A CPCI-based LLRF system for proton CT

Chengcheng Xiao, Wencheng Fang , Yiming Xu
Shanghai Synchrotron Radiation Facility (SSRF), Chinese Academy of Sciences
2Shanghai Advanced Research Institute, Chinese Academy of Sciences,

xiaocc@sari.ac.cn; fangwc@sari.ac.cn; xuym@sari.ac.cn;

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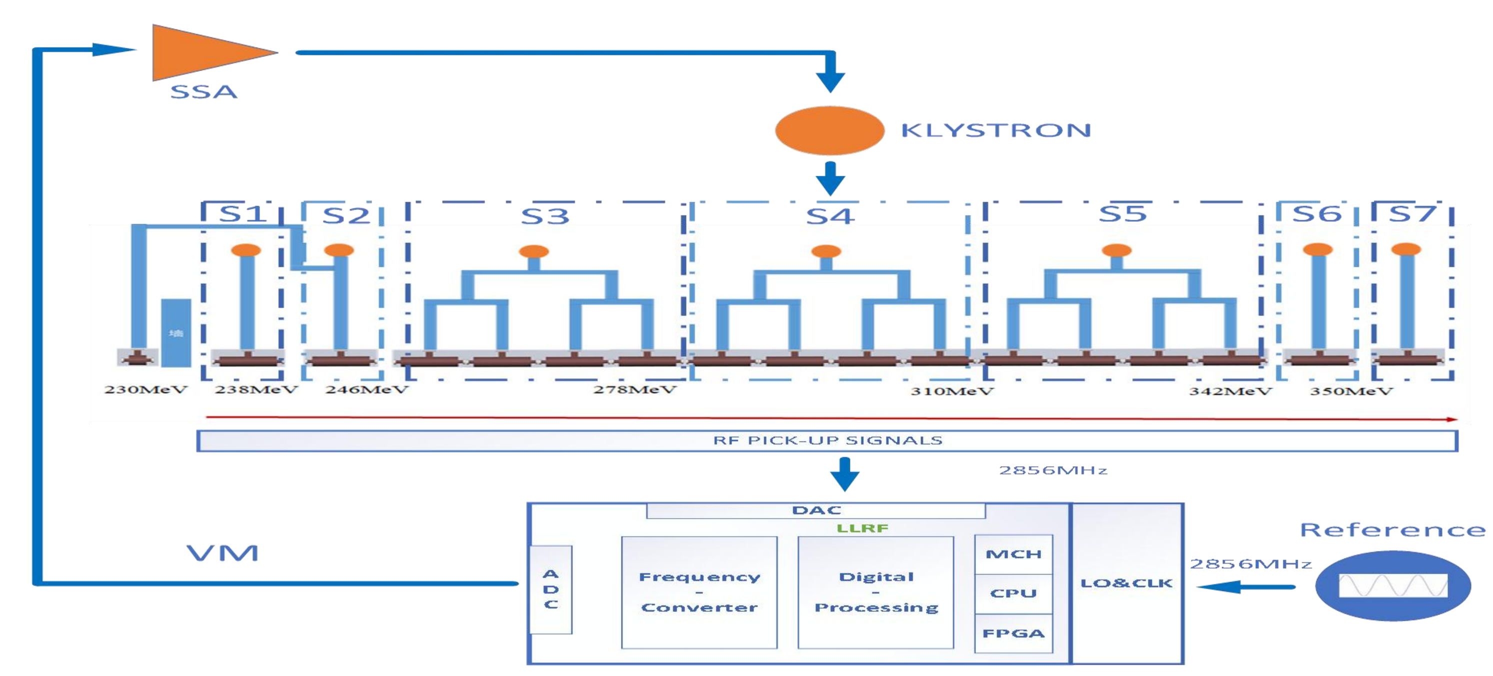
Abstract

A new proton CT(pCT) facility will be built in Shanghai Ruijin Hospital. The main structure of the proton CT includes a high gradient proton LINAC, a compact 360 degree gantry and a proton imaging platform. In the proton LINAC, 16 S band proton accelerating tube were used to increase the energy from 230 MeV to 350 MeV. To provide a more accurate and stable Radio-Frequency(RF) control, a CPCI based Low- Level Radio- Frequency(LLRF) control system was developed. In this paper, we introduce the LLRF control system both in firmware and software, which contains the front frequency conversion board with vector modulation RF output, the acquisition and digital processing board with 10 Channels 125 MSPS ADC , the clock and Local-Oscillator(LO) generator board, the RF distributions and the feedback control.

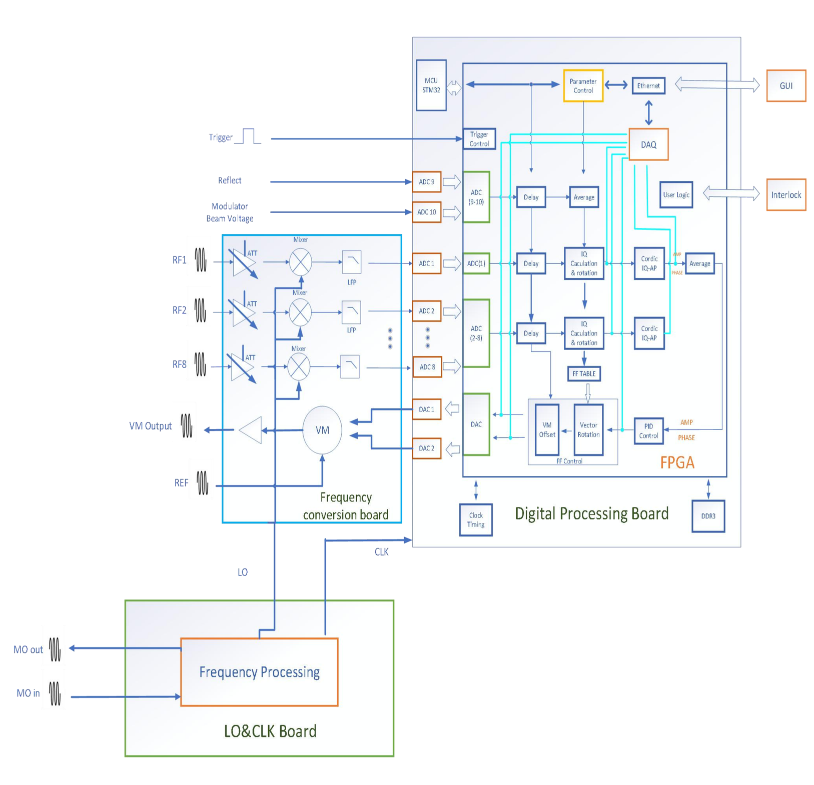
Introduction

The layout of LINAC in the Shanghai Ruijin Hospital pCT facility is shown in the figure below. The whole LINAC is based on S-band(2856 MHz) high gradient acceleration technology and consists of 16 S band proton accelerating tubes. The acceleration section adopts FODO magnetic structure for beam focusing, with an energy gain of 120 MeV and a total length of about 5 meters. The upstream end of the accelerator is also equipped with a focusing design and matching section, which converts the 230 MeV continuous beam of the synchrotron into a pulsed beam, and completes the matching between the transport line and the LINAC. After 16 S band proton accelerating tubes' energized, the beam energy was increased from 230 to 350 MeV.

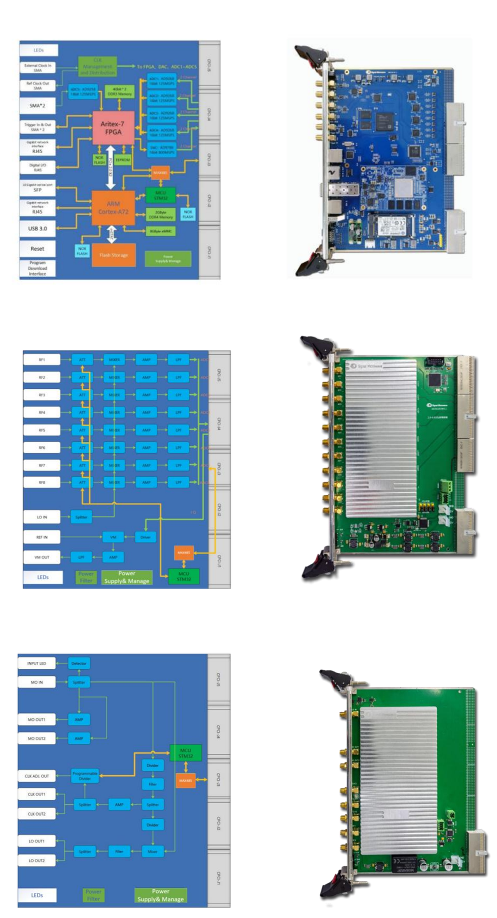


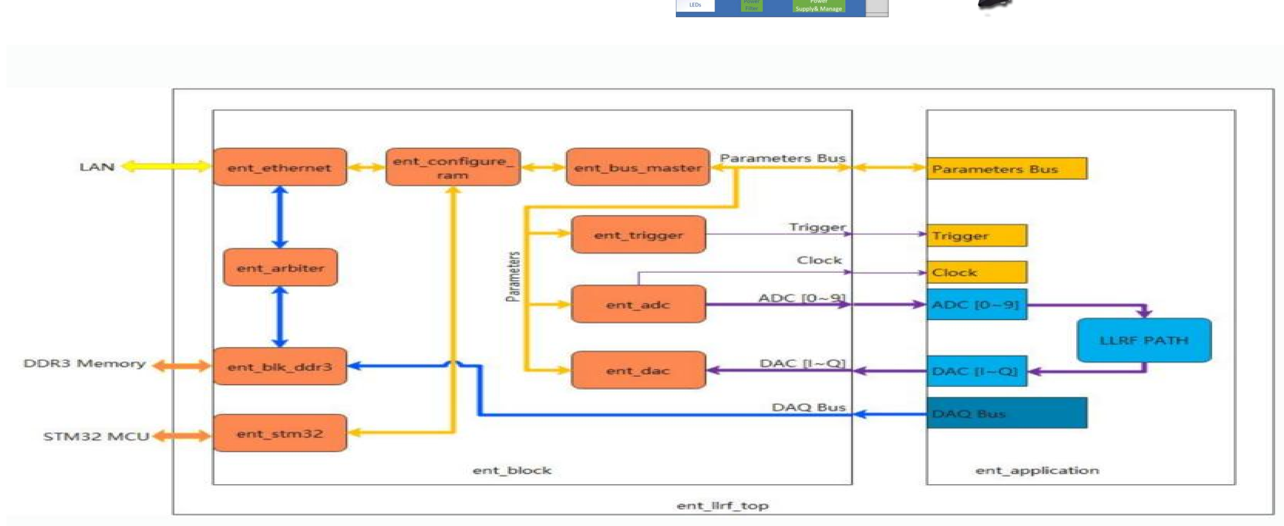
Schematic Design

The microwave signal of S band can not be sampled directly from ADCs. It can only be acquired after down-conversion to IF signal. The IF signal should be as high as possible, which is conducive to filtering and improving the processing speed of digital signal. Besides, the sampling rate of ADC should be taken into account. Only when the sampling rate of ADC and the frequency of IF signal are reasonably selected, the information in the original signal can be completely retained. The schematic and the fabricated frequency conversion board board is shown in fig.3. The frequency conversion board has 8 groups of adjustable dynamic down conversion channels and 1 channel vector quadrature up conversion channel. The pick-up signals, like the through and reflect of SSA and Klystron, are down converted from S band signals to IF signals. The built in attenuator can realize a adjustable gain of - 20- 10dB, and the serial control mode is adopted to realize the adjustable 8-channel down conversion gain through custom bus via RS485 communication interface. And for the vector modulation output, the reference signal is vector modulated by a pair of IQ differential signals to generate the drive signal of SSA.



Schematic of the LLRF control system

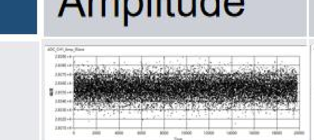
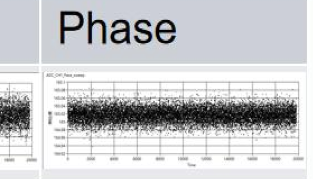
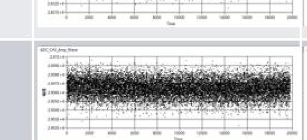
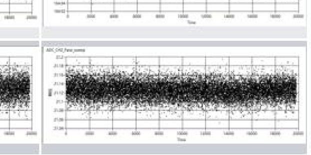
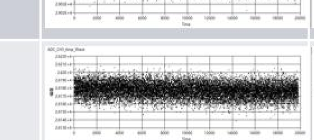
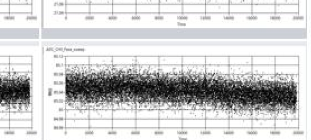
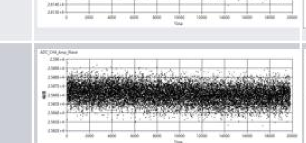
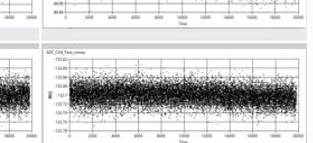
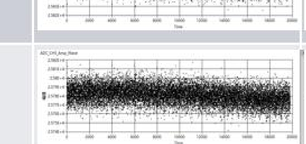
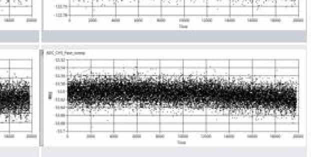
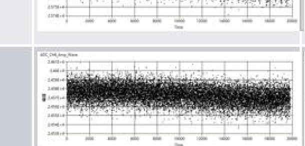
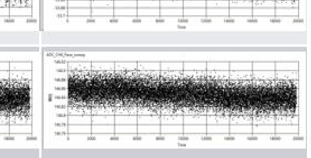
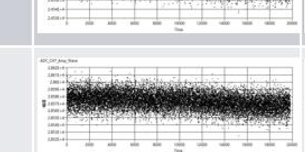
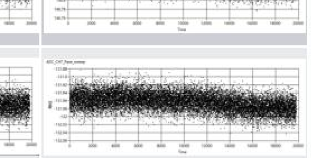
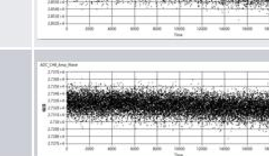
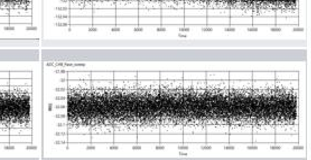




Underlying program architecture

Measurement Results

The channel consistency test showed that all eight channels achieved the required amplitude and phase stability.The stability of the LLRF system has been tested highly stable with a 0.03% Amplitude stability and 0.03-degree phase stability.

Test channel	Amplitude (RMS)	Phase (RMS)	Test performance	
			Amplitude	Phase
Channel1	0.0337%	0.0174°		
Channel2	0.0328%	0.0180°		
Chanel3	0.0336%	0.0190°		
Channel4	0.0356%	0.0173°		
Channel5	0.0360%	0.0185°		
Channel6	0.0377%	0.0188°		
Channel7	0.0388%	0.0211°		
Channel8	0.0378%	0.0180°		

Conclusion

A 16-bit 125MHz/s 8-channel CPCI based LLRF system designed for the proton CT had been designed, fabricated, and tested. The channel consistency test showed that all eight channels achieved the required amplitude and phase stability.The stability of the LLRF system has been tested highly stable with a 0.03% Amplitude stability and 0.03-degree phase stability.

中国科学院 上海高等研究院
SHANGHAI ADVANCED RESEARCH INSTITUTE CHINESE ACADEMY OF SCIENCES
SSRF