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ABSTRACT

The DIII-D Thomson scattering system has been upgraded. New data acquisition hardware was installed adding the capacity for additional spatial channels and longer acquisition times for temperature and density measurements. Detector modules were replaced with faster trans-impedance circuitry increasing the signal-to-noise ratio by a factor of two. This allows for future expansion to the edge system. A second phase upgrade scheduled for 2010–2011 includes the installation of four 1 J per pulse Nd:YAG lasers at 50 Hz repetition rate. This paper presents the first completed phase of the upgrade and performance comparison between the original system and the upgraded system. The plan for the second phase is also presented.

I. INTRODUCTION

Thomson scattering has been one of the diagnostics used for measuring the electron temperature and density in the DIII-D tokamak.[1,2] The design by Carlstrom et al. of the DIII-D Thomson system consisting of a total of eight 20 Hz Nd:YAG lasers, as shown in Fig. 1, remains unchanged. This paper discusses the system's technological modernization as well as its expansion to better study the relevant plasma edge physics since last reported.[3] The Thomson system upgrade has been divided into two phases, with the first phase fully completed. The system now has new detector electronics that incorporate analog integration as well as sample and hold circuitry, thus increasing the signal-to-noise-ratio (SNR) by a factor of two compared to the previous detector modules. Obsolete CAMAC data acquisition crates were replaced by a DT-100 system[4] that incorporate ACQ196CPCI digitizing modules. This replacement eliminates both data channel and digital memory constraints. All data acquisition, and data analysis is now done under Linux based computers. For the second phase of the upgrade, new features will include expansion of the horizontal Thomson system to observe high density and temperature gradient plasma edge physics, a redesigned laser control system incorporating field programmable gate array (FPGA) technology, the inclusion of four new 50 Hz Nd:YAG pulsed lasers and implementation of a new automatic laser alignment system.

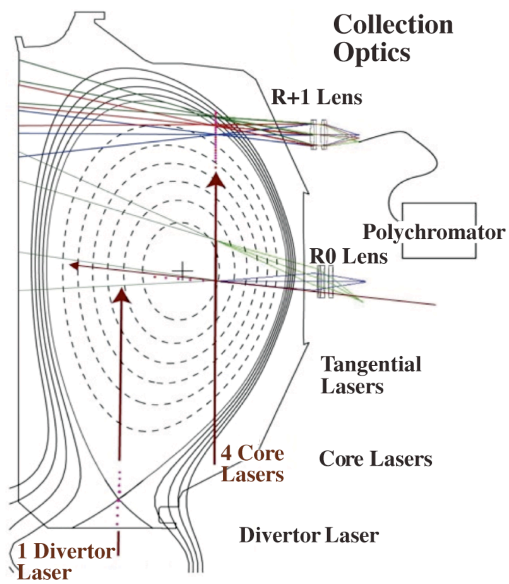

FIG. 1. Thomson system laser path inside DIII-D and viewports. Four lasers are used for the core system, three lasers for the horizontal (or tangential) system, and one laser for the divertor.

II. DESIGN

Significant changes to the system during the first upgrade phase can be put into several categories: detector module circuit redesign, installation of the DT-100 data acquisition system, all Linux based data acquisition and data analysis. The most important upgrade is the redesign of the polychromator[5] detector module.[6] A block diagram of the new detector module is shown in Fig. 2. Details of the detector module redesign can be found in Ref. 6, but the significant aspects of this redesign are the use of an IR enhanced avalanche photodiode[7] and the inclusion of a low noise high bandwidth op-amp[8] into a redesigned low noise trans-impedance preamplifier stage at the front end, which features low input noise levels as well as high bandwidth. Background white light noise rejection is done by the same subtraction scheme described in Ref. 1 with the implementations done by Deterly.[6]

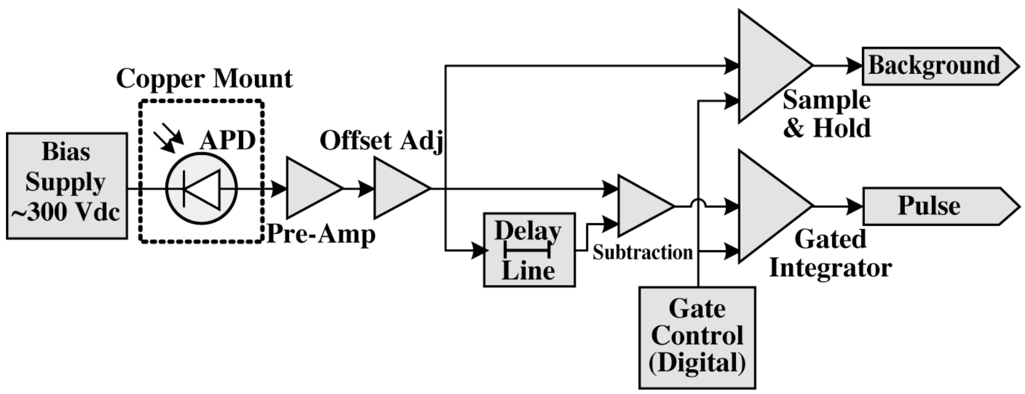

FIG. 2. Detector module block diagram. The APD is biased by a 300V power supply internal to the module, signal travels to the trans-impedance amplifier, then it is split 3 ways: (a) to the DC background sample-and-hold, (b) background+data to subtraction amplifier, (c) background (delayed) to subtraction amplifier. Subtracted signal goes to integration amplifier. [Reprinted with permission from T. M. Deterley *et al.*, IEEE. Trans. Plasma Sci. **38**, 1699 (2010). Copyright © 2010, IEEE.]

The background light is measured before the arrival of the scattered pulsed signal, which includes both pulsed signal and background light, and it is subtracted from the signal containing the pulsed data. The delay between subtracted signals is 30 ns. The detector module incorporates an analog integrating circuit for the data pulse signal as well as a sample-and-hold circuit for the background light signal to be sent to the digitizers.

Integration of the scattered pulse signal is done over a 30 ns gate. The dynamic range of the output signal levels is between approximately 0 V to -4 V and the scattered light signal integral is held for 10 μs. The digitizers use 15 bits over a dynamic range of 0 to -5 V with a sample rate of 500 ksps. At the 500 ksps sampling rate, at least four samples of the detector module output signals can be made over the 10 μs hold gate, satisfying Nyquist's sampling criterion for a DC signal. Presently only the first sample is used for data. The Thomson system has a mode of operation in which the lasers can be grouped together so that the laser pulses probe the plasma with a close pulse train. This mode is useful when trying to make measurements of fast transient phenomena such as ELMs. For running in “burst mode”[3] the DT-100 sample rate will allow for 500 kHz data bursts, this being well above the 10 kHz achieved under the legacy hardware. The DT-100 system allows for the sampled raw data to be dumped into a data stream bus and recorded directly into hard drive media storage. From here it is transferred to a local computer for processing. This significantly reduces the memory buffer constraints. Now one can take data over extended time plasma shots, without any time limitations. The new data acquisition alllows to increase the number of spatial channels twenty-fold.

III. CALIBRATION

The Thomson system calibrations consist of detector module opto-electronic calibration, polychromator spectral calibration, and Rayleigh scattering calibration. All calibrations are described by Bray et al.[9] Currently opto-electronic calibrations are performed on an independent test stand. The opto-calibration stand features a NIST traceable reference power meter and calibrations are done at a wavelength of 1064 nm with fast pulse and CW telecommunication diode lasers used as light sources. Opto-electronic calibration measures the detector module pulsed and background output gains, the statistical dark noise, and the noise on the pulse channel as a function of background CW light. A comparison plot of pulsed signal noise level versus input CW background light between old and new detector modules is shown in Fig. 3. Wavelength calibrations are done to measure total transmitted spectral gain of the complete polychromator. The wavelength calibration is done using a CW light source via a monochromator. The measurement calibrates the total spectral gain of the transmission fibers, polychromator relay lenses, interference bandpass filters and detector modules.

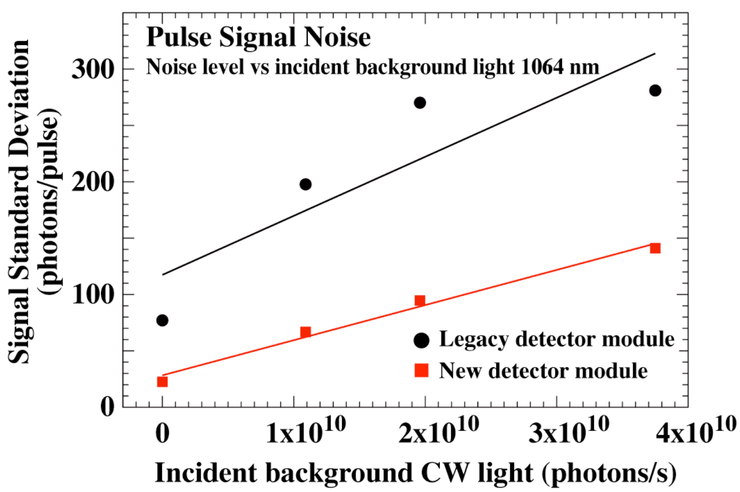

FIG. 3. Comparison of pulse channel noise from opto-electronic calibrations. By optimizing subtraction and integration gate timing due to the improved electronics, SNR can be improved by a factor of ~ 2. Calibrations are at λ=1064 nm. [Reprinted with permission from T. M. Deterley *et al.*, IEEE. Trans. Plasma Sci. **38**, 1699 (2010). Copyright © 2010, IEEE.]

Rayleigh scattering calibration is a complete system calibration done with the Thomson Nd:YAG lasers at the fundamental wavelength. The DIII-D vessel is filled with argon gas from 0 to 3 Torr in increments of 1 Torr. With the known Rayleigh cross section[10] of argon at λ=1064 nm, one can determine the absolute sensitivity of the Thomson system. Figure 4 compares Rayleigh sensitivities for the diverter system between the older and upgraded systems, showing better system sensitivity and linearity.

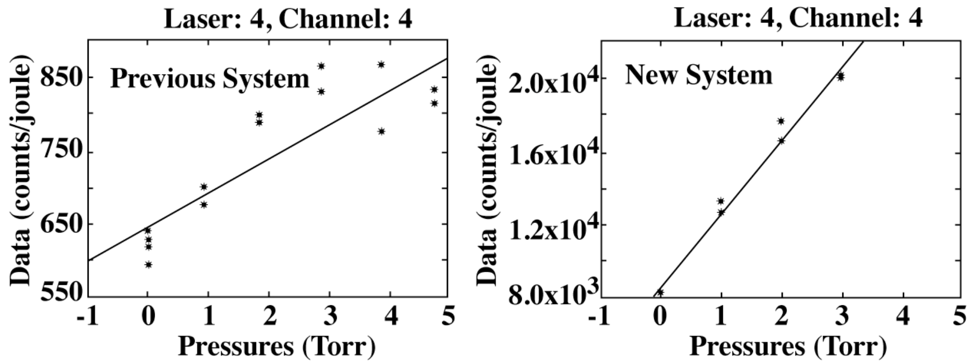

FIG. 4. Diverter Rayleigh scattering calibration comparison. Gain and linearity is much improved. [Reprinted with permission from T. M. Deterley *et al*., IEEE. Trans. Plasma Sci. **38**, 1699 (2010). Copyright © 2010, IEEE.]

IV. RESULTS

The upgraded Thomson system has been deployed and operational since the DIII-D physics campaign that started in September of 2009. The measured electron density and temperature profiles have been improved with smaller error bars reflecting the improved scattered photon statistics. The faster electronics of the detector modules make it possible to adjust the integration timing to almost completely reject the contributions of secondary light pulses produced by the reflected laser stray light. Stray light path length delay inside the DIII-D vessel is 12ns. The new op-amp used in the detector module is capable to resolve both scattered light pulse and reflected stray light pulse. Setting the 30 ns gate to only integrate over the scattered signal reduces significantly the stray light contribution. Figures 5 and 6 show the normalized pulsed data signal as a function of temperature for a typical polychromator for two reference plasma shots done before and after the upgrade, respectively. The scatter is data recorded over a 2 s window and the solid lines are the theoretical expected values. Measurement precision and accuracy are much improved. Error bars are at least 50% smaller and are a consequence of the improved SNR as seen in Fig. 3. Both shots have the same discharge parameters.

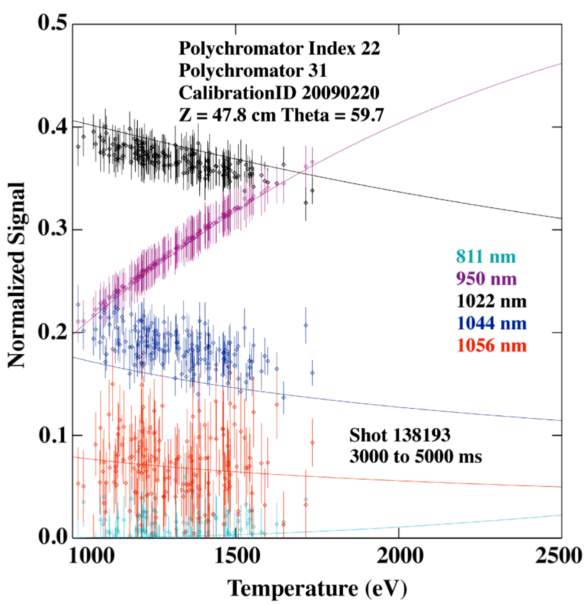

FIG. 5. Polychromator normalized signal as a function of electron temperature of reference shot, before upgrade, Dt = 2.0 s.

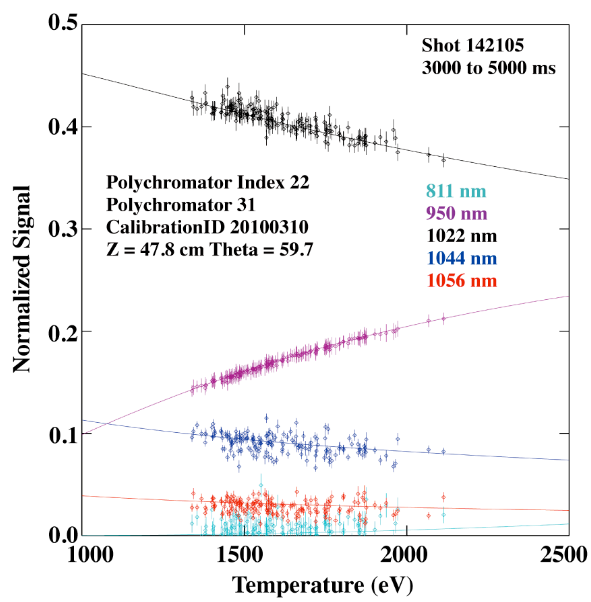

FIG. 6. Polychromator normalized signal as a function of electron temperature of reference shot, after upgrade, Dt = 2.0 s. Data accuracy and precision are greatly increased. The scatter is reduced and the error bars are reduced by at least 50%.

V. FUTURE UPGRADES

During the second phase of the system upgrade, the inclusion of four new Spectra Physics PRO-290-50 50 Hz Nd:YAG lasers will complement the existing eight 20 Hz Continuum NY80 Nd:YAG series lasers. All lasers have energy of 1 J per 8 ns pulse lasing at the fundamental wavelength. The higher laser repetition rate allows the time resolution to be increased. For the inclusion of these new lasers a new laser control system is being designed. It will implement a local FPGA that can be programmable with improved flexibility to be able to provide standard timing or burst laser firing modes with timing accuracy of $< 1\ \mu$s or better.[3] Up to twelve new spatial channels will be added to the existing system. These new channels will be placed in the horizontal system and will make measurements in the plasma edge region.

VI. SUMMARY

The DIII-D Thomson scattering diagnostic is undergoing a major technological upgrade. Improvements in sensitivity and performance have been achieved. New demands required by transition physics studies can be met by the upgrade of the horizontal system. Future upgrades also include the addition of higher repetition lasers with the system capable of supporting 16 lasers.

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