Research and Development of the Fast Orbit Feedback System for HEPS

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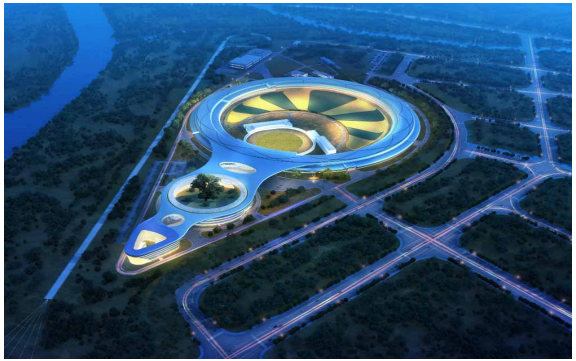
CSNS，DONGGUAN

~ 2250 km

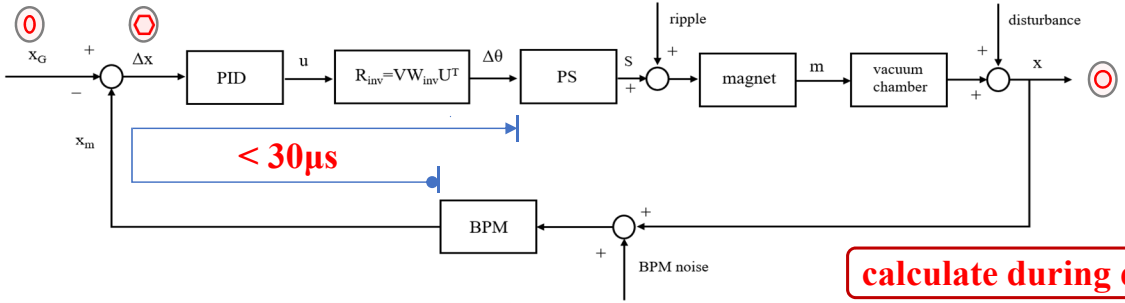


HEPS，BEIJING

Fast Orbit Feedback System for HEPS

close collaborators: Physics, BPM, Power Supply, Magnet, Vacuum, RF, TM, Control

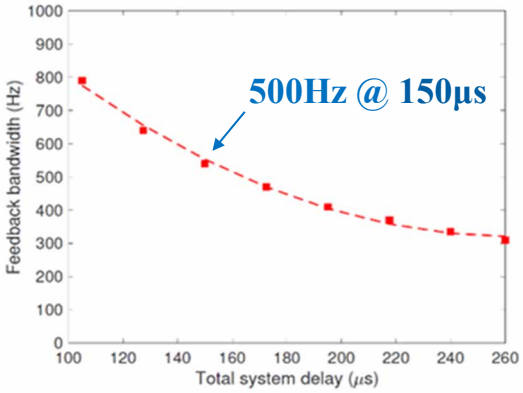
- **Physical requirement**(SR: 1360.4 m)
  - **Time :** Orbit distortion < 10%(RMS), FOFB delay < 30μs
  - **Frequency :** Closed-loop bandwidth >= 500Hz



Two key issues:

- How to reduce the latency?
  Long time stability and reliability.
- How to maintain the accuracy ?
  High performance.

✓ Bi-direction data transfer with each direction 3 channels



calculate during data transfer

The response matrix R satisfies:

$$R\,\Delta\theta = \Delta x = x_m - x_G$$
$$\Delta\theta = R_{inv}\,\Delta x$$

Δx : orbit error given
Δθ : corrector strength change
R_{inv} : **SVD** inverse response matrix

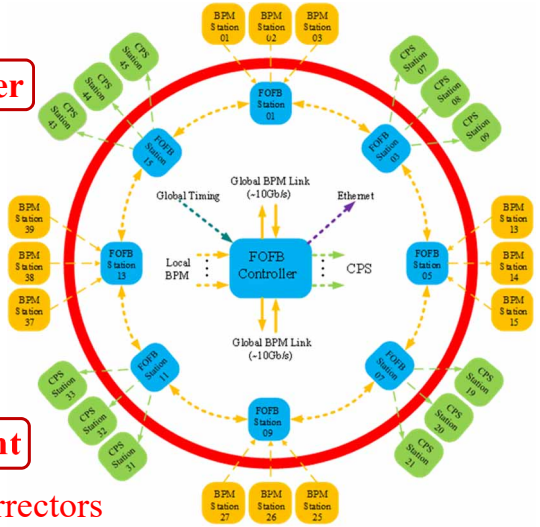
Fast corrector power supply setting value:

$$S = P\Delta\theta + S_D$$

S_D : corrector DC current

Point-to-Point

✓ 16 FOFB cells @ 1152 BPMs data @ 384 fast correctors

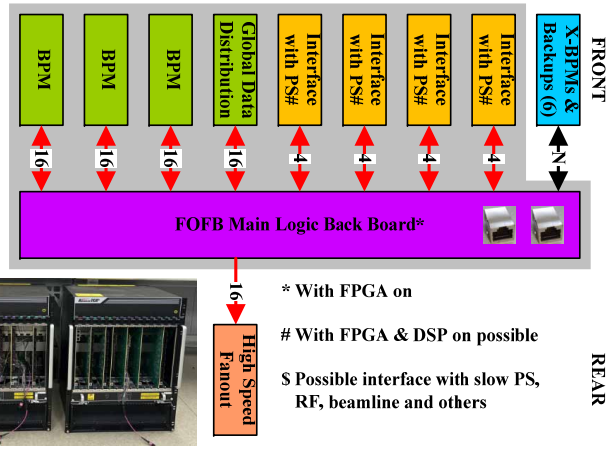


Fast Orbit Feedback System for HEPS

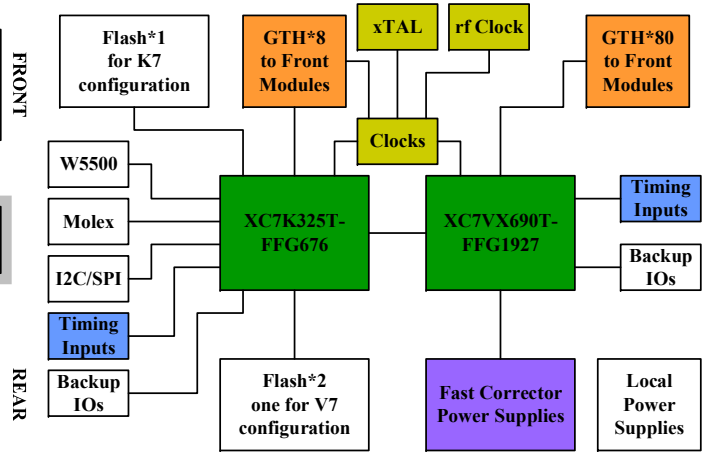
original intention: self-developed and multi-purpose, FOFB、FPS、Timing

- **Hardware design**
  (budget & performance)
  - ATCA Mechanical architecture
  - Core：Xilinx V7 + K7 FPGA
  - Interface：Muti-boards
    （BPM、TM、Fast corrector）
  - data trans：Muti-Mode Fiber
    GTH（4.76Gbps）
  - X-BPMs / RF backup

  ……

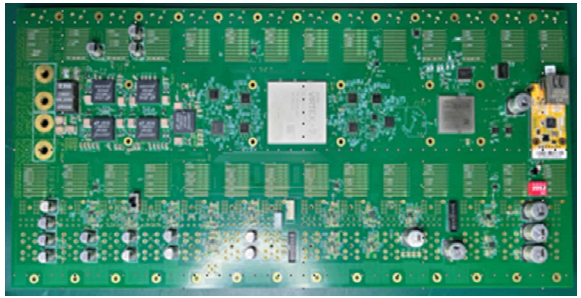


the architecture of Sub-station

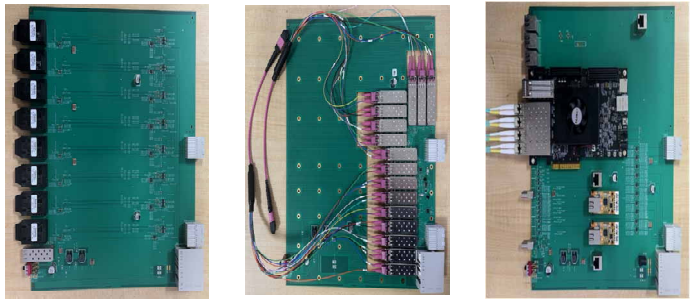


the function of core backplane

- **Hardware finalized**
  (1/4 sub-station)
  - Core backplane
  - BPM interface board
  - Fast-corrector interface board
  - Timing interface board



Core backplane



Interface boards

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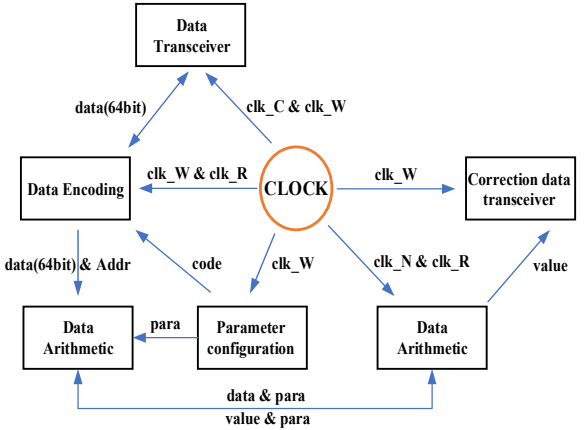
strategy: synchronized with the same clock source, ordering data, interrupt ID and FIFO

- **Logic design**(modularity)
  - A **synchronous** clock
    reduce latency and minimize resources
  - The **pipeline**
    make full use of the data transmission delay
  - Data width of calculation gradually increased
    to maintain precision

- Clock
- Data encoding
- Data storage
- Data arithmetic
- Data transceiver
- Parameter configuration
- Correction data transceiver

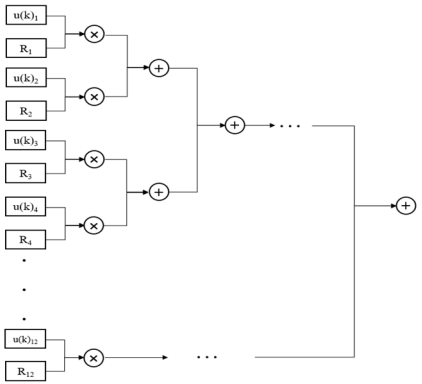


- **PID & Matrix multiplication**(DSP48E1,3600 slices; BRAM,53Mb)

The equation of incremental PID algorithm :

$$u(k)=u(k-1)+\Delta u$$
$$=u(k-1)+Kp[e(k)-e(k-1)]+Kie(k)+Kd[e(k)-2e(k-1)+e(k-2)]$$

- read 12 BPM data and 12 data mapped in the response inverse matrix (24 groups) in one pipeline cycle
- use the "binary tree" to add up the results of the 12×12 vectors to get 24 vectors in turn.



BPM	24			
↓	增加 3			
PID	e(k)	27	×	PID 系数 29
↓				
u(k)	56	×	矩阵	29
↓				
S	85			
↓	增加 5			
θ	90			
↓	增加 6			
Σθ	96			
↓	ff			
p	32			

Fast Orbit Feedback System for HEPS

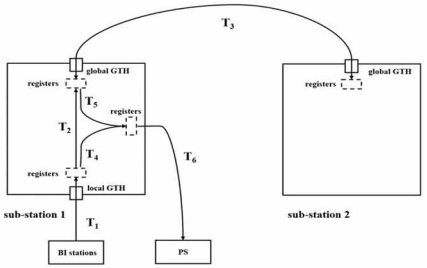
- **Time consumption and performance : meeting the requirements (~50% resources used)**
  - BPM data acquisition: T1
  - BPM data treatment: T2
  - BPM data transmission: T3
  - Matrix calculation for local BPM: T4
  - Matrix calculation for global BPM: T5
  - Fast-corrector data transmission: T6

Total consumption : ~10.5μs

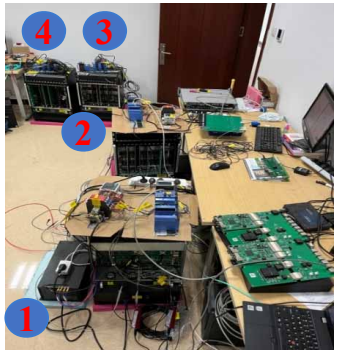
$$T_{total} = T_1 + T_2 + 8T_3 + T_5 + T_6$$

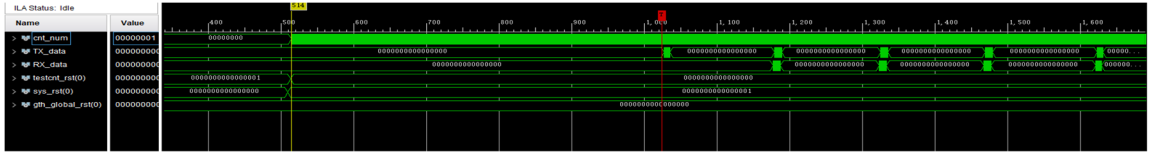
$$T_4 < T_2 + T_3$$

$$T_5 < T_3$$

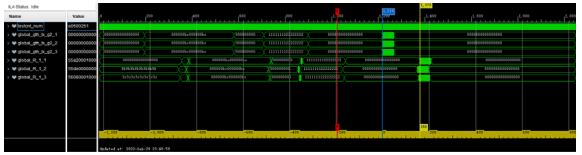


	T_1	T_2	T_3	T_4	T_5	T_6
延时	821ns	705ns	950ns	874ns	773ns	620ns

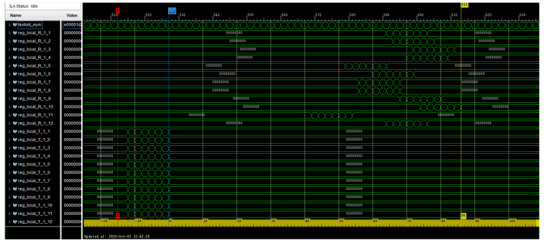




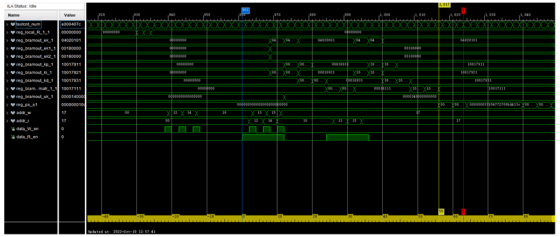
Transfers 64-bit data between sub-stations(comma detection to align words)



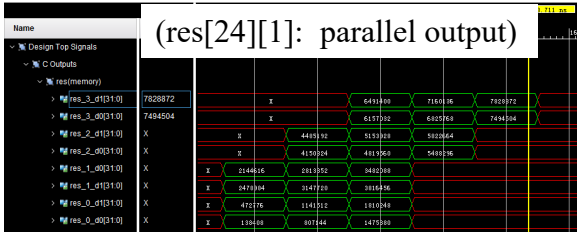
global BPM data transmission :950ns



local BPM data transmission :850ns



Pipeline : 470ns



Matrix operation(cell): 53ns

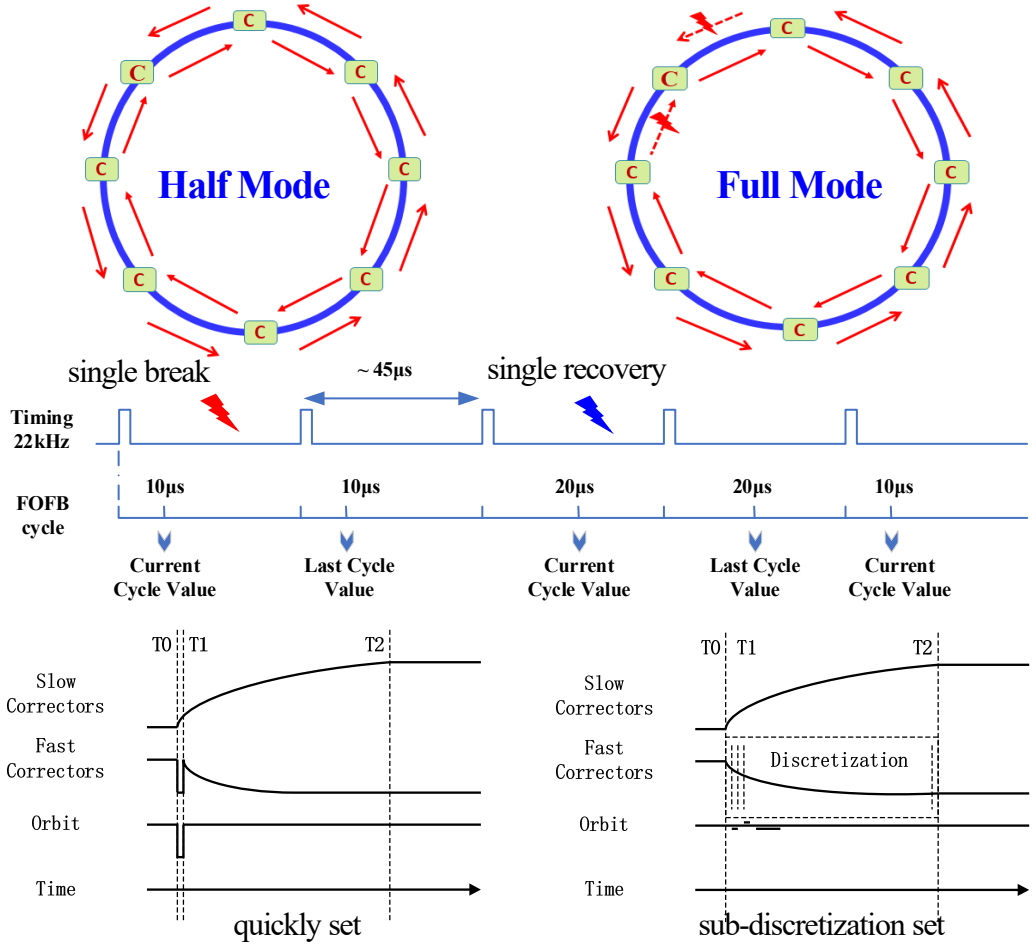
Fast Orbit Feedback System for HEPS

- **Half ring mode or full ring mode**
  - normal:
    the data only transfer half a ring
  - if disconnection:
    part of data transfer the whole ring

The correction settings does not change much between two adjacent cycles (PID)

- **Synchronized orbit correction**
  - Local orbits may not be well corrected by the FOFB due to the slow drift and few fast correctors
  - Both fast and slow correctors used for orbit correction, settings synchronized to minimize disturbances

synchronization!



Fast Orbit Feedback System for HEPS

Summarize

- ✓ All hardware for the 4 sub-stations manufactured, installed and tested;
- ✓ Main logic design finished, further development and test on going.
- ✓ The overall delay is about 10μs, fulfilling the requirements.

Thanks for your attention !