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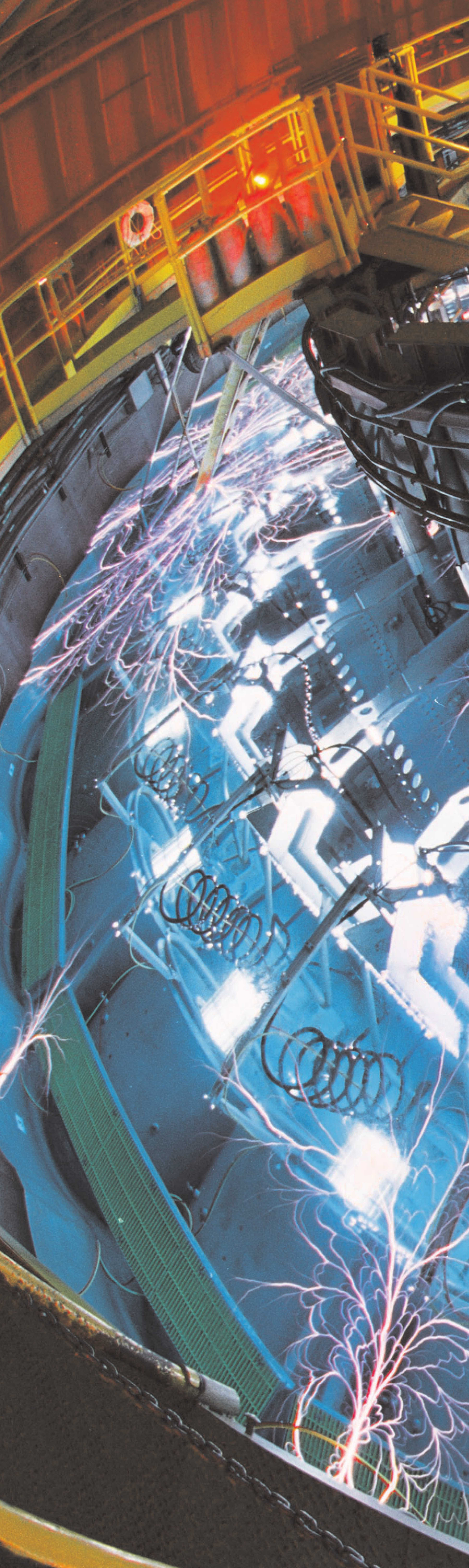

IEEE-PPC-2015:
HARDWARE AND SOFTWARE UPGRADES FOR THE SATURN DATA ACQUISITION TRIGGERS AND TIME BASE

(work supported by the Dept. of Energy)

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INTRODUCTION

The Saturn X-ray accelerator is comprised of 36 individual energy storage and transmission line modules that are azimuthally symmetric, like the spokes on a bicycle tire, with the module energy flowing into a center region. Physically, module energy is initially stored in a Marx bank at 13 meter radius and flows radially inward terminating at a 1.1 meter radius center. The center energy is delivered to the 0.15 meter radius diode load, via a set of parallel conically shaped magnetically insulated transmission lines (MITLs) , resulting in the production of X-ray from the diode. Good diode X-ray yield (FWHM =~ 20e-9 seconds) requires a fast MITL energy pulse rise-time dictating that energy arrival times from all 36 modules occur with a minimum of time separation.

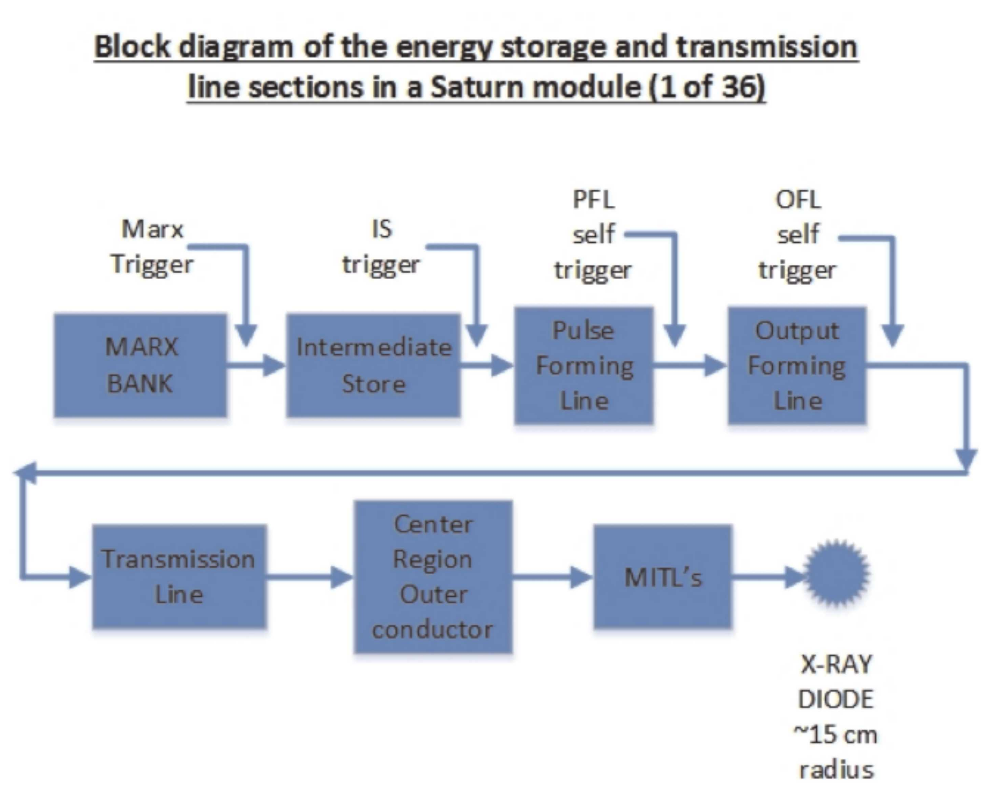


Fig. 1 Block diagram of Saturn module (1 of 36).

The energy for each Saturn module originates from a 32 stage Mark bank. Marx output charges an intermediate storage (IS) circuit achieving some energy rise-time pulse sharpening. The electrically triggered IS switch output energy flows into the pulse forming line (PFL), the output forming line (OFL), the transmission line (TL) and then into the center region (fig 1). Energy rise-time pulse shaping is achieved during this transit via the use of self-breakdown switches within the PFL and OFL sections.

To monitor the energy flow and pulse shaping within each module there are over 200 current and voltage probes. Due to its physical appearance, the IS switch trigger monitor is referred to as the "Bird cage." The probes common to module sections are grouped together and digitally recorded in a single rack of nine (9) scopes with 4 channels per scope. Also, a rack of scopes monitors the center section currents and diode X-ray output and a rack is devoted to probes monitoring the trigger systems. Thus, we have a minimum of eight (8) scope racks corresponding to the Marx, IS, Bird cage, PFL, OFL, TL, center and triggers.

Ideally, all scope racks will have time bases that are linked quantatively with each other allowing probe signals across racks to be time-tied to each other. This typically requires that the scope triggers originate from a single location, but this isn't essential if accurate timing reference measurements are made. However, the present data acquisition (DAQ) personnel found that the triggers to the scope racks originated from various sources and accurate time references linking them together did not exist. Also, it was discovered that the DAQ software has a "bug" and incorrectly calculates the scope time base values for approximately 70% of the scopes. Thus, prior to the fixes outlined below, an accurate time overlay of the signals from different signal types could not be accomplished.

THE SCOPE TIME-BASE CORRECTIVE ACTIONS

The corrective actions to time tie the DAQ scope time bases to a common reference required a combination of hardware and software fixes and are summarized as follows:

1) Change the DAQ trigger circuit so all scopes are triggered from a single trigger source.
2) Define a common T-zero reference time and signal.
3) Measure the time delay for each scope trigger with regard to the T-zero reference.
4) Record and archive this time delay for later calculations.
5) Write a program that applies the appropriate time correction for each data set.

SINGLE TRIGGER SOURCE

The DAQ trigger circuit has been modified and now utilizes a single trigger generator (STG) located within the DAQ screen room to provide the scope triggers for all DAQ scopes located in the main DAQ screen room. In the event of a pre-fire, we have or-gated a pre-fire detection circuit with the main command trigger at the STG input so that valuable pre-fire probe signal information is not lost. The present trigger circuit is shown in figure 2; the STG for this circuit is device DG535 #1.

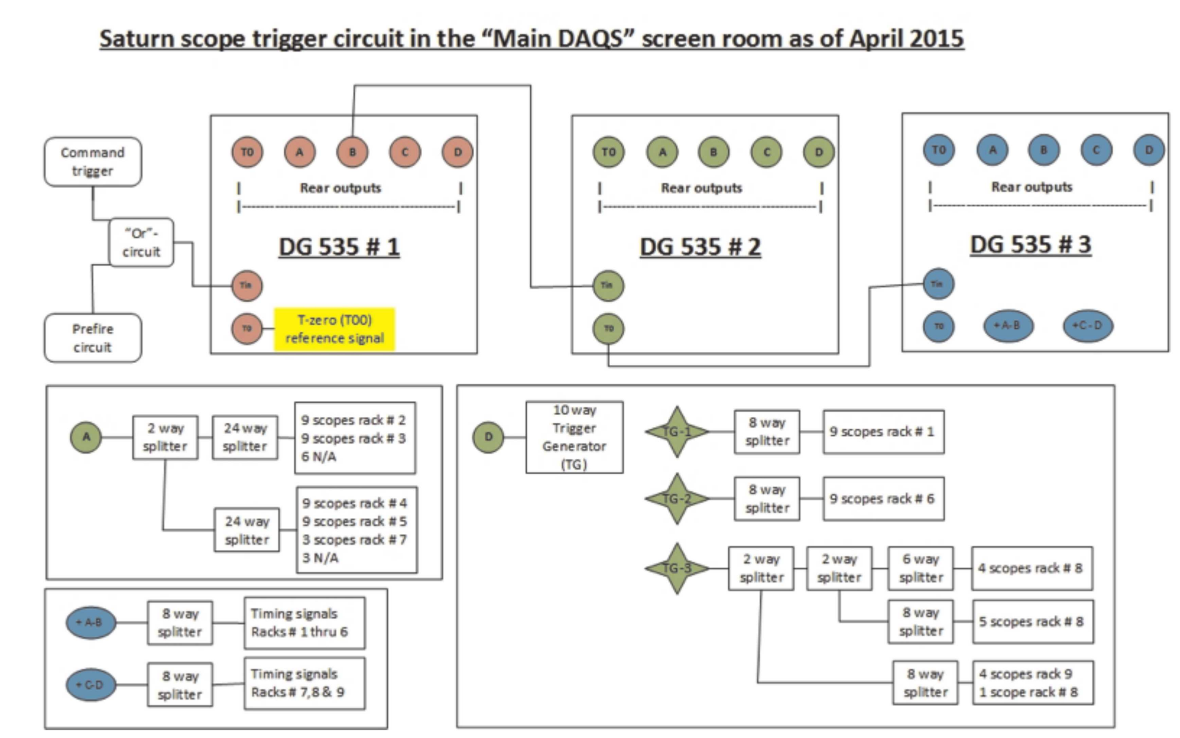


Fig. 2 Saturn Main DAQ scope trigger circuit.

DEFINE "T-ZERO" REFERENCE / MAKE MEASUREMENTS / DAQ ENTRY

In theory one can define many T-zero timing reference points whereby the only requirements are reproducibility and reliability. We have chosen our reference T-zero time to correlate with the rising edge of the output signal labelled T00 from signal generator DG535#1 (fig 2). This signal choice meets our requirements and also provides a convenient signal pickoff for the DAQ operators to use when measuring the scope trigger delay times.

We measure the time difference between the T-zero reference and the scope trigger input signal. This time measurement is required for each scope trigger input signal. These measurements need to be input into the DAQ program so they can be accessed by the time correction routines.

Due to the DAQ software being embedded in six (6) computers we did not want to jeopardize our DAQ systems by modifying the source code. Recognizing that the DAQ software program contains a rarely used data entry location, originally reserved for "time-of-flight" delay values, we use this entry location for the "time-of-scope-fire" and enter the scope trigger delay time as a negative value. When an actual "time-of-flight" value is required, DAS personnel simply increase the original cable delay value by an equal amount or conversely they can add the TOF value to the negative signal cable delay time.

SOFTWARE TIME SHIFT PROGRAM

The DAQ software program creates two data files for every test. The HDR data file contains the scope setup and probe diagnostic information for each DAQ channel. The BIN data file contains the binary formatted probe signal data and reflects the data returned by the digitizing scope after the DAQ program has processed the data using values obtained from the HDR file. Some of the automated DAQ processing involves multiplying the scope data by signal attenuators and probe gage values and time correcting for signal & scope delay times. Though the DAQ operator can "turn-off" the vertical (volts) data manipulation, the horizontal (time) shifting routines are always performed.

Unfortunately, for some models of digitizing scopes the DAQ program incorrectly processes the scope start times. For example, for Tektronix scope models TDS-224 and TDS2024, the BIN file "time of first point" always equals 0.00 seconds independent of the scope trigger times. The fix for this problem entails extracting the relevant information from the BIN and HDR data files to recreate and apply the correct scope time data. The formulas for the scope time of first point, T(1st), and the entire time data array, T(n), can be expressed by:

$$T(1st)=TOF+HD-SD-(((\#pts*dT))/2)$$
$$T(n)=T(1st)+dT*n$$

Where:

TOF = time of scope fire (seconds) HD = horizontal delay time (seconds)
SD = signal delay time (seconds) #pts = number of points in the data set
dT = time per point (seconds) n varies from 1 thru #pts

For Saturn test # 4214, plot overlays of some module # 1 signals with and without time correction are shown in figure #'s 3 and 4. A summary of the scope time of first point, test # 4214 module #1 signals, for the original and corrected time bases is presented in table 1.

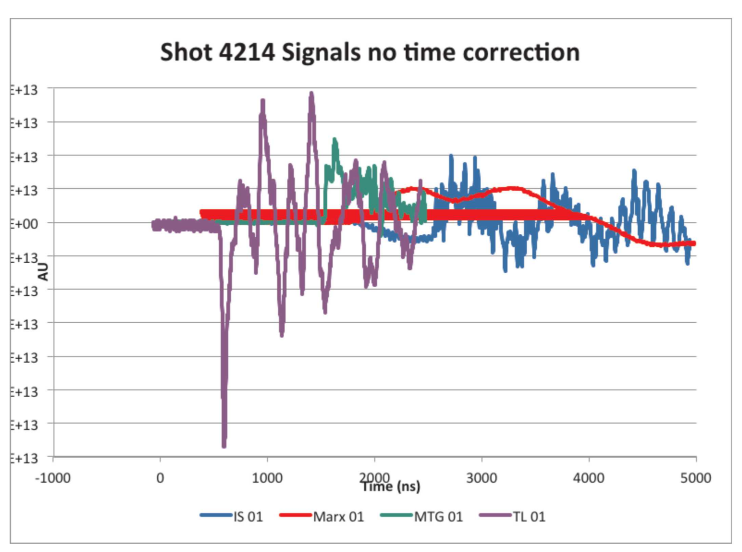


Fig. 3 Saturn shot 4214 module 1 signals, no time correction.

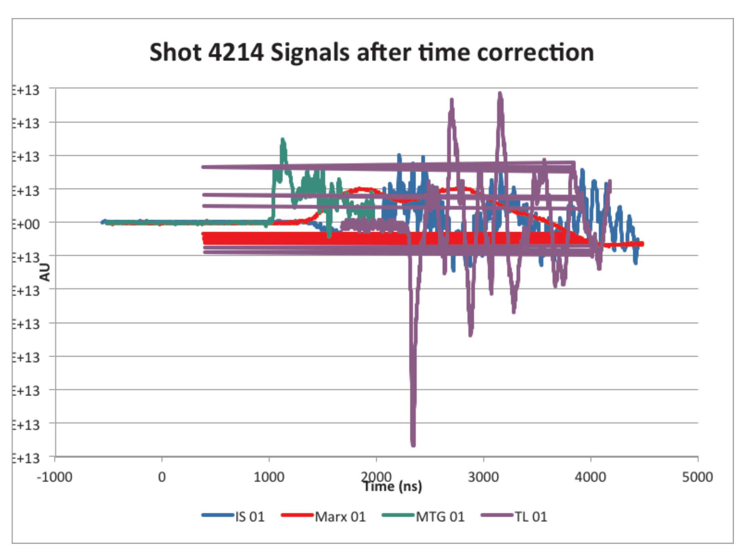


Fig. 4 Saturn shot 4214 module 1 signals after time correction.

Module # 1 Section	Scope time of first point, (nanoseconds) Raw	after correction	Time difference (seconds)	Scope type
MTG	-25	-525	500	TDS 224
MARX	-10	-510	500	TDS 224
IS	-57	-557	500	TDS 224
Birdcage	-30	-530	500	TDS 224
PFL	-85	1665	1750	TDS 2024
OFL	-65	1685	1750	TDS 2024
TL	-69	1681	1750	TDS 2024

Table 1 Display of calculated time of first points for module # 1 signals from Saturn shot # 4214 with and without time correction. Note the shaded rows have signals displayed in figures 3 and 4.

A way to quantify our scope time tying efforts involves the use of timing signals designed to have equally timed signal starts. We monitor each signal in a different scope rack and measure the signal arrival times. Assuming scopes common to each rack trigger similarly, the variation in measured times is a measure of the certainty of the time base of the entire DAS system. We performed five timing signal tests on Dec 16, 2014 with twelve timing signals per test. Defining the timing variation as the time difference between the signal start of the earliest and latest signals, our timing variations for twelve signals were 1.8, 1.7, 2.0, 2.0 and 1.8 nanoseconds for test #'s 1015, 1016, 1017, 1018 and 1019, respectively.

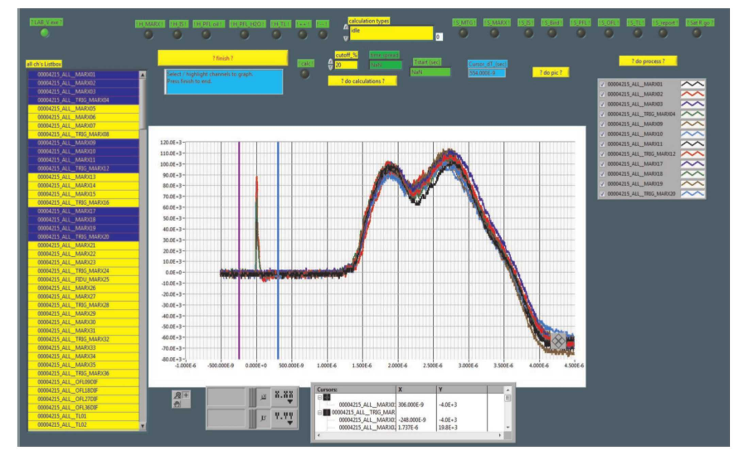


Fig. 5 Screen shot of data viewer with automatic time correction. The main image display is for data plotting, shown here are some Marx CVR probe signals from Saturn # 4215.signals after time correction.

We have built the time shift calculator routines into a Lab VIEW data viewer program. Figure 5 is a "screen shot" of the viewer displaying some signal data from Saturn 4215. The viewer program also automatically outputs the corrected data set into a separate "XDAMP" format data file and, if desired, will create individual ASCII spreadsheet files. After building this data viewer program, we have expanded the program capabilities to include the determination of the signal arrival times within a module section (i.e. Marx, IS, PFL, OFL, TL) so that the time variations across all 36 modules can be determined. For example, figure 6 is the time scatter plot for the TL module section and figure 7 is an overlay of the scatter plots from the Birdcage, IS, PFL, OFL, and TL module sections. We have automated this type of time spread calculator for all module sections and this information can be available minutes after the DAQ data has been collected. We have also built a Word document report generator into the data viewer to provide documentation to the DAQ system operators. For example, table 2 was created by the report generator using data from Saturn test 4215. This type of information and display is useful because it can provide guidance with respect to problem areas within the Saturn machine, allowing a faster turnaround to fix or adjust bank operating parameters to optimize Saturn performance.

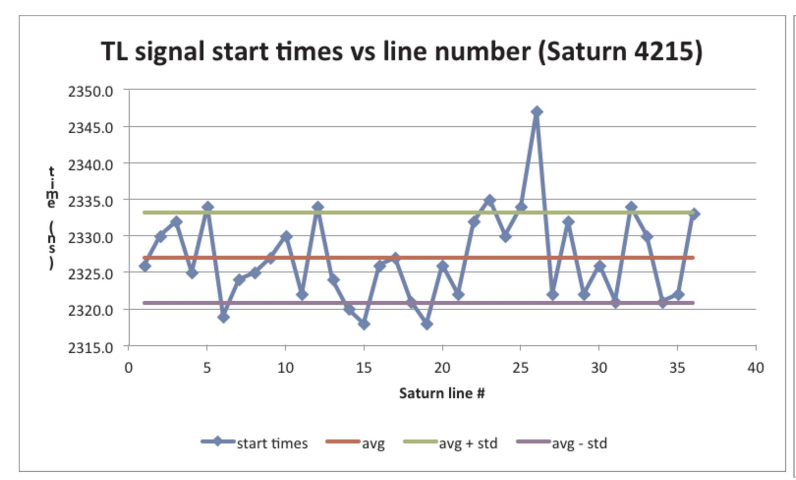


Fig. 6 TL section signal start time vs Saturn line #. Note data from Saturn test #4215.

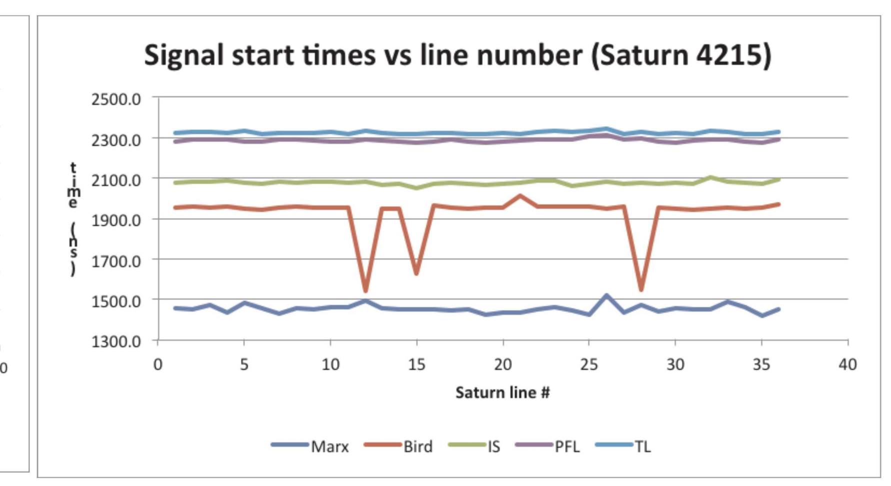


Fig. 7 Signal start times for the Marx, Bird, IS, PFL, and TL module sections (Saturn 4215).

Section Name	spread (sec)	mean (sec)	std.dev (sec)	T_Early (sec)	Early signal	T_Late (sec)	Late signal	% thresh	T_start (sec)
SATURN MTG	2.306E-8	1.041E-6	6.604E-9	1.028E-6	MTG05	1.051E-6	MTG02	20	2.500E-7
SATURN MARX	1.032E-7	1.454E-6	2.082E-8	1.418E-6	MARX35	1.521E-6	MARX26	20	5.000E-7
SATURN Bird Cage	4.703E-7	1.924E-6	1.088E-7	1.542E-6	TRIG_BD CG_12	2.013E-6	BDCG21	20	7.500E-7
SATURN IS	5.498E-8	2.077E-6	8.886E-9	2.049E-6	IS15	2.104E-6	TRIG_IS3 2	20	5.000E-7
SATURN PFL	3.916E-8	2.289E-6	8.167E-9	2.275E-6	PFL35	2.315E-6	PFL26	20	5.000E-7
SATURN OFL	3.380E-8	2.290E-6	7.009E-9	2.279E-6	OFL35	2.313E-6	OFL26	20	5.000E-7
SATURN TL	2.897E-8	2.327E-6	6.216E-9	2.318E-6	TL19	2.347E-6	TL26	20	5.000E-7

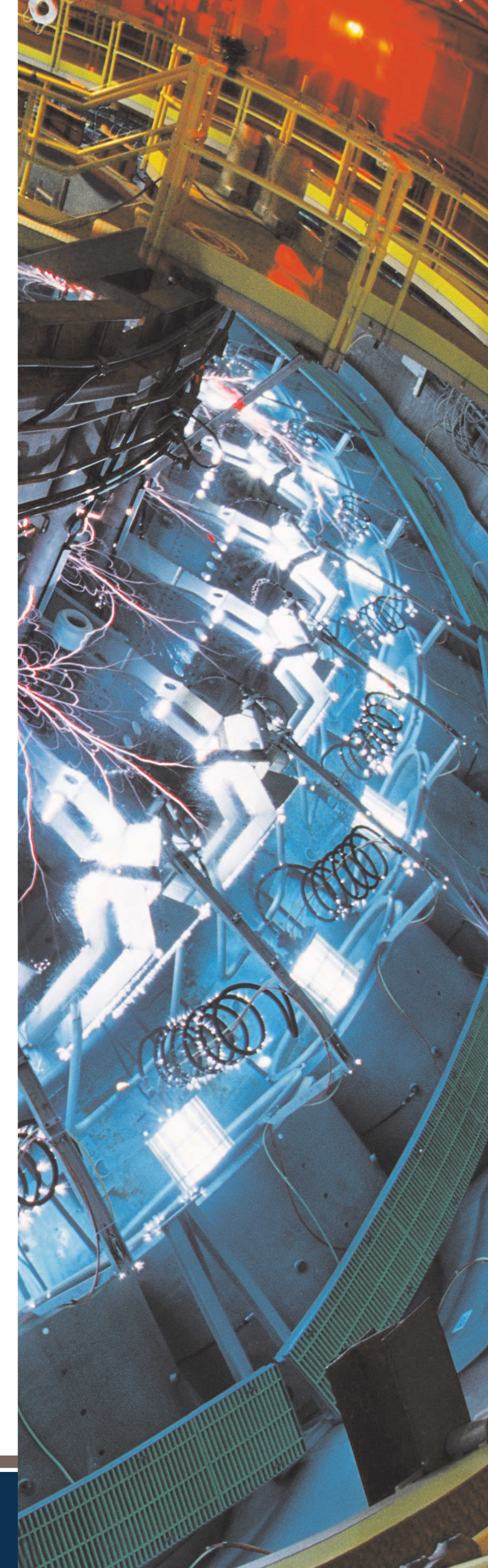
Table 2 Time spread summary (Saturn 4215)

PRESENT AND FUTURE WORKS

The data viewer program will be enhanced with more advanced signal processing programs. The scope trigger circuit will be modified to achieve a faster trigger rising edge and increased trigger voltage. We will modify the timing signal circuit in a similar fashion. We will duplicate the fixes outlined here for the DAQ system located at the HERMES III accelerator. The present DAQ computer systems are being upgraded to Windows 7 and we are now examining various GPIB communication systems to include PCIe-GPIB, ENET-GPIB and PXI-GPIB.

ACKNOWLEDGEMENTS

The encouragement and guidance of the Saturn and Hermes crew was of great help during the course of this work. I'd like to specifically thank Ray Thomas for also providing us with the opportunity and the freedom to implement the changes necessary to accomplish this work.



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