuum chamber. The optical occlusion of these beams by the floating coil measures the deviation of the floating coil from its desired position and orientation. These measurements are input to a real-time digital control system that controls the current in nine external magnets and calculates the vertical position, horizontal position, and tilt of the coil. This feedback control system compensates for any deviations in its position by adjusting the current in the levitating coil to adjust vertical position and by activating auxiliary control coils to compensate for slide and tilt. Validation tests of the laser detection systems will be presented.

LDX Overview

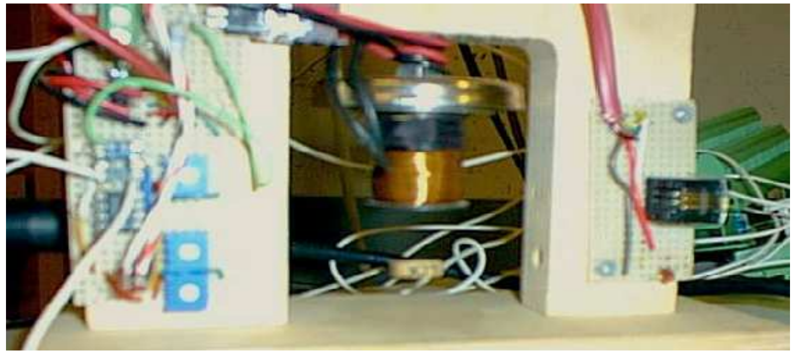


- LDX looks at a dipole magnetic field for plasma confinement
- Ultimate experimental goals require that the F-Coil float

F-Coil Levitation

- LDX will use a coil attracting the Floating Coil from above to counteract gravity
- This geometry is unstable to vertical motion
- Earnshaw’s Theorem tells us that it is not possible to create a system with DC electromagnets that will be stable with respect to each degree of freedom
- Tilt, slide, and rotational degrees of freedom are stable, but require external control to add damping to the system
- Vertical instability in the system requires a feedback system
- Oscillations in the system will occur with a frequency on the order of 1 Hertz

Levitated Cheerio Experiment



- The Levitated Cheerio Experiment (LCX) is a proof of concept experiment designed and built by Dr. Darren Garnier
- The physics for the Levitated Dipole Experiment are the same as those for the Levitated Cheerio Experiment, but on a much larger scale
- LCX proves the experimental feasability of a vertical-stabilizing feedback system

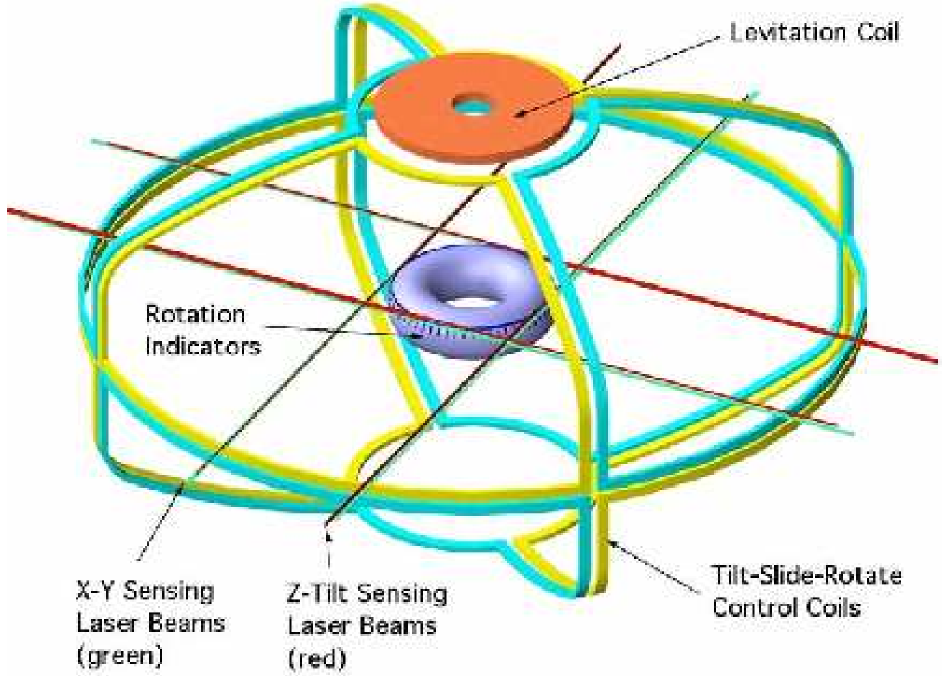
Design Objectives

The system must be designed to meet the following specifications:

- 1 kHz response to avoid phase delay in the feedback system
- 1mm sensitivity
- Insensitive to background light/noise
- Must work at a distance of > 2.5 meters

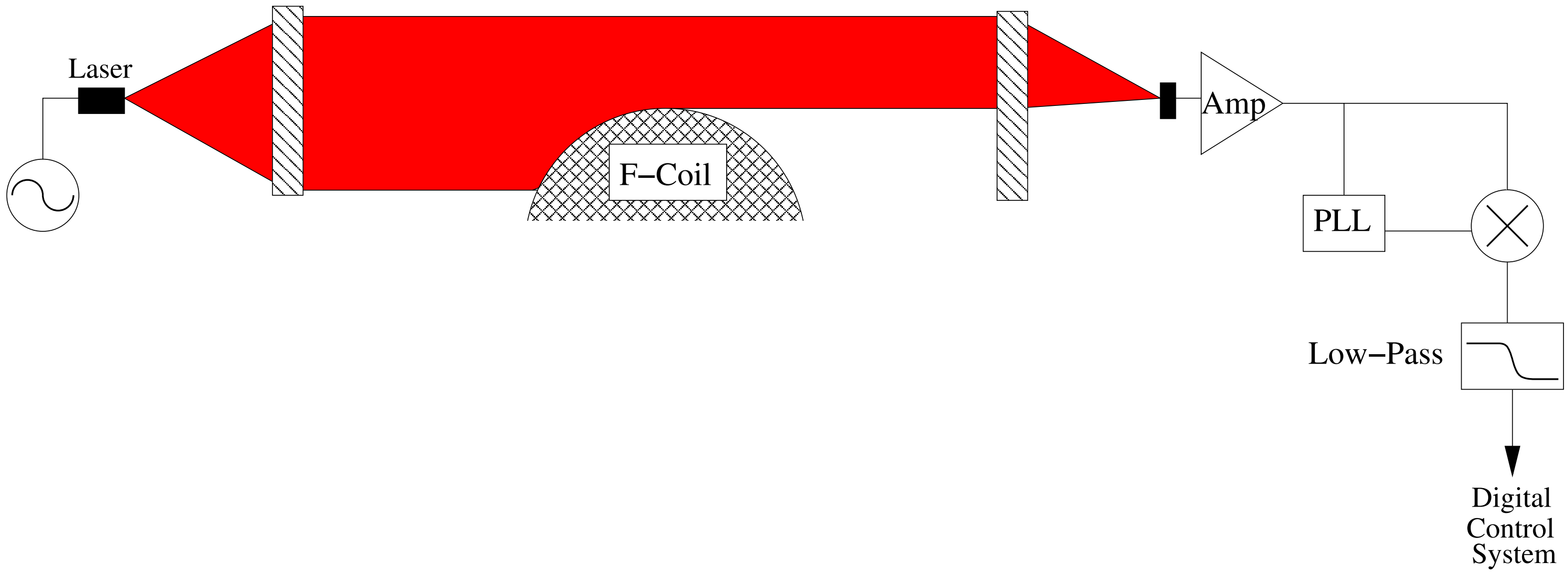
A search for commercially available position measurement devices has yielded no good solutions, leading to the development of our own system.

System Diagram



- The control system will use an optical position detection system designed specifically for LDX. Eight position detection channels will give information about the five degrees of freedom in the system.
- A digital feedback system will provide the control to the L-Coil current, stabilizing the vertical position of the F-Coil.
- Auxilliary coils will be used to damp oscillations in the other degrees of freedom.

Position Detection System

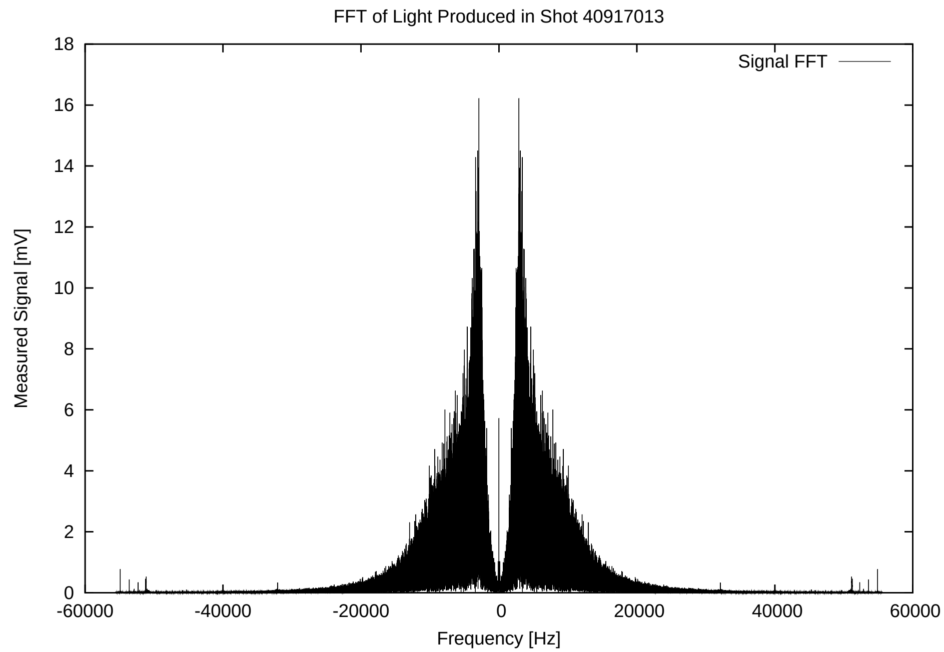


- A laser source is driven with an oscillating current source to produce a wide beam of amplitude-modulated light
- The F-coil occludes some portion of the light

Position Detection System

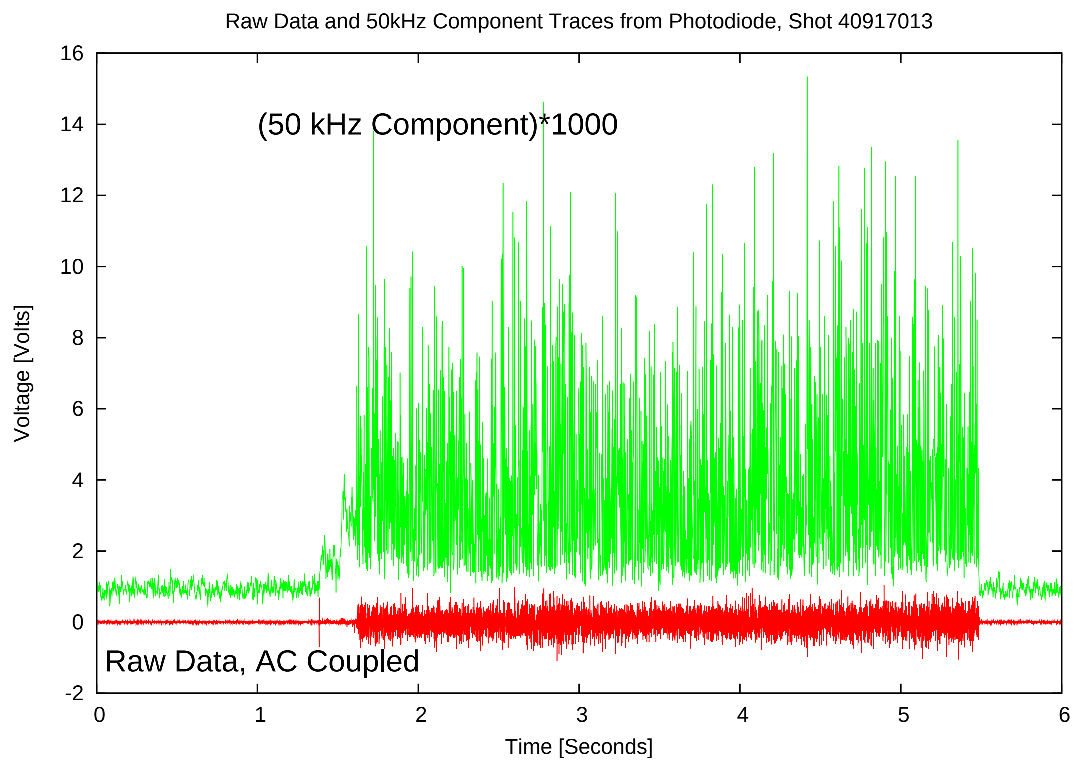
- A photodiode receives the remaining light on the opposite side of the vacuum chamber. The amount of light received is inversely proportional to the amount of the beam blocked.
- A phase locked loop (PLL) will produce an output from a voltage controlled oscillator (VCO) phase locked to the signal from the photodiode.
- The signal from the photodiode will be mixed with the signal from the VCO to produce sum and difference signals. These will be low-pass filtered to produce a DC signal indicative of the F-coil position.
- This signal will be digitized and passed to the feedback control system.

Modulation Frequency



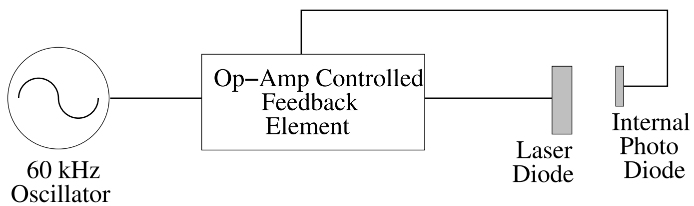
- Need 1kHz bandwidth
- Modulation frequency should not be produced by plasma
- Limit the system to frequencies of commercially available oscillators
- 60 kHz was chosen. There are commercially available 60kHz oscillators, and, as the figure shows, little light amplitude modulated above 40kHz is produced by the plasma.

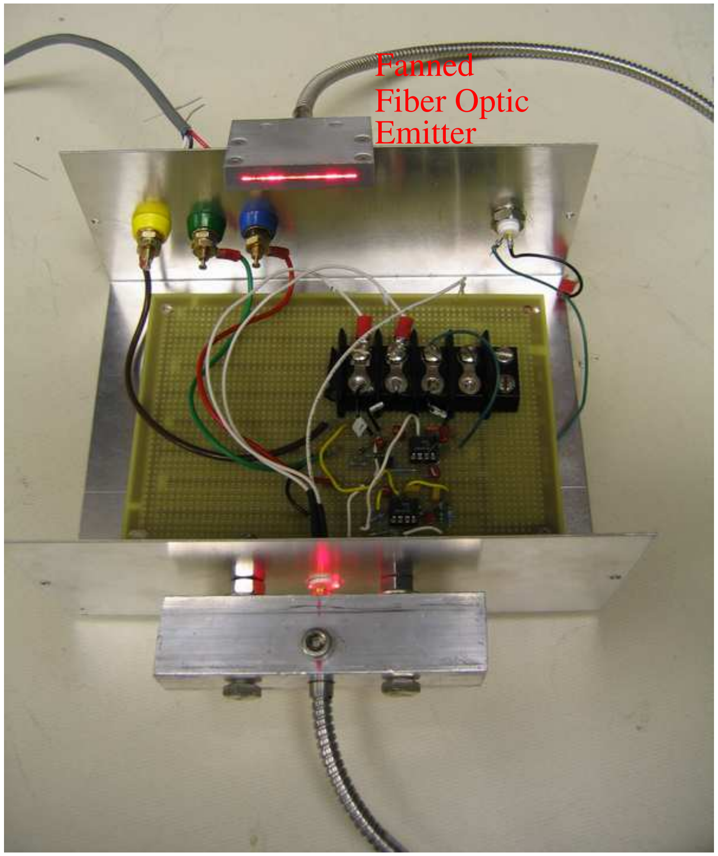
Modulation Frequency



- The 60kHz component was just outside of the bandwidth of the photodiode digitization system, but we can get a feel for the trend of the 60kHz component over a shot by looking at the 50 kHz component
- The magnitude varies by a factor of 10 over the course of a shot, but is still a small component of the background
- 60kHz modulation should encounter little interference produced by the plasma

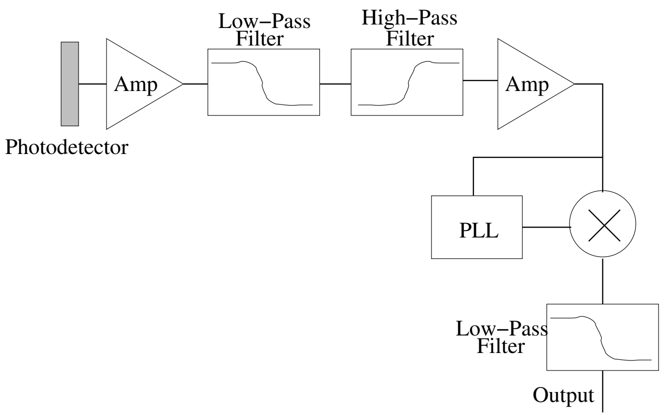
Laser Diode Driver

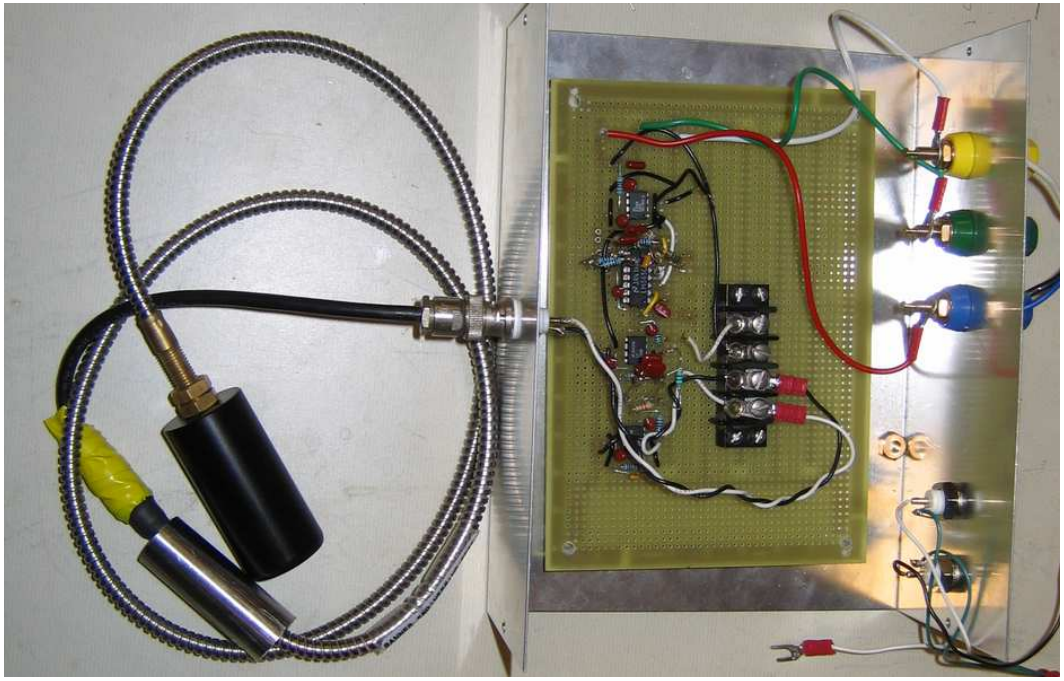




- A crystal oscillator circuit provides the 60kHz modulation circuit
- An op-amp and transistor regulate the current to the laser diode with feedback from the diode’s internal photodiode
- The laser diode is coupled to a fiber optic cable with a line output

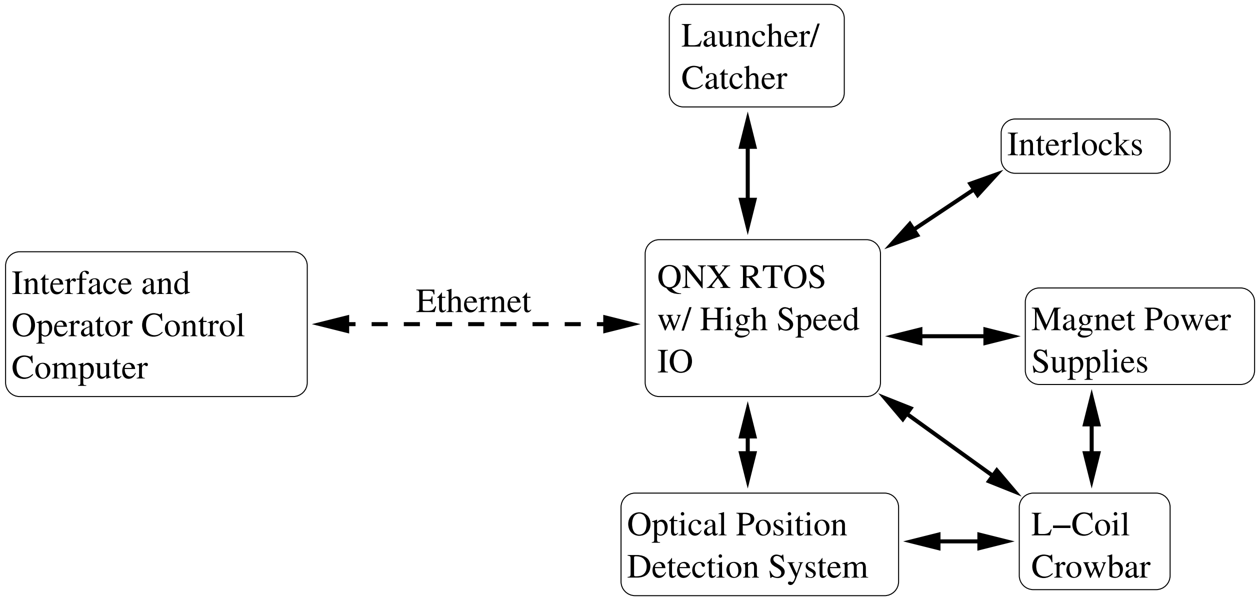
Receiver





- The photodiode's current signal is converted to voltage and amplified by a transimpedance amplifier
- The signal is high-pass filtered and AC coupled to remove noise
- The signal is passed to the PLL to produce a phase-locked VCO signal
- The original signal and the signal from the VCO are mixed, and the resulting signal is low-pass filtered at 1kHz

Digital Control System



- The digital control system will use a Real Time Operating System to analyze the digitized signal from the position detection system and to provide feedback to the magnet power supplies.
- The system will include several interlocks, and will be able to trigger the L-Coil Crowbar Circuit in case of an F-Coil runaway.
- Operators will have an interface to the control system through a network connection.

Future Work

- A prototype of the optical detection system will be working soon
- Optical detection system channels will be manufactured this winter
- The digital feedback system will be programmed this winter
- Complete system testing and levitation operations will begin in the spring of 2005