RF REFERENCE DISTRIBUTION SYSTEM FOR THE J-PARC LINAC

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Abstract

The J-PARC (Japan Proton Accelerator Research Complex) linac, which is 300 m long, consists of a 324-MHz accelerating section of the upstream part and a 972-MHz section of the downstream part. In the klystron gallery, a total of about 60 RF source control stations will drive the klystrons and solid-state amplifiers.

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 for all of the low-level RF control systems and the beam-monitor systems. The RF reference (12 MHz) is distributed to all stations optically. Low-jitter E/O and O/E with temperature stabilizers were developed. The reference is optically amplified, divided into 17 transfer lines, and delivered through PSOF (phase-stabilized optical fiber), the temperature of which is stabilized by cooling water. Each of the transmitted signals is divided more into 4 signals by an optical coupler.

Our objective concerning the phase stability of the reference aims at less than ±0.3° at a frequency of 972 MHz.

INTRODUCTION

J-PARC accelerators [1] are now under construction at the JAERI Tokai site. The linac of the J-PARC, which is about 300 m long, provides 181-MeV (400-MeV in the future) proton beam to the 3-GeV, 1-MW rapid-cycling synchrotron (RCS). For this linac, 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, 60 arrays of 12 EIA-standard 19-inch racks will be installed as the 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°. Therefore, 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.

On account of pulse operation of 500-μs beam duration and 50-Hz repetition, the timing control signals must be distributed in analogy with the RF reference.

This paper presents the final design of the RF reference distribution system in detail, including the timing reference distribution.

RF REFERENCE DISTRIBUTION LINE

A block diagram of the RF reference distribution system is shown in Fig. 1. The 12-MHz RF reference is distributed to about 60 low-level RF (LLRF) control systems of klystron and solid-state amplifier stations (RFQ,

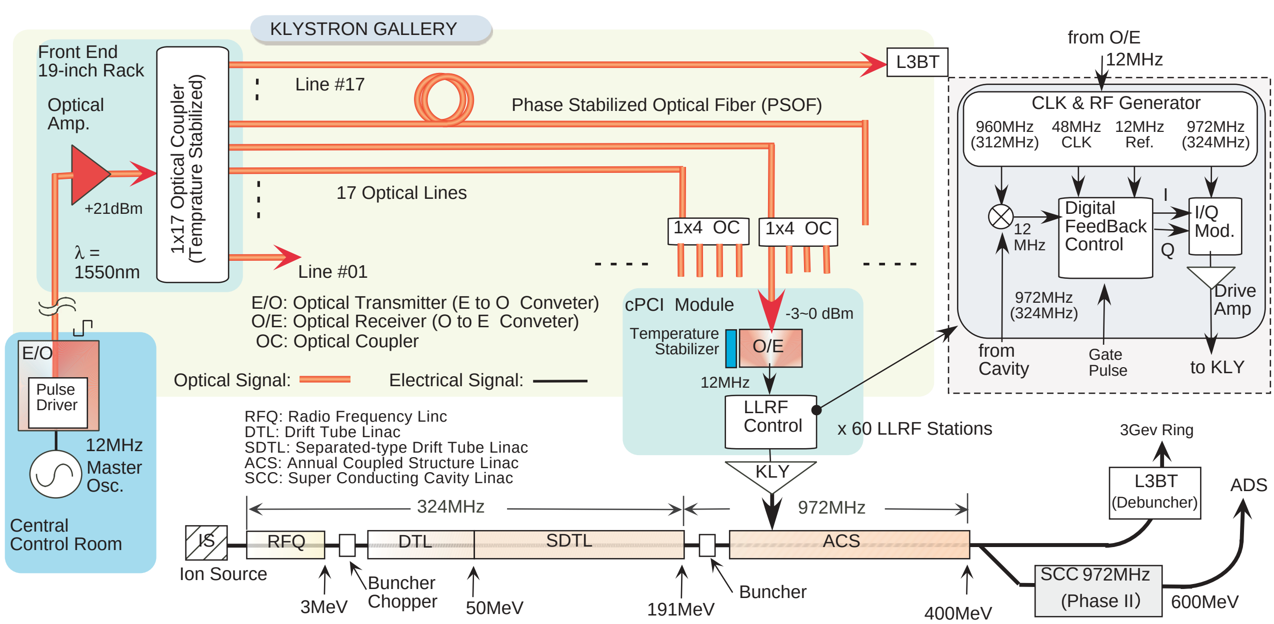

Figure 1: Block diagram of the RF reference distribution system.

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buncher, chopper, DTL, STDL, ACS and debuncher) through optical links. As shown in the figure, the electrical RF reference signal (12 MHz) generated by a master oscillator at the central control room is optically transferred to the linac klystron gallery. It is then directly amplified and divided into 17 optical transfer lines by an optical star coupler at the front end of the gallery. In order to apply an optical amplifier, a wavelength of 1.55-μm wavelength has been chosen for the optical source. 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 by an optical coupler. Each of them is received by an O/E and converted to an electrical signal at each station.

An accelerating RF of 324 MHz or 972 MHz is generated by a VCXO with PLL synchronizing with the distributed 12-MHz reference at each local station. Although the fast-change (over 1 kHz) phase jitter is suppressed by the VCXO-PLL, stabilizing temperature drifts of the reference becomes very important.

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 [2]. This system controls the I/Q components of the RF signal, as shown in Fig. 1. Feedback and feed-forward control is performed by a combination of FPGAs (field programmable gate array) for the fast and simple processing and DSPs (digital signal processor) for slow and complicate processing. At the present stage, a compact PCI (cPCI) bus module and a Windows OS system is used as an integrated development environment in order to make it easy for us to develop the software of FPGAs, DSPs and a CPU host.

OPTICAL CABLES

The phase stability directly depends on the characteristics of the optical components. For the optical transfer line, phase-stabilized optical fiber (PSOF) is adopted. In the 300-m signal transfer, the dispersion and power loss in PSOF are negligible when using of a Distributed Feed Back (DFB) laser diode for the E/O. The thermal coefficient of the PSOF is generally less than 1 ppm/°C, while that of normal fiber is greater than 6 ppm/°C. In order to reduce the thermal coefficient, single-mode silica fiber is coated with a liquid-crystal polymer, the thermal-expansion coefficient of which is negative [3]. However, these days, only Furukawa Electric Ind. Ltd Japan manufactures the PSOF.

The room temperature in the gallery will be controlled at 27±2 °C during operation. From our measurement result, the thermal coefficient of Furukawa's PSOF is 0.4 ppm/°C (0.2°/300m/°C for 972-MHz frequency) at a temperature range from 25 °C to 30 °C [4]. This characteristic does not satisfy the required stability. In order to keep the phase change due to the optical cable within ±0.1°, the temperature change of the PSOF should be controlled to be ±0.5 °C by a cooling water system, the temperature stability of which is ±0.1 °C. As shown in Fig. 2, optical cables and cooling water pipe will be installed in an insulated duct. The duct will be set in a cable trench under the floor. Also 1x4 optical couplers will be put in the insulated duct in consideration of the measured result of its temperature characteristic for phase stability [5].

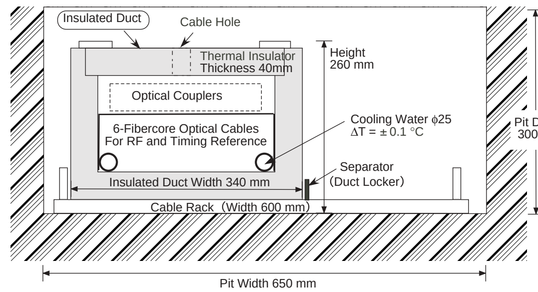

Figure 2: Cross section of the insulated duct set in the under-floor cable trench.

OPTICAL TRANSMITTER/RECEIVER

For improvements in the stability, new O/E and E/O were developed for this system. They were manufactured by Graviton Co., Ltd. Japan [6]. The O/E, which has a temperature stabilizer with a peltier device, is compact and is mounted on a cPCI board (RF & CLK generator), as shown in Fig. 3. The photo detector is pigtail type in order to finally make fusion splices for fiber connections through all optical paths in order to prevent phase instability due to connector vibration.

The E/O and O/E, the transmission bandwidths of which are wide (0.1 MHz ~ 2 GHz), have a pulse driver (limiting amp.). This makes a 12-MHz clock signal shorter rise time pulse than 200 ps to reduce the transfer jitter. Figure 4 shows the measurement result of the transfer jitter of the optical link including the optical amplifier using a Tektronix TDS8000B. It can be said that the jitter is less than 1 ps (rms), which is the design value.

The measured temperature dependence of the phase change in the E/O and O/E is shown in Fig. 5. The thermal coefficients of the E/O and O/E are 0.17 and 0.02°/°C, respectively, for a frequency of 972 MHz. The phase change due to the O/E can be lower than 0.1° for a gallery temperature change of ±2 °C. On the other hand, the E/O, which is the only one in this system, should be operated in a thermal chamber in order to keep the phase change within ±0.1°.

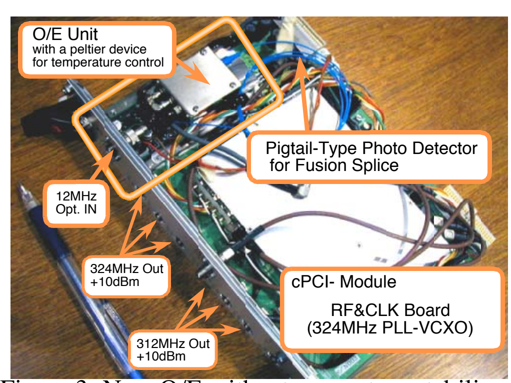

Figure 3: New O/E with a temperature stabilizer.

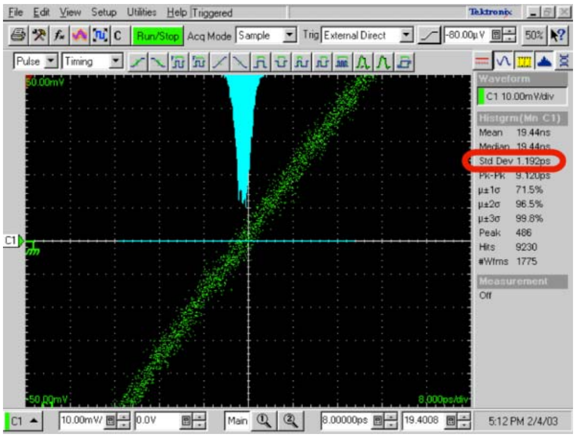

Figure 4: E/O-O/E transfer jitter measured by using a TDS8000B. Because the jitter of the measurement system is about 0.8 ps, the net jitter is Sqrt(1.2^2-0.8^2) = 0.9 ps.

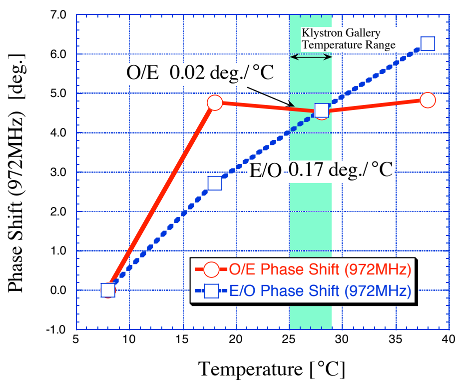

Figure 5: Temperature characteristics of the new E/O and O/E.

TIMING REFERENCE DISTURIBUTION

For 50-Hz pulse operation, a timing reference (trigger) signal is required for all control systems. The J-PARC accelerator timing system uses the following 3 signals to control the trigger timing: (1) a 50-Hz trigger clock, (2) a 12-MHz clock (master clock to count trigger delay), and (3) a control code (16-bit serial, called "Type") [7]. A set of these 3 signals is called the timing reference in this paper.

The method of distributing the timing reference in the linac follows that of the RF reference distribution as shown in Fig. 6. However, source signals are electrically divided into 17+3 signals, and will be distributed to not only the 19-inch rack control stations in the klystron gallery, but also the linac control, the ion source power supply and the DTL Q-magnet power supply rooms. A 3-channel optical transceiver and a fanout module, which can transfer the 3 signals all together, have been developed for the J-PARC timing system [7]. Normal single-mode optical cables are used for the timing reference distribution, because high phase stability is not required. However, 17 optical transfer cables are installed in the insulated duct used for the PSOF's. Then, as shown in Fig. 7, the reference signals will be provided to each control station from the optical transfer line.

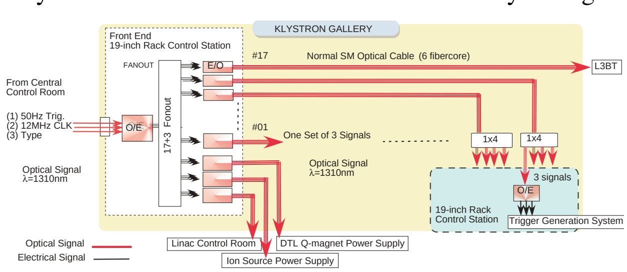

Figure 6: Layout of the timing reference signal distribution system.

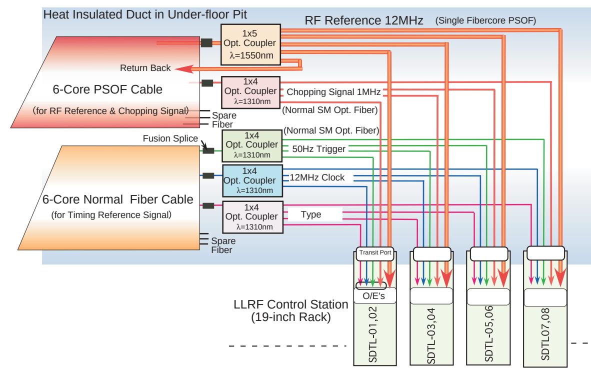

Figure 7: Providing RF and timing reference to each control station.

SUMMARY

The final design of the RF reference distribution system for the J-PARC linac is shown. The reference (12 MHz) is optically amplified and distributed to all control stations. Optical transfer cables will be installed in the insulated duct with cooling water pipes, the temperature stability of which will be ±0.1°C. A compact new O/E with a temperature stabilizer was developed. A jitter of less than 1 ps (rms) will be achieved in the optical transfer.

The timing reference (a set of the 3 timing control signals) for the whole linac will be distributed in a way similar to the RF reference distribution.

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