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Enhancing detection sensitivity of SST-1 Thomson scattering experiment

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ABSTRACT

Thomson Scattering System (TSS) is the main diagnostic to extract electron temperature and density of steady state superconducting (SST-1) tokamak plasma. Silicon avalanche photo diode is used with low noise and fast signal conditioning electronics (SCE) to detect incoming Thomson scattered laser photons. A stringent requirement for the measurement is to detect high speed and low level light signal (detection of 100 numbers of Thomson scattered photons for 50 ns pulse width at input of active area of detector) in the presence of wide band electro-magnetic interference (EMI) noise. The electronics and instruments for different sub-systems kept in laboratory contribute to the radiated and conductive noise in a complex manner to the experiment, which can degrade the resultant signal to noise ratio (SNR <1). In general a repeated trial method with flexible grounding scheme are used to improve system signal to noise ratio, which is time consuming and less efficient. In the present work a simple, robust, cost-effective instrumentation system is used for the measurement and monitoring with improved ground scheme and shielding method to minimize noise, isolating the internal sub-system generated noise and external interference which leads to an improved SNR.

1. Introduction

Steady state superconducting tokamak (SST-1) Thomson scattering (TS) system [1] is designed to operate using six high power Nd:YAG lasers operating at fundamental frequency ($\lambda = 1064$ nm) with pulse width of 8 ns. Thomson scattering is an important diagnostics for the estimation of electron temperature and density profile of the tokamak plasma. The photons from laser light get scattered by the free electrons and the scattered photons are collected as well as spectrally dispersed to five bands for the detection. As the Thomson scattering cross section is very small, the numbers of scattered photons collected from the tokomak plasma are very small. Detection of such a very low flux of photons requires high sensitive detectors with response at this wavelength. IR (Infrared) enhanced Si-Avalanche photodiodes (APD) with thermo-electric cooler (TEC) is one of the best options available for this purpose. SST-1 TS system uses TEC cooled APD sensor from Hamamatsu (Model – S8890) to measure scattered photon flux for the measurement of the plasma parameters. The output signal from these sensors is in nano-ampere (nA) range at bandwidth of 50 MHz ($\sim$20 ns). The low level of the current output ($\sim$100 nA corresponds to 100 photons whereas 45 nA is the sensors dark current) of APD is amplified ($\sim$90 K @50 MHz) to measure scattered photons at 50 MHz bandwidth and plasma background signal at 300 KHz. The detector signal conditioning electronics (SCE) and current to voltage conversion gives $\sim$10 mV output corresponds to 100 photons at 50 ns pulse width. The expected noise level is <5 mV, which is contributed from the detector internal noise and SCE. This leads to signal to noise ratio (SNR) of $\sim$2 (6 dB). Any further increase in noise level of the order of 5 mV can affect the accuracy and sensitivity of the TS system performance.

The detection of 10 mV @ 50 MHz scatter signal with average SNR of >1 (0 dB) is crucial part of the TSS due to (1) susceptibility of sensitive detector and SCE (large gain, wide bandwidth) to external noise sources (2) no storage of fast signal output, so it cannot be recovered later in case of any random noise at post processing stage (fast integrator electronics, timing and synchronization section, PXI based data acquisition system) (3) external interference from different sub-systems and power line (4) multiple grounding loops due to multiple channels of SCE (5) mixed signal operation (6) detector electronics inter-channel interference (7) effect of mechanical and physical constraint of detection system layout.

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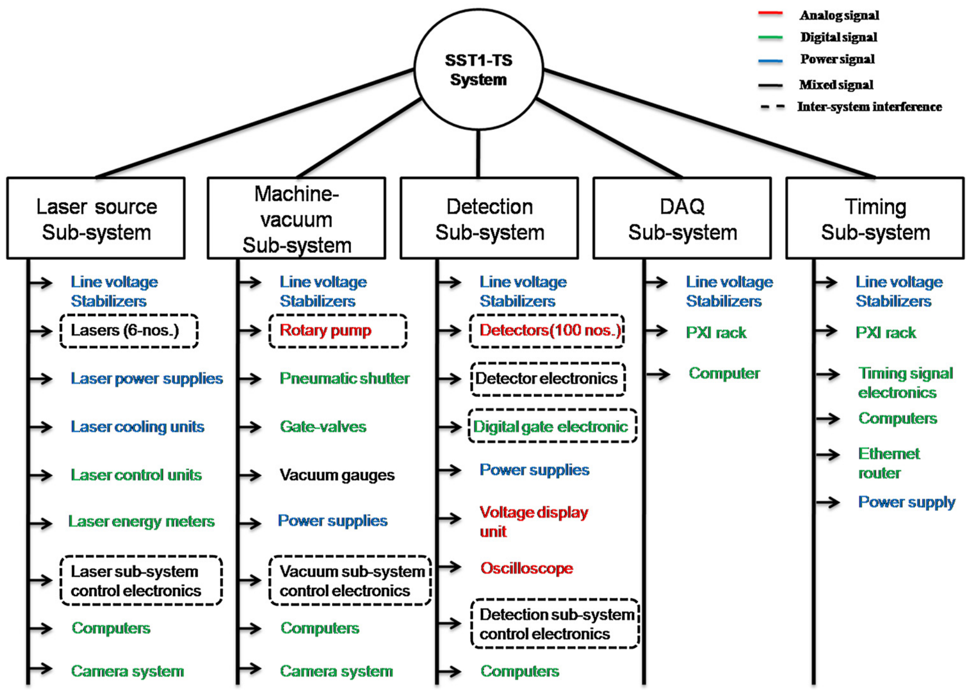

Fig. 1. Schematic of TS sub-systems showing different components at system level which contributes interference.

Table 1
Different type of signal channels in TS experiment.

Sl. no.	Signal types	Signal name	Frequency range	Total channels
1	Analog	TS signal	≤50 MHz	100
2	Analog	Plasma background signal	≤300 KHz	100
3	Analog	Integrated TS signal	<25 MHz	100
4	Analog	Integrated Plasma background signal	<250 KHz	100
2	Digital	Timing, gain, status, Gate, control	<1 MHz	~150
3	Analog	Temperature, flow, HV control	<30 Hz	~200
4	RS232, Fire-wire, PCI, PXI, USB, Ethernet, Wireless	Laser, CCD, Control system	Kbps to Mbps	~50

The measured background signal (without plasma) of electronics under best optimized conditions for SST TSS was ~18 mV. Higher noise level could be attributed due to EMI pickup/ground noise pickups from, selected resistor value in circuit needed for the operating gain of SCE, parasitic and distributed components of the circuit, radiated EMI from self-generated/lasers/other electronic equipment, conductive interference, RLC (Resistor, Inductor, Capacitor) value of formed signal return path, other surrounding and sub-system interference. The achieved average value of SNR is ~0.845 (−1.5 dB) for the detection of ~100 photons. The SNR should be >1 for the acceptable measurement.

To evaluate the source of pickups noise and to improve the overall SNR of the TSS experiment, measurement of noise (interference) from each source is measured using oscilloscope at the signal path and spectrum analyzer using field probes at (1) different stages of SCE detector section (individually from each detector and by considering the effect of five SCE detector inter-channels coupling for one filter polychromator or with others). (2) inside filter polychromator power supply rack; (3) at Field Programmable Gate Array (FPGA) based control card (4) at laser source sub-system (5) at vacuum sub-system, (6) at timing system, (7) at gated integrator electronics [2] (8) at PXI based data acquisition (DAQ) sub-system etc. The electronics section is classified in three ways as per their functionality; (A) analog section (B) digital section (C) mixed signal (analog and digital) section. The target was to achieve back ground current (background noise level) close to the calculated value as per specification of APD and other sources during tokamak plasma experiment.

Significant number of literatures [3–11] are available for studying the EMI from DUT (Device under test), susceptibility to EMI of DUT, and mitigation techniques to reduce the EMI at circuit level. In this article we describe about the degradation of performance of standalone system upon the introduction of other sub-systems and reduction of SNR of whole system due to different types of interferences. The SNR of the whole system improved substantially with the mitigation techniques described in this article such that the signal detection level has improved significantly.

2. Thomson scattering subsystems layout

The SST-1 TS system can sub divide to five main sub-systems [12]; (1) laser as light source (2) vacuum subsystem: tokamak machine interfacing vacuum drift tubes and associated gate valves and gauges (3) scattered light detection system (4) data acquisition (5) control, timing and synchronization. Fig. 1 shows a schematic representation of distribution of different sub-systems consisting electronics/timing and control/power supply which contribute the noise to the detector output.

The light source consists of six Nd:YAG lasers (1.6 J @ 30 Hz and 8 ns pulse duration), its power supply, timing and control systems. The vacuum sub-system consists of interlock control system consisting gate-valves, pressure gauges, and pneumatic shutters. The detection sub-systems have twenty filter polychromators [13].