

# THE PRELIMINARY LONG-TERM SLOW DRIFT CALIBRATION STUDY IN LOW-LEVEL RF SYSTEM

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## Abstract

The phase drift of the RF signal in the low-level radio frequency (LLRF) system is observed in the long-term operation, which limits the performance and stability of the LLRF system. The long-term drift was reproduced in the lab. Its effect and sources of error were explored in the simple LLRF46 board and the simplest LLRF system. It is founded that the temperature will significantly lead to the phase distortion of the two signal channels, although with the same electron device. The distortion will finally cause the long-term drift with temperature floating. A fixed phase calibration signal (CAL signal) is applied to deal with the signal channels difference. The preliminary tests were conducted and the results were analysed.

## INTRODUCTION

The low-level radio frequency (LLRF) system controls and stabilizes the cavity RF in the accelerator system. The phase distribution system sends accurate phase information from the far-end to each LLRF client. The LLRF system performs digital phase discrimination, filtering, and phase locking on the obtained reference phase information and the microwave used for particle acceleration. A large slow drift was observed in the LLRF system, which will limit the future experiments on the accelerators [1]. There is still no clear analysis of the internal mechanism of the slow drift, the degree of its influence, and how the environmental temperature affects the system. This paper mainly explores the causes of the long-term slow drift of the LLRF system, as well as the mechanism and the degree of influence of the slow drift.

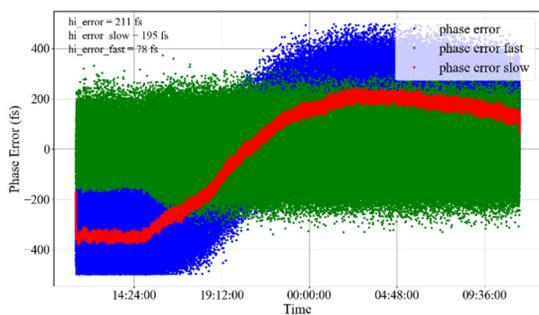


Figure 1: The test results of monitoring LLRF system of the mutual monitoring and detecting experiment.

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## REPRODUCTION OF LONG-TERM SLOW DRIFT EXPERIMENT OF LLRF SYSTEM

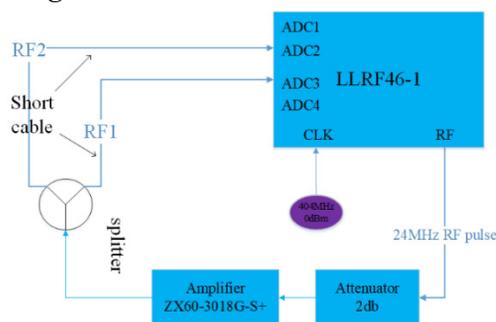
The Tsinghua timing and synchronization system was adopted in the photo-injector of Xi'an gamma-ray light source. The similar long-term slow drift was also found in the deployment and test. The mutual monitoring and detecting of two LLRF subsystems experiment (dual-machine test) was also applied [2-3], the test result of the monitoring LLRF system is shown in Figure 1.

In the 24-hour mutual monitoring and detecting experiment of Xi'an gamma-ray light source, the reference (REF) signal of the LLRF system varied about 12ps for about one day. A slow phase drift about 600fs p-p was observed by the monitoring LLRF system, which further verified the slow drift results obtained in the Tsinghua Thomson scattering X-ray (TTX) dual-machine test at Tsinghua University [1]. Therefore, in the actual system operation process, it is difficult to meet the experimental requirements for the system to have ~ps level/day slow drift. Therefore, it is essential to achieve the long-term stability of the LLRF system by suppressing the slow drift of the system.

## THE SIMPLEST BOARD EXPERIMENT RESEARCH BASED ON LLRF46 BOARD

We need to have a more comprehensive understanding of the system slow drift. Firstly, whether there would be a similar slow drift phenomenon of the system was explored in the simplest system from the simplest board experiment study based on LLRF46 boards.

### Study of the Differences Between ADC Channels of the Single Board



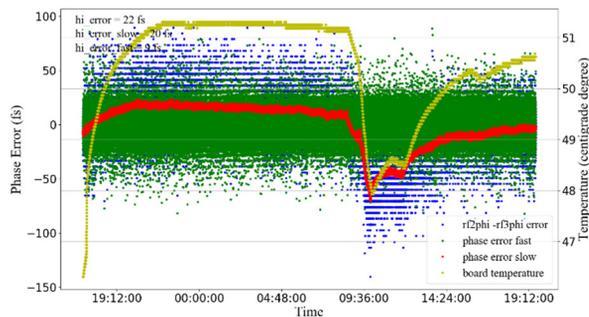


Figure 2: The simplest board double channel difference test configuration and result.

LLRF46 board had 4-route ADC channel and 2-route DAC channel [4-5]. There were 2 channels of ADC to collect the REF signal and the RF signal, respectively, and 2 channels of DAC to output RF signals respectively in Tsinghua timing and synchronization system. In the simplest two-channel experiment, RF signals output from LLRF46 board respectively enter into the two-channel ADC channel through the power divider to explore the differences between the two ADC channels on the board. It was important to note that the RF signal was operating at 24MHz. As seen from the experimental results, the phase error of the signals of the two ADCs had a slow drift directly related to temperature, indicating that the two ADC circuits showed differences in temperature sensitivity (from SMA (SubMiniature version A) port to ADC chip). Thus, the influence of such differences should be carefully considered in the subsequent design and experiment.

### System Correction by Adding Calibration Signals

In order to correct the difference in temperature characteristics of different ADC circuits of LLRF46 board, the idea of adding a correction signal for signal phase deviation correction was put forward:

$$Error = (RF1 - RF2) - (RF1\_CAL - RF2\_CAL)$$

The LLRF46 board output a calibration signal (CAL for short) with fixed amplitude and phase, which was combined with two RF signals to enter their respective ADC channels. The phase error of RF signals on two paths could be reversely deduced for correction by calculating the change of phase error of CAL signals on two paths, and the signal noise difference error could be eliminated.

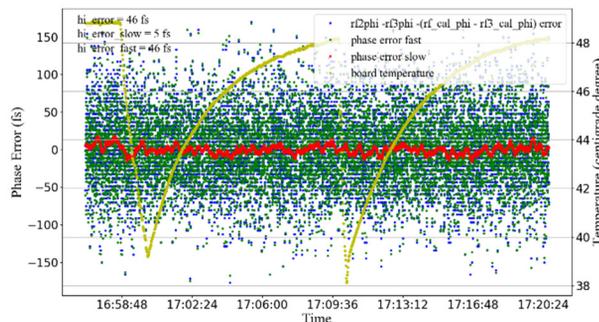
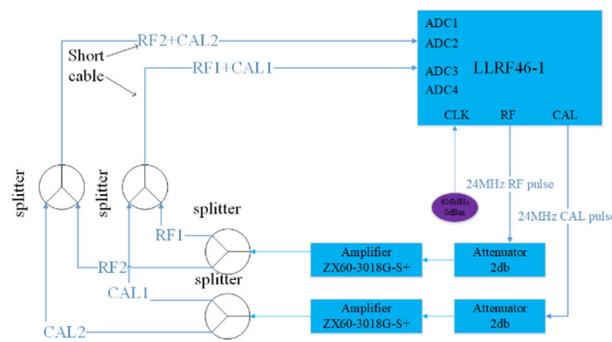


Figure 3: The test configuration and result of slow drift correction by adding calibration signals.

We controlled the board temperature and detected the phase error of the signals. As shown in Figure 3, after the addition of calibration signals, the slow drift of the signal phase difference between the two ADC channels disappeared and did not change with the change of temperature.

### Mutual Monitoring and Detecting Test of the Simplest Board LLRF System

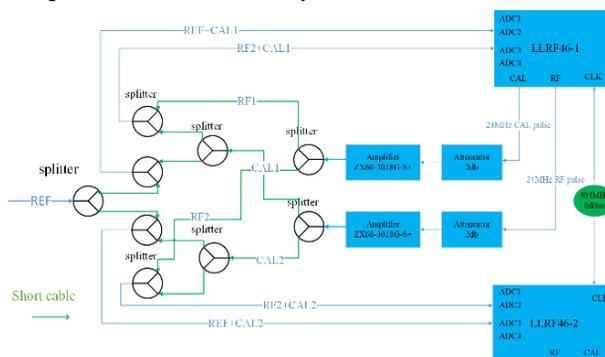


Figure 4: Mutual test experiment of single LLRF46 board.

In order to reproduce the phenomenon of slow drift, the mutual monitoring and detecting test experiment of the single board was built, as shown in Fig. 4. Short SMA connectors (~1cm) were adopted for the outer part of the control loop. The temperature change of the board was artificially changed, and the phase change of the monitoring system and the control system was detected, as shown in Fig. 5.

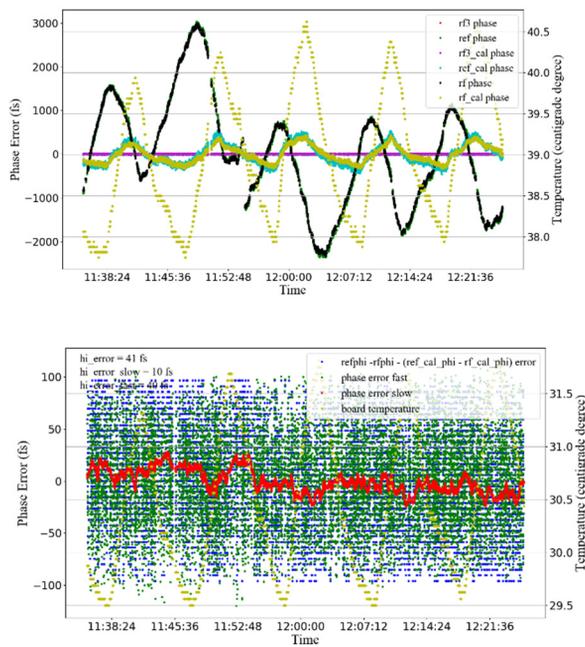


Figure 5: The signals phase and the result of the monitoring system in the single board mutual test.

As shown in the above Figure 5, 24MHz RF signal changed 2°C, ~5ps phase error peak-peak. There was a slow drift about 30fs, which is small enough after corrected.

At the same temperature difference  $\Delta T$ , the slow drift of phase error on the monitoring machine was recorded, and the relationship between the slow drift at fixed  $\Delta T$  and line length difference of the out of control loop part  $\Delta L$  was obtained:

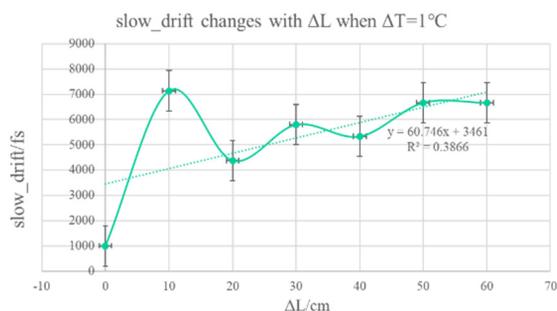


Figure 6: The relationship diagram between slow drift at fixed  $\Delta T$  and  $\Delta L$  line length.

The Figure 6 presented that correlation immunity order constrains nonlinearity. Based on the results of the repeated experiments, there was no obvious regularity between system slow drift and the length difference  $\Delta L$  part. The slow drift is largely due to the LLRF system itself.

## CONCLUSION

The artificial circuit part of LLRF46 board was obviously affected by the temperature, and there were differences between different ADC channels, which needed to be fully considered during system design and operation. The

difference in a signal variation on different channels could be corrected by using a fixed phase calibration signal (CAL signal) and target RF signal superposition. The mutual monitoring and detecting test result also approve the effective of the introduction of the CAL signal for phase drift calibration. The line length difference of the out of control loop parts takes up a small amount of influence on system slow drift.

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