

SUB-SAMPLE TIME-BASE RESOLUTION IN A HETEROGENEOUS DISTRIBUTED DATA ACQUISITION ENVIRONMENT

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Abstract

We have developed a reference timing system to verify and correct the time-bases for acquired time series data. This system allows for sub-sample time registration of data acquired from separate diagnostics using heterogeneous data acquisition hardware. The system was designed to recognize and repair several types of timing discrepancies including trigger recognition and configuration differences, clock rate slew, and data acquisition errors such as lost or mislabeled samples. When used as a dedicated time-reference standard, the system relaxes the requirements for cross-diagnostic data acquisition synchronization; time-bases can be unambiguously resolved from hardware that uses asynchronous clocks and triggers.

This paper describes an automated system for generating sub-sample accurate time-bases across multiple diagnostic systems on the Alcator C-Mod device, a magnetic-confinement fusion experiment. The system has been demonstrated to accurately determine the times of measured phenomena in order to track point of origin and propagation around the experiment. In addition, timing errors in signals can be easily flagged and corrected.

The initial installation has been applied to a variety of diagnostics, including fast, optically-based fluctuation diagnostics and plasma-sampling probes. These diagnostics are physically distributed around the experiment cell, have disparate digitization rates (0.1 MHz to 10 MHz) and operate with both synchronous and asynchronous clocks and triggers.

INTRODUCTION

Alcator C-Mod is a high magnetic field tokamak research facility located at the MIT Plasma Science and Fusion Center in Cambridge MA [1], producing high-density, high-temperature plasmas under conditions approaching that needed for thermonuclear fusion. An extensive array of diagnostic systems is employed in this research, spanning time scales of several minutes and resolving transient events to the sub-microsecond level. The typical experiment shot cycle takes about 20 minutes with about two minutes of hardware setup, 4 seconds of pre-plasma activities, and 2 seconds of plasma. Data is collected over the next seven minutes with the bulk of the 4 to 5 GB of data available within the first four minutes. We employ a distributed high-speed timing system [2], which in theory provides microsecond accuracy for clocks and triggers in the diagnostic racks. The diagnostic data are acquired by heterogeneous devices tailored to the

needs of the specific measurements and distributed around the experiment cell. Many diagnostics are on their own electrical grounds. While this timing system has served us well, uncertainty arises on occasion as to the precise times of measured samples. In addition, there are cases where we would like to correlate measurements from independent diagnostics to a time accuracy at least equal to the sampling interval.

MOTIVATION

Timing uncertainty arises from a number of disparate sources. In a perfect world, all hardware would behave flawlessly as documented, and its operation would be perfectly understood by software developers and users; it would be configured correctly, both in terms of physical connections and software configuration.

Different data acquisition equipment often have particular triggering and clocking behavior. Some digitizers clock and/or trigger on rising edges others on falling edges. Some digitizers trigger on the first or second rising edge after a falling edge etc. These behaviors are not always well documented by the manufacturers, and it is relatively expensive to categorize them exactly for every digitizer model. In addition, things do not always work as documented.

Various hardware limitations sometimes necessitate the use of independent clocks for sampling, and these clocks are not tied to the central timing system. In these cases, not only the precise frequency but also the phases of these clocks are unknown.

Another source of timing uncertainty lies in the hardware and software configuration. It may be known that a digitizer triggers on a falling edge, but the user can mistakenly describe the trigger as the time of rising edge.

Finally, there are cases where we would like to correlate the times of measurements taken by heterogeneous equipment at varied locations around the torus hall, to sub-sample accuracy.

SOLUTION

We have developed and optically distributed timing signature signal [3], which can be digitized by any diagnostic that requires verification of its sample timestamps. The signal, shown in figure 1, has 19 bit encoded values on a 1 kHz waveform. Analysis of this waveform provides accurate timestamps for all measurements, independent of the classes of errors as outlined in the motivation section.

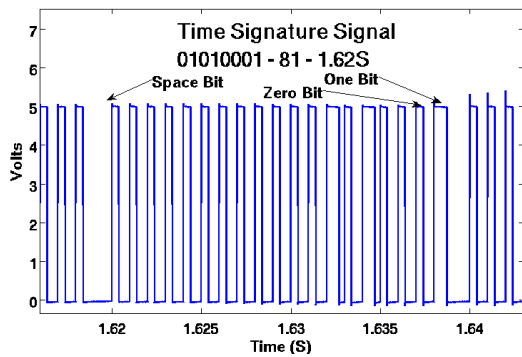


Figure 1: Time signature waveform at 1.62 seconds.

Hardware

The Timing Signature Transmitter is implemented on a C-Mod General Purpose CPLD Board, which has a 6U Eurocard form factor. This board uses an inexpensive Atmel ATF1508 CPLD (\$10US) with 128 macrocells. The timing signature logic uses 66% of the chip resources. The board has flexible front panel I/O with up to twelve fiber optic or Lemo connectors. We can drive up to three I/O panels from a single CPLD. One I/O point is required for a Gate/Reset Input. The others (up to 35) are available for user outputs.

The transmitter time-base is an Oven Controlled Crystal Oscillator (OCXO) with a total frequency tolerance (initial accuracy, temperature drift, and aging) of 2.5 ppm. The operating frequency is 20 MHz which allows for a timing resolution and maximum jitter of 50 ns. We distribute the Timing Signature Waveform to all users via optical fibers. We have developed two types of Timing Receiver, both of which fit on small 3U cards:

- Users with slower, inexpensive digitizers typically have spare channels so they can record the timing signature during the entire shot. These receivers are very simple, just a 25 MBd F/O RX (HFBR-1414) and a CMOS driver (MIC4426).
- Users with faster, more expensive digitizers may not have spare channels. We have receivers that allow them to multiplex the timing signature waveform and an analog signal. They can digitize data during the plasma shot as usual, but switch to the timing signature at the beginning and end for partial validation.

Software

The simplest analysis of the timing signature waveform allows us to identify uniquely the times of the samples at the digitizer's sampling rate. We coerce the values of any samples that happened to fall on the rising and falling edges of the signature waveform to the nearest low or high value. We can then find the sample numbers for all the edges and look for the gaps between the encoded timestamps and read off the times. This is sufficient for most cases. For diagnostics that need to be more precisely correlated time, further analysis of the waveform provides this.

The timing signature waveform has a rise time of approximately 50 ns. By looking at the samples that fall on the edges of this waveform, we can accurately assign the times of those samples at least to the nearest 50 ns. If necessary the actual value of the samples, combined with the slope of the rise time provides even greater resolution. Figure 2 shows examples of such samples. Of course, to resolve times that this accuracy requires a homogeneous fiber plant or knowledge of the lengths of all of the fibers.

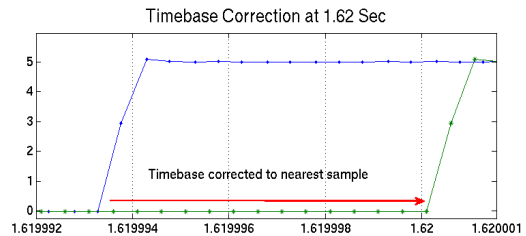


Figure 2: Timebase correction to nearest sample at 1.62 seconds.

Finally, by looking for anomalies in the entire waveform more subtle problems with the recorded data, such as missing or repeated samples, can be identified.

RESULTS

The initial installation of the system included three diagnostics measuring events at different locations around the torus-shaped experimental device.

- An optical fluctuation diagnostic that images local plasma emission in two dimensions and measures changes in light emission at frequencies up to 1 MHz. The diagnostic is used to study the turbulence as the edge of the plasma with spatial structure from ~0.3-6 cm and at frequencies <~ 1 MHz.
- An array of plasma-sensing probe diagnostics, including fixed and spatially-scanning Langmuir probes, wall surface temperature thermocouples and calorimeter probes. Sampling frequencies of 0.1, 0.5 and 5 MHz are simultaneously employed. This cluster of diagnostics is located in a bay that is +90 degrees around the torus from the optical diagnostics.
- A second array of plasma-sensing probe diagnostics, similar to above, but located -90 degrees from the optical diagnostics.

The initial installation on the optical fluctuation diagnostic provided immediate useful results. It was observed that the digitizers sometimes returned 64 extra samples. It was important to know the timestamps of the extra samples. Did they occur at the beginning of the waveform, scattered throughout the waveform or at the end? By looking at the recorded timing signature, see figure 3, we could immediately determine that they were at the end and could be ignored. This figure also shows that all three of the digitizers used for this diagnostic are sampling concurrently as expected.

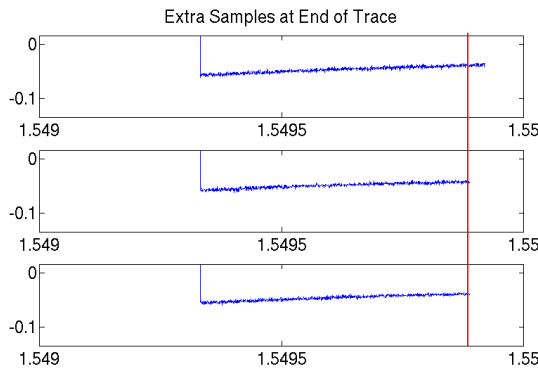


Figure 3: Three digitizer traces from optical diagnostic with extra samples at end of first trace.

The probe diagnostics provide significant timing challenges. They are located on opposite sides of the torus; they have signals digitized with heterogeneous hardware at disparate rates, and some of the digitizers are operating on internal clocks. By recording the time signature signals in each of the racks we can absolutely correlate the probe measurements –both with each other and with the optical fluctuation measurements. An experiment to measure the propagation of a filament of hot plasma expelled from the hot part of the plasma into the plasma periphery is illustrated in Fig. 4. The time delay between the observation of the arrival of the filament at the divertor and its expulsion at the mid-plane is clearly seen in the Figure. The timing signature signals verify the time-bases of the measurements, thus confirming the 46 microsecond propagation delay.

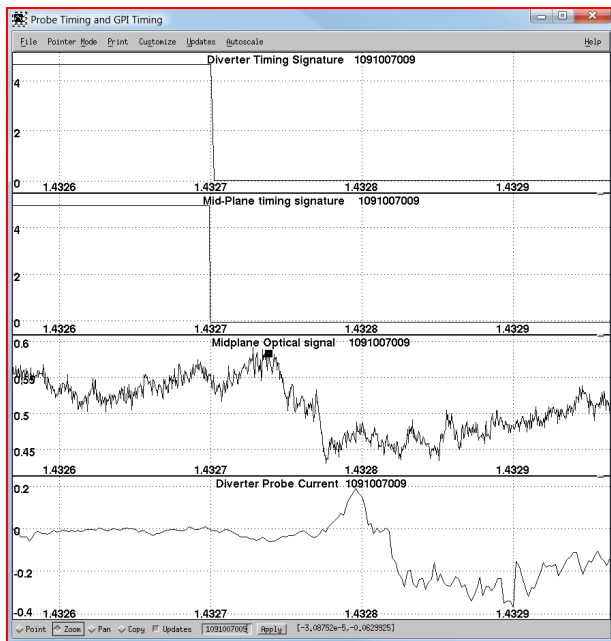


Figure 4: Timing signatures (top panels) and signals of a rapid, but not instantaneous propagation of plasma transport event from mid-plane to divertor regions.

CONCLUSIONS

A simple timing reference system has been constructed and demonstrated to provide absolute time registration for spatially distributed heterogeneous diagnostics. It does not rely on the accuracy of the diagnostic's presumed time base and it corrects for potential errors in the hardware and/or software setup. Even in cases where the timestamps of data are controlled and well characterized, the system provides independent time base verification.

This hardware also can provide sub-sample timing accuracy by observing samples found on the edges of the timing signature signal.

There are two obvious extensions to the system that would provide wider applicability. Instead of synchronizing the master clock to a local oscillator, it could be synchronized to an external time source. GPS time sources are widely available. This would allow us to synchronize measurements acquired during our experiment the slow speed plant control system. Related to this we would need to provide time signature signals in a variety of frequencies, and bit widths.

In the future we plan to deploy this on most of the diagnostics at Alcator C-Mod.

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REFERENCES

- [1] Hutchinson, I.H., et al., Phys. Plasmas 1 (1994) 1511.
- [2] V. Schmidt, G. Flor, G. Manduchi, I. Piacentini, The timing system of the RFX Nuclear Fusion Experiment, in: Proceeding of the International Conference on Accelerators and Large Experimental Physics Control Systems. KEK, Tsukuba, Japan, November 11–15, 1991, pp. 367–370.
- [3] J. Stillerman, W. Burke, B. Labombard, “An optical timing verification system for Alcator C-Mod”, Conference Proceedings, IAEA Seventh IAEA Technical Meeting on Control, Data Acquisition, and Remote Participation for Fusion Research, 2009, to be published in Fusion Engineering and Design.