Noise Assessment of Temperature Probes for Torsion Pendulums

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1 Introduction

A torsion pendulum is a device used to make accurate measurements of various macroscopic forces. The Eöt-Wash group, based at the University of Washington in Seattle, uses these pendulums to measure the gravitational force and look for hypothesized forces that are coupled to spin. Each of these experiments has a unique pendulum that hangs from the top of a torsion balance apparatus by a thin tungsten fiber. As various forces interact with the pendulum, a torque is exerted along the fiber axis, and the pendulum is set into oscillation. To measure the amplitude of these oscillations, a laser is reflected off the pendulum into a series of mirrors, which eventually direct the beam to a detector located some distance away. The large distance from the pendulum to the detector amplifies any movement of the pendulum. On a typical day, the detector for a torsion pendulum is able to discern a harmonic oscillation of 1 nrad. To get a sense of this angle, imagine two lines traveling from Seattle to San Francisco separated by 1 nrad. If the lines were connected in Seattle, then in San Francisco, they would be only one millimeter apart!

2 Why test for gravity?

One experiment that is being conducted by the Eöt-Wash group involves tests of the gravitational inverse square law. One reason for doing these tests is to gather evidence for or against string theory. String theory predicts additional dimensions that would cause breakdowns in Newton’s inverse square law. Thus, finding variations in this law would give additional evidence for string theory, while finding no variations would restrict the size that these extra dimensions could be.

The pendulum that is being used for tests of the inverse square law consists of a gold-coated aluminum plate drilled with a number of holes in circular formation. Under the pendulum is a rotating plate drilled with holes of the same spacing. As the plate rotates, the potential energy of the pendulum (due to the gravitational force between the plates) reaches a minimum when the holes are aligned and maximum when the holes are not aligned. This means that there will be a torque on the fiber with a period equal to the time that it takes to move from one hole to the next. Measurements are taken at various distances between the pendulum and test mass. Breakdowns in the law would show a deviation in the magnitude of these oscillations from what is predicted by the inverse square law.

3 Why test for spin dependent forces?

There are currently two pendulums that have been constructed in order to test for spin dependent forces. One has been constructed to test for the existence of the axion - a particle with very little mass and no charge that was theorized to resolve the strong-CP problem in quantum chromodynamics. The particle would act as a carrier for a new, macroscopic, P and T violating force and is a viable candidate for dark matter. The pendulum to test for the axion is made of a laser cut silicon wafer. The wafer is suspended between two electromagnets (pole gap = 3mm), which acts to polarize electron spins so that they make a loop around the fiber axis. As the current oscillates, the net direction of the electron spin shifts back and forth. Virtual axions mediate a macroscopic force between the polarized electrons in the electromagnet and the nucleons in the silicon wafer. The sign of the torque on the pendulum will depend on the direction of the magnetic field. Thus, there should be a recognizable signal (which corresponds to the axion force) at the frequency at which the current in the electromagnet oscillates.

The second spin pendulum was created to test for spin dependent forces on a larger scale. It is used to test for forces that have a specific direction relative to the Cosmic Microwave Background and for forces exerted by the sun and the earth. The pendulum consists of four octagonal stacks of SmCo and Alnico magnets. One half of the octagon is made of SmCo magnets, while the other is made of Alnico magnets. Electron spin provides 94% of the magnetism for Alnico, while only 63% of the magnetism for the SmCo; the remaining field is provided by the orbital of the electron. Each ring is magnetized to annihilate leakage fields so that only a net spin polarization remains. The pendulum is then hung on the balance and rotated (along with the laser detector) in the lab frame. If these macroscopic spin dependent forces do exist, then they can be seen as a torque on the pendulum at the frequency of rotation.

4 What problems can temperature cause?

With all of the pendulums, there are certain obstacles that need to be overcome to understand the accuracy of the measurements. Outgassing and the material expansion are two phenomena that can cause problems as the temperature fluctuates. Outgassing is the evaporation molecules, mostly water, from the surface of a material, the rate of which depends on the temperature of the material. Outgassing can become problematic if different parts of the pendulum are at different temperatures, or if adjacent surfaces are at different temperatures. The various rates of evaporation caused by these different temperatures will act to produce a net torque on the pendulum. The expansion of the materials near the fiber suspension is also a problem because it can cause the suspension to tilt, which in turn puts a measurable torque on the fiber.

5 Temperature Circuits

To understand the problems caused by temperature, the Eöt-Wash group uses three different temperature probes and circuits which include: a platinum RTD (Resistive Temperature Device), a thermistor and an AD590. The platinum RTD has a positive correlation with temperature. Thus, as the temperature increases, the resistance of the device increases. The thermistor has a negative correlation with temperature, and so as the temperature increases, the resistance decreases. Finally, the AD590 is an integrated circuit that uses the temperature dependent properties of silicon based transistors to emit a current that is proportional to the absolute temperature in degrees Kelvin.

The RTD circuit sends a constant current over a platinum RTD and a temperature compensated resistor. The resistor is matched to the resistance of the RTD at the middle of the desired temperature range. The constant current is created with a Ref102 precision 10V regulator which drops over another temperature compensated resistor that is buffered to the common pin of the Ref102. The voltage drops over the RTD and resistor are amplified by two AD621 ICs (Instrumentational Amplifiers), and then the difference between these voltages is amplified by a final stage AD621 IC, the output of which is connected to the DAQ (Data Acquisition) to record the voltages.

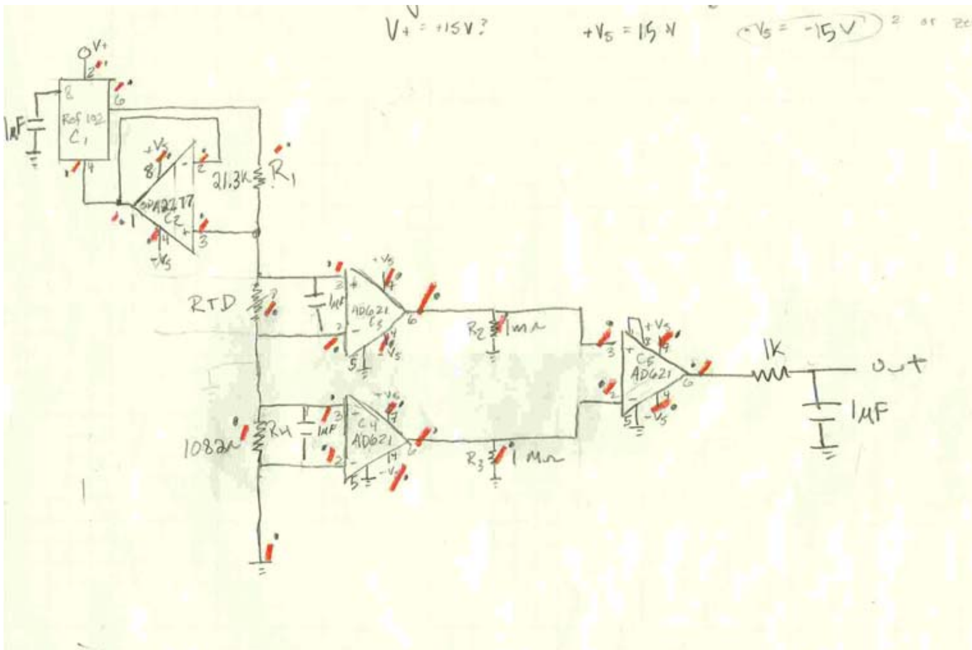

Figure 1: Platinum RTD Circuit

The thermistor circuit is centered around a whetstone bridge made of three temperature compensated resistors and a thermistor. The resistors are chosen such that at the middle of the temperature range, the resistance of the thermistor is equal to the resistance of the other resistors. The midpoints of the bridge are connected to the input leads of an INA114 Op Amp, which multiplies the voltage difference. The output of the Op Amp is then connected to the DAQ.

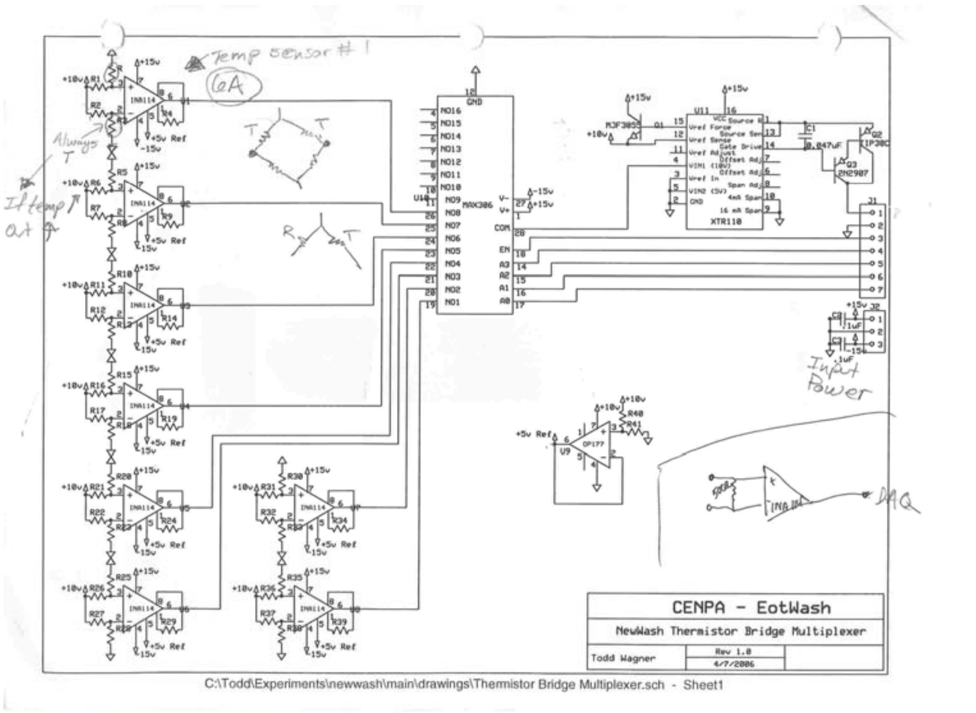

Figure 2: Thermistor Circuit

The AD590 is connected to a circuit that converts the AD590 current to a voltage using a OPA2277 Op Amp that and a temperature compensated resistor that is used to set the center of the temperature range. The output of this stage is then compared to a precision 5 Volt reference using an AD621 which is connected to the DAQ.

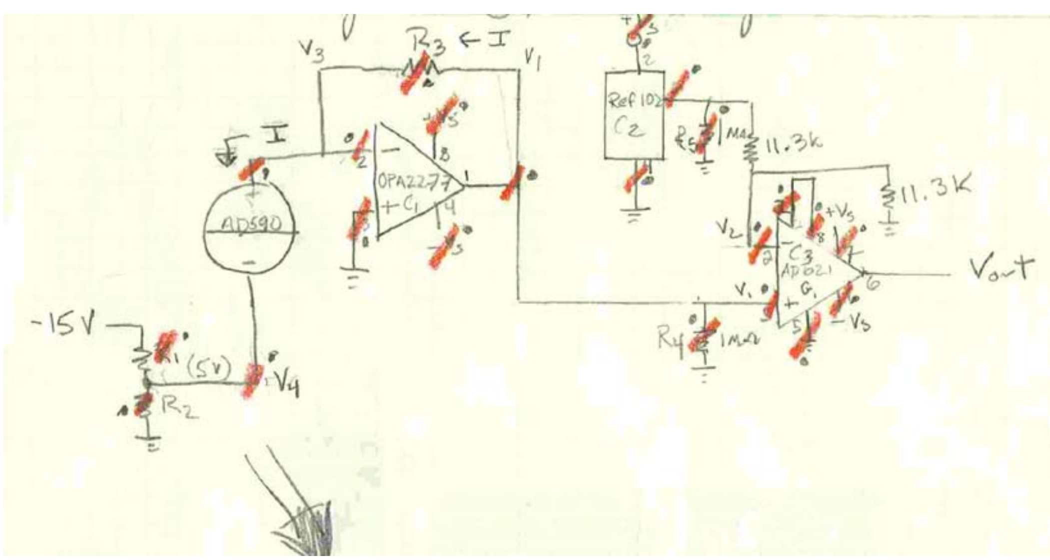

Figure 3: AD590 Circuit

6 Noise Testing

Noise is a potential problem in all of the circuits because it hinders our ability to know the temperature exactly. Because the noise performance of these circuits was unknown, I worked on figuring out which of them was the best in this aspect. I rebuilt two of the temperature probe circuits, and was able to obtain an original copy of the thermistor circuit. Then I decided to mount the probes on a copper block to keep the temperatures equalized. In order to fix the probes to the block, I drilled holes in brass bolts and glued them onto the inside with thermally conductive glue. Then I drilled and tapped holes to put the bolts in, and used thermal grease as a conductor between the two metals. I attached wires to the probes and twisted together each pair to reduce electromagnetic interference. Next, I put the apparatus in a temperature-controlled room near the Lorentz spin pendulum.

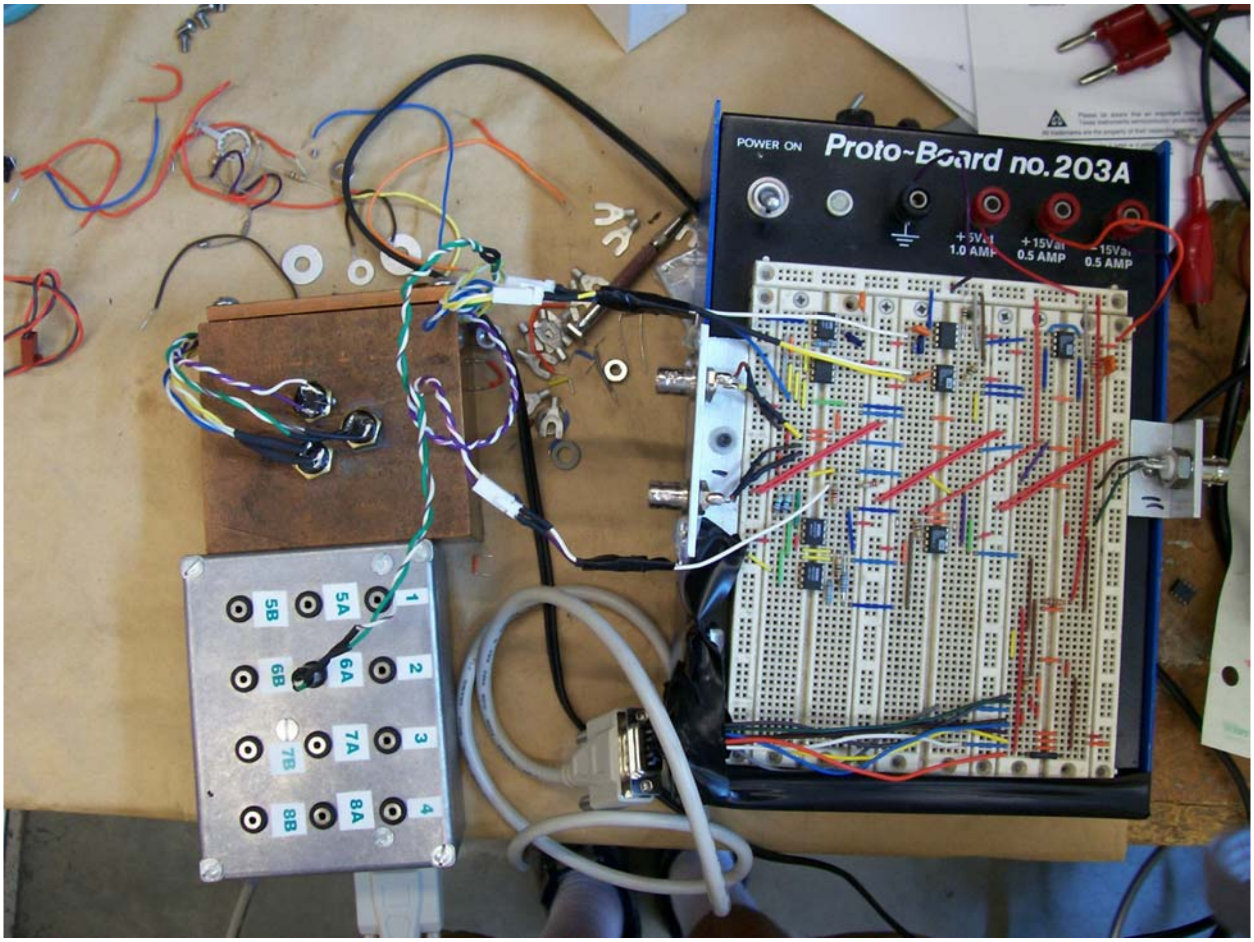

Figure 4: Temperature Circuits and Copper Block

7 Results

Temperature data was taken for a couple of days. The data was plugged into a Fourier transform program and graphed as Amplitude (deg C/rt(hz)) vs. frequency (hz). The sum of all noise at the pendulum frequency (including real temperature fluctuations) was compared for the three circuits at the pendulum frequency. The platinum RTD circuit had the lowest level of noise, while the thermistor had the highest level of noise. Thus we concluded that the platinum RTD is the best circuit out of the three. More tests are ongoing to compare an improved version of the platinum RTD circuit to a different version of the AD590 circuit.

8 Buffered Low Pass Filters

Another project that I worked on was to make a panel of five buffered low pass filters for the axion spin pendulum. These circuits were necessary to cut out higher frequency noise that was coming from the magnet current and temperature detector outputs. The DAQ that reads the output voltage of the circuit works by sampling and holding the voltage. If high frequency noise were allowed to pass to the DAQ, then the chance of sampling the wrong value would be much greater.

The circuits I built involve a basic low pass filter with a time constant around 50 Hz. An Op07 Op Amp buffers the output of the low pass filter, and the slight offset voltage of the Op07 is trimmed by a 20K potentiometer. The buffer is necessary to stop the output voltage from drooping more than .1 mV when it is read with a voltage meter (which has an intrinsic resistance that effects the circuit.) The circuits are soldered onto prototype board, which rests in a small aluminum box. The inputs and outputs of the circuit are connected to a stainless steel panel with coaxial cable and BNC connectors.

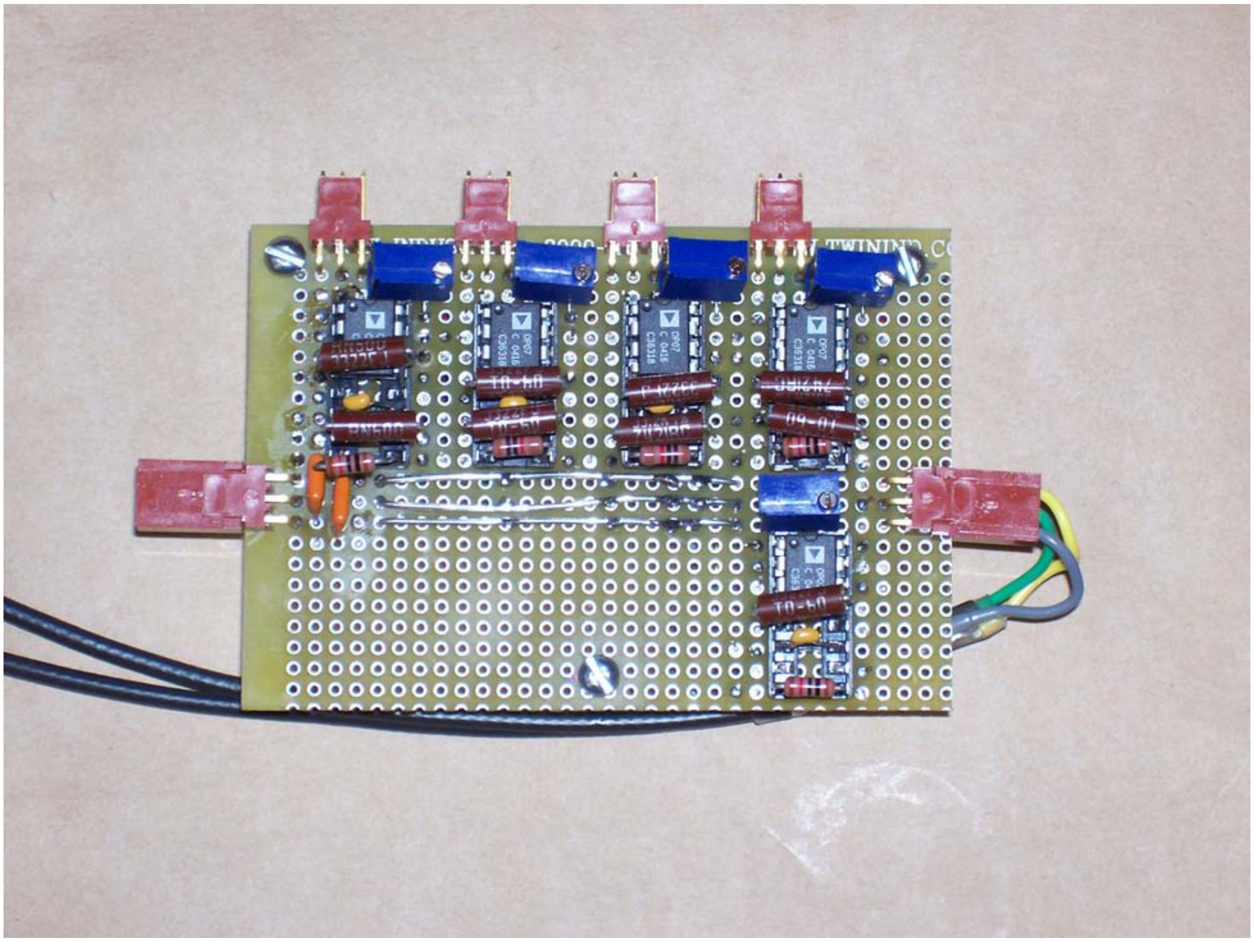

Figure 5: Low Pass Filter Circuits

8 References

1. B.R. Heckel. Torsion Balance Tests of Spin Coupled Forces
2. B.R. Heckel. Extra Dimensions, Scalar Fields, and CPT: New Tests of Nature's Oldest Force