Development of MTCA.4-Based LLRF System at SSRF

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Outline

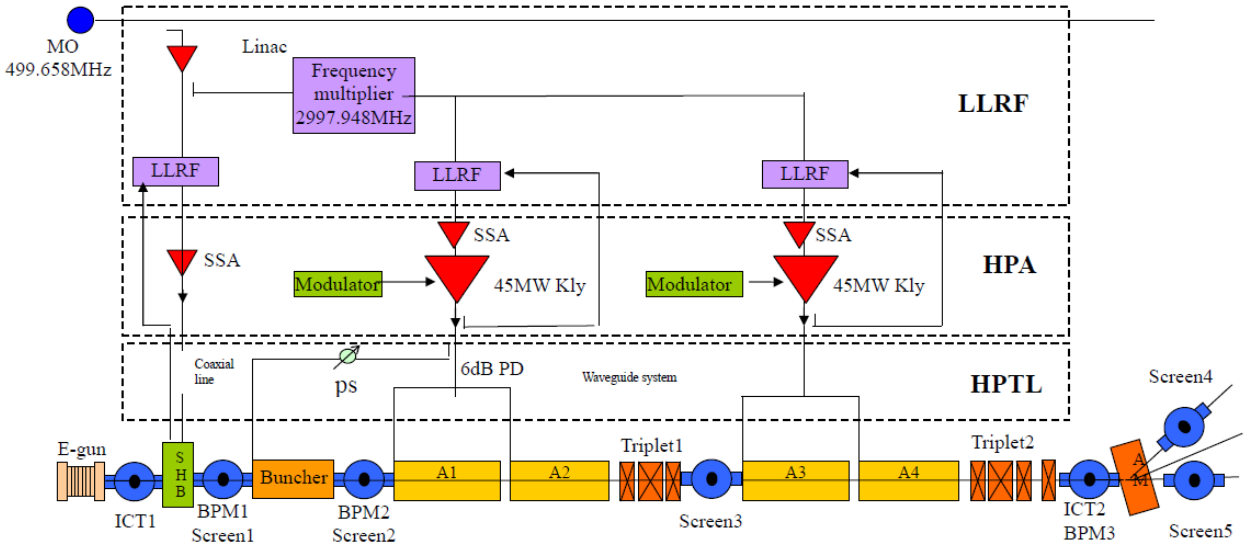
- New projects based on MTCA.4
  - Sirius Linac
  - DCLS
  - SXFEL
  - UED
- Projects updated to MTCA.4
  - SSRF Linac
  - PNS
- Future Applications

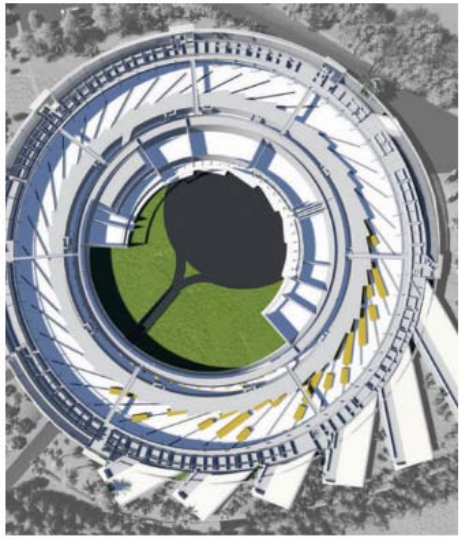
New projects based on MTCA.4

SIRIUS Linac

2014.09, a MicroTCA training was held at SINAP.

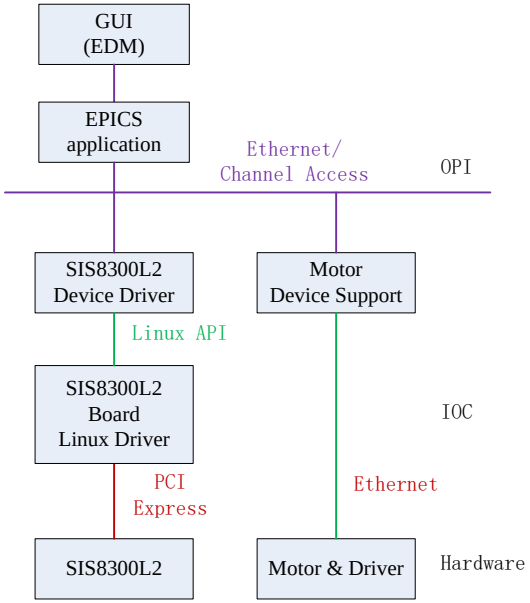
2014.11, we got the first MicroTCA platform.

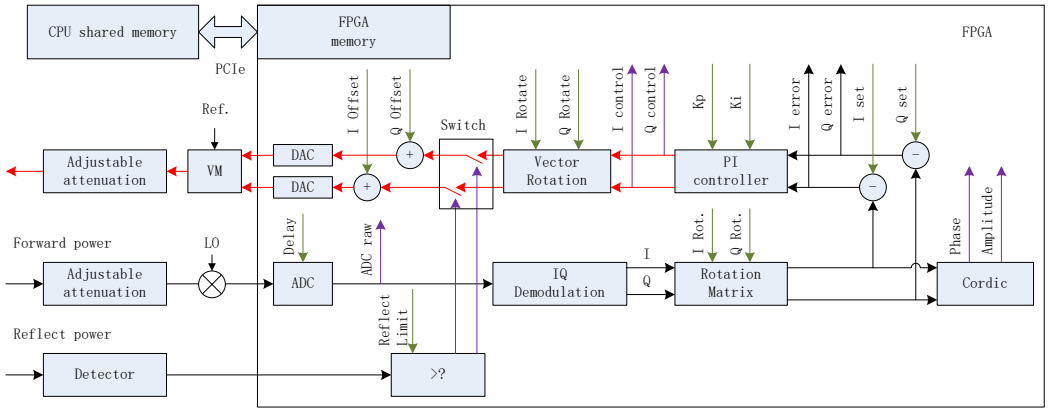




Parameters	Values	
Energy	≥150MeV	
Normalized emittance(rms) in each plane	≤50πmm・mrad	
Relative energy spread(rms)	≤0.5%	
Pulse to pulse energy variation	≤0.25%	
Pulse to pulse time jitter	≤100ps	
Pulse to pulse beam position variation(rms)	≤0.2mm	
Beam profile	Pulse charge	Pulse duration
Multi-bunch mode	≥3nC	150~300ns
Single-bunch mode	≥1nC	≤1ns
Working frequency	2997.948MHz,499.658MHz	
Repetition rate	≤10Hz	

Sirius, a 3 GeV synchrotron light source at the Brazilian Synchrotron Light Laboratory (LNLS) in Campinas, Brazil



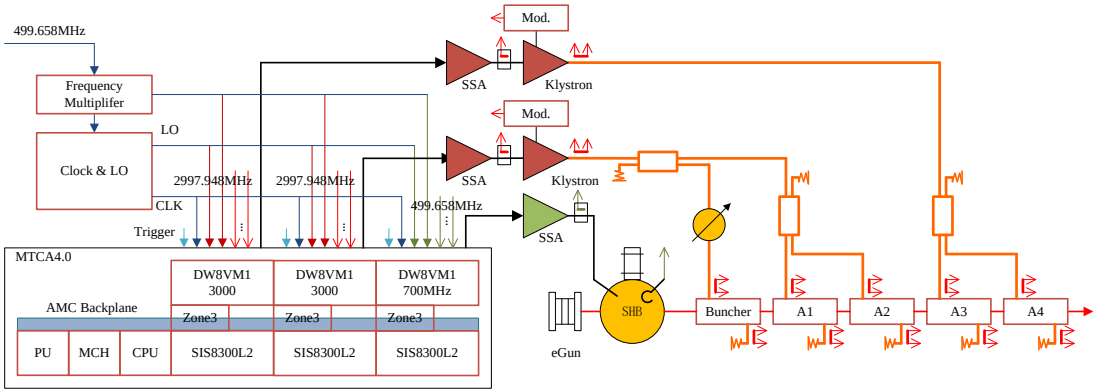


Software and firmware

Hardwares

Digitizer
- SIS8300L2*3

RF frontend
- DWC8VM1 3000*2
- DWC8VM1 700MHz*1

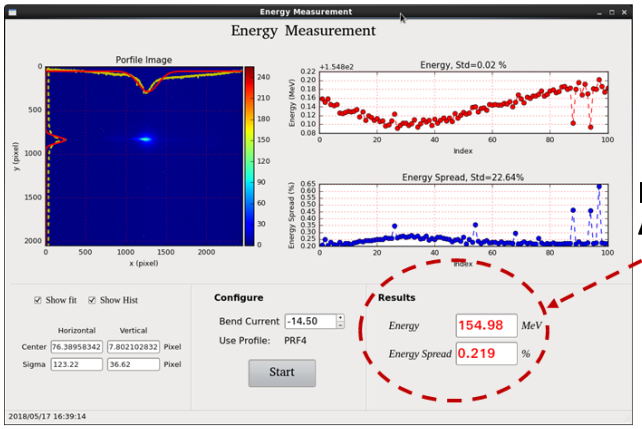


Layout of RF system

Installation
2018.03.19

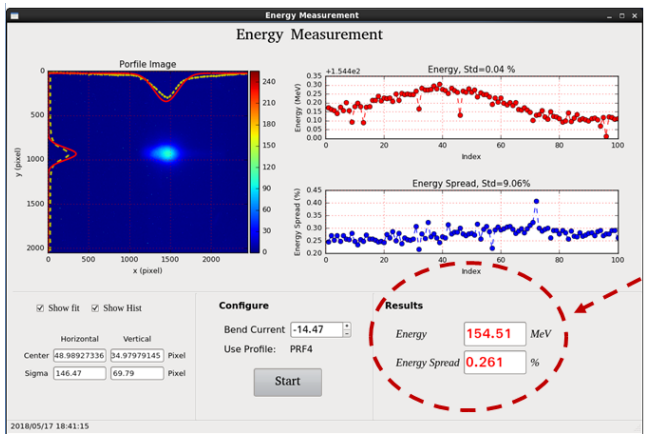
Acceptance testing
2018.05.18

Item	Requirements	Actual values		
		SHB	Kly.1	Kly.2
Amplitude stability	<±1%	±0.2%	±0.3%	±0.2%
Phase stability	<±1.0°	±0.1°	±0.4°	±0.5°



E:155MeV
ΔE:0.22%

Single- bunch

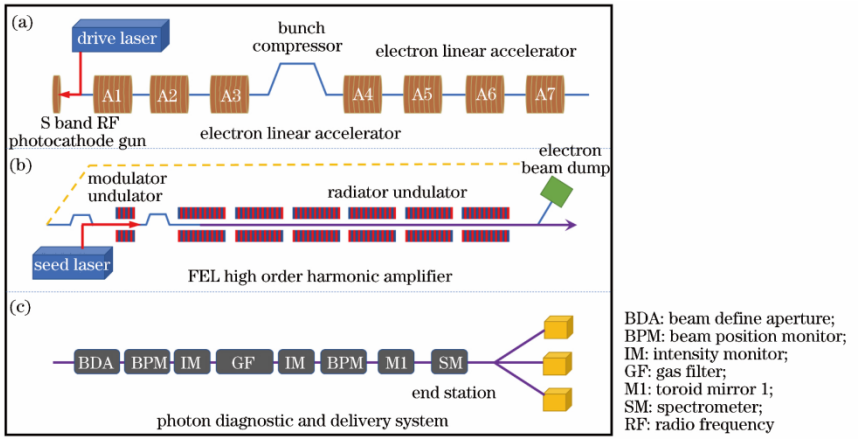


E:154.5MeV
ΔE:0.26%

Multi-bunch

DCLS

Dalian Coherent Light Source (DCLS), as the first FEL user facility in China, works at extreme ultraviolet(EUV) wavelength region, is an ideal light source for excitation of valence electrons and ionization of molecular systems with high efficiency



Dalian Institute of Chemical Physics, CAS

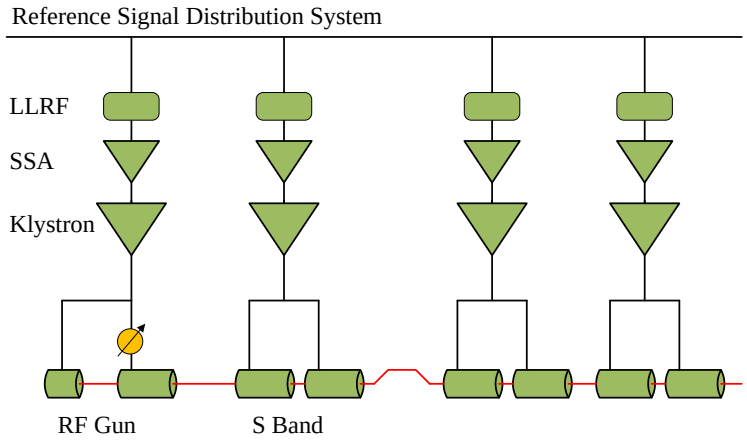
Parameter	Value	Unit
Beam energy	300	MeV
Relative energy spread	1×10^{-4}	
Normalized emittance	1-2	mm·mrad
Peak current	300	A
Seed laser wavelength	240-360	nm
Seed laser width (FWHM)	1.0	ps
Radiator period length	30	mm
Radiator parameter	0.3-1.6	
FEL wavelength	50-150	nm
FEL pulse energy	≥100	μJ
Photon flux	10^{12}	#/pulse

Clock & LO

MTCA.4 crate
- SIS8300L2*2
- DWC8VM1 3000*2

Solide State Amplifier1

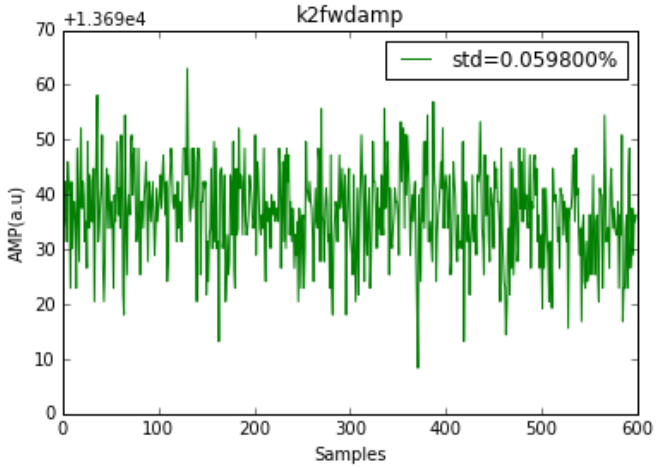
Solide State Amplifier2

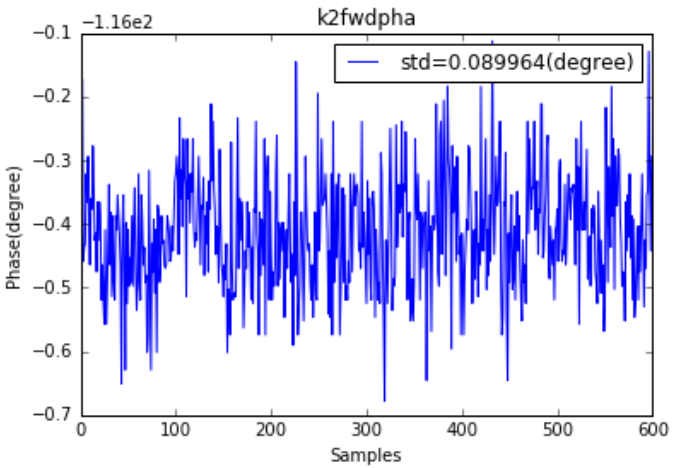


Characteristics	value	unit
Working frequency	2.856	GHz
Repetition rate	1～50	Hz
E field gradient（max）	～20	MV/m
Energy gain（max）	～60	MV
Amplitude stability (rms)	<0.08	%
Phase stability (rms)	<0.1	Deg.

Two sets of downconverter and digitizer are integrated in one crate to control two power sources. The MicroTCA.4 crate is installed in a cabinet, with temperature stability ±0.1ºC

Installation
2016.04
DCLS generated first laser light
2016.09





Item	requirements	Actual value
Amplitude stability	<0.08%(rms)	0.06%
Phase stability	<0.1° (rms)	0.09°

SXFEL

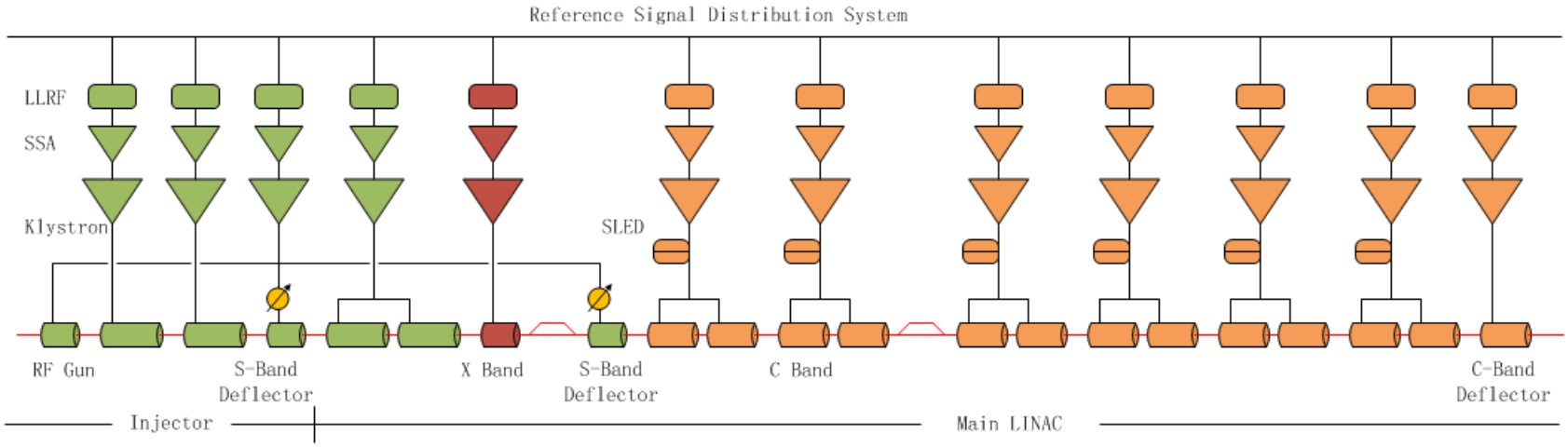
The Shanghai soft X-ray Free-Electron Laser facility (SXFEL) is under commissioning at the Shanghai Synchrotron Radiation Facility (SSRF) campus.

Parameter	Value	Unit
Beam charge	≥0.5	nC
Beam energy	≥840	MeV
Energy spread	≤0.15	rms. %
Peak current	≥500	A
Beam length (FWHM）	≤1	ps
Normalized emittance	≤2.5	mm·mrad
Repetition rate	10	Hz

RF sources:

- 4 S-band
- 7 C-band
- 1 X-band

Characteristics	Unit	S Band	C Band	X Band
Working frequency	GHz	2.856	5.712	11.424
Repetition rate	Hz	1～10	1～10	1～10
E field gradient (max)	MV/m	20	40	80
Energy gain (max)	MV	60	72	80
Amplitude stability (rms)	%	<0.04	<0.04	<0.04
phase stability (rms)	Deg	<0.09	<0.18	<0.36



The RF layout of SXFEL Test facility

Two sets of downconverter and digitizer are integrated in one crate to control two power sources. The MicroTCA.4 crate is installed in a cabinet, with temperature stability ±0.1ºC

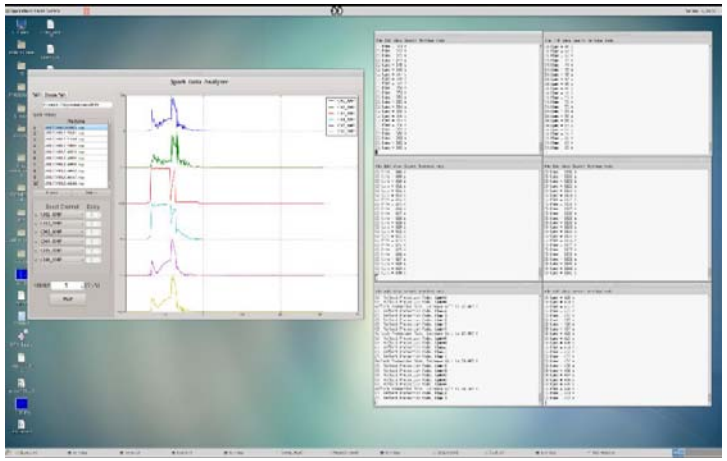
LLRF cabinet:
1.Reference signal
2.CLK & LO
3.MicroTCA.4 chassis
- SIS8300L2*2
- DWC8VM1/DWC8VM1HF

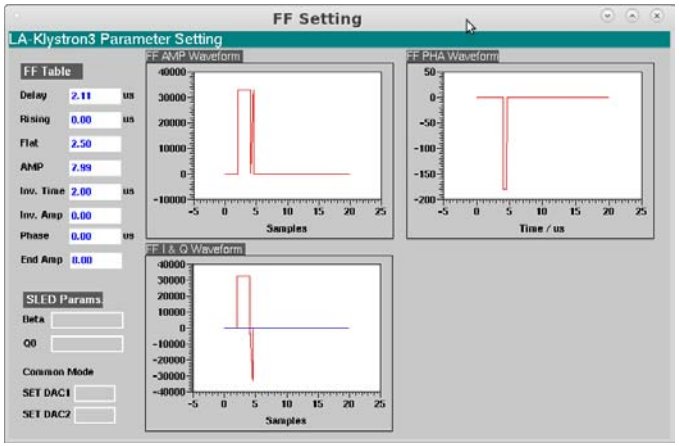
4.Trigger(TTL-LVDS)
5.Solide state amplifier *2

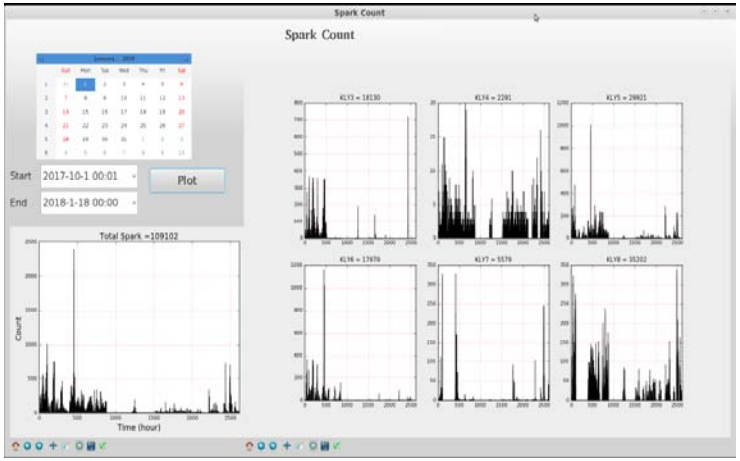
For X band, a mixer chassis is used to downconverter X band signal to S band, and upconverter S band to X band.

HLA: Interlock, breakdown monitor and analysis

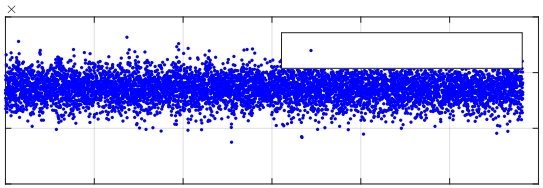
- A reverse-phase waveform is generated for SLED
- Facility environment is more complicated, RF structure is easy to interrupt to breakdown
- All the device operate status should be monitored all time
- Structure and high power device are protected when breakdown, power is stopped 10s in the LLRF firmware, dropped the high voltage of the modulator, and them ramped slowly
- All the operation during breakdown events is controlled automatically on the software layer.
- All the data before and after the breakdown events are stored, and could be analyzed for any time duration.

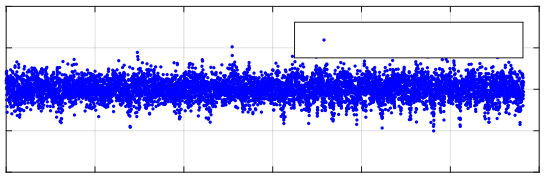


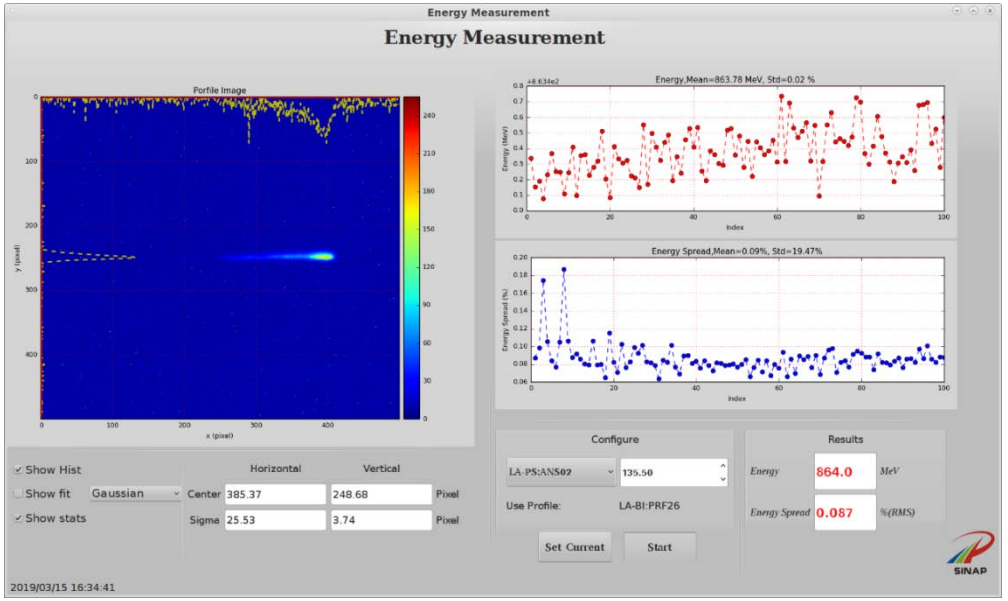




Installation
2016.10
Acceptance testing of LINAC
2019.03







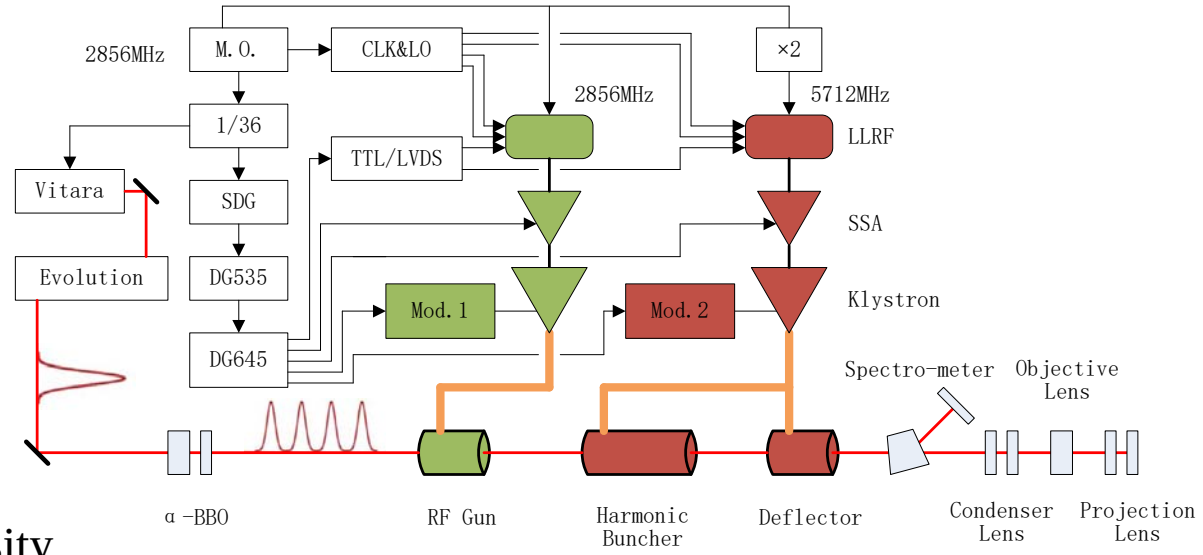
Parameters	Amplitude (rms)	Phase (rms)
S-band	0.02%	0.05
C-band	0.05%	0.1
X-band	0.105%	0.37

Parameter	requirements	Actual value
Beam charge (nC)	≥0.5	0.52
Beam energy (MeV)	≥840	850
Energy spread (rms. %)	≤0.15	0.09
Peak current (A)	≥500	550
Beam length （FWHM）(s)	≤1	0.95
Normalized emittance (mm·mrad)	≤2.5	1.7/2.2
Repetition rate (Hz)	10	10

UED&UEM

Ultrafast Electron Diffraction and Microscopy (UED&UEM) provides sufficient temporal and spatial resolution for studies of a wide array of ultrafast science, drived by a Mev accelerator.

Characteristics	S-Band	C-Band
Working frequency(GHz)	2.856	5.712
Repetition rate (Hz)	10～100	10～100
Amplitude stability (rms, %)	<0.08	<0.08
Phase stability(rms, deg.)	<0.09	<0.18
Klystron power(MW)	5	5



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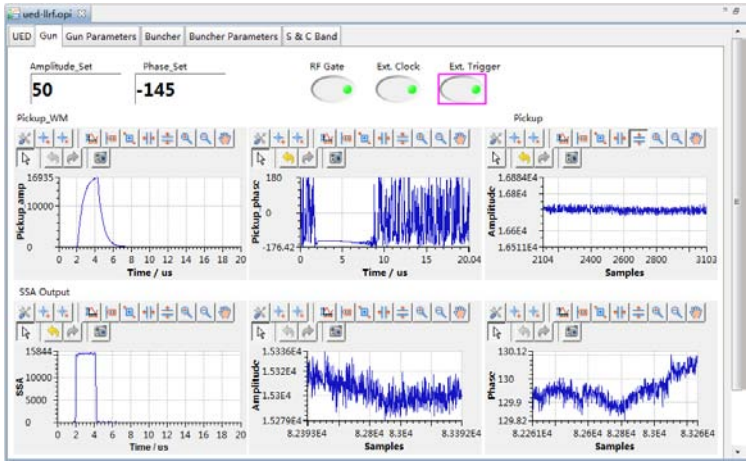
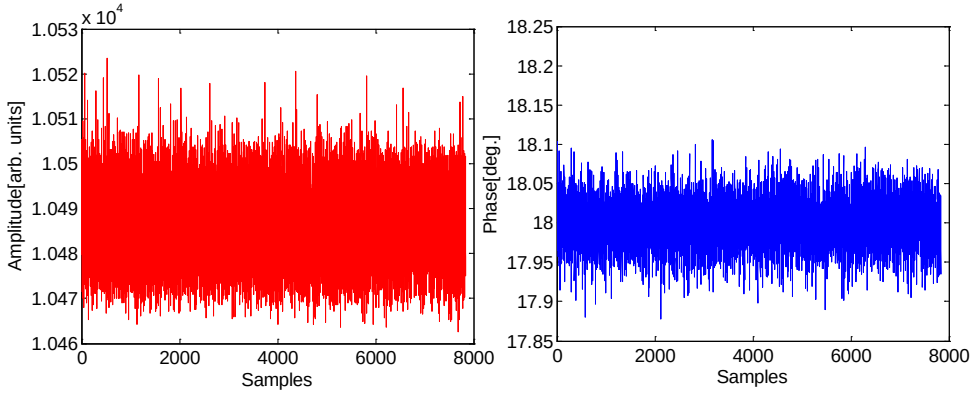
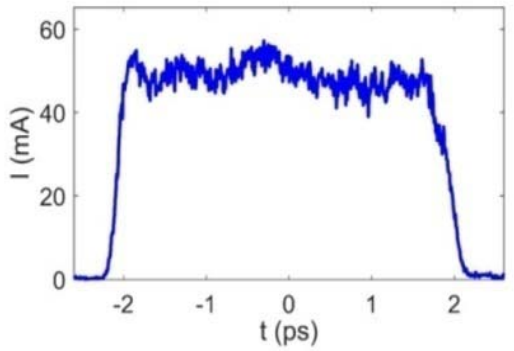


CSS interface

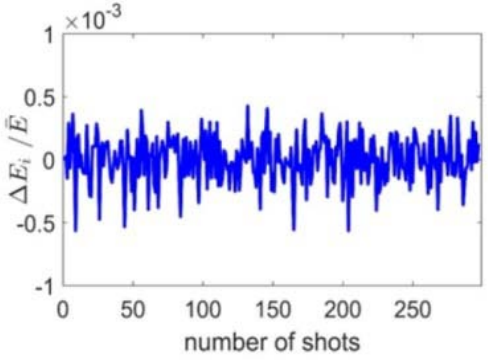


Amplitude and phase stability

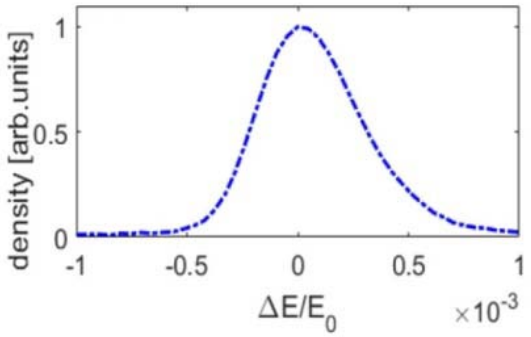
amplitude : 0.06% (rms), phase : 0.03º (rms)



Beam length

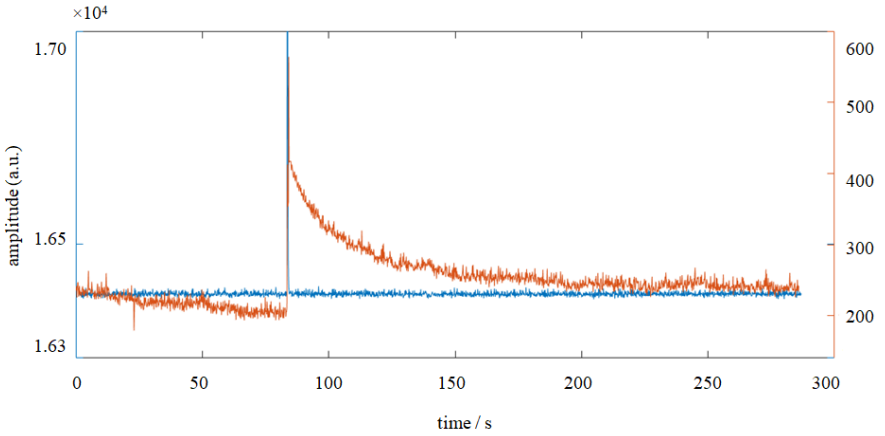


energy stability

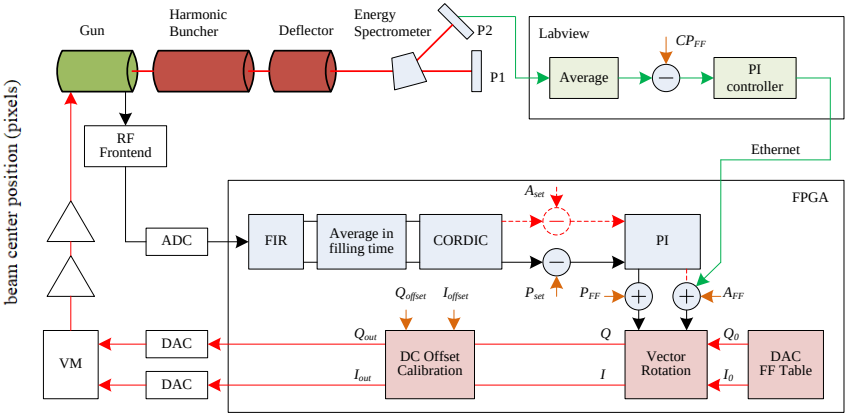


energy spread

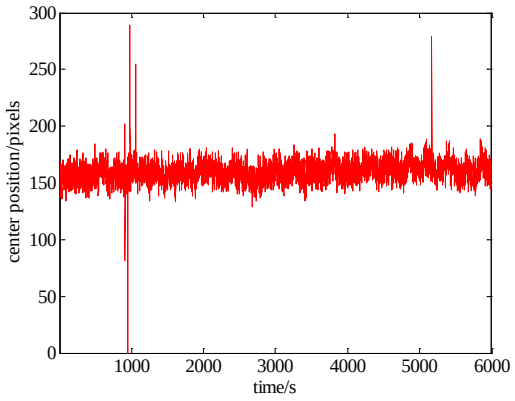
Sometimes an rf gun arc might happens during the accelerator running, causes a cavity detuning and beam loss, then result in a beam energy change. An energy feedback is applied to Low Level RF (LLRF) system after improvement of amplitude-phase loop, using a real-time feedback of the beam center position to regulate the output amplitude of LLRF,

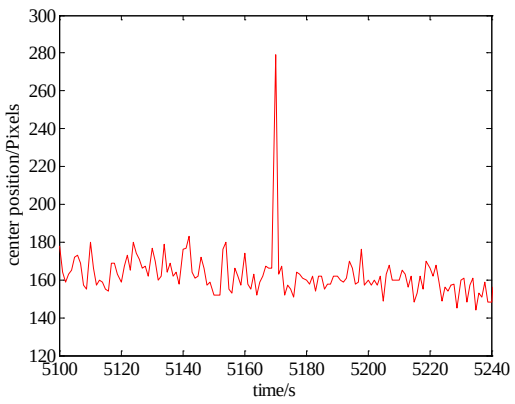


Pickup amplitude and beam center position

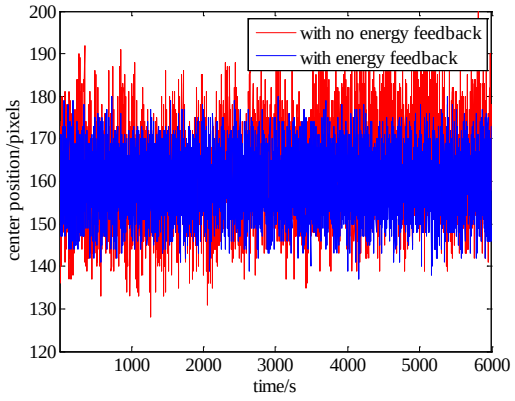


Scheme of energy feedback





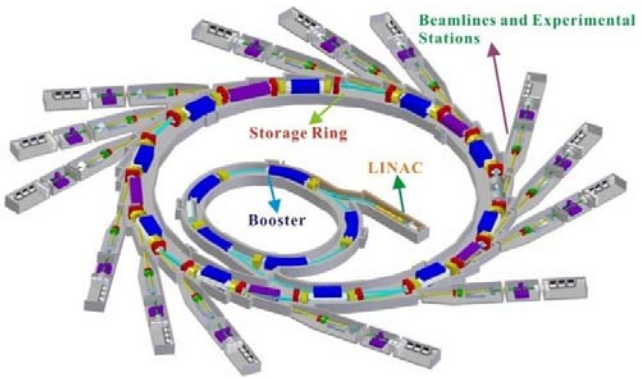
Response for rf gun arc after added energy feedback

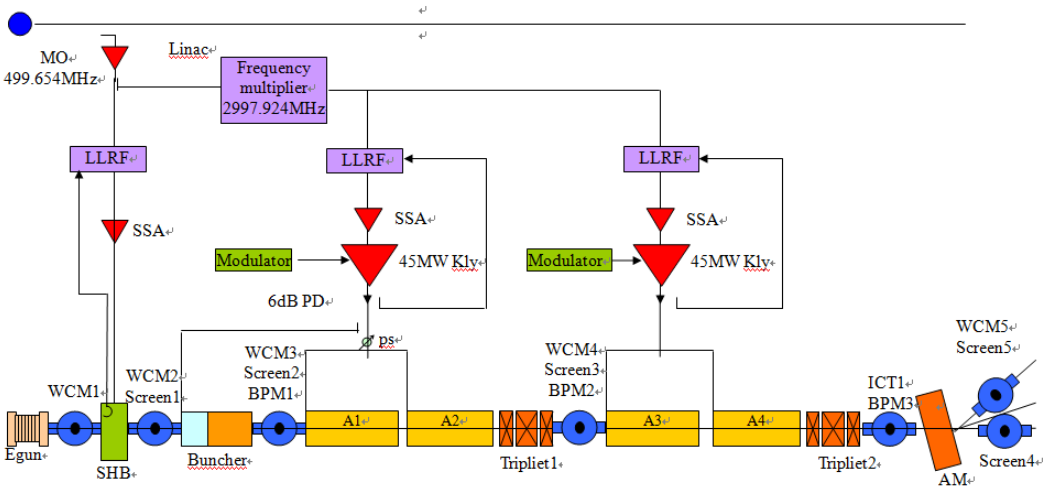


Center position stability

Projects updated to MTCA.4

SSRF





Shanghai Synchrotron Radiation Facility (SSRF) is composed of a 150 MeV linear accelerator, a 3.5 GeV booster, a 3.5 GeV storage ring, beamlines and experimental stations.

LINAC is used as an injector for the booster. The electrons generated by an electron gun are accelerated by 4 travelling wave RF tubes to 150 MeV.

1.Frequency multiplier
2.Monitor
3.PXI chassis (Windows+Labview):
- ICS-572(2AD,2DA)
- pxi-5651, Signal generator
- PXI-9816D, Digitizer
  4ch 16-bit 10MS/s

4. RF frontend(2998MHz)
5.RF frontene(500MHz)
6.Motor driver
7. CLK & LO
8.Powermeter

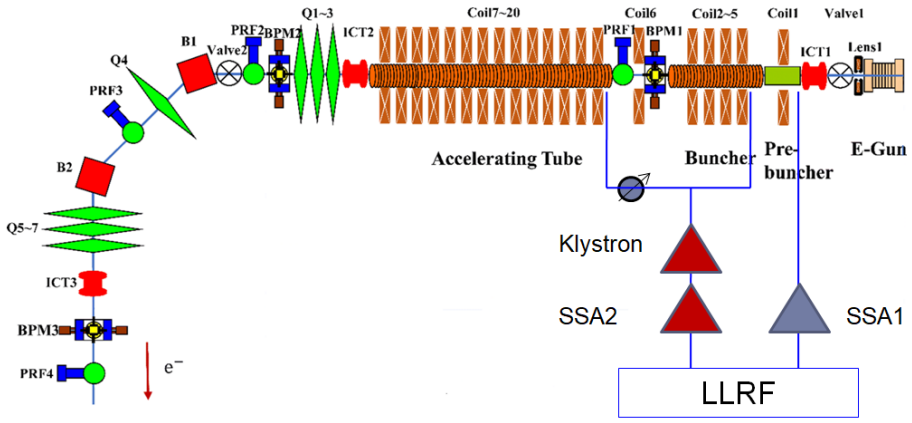
1.CLK & LO
2.MicroTCA.4 chassis
- SIS8300L2*3
- DWC8VM1 3000*2
- DWC8VM1 700MHz*1

3.Trigger(TTL-LVDS)
4.Frequency multiplier

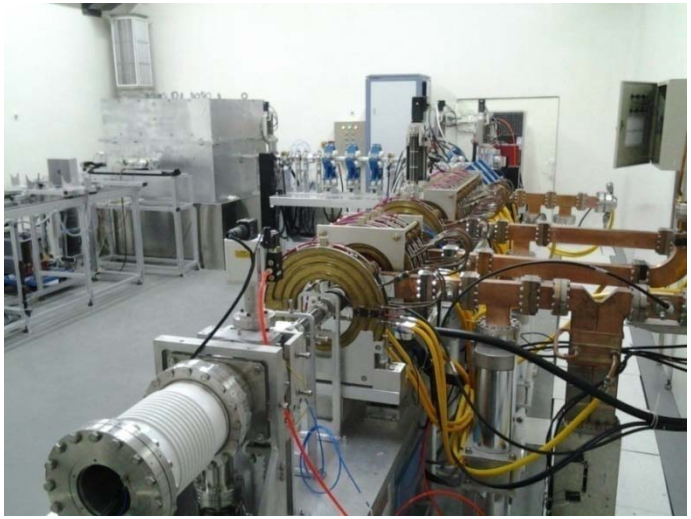
Solid State Amplifier

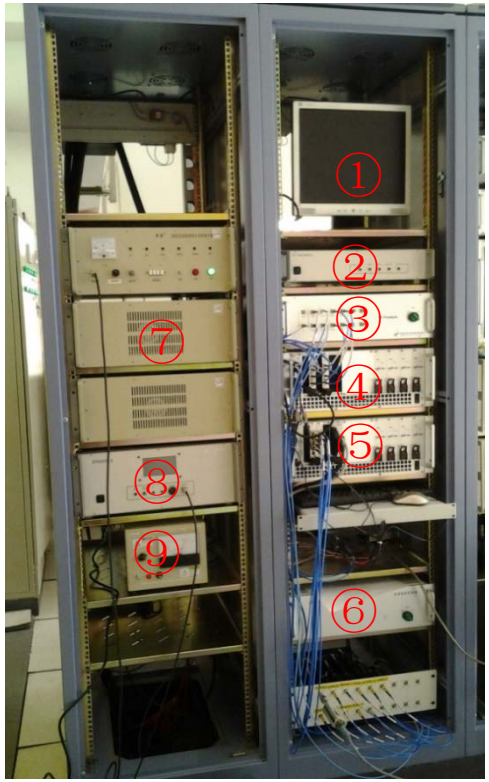
PNS

A Photo Neutron Source (PNS) linac is an auxiliary project of the Thorium Molten Salt Reactor Energy System (TMSR) program.
The application of the PNS focuses on thermal neutron data measurement with a relatively lower neutron flux



Beam energy	15MeV
Beam average Power	1.5kW
Stability of the beam current	1%
Working frequency	2856MHz
Pulse width	0.5-3.0us
Repetition rate	10-70Hz

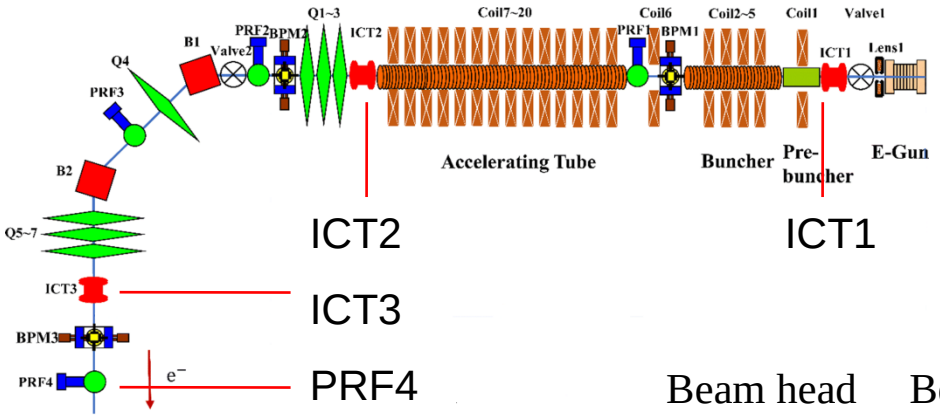




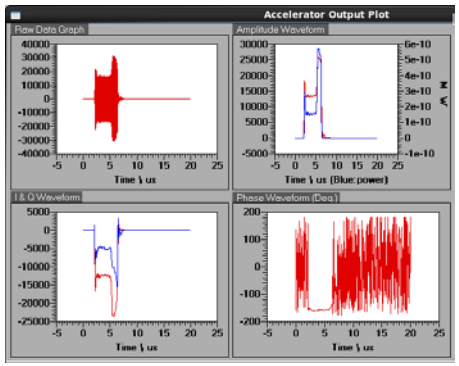
1. Monitor
2. Master oscillator
(including clock and LO)
3. RF frontend
4. cPCI chassis (Linux+EPICS):
- X6-400M,digitizer
2 channels 14-bit,400 MSPS ADC
2 channels 16-bit,500 MSPS DAC
5. cPCI chassis (Windows+Labview):
- MIC-3714, multifunction card
4 channels, A/D, 30MS/s
- cPCI-7230, digital I/O
32-ch isolated DIO
- PXI-8164, motion controller
4-axis step motion controller
6. Motor driver and power supply
7. 4Kw Solid state amplifier
8. 1Kw Solid state amplifier
9. Ion pump

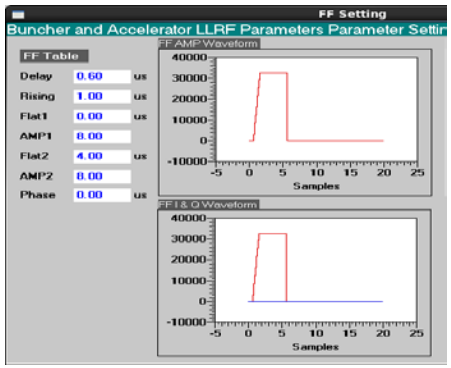
1. Clock and LO
2. MTCA.4 crate
- SIS8300L2*2
- DWC8VM1 3000*2
*Motor controller is integrated in beam diagnostic system

cPCI-based LLRF and MTCA.4-based LLRF



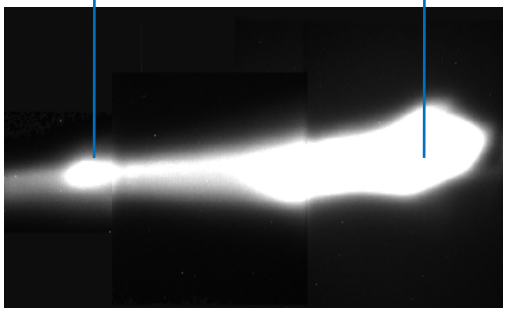
The accelerator has a heavy beam loading, generates a beam loss after the high-power transportation beamline (HPTB) section. A feedforward table is used to compensate the beam loss, increases the transmission efficiency.



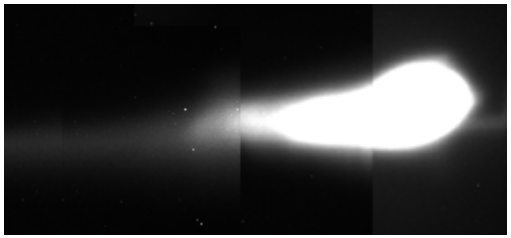


Beam head 17MeV

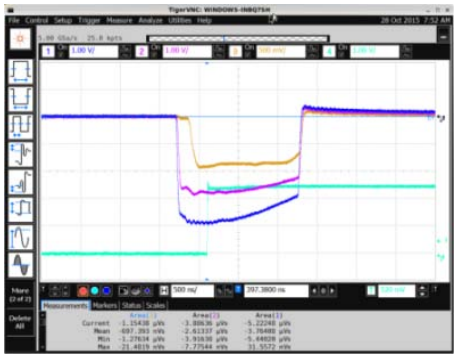
Beam center 15MeV

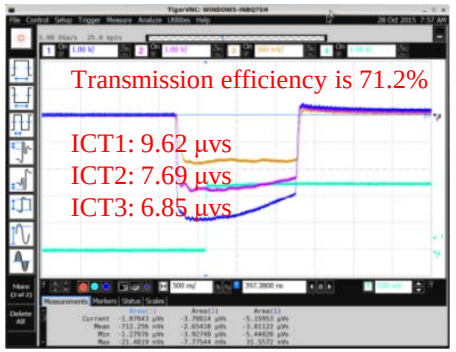


No feedforward



With feedforward





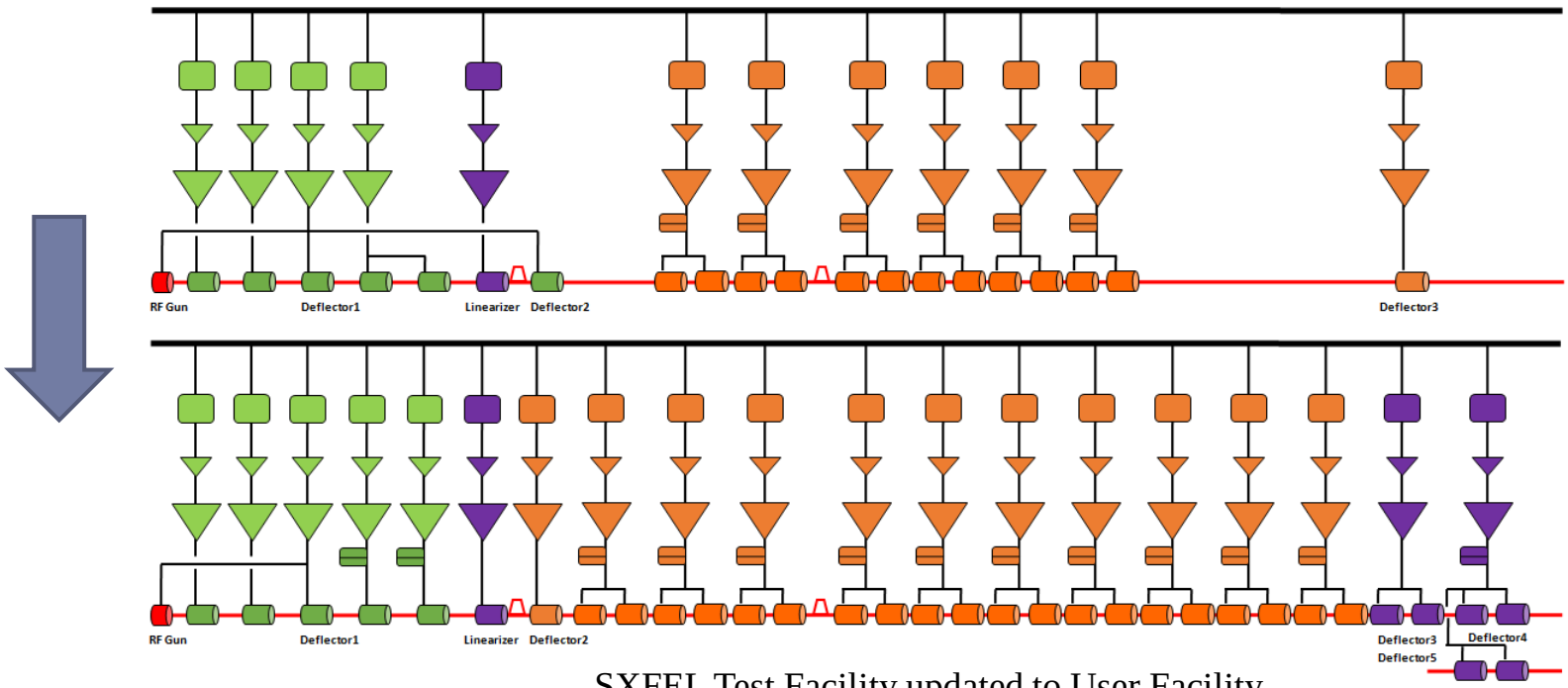
Future applications

SXFEL user facility

Power sources

- 4 S-band→5
- 7 C-band → 11
- 1 X-band → 3

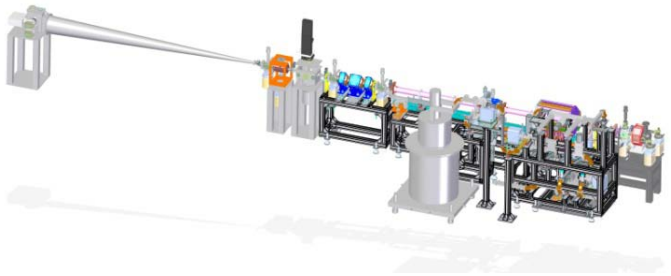
Parameter	TF	UF	Unit
Beam charge	≥0.5	≥0.5	nC
Beam energy	≥840	≥1500	MeV
Energy spread	≤0.15	≤0.15	rms. %
Peak current	≥500	≥700	A
Beam length (FWHM)	≤1	≤0.7	ps
Normalized emittance	≤2.5	≤1.5	mm·mrad
Repetition rate	10	50	Hz



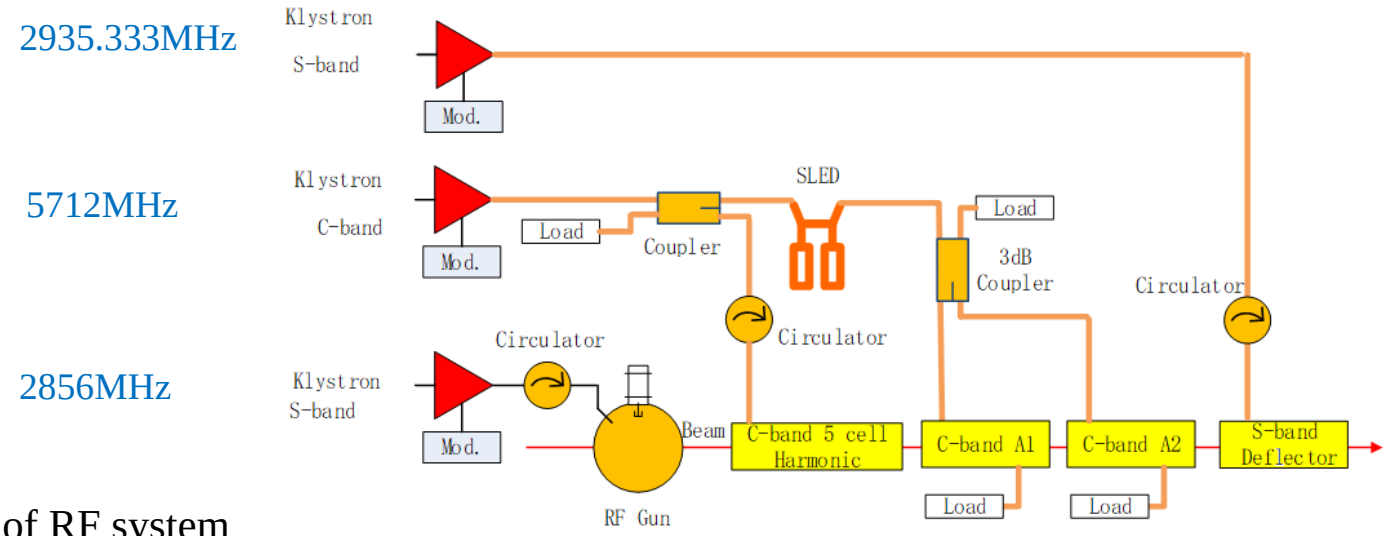
SXFEL Test Facility updated to User Facility

Electron probe in laser plasma

The facility is used in studying application of electron probe in laser plasma, located at Shanghai Jiaotong University.



Beam energy:100MeV
Repetation rate:10Hz



Scheme of RF system

Thanks for your

attention!