

Summary Report on an Engineering Review of the DUMAND Trigger Processor

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1 Scope of this Document

This report summarizes the results of an engineering review of the central portion of the DUMAND shore station data acquisition system, known as the Trigger Processor (TP). This system will be described in more detail below. The intent of this report is to make these results known internally to the DUMAND collaboration and also to other sponsors or reviewers of DUMAND for whom this information is important in assessing the status of the shore station subsystem of the detector.

This report does not attempt to provide a complete assessment of the functionality of the TP system, since the 2-day review was too brief to perform such an assessment. It can, however, give an estimate of the likelihood that the present system is converging toward a functionality which meets the original specifications. This report will provide guidance on this topic, although the final decision on whether to pursue a different design rests with the DUMAND council since it will have major impact in a number of areas.

2 Trigger Processor design

The basic components of the system are the clock correction board (CCB), the first level processor (FLP), the data harvesting digital signal processor (DSP), the gatekeeper/crate-controller computer, and the data archiving computer, a SUN sparcs-2. These are shown in figure 1. The CCB receives the serial data from the shore cable fiber, converts it to a parallel word, does some arithmetic functions on the time bits to re-synchronize the incoming data with a master clock, and provides this synchronized data to the FLP for trigger formation.

The FLP provides a number of hardware triggers, described elsewhere, called T3s, T3skips, CM events, longons, and error conditions.

These trigger conditions cause the FLP to provide an interrupt to the DSP which then reads the data stored in a FIFO in the FLP. The DSP searches for some further trigger conditions involving total energy of an event or cross-string triggers, and then notifies the 68040 of the event. The 68040 reads the event and notifies the Sparc, which then reads the data over an ethernet link. A more complete description may be found in the document produced by the Wisconsin group, attached to this report as appendix 1.

3 Trigger Processor Test setup

Since it had not been possible to develop an accurate string data simulator for testing the TP in Wisconsin prior to its arrival in Hawaii, the main goal of this review was to observe the performance of the system using actual data from the functioning string and string controller. To assess its efficiency, a parallel trigger and data acquisition system was developed, called the monster buffer system (MBS), since it uses a large circular buffer to provide a cache for the string data. The MBS was based largely on the system used for low-efficiency data-taking during the December 1993 cruise.

The primary effort during the review was to compare the results of the 2 systems, with the caveat that neither had been independently verified. The MB system was, however, known to produce correct results for triggers generated by artificial light-pulser data with known amplitude, and gave distributions of cosmic ray events which were consistent with standard cosmic ray rates.

3.1 Monster Buffer system description

3.1.1 Monster memory Buffer

The monster memory buffer (MMB) was originally devised to store a certain amount of the SC digitizer data on the fast data stream, so that the data can be examined thoroughly for hardware debugging and system monitoring purposes. Because the MMB can store large enough amount of the SC data to have all the hits caused by a muon and send them to a computer, it can be used as a separate data taking system independent of the CCB-TP system. Currently, the maximum amount of the data it can store is 1 M byte, or 400 k transitions of the modules including the roll over words and null words. This can be increased up to 8 M byte, simply by adding memory to the MMB. The data is to be harvested by IBM-PC via parallel data I/O card (model and manufacture ?), either when the predetermined amount of memory is filled with the data or when an external trigger pulse comes in.

This is the system we used to take data while we were deploying the first string and the shore cable in Dec. '93. The MMB is capable of accepting triggers, as mentioned above, but we did not have any trigger source at the time of the deployment. This is the reason why we forced to take data whenever the MMB was filled with data. The raw data rate on the digitizer data stream is about 3 M transitions/sec when all the modules are turned on. In this data rate, the entire MMB would be filled with the data within 0.15 seconds, which made our detector live time at the deployment be 1 % combined with the fact that harvesting the entire MMB data takes about 15 seconds for the PC.

3.1.2 NIM trigger

A NIM module pulse generator (NIMbox) was developed to lessen this live time problem of the MMB data taking system by providing a way to trigger the MMB. The NIMbox monitors the SC digitizer data stream and generates module hit pulses of predetermined width whenever it sees an up transition of the appropriate modules in the data stream. Using these module pulses with the regular NIM coincidence logic units, one can generate reasonably efficient trigger pulses.

There is a minor complication on using this pulse, for the time differences between the module hits at the digitizer input are not preserved in the pulses coming out from the NIMbox. The time difference between the module pulses at the NIMbox is determined by when the transition of the hits are stuffed into the data stream. For example, if all the module get a pulse at the same time, the time difference between the module pulses at the NIMbox is as much as 960 ns ($40 \text{ ns/transition} \times 24 \text{ up transitions}$). This effect has to be taken care by expanding the coincidence window to an order of 1 μsec . A narrower coincidence window can be used with the risk of missing some triggers depending on the number of transitions sent through the data stream at the time the coincidence condition is satisfied.

3.2 CCB system description

The clock correction board was developed in prototype form at the University of Washington by Hans Berns. Since he functioned also as a reviewer of a portion of the TP system, he had to assume the alternate role of reviewee for the discussion and testing of the CCB.

3.2.1 CCB functionality

The basic functional requirements of the CCB are:

- demultiplexing and time-stamping the OM data with corrected times;
- flagging error conditions and setting appropriate bits;

- passing on corrected and flagged OM data to the FLP;
- decoding the hydrophone data contained in the rollover words and passing it on to the hydrophone receiver board.

The CCB also provides the optoelectronic interface to the shore cable fiber, that is, it converts the serial optical input to a parallel set of data words before the other functions are performed.

3.2.2 CCB test setup

The CCB was tested prior to the review by logic analyzer methods and found to be functional after some revision of the design to correct timing problems found in the initial revision of the prototype. Comparison of the data between the MB and FLP system was the best way to determine if the data throughput was correct. The hydrophone words were checked by comparison of a synchronous audio-frequency signal from input at the string controller to the output at a test point on a hydrophone receiver board that accepted the data from the CCB hydrophone output.

3.3 Data-taking conditions

3.3.1 Clock correction board

Various audio signals were played through the system with actual OM data also received in the string controller. Lost rollover words were tagged by a separate counter. A square wave input with frequency up to 50 KHz was used to test the reliability of the reconstruction of the signal after passing through the entire SC-fiber-CCB system.

3.3.2 Trigger Processor and Monster Buffer

A 3-fold coincidence of any modules in the test string with a coincidence window of 150 ns was used to take a comparison data set for the CCB-FTP system. Occasionally, the MMB-NIMbox system failed to get a event that had been taken with the other system. This could have been caused either by the slightly longer dead time of this system compared to the CCB-FTP one or by a narrower coincidence window than that required to get all the 3 fold coincidence. For example, this system will fail to trigger the 3 fold events if each of three coincidence hits comes into the digitizer sequentially after the completion of the other hits. But, there is no inherent bias on this system against the number of hits involved in an event.

For these data taking runs, the input discriminator for the string controller inputs of channels 3 and 4 (OM3 and OM4) were too flaky to be used and produced many FIFO

overflow error. They were thus turned off. OMs 1 and 2 were also turned off during the data taking since they could not participate in the trigger, though in hindsight this was probably the wrong thing to do since they could have produced hits in real events.

OM10 could not be turned on during these tests. It is a European Optical module, but it is unknown what the problem was with this OM.

The OM discriminator thresholds and HVs were adjusted so that the average rates were less than 1 KHz. This was done to remove random triggers from consideration and select on only those events originating from cosmic ray air showers, producing Cherenkov radiation by particles passing through the glass of the housings. To produce some reference triggers in the data stream, the optical pulser inputs to channels 5,6,7 were retained at a fixed rate of 10 Hz. The cosmic ray trigger rate was found to be a few Hz.

4 Results

4.1 CCB tests

These tests fell into two different areas: those involving the OM data and the FLP, and those involving only the hydrophone data. In addition to the data testing, we note that at one point during the testing, apparent flakiness in the CCB hotrod link was noted, and may have been due to lack of proper heat-sinking of the hotrod.

4.1.1 Hydrophone data tests of the CCB

Qualitative performance was verified by audio signals played back through speakers after transmission through the SC-CCB system. No obvious problems were seen. A more quantitative test was done using a square wave, 50% duty-cycle signal (the calibration output from an oscilloscope) which could be varied in frequency (but not in pulse shape, except by introducing some RC filtering; thus the risetime was of order 5 microseconds).

With this signal at 25-50 kHz, the signal was still recovered, although with considerable phase and amplitude noise. Most of this noise was attributable to the aliasing effects of the fast rise/falltime of the square wave, and the signal recovery was reasonable in spite of this. However, some of the phase noise may be due to effects of the jitter in rollover times caused by the presence of real stochastic OM data and noise, which dominate the data stream from which the hydrophone data are extracted.

4.1.2 OM data tests of the CCB

The most effective way to determine that the CCB was functioning properly in dealing with the OM data was to observe the output of the FLP system and test the data for consistency

with the input signal, by comparison with calculated values and the MBS results. Of course this assumes reasonable functionality of the FLP-DAQ system as well, and this was achieved as a prerequisite to the review. Thus the CCB testing done here effectively reproduced what was done in Madison to prepare the FLP for operation (using a data simulator) with some final adjustment of the front-end timing so that the CCB-FLP handshaking was correct in the data transfer. What was then tested was the ability of the CCB to correctly demultiplex, time-tag, and insert error flags into the data.

To do this an optical square wave pulse with a width of about 50 ns was sent into three of the string controller OM receiver channels (5,6,7). After digitization at the SC and transmission through the SC-hotrod-laser link, the signal was received and split so that the MBS and CCB would have identical but independent inputs. The MBS trigger was set to accept 3-fold coincidence on these channels and the signal was sent in synchronous repetition at rates of between 1 Hz and 10 Hz typically (or up to 10 KHz to set optical receiver thresholds, etc.)

Both the MBS and FLP system triggered on this signal and the data was recorded. After correcting the FLP data for the energy lookup table effects, it was evident that the two systems gave identical answers with no anomalies observed in either system at rates up to 10 Hz. Since the next step available at the time was 100 Hz, and this caused loss of efficiency for both systems, the results were not useful for CCB tests.

The error flagging could not be checked quantitatively because of the time constraints, but logic analyzer tests were done prior to the review to confirm that error flags were correctly set under controlled conditions. Berns added an audible indicator to the CCB which proved useful in determining both FIFO overflow conditions and parity errors. This beeper, which was driven by the detection of the error conditions, was found to track well the presence of such errors as noted independently in the condition of the data, both in the MBS, and (as far as could be tested) with the FLP. The MBS counted error flags for each data buffer, but the FLP software (although it may be capable of it) was not configured to track or count error conditions.

4.2 FLP tests

These fall into two types: controlled tests using optical pulser signals with controllable widths and delays; and random cosmic ray triggers. A laser trigger was also available during the test using the newly arrived calibration module, but there was insufficient time to include these tests in the review. We were also unable to test any of the scaler functions of the FLP, or any of the DSP-generated triggers.

There are a number of known problems with the FLP in terms of meeting the original system specifications. Those noted during the meeting are:

- Long-on handling is incorrect—the long-on is generated, but the longon itself does not

become automatically excluded from trigger conditions, and may become part of a coincidence;

- There is presently no distinction made between EOM and JOM;
- Error-based triggers, such as FIFO overflow, parity, and other error conditions, are presently not generated.
- There is no calibration module trigger implementation.

None of these problems were addressed during the meeting.

4.2.1 Coincidence Window, simple T3 and T3skips

Before checking the response of the system to actual cosmic ray triggers, A test of the coincidence window was performed by introducing a variable delay into the optical pulser inputs to 5,6,7 and watching the trigger rate for T3s in the FLP system. The window was found to track accurately with the delay introduced and triggers fell off quickly over a change of about 2-3 ns, showing that the window has a clearly defined edge. The size of the window was also found to be accurate to within 1 ns. A similar window check was done with T3skips and it was found to also be accurate.

This test also checked the basic functionality of the T3 and T3skip coincidence forming hardware and this was found to be accurate and 100% efficient at 10 Hz or below. At 100 Hz, about 30-40% of the triggers were lost. This is discussed more in the next section.

4.2.2 Cosmic Ray trigger tests of the FLP

Initial tests of the FLP system in comparison with the MBS indicated that there were two effects in which the FLP corrupted or lost events that it should have recorded. The MBS also lost events occasionally due most likely to the deadtime effects. These two effects are:

- High multiplicity events (occurring at a rate of about 0.1-0.2 Hz) were being missed by the FLP system.
- The FLP showed a 0.2-0.4 s deadtime after these high multiplicity ($N_{\text{hits}} > 14$ in one microsecond) events.

On the other hand the FLP system appears to have been somewhat more efficient than the MBS. About 10% of events were missed by the MBS compared to the FLP, explainable by the differences in trigger conditions and the relatively long deadtime (10-15ms) of the MBS after triggers. The FLP deadtime is estimated to be of order 200 microseconds; however,

the actual throughput is limited to about 30 Hz mean rate, because of the bottleneck at the VME gatekeeper (according the D. Nicklaus).

These effect of large events can be seen by looking at a section of the actual data. The following shows first a section of FLP-TP data, then the MBS data for the same series of events, including the optical pulser triggers which come in every 0.1 s.

First the data as taken by the FLP-SUN system (the "width" here is in 5 ns ticks; the time in 1.25 ns ticks):

type	chan	width	time	----	coinc.

E 3586	6	699597	663	44805291 61582507 699597	32 -1024
H 9	22	255	1869	-1.000000	T1
H 9	23	9	1894	-1.000000	T2
H 9	20	3	1902	-1.000000	T3s
H 9	23	2	1941	-1.000000	T1
H 9	23	7	1961	-1.000000	T1
H 9	23	86	2059	-1.000000	T1
E 3587	3	734989	664	44805291 61582507 734989	32 -1024
H 9	5	12	1458	-1.000000	T1
H 9	6	12	1468	-1.000000	T2
H 9	7	12	1476	-1.000000	T3
E 3588	0	795768	665	44805291 61582507 795768	48 -1024
E 3589	3	1047684	666	44805291 61582507 1047684	32 -1024
H 9	5	12	1305	-1.000000	T1
H 9	6	12	1315	-1.000000	T2
H 9	7	12	1323	-1.000000	T3
E 3590	3	77282	667	44805291 61582507 77282	32 -1024
H 9	5	12	1012	-1.000000	T1
H 9	6	12	1022	-1.000000	T2
H 9	7	12	1030	-1.000000	T3

Then the data as taken by the MBS (here the width and time are both in 1.25 ns ticks):

type	chan	width	time	----	coinc.

L Longon on OM 22 at time 13468493					
E 194	5	-1 -1 -1 -1	13152	1	-32768
H 9	22	1023	1869	-1.0	T1
H 9	23	36	1894	-1.0	T2
H 9	20	15	1902	-1.0	T3s

H 9	23	8	1941	-1.0	T1
H 9	23	29	1961	-1.0	T1
E 205 3 -1 -1 -1 -1 13626 1 -59392					
H 9	5	48	1458	-1.0	T1
H 9	6	48	1468	-1.0	T2
H 9	7	49	1476	-1.0	T3
L Longon on OM 15 at time 14729135					
L Longon on OM 22 at time 14729136					
E 217 21 -1 -1 -1 -1 14383 1 -48128					
H 9	15	1023	1967	-1.0	T1
H 9	22	1023	1968	-1.0	T1
H 9	17	46	1978	-1.0	T2s
H 9	14	35	1984	-1.0	T3s
H 9	16	48	1985	-1.0	T3s
H 9	9	33	1985	-1.0	T1
H 9	11	31	1990	-1.0	T2s
H 9	19	40	1992	-1.0	T3s
H 9	23	166	1993	-1.0	T2
H 9	18	31	1993	-1.0	T3s
H 9	8	36	1994	-1.0	T3s
H 9	21	43	1998	-1.0	T3s
H 9	20	30	1998	-1.0	T3s
H 9	12	50	2001	-1.0	T3s
H 9	13	166	2005	-1.0	T3s
H 9	24	13	2011	-1.0	T3s
H 9	17	111	2032	-1.0	T3s
H 9	16	118	2033	-1.0	T3s
H 9	14	25	2033	-1.0	T3s
H 9	19	19	2039	-1.0	T3s
H 9	8	7	2046	-1.0	T1
E 218 16 -1 -1 -1 -1 14384 1 -49152					
H 9	12	29	1027	-1.0	T3s
H 9	14	18	1034	-1.0	T2s
H 9	17	430	1119	-1.0	T2sQ
H 9	14	321	1125	-1.0	T1Q
H 9	16	372	1127	-1.0	T3sQ
H 9	9	318	1128	-1.0	T1Q
H 9	18	316	1134	-1.0	T3sQ
H 9	23	288	1135	-1.0	T3sQ
H 9	8	317	1135	-1.0	T2Q
H 9	11	279	1136	-1.0	T3sQ
H 9	19	315	1137	-1.0	T3sQ

H 9	21	362	1140	-1.0	T3sQ
H 9	20	188	1143	-1.0	T3sQ
H 9	12	402	1143	-1.0	T3sQ
H 9	13	340	1147	-1.0	T3sQ
H 9	17	13	1611	-1.0	T1
E 226 3 -1 -1 -1 -1 15047 1 -7168					
H 9	5	47	1164	-1.0	T1
H 9	6	48	1173	-1.0	T2
H 9	7	48	1182	-1.0	T3
E 238 3 -1 -1 -1 -1 15703 1 -23552					
H 9	5	48	1893	-1.0	T1
H 9	6	48	1903	-1.0	T2
H 9	7	49	1911	-1.0	T3
E 241 3 -1 -1 -1 -1 16254 1 -63488					
H 9	5	47	1599	-1.0	T1
H 9	6	48	1608	-1.0	T2
H 9	7	48	1617	-1.0	T3
E 252 3 -1 -1 -1 -1 17118 1 -30720					
H 9	5	48	1305	-1.0	T1
H 9	6	48	1315	-1.0	T2
H 9	7	49	1323	-1.0	T3
E 259 3 -1 -1 -1 -1 18051 1 -3072					
H 9	5	48	1741	-1.0	T1
H 9	6	48	1751	-1.0	T2
H 9	7	49	1759	-1.0	T3

The MBS data shows that a large cosmic ray shower induced event produced at least 36 hits over a 200 ns period. All of the 13 JOMs hit produced a Q pulse, and there were some tubes with multiple pulses which may be afterpulses or may be due to the shower itself. The shower generated two "events" in the MBS because the times cross a microsecond boundary.

Inspection of the FLP data shows that, although this event formed a trigger, all of the hits were "erased", and the system was dead for the following 0.3 seconds, as is seen by the missing optical pulser events. On the other hand, in some cases an event with more than 14 hits was recorded by the FLP, as in the following data:

type	chan	width	time	----	coinc.

E 3823	17	732797	901	44805291 61582507 732797	32 -1024
H 9	15	83	1907	-1.000000	T1
H 9	14	5	1917	-1.000000	T2
H 9	16	17	1921	-1.000000	T3s

H 9	19	5	1930	-1.000000	T1
H 9	21	8	1935	-1.000000	T2s
H 9	14	0	1978	-1.000000	T1
H 9	21	1	1985	-1.000000	T1
H 9	16	5	1992	-1.000000	T1
H 9	21	3	2034	-1.000000	T1
H 9	14	55	2083	-1.000000	T1
H 9	16	109	2086	-1.000000	T2s
H 9	21	79	2100	-1.000000	T1
H 9	19	22	2101	-1.000000	T2s
H 9	16	5	2546	-1.000000	T1
H 9	16	9	2594	-1.000000	T1
H 9	16	9	2645	-1.000000	T1
H 9	16	2	3013	-1.000000	T1

The events after 2101 (the last Q pulse) are not part of the physical shower but were included because they were in the microsecond buffer. The "0" width in channel 14 is due to truncation in the energy lookup table.

In summary, the FLP system appears to perform well and efficiently in triggering on random cosmic ray data. Both T3 and T3s events are seen in the data with proper trigger characteristics. The absolute efficiency is difficult to estimate since the MBS suffers from trigger inefficiency as well, but it appears that the efficiency of both systems is relatively high since the cosmic ray trigger rates are about what is expected from the layout of the optical modules in the van.

5 Recommendations

The following are the recommendations of the engineering reviewers to the collaboration as to how we should proceed with the testing and or production of a DUMAND trigger processor system.

5.1 CCB

It is our assessment that the CCB prototype performed well during the tests and is compliant with the specifications that we were able to check during the review. However, the one major area that we were unable to test, the actual clock correction function, must still be demonstrated to be working before this system can go into production.

We recommend:

- That the Washington group produce a printed circuit version of the CCB in its final

form as used at the review;

- That the PC version be used to perform further tests with an actual string as soon as possible to determine the possible limitations in bandwidth of the acoustic data transmission under conditions of actual OM data present in the data stream.
- That particular attention be given to the socketing and heatsinking of the hotrod and other components of the data link on the board.
- That a self-test section be included in on-board to test the clock correction section of the board, so that this section can be exercised and validated to first order.

5.2 FLP

The FLP in prototype form, along with the VME data acquisition system (including DSP boards and SUN data harvest computer) appear to all function within the range we were able to test during this review. Thus we can consider this as a first-stage or prototype critical design review, and we feel that the system has passed this level. The prototype can probably function as is for ocean testing of the system, although we feel uncomfortable with the loss of the large-multiplicity events, since these events are the most interesting from the point of view of the physics involved.

In light of this we recommend:

- That a printed circuit version of the FLP be produced as soon as possible;
- That the PC version be modified to allow the 64K cache memory to be accessed across the VME bus so that the 14-word per microsecond limit may be exceeded (this also allows access to the raw data);
- That the gatekeeper system be replaced with a Sbus-to-VME controller (external SUN) to avoid the present data harvest bottleneck;
- That the specifications regarding longons, error triggers, and CM triggers be fully implemented and tested before the system goes into a production (3 string) version.
- That another review be performed to determine whether the first generation PC prototype can go into production. This should take place as soon as possible after the above recommendations have been implemented.