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Embedded Calibration System for the DIII-D Langmuir Probe Analog Fiber Optic Links [a)]

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This paper describes a technique for simultaneously measuring offset and gain of 64 analog fiber optic data links used for the DIII-D fixed Langmuir probes by embedding a reference voltage waveform in the optical transmitted signal before every tokamak shot. The calibrated data channels allow calibration of the power supply control fiber optic links as well. The array of fiber optic links and the embedded calibration system described here makes possible the use of superior modern data acquisition electronics in the control room.

I. INTRODUCTION

Modern (post-CAMAC) data acquisition electronics provide faster sampling rates and longer data windows but are incompatible with the harsh environment in the tokamak experimental hall and must be located remotely with isolated communication for data and control signals. Langmuir probes (LP) have even more strict requirements than typical tokamak diagnostics as they are connected electrically to the tokamak plasma, require more high voltage isolation, and need to be able to measure DC voltages as well as fluctuating signals. Formerly, due to a lack of suitable isolators with the desired frequency response and voltage isolation capability, the LP digitizers and power supplies stored diagnostic data at vacuum vessel potential and utilized isolated AC power for all the electronics.

To use a post CAMAC digitizer system, we developed a plan to move all LP signals out of the experimental hall using fiber optic links. One type [1] of analog optical isolator (DC-10 MHz) has been successfully used at DIII-D but, as with all analog optical links, there is a concern that the DC offset and gain may change due to variations in temperature or fiber transmission. Routine use of fiber optic transmitters and receivers requires frequent calibration of the fiber links. More sophisticated automatic calibration techniques have been used elsewhere [2, 3] but here we avoid use of automatic gain control in the electromagnetically noisy environment of the tokamak experimental hall. Instead we use a simpler method of calibrating the fiber links by post-processing the stored raw data signals. By embedding a calibration signal in the front end of every data record, the offset and gain for each channel can be determined on every tokamak shot after the data is stored.

II. DESIGN OF DATA CALIBRATION SYSTEM

In this system we desire to send known reference signals over the optical links before the actual experimental data is present and later use that information to calibrate the following data record. The basic components of the calibration circuit for one channel are shown in Fig. 1. By using a multiplexer, four reference signals can be sequentially transmitted through all fiber links during the calibration window. The "ground" calibration signal yields the offsets due to the fiber links at the digitizer inputs. The other reference signals allow gain to be calculated. During the calibration window, all reference signals are transmitted through all the fiber links instead of the normal data signals when the calibration system is enabled and a set of solid-state relays are activated. An example of the calibration signal is shown in Fig. 2.

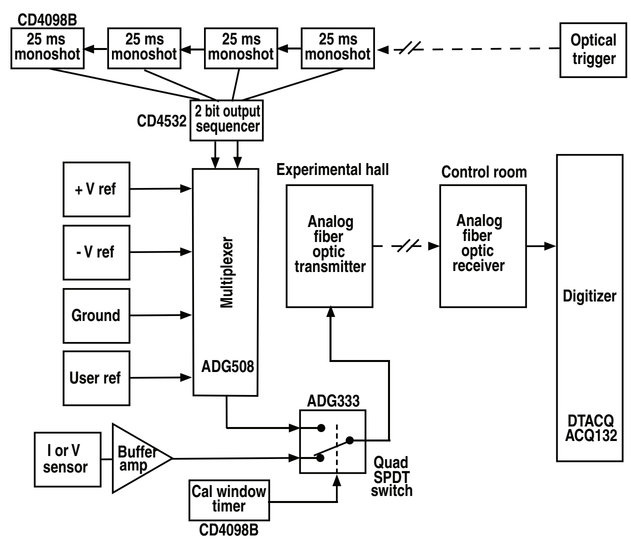

FIG. 1. This figure shows the main components of the optical link calibration circuit. There are four such circuits with 16 channels each. The optical trigger from the control room goes over a glass fiber (dashed line) to the tokamak hall to start the calibration sequence and enable the 100 ms calibration window timer. The multiplexer switches out four reference voltages in sequence to 16 SPDT solid-state relays (only one channel shown) that connects the calibration voltages to the fiber links and sends the signals on to the control room digitizers. After the data is stored, the embedded reference voltages can be used to calibrate all 64 data records.

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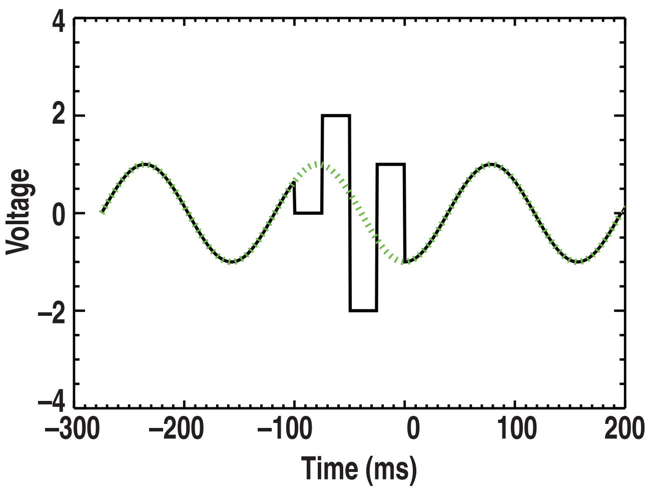

FIG. 2. This figure shows a simulated calibration voltage sequence as would be stored in the control room digitizer record. The dotted line shows the normal data signal during the calibration window when the reference voltages are sent out over the optical link. The four reference voltages are ground, V=+2V, v=-2V, and V=+1V, set by precision diodes sold as voltage references. The Langmuir probe sweep frequency is normally 500-1250 Hz, but is slowed down here for clarity.

Precision voltage references can be easily acquired with accuracy better than 1 mV. The input reference signals were chosen to be about 80% of the fiber link maximum and minimum input levels (+/- 2.5 V) to cover most of the useful range without saturating the fiber link at either end due to offset drift. We are assuming the drift will always be less than 10% of the full 5 V range (0.5 volts). The multiplexer only cycles once per shot after receiving an optical trigger. Unity gain buffer amplifiers are used to provide high impedance inputs to the passive voltage and current sensors used for the Langmuir probe sensors instead of the 33 KOhm input impedance of the fiber links. The buffers also provide protection of the other components from voltage spikes and have a frequency response that utilizes the full 10 MHz bandwidth of the fiber link. The links transmit 890 nm light through a multimode 62.5/125 micron glass fiber.

The new data acquisition system stores 64 data channels corresponding to current and voltage signals for 32 Langmuir probes. These 64 channels are divided into four groups of sixteen corresponding to the maximum number of current and voltage signals in one electronics rack of eight kepco [4] power supplies. For each group of sixteen channels, we made a separate calibration printed circuit board with four quad buffer amplifiers, four quad channel SPDT solid state switches, and one set of reference voltages from precision diodes that are sequentially switched out to the SPDT switches with our main multiplexer. One set of internally generated timing pulses from four monostable multivibrators drive an 8 bit priority encoder to generate a 2 bit sequencer code for controlling which reference voltage appears at the multiplexer output. The entire calibration sequence is only enabled during a 100 ms window before the tokamak shot. The interface of all signals with the calibration board is done with coaxial cables with SMA connectors to match the input of the fiber links used.

III. DETAILS OF THE CALIBRATION SEQUENCE

When the control room data acquisition system is triggered, an optical trigger pulse is generated that travels 90 meters down a glass fiber to start the calibration voltage sequence in each of the 16 channel calibration circuit boards in our four electronics racks near the tokamak. An enable timer is simultaneously triggered that enables the 100 ms calibration sequence. Four monostable multivibrators, corresponding to our four calibration voltages, trigger each other in sequence and drive an 8 bit priority encoder that generates a two bit command to select the main multiplexer output. The sequence of four two-bit commands causes the multiplexer to output each of our 4 references voltages to all sixteen inputs of an array of single-pole double-throw (SPDT) switches. These switches, during the 100 ms calibration window, output the reference voltage sequence instead of the regular Langmuir probe data signal to each of 16 fiber optic data link transmitters. At the end of the calibration sequence, the SPDT solid-state switches go back to transmitting the regular Langmuir probe data signals into the fiber links.

IV. NEW LP DATA ACQUISITION SYSTEM

The digitizer begins storing data 100 ms before the t=0 trigger for the start of the tokamak plasma discharge. During this window, the optical trigger from the control room initiates one cycle of the calibration circuits near the tokamak which then transmit the reference voltage signals (set by precision diodes with reverse bias) over all 64 channels through a set of dedicated 90 meter long 62.5/125 micron glass fibers to two DTACQ ACQ132 digitizers [5] back in the control room. Each channel is digitized at 1 Megasample per second for 8 seconds to cover the entire tokamak shot. Since we record the entire time history of the shot, setting or moving a fast time window is no longer required and all the important experimental events happening during the tokamak shot will be captured. Since the calibration circuit allows us to transmit calibrated signals into the control room over fiber optics, the faster digitizers can be used. The number of points now available to use in each I/V characteristic analysis is ten times more than previously. During the Langmuir probe analysis, the reference signals in the beginning of the Langmuir probe data record are used to set the gain and offset of the data signal. With four reference voltages, the linearity can be checked as well. This greatly improves the quality of the fits used to determine particle flux, electron temperature, and density at the DIII-D diverter target plates.

IV. POWER SUPPLY CONTROL CALIBRATION

The Langmuir probe kepco power supplies are controlled individually by separate drive signals sent over a similar type fiber link from the control room to the power supplies near the tokamak. These control signals are generated by a DTACQ AO32 analog output module which has 32 analog outputs controlled through a custom made graphical user interface adapted from the previous power supply control system. Several waveforms and frequencies can be selected depending on the data requirements of the tokamak experiment. Using the fiber link data channel calibrations determined as described in the previous section, the power supply control signals can also then be calibrated. These drive signals are going over fiber links that are also subject to the same issues of offset and gain uncertainty. By comparing the calibrated voltage signals coming back from the voltage sensors at the power supplies, the offset and gain in the power supply control signals can be determined and this information can be used to accurately control the power supply voltages. The power supply current is a result of the plasma response to the power supply drive voltage, and is set only by the probe area and plasma conditions we are seeking to measure.

V. SUMMARY

Using a technique to calibrate the offsets and gains of analog fiber optic data links allows the current and voltage data signals to be transmitted to the control room. This capability allows usage of a modern data acquisition system in the DIII-D control room that can store 64 channels of Langmuir probe data at 1 Megasample per second for 8 seconds. This technique is possible through the use of a remote calibration circuit that embeds a series of reference voltages into the data record for each channel before the tokamak shot. This new faster data acquisition system will increase the number of points used for I/V analysis by 10X and improves the quality and quantity of Langmuir probe data available in DIII-D tokamak experiments. Using the data signal fiber link calibration, resulting from our embedded calibration reference signals, the power supply control fiber link offsets and gains can also be determined.

VI. ACKNOWLEDGEMENTS

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