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DEVELOPMENT OF RF REFERENCE DISTRIBUTION SYSTEM FOR HEFEI ADVANCED LIGHT FACILITY*

Kunlin Wu, Baiting Du†, Shaohang Ma, Shancai Zhang, Jian Pang, Shaoxiang Dong
National Synchrotron Radiation Laboratory, University of Science and Technology of China, China

Abstract

The Hefei Advanced Light Facility (HALF) is a diffraction-limited storage ring-based light source consists of a 180 m linear accelerator and a 480 m storage ring. The RF reference signal included 499.8 MHz and 2856 MHz are generated from two phase-locked master oscillators and transmitted to the RF system, beam position monitor system, timing system and beamline station by the phase stabled coaxial cables which are installed in the ±0.1℃ thermostatic bath. The RF Reference Distribution System (RF-RDS) are developed to realize the phase synchronization and transmission with low phase noise for long distance. The continues wave amplifier is manufactured to generate RF power of 10 W, with the added phase noise being less than 1 fs (10 Hz~10 MHz). The phase noise of each receiving terminal is estimated to be less than 30 fs (10 Hz~10 MHz). The design of RF-RDS and experimental result are discussed in this paper.

INTRODUCTION

The Hefei Advanced Light Facility (HALF), a fourth-generation synchrotron radiation light source, is being developed by the National Synchrotron Radiation Laboratory. It is based on a diffraction-limited storage ring and has been under construction since 2023. The HALF comprises a 2.2 GeV linear accelerator and a storage ring spanning approximately 480 meters in circumference [1].

The main specifications of the storage ring are detailed in Table 1.

Table 1: Main parameters of the HALF storage ring

Parameter	Value
Energy /GeV	2.2
Current /mA	350
Circumference /m	479.86
Number of cells	20
Natural emittance /pm·rad	85.8
RF frequency /MHz	499.8

In the HALF design, the low-phase-noise reference signals with long transmitted distance are required for the linear accelerator, RF system of storage ring, BPM system, timing system, and beam line station. The RF Reference Distribution System (RF-RDS) is developed to ensure the stable operation of HALF.

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† Corresponding author, email: dbt@ustc.edu.cn

Table 2: Main Parameters of the Ring Master Oscillator

Parameter	Value
Ring frequency	499.8 MHz±6 kHz
Frequency jitter	< 0.66 Hz
Frequency accuracy	< 0.1 Hz
Adjusting step	< 1 Hz

SCHEME OF RF REFERENCE DISTRIBUTION SYSTEM

The layout diagram of the RF-RDS is shown in Figure 1. The RF-RDS comprises two components: the variable oscillators and the reference lines.

In this scheme, we employ large-diameter coaxial cables to minimize signal attenuation and improve the signal-to-noise ratio by increasing the minimum signal power (minimum signal power > 10 dBm), utilize stable phase cables and constant temperature slots to suppress phase drift, and restrict the cables' maximum transmission power to < 43 dBm (@2856 MHz CW mode) to prevent excessive heating [2, 3].

Master Oscillators

The two master oscillators will generate the high-frequency reference signal for the storage ring and microwave reference signal for the LINAC, respectively. The storage ring signal source is housed in the storage ring's high-frequency system equipment room and generates a frequency of 499.8 MHz. The LINAC signal source is situated near the linear accelerator's electron gun and generates a frequency of 2856 MHz with ultra low phase noise being less than 22 fs (@10 Hz~10 MHz).

The two signal source are installed in the thermostatic cabinet with temperature fluctuated range of being less than ±0.5℃ to decrease the phase drift, and phase locked by the 100 MHz signal with long distance of approximately 500 m [4–6]. The specific parameters of the signal sources are shown in Tables 2 and 3 which are required from the physical design.

Starting from the master oscillator in the high-frequency system equipment room, two reference signal lines are arranged circumferentially to transmit 499.8 MHz reference signal to 10 beam measurement stations located along the storage ring.

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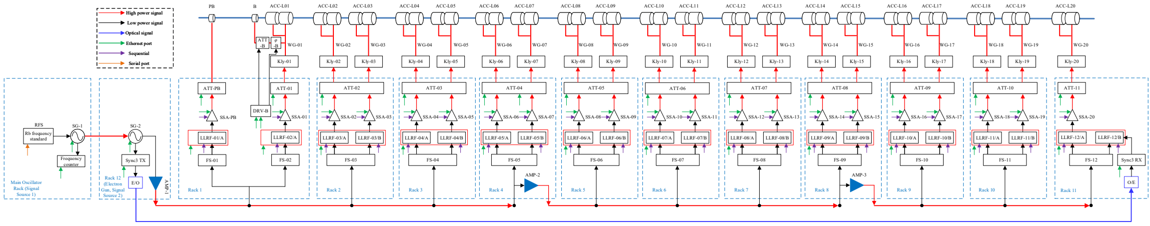

Figure 1: Layout diagram of RF-RDS and microwave system.

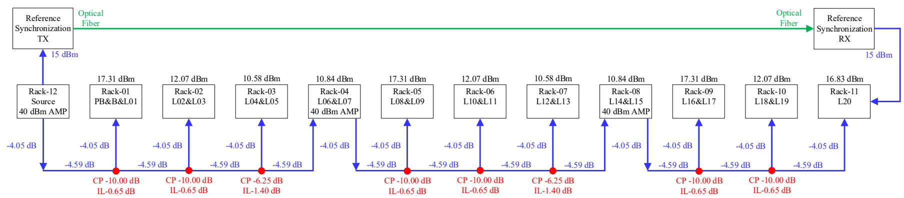

Figure 2: Layout diagram of reference line for linear accelerator.

Table 3: Main Parameters of the LINAC Master Oscillator

Parameter	Value
LINAC frequency	2856 MHz±34.3 kHz
Phase noise	≤ 22 fs(@10 Hz~10 MHz)

Reference Line for LINAC

The microwave signal of 2856 MHz, output by the signal source, is amplified by three 40 dBm low phase noise solid-state amplifiers and transmitted to the frequency synthesizer of each RF station along the reference line. The signal power generated by the frequency synthesizer is 13 dBm, with frequencies of 476 MHz (pre-buncher) and 2856 MHz (buncher, accelerating tube), respectively.

The linear accelerator's reference line is laid out along the klystron corridor, spanning approximately 180 meters and operating at a frequency of 2856 MHz. The reference signal is transmitted using the Andrew LDF2-50 stable phase cable. All the directional coupler and cable are installed in the constant thermostatic bath with temperature fluctuated range of ±0.1℃, which divide the reference signal to 11 LLRF stations. Table 4 details the specific parameter indicators for the LINAC's reference line.

Owing to the long geometric length of the HALF injector, the reference signal must be amplified for relay to ensure that all RF stations can receive the signal with a power be more than 10 dBm. The CW mode power amplifier is developed that can amplify reference signals to 40 dBm with stable amplitude and phase, as well as low added phase noise of being less than 1 fs (@10 Hz~10 MHz). The phase noise of 2856 MHz signal amplified by three CW amplifiers is estimated to 28 fs. The layout of the LINAC's reference line is depicted in Figure 2.

To monitor the drift of long-distance reference signals, we utilize a fiber-optic-based reference signal synchronization system with phase sta-bility of 40 fs/day (@2856 MHz). The optical signal is transferred to electrical signal by the receiving terminal of the synchronization system. The phase drift between electrical signal by coaxial cable and optical signal by optical fiber are measured and calculated by the LLRF system and to be determined as the total phase drift of reference line [4].

Table 4: Main parameters of the reference line for LINAC

Parameter	Value
Length	Approximately 180 m
Constant temperature	±0.1 °C
Cable type	Andrew LDF2-50, 13 mm
Temperature geometrical coefficient of cable	3 ppm m/°C
Theoretical phase drift	±0.21°(@180 m, 2856 MHz)
Theoretical power loss	−59 dB
Amplifier output power	40 dBm×3

TEST RESULTS OF PHASE STABLIZED CABLES

Coaxial cables with phase stablized characteristics are extensively employed in the design of the RDS. The performance of these cables, primarily their phase drift as a function of temperature, significantly impacts system operation and constructed cost. By using a network analyzer and a constant temperature bath, we measured the phase shifts in both cables at three frequencies: 100 MHz, 500 MHz, and 2856 MHz, as a geometrical coefficient of temperature. The test results are depicted in Figures 3 and 4.

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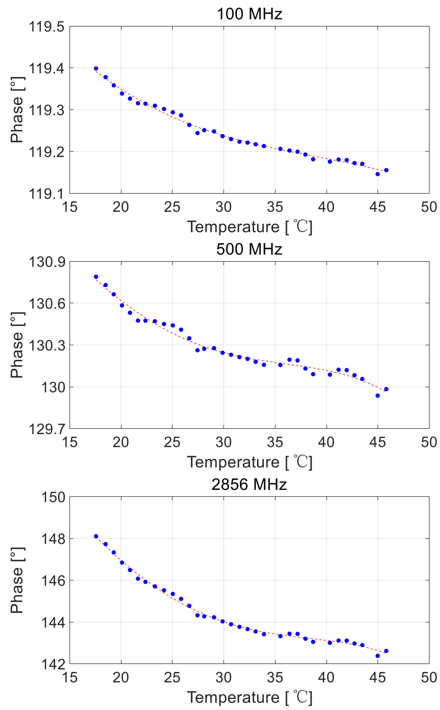

Figure 3: Test results of phase stable cable-HCTAYZ-50-22.

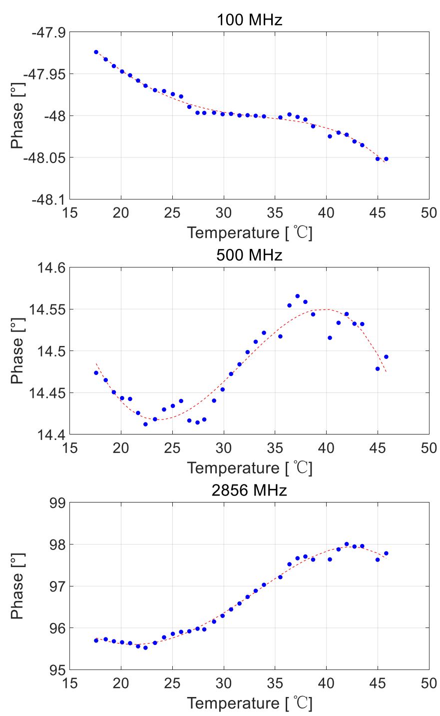

Figure 4: Test results of phase stable cable-LDF2-50.

After comparative testing of TRIGIANT's HCTAYZ-50-22 and Andrew's LDF2-50 from 18℃ to 45℃, we ultimately selected the LDF2-50 to construct the RF-RDS. The temperature of the bath is determined of 42℃ which is consistent with the cooling water of accelerating tube to decrease the constucted cost of water cooling system.

CONCLUSION

In this paper, the RF Reference Distribution System (RF-RDS) is developed to meet the required reference signals of the HALF RF system, beam position monitoring system, timing system, and beamline stations with long distance transmission and low phase noise. The continuous wave power amplifiers are developed to generate sufficient RF power, with an additional phase noise of less than 1 fs (@10 Hz~10 MHz). The phase noise of received signal for each RF station is estimated to be less than 30 fs (@10 Hz~10 MHz), meeting the designed requirements of HALF.

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