Integrated dissemination system of F-T-D for radio astronomy; and absolute phase synchronization

Bo Wang
Department of Precision Instrument
Tsinghua University

2020.3.12
Outlines

• Background

• Principle of the integrated dissemination system

• Test results

• Preliminary results of absolute Phase synchronization
Interferometric Radio Astronomical Observation

1, Time Dissemination and Synchronization
- Signal recorded at the receptors with high precision, enabling pulsar timing and VLBI
- Phasing up the array by limiting the fringe window

2, Frequency Dissemination and Synchronization
- Keeping coherence during observation

3, Data Dissemination
- Transferring the digitized data to central station

Phase synchronization
Coherent Observation

\[ \Delta \tau = \Delta \tau_{geo} + \Delta \tau_{clock} + \Delta \tau_{teles} + \Delta \tau_{atm} \]
Requirement for the integrated system

In e-Merlin system, there is only one single fiber from Jodrell Bank Observatory to Cambridge and there is also only one single fiber from Jodrell Bank Observatory to Darnhall.

http://www.e-merlin.ac.uk/
Outlines

• Background

• Principle of the integrated dissemination system

• Test results

• Preliminary results of absolute Phase synchronization
Using DWDM, the highly-stable frequency dissemination, time synchronization and data transfer can be simultaneously achieved over a single optical fiber link.

**Integrated dissemination system for F, T and D**

**Advantages:**
1. Saving fiber resources
2. Making the system simpler
1) Part of frequency Dissemination

\[ V_0 = \cos(2G \, t + \phi_0) \]
\[ V_1 = \cos(1G \, t + \phi_1) \]
\[ V_2 = \cos(2G \, t + \phi_0 + \phi_p) \]
\[ V_3 = \cos(1G \, t + \phi_1 + \phi'_p) \]
\[ V_4 = \cos[1G \, t + \phi_0 + \phi_p - \phi_1 - \phi'_p] \]
\[ V_5 = \cos(\phi_0 + \phi_p - 2\phi_1 - \phi'_p) \]
\[ \phi_p = \dot{\phi}'_p \]

\[ V_5 = \cos(\phi_0 - 2\phi_1) \]

Products

Engineering Products
All modules highly integrated
Automatic, robust and cheap
A typical White Rabbit system

\[ \lambda_1 \neq \lambda_2 \quad \text{delay}_{MS} \neq \text{delay}_{SM} \]
The calibration of fiber asymmetry coefficient $\alpha$

1. Connect Master and Slave via a short fiber $f_1$ (a few meters long).
2. Set appropriate parameters ($\Delta T_{XM}, \Delta T_{XM}, \alpha$) to 0.
3. The delay$_{MM1}$, $\varepsilon_M$ and $\varepsilon_S$ can be directly read from the monitors.
4. Record the delay$_{MM1}$, $\varepsilon_{M1}$ and $\varepsilon_{S1}$.
5. Use the same way to record the delay$_{MM2}$, $\varepsilon_{M2}$, $\varepsilon_{S2}$, delay$_{MM3}$, $\varepsilon_{M3}$ and $\varepsilon_{S3}$.

\[ \delta_1 = \text{delay}'_{MM3} - \text{delay}'_{MM1}, \quad \delta_2 = \text{delay}'_{MM3} - \text{delay}'_{MM2} \]
\[ \varepsilon_M = \delta_1 - \text{delay}_M \]
\[ \varepsilon_S = \delta_2 - \text{delay}_S \]

\[ \alpha = \frac{2(\text{skew}_{PPS2} - \text{skew}_{PPS1})}{\frac{1}{2} \delta_2 - (\text{skew}_{PPS2} - \text{skew}_{PPS1})} \]
\[ \alpha_N = 2^{40} \left( \frac{\alpha + 1}{\alpha + 2} - 0.5 \right) \]

For White Rabbit switch

For White Rabbit PTP Core
For the fiber whose both ends are not in the same location

The method used for the calibration of buried fiber from SKA-TEL-SADT-0000410-SADT.STFR.UTC-DDD(Mid) document

A calibration fiber is needed for calibration!

The calibration process is complicated!
In e-Merlin system, there is only one single fiber from Jodrell Bank Observatory to Cambridge and there is also only one single fiber from Jodrell Bank Observatory to Darnhall.

http://www.e-merlin.ac.uk/
A Single wavelength WR method was proposed with two laser lights using the same wavelength to eliminate the effect of chromatic dispersion.

Xu Yuan et al., Chinese Optics Letters, 15, 101202 (2017)
Outlines

• Background

• Principle of the integrated dissemination system

• Test results

• Preliminary results of absolute Phase synchronization
Collaborative research at Jodrell Bank Observatory, Aug-Nov, 2019
The test of the integrated dissemination system over 48 km fiber

The schematic diagram of the integrated dissemination system test over 48 km fiber link, which consists of 28 km buried fiber from Jodrell Bank Observatory to the Pickmere dish and 20 km fiber spool at Jodrell Bank Observatory.
1) **Frequency transfer stability**

In any 10-minute interval, the phase drift of the integrated system is less than 3 mrad.
2) Time synchronization error

Adjacent-Averaging algorithm shown as red line is used to smooth the time deviation.
3) Bit error rate of data transfer

Bit error rate (BER): the number of bits with errors transmitted over a period of time divided by the total number of bits transmitted.

Forward error correction (FEC): a technology for controlling data transmission errors.

The output Bit error rate with and without Forward Error Correction

If the input BER is less than 1E-6 before FEC, it will be completely error free after FEC.
Outlines

• Background

• Principle of the integrated dissemination system

• Test results

• Preliminary results of absolute Phase synchronization
Interferometric Radio Astronomical Observation

1, Time Dissemination and Synchronization
- Signal recorded at the receptors with high precision, enabling pulsar timing and VLBI
- Phasing up the array by limiting the fringe window

2, Frequency Dissemination and Synchronization
- Keeping coherence during observation

3, Data Dissemination
- Transferring the digitized data to central station

Phase synchronization
Coherent Observation

\[ \Delta \tau = \Delta \tau_{geo} + \Delta \tau_{clock} + \Delta \tau_{teles} + \Delta \tau_{atm} \]

- Small aperture
- Multi observation units
- Long baseline

- Observation resolution
- Sensitivity
- Field of view
Phase Synchronization v.s. Frequency synchronization

**Frequency Synchronization**

- Local Site
- Remote Site
- $\Delta \phi = ???$

**Absolute Phase Synchronization**

- **Stable** and **Repeatable** Phase Difference
Principle

Multi-Access Phase Transfer

- Ensure $\phi_p(\text{forward}) = \phi_p(\text{backward})$

Experimental Setup

- Local and remote sites locate at the same place and access to the same frequency reference;
- Absolute phase synchronization at arbitrary point;
- Anti-nonlinear-effect (ANE) mixing is adopted.

The 25 km fiber spool in the fiber link is placed in a temperature variation box (TVB).

TVB changes rapidly
20°C per hour

± 14 mrad around 1.74π rad
<0.7 % of full cycle
± 1.13 ps

Room temperature

± m14 rad around 1.74π rad
<0.7 % of full cycle
± 1.13 ps

Stable!
Restart

Reference oscillator Restart
±2 mrad around 1.741π rad

Assistant Signal Restart
±2 mrad around 1.741π rad

Power Restart
±1 mrad around 1.740π rad
(After system “warm-up”)

Consistency within 6 mrad
Repeatable!
**Fiber Route Changes**  
Consistency within 98 mrad

10m fiber removed  
1.742\(\pi\) rad to 1.731\(\pi\) rad

2km fiber removed  
1.731\(\pi\) rad to 1.711\(\pi\) rad

Repeatable!
Intermediate-Access Node Changes

Point A to Point B

1.713\pi \text{ rad to } 1.723\pi \text{ rad, it is } \sim 85 \text{ mrad around } 1.74 \pi \text{ rad}

Within 2% of full cycle

Repeatablible!
Conclusion

• Design an integrated F-T-D dissemination system, and perform field test at Jodrell Bank Observatory. Test result can fulfill the Radio interferometric observation requirement.

• Report our preliminary experimental results on the absolute phase synchronization. Phase difference between two remote sites is kept within 2% of the full cycle under different conditions (restart, change fiber route, change the access node). May be applied in SKA2.
Thanks!