Design and Optimization of the CSA-based Readout Electronics for STCF ECAL

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1. Introduction

Super Tau-Charm Facility (STCF) is one of the important options for accelerator-based particle physics after Beijing Electron-Positron Collider (BEPC-II) in China, which aims at ultra-precise measurement and new physics search in tau-charm energy region with about 100 times higher luminosity. The conceptual layouts of the collider and its detector are shown in figure-1. The electromagnetic calorimeter (ECAL), as an important part of the spectrometer, needs to meet demand of high-efficiency and high-resolution gamma detection, electron and hadron discrimination, etc. Pure CsI (pCsI) is selected as the scintillation crystal for STCF ECAL owing to its fast response (30 ns decay time), high mass density and adequate radiation hardness. Due to the relative low light yield of pCsI crystal and the strong magnetic environment in the experiment, avalanche photodiode (APD) is proposed to convert the scintillation light into current signal with an internal gain of about 50 at the recommended operating voltage.

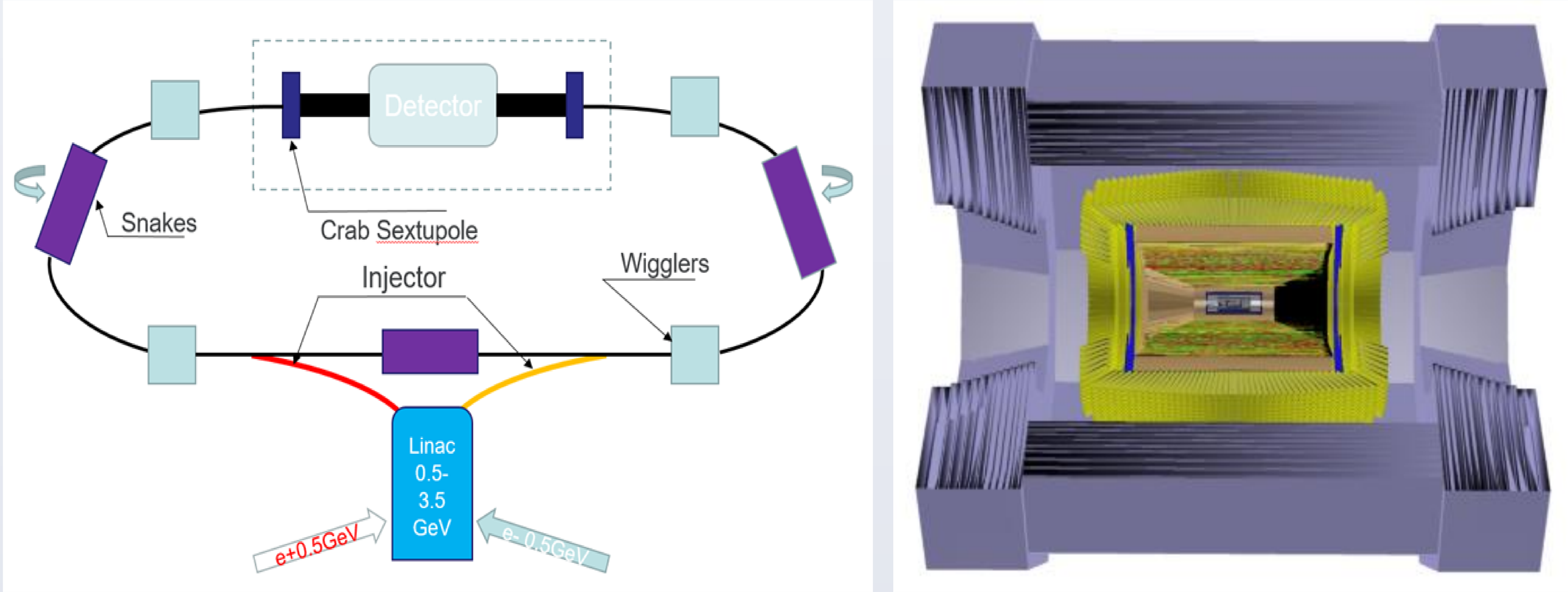

Figure-1. The conceptual layouts of STCF collider (left) and its detector (right).

Charge sensitive amplifier (CSA) which has the feature of low noise and high charge measure performance has been used to read the APD signal. Considering the large capacitance of APDs (tens to hundreds of picofarads) which may result in poor noise performance, a low noise field effective transistor (FET) input stage is adopted. Then, a $CR-RC^2$ shaping circuit is employed to improve the signal-to-noise ratio (SNR), and the shaped analog signal is digitalized by an ADC chip. Digital data are pre-processed by FPGA and transmitted to the upper computer via Ethernet. The circuit block diagram and PCB (Front End Board and Back End Board) pictures are shown in figure-2.

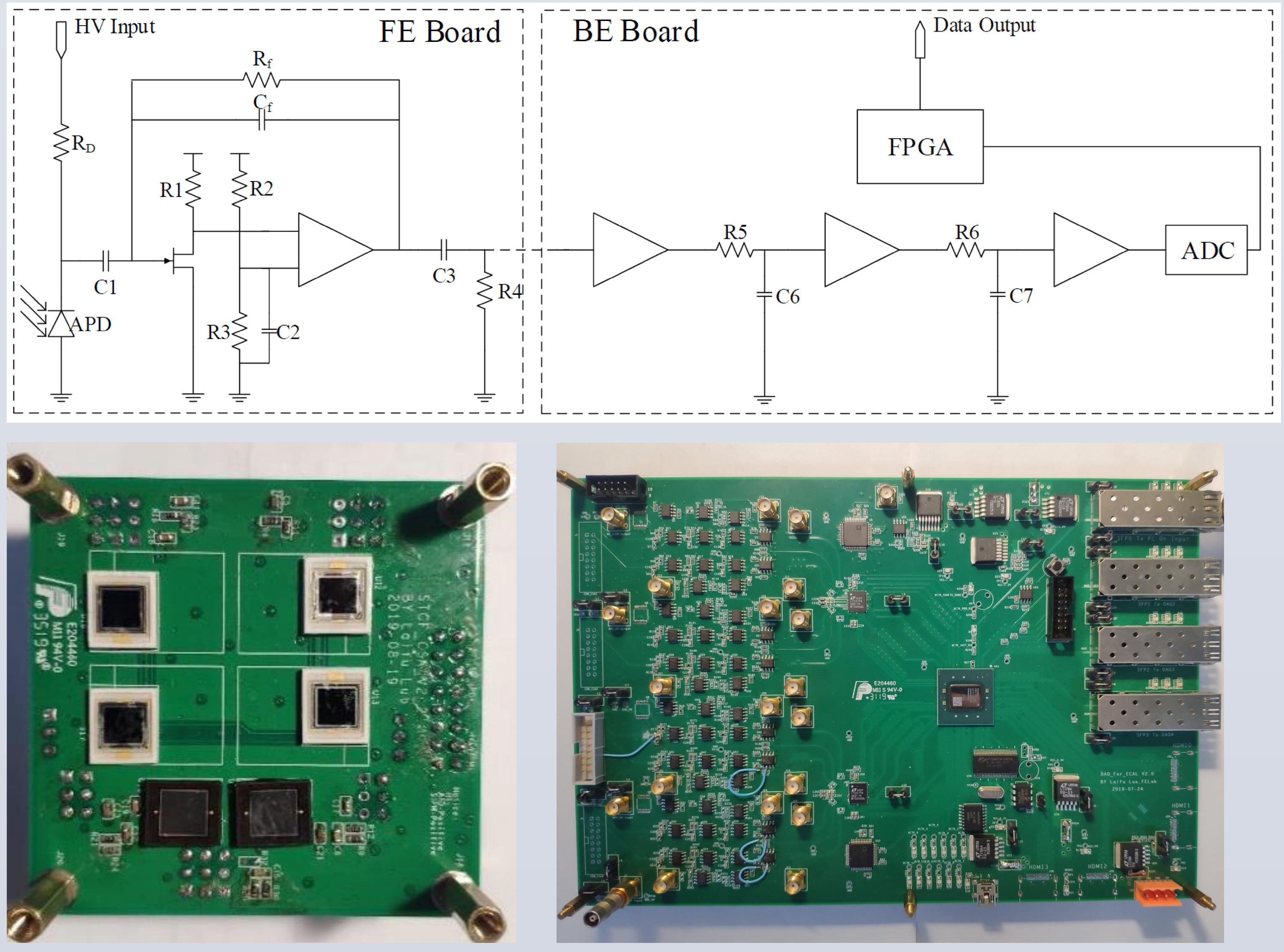

Figure-2 Circuit block diagram (Top), PCB picture of FEB (Bottom left) and BEB (Bottom right).

2. Noise Equivalent Circuit Establishment

In this paper, the noise of APD and JFET-based CSA has been studied for pure CsI crystal which is a basic option for STCF ECAL. A noise equivalent circuit is established and discussed for the specific readout structure, which contains eleven noise sources including APD leakage current shot noise, feedback resistor thermal noise, JFET channel thermal noise, etc. Figure-3 is the detailed Front End Board noise equivalent model circuit.

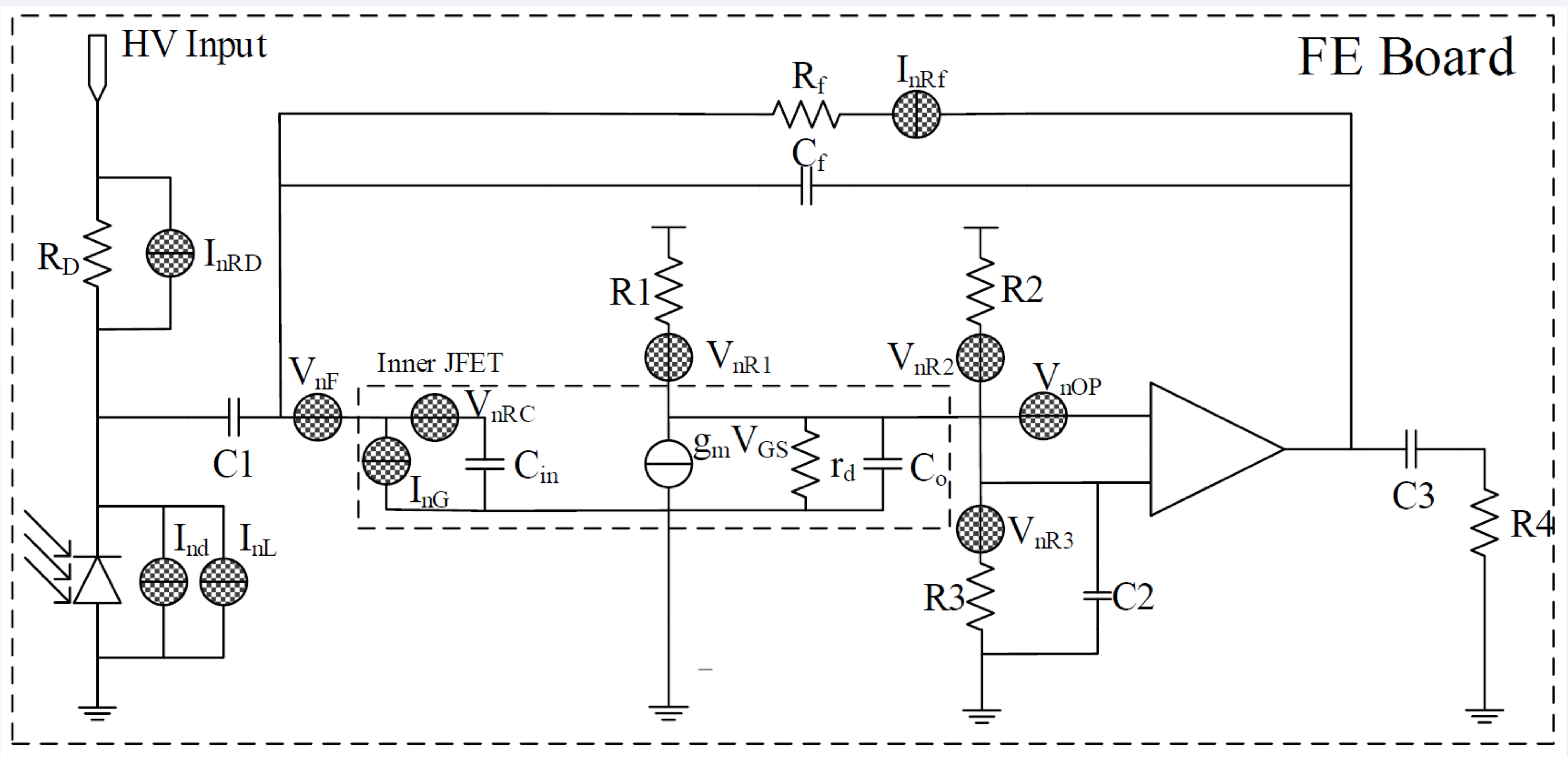

Figure-3. The equivalent circuit of the Front End Board containing eleven noise sources.

3. Performance

After the preliminary optimal working point was obtained through the theoretical calculation of noise, the electronic noise test was carried out and the result is shown in figure-4. The relationship between system noise and input capacitance indicates that 3-JFET input stage has better noise performance in the case of large input capacitance (Hamamatsu S8664-1010 APD), while 2-JFET structure is not much worse than 3-JFET in all capacitance range Covering Hamamatsu S8664-0505).

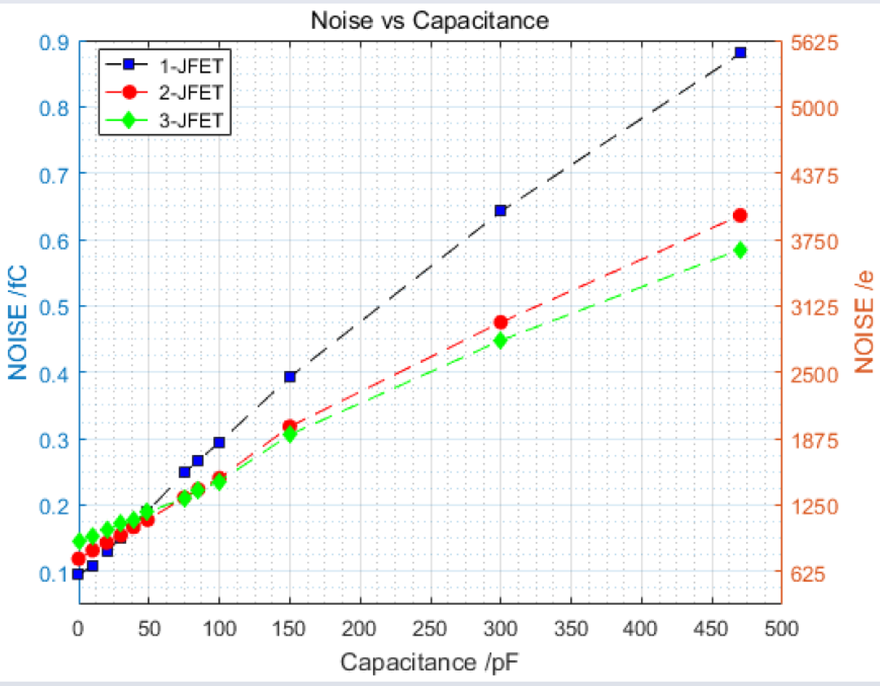

Figure-4 The electronic noise with different input capacitance.

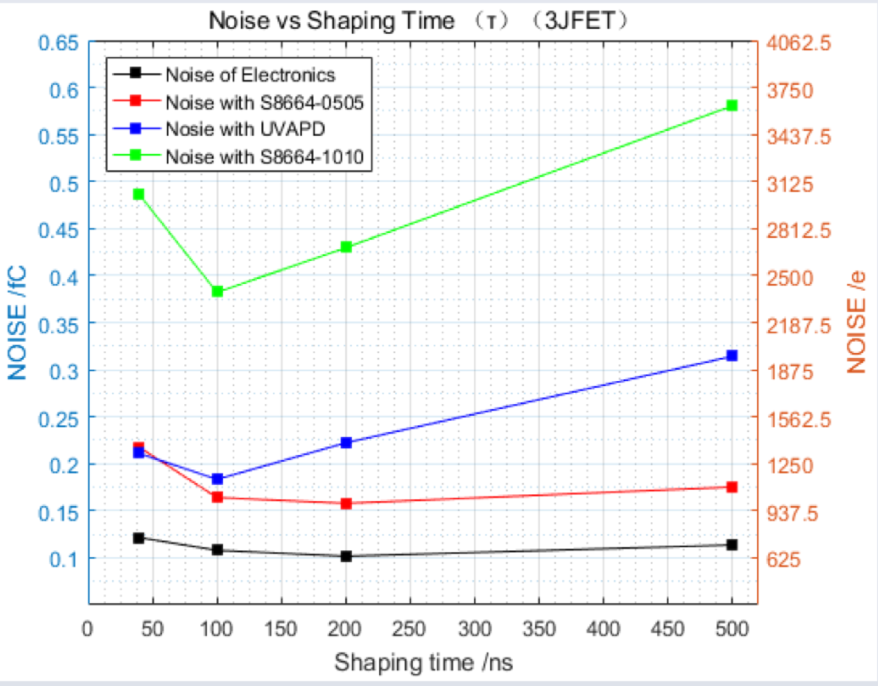

Figure-5 Noise of the readout system at different shaping time

CSA with 3-JFET as input stage is utilized to examine the noise performance of the readout system with three different APDs: Hamamatsu S8664-0505, Hamamatsu S8664-1010, and Hamamatsu UVAPD.

Noise of the readout system with these three types of APDs at different shaping time is measured, on the condition of an operating voltage with 50 gain. The detailed experimental results are shown in figure-5. The result shows that the noise of UVAPD is similar to S8664-0505 when the shaping time is less than 100 ns. Hence, UVAPD would have better performance because of the higher quantum efficiency. S8664-1010, which has twice as much noise as S8664-0505, would achieve similar performance considering the size of area.

In conclusion, an equivalent noise charge of 675 electrons of electronics alone and 1025 electrons with S8664-0505 APD attached is realized.

4. Conclusion

A CSA-based electronics system is designed to readout the signal of pCsI crystal, which is the basic option of STCF ECAL. Noise optimization of the readout scheme for large input capacitance is carried out. System with 3-JFET (2SK715) input stage CSA and 100 ns shaping time has the best noise performance after testing. A noise level of 675 electrons for electronics alone and 1025 electrons with S8664-0505 APD connected is realized.

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