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Prototype of White Rabbit Based Beam-Synchronous Timing Systems for SHINE

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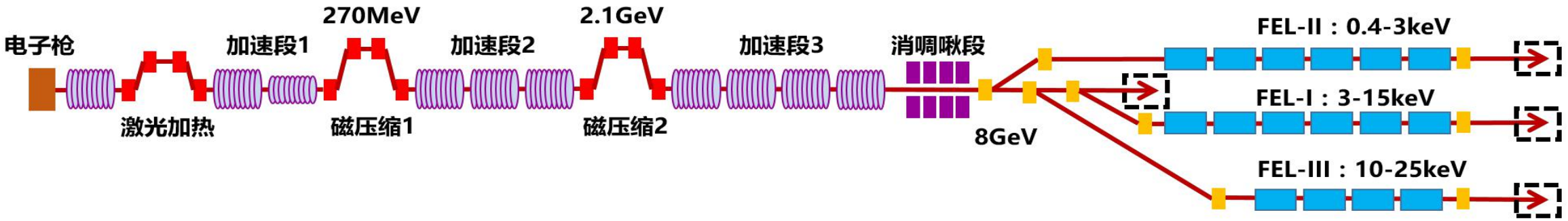
SHINE

Outline

- Overview
- Architecture of SHINE Timing System
- Prototypes Development
- Conclusion

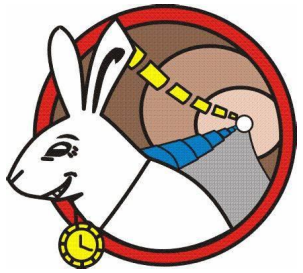
SHINE Project

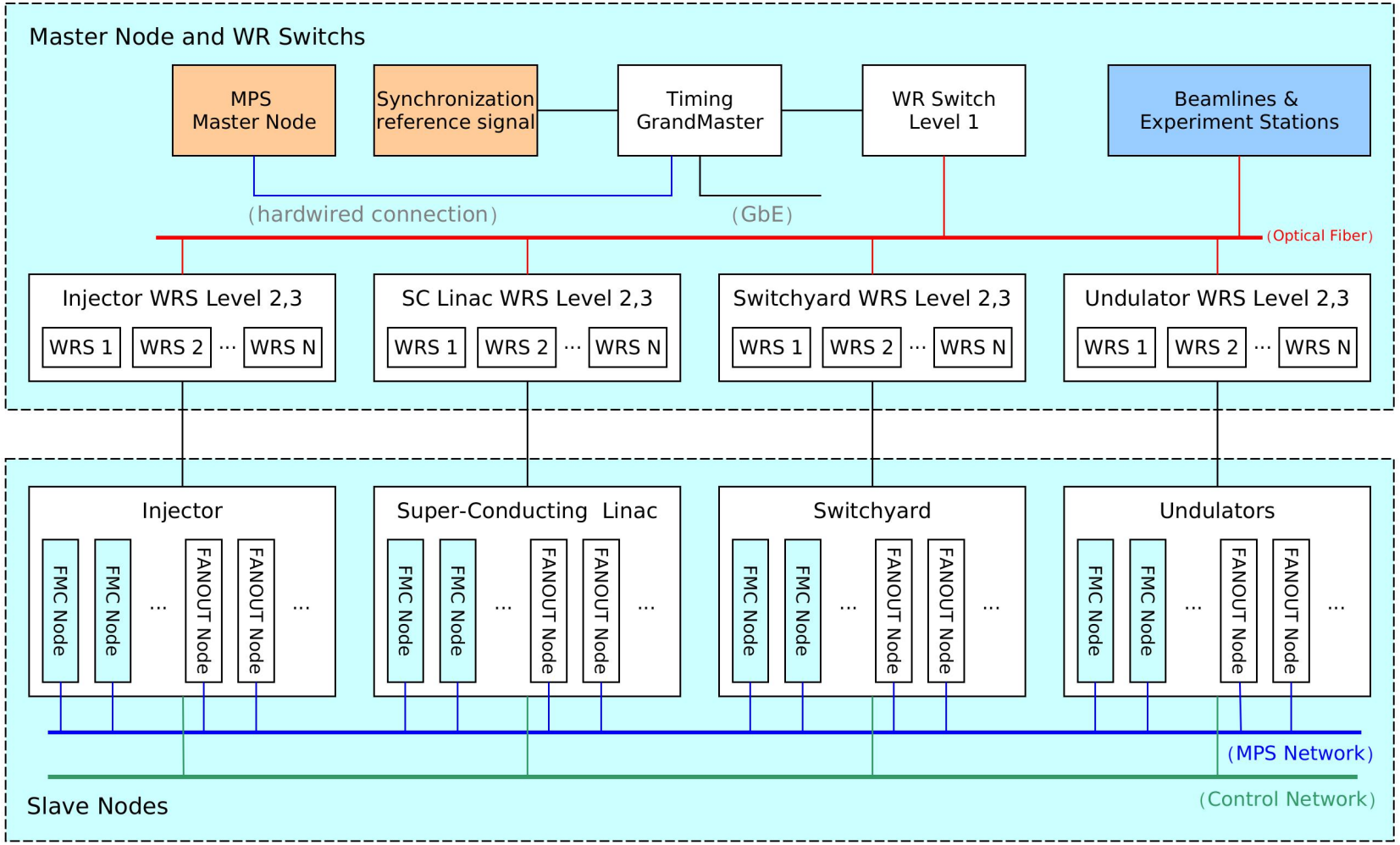
- Shanghai High repetition-rate XFEL(X-ray free electron laser) aNd Extreme Light facility (SHINE)
- First hard X-ray FEL facility in China



e-beam : 8 GeV	Photon Energy : 0.4 - 25 keV
Pulse duration : 1 - 100 fs	Repetition : 1.0030864 MHz
Total length : 3.1 km	Underground : ~ 29m

SHINE Timing System





1 GrandMaster Node, ~ 600 Slave Nodes, 3 Layers ~ 80 WRS

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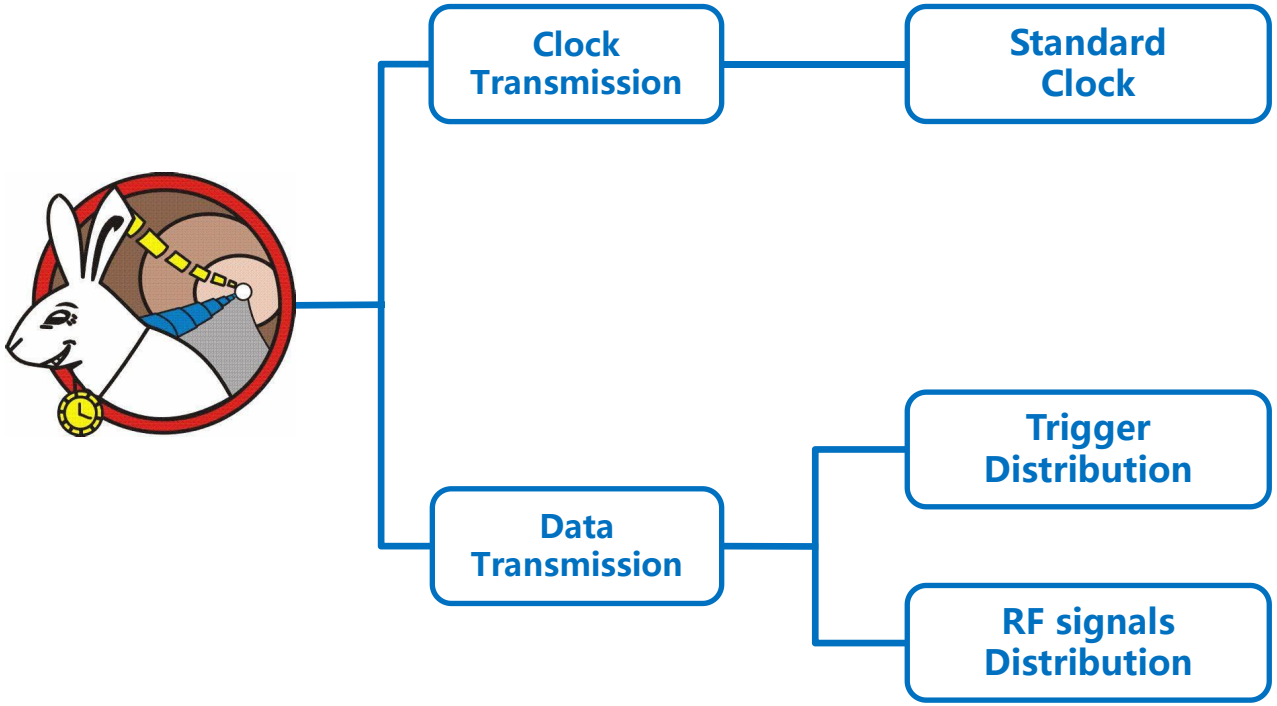
SHINE Timing System

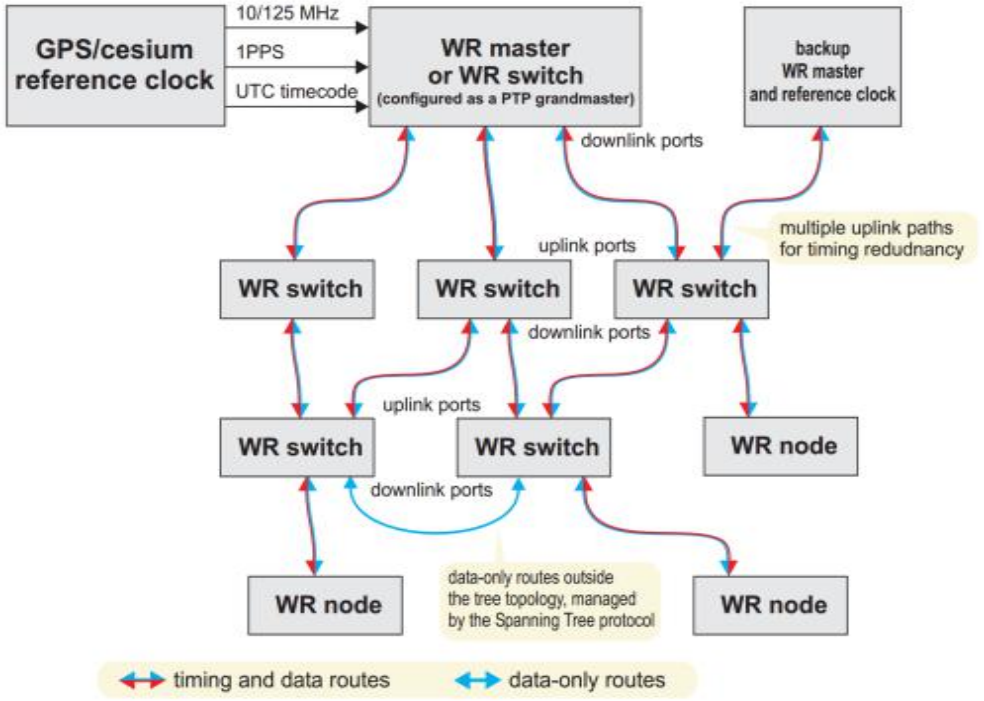
1) Beam-synchronous trigger signal distribution
   - Precise distribution and synchronization of the 1.003086MHz (1300/1296) timing signals over a long distance of about 3.1 km
2) Random-event trigger signal distribution
   - Extension function of the timing system
   - Various event signals, such as beam loss, machine snapshot, etc.
3) Data exchange between nodes
   - May be used for local beam parameter feedback

SHINE Timing System



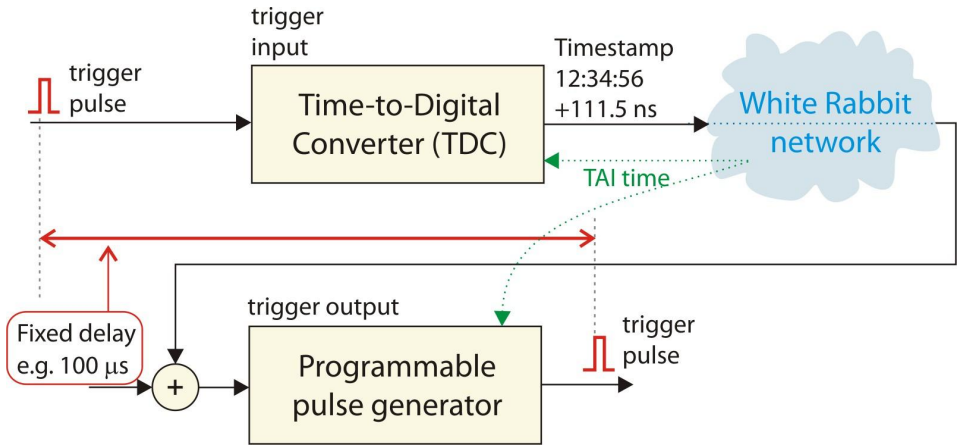
SHINE Timing System

- Standard Clock Transmission
  - Standard White Rabbit network operating clock 125/62.5MHz
  - If the SHINE repetition frequency is 1.0MHz, 1.3GHz RF input signal can be divided to 10MHz as the reference signal
  - The Salve node output the trigger signal at the specified time（1us, 2us, 3us, ...）
  - Jitter < 10 ps

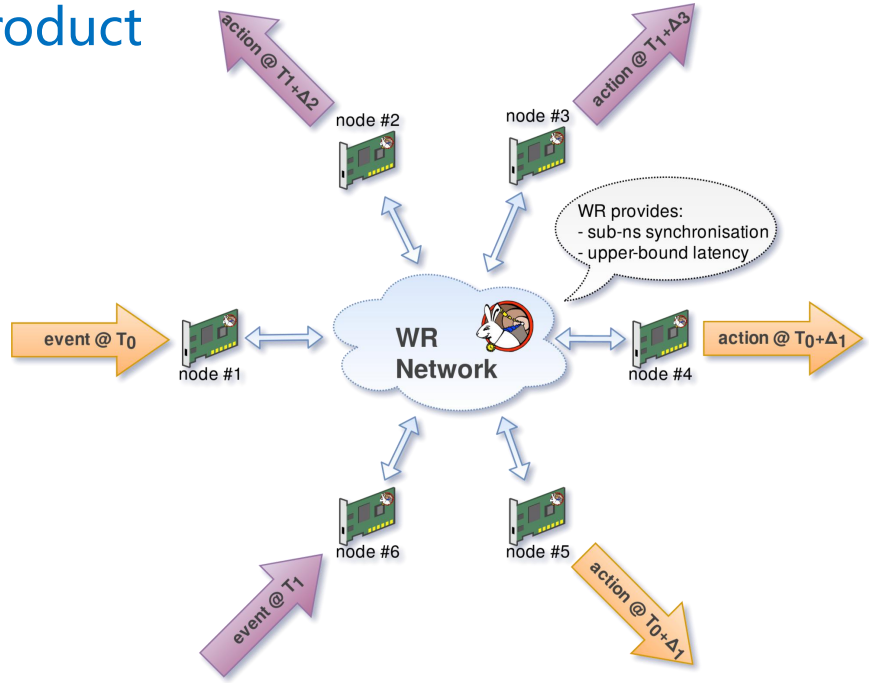


SHINE Timing System

- Random Trigger Distribution
  - White Rabbit Trigger Distribution (WRTD) is a generic framework for distributing triggers (events) between Nodes over a White Rabbit network.
  - For SHINE, the network bandwidth is limited, the jitter will increase
  - 10 Gigabit White Rabbit Switch, no commercial product



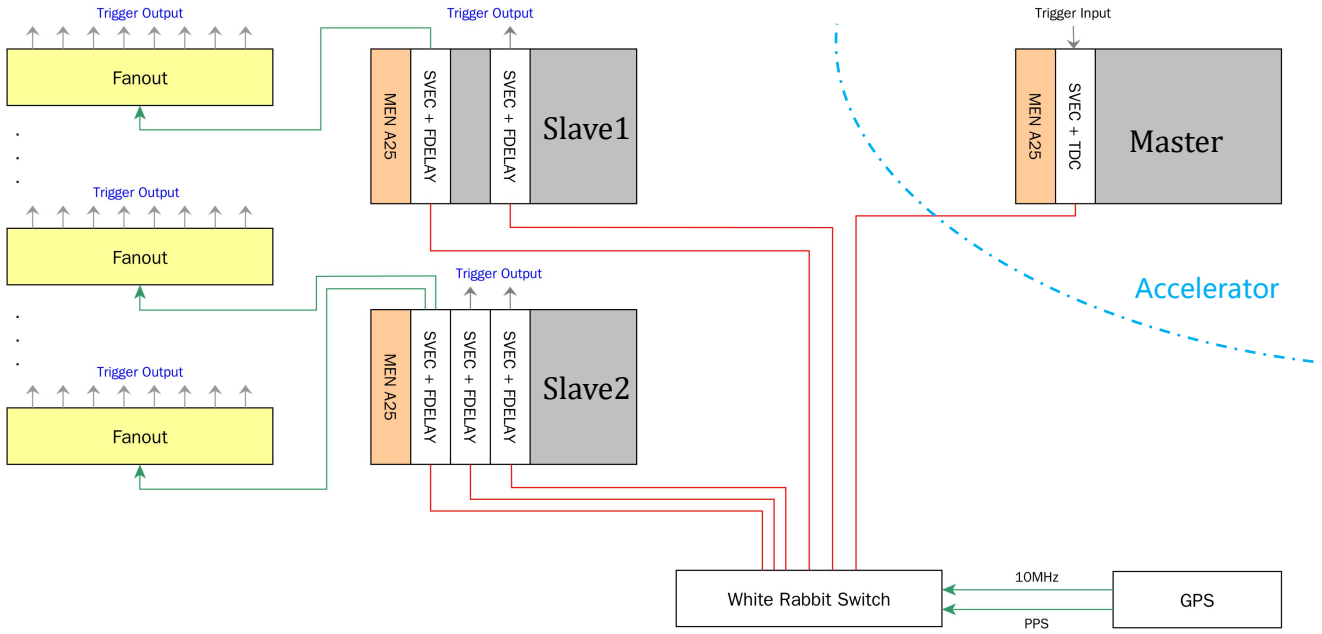
White Rabbit Trigger Distribution, ICALEPCS 2017



https://ohwr.org/project/wrtd/wikis

SHINE Timing System

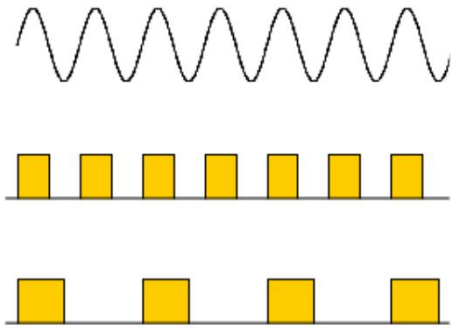
- Random Trigger Distribution
  - SXFEL-UF (Shanghai soft X-ray Free-Electron Laser User Facility)
  - SVEC - VME with FMC TDC 1ns 5cha and FMC DEL 1ns 4cha

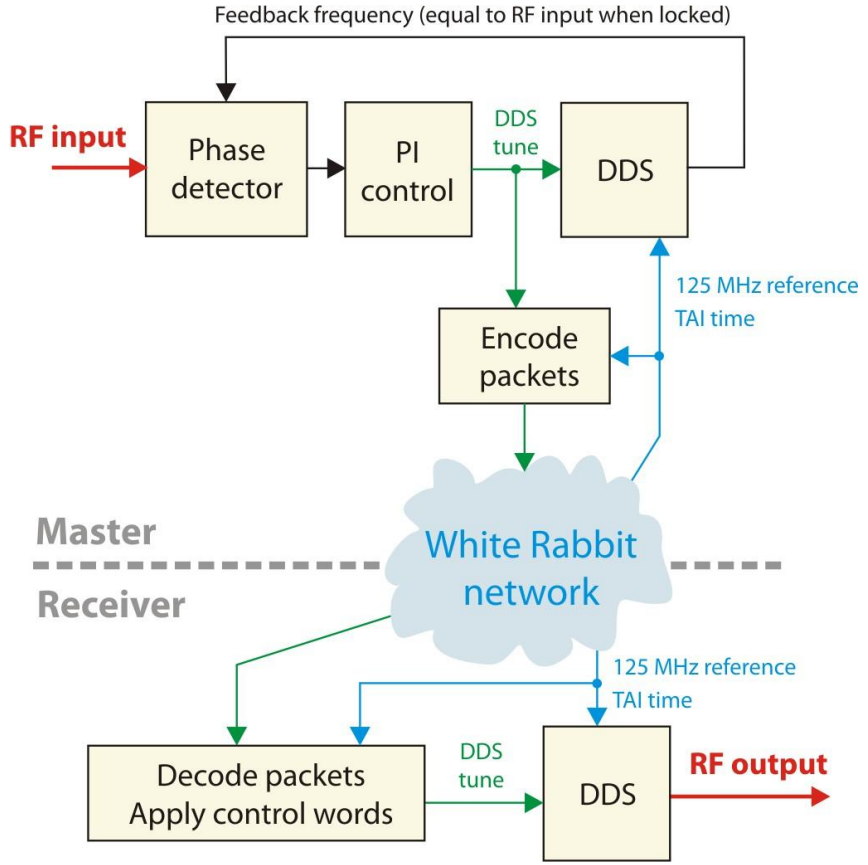


SHINE Timing System

- RF signals Distribution
  - All nodes have the same reference frequency and time
  - Master phase locks its DDS to the RF input
  - Broadcast the DDS control words, including a TAI timestamp
  - All receivers update their DDSes with the received control word at the same moment (+some fixed delay)

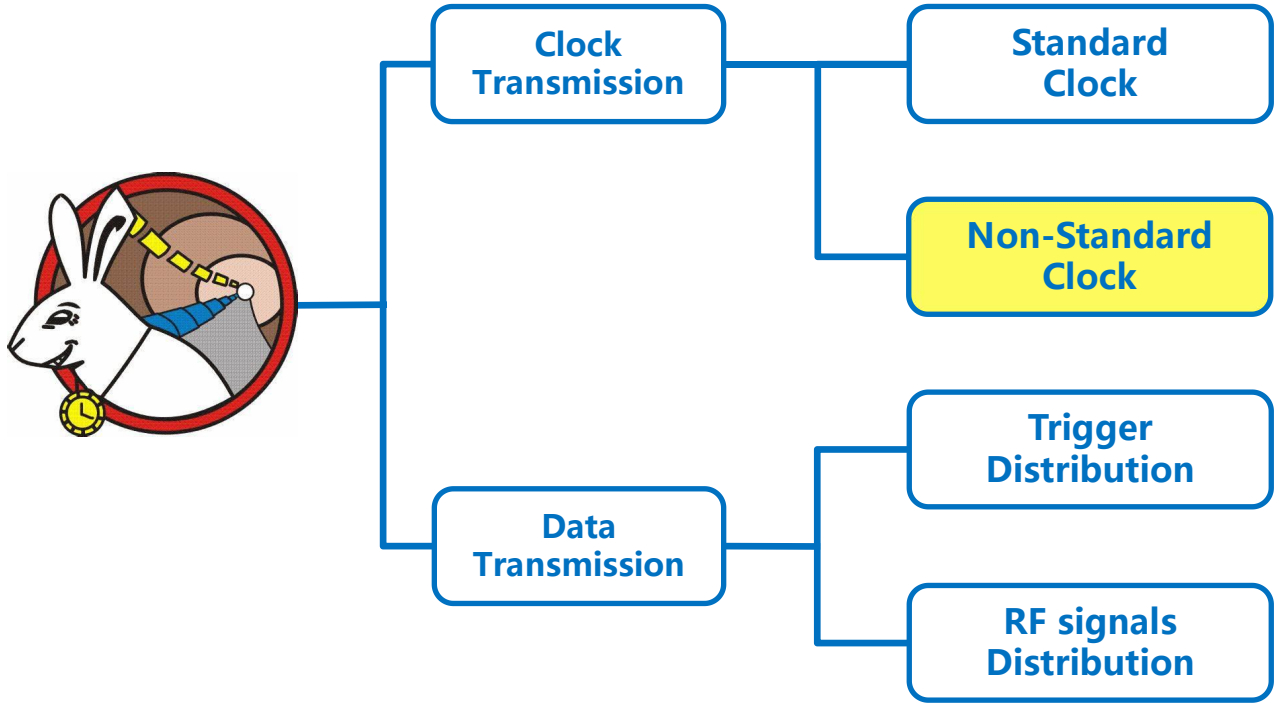
Can the sine be converted to editable pulse signal?





Distribution of RF signals using WR, ICALEPCS 2017

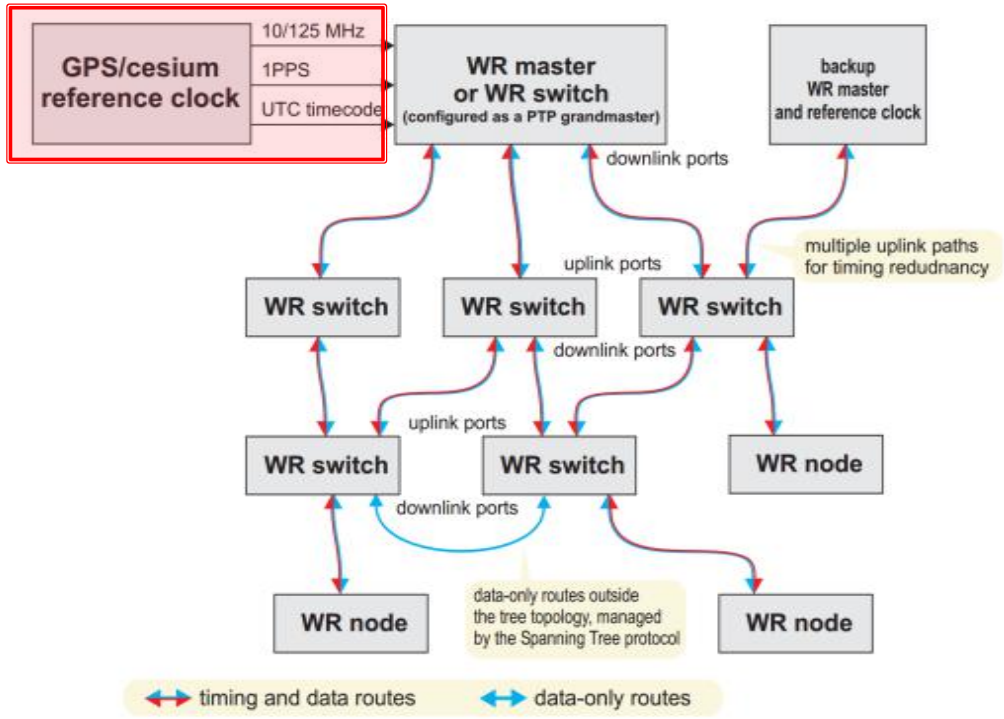
SHINE Timing System



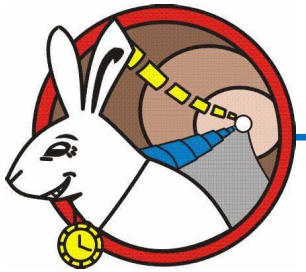
SHINE Timing System

- Non-Standard Clock Transmission
  - The repetition frequency of SHINE is 1.0030864MHz (1300/1296)
  - 1.3GHz RF reference signal can be divided to 1.0030864MHz as a reference signal

Can the White Rabbit frequency be changed from 125/62.5MHz to 125.385/62.693MHz?



SHINE Timing System



- Clock Transmission
  - Standard Clock
  - Non-Standard Clock
- Data Transmission
  - Trigger Distribution
  - RF signals Distribution
    - Pulse Distribution

Prototype I

Prototype II

1

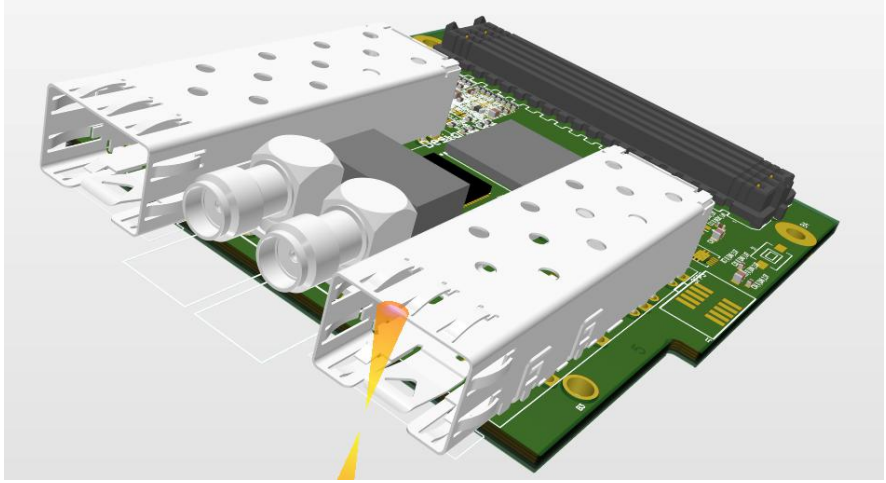
2

3

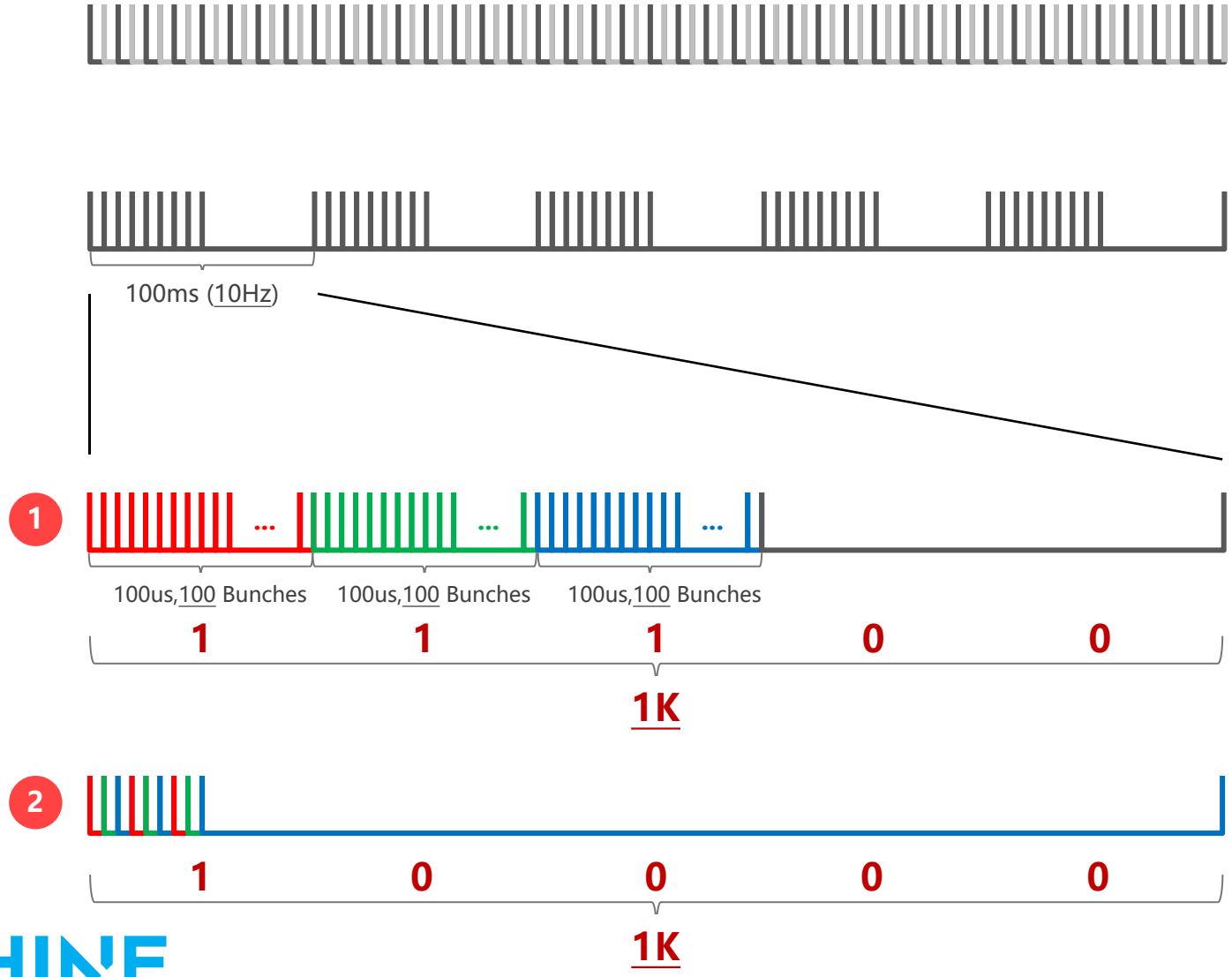
Prototype

1) Beam-synchronous trigger signal distribution
   - Master node: reference signal and PPS signal
   - Slave node: machine clock with division or mask，adjustable delay and pulse width
2) Random-event trigger signal distribution
   - Master node: 4 channals pulse inputs < 1 kHz
   - All slave nodes output at the same time

     (+ fixed delay)



Prototype Mask mode



Continuously / equispaced filled

Train filled

A x B x C

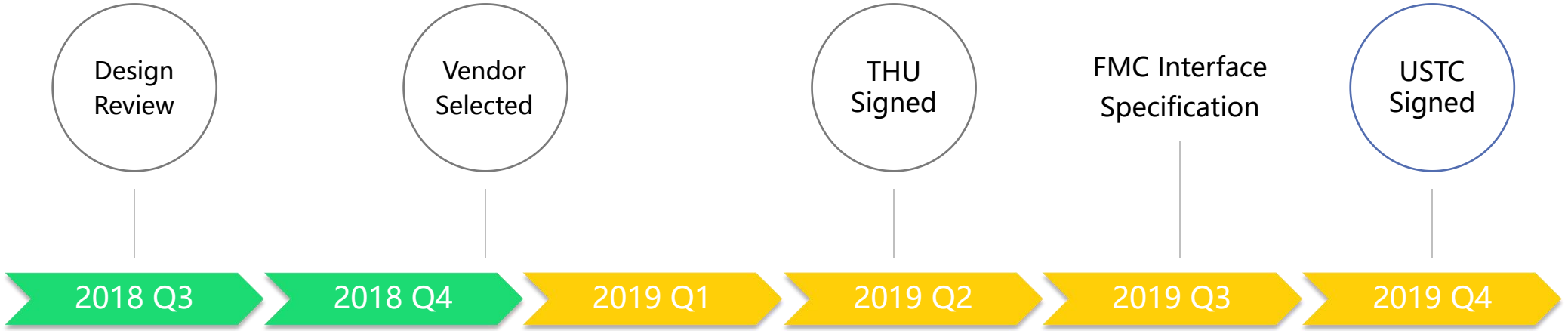
For example: 10Hz x 1K x 100

- A (10Hz) : Train repetition rate
- B (1K) : Train editing unit

  10000..., 11000...
- C (100) : Arbitrary generator

SHINE

Road Map



Design

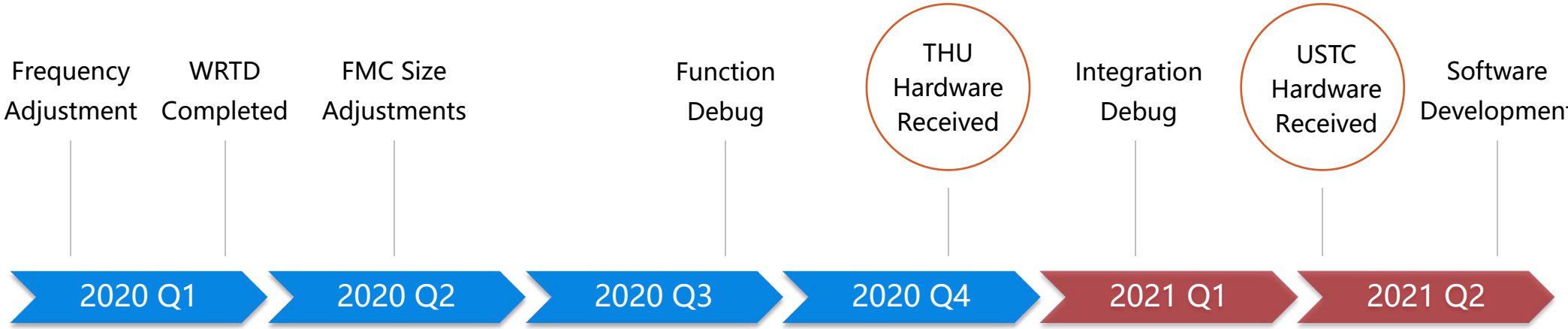
- Technical route selection
- Prototype design review
- Potential vendor selected

Verification

- Non-standard clock verification
- Pulse signal distribution verification
- Artix-7 and Kintex-7 development and debug

SHINE

Road Map



Design

- Hardware version 1 design and testing
- Hardware version 2 design and testing
- Continuous adjustment and optimization

Debug

- Integration debug and performance testing (master - switch - slave nodes)
- Firmware and software development

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Prototype I

- Minimize modifications to the standard White Rabbit Protocol
- Replace the VCXO(Voltage- Controlled Crystal Oscillator) using customed 27.083MHz oscillator
- Operating frequency is 67.708MHz (1.003086MHz x 135/2)

- Change the frequency to 64.197530MHz (1.0030864MHz x 64, 52/81 x 25MHz x 4)
- Easy to generate 2^N divisions and obtain machine clocks
- Clear proportional relationship between the pseudosecond and the standard second

Standard time : [seconds : nanoseconds : subnanoseconds]

Non-standard time : [pseudo-seconds (~0.9969s) : clock integer period (~15.5769ns) : phase]

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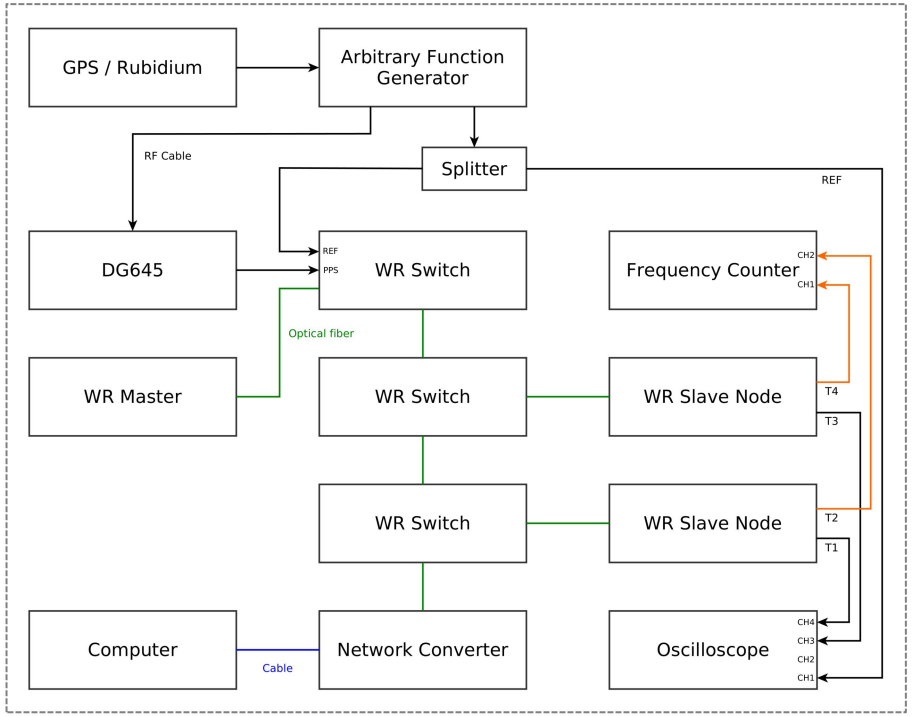
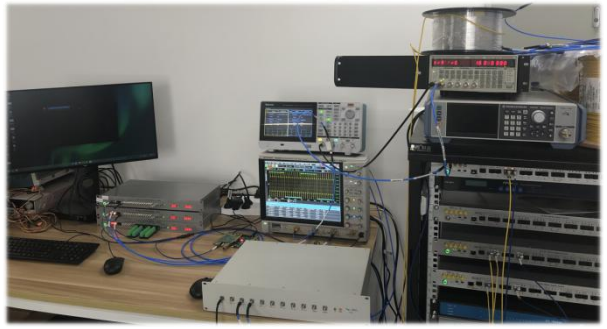
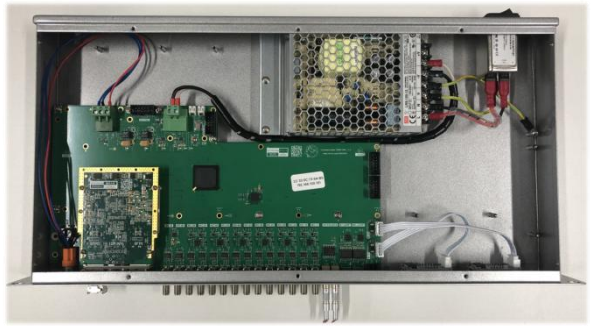
Prototype I

- Beam-synchronous trigger signal distribution
  - Jitter < 10ps (3 Layers WRS, 5km)
- Random-event trigger signal distribution
  - Jitter < 60ps







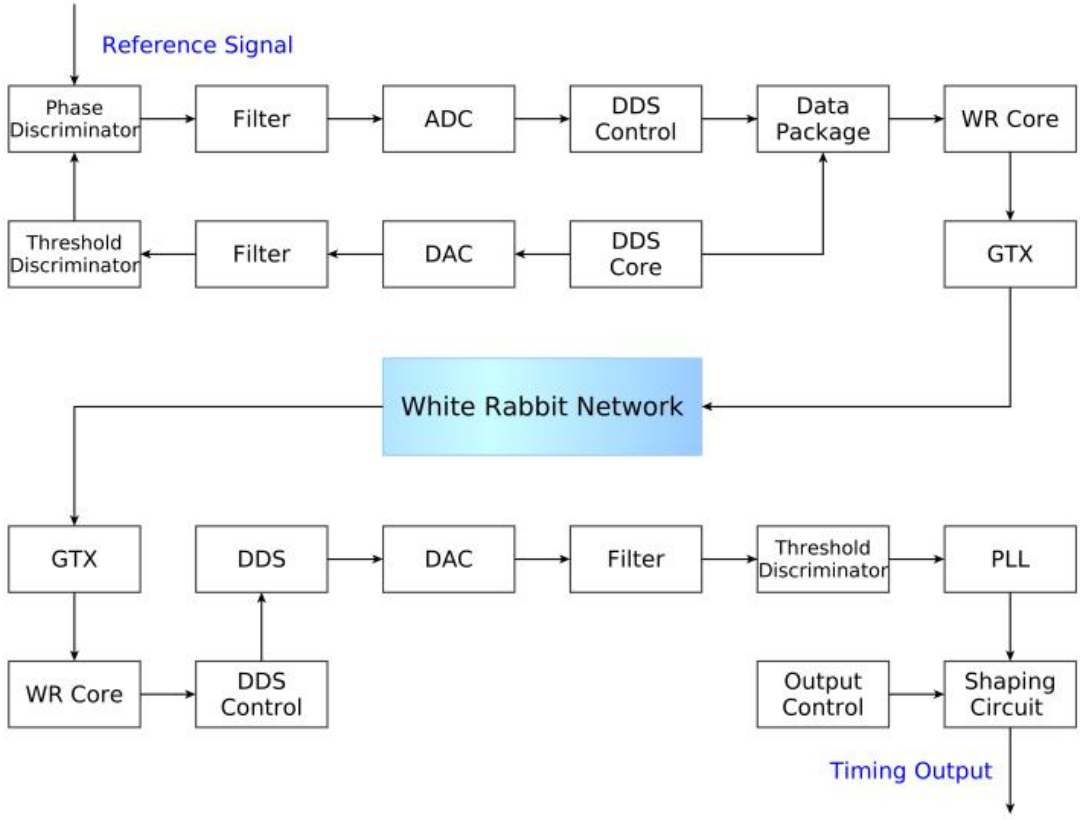
Jitter between the slave node outputs and reference signal : 9.535ps
Jitter between slave nodes outputs : 4.791ps

Slave Node

Prototype II

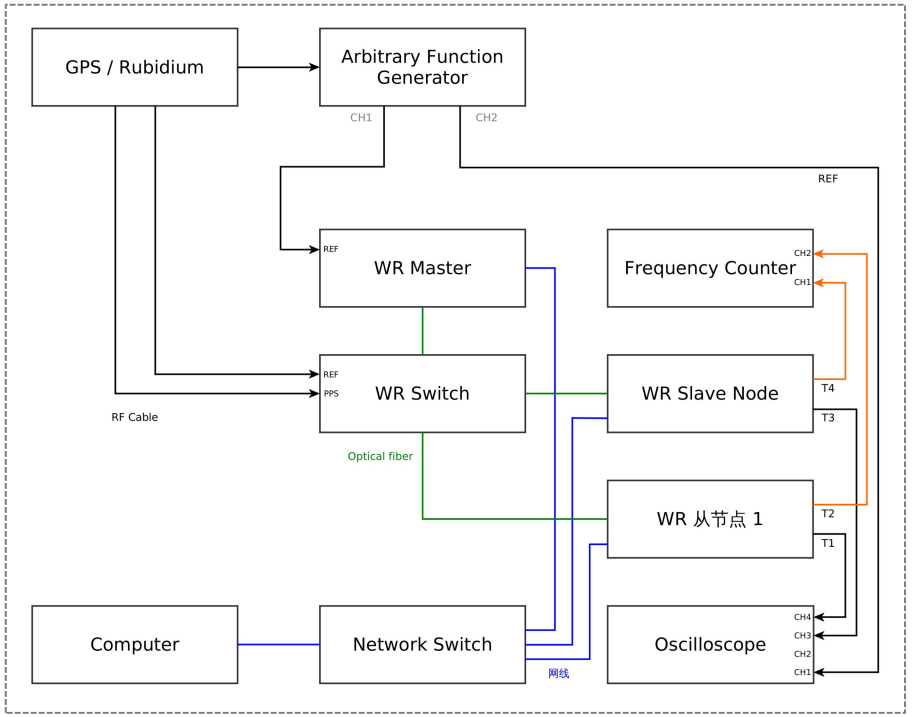
- Clock (125/62.5MHz) distribution and synchronization based on standard White Rabbit network

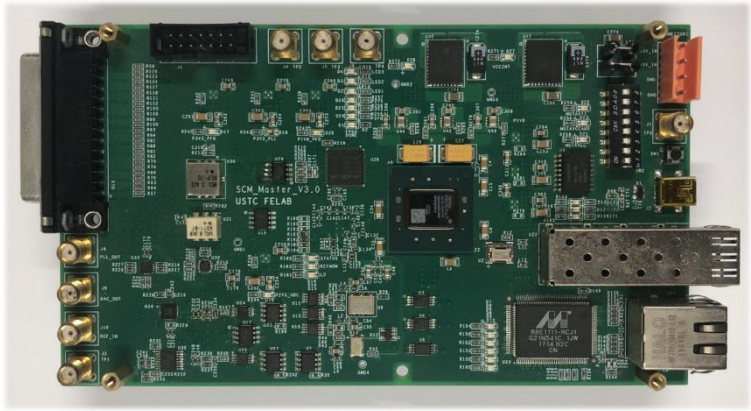
- The DDS (Direct Digital Synthesis) and D flip-flops (DFFs) are adopted for RF signal transfer and pulse configuration.
- Off-chip delay for beam-synchronous trigger and on-chip delay for random-event trigger



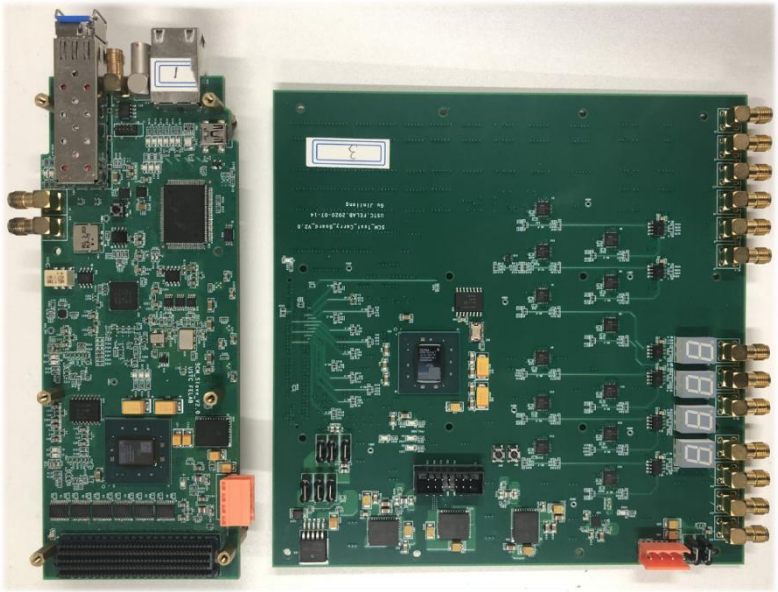
Prototype II

- Beam-synchronous trigger signal distribution
  - Jitter < 20ps (1 Layer WRS, 5km)
- Random-event trigger signal distribution
  - Jitter < 35ps





Master Node



Slave Node

Conclusion

- Two prototype systems were developed, both containing three functions: beam-synchronous trigger signal distribution, random-event trigger signal distribution and data exchange between nodes.
- The non- standard clock transmission was proposed and verified.
- The prototype development has just been completed and we will do further test and evaluation for the SHINE project.


Thanks for your attention !
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