An Improved Detector Electronics and Data Acquisition System Design for Thomson Scattering Diagnostic on DIII–D

* C. Liu, C.L. Hsieh, B.D. Bray, D. Sellers, General Atomics – The detector electronics and data acquisition system for the Thomson scattering diagnostic on DIII-D is being upgraded to replace the present CAMAC-based system. Besides more modern electronics, the proposed design contains a number of improved features. For instance, to reduce the gain drift with temperature in the avalanche photodiode, the diode will be mounted on a thermally insulated copper block and maintained at an elevated temperature using feedback control. Since the plasma background light plays a dominant role in the measurement noise, a model is used to analyze the noise contribution in regard to the time widths of the electronic output pulse and the signal integration gate. The building blocks of the detector electronics are GHz OpAmps and the ns analog switches. The method of differential gating [1] is used to cancel the charge injection induced by the high speed operation in the analog switch.

I. INTRODUCTION

• The present Thomson Detector Electronics and DAQ system is CAMAC based and it is getting so old that many of its modules are no longer supported by the manufacturer.

• The intent for the upgrade is to replace the existing system. Taking this opportunity we have asked ourselves what can we do to help the overall measurement quality. For instance, can we reduce the systematic errors and can we try minimizing the noise contribution from the plasma background light?

• One of the systematic errors in the measurement, we believe, is due to the drifting of the detector gain with the surrounding temperature. Hence, it is desirable if we can feedback control of the detector temperature to less than half a degree.
• The plasma background light is frequently the dominant noise source, especially in the plasma boundary and diverter region. It appears desirable if we can narrow the time span of the measurement, that is, to reduce further both the preamp’s output pulse width and the integrator’s gate width so to reduce the noise contribution from background fluctuation.
• The function of Thomson Detector Electronics and DAQ system is to convert
  Number of Thomson photons $\rightarrow D_p$,
  Plasma background light level $\rightarrow D_b$,
where $D_p$ and $D_b$, the digitizer output, are just two numbers.
• The design of the upgrade system divides the system into the following sections:
  1) Detector Mounting Assembly with temperature control,
  2) Detector Electronics,
  3) Data Acquisition.
FIG. 1 FUNCTION OF THOMSON DETECTOR ELECTRONICS & DAQ SYSTEM
II. Detector Assembly with temperature control

- Mechanical arrangement of Detector Assembly — Heat sink and Thermal isolation
- Temperature Feedback Control
- Tests ----
  - Detector Gain Vs Temp
  - Gain Stability with Temp Control
Fig. 2  Front and backside of the copper block used as the heat sink to mount the SiAPD detector.
Fig. 3 Front and back of the detector mounting assembly.
Fig. 4 Detector Gain Vs Temperature With/Without Temperature Control
III. Detector Electronics

- Detector Electronics is divided into the following sections:
  
  1) Detector Pre-Amp;
  2) Timing Control;
  3) Driver for Analog Switch;
  4) Background Track and Hold;
  5) Differential Gated Integrator.

- We have incorporated the GHz Op-Amp (OPA 657 from Burr Brown) and the nSec Analog Switch (SD210 from Linear System) as the building blocks in the electronic design.
FIG. 5 BLOCK DIAGRAM OF THOMSON DETECTOR ELECTRONICS & DAQ SYSTEM
IV. Detector Pre-Amp Section

- Effect of $R_f$ and $C$: since at low frequencies $S = i_d R_f$, $S$ increases with $R_f$. At high frequencies the intrinsic and stray capacitance becomes important. After a certain point, further increases in $R_f$ mostly widen the pulse width of the signal, not much increases in the signal amplitude.

- As the output pulse width $\tau$ increases, the signal will carries more fluctuation from the plasma background light because of the noise accumulation from the light that arrives before the Thomson pulse.

- For the output signal to maximize the gain while minimizing the background fluctuation in the pulse signal, the parameter $S/\sqrt{\tau}$ is used as a guide to determine the optimal choice of $R_f$. 
• A range of $R_f$ values have been tried in the test setup, it appears that $R_f = 40K\Omega$ is close to the peak of $S/\sqrt{\tau}$.
• For $R_f = 40K\Omega$, the pulse width at the output is about 17-19 nSec (FWHM) for an input light of about 6-8 nSec (FWHM).
• The detector assembly has been designed as an independent unit with the temperature control and the dc/dc voltage converters all in one place. The Pre-Amp has a buffer at the output to drive 50Ω cable.
FIG. 6 DETECTOR PRE-AMP SECTION
Fig. 7 Light Input and Pre-Amp Output Of Detector Pre-Amp Assembly
V. Timing Control & Analog-Switch Driver

• Upon receiving a master trigger, the timing control section generates 3 gates for the operations of the Track/Hold (T/H) and the Differential Gated Integrator (DGI).

• ECL logic is used internally in order to maintain the timing accuracy of 1 nSec.

• The analog switch needs a gate voltage of 12 volts with a rise/fall time of about 1-2 nSec. A special driver circuit is needed to operate the switch.
• Charge Injection effect --- During the opening and closing of the analog switch, a certain amount of charges induced by the gate will be left on the source/drain side of the switch. We use the differential circuit to balance out the charge injection effect as suggested by Wang.


• The fast switching generates a lot of radio frequency noise on the circuit board. The noise needs to be shielded away properly.
FIG. 8 TRIGGER AND GATES OF THE TIMING CONTROL SECTION
Fig. 8 Trigger and Gates of the Timing Control Section
Fig. 9 Analog Switch: Switch Gate and Its Charge Injection Effect
VI. Track/Hold

- The T/H is to sample the background light at about 10 nSec before the arrival of the Thomson pulse signal and to hold its value for about 10 μS.
- The T/H is constructed using the analog switch SD210 with a differential arrangement to cancel the charge injection.
- The droop rate is small because of the use of FET Op-Amp (OPA 656) as the buffers.
FIG. 10 DIFFENTIAL ARRANGEMENT OF TRACK/HOLD CIRCUIT
Fig. 11 Operation of Track/Hold
VII. Differential Gated Integrator

- This is a fast integrator with the gate duration of about 20-30 nSec. And the output can be held for 10μS with no noticeable drooping.
- Two pairs of SD210 are used, one for the gate operation and the other for the short and holding actions across the capacitors.
- The differential arrangement is to cancel both the plasma background and the charge injection induced in the operation of the analog switches.
FIG. 12 FAST DIFFERENTIAL GATED INTEGRATOR
Fig. 13 Operation of the Differential Gated Integration
VIII. Summary

• An upgraded system is being designed to replace the existing Detector Electronics and DAQ system on DIII-D Thomson diagnostic.

• For improving the gain stability of the detector, a new detector mounting arrangement allows the detector temperature to be feedback controlled.

• The GHz Op-Amp (OPA 657) and nSec analog switch (SD 210) are employed as the building block in the electronics design.
• The balance of high signal gain but narrow pulse width, as defined by the parameter $S/\sqrt{\tau}$, is being sought to minimize the noise contribution from the plasma background.
• Work (except the DAQ section) has progressed to the prototype phase.