Upgrades and Maintenance on the Silicon Detector at CDF

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Research Advisor: ______________________________________
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ABSTRACT

Maintenance and Upgrades on the Silicon Detector at CDF
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The CDF Run II silicon detector is the largest operating silicon detector in high-energy physics. Its 722,000 channels spread over 7 m^2 of silicon microstrip sensors allow precision tracking and vertexing. The CDF silicon detector played a critical role in the discovery of B_s mixing and is used extensively for the current Higgs Boson searches. Over the last 7 years, the detector efficiency has remained stable at 95% after the Run II commissioning period. While originally designed to withstand radiation doses equivalent to a period of 3 fb^{-1} of data, the CDF silicon detector will have to last until the end of Run II when 10 fb^{-1} of data is expected to be delivered. The paper presents the observed effects of infrastructure aging and the solutions implemented to prevent them, with the emphasis on work during the summer 2009 shutdown. We discuss upgrades in the data acquisition component testing, testing and installation of power supply modules, and the repair work performed on the detector cooling system. Taken actions ensure that CDF silicon detectors can run at high efficiency in 2010 and beyond.

1. INTRODUCTION

The Collider Detector at Fermilab (CDF) is one of two particle detectors located on the Tevatron, which is currently the world's highest-energy running particle accelerator. Designed for precision particle tracking and vertexing, CDF's silicon sub-detector was constructed as a vital element of the CDF tracking system [1]. It is capable of detecting and recording various events with the purpose of not only discovering new particles, but also studying the properties of known particles. In this way, the detector has become critical to both the growth and development of elementary particle physics, and it can even be partially attributed to the discovery of the top quark by CDF and its sister experiment, DØ, in 1995 [2]. It also played a crucial role in the discovery of B_s mixing and is used extensively for the current Higgs Boson searches.

Because the silicon detector is such a significant contributor to particle physics, we must constantly monitor the status of the experiment to make certain that all components are running properly. While the beam is turned on, high-radiation levels in the collision hall prevent various maintenance operations. This summer, the Tevatron went into what is expected to be its last major shutdown before permanently turning off. We used this time to perform maintenance, repairs, and upgrades on various aspects of the silicon system, including the power supplies for the silicon ladders, the data acquisition (DAQ) system, and the cooling system.

The high-voltage power supplies are located in the CDF collision hall, where electronic noise and power dissipation in cables can be kept as low as possible [3]. Radiation emitted by particle collisions is thought to be one of the main reasons power supplies sustain damage while the beam is running [4]. Placing the power supplies in the top four corners of the collision hall aids in minimizing the level of radiation exposure, but failure of power supplies is still observed. In 2005, reported power supply failures occurred at the average rate of nine failures per month, a rate that has significantly decreased over the years due to maintenance and upgrades [5]. During the ten-week shutdown this summer, we repaired and replaced faulty power supplies in an attempt to keep this number as low as possible. Supplies with irregularities were removed, sent for repair, and then tested to ensure the repairs were successful. We employed this method in order to decrease the amount of down time due to power supply failures while increasing the amount of time spent taking data.

The silicon DAQ system is responsible for transferring and recording data. When an event occurs inside the silicon detector, the CDF clock and trigger supervisor (TS) sends clock and trigger signals to the silicon readout controller (SRC), which is the core component of the DAQ [6]. The trigger system works with the DAQ system to record only the most interesting of events. Our main focus was to upgrade the Bit Error Rate Test (BERT) test stand used on DAQ components so that damaged hardware may be quickly and easily tested and replaced. In the past, the test stand has faced several obstacles, causing the results to be unreliable with high-error rates. During this shutdown, we collected and analyzed test stand data in order to understand these rates and calibrate such tests. We did this by tuning the temperature at which the transmitter laser components have to be kept such that sufficient light is emitted while failure due to condensation is avoided. In this way, we found the optimal temperature at which the test stand should be operated so that we can test enough spare hardware to last us through the end of the Tevatron's final run.

The cooling system helps to maintain a cool environment inside the detector. Without this system, the detector would not be able to dissipate much heat, and the entire device would become damaged. During the 2006 Tevatron shutdown, coolant in the lines turned highly acidic, which is thought to have corroded the various metallic components and caused the leaks that were discovered almost one year later [7]. Many holes and blockages were repaired in 2007, but new leaks may have formed since then. We analyzed cooling system data from 2004 to 2009 in order to determine if we needed to repair any other spots in the cooling lines. This process should increase the life of the cooling system so that the detector can continue to take accurate data until the end of the Tevatron run.

With the Tevatron in its final years, it is our goal to take as much data as possible with the silicon detector while we still can. In order to ensure this, it is important that all components of the detector are working properly. We made this possible by performing maintenance and upgrades on the power supplies, DAQ system, and cooling system. We provided several newly tested and repaired power supplies for installation in the collision hall. By updating the BERT test stand, we provided means to accumulate spare components for the DAQ system. Finally, we analyzed cooling system data to create plots that give insight on areas of possible leaks and blockages in the cooling lines. Through all of these efforts, we have helped to extend the longevity of the silicon detector by providing means to perform as long as possible through the rest of the Tevatron's run.

2. MATERIALS AND METHODS

i. Detector Overview

Seven central and eight concentric layers of silicon sensors come together to make up the three sub-units of CDF silicon, which are called the silicon vertex (SVX-II), the intermediate silicon layers (ISL) and layer 00 (L00) (see Figure 1). The core unit of the silicon detector, SVX-II, is made up of a total of five layers of double-sided silicon sensors arranged such that there are 12 30^{o}-wedges that can each be treated individually. This segmentation allows for the silicon vertex trigger (SVT) to identify tracks with large impact parameters [6]. Located between SVX-II and the main tracking chamber, ISL consists of one central and two forward layers of double-sided silicon used to extend the forward and backward coverage of the detector [8]. L00, the innermost layer, is unique in that it consists of one layer of single-sided silicon strips created to improve impact parameter resolution [6]. When the proton-antiproton beam is on, these three subunits come together with the power supplies, DAQ system, and cooling system to form the basis of the CDF silicon detector.

ii. Power Supplies

The high-voltage power supplies used for the silicon detector were customized by Costruzioni Apparecchiature Elettroniche Neucleari S.p.A. (CAEN) specifically for CDF. There were 114 power supplies that were mounted into 16 different crates, with four crates at each of the top four corners of the collision hall [9]. Monitoring these supplies through control room computers allowed us to find modules with incorrect current or voltage readings. After identifying these potentially faulty modules, we went into the collision hall to remove them. We did this by turning each crate off, waiting 10 minutes for the capacitors inside the crates to discharge, and then carefully pulling out each module. Upon being taken from the collision hall, these power supplies were tested for radiation using a frisker and then sent out for repair.

When the power supplies came back, we used a voltmeter to check the voltages of each channel before beginning a burn in test. The test consisted of hooking up the modules to a power supply test stand and turning them on for a 24-hour period. During this process, the modules were constantly monitored by a program we use to analyze the efficiency of the supplies. By using the channels monitor through the main menu of the program, we were able to tell if a module had tripped or remained working during the burn in test (see Figure 2). If all channels were still running after 24 hours, we went on to the stability test. For this test, the module is run for 700 120-second cycles, with two readouts during each cycle. This means that during each cycle, the supplies are switched on and off, and voltage and current readings are recorded twice. All of the readouts were sent to a text file, which we later used in conjunction with ROOT version 4.00/08 to create two histograms for each channel. These histograms plotted either current or voltage and were used to determine whether a power supply was functioning properly or not. Modules that passed both tests were entered into the CDF silicon detector power supply database, and then either stored for future use or taken down to the collision hall to be installed. Modules that failed either test were sent back for repair. For more information on removing, testing, and installing silicon detector power supplies, view references 10 and 11.

iii. The DAQ System

The DAQ system is a central component of the silicon detector, consisting of various sub-components that come together to perform a number of tasks critical to the functionality of the detector (see Figure 3). The DAQ task that we focused on improving during this shutdown was the converting of electrical signals to optical signals, which is done in order to analyze and record events that occur inside the detector [12]. Dense optical interface modules (DOIMs) are used to do this, with the transmitter modules (TXs) sending information to the receiver modules (RXs) [5]. The system is shared between all three silicon subunits, so in order for the detector to continue taking data, the TXs and RXs must be constantly working.

BERT test stand was invented to test these components so that whenever they fail, they can be replaced as quickly and easily as possible (see Figure 4). An issue that greatly affects the efficiency of the test stand is that TXs and RXs are incredibly sensitive to external conditions, meaning that testing sometimes results in many errors even if the modules are working properly. Our job during the shutdown was to upgrade the test stand to give accurate test results, despite the limitations. We did this by testing for the optimal operating temperature for the chiller connected to the cooling lines. This temperature would ideally keep the electronics as cool as possible and under similar conditions as in the collision hall, without producing an excess of condensation that may short-circuit the equipment. To minimize condensation, we built an enclosure that is kept at low humidity levels during the tests. We also installed new temperature probes such that we could record the temperatures once per minute during the 24-hour tests in order to rule out errors from malfunctioning cooling components. Finally, we discovered the optimal temperature by running tests on working TXs and RXs at a variety of chiller temperatures. We then used ROOT to plot the error rate as a function of temperature, and we analyzed the graphs to find the optimal running temperature. More information on the testing process and setup of the DAQ system can be found in reference 12.

iv. Cooling System

The silicon detector cooling system has two different chillers for the coolant contained in two separate cooling lines: the ISL, which also cools portcards, and SVX, which also cools L00. The SVX chiller contains 30% ethylene glycol and 70% water at -10 ^{o}C, while the ISL chiller contains 100% distilled water at +6 ^{o}C. The ISL and SVX lines are separated further, into the east and west portions. In each section, coolant flows through supply manifolds, into the cooling lines, and out return manifolds (see Figure 5).

The major issue with the cooling system revolves around the fact that in 2007, the coolant in the ISL lines became acidic, with a pH of about 2 [13]. This acidic coolant reacted with the aluminum piping to form holes that were repaired during a ten-week shutdown in the summer of 2007. During this repair process, DP-190 epoxy was used to block holes from leaking, the coolant was replaced with pure distilled water, and the vacuum pumps were set well below atmospheric pressure to prevent coolant from escaping from any unnoticed holes.

Although the leaks seem to be fine for now, it is important to view cooling system data so that we can decide if further actions need to be taken. We used ROOT to create plots of various data taken from August 2004 to June 2009. By creating and analyzing these plots, we were able to see how the cooling lines have changed over the past five years, helping us to form a better idea of what maintenance needs to occur in the near future. The plots also aided in deciding whether or not past maintenance techniques on the cooling system were successful. With this knowledge, we should be able to extend the life of the cooling system well into the final run of the Tevatron. For more information on cooling system maintenance, view reference 14.

3. RESULTS

i. Testing Power Supply Modules

Overall, we had 21 power supplies that would ideally be removed, repaired, and replaced during the shutdown. For each test we ran, histograms of both voltage and current were produced. The plots had a color scheme to make analyzing easy: green corresponded to a working channel, yellow represented a channel that may have failed, and red indicated that the power supply module was still in need of repair. When the voltage and current remained stable during a test, the plots showed a low number of bins and came out green. Conversely, when there were many voltage or current jumps, the plots had a high number of bins and turned red. Noting the colors of the plots made it simple for us to declare whether a module was working or not. Figure 6 shows an example of histograms created for some of the channels of an SVX power supply.

ii. Error Rate versus Temperature for the BERT Test Stand

We ran the BERT test stand with the chiller set at each temperature in one degree increments from 6 ^{o}C to 12 ^{o}C. After 24 hours, the tests were stopped and the errors observed per word sent, or the error rate, was recorded. Several trials were run to find the average error rate produced at each temperature tested. These average rates were then plotted versus operating temperature of the chiller at the test stand (Figure 7). Viewing this graph, we saw that most of the points seemed to fit the curve of a positive exponential.

iii. Temperature versus Time in 6F-C-3 of ISL East

This summer, we created plots of temperature versus time, flow versus time, heat load versus time, flow versus pressure, flow versus vacuum, and vacuum versus time for ISL and SVX east and west cooling lines, which are all available in reference 15. One of the most useful plots was the temperature versus time graph for the return temperature in an ISL east cooling line called 6F-C-3 (see Figure 5). The plot, which can be seen in Figure 8, contained various suspicious jumps that led us to performing a rate of rise test.

iv. Rate of Rise for 6F-C-3

A rate of rise test was done in order to see if the jumps of the temperature versus time graph of 6F-C-3 were indicative of a leak. During the test, we closed the coolant valves off and hooked a vacuum pump to its return manifold. The idea was to decrease the pressure in the line and then monitor it closely. If there was a sudden sharp increase in the pressure of the line, that would mean that the line contained holes that allowed air to seep in. The "rate of rise" of the pressure would give us more information on any holes that may be present. After performing the test, a pressure versus time plot was created to analyze the results (see Figure 9).

4. DISCUSSION AND CONCLUSION

i. Analyzing Voltage and Current Histograms

The voltage and current histograms created during power supply testing were used to declare whether or not a module was a good spare. In Figure 6**,** we see current histograms produced for one of the modules, SVX-19. As evident in the figure, current jumps occurred in channel DVDD0, causing the corresponding plot to turn red. The opposite situation can be seen in the histogram for VBIAS10, which shows a steady current throughout the entire stability test. The plot turned green, indicating a fully functioning channel. Although this channel was working properly, the module was sent back for repair due to the failure of DVDD0, and an entry was made into the database stating what had happened. For more information on power supply work that was completed during this shutdown, view reference 16.

The entire process of testing, repairing, and reinstalling power supplies repeated for many faulty modules taken from the collision hall over the ten-week shutdown period. Even so, we did not meet our goal of all of the 21 power supplies. This work will be completed in the near future, extending through the resumption of beam operations if necessary. In addition, detectors located on the Large Hadron Collider (LHC), which operate using similar power supplies, can use the information obtained from our power supply tests to perform tests of their own.

ii. Discovering the Optimal Running Temperature

By analyzing Figure 7, we found the optimal running temperature of the BERT test stand. We noticed that there was only one point that did not fit the curve. After much consideration, we decided to ignore this point and assume that the positive exponential curve is a good model of the effects of operating temperatures on error rates of the BERT test stand. In doing so, we concluded that the highest operating temperature with a near-zero error rate was the optimal running temperature for the test stand. After viewing the graph, we declared that the best running temperature was 9 ^{o}C. This temperature gave the smallest amount of errors while still being as high as possible, allowing for almost no condensation as well as little to no errors.

After creating the plots of error rate versus time, we noticed an unexpected jump at 10 ^{o}C. Taking the average rate should have prevented jumps from happening, but for some reason, this particular point did not fit the same positive exponential curve as the other points. We had attached thermometers directly to the TXs, allowing us to monitor the temperature of the DAQ components over time. We found that during one of the tests run at 10 ^{o}C, there was a 10-minute-long temperature spike that may have been due to a chiller malfunction. This spike could have caused the point to shift away from the curve on the graph. In the future, further testing will be done in order to assess the need to replace the chiller, and these results will be used to help make the BERT test stand more reliable.

iii. Using the 6F-C-3 Plots

The temperature versus time plot for 6F-C-3 caused us to conclude that the temperature in the cooling line was completely unstable. Due to this instability, we decided to further investigate the possibility of leaks in this cooling line. We did this by performing a rate of rise test on 6F-C-3, which fully supported our thoughts that the line may contain holes. The results, seen in Figure 9, showed an incredibly high rate of increase in pressure after the vacuum pump had been switched on. These results provided evidence of holes, confirming our suspicions that 6F-C-3 had been leaking.

The holes we discovered will be repaired in the near future. Because we do not know exactly where the holes are, other tests need to be performed first. We will then either patch up the holes with epoxy, which proved to be a successful method in the past, or block off 6F-C-3 altogether. Blocking the line is a method that will be used as a last resort only if we discover that the holes are too far away for us to reach and repair. Other future work includes further analysis of the plots we constructed this summer. With a little more effort, we may be able to use data analysis to discover and repair every single hole or leak in the silicon detector cooling lines.

iv. Benefits of Upgrades and Maintenance on the Silicon System

The Tevatron is expected to permanently shut off toward the end of 2011. The 2009 shutdown may have been our last chance to perform several weeks of maintenance and upgrades on the silicon detector at CDF. We used this time to repair, test, and replace faulty power supplies from the collision hall. We also updated the DAQ BERT test stand to be more accurate so that we can quickly and easily replace DAQ components in case they fail while the beam is on. Finally, we analyzed five years of data from the silicon detector cooling lines to better understand where leaks and holes may be present. When possible leaks were discovered through this method, we obtained more information by performing rate of rise tests. Through all of these techniques, we have been able to improve the overall performance of the silicon detector. We successfully extended the lifetime of silicon components, thus increasing the possibility that the detector will last throughout end of the Tevatron.

5. ACKNOWLEDGEMENTS

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7. FIGURES

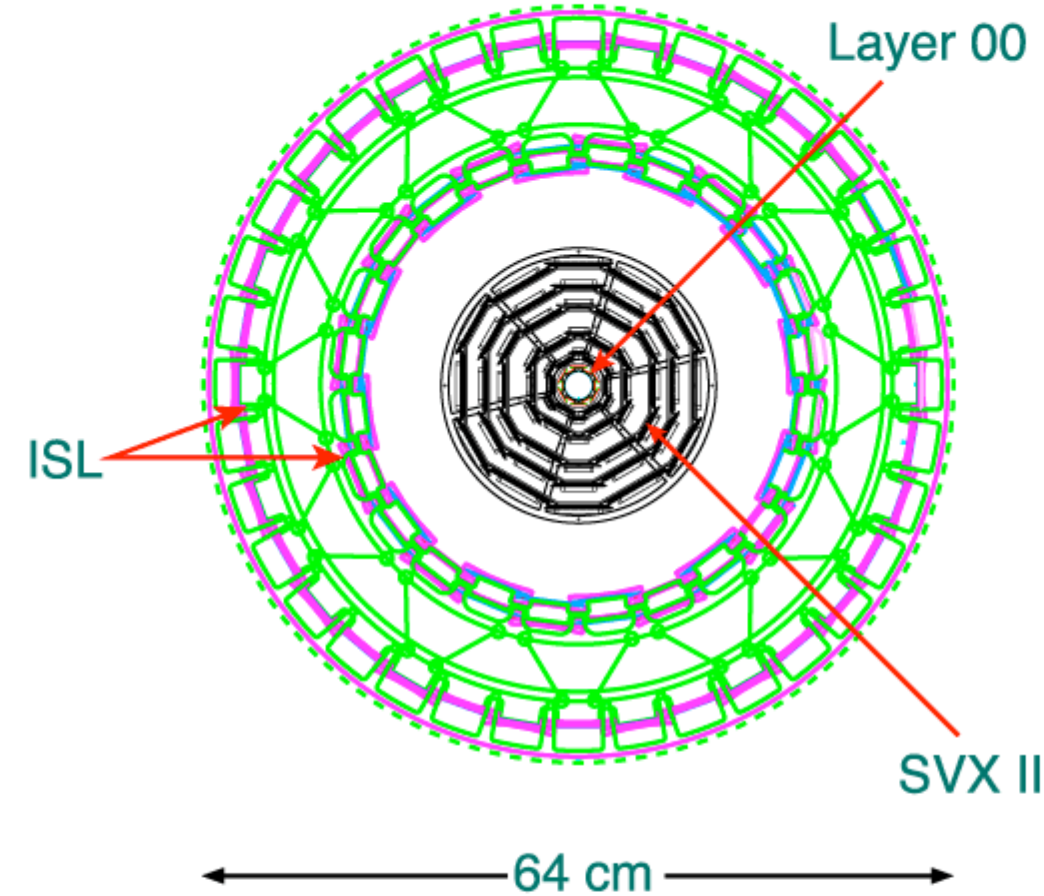

Figure 1: An end view of the CDF silicon detector.

Channel	Vmax	Rup	Rdwn	Trip	Status	Ch#
DVDD4	8	10	10	500.0	E-trip	0
AVDD4	10	30	30	1000.0	E-trip	1
VBIAS40	150	10	20	1000.0	E-trip	2
DVDD3	8	10	10	1000.0	E-trip	3
AVDD3	10	30	30	1000.0	E-trip	4
VBIAS30	150	10	20	1000.0	Ovv	5
DVDD2	8	10	10	1000.0	E-trip	6
AVDD2	10	30	30	1000.0	E-trip	7
VBIAS20	150	10	20	1000.0	Ovc	8
DVDD1	8	10	10	1000.0	Off	9
AVDD1	10	30	30	1000.0	Off	10
VBIAS10	200	10	20	1000.0	Off	11
DVDD0	8	30	30	1000.0	On	12
AVDD0	10	30	30	1000.0	On	13
VBIAS00	200	10	20	1000.0	On	14
VDOIM2	4	10	10	1000.0	On	15
VDOIM5	8	30	30	1000.0	On	16
DTERM	4	30	30	1000.0	E-trip	17

Figure 2: The channels monitor for an SVX module during a burn in test. If the module had passed, all channels would be marked “On” under the “Status” column. As we can see, some channels were turned off (Off), some failed due to over current (Ovc) or over voltage (Ovv), and some failed due to externally tripping (E-trip). This module failed the test and was sent back for repair.

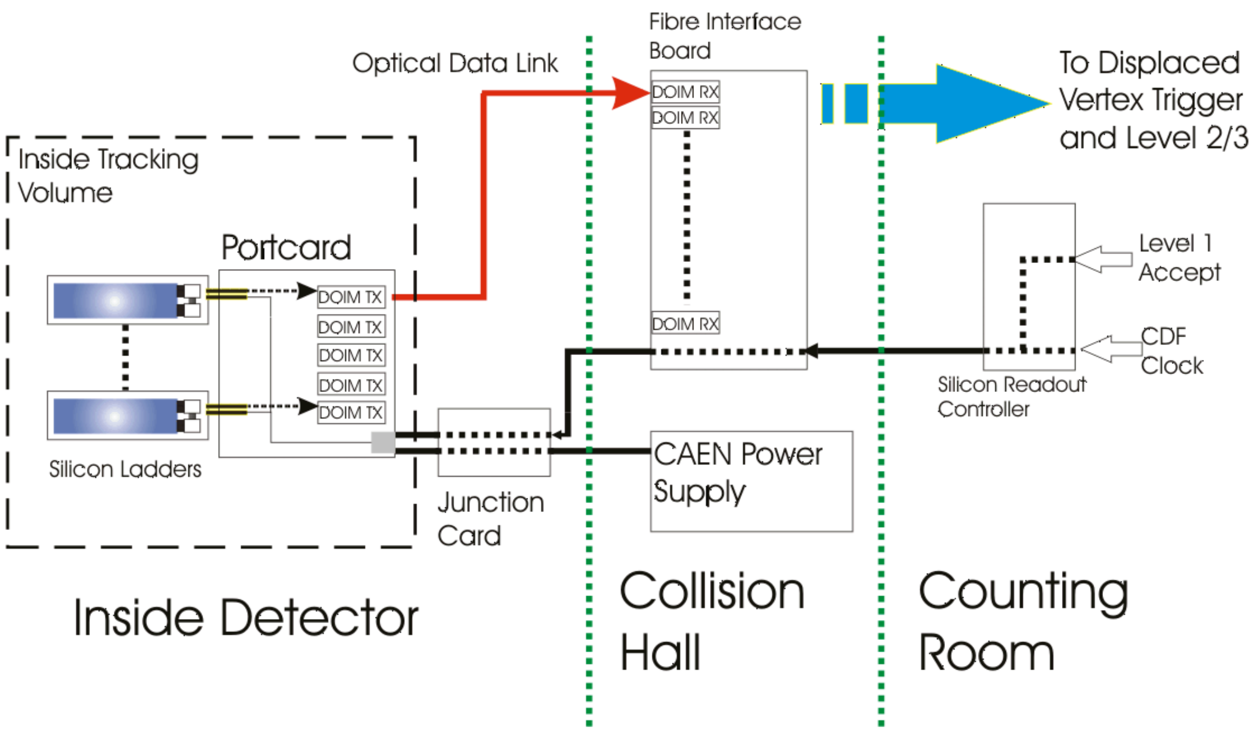

Figure 3: A schematic of the silicon DAQ system. When an even occurs inside the detector, information is sent from the silicon ladders into the TXs, which then transfer the data to the RXs.

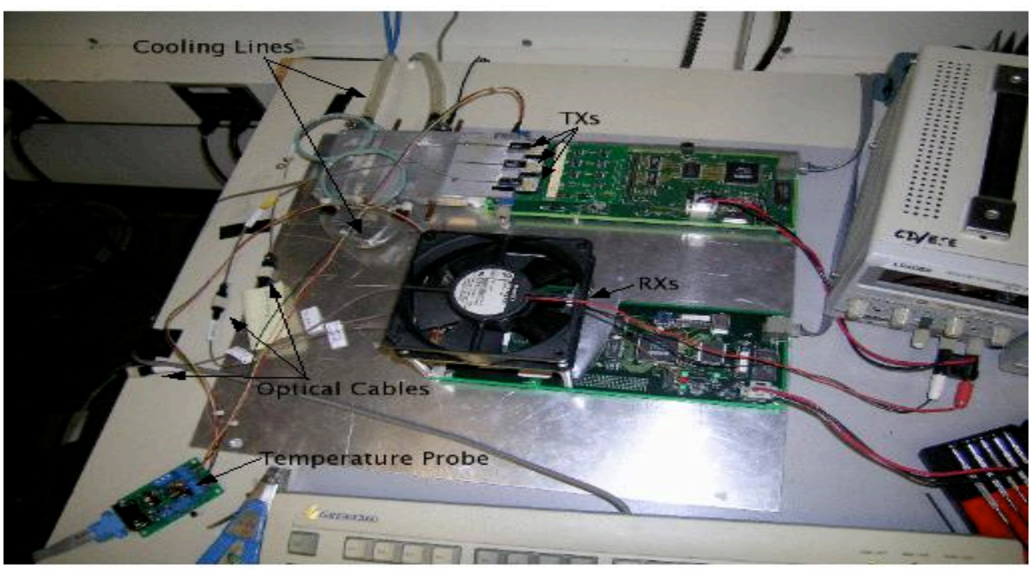

Figure 4: The BERT test stand is used to test TXs and RXs. Information travels from the TXs, through the optical cables, and into the RXs. If the Information sent does not match the information received, an error is recorded. Cooling lines are used to keep the electronics at a low temperature, which is constantly monitored by the temperature probe.

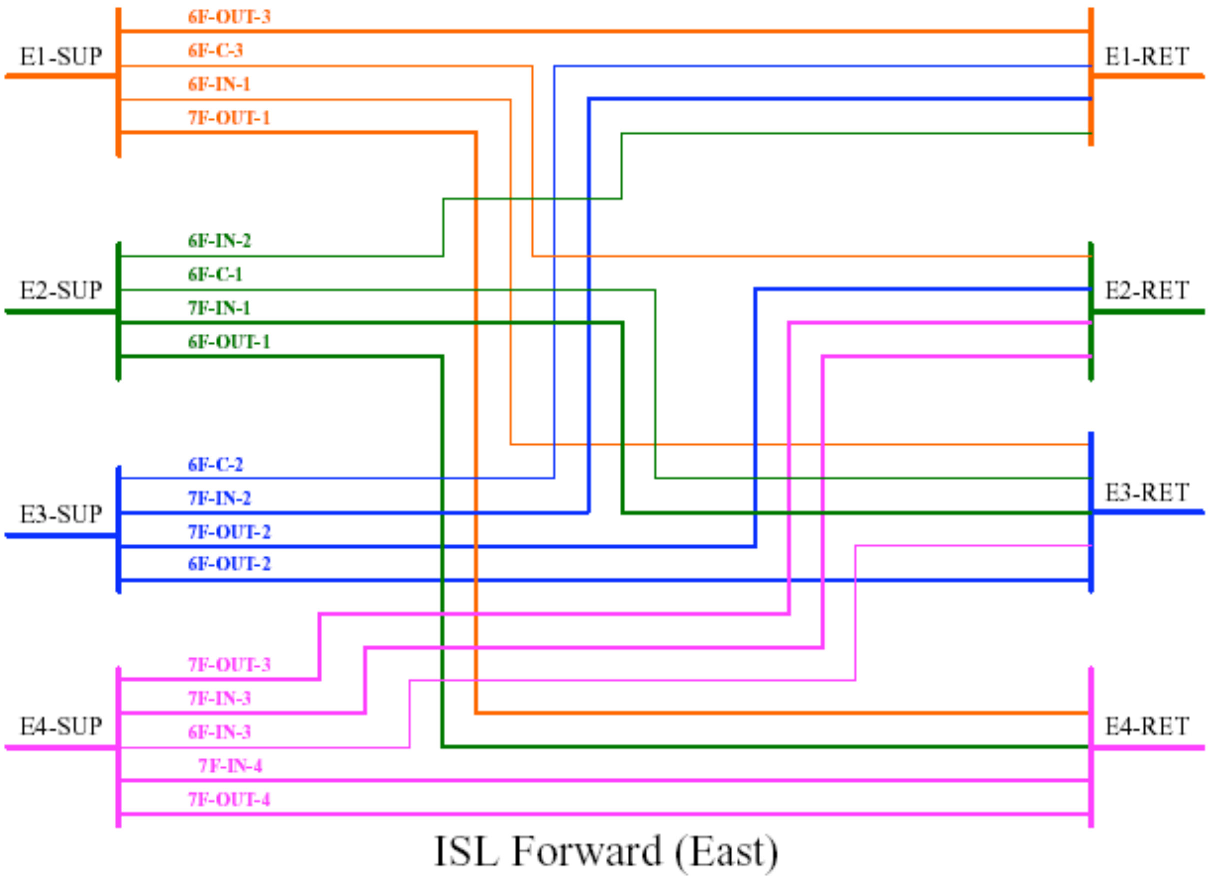

Figure 5: The setup of the ISL east cooling system. The coolant flows through the supply manifolds, into the cooling lines, and out the return manifolds before going back to the chiller and being pumped through again. 6F-C-3, the second line from the first supply manifold, was discovered to have a leak through our testing.

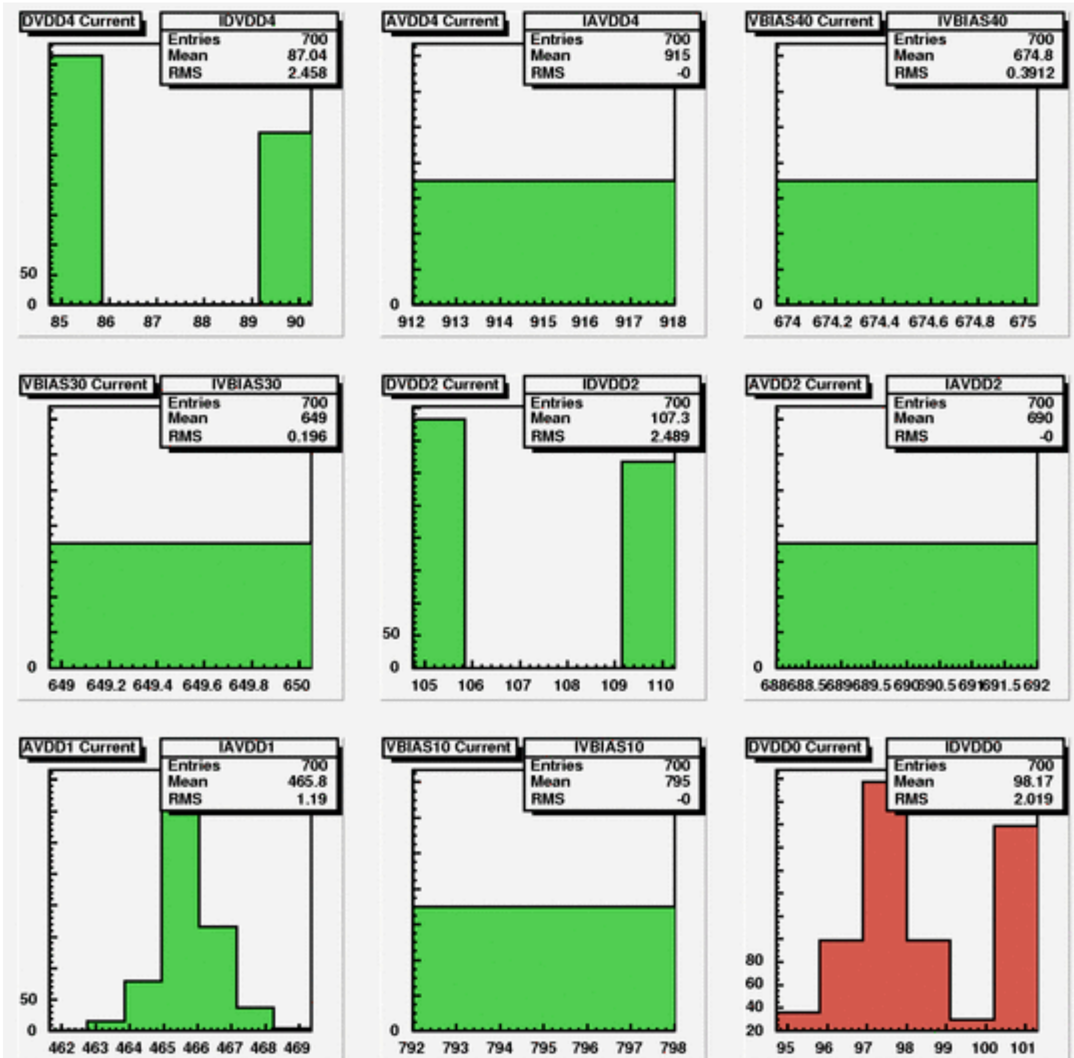

Figure 6: Current histograms produced for some of the modules of SVX-19. DVDD0 failed due to jumps on current, while the other channels, including VBIAS10, passed due to a stable current. The module was sent back for repairs on channel DVDD0.

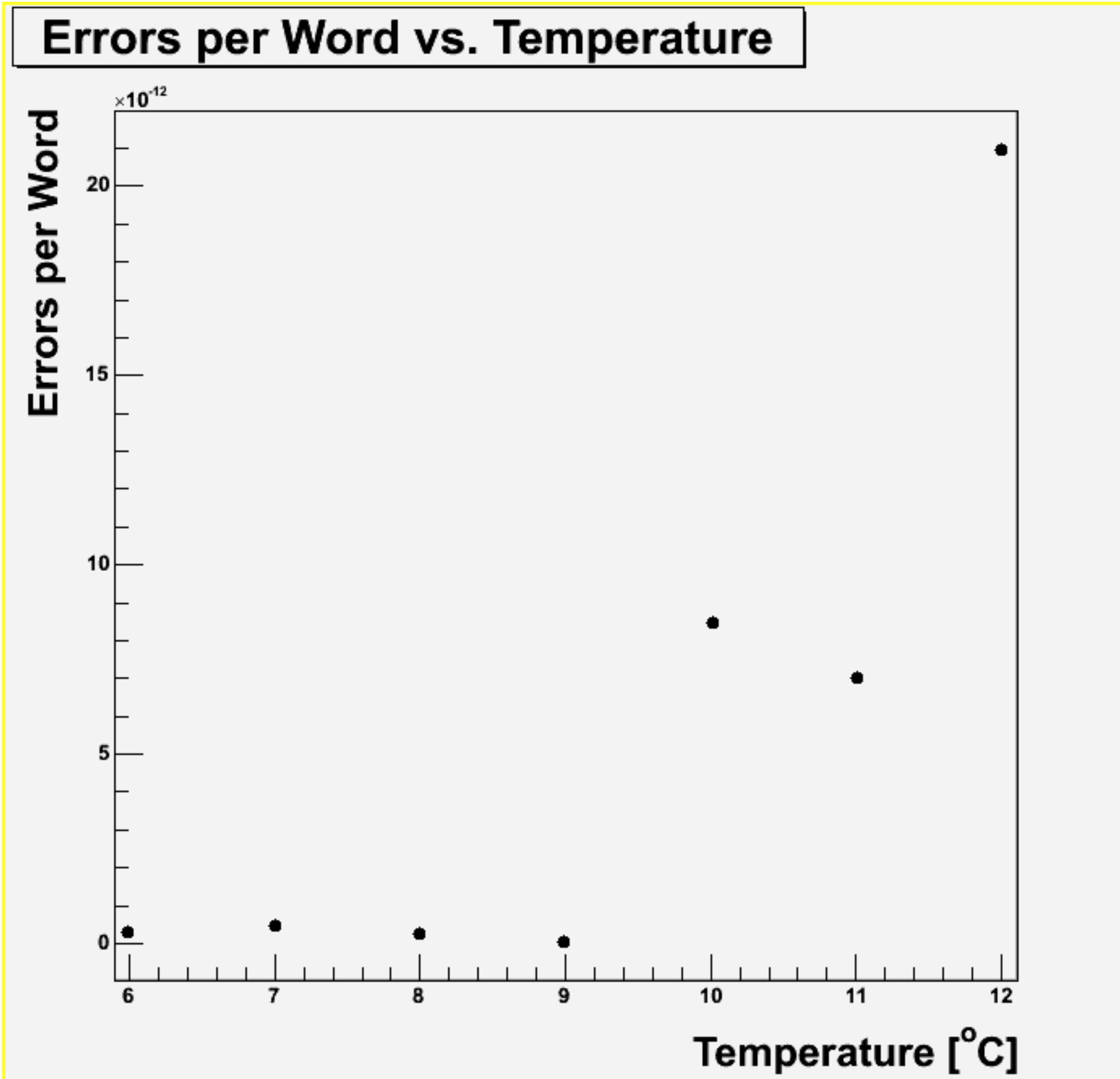

Figure 7: The errors per word, or error rate, of the BERT test stand for various chiller temperatures.

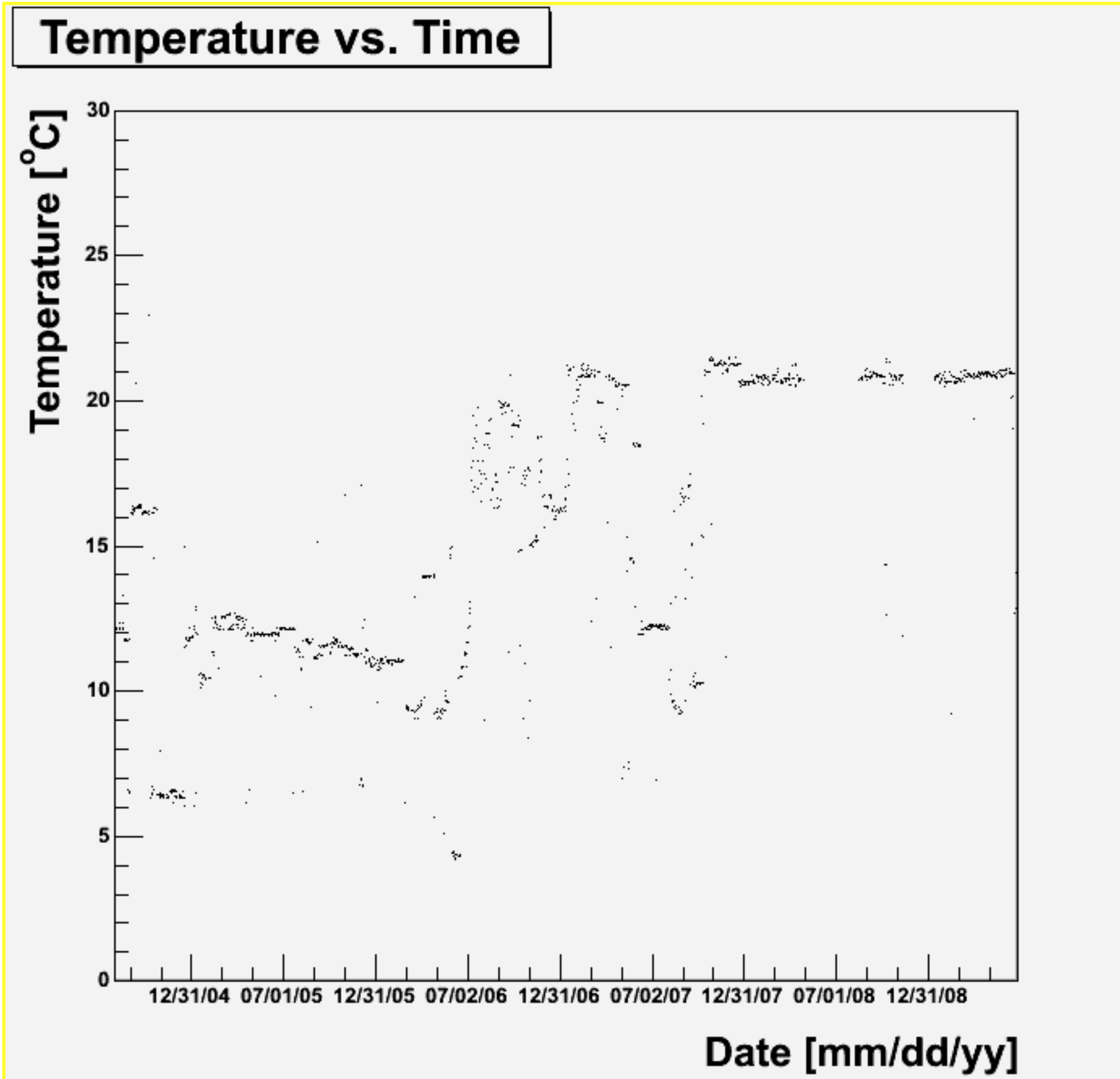

Figure 8: The temperature versus time plot for 6F-C-3, one of the ISL east cooling lines. After noting the instability of the graph, we concluded that the line might have a leak.

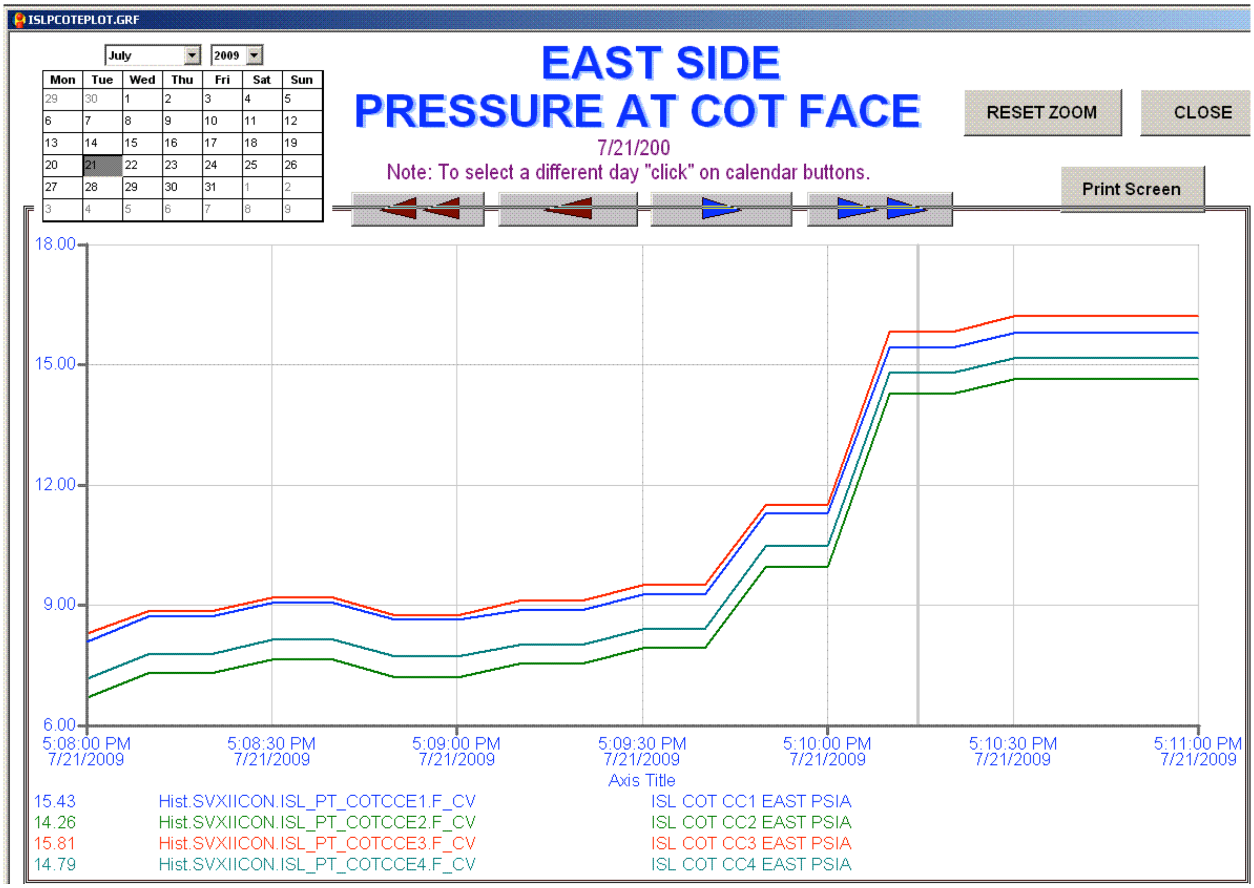

Figure 9: The results of the Rate of Rise test on ISL east. The sharp slope that occurred at 5:10:00 PM indicated a leak in the system.