Understanding and Testing of CLEO Electronics

Byron Johns

School of Engineering and Technology
Hampton University: Hampton, VA, 23668

Abstract

The CLEO detector is a high energy physics detector that analyzes particle collision events generated by the CESR storage ring. The Crystal Calorimeter and Drift chamber parts of the detector need regular maintenance and occasional repairs to keep the detector up and running. MQT boards, TQT boards, and M/S boards needed to be repaired. Each electronic board has to be individually tested for shorts, good signals coming in and out of each channel, good pedestal readings, and linearity checks. In addition, each board had its own tests to pass in its respective program. Each problem that was discovered in the board was worked on; this included repairing and replacing various chips, reconnecting broken traces, disconnecting parts that caused shorts in the board, replacing dead resistors and capacitors, which all are important to a good signal readings from each board. Repairing these parts will leave more spare electronics to be used for the Crystal Calorimeter and Drift Chamber for CLEO.

Introduction

The Crystal Calorimeter (CC) and Drift Chamber (DR) are two major components in the CLEO Detector. In order to keep the CC and DR up and running, spare parts need to be maintained. The M/S, or **M**ixer/**S**haper electronics mix and shape signals from the photodiodes on the back face of each crystal, sending a board-sum signal to the trigger, and a sum for each crystal onward to the MQT boards. The MQT boards are used to perform **M**ulti-range integration of signals from the M/S boards, converting charge (**Q**) to time (**T**). Once the charge is converted to time, the TDC boards will be used to convert the time to a digital number that CLEO can use. These two boards are used in the Crystal Calorimeter. The TQT boards are used in the Drift Chamber to convert preamp signals into **T**rigger, Charge (**Q**), and **T**ime signals. All three of these electronics needed repair, which was my task for this summer.

Step I: MQT Repair

The first step in creating spare electronics for the CLEO detector was repairing the MQT boards that will be used in the Crystal Calorimeter. Each MQT board consists of 32 LeCroy MQT chips, one chip per channel. Every MQT board takes output from two M/S boards. The MQT testing involves the following steps:

1. Check read-back of ID string

2. Check for Sbus errors when writing to electronically-adjustable resistors

3. Measure pedestal positions and widths, checking widths and separation

4. Change offset current as controlled by resistors and verify that pedestals shift as expected

5. Measure electronic gain, slope, and intercept

6. Verify that for small pulse-heights the edge-order of the three ranges does not become confused by monitoring their widths as a region of small signal size is scanned.

One of the main problems that occurred with the MQT boards was they would fail the pedestal test. This was often fixed by replacing the LeCroy chip. Often chips that would fail in one board would work well in another board, or even on the same board in a different channel. The reason for this has yet to be discovered. Occasionally the chips would develop an internal short during testing that would literally rip the face off the chip and cause flames and oily smoke to develop, which ruins the socket. It's actually pretty cool! Another error that would occur is that a channel would have no hits. Then I could pull out the schematics for the board and use the oscilloscope to trace for the bad signal. Sometimes I would have to trace from the input of the board through the bad channel all the way to the output to find the signal. I would have to command the program to "pulse" which would send signals out constantly to the boards so that the scope could pick up a steady signal. Often errors could be due to assembly error such as parts mounted in the wrong orientation. If pins were soldered together in wrong places it could cause a short. The toughest part of this assessment was probably finding which chips would work in which channel in which boards. When it was all said and done, the CLEO CC now has more spare MQT boards to use.

Step II: M/S Repair

The next step was to repair the M/S boards. Each M/S board handles 16 crystals, each with four photodiodes glued to the back. The four photodiodes for a crystal are *mixed* together into a sum for that crystal. The sum is then *shaped* into a signal with amplitude proportional to the amount of light in the crystal. So there are 64 separate signals for 16 crystals that enter the board and they are mixed and shaped into one signal per crystal. The M/S power supplies were built around the same time that the boards were built. They supply not only the power voltages required for the digital M/S logic, but also the preamp power (four separate supplies of 15V, one for each photodiode) and a bias voltage applied to the photodiode to decrease the noise. Having too much bias voltage will lead to a large leakage current which will increase the noise.

The test program that is run, written by Tom Meyer, is written to test two M/S boards at once. The steps for testing the M/S boards were:

1. Check for shorts between the preamp power connection using an ohmmeter and specialized fanout box.

2. Check that all front panel LED's on each board light when power is turned on.

3. Check digital read-back of SUM and GAIN Sbus registers

4. Check pedestal noise levels for each diode circuit by measuring MQT pedestal widths with a single diode enabled at a time, connected to real preamps.

5. Check linearity of M/S shaping stages for each diode circuit for the full range of calibration pulse-heights.

6. Check that the BDSUM signal is output properly to M/S backplane for a single calibration pulse-height by observing with an oscilloscope the signal at the trigger output of the crate controller.

Even though the output of the four photodiodes are summed together, a failure of a single circuit does not eliminate all the information from the crystal the circuit is associated with. The common problem that occurred was when one of the circuits wasn't read on a channel. Each of the 16 channels on the board have four circuits (A,B,C,and D). So when the linearity test was done, it had to be done with each circuit on each channel. Since the M/S boards were made many years ago and are older circuit boards, a lot of the parts are sticking up out of the board, as that is the way they were mounted. So any person picking up the board could accidently bend and break one of the resistors with their finger causing damage to the board.

Most of the common problems that arose when testing the boards was the failure of individual circuits. These circuits could just not work, or be very noisy. Common errors were digital errors due to broken logic in the board, broken charge-injection FET's, blown fuses which would cause the LED's not to light up, and also problems with the trigger BDSUM signal. Often there would be a LED light that wouldn't light up like it should when the power was turned on on the test stand. This was often due to a blown fuse in a circuit. Simply replacing the fuse would fix the LED light each time. Another problem that would arise in one or more circuits per channel on the board would be when the slope of a fit to data would be very small on the linearity and gain test. Whenever there would be a problem on just one circuit and not the whole channel (which would show up as each circuit was tested individually during the linearity test, and when testing the gain and noise the program would tell which circuit the problems were in) it could often be due to bad components. I would use the schematics papers for the M/S boards to see how the circuit was laid out. Then, just like with the MQT boards, I could go through the circuit to try to find the bad components. First I used the oscilloscope to look at the signal coming out of the preamp cables into the board, then look at the signal output through the components. I would also use the voltmeter to look at the connections, to see if maybe something had come disconnected or wasn't completely soldered down.

The fun came when I had to replace the parts. The hardest part to replace had to be the transistors in the circuits. I used little wire snippers to try to cut each of the 14 little pins on the part, which were surrounded by various capacitors and resistors. So I had to make sure I didn't catch any of the other parts with the wire cutters. once I cut the pins, I removed the transistor, but the little pieces of metal pins were still all soldered in the holes. Now instead of using solder wick, I used this little solder suctioning tool. I would melt the solder with the solder iron from the back of the board, then use this suction tool to simply suck the metal pins and the solder one by one up out of the board. It got easier each time with practice. Sometimes the pins would be stubborn and not come out, so I used a little needle-like tool to poke the pieces out when I could.

Occasionally there would be a short in the board, but I was unable to fix any of them. My mentor, Selina, and I, would use the voltmeter to look for connections that shouldn't be by comparing them with another good board. With so many components on the board and so many connections, this was like trying to find a needle in a hay stack! When you have a short, in these boards, I say if one thing is connected, then everything is connected! One small drop of solder in a place it shouldn't be could connect, say, pin A on a chip to pin B on a chip. This piece of solder will not easily be seen, if noticed at all! So everything that pin A is connected to and pin B is connected to will connect. And everything that the chip is connected to will connect to those connections, and so on, making the use of a voltmeter helpless.

Replacing parts was the primary job in repairing these Mixer-Shaper boards. Now that I have worked on them all summer, CLEO has about 19 spare M/S boards, when at first they didn't have any! There are still several bins of boards that need repair for the future, but these 19 boards that I have repaired as spares is a good start!

Step III: TQT Repair

The final part of my project was to fix the TQT boards which are used in the Drift Chamber of the detector to convert the signals from the preamps into trigger, charge, and time signals. Each TQT board has 48 channels (Channels 0-47). The signal comes in from the preamp cables in the actual detector, but during testing, we simulate the signal by using a LeCroy pulse generator. The steps for testing the TQT electronics are as follows:

1. Check the trigger output for each channel on the board, the trigger decides when there is an actual collison of particles, or an event, in the detector, and records the data, so this is very important.

2. Check the timing hits for each channel, making sure that the signal hit arrives on time.

3. Check the charge pedestal width and if the pedestal hits come at the expected time.

4. And as always, check the linearity of the channels.

On the TQT boards there is an Altera chip that has to be programmed for each board. If that chip doesn't boot, then you won't see any trigger output out of any channels. If the rest of the board functioned OK, it was set aside to be used in the ZD (which is a new drift chamber being built), that will not be used in the trigger. Other times when there would be no trigger output on any of the channels, then I would look through the schematics of the circuit, looking for something that would cause every channel to be bad. I found that all channels are connected to a translator threshold circuit. The threshold sets a limit that a signal must reach in order for it to be a hit. If the signal is below this threshold, it can be written off as noise or something. First I tried replacing the resistors in that circuit, but that proved no luck, so I replaced the AD817 which is a high-speed, low power, wide range amplifier chip. This proved to help at least give a trigger reading out of the channels, but it was still a bad reading. When there was a problem with just one channel, I could pull out my old friend Mr. Oscilloscope and start poking around. I would start by looking at pin 6 of the receivers, which is the signal output pin, for the bad channels. The signal from the preamps (or in this testing case, the pulse generator), had to first go through the receiver. There are two different signals that come out of the receivers. There is the timing signal and the charge pulse signal. The signals split up and go through different parts of the board for each channel. The signal coming from the charge pulse will sort of look like one period of a cosine wave. The amplitude of these signals represents integrated charge on the wire. The timing signal is a square pulse, which marks when the signal hits. Often I would see a bad signal coming from the receiver which would mean no signal or a bad signal was going through that whole channel. In this case I would replace the receiver. When the receiver was OK, I would follow the schematics searching through the rest of the channel looking for a bad signal, comparing the signals to the good channels.

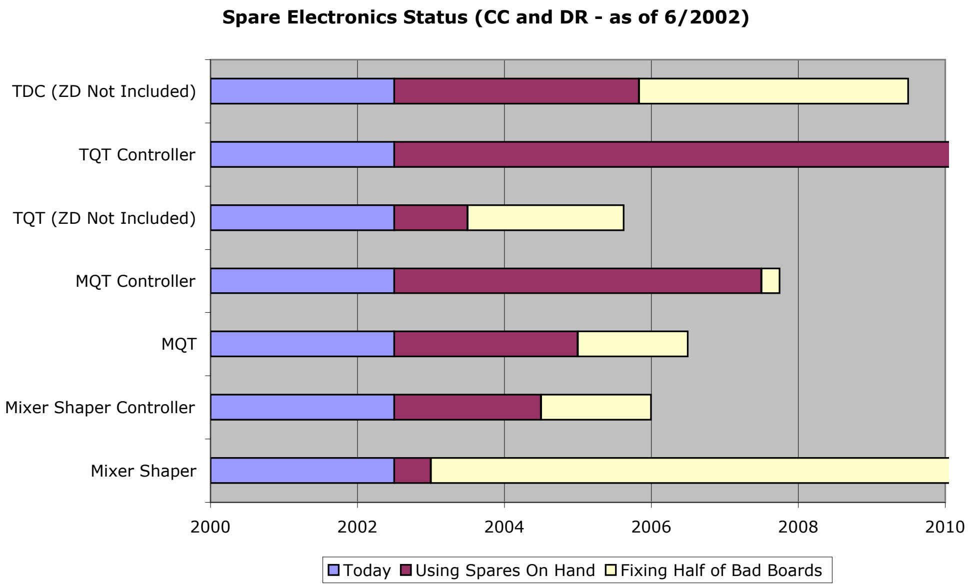
Most of the time all of the boards and each channel would pass the timing hits test. Any error was usually due to something minor like the noise. This error was negligible because the boards are surrounded by various running electronics and machines all throughout the lab. Also the TQT boards, like the M/S and MQT boards, are placed on an extender card so that it is easier to check for signals with the oscilloscope if the board is sticking out of the crate. So this noise is expected, just like the timing hits could be a little off for the extra 18 inches (about the length of the extender card) that the pulse has to travel to from the pulse generator cables to the FastBus crate. When the noise was extremely high, like over 5 times the width of the good channels, then I would look around the board for a signal with the scope in search of error.

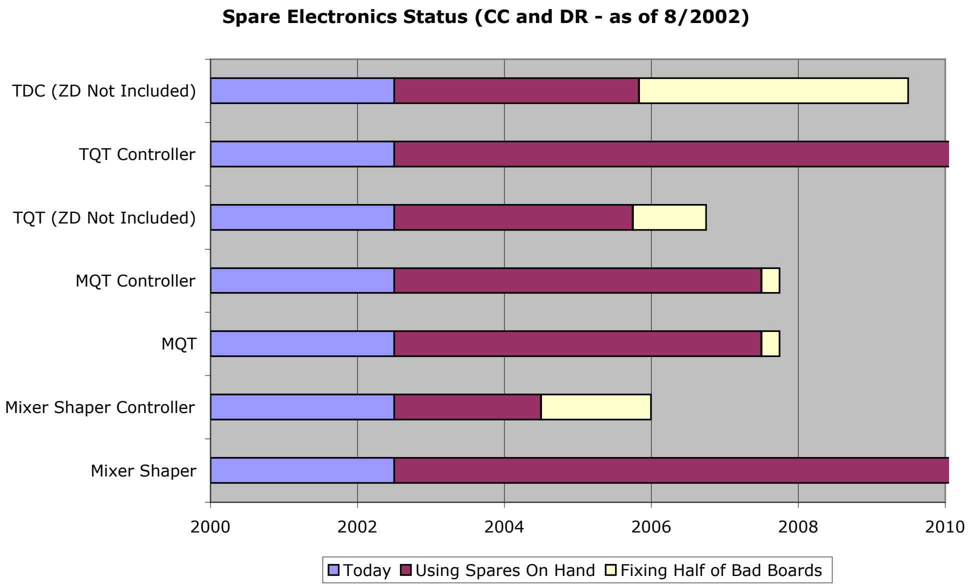
The linearity was the main test, as always, where we could see if the signal out of the board was linearly proportional to the signal in. One of the reoccuring problems would be that a channel was flat, meaning it would see no hits, have no slope or a very small slope, and have no intercept or a very large intercept. This problem could often be solved by replacing one of the components on the board that was bad in that channel. The op-amp chip where the signal comes through not long after it comes through the receivers was the bad part for a few times. Other times there were external wires that were needed to connect a pin from a chip to another pin on the same chip or even a different chip, because of missing or damaged pads underneath that you would solder the chip pins too. When replacing a chip it was possible to disconnect a trace in the board, which would require small thin external wires to be soldered on to repair the broken connection. There are also these microscopic resistors on the back of the board (really about the size of dust molecules) that would break or simply be accidentlly scraped off unnoticably. These were also the reason for bad channels. All in all most problems encountered were due to bad or dead components on the board that just hadn't been spotted yet, and once fixed or replaced, would solve most problems.

Conclusions

There are still several kinds of electronics that need maintenance and repair. Most of the TQT boards have been repaired, there are still several bins of M/S boards, and some MQT left. The problem with the MQT's is that the manufacturer has stopped making the LeCroy chips that are used in each channel, so all CLEO can do in the future is keep switching around chips, since some chips will fail in some slots but pass in others. Boards can still be fixed by going through the same steps that I have. It may be a matter of trial and error in replacing parts that may be the problem, because you may replace something that wasn't the problem in the first place. On the following page there is a chart of the CLEO electronic spares that are available now after I have been working, compared to those at the beginning of the summer. The first bar (the gray bar) represents where we are now with the electronic spares we have. The dark bar (in the middle), shows how long CLEO can last with the spares they have before I started working (on the first chart), and how long they can last now with the spares that I have repaired (second chart). The light colored bar (the last bar) shows how long CLEO can last if they repair half of the spares that they have left over. Notice the biggest change is in the M/S boards, CLEO now has enough of those to last through the year 2010, when at first they could only last into 2003!

This program was a valuable learning experience for me. I learned more about how electronics work and how to repair electronic components. I also learned how to use an oscilloscope to find where a bad connection may be in a circuit. I learned that even having the slightest touching of two small metal parts in a closed circuit could cause a short, blow a fuse, or do some other damage. Seeing how scientist work in the work place made me know that I won't be a physicist, but I knew that months ago when I switched my major to Electrical Engineering. I think I will still major in EE because I want to learn more about electronics and it is still interesting to me. More than likely I may go to graduate school for Automotive Engineering to learn more about cars. I feel the more experience I have with research programs/internships, the better feel I will get for what career I want to choose.


Spare Electronics Status (CC and DR - as of 6/2002)
TDC (ZD Not Included)
TQT Controller
TQT (ZD Not Included)
MQT Controller
MQT
Mixer Shaper Controller
Mixer Shaper
2000
2002
2004
2006
2008
2010
Today
Using Spares On Hand
Fixing Half of Bad Boards


Spare Electronics Status (CC and DR - as of 8/2002)
TDC (ZD Not Included)
TQT Controller
TQT (ZD Not Included)
MQT Controller
MQT
Mixer Shaper Controller
Mixer Shaper
2000
2002
2004
2006
2008
2010
Today
Using Spares On Hand
Fixing Half of Bad Boards

Acknowledgments

I would like to thank everybody who helped me on my project. My mentors Selina Li who is a graduate student at the University of Minnesota, and Matt Shepherd who is a graduate student here at Cornell, for their guidance and support. I'd also like to thank Tom Meyer who wrote the programs needed for the electronics testing, and for his assistance to me and my mentors in the project. A special thanks to Chris Stepaniak for helping me with some computer programming languages that I had never used before, including this *LATEX* format that this report is written in! And finally, thanks to Rich Galik, Lora Hine, and Monica Wesley for giving me the opportunity to participate in this program, which has been a valuable experience. This work was supported by the National Science Foundation REU grant PHY-9731882 and research grant PHY-9809799.

References

- Care and Feeding Manual for the CLEO III Calorimeter website, created by Tom Meyer.

  `http://www.lns.cornell.edu/~tom/cleoiii/cc`

- Cleo III Electronics manual hard copy, printed by Tom Meyer