

深圳中能高重复频率X射线自由电子激光

Shenzhen Superconducting Soft X-ray Free Electron Laser:S³FEL

Development of MicroTCA System for the Shenzhen IASF Pre-study:
Overall System and Beam Diagnostics

IASF

Beam Diagnostics Group

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目录

CONTENTS

1

Overall System

2

Beam Diagnostics System

3

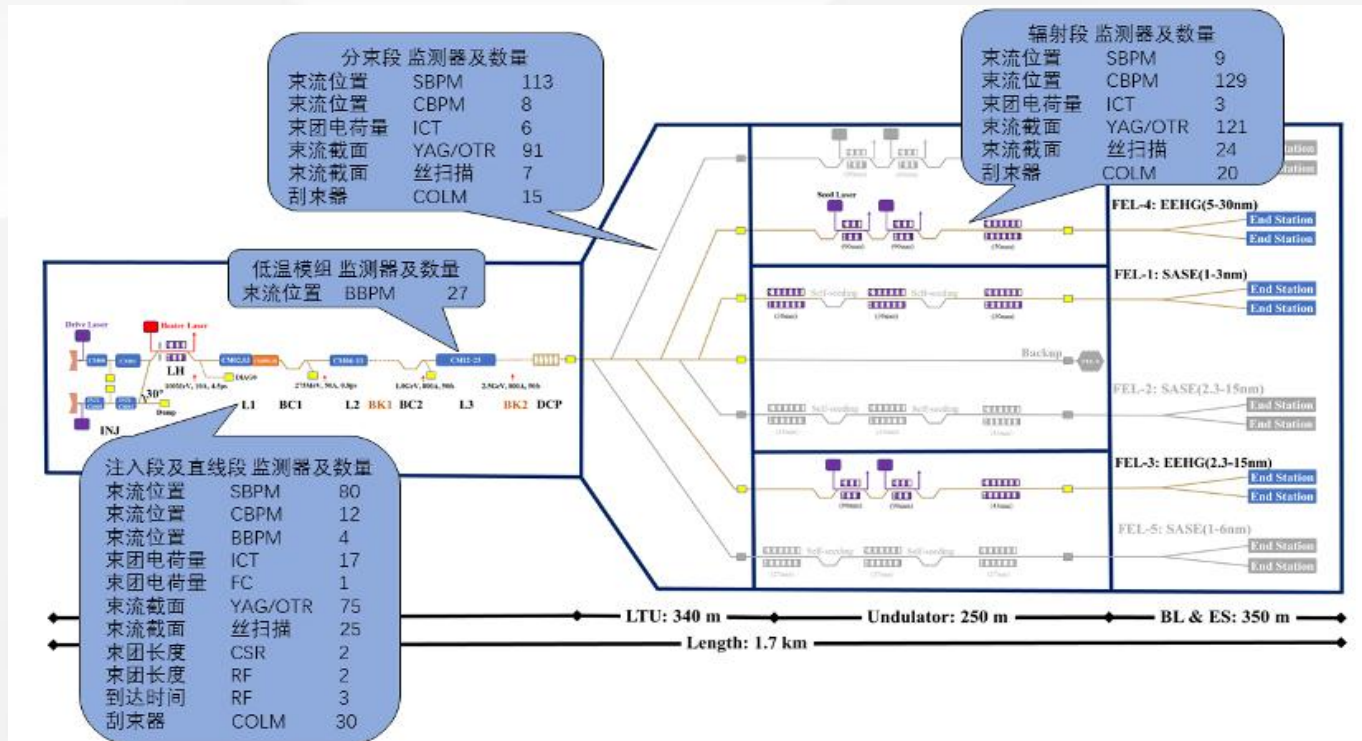
Summary and Future plan



1

Overall System

Overall System —— Why MicroTCA?

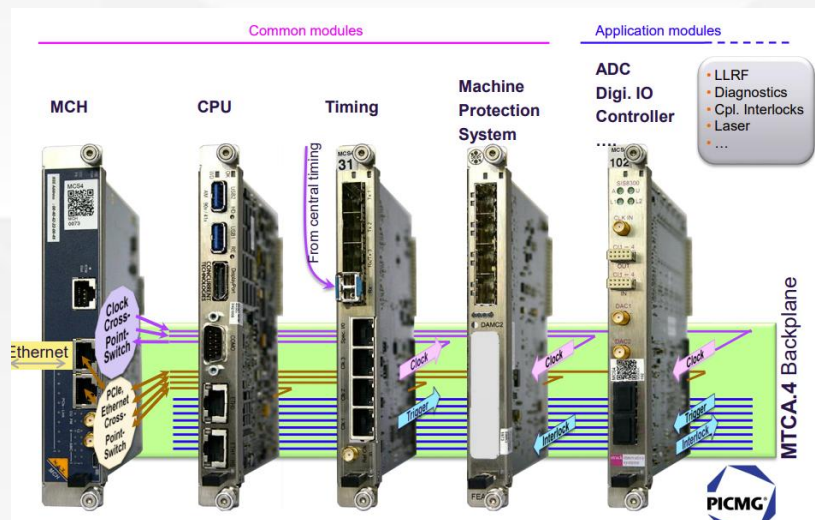


S³FEL is a massive fourth-generation FEL light source located in Shenzhen, China.

For the beam diagnostic-related SBPM, CBPM, ICT, and wire scanner systems across the entire facility, the total number of associated electronics units is approximately **800**. In such a large-scale project, the following issues are critical for our team :

- Minimize wiring/cabling and space occupation as much as possible.
- Reliable remote unified control and status monitoring is really necessary.
- Unified general-purpose DAQ electronics.

➤ Overall System — Why MicroTCA?



Compact structure, space-saving, significantly reduced wiring

- Compared with standalone modules, space usage is reduced to about 40%.
- Thanks to the MTCA backplane MLVDS bus, it can reduce wiring numbers by more than 30%.



SBPM AFE & DAQ
standalone carrier

size: 1U

$1U \times 4 = 4U$



timing-EVO/EVE
standalone carrier

size: 1U

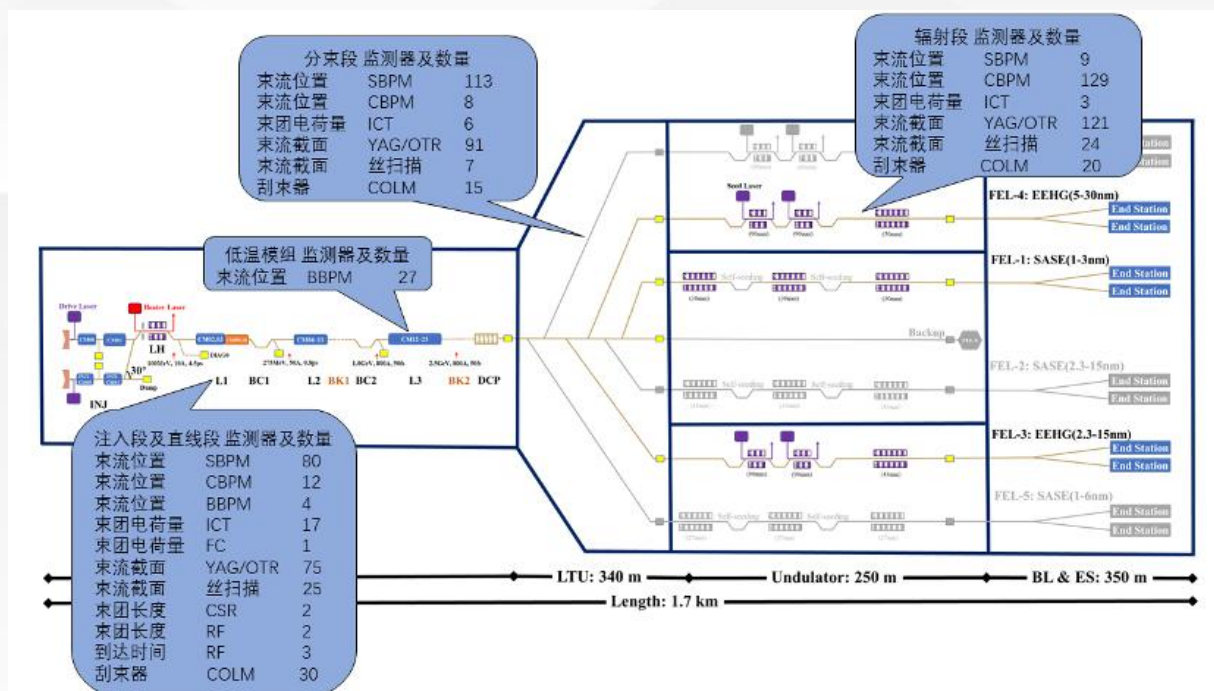
total size: 5U



2U/3U
MicroTCA system



Overall System — Why MicroTCA?



With a straight-line distance of 1.7 km, it would be a disaster without reliable remote management.

- A stable and reliable remote management system is essential for large-scale scientific facilities.
- Thanks to the collaboration between the MCH and MMC, we can easily achieve remote status monitoring for each AMC card: Power on/off, Temperature monitor, and even batch updates of bitstreams and flash of FPGA.

>> Overall System — Power Supply and Ripple Test

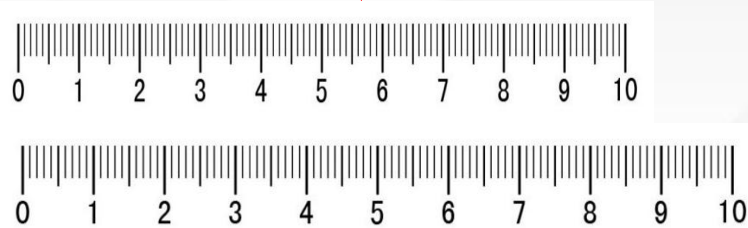
Ripple Test Load Conditions				Measured Ripple (AMC3)	
Slot MP_3.3V	SlotPP_12V	Total PSU PP_12V	Fan Status	MP_3.3V	PP_12V
0.089A	0A	1.5A	Low Speed	7.6mV	6.4mV
0.155A	3.75A	9.0A	Full Speed	5.6mV	7.2mV
0.216A	7.75A	13A	Full Speed	5.2mV	5.6mV



Ideal ADC



ADC work with
power supply ripple



test supported by



➤ Overall System — Carrier



2U–3U carrier:

Advantage:

- Lightweight

Disadvantage:

- Wastes some performance of the CPU and MCH PCIe switch



9U–10U carrier:

Advantages:

- High integration density; maximize utilization of the MCH PCIe switch capability.

Disadvantage:

- Too heavy... ..
- if the data traffic of each card is very high, it poses a challenge to overall system performance, such as packet loss rate.

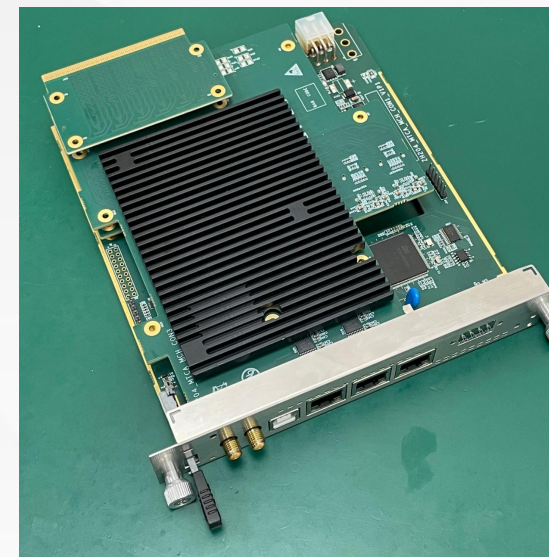
➤ Overall System —— CPU



NAT-MCH



MCH-YZI



MCH-JYTL

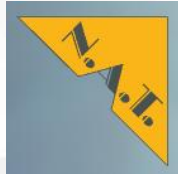


Both domestic and international products are mature, and testing has shown that they all meet our requirements.

>> Overall System —— MCH



NAT-MCH



MCH-YZI

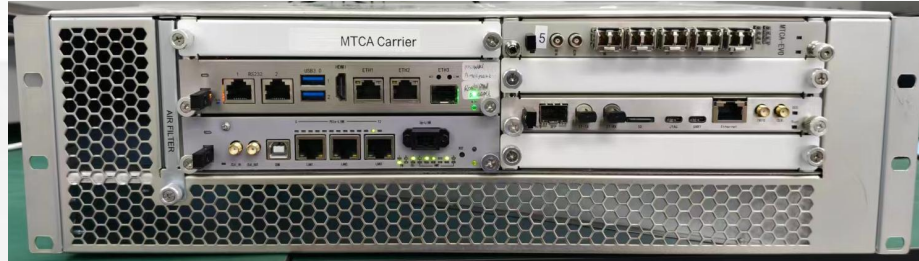


MCH-JYTL

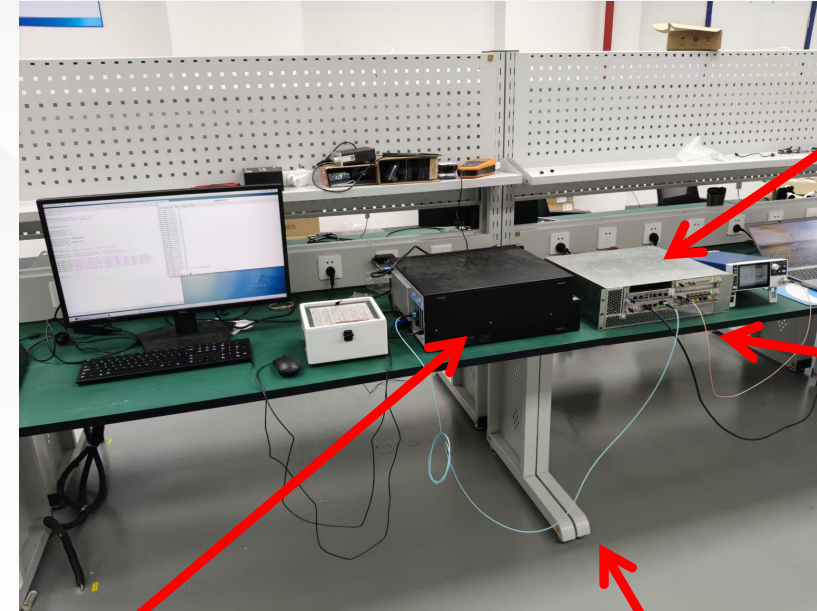


The MCH Uplink capability added in recent years has opened up more possibilities for MicroTCA systems.

➤ Overall System —— Standalone & Uplink



Standalone Module Chassis:
Root Complex Upstream: AMC-CPU



High-Performance Server

fibre

MTCA carrier

MCH Uplink
MPO

MCH PCIE Uplink System:
Root complex Upstream: PC/High-Performance Server outside

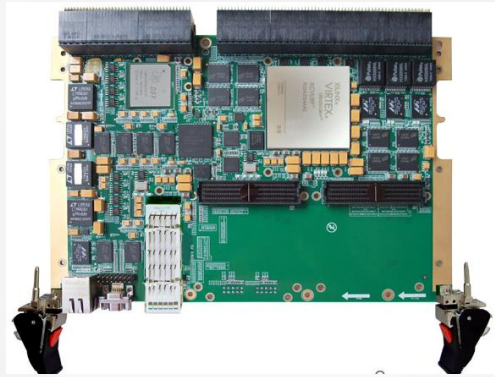
Uplink Function Application: Through the MCH Uplink fiber, a 16-lane Gen3 PCIe link can be realized, enabling connection to an external higher-power PC or a GPU-equipped AI server to enhance performance and reduce costs.

Specific application scenarios are still under R&D discussion (Good ideas are welcome ^_^).

2

Beam Diagnostics

➤ Beam Diagnostics — General-Purpose DAQ System R&D Background



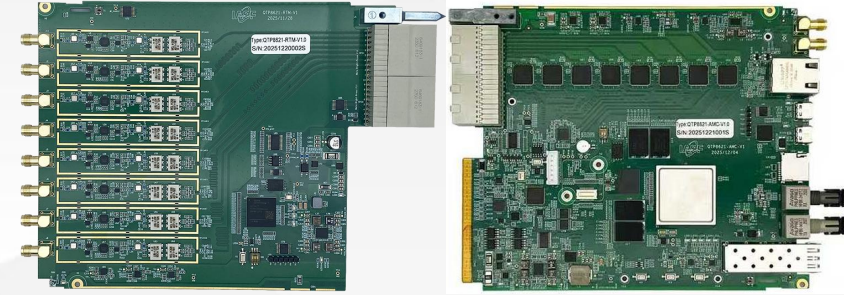
VPX



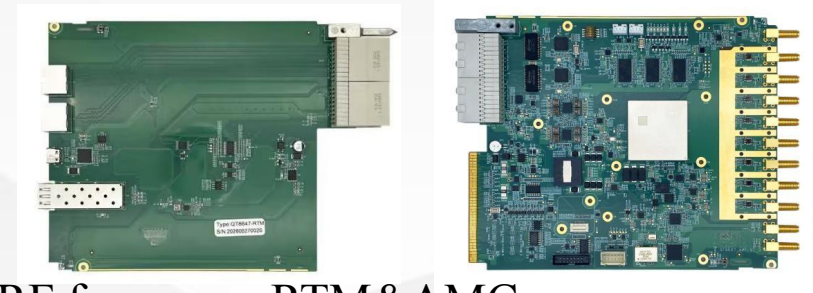
PXIE



Standalone



medium/low frequency RTM&AMC
8 channel | max 250Mps | DC~900M bandwidth
Typical Applications: **SBPM**、wirescan、fast protection

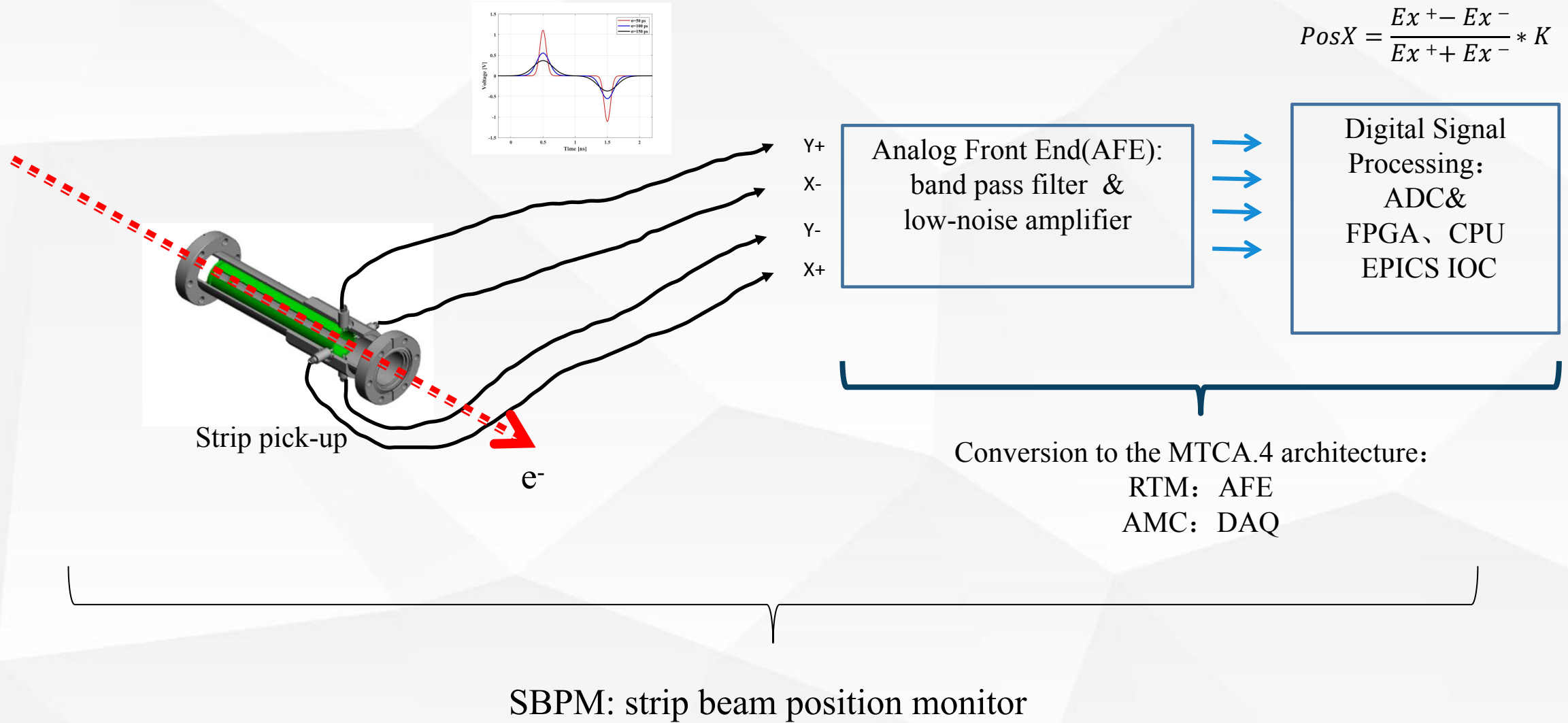


RF frequency RTM&AMC
8 channel | max 5Gps | DC~6.5GHz bandwidth
Typical Applications: **CBPM**、IM、GMD

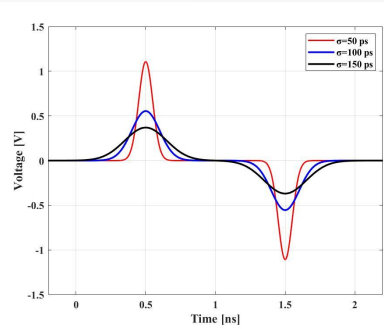
Based on past experience in light source construction, when different systems use DAQ systems of different standard, the installation, management, and secondary development become relatively more complex.

We have developed two RTM & AMC solutions, respectively targeting medium/low frequency DAQ tasks and RF-band DAQ tasks.

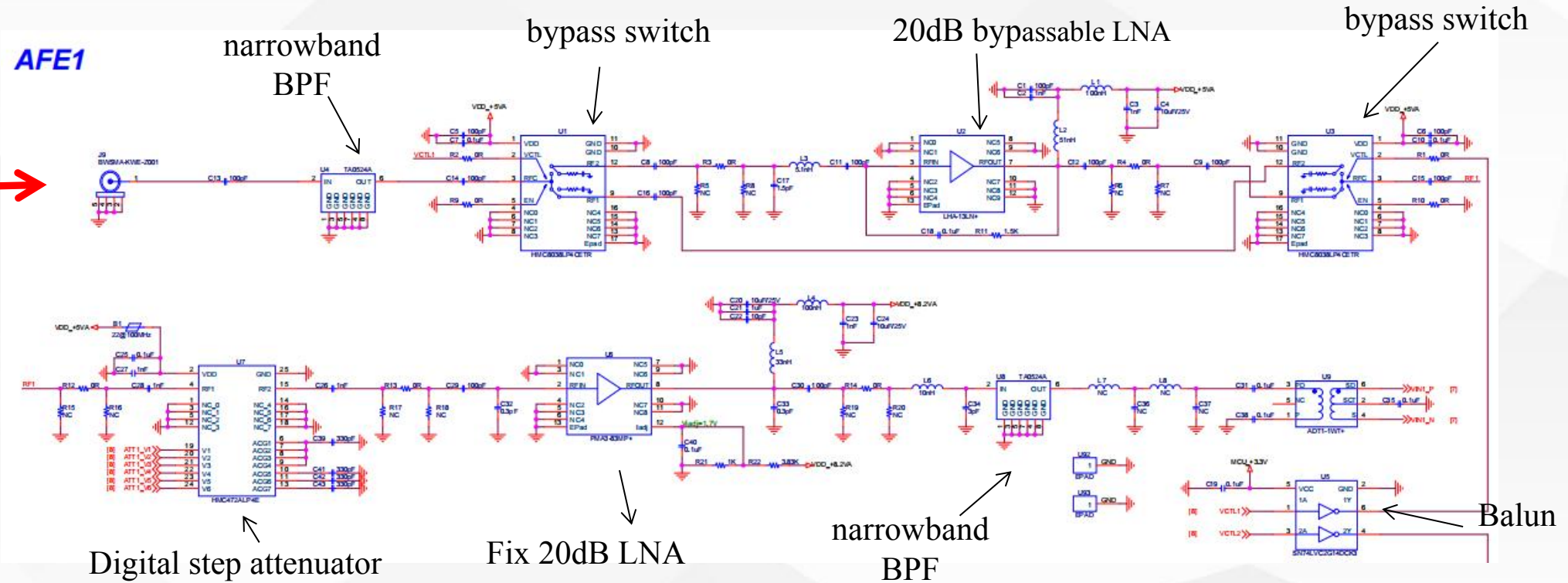
Beam Diagnostics — SBPM Background



overall system Control — Design for AFE

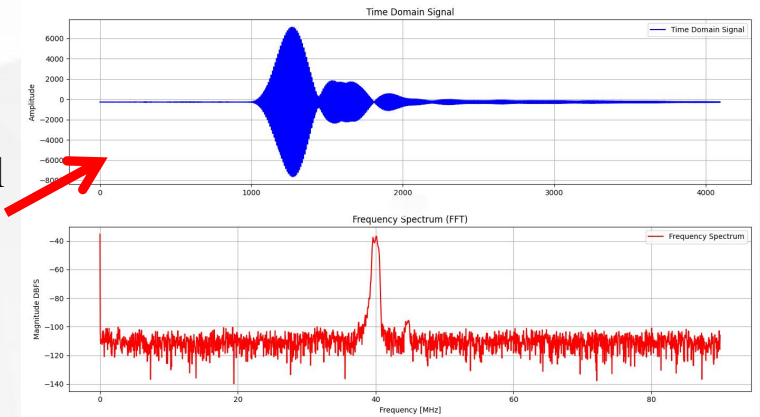


Input signal of Strip pick-up

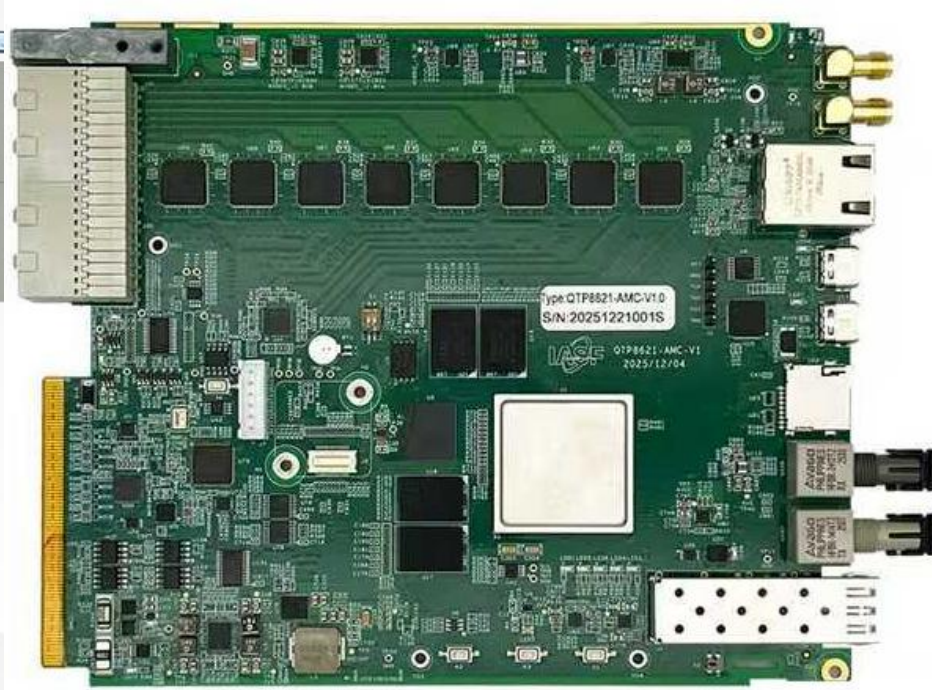
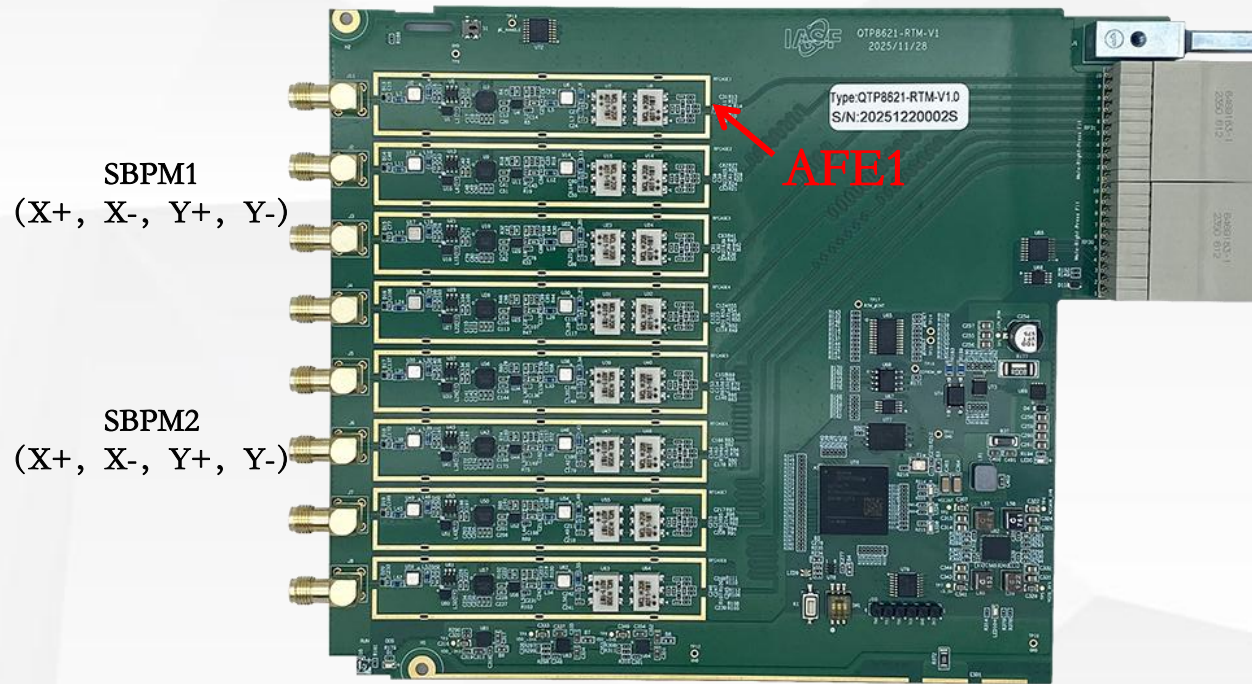


- A narrowband bandpass filter is used to stretch the short-pulse signal at the AFE input.
- An attenuator and a bypassable LNA are used to adjust the dynamic range of the SBPM.

Output signal to AMC



➤ Beam Diagnostics — SBPM RTM & AMC



Ext clock
Ext trigger
ETH
JTAG
UART
SD
ST fibre
SFP timing

Meets the requirement of simultaneous connection of two SBPM pickups,

- 8 channels with 8 AFE & 8 AD9467
- FPGA: ZYNQ7z100
- Supports internal/external clock switching, supports event timing standard protocol, enables event code triggering and hardware timestamp decoding.
- Trigger modes: front panel external trigger, self-trigger, backplane M-LVDS bus trigger, and event code trigger.
- Interlock output modes: front panel ST fiber, backplane M-LVDS bus (port 19-20).

➤ Beam Diagnostics — SBPM test on site



Test site at the first SBPM pick-up in the straight section of the Dalian Coherent Light Source.

A total of 300 beam shots were collected. The position of each shot was calculated, and the standard deviation was then multiplied by the calibration factor of the SBPM probe to obtain the actual resolution.

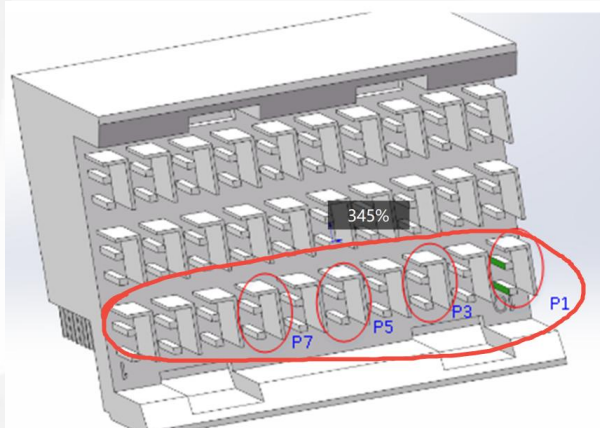
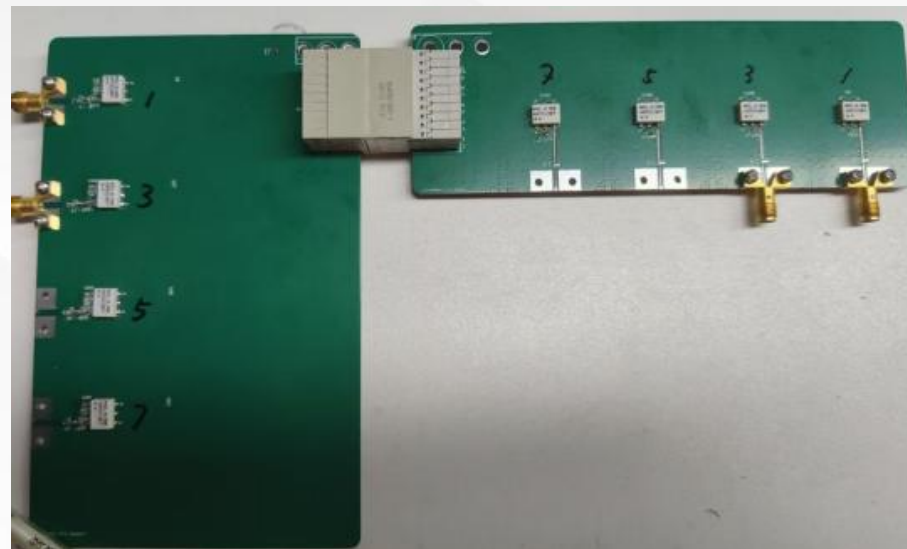
- X-direction position resolution: $2.256 \mu\text{m} @ 500 \text{ pC}$
- Y-direction position resolution: $2.201 \mu\text{m} @ 500 \text{ pC}$

Generally, the position resolution requirement of the SBPM system is better than $10\mu\text{m}@500 \text{ pC}$.

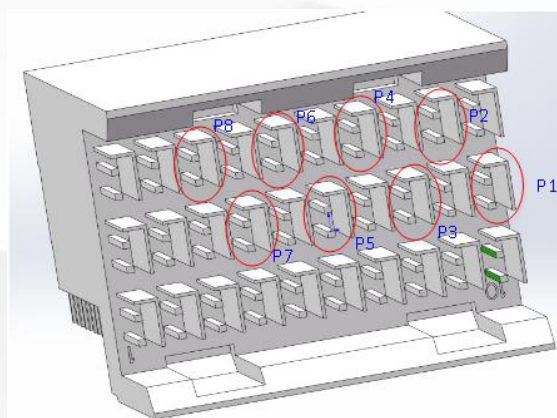
➤ Beam Diagnostics — Zone3 crosstalk problem@500MHz

表③，机箱内测试，加屏蔽罩

机箱内bin文件采集		采集长度65536点		加挡板槽		加屏蔽罩		
180M	CH1	CH2	CH3	CH4	CH5	CH6	CH7	CH8
CH1	0.00	58.44	47.57	56.87	53.40	56.60	54.65	56.37
CH2	62.88	0.00	64.65	81.38	65.75	67.32	65.22	66.42
CH3	48.03	62.92	0.00	62.71	48.75	60.55	56.15	59.93
CH4	67.56	70.89	63.66	0.00	62.37	70.11	66.25	68.71
CH5	58.24	65.73	51.98	68.29	0.00	66.72	53.43	63.23
CH6	70.53	75.00	70.63	76.16	63.11	0.00	63.53	77.83
CH7	60.96	66.03	59.81	64.21	52.56	70.30	0.00	64.73
CH8	70.94	74.74	71.35	73.87	71.17	66.79	66.37	0.00



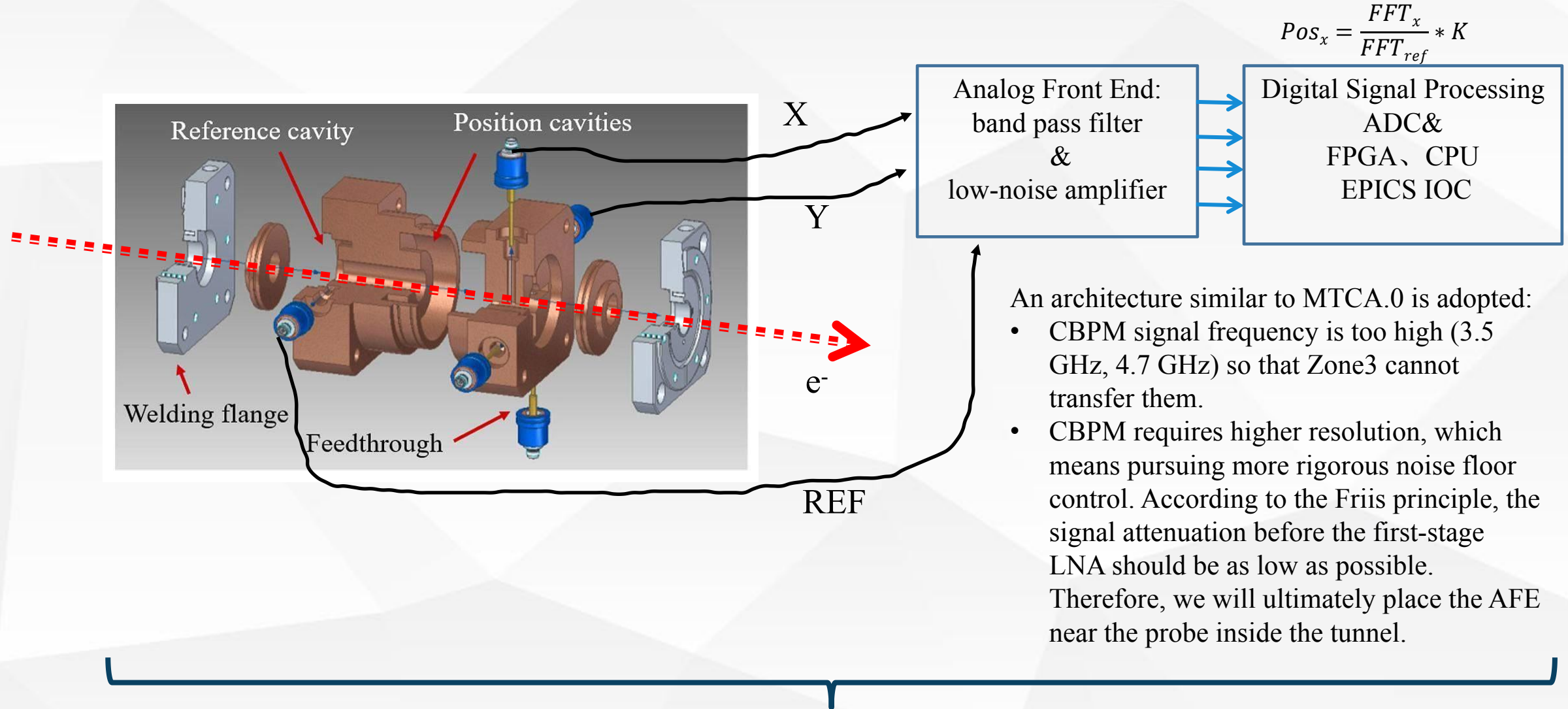
Crosstalk
P1-P3: 87dB
P3-P5: 75dB
P5-P7: 77dB



Crosstalk
P1-P3: 59dB
P3-P5: 51dB
P5-P7: 53dB

We need help:
the issue of stable transmission of mid- and high-frequency signals in Zone 3 has been troubling us for a long time, and we are very much looking forward to trying the latest version of the Zone 3 connector (Thanks to Prof. Liu Fang for the information.).

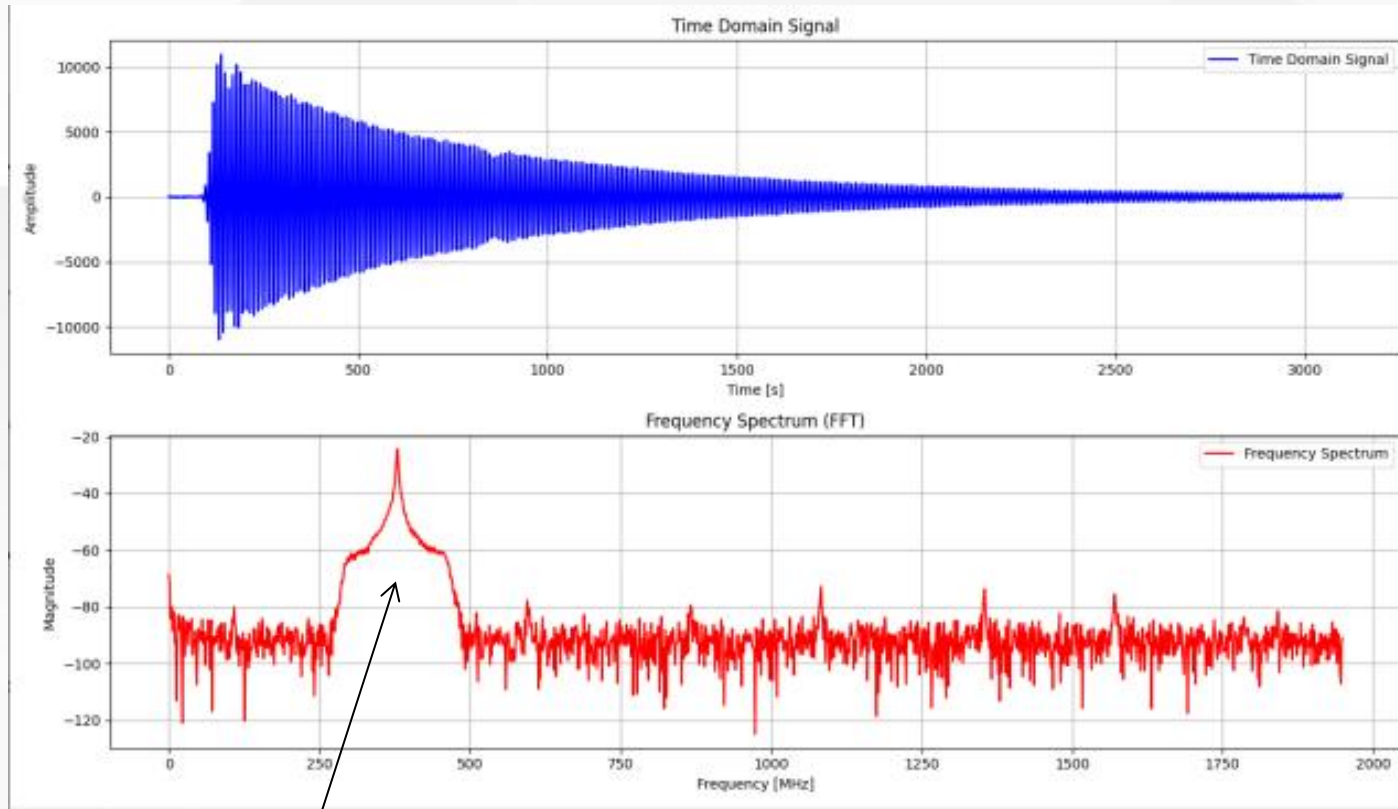
➤ Beam Diagnostics — CBPM Background



CBPM: cavity beam position monitor

➤ Beam Diagnostics — CBPM Signal Analyse

Time domain of
CBPM signal



Frequency domain of
CBPM signal

For CBPM applications, only the FFT value at the peak frequency point (or within a very narrow bandwidth) is of interest. Therefore, there are two core requirements for the ADC performance:

- Noise Spectral Density(NSD): As the name implies, it directly affects the FFT amplitude near the frequency point.
- Crosstalk: Because the peak frequencies of the position cavity probe and the reference cavity probe is about the same, crosstalk directly affects the accuracy and resolution of the position calculation.

➤ Beam Diagnostics — CBPM RTM & AMC

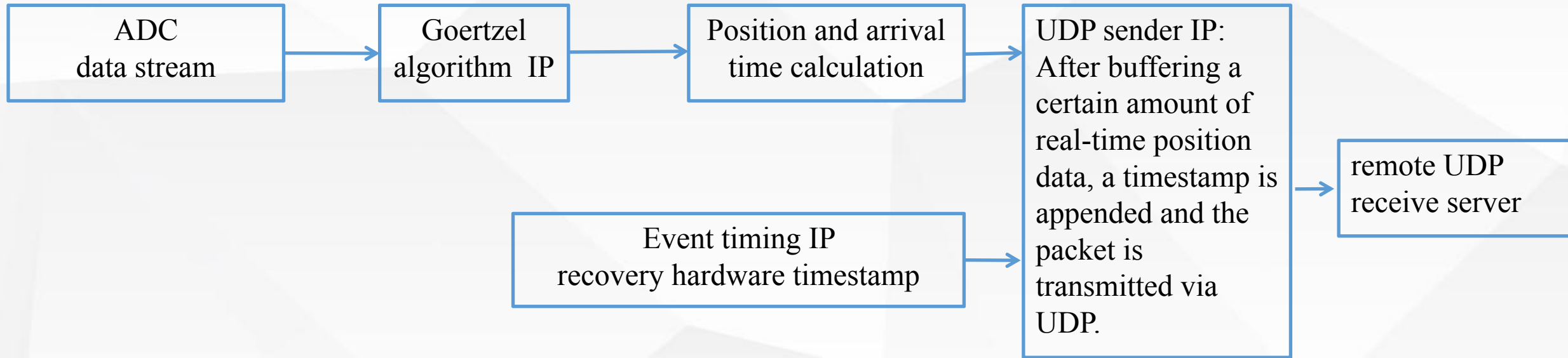


To meet the requirement of simultaneous connection of two CBPM pickups.

The RF signal passes directly through the AMC board, while the RTM implements auxiliary functions such as network, JTAG, and SFP.

- FPGA: RFSoc 47DR, 1156-pin. To simplify layout, only 8 ADCs are routed out from the BGA. With up to 5 Gbps sampling rate, 6 GHz bandwidth, and 14-bit resolution, it can meet the requirements of most RF direct sampling DAQ applications in the accelerator field.
- Supports internal/external clock switching, supports event timing standard protocol and hardware timestamp decoding.
- Trigger modes: front panel external trigger, self-trigger, backplane M-LVDS bus trigger and event code trigger.

➤ Beam Diagnostics — CBPM 1MHz Real Time Cal FPGA Scheme



- Instead of performing a full-pin FFT, 1MHz real time calculation FPGA will implement a Goertzel algorithm (faster than single-point frequency DFT), computing only the amplitude and phase at the known frequency.
- The UDP and event timing timestamp sections are the same as the SBPM FPGA design.
- The overall function is still under development.

Beam Diagnostics — CBPM Lab Test



3500MHz sin test signal

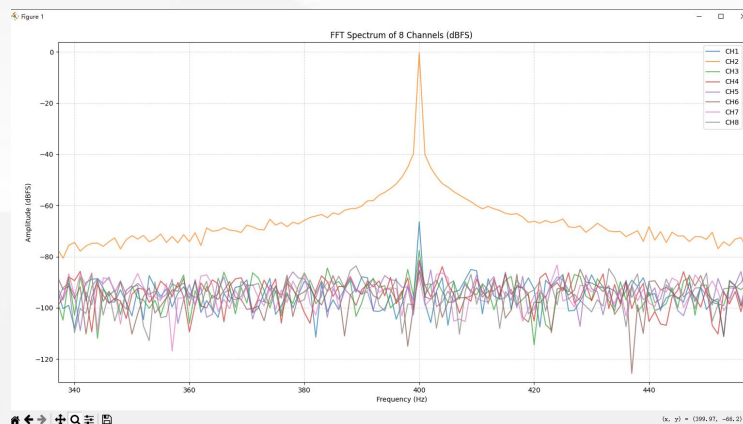
216.666MHz ext clock source

MTCA RFsoc AMC

Basic functions have been initially developed and tested on board in the laboratory, including:

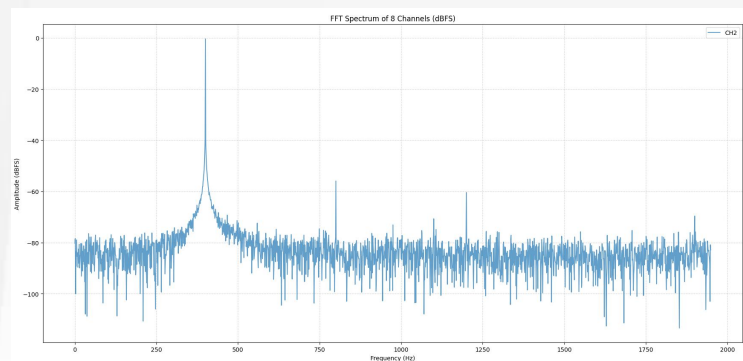
- FPGA part (AXI waveform transmission, interrupts, clock configuration)
- EPICS IOC
- CS-Studio interface

Beam Diagnostics — CBPM Key Parameter Verification



3500MHZ	7.5dBm							
	CH1	CH2	CH3	CH4	CH5	CH6	CH7	CH8
CH1	0	65.81	94.58	98.87	84.77	109.22	95.9	97.08
CH2	59.95	0	71.14	80.66	72.71	96.52	84.32	86.16
CH3	92	64.42	0	60.95	75.89	84.89	92.74	87.82
CH4	91.78	82.96	69.55	0	65.13	81.18	83.4	84.89
CH5	83.85	72.69	81.27	62.14	0	53.88	72.97	82.41
CH6	95.88	82.33	94.71	82.92	60.87	0	53.6	75.77
CH7	93.57	76.44	100.65	85.28	81.55	52.46	0	58.27
CH8	86.29	72.35	94.64	85.91	77.09	73.55	52.87	0

Crosstalk Test



关闭Dither功能, NSD测试, 加信号								
	CH1	CH2	CH3	CH4	CH5	CH6	CH7	CH8
CH1	-148.54	-153.35	-153.21	-153.42	-153.33	-153.41	-153.42	-153.38
CH2	-153.59	-148.47	-153.33	-153.29	-153.13	-153.22	-153.4	-153.2
CH3	-153.07	-153.16	-148.27	-153.23	-153.05	-153.31	-153.15	-153.4
CH4	-153.05	-153.31	-153.39	-148.51	-153.14	-153.28	-153.22	-153.17
CH5	-153.09	-153.04	-152.9	-152.96	-148.39	-153.43	-153.36	-153.27
CH6	-153.81	-153.74	-153.44	-153.58	-153.49	-148.01	-153.24	-153.4
CH7	-153.33	-153.45	-153.1	-153.21	-153.31	-153.34	-148.47	-153.46
CH8	-153.08	-153.35	-153.11	-153.21	-153.25	-153.06	-153.16	-148.41

NSD Test

Key parameter verification:

With 3500 MHz sin input signal and 3900 Msps sampling rate, the NSD of each channel is basically better than -148 dBFS/Hz @ 3900 Msps. The isolation of most channels is better than 60 dB, with a few channels around 50 dB. Hardware revision is currently in progress (BGA optimization, RF connector optimization).

Acceptance requirements: with a 3500 MHz input sin signal, the isolation of each channel should be better than 60 dB, and the NSD should be better than -145 dBFS/Hz @ 3900 Msps.



3

Summary

Why MicroTCA:

- Compact structure, space saving, and a significant reduction in wiring.
- A stable and reliable remote management system, which is essential for large-scale scientific facilities.

Overall System Control:

- Chassis, power supplies, CPU, and MCH all have complete and mature ecosystems available from both domestic and international vendors.

Beam Diagnostics:

- SBPM: Standard MTCA.4 specification, tested under actual beam conditions. X-direction position resolution: $2.256\text{ }\mu\text{m}@500\text{ pC}$; Y-direction position resolution: $2.201\text{ }\mu\text{m}@500\text{ pC}$.
- CBPM: Similar to MTCA.0 specification, RF direct sampling based on RFSoc 47DR. Basic software + FPGA development and key parameter testing have been completed. The key RF specifications of concern have passed testing.

Future Plan:

- More than 90% of S³FEL electronics will be based on the MTCA architecture, ensuring stable and smooth operation across all systems.
- Deploy AI servers based on the Uplink function to explore automatic light tuning, etc.
- Test of the latest Zone3 connectors.

Thanks

欢迎各位老师交流提问
谢谢