RF REFERENCE DISTRIBUTION SYSTEM FOR THE 400-MEV PROTON LINAC OF THE KEK/JAERI JOINT PROJECT

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Abstract

For the high-intensity proton linac of the KEK/JAERI joint project, the error of the accelerating field must be within ± 1 degree in phase and ± 1% in amplitude. Thus, a high phase stability is required to the RF reference distribution system. A 12-MHz RF reference is converted to an optical signal, and is distributed to 50 low-level RF control systems of klystron and solid-state amplifier stations through optical fiber links (E/O, O/E and optical fibers). Phase-stabilized optical fiber (PSOF) will be used as an optical transfer line. The characteristics of general-purpose optical components (E/O, O/E, PSOF) were measured. Their performance is not sufficient to satisfy the requirements. New optimized E/O and O/E for this linac will thus be produced. The total stability of the RF reference transfer system with new E/O and O/E will be evaluated.

1 INTRODUCTION

In the KEK/JAERI joint project for the high-intensity proton accelerator facility [1], the RF source for the injector (400-MeV proton linac) will power twenty accelerating cavity modules (an RFQ, 3 DTLs and 16 SDTL modules) operated at a frequency of 324 MHz, and twenty-three ACS modules operated at a frequency of 972 MHz. For the buncher, chopper and debuncher cavities, three 324-MHz RF sources and four 972-MHz RF sources are required. To achieve the requirements of both the 3-GeV ring and the ADS, the maximum pulse width and repetition rate are 620 μs, including the cavity build-up time, and 50 pps, respectively. Because RF sources must maintain the correct accelerating field within an amplitude error of ±1% and a phase error of ±1°, a digital feedback and feed-forward control system with high intelligence is required. Therefore, for the control systems, the reference clock signal, which is distributed to all of the power amplier stations (4 solid states and 46 klystrons), should be more highly stable. Our objective for the RF reference aims at within ±0.2° for the phase stability.

2 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 50 low-level RF (LLRF) control systems of klystron and solid-state amplifier stations (RFQ, buncher, chopper, DTL, STDL, ACS and debuncher) through optical links (E/O, O/E and optical cables). As shown in the figure, the electrical RF reference signal (12 MHz) generated by a master oscillator is converted to optical signals by an E/O, and is then divided into 14 optical transfer lines by an optical star coupler. One optical line provides the RF reference for 4 klystron stations. The transmitted

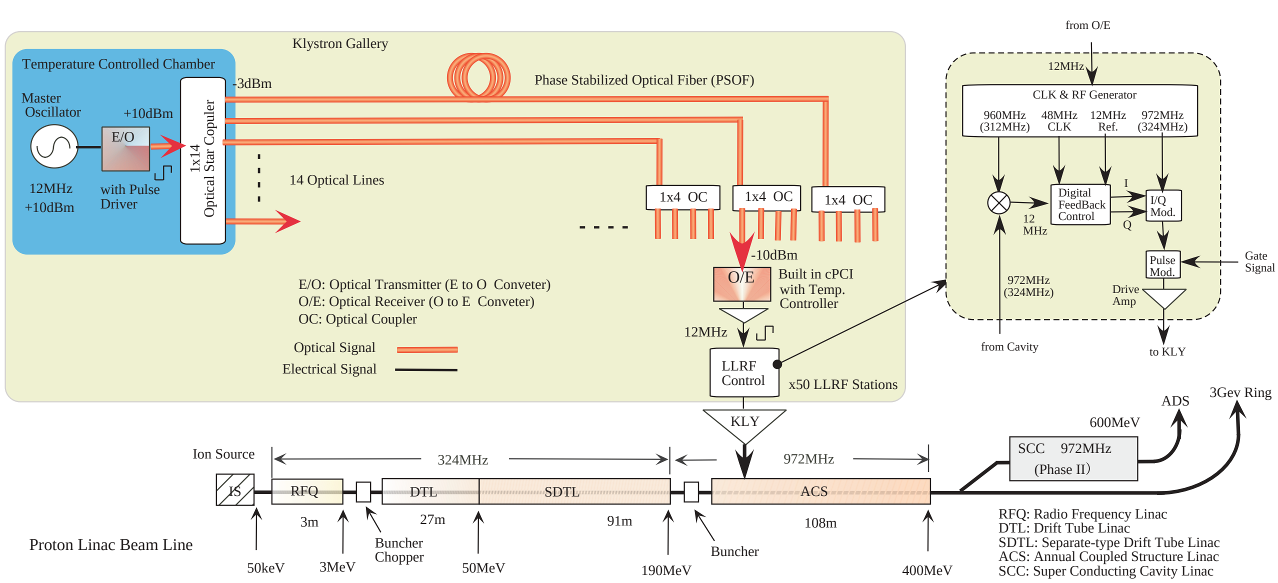

Fig. 1: Block diagram of the RF reference distribution system.

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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. The merits of optical transfer are: a) very low loss, b) free of electrical noise, and c) high stability against temperature change. All components of this distribution system will be installed into the klystron gallery.

The accelerating source RF (klystron driving signal) 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 phase jitter is suppressed by the VCXO, for very slow-change phase jitter stabilizing the temperature drifts 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 I/Q components of the RF signal as shown in Fig. 1. The feedback and feed-forward control is performed by a combination of FPGAs (field programmable gate array) for 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.

3 PHASE-STABILISED OPTICAL CABLE

Since the reference RF is delivered trough optical links, the phase stability directly depends on the characteristics of the optical components (E/O, O/E and optical fiber). For the optical transfer line, phase-stabilized optical fiber (PSOF) is required. The thermal coefficient of PSOF is generally less than 1 ppm/°C, while that of normal fiber is about 6 ppm/°C. In order to reduce the thermal coefficient, the silica optical fiber is coated with a liquid-crystal polymer, of which the thermal-expansion coefficient is negative [3]. For this linac with a total distance of about 300 meters, the dispersion and power loss in PSOF are negligible for both 1.31 μm and 1.55 μm wavelengths of the Distributed Feed Back (DFB) laser.

There are two types in PSOF: one manufactured by Sumitomo Electric Ind. Ltd Japan; the other by Furukawa Electric Ind., Ltd Japan. However, these days, only Furukawa Electric Ind. Ltd Japan manufactures PSOF.

The temperature dependence of the transmission delay time of both the Sumitomo and Furukawa PSOF was measured. The result is shown in Fig. 2. About 1 ppm/°C and 0.4 ppm/°C were obtained at temperature from 25 °C to 30 °C, respectively. The characteristics of all measured fibers of the same type agree with each other. No remarkable difference was observed between 1.31 μm and 1.55 μm wavelength transmission. Our results are different from published data in [3][4]. Although the reason for the difference is no evident, it is considerable that the characteristic depends on whether the cable is tightly or loosely rolled on a drum.

The room temperature will be controlled at 27 ±2 °C during operation. When the thermal coefficient is 0.4 ppm/°C, a room-temperature change of ±2 °C induces about a ±0.4° phase change for 300-m transmission at 972 MHz RF. This characteristic does not satisfy the required stability. In order to keep the phase change due to the optical cable within ±0.05°, the temperature change of the PSOF should be controlled to be ±0.2 °C by a cooling water system.

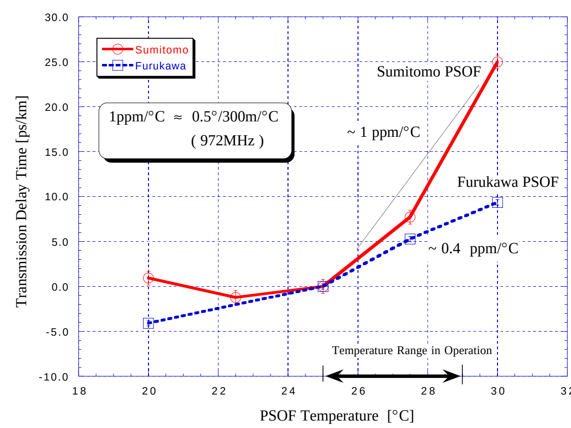

Fig. 2: Measured temperature dependence of the transmission delay time of the PSOF.

4 OPTICAL TRANSMITTER/RECEIVER

With respect to the required stability, Ortel 3540A and 4510A, which are widely used for analogue signal transfer, are candidates as required E/O (optical transmitter) and O/E (optical receiver), respectively. There are few other candidates matching the required performance. In our use, however, Ortel's E/O or O/E has some mismatches; for example, they are suitable for use with higher frequency (12 MHz is too low), the O/E has to be very compact in order to be installed into the cPCI module of the digital feedback system, etc. Thus new optimized E/O and O/E for this linac were designed. A trial product E/O (λ = 1.55 μm) was produced by Graviton Ind. Ltd Japan [6], which is called Graviton LD-1500 in this paper.

The stability characteristics of the Ortel 3540A, 4510A and Graviton LD-1500 were measured. Figure 3 shows the long-term phase stability in 324 MHz signal transmission through the optical link. A phase stability of ±0.04° (±0.12° for 972MHz) was obtained for about 6 hours. Figure 4 shows the temperature dependence of the delay time of the E/O and O/E. The thermal coefficients of Ortel E/O and O/E are 0.75 and 1.25 ps/°C, respectively, and that of the Graviton E/O is 0.5 ps/°C. From these results, it is needed that the E/O should be operated in a thermal chamber. On the other hand, an O/E is to be built in the cPCI module of the digital feedback system at every drive station. It should be equipped with a peltier device for temperature control.

Presently, proper E/O and O/E are under the construction. The timing jitter of the optical transmission is designed to be lower than 1 ps (rms). Their performance will be measured in the autumn of 2002.

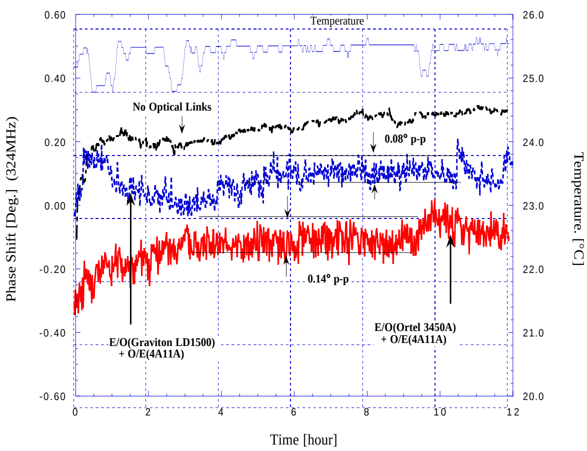

Fig. 3: Long term stability of the E/O-O/E link. A phase stability of ±0.04° (324MHz) was obtained for about 6 hours.

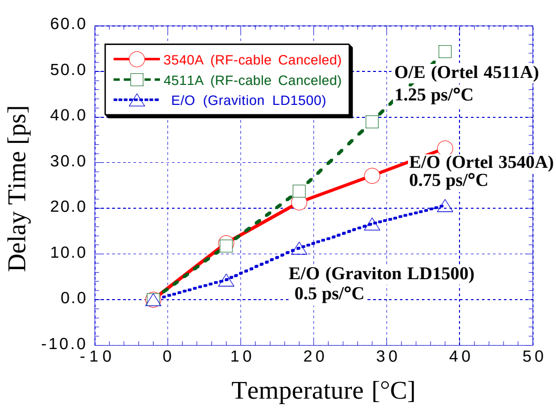

Fig. 4: Temperature characteristics of the E/O and O/E.

5 FEEDBACK LOOP

When an active phase-lock system is required for the stability of the reference distribution, we plan a feedback control, as shown Fig 5. The feedback loop consists of a fiber grating which returns back a part of the optical signal in the same fiber, an optical delay module for phase control, an optical circulator which picks out the backward signal, an O/E and a phase detector. In this system, an optical amplifier is required because the output power of an E/O is not sufficient. A stability test of the optical amplifier and an evaluation of the performance of each optical component are in pregress. The 1.55 µm wavelength of the E/O is valid for the use of an optical amplifier.

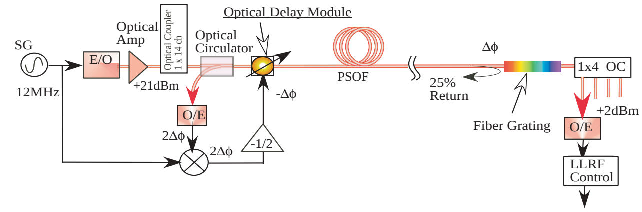

Fig. 5: Proposed phase feedback system of the optical transfer line using a fiber grating and an optical delay module.

6 SUMMARY

For distributing the RF reference, the temperature characteristics of the PSOF were measured and a thermal coefficient of 0.4 ppm/°C was obtained. It is not sufficiently low for the requirements. We will control the temperature change of the optical cable to be within ±0.2 °C by using a cooling water system.

Also, the performances of the E/O and O/E were evaluated. Although good long-term stability can be expected, because of the temperature characteristics, it is necessary to control the temperature to be constant. An O/E is to be built in the cPCI module of the digital feedback control system at every LLRF control station. It should be equipped with a peltier device for temperature control. The production of new optimized E/O and O/E is in progress. The performance of the total system will be evaluated soon.

The introduction of an optical feedback system and an optical amplifier for the RRF reference distribution is proposed, if needed. The performance of the system is under evaluation.

AKNOWLEDGEMENT

We would like to deeply thank Dr. T. Naito, Dr. K. Ebihara and Dr. M. Suetake (KEK), who gave me much help and information about the optical system and components.

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