NSRL 中国科学技术大学 国家同步辐射实验室 NATIONAL SYNCHROTRON RADIATION LABORATORY

The MicroTCA.4 based LLRF system and other applications at NSRL

reporter: Chunjie Xie

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Out line

The introduction of NSRL

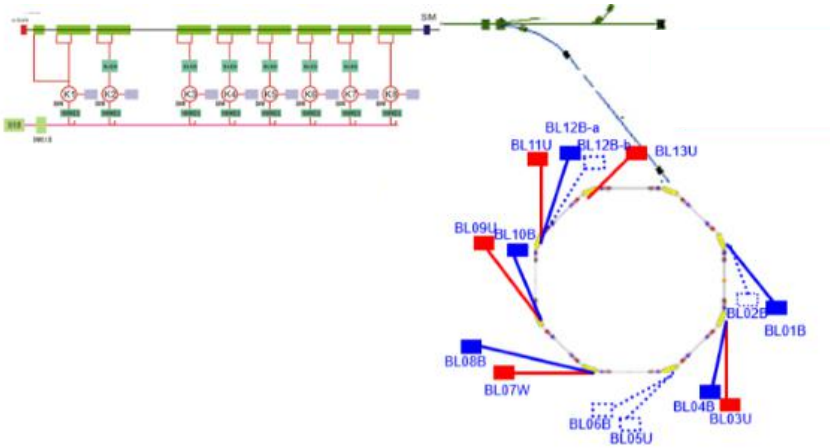
HLS II brief introduction

linear segment (8 sections)

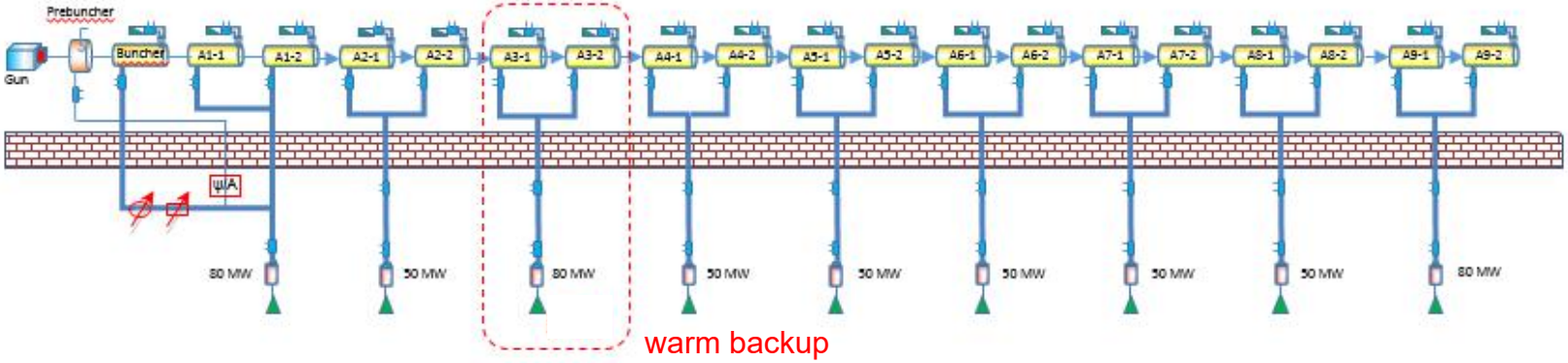
- electron energy 0.8GeV
- repetition frequency 1Hz
- working frequency 2856MHz

storage ring

- perimeter 66.13m
- frequency 204MHz
- current 400mA
- harmonic number 45



a 800 MeV synchrotron light source at the National Synchrotron Radiation Laboratory (NSRL) in university of science and technology,Hefei,China

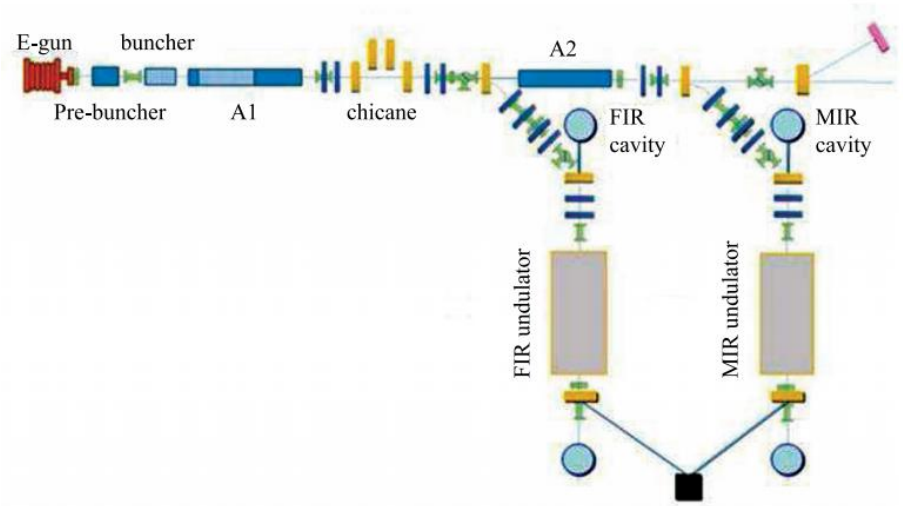


warm backup

The introduction of NSRL

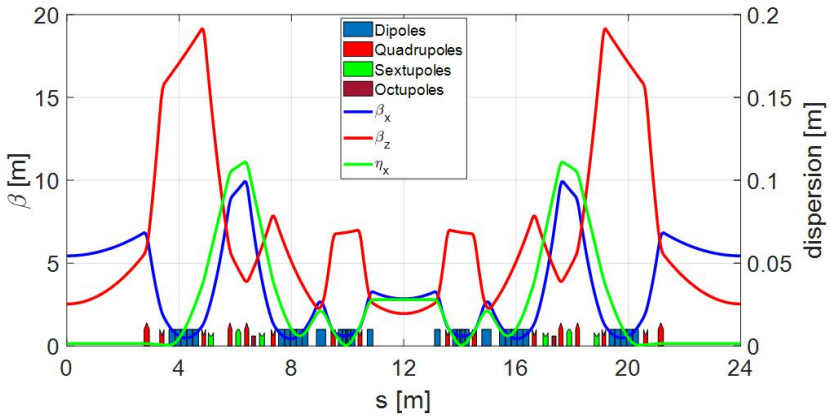
IRFEL brief introduction

Parameters	Specification
Covering spectrum	2.5 ~ 200 μm
MIR FEL oscillators	2.5 ~ 50 μm
FIR FEL oscillators	40 ~ 200 μm
Macro-pulse length(FW)	5~ 10 μs
Repetition of macro-pulse	20 Hz
Macro-pulse energy	~100 mJ
Micro-pulse length (RMS)	5 ~ 10 ps
Micro-pulse energy	1 ~ 50 μJ
Bandwidth	0.3 ~ 3 %
Continuous tunability	200 ~ 300 %

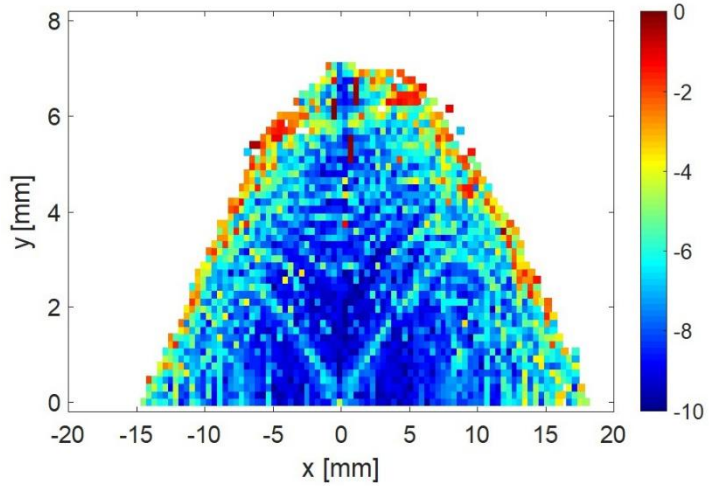


The linac drives two FEL oscillators to generate mid-infrared and far-infrared free electron lasers. Two accelerating tubes (A1, A2) are used to accelerate the electron beam to the maximum energy of 60 MeV. After the first accelerating tube the beam was extracted into the FIR oscillator, to leave enough space between the two oscillators.And it is under commissioning now.

Pre-R&D of Hefei Advanced Light Facility (HALF)



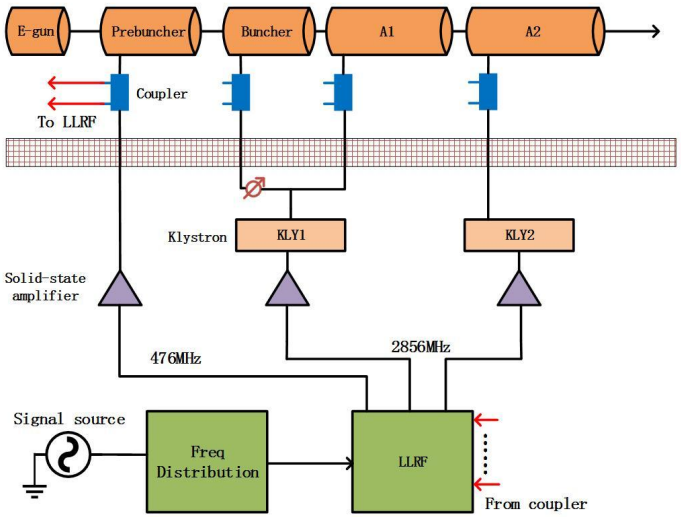
Energy	2.2 GeV
Circumference	480 m
Number of periods	20
Natural emittance	85.5 pm·rad
Transverse tunes (H/V)	48.16/17.16
Natural chromaticities (H/V)	-75/-59
Momentum compaction factor	8.1×10^{-5}
Damping partition numbers (H/V/L)	1.44/1.0/1.56
Natural damping times (H/V/L)	24.6/35.4/22.7 ms
Natural energy spread	0.65×10^{-3}
Straight sections	20×5.5 m & 20×2.2 m



courtesy by Prof. Zhenghe Bai of NSRL

MTCA based LLRF

MTCA based LLRF application at NSRL



Hardware

- MTCA Architecture
- 1 LLRF system per cavity
- AMC SIS8300L2 IQ demodulate and data process
- RTM DWC8VM1 down/up conversion

Software

- VHDL /Verilog developments
- EPICS developments

used on normal conducting linac(include HLS II and IRFEL)

MTCA based LLRF

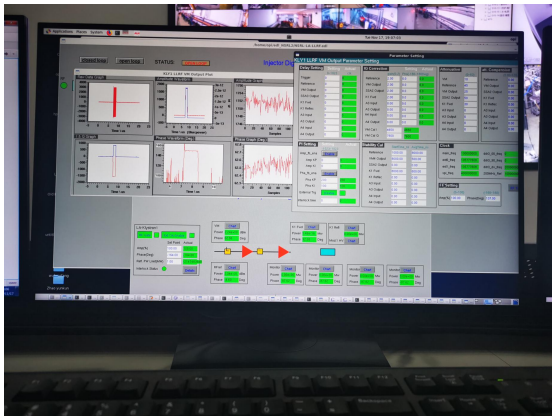
running status of LLRF

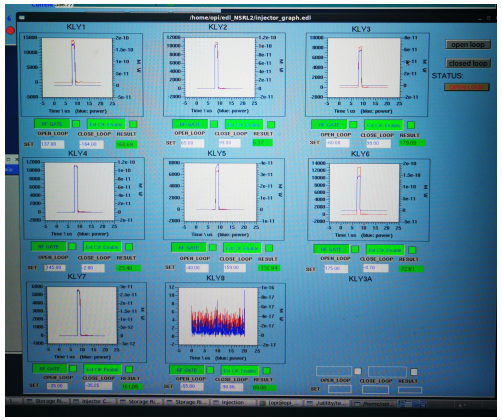
1.MicroTCA.4 crate

2.power amplifier

3.frequency synthesis system

4.signal source

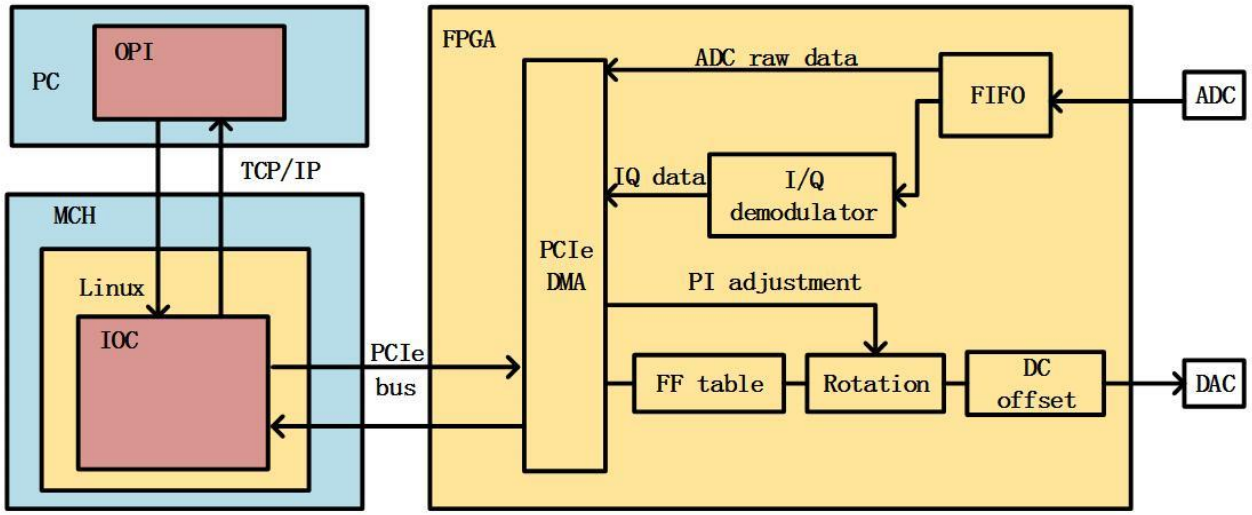




the digital LLRF system upgrade was completed in 2018

MTCA based LLRF

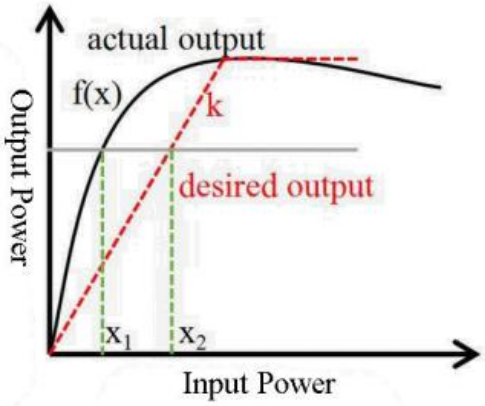
our schematic of LLRF



- ADC sample signals
- upper computer calculate the amplitude and phase and transmit PI parameters via ethernet
- set flat length, amplitude, phase and delay of the output pulse by feed-forward(FF) table
- FPGA complete rotation and offset compensation
- the IQ data are transmitted to DAC and modulate to 2856MHz

New algorithms on LLRF

in-out amplitude predistortion model

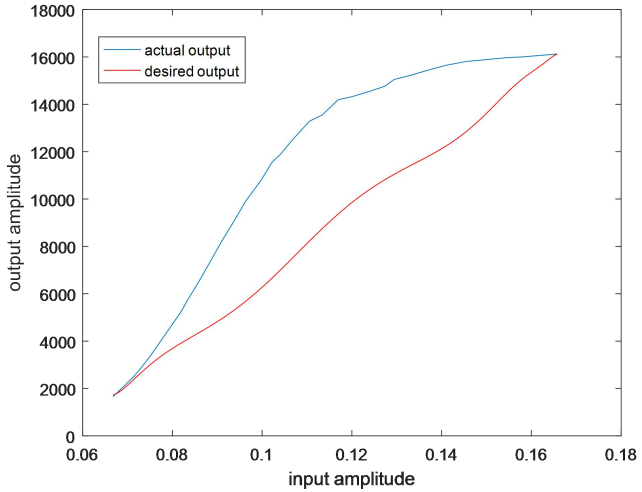


$$f(x_1) = kx_2$$

$$x_2 = \frac{1}{k} f(x_1)$$

$$x_1 = g(x_2)$$

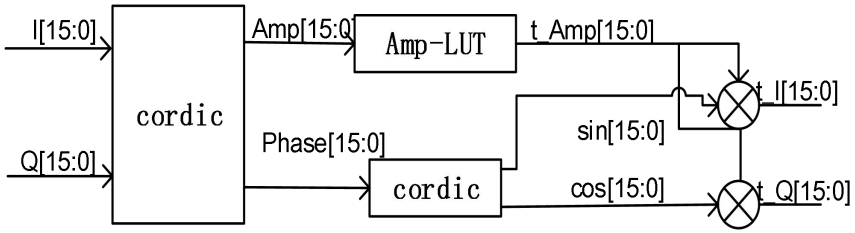
$g(x)$ is the predistortion function



use 4-order polyfit fit the input amplitude and output amplitude model
the right picture shows the simulation result of linearization(red curve is the desired one,blue curve is the actual curve)

New algorithms on LLRF

FPGA implementation



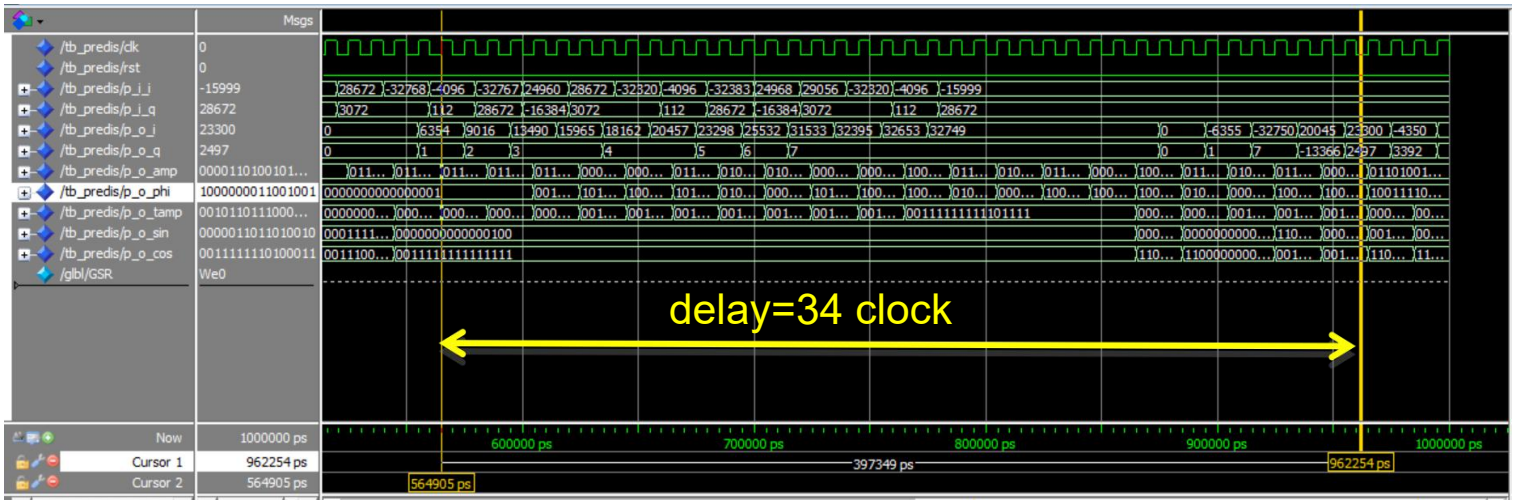
1. use cordic algorithm convert IQ to amplitude and phase and then back to IQ
2. use LUT to convert the amplitude
(the LUT is nonlinear to improve the precision)
3. send the converted amplitude to multiplier and generate new IQ data

advantages:
make LUT is easy

disadvantages:
the phase conversion error and delay depends on the order of cordic
the effect of input amplitude on output phase is not considered

New algorithms on LLRF

FPGA implementation



result

clock delay=34(0.32us),clock period=105.76MHz，for repetition frequency 20Hz is negligible

the amplitude control have been tested and effects

higher order cordic can improve the conversion precision

New algorithms on LLRF

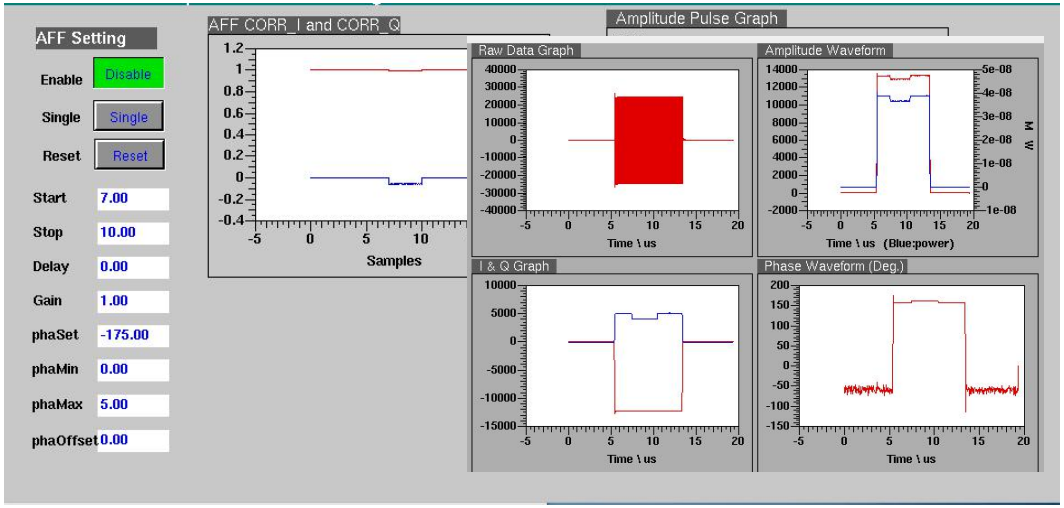
phase control on saturation area:

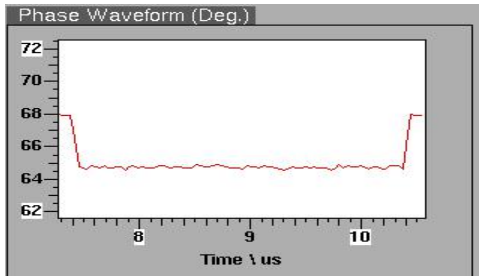
compute the phase error and rotate the feed-forward table to get the proper angle

$$I = I\_feedforward * \text{corr}\_I - Q\_feedward * corr\_Q$$

$$Q = I\_feedforward * \text{corr}\_Q + Q\_feedforward * corr\_I$$

$\text{corr}\_I, corr\_Q$ determined by klystron output





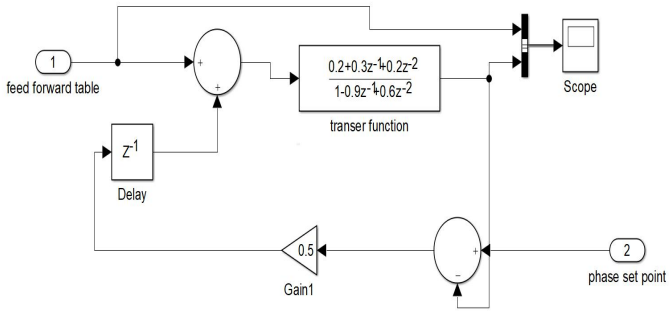
left is the control interface, right is the feed-forward output of phase

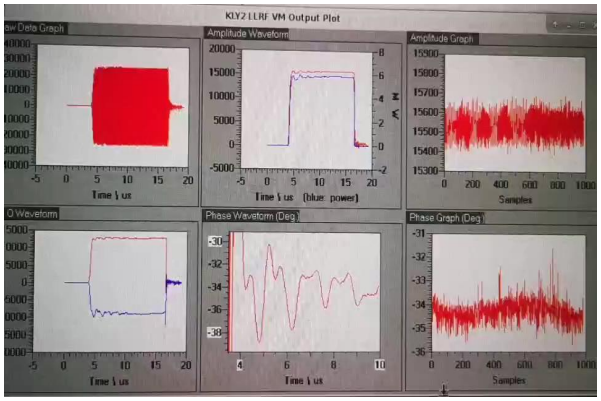
New algorithms on LLRF

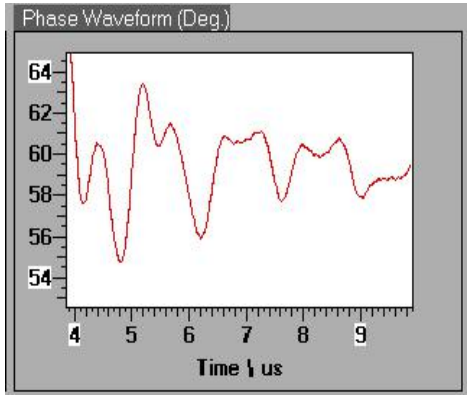
phase control on saturation area:

- 10 degrees ripples
- pulse to pulse fluctuation over 3 degrees

though the simulation prove the effectiveness, it cannot simulate the fluctuation pulse to pulse, the algorithm need to keep optimizing







New algorithms on LLRF

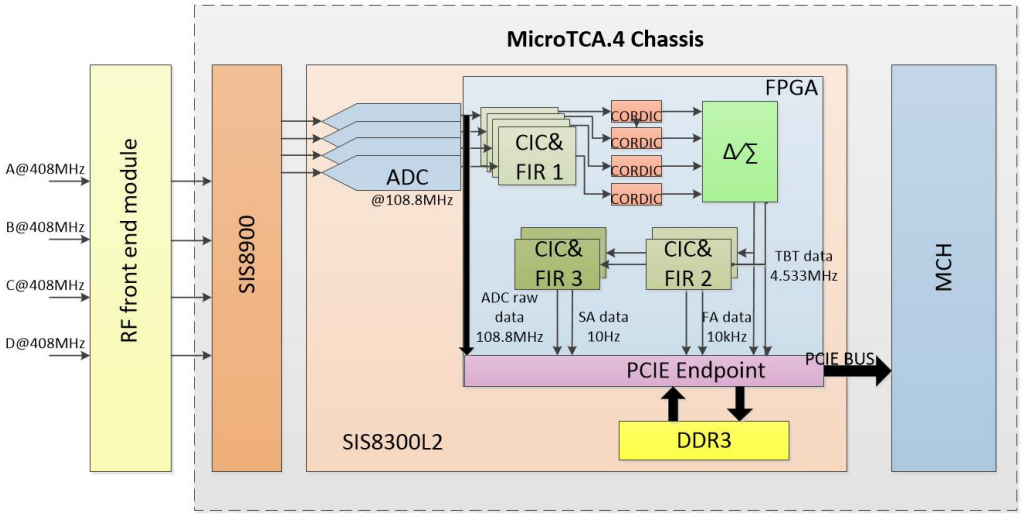
Next plan:

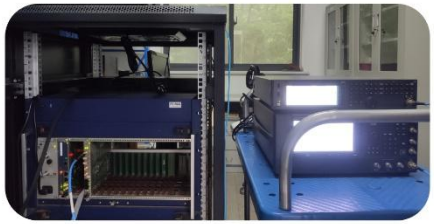
1. establish the input-to-output model of klystron in both amplitude and phase

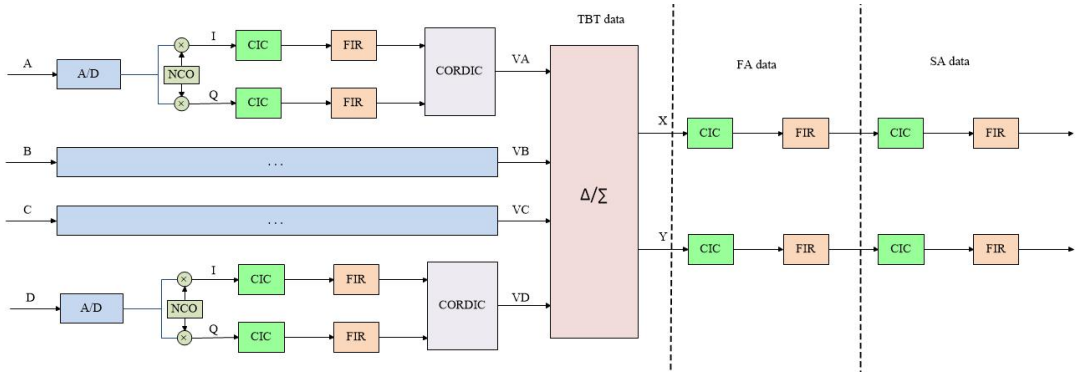
2. find the reason of waveform fluctuation

3. continue to optimize phase control algorithm

MTCA-based BPM

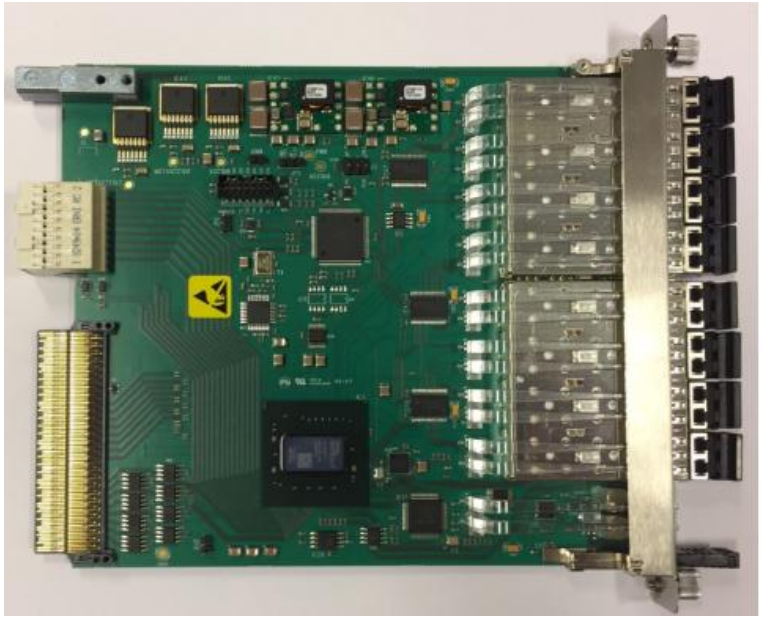






courtesy by Yu Liang of NSRL

MTCA-based Timing System



mTCA-EVM-300

mTCA-EVR-300U

MTCA-based Event Master(mTCA-EVM-300) and Event Receiver(mTCA-EVR-300U) from MRF, will be tested and estimated for HALF.

courtesy by Prof. Chuan Li of NSRL

Summary

1.MicroTCA.4 based LLRF control system completed in 2018.

2.LLRF is in operation and continue to optimize.

3.designed BPM electronics based on MTCA.

4.estimation about timing for HALF will be made.

Thank you for your attention !