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A NOVEL DOUBLE SIDEBAND-BASED PHASE AVERAGING LINE FOR PHASE REFERENCE DISTRIBUTION SYSTEM

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Abstract

Coaxial cable based solution is one of the important scheme in Phase Reference Distribution System. A novel double sideband-based phase averaging line has been developed in Tsinghua accelerator lab. The sender chassis generates the 2856 MHz signal as the forward signal and receives the reflected double sideband signal (2856 MHz-1.19 MHz, 2856 MHz+3.57 MHz) from the receiver. The forward signal is phase-locked with the reference signal, and the forward signal and the sideband signal are adjusted by the FPGA virtual delay line. The preliminary experiments result shows the phase stability can achieve about 170 fs RMS point to point phase distribution under signal distorted by the phase shifter and achieve 178 fs RMS level phase stability with two clients.

INTRODUCTION

PRDS (Phase Reference Distribution System) is served to distribute long-term and high stability phase reference signal to the clients along the accelerator, i.e., the LLRF systems of the electron guns and the accelerate tubes.

The optical fiber based solution and coaxial solution are the two main method in PRDS. The optical fiber based solution can achieve several tens femtosecond synchronization in kilometer scale facility and has potential to several femtoseconds. However, the laser module is expensive and sensitive to the environment, which needs carefully maintenance. Coaxial cable solution is simple and not so fragile as the laser fiber. The coaxial cable method is suitable for some ~hundred meters scale accelerators which required not so high precise phase stability (several hundreds fs) in long term operation. What's more, the coaxial cable method is much cheaper and easier later maintained.

Cable Phase Reference line system was first proposed by Josef Frisch, David G. Brown and Eugene L. Cisneros in SLAC for Next Linear Collider accelerator for the radiation in the tunnel (estimated at ~1 R/Hour) prohibiting the use of fiber optics for distribution [1]. Brian Chase and Ed Cullerton performaced the simulation using Agilent ADS to find optimum cable length, and verify a procedure for the 1.3 GHz Phase Averaging Reference Line for Fermilab's NML accelerator [2]. An automatic interferometer tap point adjustment method was proposed by Czuba K, Antoszkiewicz K, Simrock S, et al. to measure the reflected signal and match it with the forward signal. The drift suppression factor is also measured to find the maximum drift suppression [3].

CABLE-BASED PHASE REFERENCE DISTRIBUTION SYSTEM

Usually, the coaxial cable reference line is designed to send the reference signal through the cable and the end of the line is short to totally reflect the RF signal. The forward and reflected signals are coupled by the dual directional couplers, and the summed signal is the averaged phase which does not impacted by the variation of the cables. A phase locked loop to applied to hold the summed signals locked with the reference signal. The non-ideal components, such as the couplers, are the main effects that will lead to the phase deviation.

The Scheme of the PRDS

The scheme of the cable-based phase reference distribution system in Tsinghua is showed in Fig. 1. The sender, receiver and client chassises share the same hardware which has been presented in [4], which has 4 ADC signal input, 2 DAC signal output and is the signal precession is achieved in the LLRF46 board. These chassises are deployed with different algorithms to implement different functions. The reference signal is from a low noise VCXO at 119 MHz, using the topology of limited multiple, divider and mixer to generate the 2856 MHz RF CW signal and 404 MHz frequency for FPGA board clock. The 404 MHz clock signal is divided to several route for the sender, receiver and clients chassis.

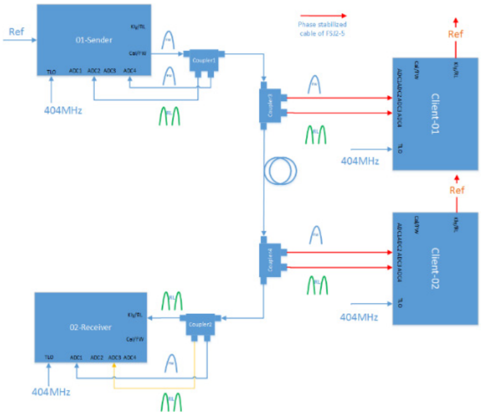

Figure 1: The cable-based phase reference distribution system.

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The digital signal processing design of the sender module is shown in Fig. 2, the sender chassis generate the 2856 MHz forward signal through the cable to the receiver chassis. In order to keep the phase unchanged at the line end, the Elec-control phase shifter is a common way to be inserted in the reference line to adjust the cable length variation. However, the RF power will have effect on the phase-shifting characteristics to bring in a new error source. Therefore, we apply a register in the FPGA to be the “virtual delay line” with a subtractor and an adder. We can achieve an ideal bidirectional phase shifter to keep the line end RF phase stable by changing the “virtual delay line”. Two PI loop are used in the sender module DSP design, one is for the phase lock of the forward signal and reflected signal by adjusting the “virtual delay line”, the other PI loop keep the reflected phase following the external reference phase.

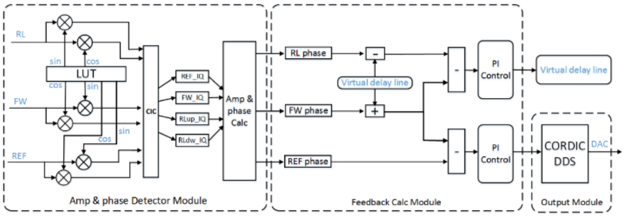

Figure 2: The digital signal processing design of the sender module.

In our scheme, the reflected signal is changed to a double sideband RF signal (2856 MHz - 1.19 MHz, 2856 MHz + 3.57 MHz), which is generated by the receiver chassis, as showing in Fig. 3. The phase of the double sideband RF is locked to the summed phase of the coupled forward and reflected signals to achieve “the short end” of the reference line.

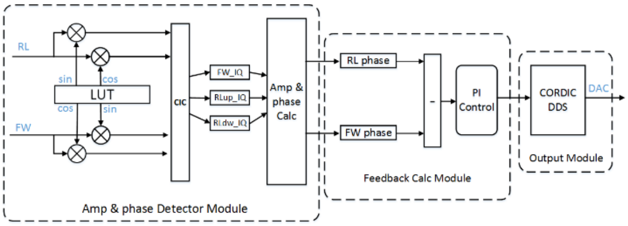

Figure 3: The digital signal processing design of the receiver module.

At the sender module, the summed phase of the coupled forward signal and reflected signal is locked with the phase of the external reference signal. Therefore, the basic point-to-point reference distribution is achieved. What’s more, we can easily pick up the reference phase by inserting the dual coupler along the reference cable line. The coupled signals are detected by digital phase discriminator and summed to get the distributed reference phase for clients like the LLRF system and laser-RF synchronization system, as shown in Fig. 1.

In the traditional phase reference line scheme, the return loss and the cross isolation of the couplers are the main factors leading to the phase variation. The amplitude of the forward and reflected signals are hard to adjust the same and it will cause phase error when they are summed by the combiners. The novel double sideband reflected signal scheme is proposed to deal with these problems. The influence of the return loss will be reduced nearly by half, such as from ~35 dB to ~70 dB. Similarly, the cross isolation impact will also be halved after the double band signal reflected and then coupled. What’s more, the digital phase detecting and summing are unaffected by the difference of forward and reflected signals amplitude.

The Main Components of the Reference Line

The couplers and coaxial cables are the main components in the reference line. We apply the coaxial high-power, wideband bi-directional coupler Mini-Circuits’ ZFBDC16-63HP+ which support applications from 700 to 6000 MHz and provide high directivity, low mainline loss, and excellent return loss, the main character parameter is shown in Fig. 4.

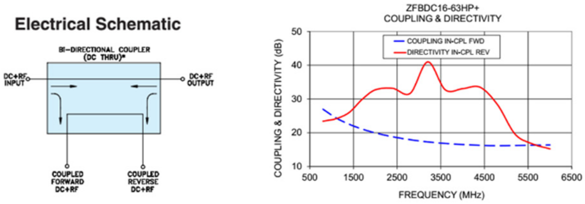

Figure 4: The main parameter of the ZFBDC16-63HP+ coupler.

The real couplers parameters tested by R&S®ZVA 40 network analyzer, the central frequency is 2856 MHz and the span is 100 MHz, the coupling is about 18 db and the directivity is about 37 db, the return loss is about 25 db, and the mainline loss is about 0.06 db, the typical results are shown in Fig. 5.

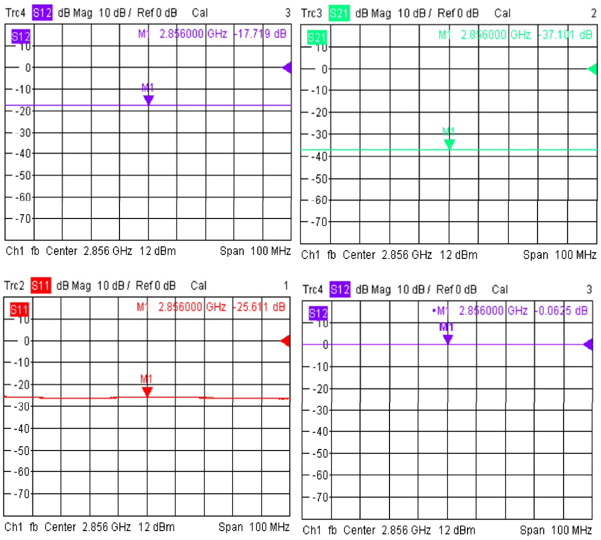

Figure: 5 the typical parameter of the coupler test by R&S®ZVA 40.

Andrew FSJ 2 coaxial cable was chosen for the cable between the couplers because of its excellent temperature stability, and a plot of its temperature characteristics is shown in Fig. 6.

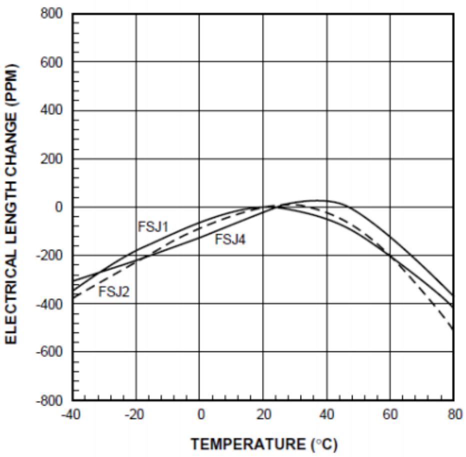

Figure 6: Andrew FSJ 2 electrical length change vs. temperature.

THE PRELIMINARY PERFORMANCE OF THE PRDS

The Test of the Point to Point Phase Distribution Phase Average Line

The basic point to point phase distribution line is shown as Fig. 7. The sender chassis generates the 2856 MHz RF CW signal to the receiver chassis, and the receiver chassis reflects the double sideband RF signal backward. The forward and reflected signals are picked up by the two couplers to complete the phase loop lock.

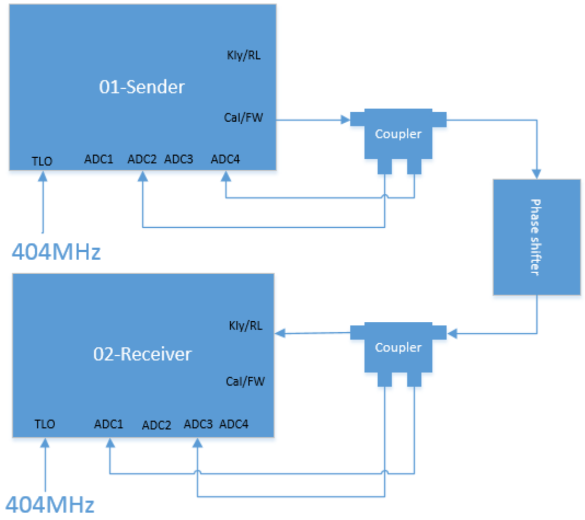

Figure 7: The point to point phase distribution phase average line.

By adjusting the phase shifter, the forward signal phase is changed quickly and the reflected phase should be kept constant by the phase locking. The result is shown in Fig. 8.

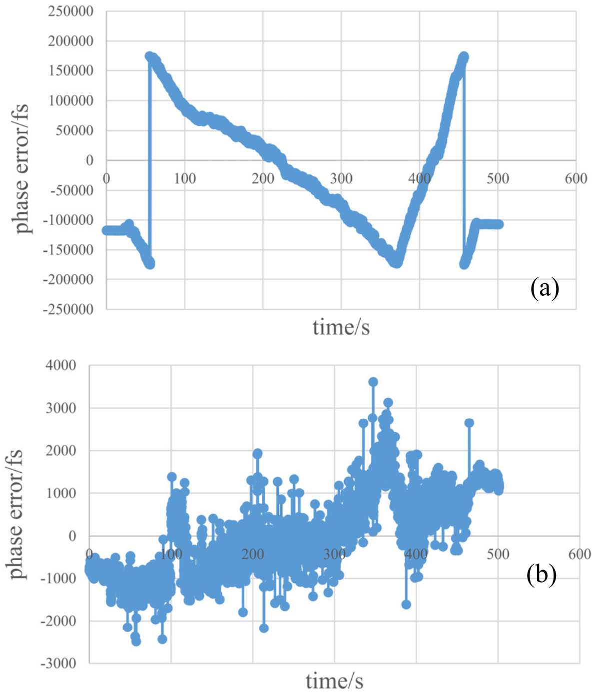

Figure 8: The test result of the point to point phase distribution phase average line: a) The forward signal phase is changed a circle (about 350 ps peak-peak) by the phase shifter; b) The locked phase at the receiver chassis is controlled under 169.78 fs RMS.

As shown in the Fig. 8a, the phase shifter is used to simulate the perturbation of the environment; the forward signal phase is disturbed about 350 ps peak-peak. The phase average result is shown in Fig. 8b, the averaged phase error is about 170 fs RMS, which means the point-to-point phase distribution is worked and successfully compressed the phase distortion along the phase average line.

The Performance of the PRDS with Two Clients

We can use the couplers to pick up the forward and reflected signals, and do the digital phase detecting to get the average phase as reference for the clients, as shown in the Fig. 1. The performance of the phase distribution phase average line is characterized by the phase value difference of the two clients, which is shown in Fig. 9.

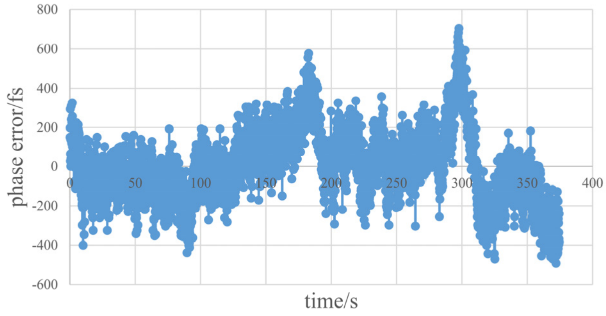

Figure 9: The performance of the PRDS with two clients.

It is seen from Fig. 9 that the average phase value difference between the two clients is about 178 fs RMS in ~6 min. The whole demo system is placed with about 3 meters scale and the whole experimentation was carried out under the room temperature. The main phase error source may be the phase detecting noise, which may be limited by the electronics. The more clients and longer time period experiments will be done in the near future to ensure this novel double sideband phase reference line scheme can be more practicality.

CONCLUSION

A novel double sideband coaxial based phase averaging line for phase distribution system is proposed and built in Tsinghua accelerator lab. The double sideband reflected RF signal (2856 MHz - 1.19 MHz, 2856 MHz + 3.57 MHz) is applied to deal with the non-ideal characteristic of the couplers. A "virtual delay line" method is proposed to achieve an ideal bidirectional phase shifter to keep the line end RF phase stable. The point to point phase distribution phase average line and the demo system with two clients is built. The primarily experiments result shows the double sideband coaxial based phase averaging line can achieve about 178 fs RMS phase error of two clients.

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