PERFORMANCE OF RF REFERENCE DISTRIBUTION SYSTEM FOR THE J-PARC LINAC

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Abstract

Installation of the J-PARC linac machines (Phase I) has been almost completed and the beam commissioning will be started in December this year.

The error of the accelerating field must be within ±1° in phase and ±1% in amplitude. Thus, high phase stability is required as an RF reference. Our objective concerning the phase stability of the reference aims at less than ±0.3°.

Last year the installation of the RF reference distribution system was completed. The reference signal is optically distributed to all of the low-level RF control systems by using E/O, O/E, Optical Amplifier and Optical Couplers and so on. The performance of this system was evaluated. The phase stability of ±0.06° was obtained.

INTRODUCTION

J-PARC Linac, which is about 300 m long, provides 181-MeV proton beam to the 3-GeV rapid-cycling synchrotron (RCS) at the first phase (Phase I) [1]. In the Phase II it will be upgraded to 400 MeV by using ACS cavities. The RF source will power 20 accelerating cavity modules (an RFQ, 3 DTLs and 16 SDTL modules) operated at a frequency of 324 MHz and 21 ACS cavities operated at a frequency of 972 MHz (Refer Fig. 1). Furthermore, solid-state amplifiers will drive the buncher, chopper and debuncher cavities. In addition to the RF systems, the beam-monitor systems, the magnet power supply and so on, are installed in the klystron gallery. Totally, about 60 arrays of 12 EIA-standard 19-inch racks will be installed as control stations for these systems over the whole area of the klystron gallery. An RF reference signal must be distributed to all of these control stations.

Because the momentum spread (Δp/p) of the RCS injection beam is required to be within 0.1%, the RF sources must maintain the correct accelerating field within an amplitude error of ±1% and a phase error of ±1°. For the phase stability the RF reference signal should be more highly stable. Our objective for the RF reference aims at within ±0.3° at a 972-MHz frequency for phase stability.

Installation of the J-PARC Linac machines was almost completed for the Phase I, and the beam commissioning will be start in December this year.

This paper reports the performance of the RF Reference distribution system. The predominant feature of this system is distribution by dividing an amplified optical signal. For the detail of each component (O/E, E/O and so on), refer to [2-3].

The frequency of the RF reference has been 12MHz reported thus far [2-3], but it was changed to 312MHz finally. The reason of this change is described briefly in this paper.

RF REFERENCE DISTRIBUTION

Figure 1 shows a block diagram of the RF reference distribution system. The photographs of the installed equipments are shown in Fig. 2~4.

The 312-MHz RF reference is distributed to about 60 low-level RF (LLRF) control systems through optical links. As shown in the figure, the RF reference signal

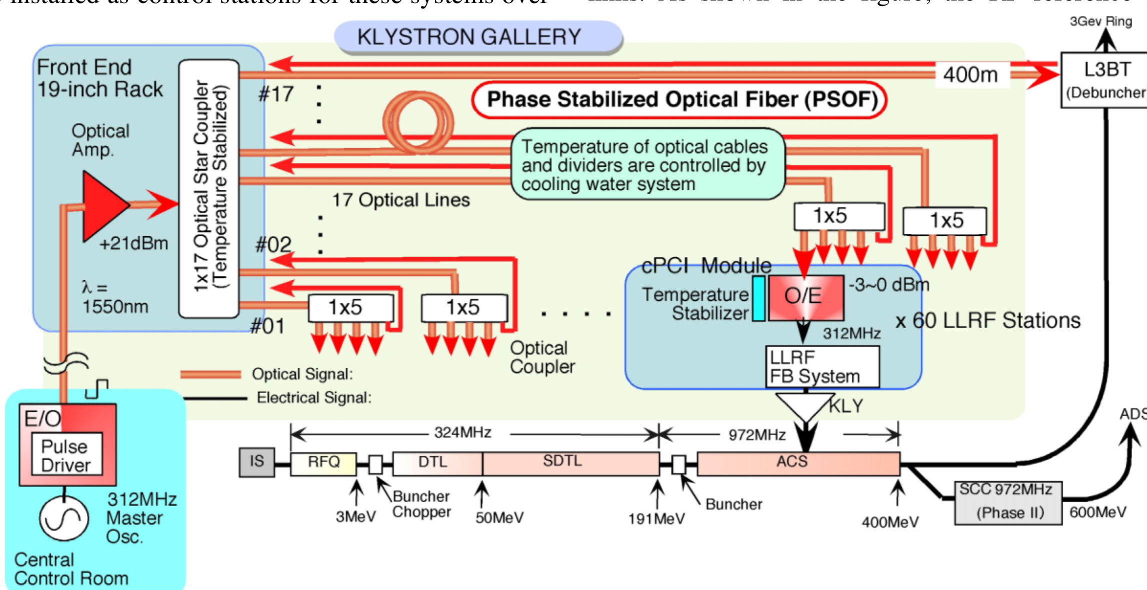

Figure 1: Block diagram of the RF reference distribution system.

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(312 MHz) generated by a master oscillator at the central control room is optically transferred to the linac klystron gallery. It is then directly amplified (to Max +21 dBm) and divided into 17 optical transfer lines by an optical star coupler at the front end of the gallery (Fig. 2). One of the 17 transfer lines provides an RF reference for each of 4 klystron stations; thus, the transmitted optical signal is divided into 4+1 by an optical coupler: Four of them are received at each station for the LLRF control, and one of them is returned back to the front end for phase monitor.

For the optical transfer line, phase-stabilized optical fiber (PSOF) is adopted. Furthermore the temperature change of the PSOF should be controlled to be within ±0.5 °C by a cooling water system in order to achieve the required phase stability [3]. The temperature of the cooling water is controlled to be 27±0.1 °C. As shown in Fig. 3, the optical cables were installed in an insulated duct with cooling water pipe. The duct was set in a cable trench under the floor. Also 1x5 optical couplers were put in the insulated duct.

Figure 2: The 1x17 optical coupler in an oven.

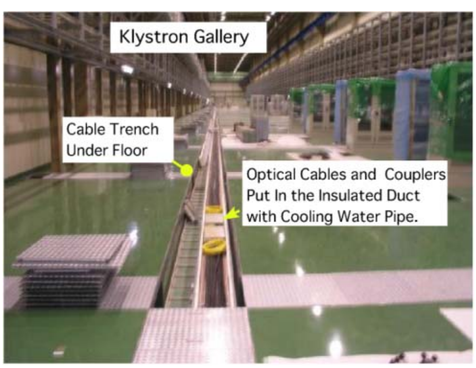

Figure 3: Installation of the optical cables and optical couplers in the insulated duct.

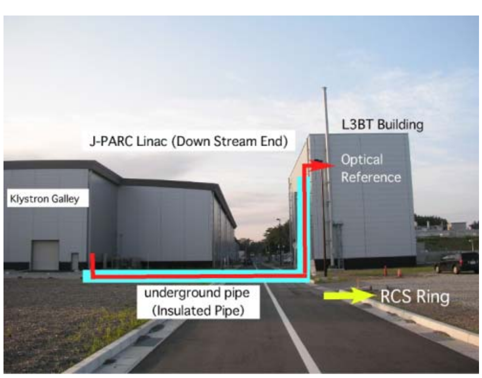

Figure 4: Passing an optical cable to the L3BT building through an insulated underground pipe

In the L3BT section (between the end of the ACS section and the RCS injection) a debuncher will be installed in the future (Fig. 1). In order to control of the RF source for the debuncher, the RF reference signal should be provide to the L3BT building which is separated from the klystron gallery. As shown in Fig. 4, the optical cable for the L3BT (second floor) is put through an insulated underground-pipe with cooling water pipes.

To stabilize the amplitude and phase of the field in the accelerating cavity, a digital feedback and feed-forward technique is used in the LLRF control system [4]. This system controls the I/Q components of the RF signal as shown in Fig. 5. An accelerating RF of 324 MHz (or 972 MHz is generated by a VCXO phase-locked with 12-MHz signal divided from the 312-MHz reference at each local station (Fig. 5). The phase and amplitude of the cavity field is detected by sampling the 12-MHz signal down-converted with 312-MHz LO which is just the RF reference.

In the original design the frequency of the reference was 12 MHz; then the 312-MHz LO and 324-MHz accelerating RF were generated by the PLL-VCXO at the local station as synchronizing with the 12-MHz reference [2-4]. However, it is found that the temperature dependency of the PLL-VCXO generation of the 312 MHz and 324 MHz was larger than the expectation: the phase shift due to the temperature change was not negligible. Therefore, as shown in Fig. 5, the 312-MHz LO is directly given by the RF reference in the current design. In this case, the phase shift of the LO is reduced to the temperature dependency of the amplifier only. It is enough small. On the other hand, the phase of the 324-MHz accelerating RF will be locked by the feedback-control; thus the phase change in the PLL-VCXO generation of the 324-MHz RF does not become a problem if the 312-MHz LO is stable.

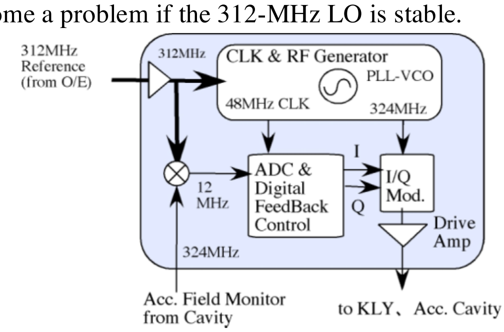

Figure 5: Feedback control system. Refer to [4] for the detail.

PERFORMANCE EVALUATION

Dividing Uniformity of Optical Coupler

For reduction of the jitter, the optimum signal level received by the O/E is -3±1 dBm; thus the dividing uniformity of the optical couplers is important.

Figure 6 shows the power level of all transferred signals including the returned back signals. By adjusting output power of the optical amplifier, -3±1 dBm was obtained. This means that high uniformity of ±1 dB was achieved in dividing into 17x5 (=85) signals by using the optical couplers.

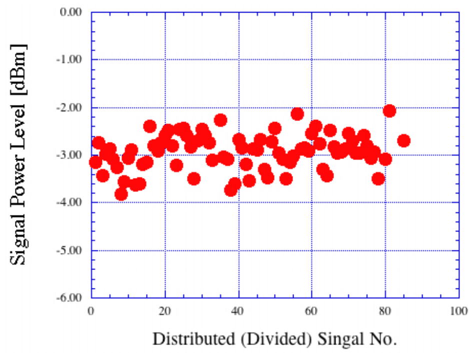

Figure 6: Distributed optical signal power.

Phase Stability

The phase stability of the practically installed system shown in Fig. 2~4 was measured. The performance of individual component under development has been already reported in [2-3].

Figure 7 shows the method of the evaluation. As shown in the figure, the phase between two returned signals from the stations of the RFQ and the L3BT respectively. For the phase detection a function of vector measurement in "Microwave Transition Analyzer (HP70820A)" was used. The cooling water temperature was controlled to be 27±0.1°C during the measurement. Figure 8 shows the result. The phase change of the 312-MHz reference was within ±0.06° in 4-day measurement while the room temperature change was about 3.5 °C in the klystron gallery. In the L3BT building the temperature change might be bigger than that in the klystron gallery. The required stability was achieved. But for the 972-MHz case (three times of this case) the stability margin will be not enough.

SUMMARY

The installation of the RF reference distribution system was completed for the J-PARC Linac. The performance of the system was evaluated. The phase change of the RF reference was within ±0.06° in 4-day measurement. This result satisfies the required stability, but for the 972-MHz case, the margin will be not enough.

REFERENCES

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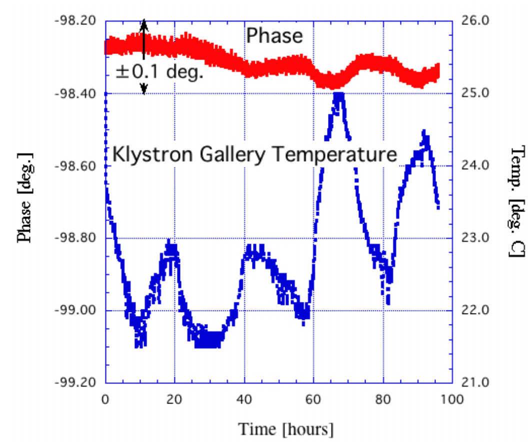

Figure 8: Result of the measurement of the phase stability of the RF reference.

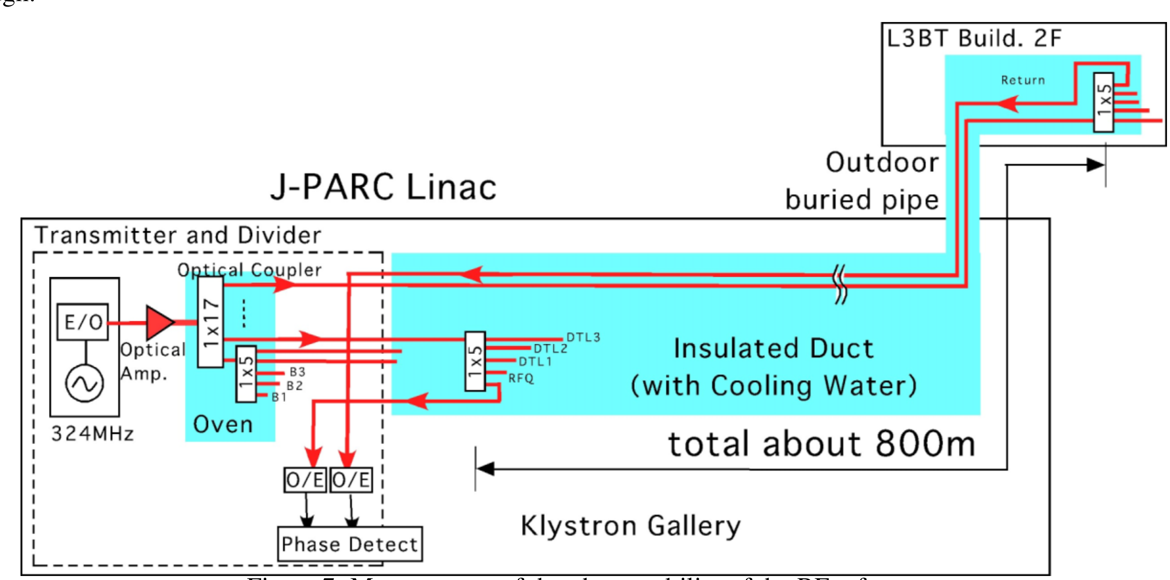

Figure 7: Measurement of the phase stability of the RF reference.