UPGRADE OF THE RF REFERENCE DISTRIBUTION SYSTEM FOR 400 MeV LINAC AT J-PARC

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Abstract

In the present J-PARC Linac, the negative hydrogen is accelerated by 181 MeV using RFQ, DTL, and SDTL which have the resonance frequency of 324 MHz [1]. The injection beam energy will be updated to 400 MeV by adding the Annular Coupled Structure (ACS) section. The ACS cavities have the resonance frequency of 972 MHz.

Two kinds of the RF reference signals had to be prepared for this upgrade and so a new oscillator to generate the RF references was installed at J-PARC Linac. The phase noise of the output signals in this oscillator was measured by a signal source analyzer. The jitter, which was estimated from the integration of the phase noise from 10 Hz to 1 MHz, was obtained to about 40 fsec. It was two order smaller than that of the previous system (about 1700 fsec) by the installation of new oscillator and the optimization of the transmission path of the master clock. It satisfies the requirement of the phase stability (±0.3 deg.) for the RF reference distribution system. Moreover, the high-accuracy synchoronism of two kinds of frequencies, 324 MHz and 972 MHz, was confirmed by the sampling oscilloscope.

RF REFERENCE DISTRIBUTION

The accelerator systems of J-PARC are controlled using 12 MHz master clock in Center Control Room (CCR). The present low-level radio frequency (LLRF) system is based on the reference signal of 312 MHz which is synchronized with the master clock [2]. The 312 MHz signal is optically amplified and divided, and then distributed to each control station. The 324 MHz RF is generated in each station as the acceleration frequency of the present system. Then, the RF reference is used as the local oscillator (LO). The quality of the injection beam in J-PARC Linac has to be within 0.1% in $\Delta p/p$ due to the momentum acceptance of the next synchrotron. The stability of the acceleration field and the phase in the Linac RF are less than 1 % and 1 deg., respectivly. Therefore, the requirement of the RF reference distribution system is <0.3 deg. in the stability of phase [3, 4].

Figure 1 shows the J-PARC Linac RF reference distribution system for the 400 MeV Linac upgrade. The 12 MHz master clock generated in CCR, is converted from the electrical signal into the optical and transmitted to each accelerator facility such as Linac Klystron Gallery. Here, two kinds of the RF reference synchronizing with the master clock are generated by new oscillator. The 312 MHz optical signal is amplified and divided into 17 optical transfer lines by an optical star coupler. The coupler is arranged in the thermostatic chamber for the suppression of the phase stability. Additionally, the phase-stabilized optical fiber (PSOF) is adopted as transfer lines and they are put in the insulated duct with the cooling water system whose temperature is controlled within ±0.1 °C [3]. One of the 17 lines is divided into more 5 by an optical coupler. Each reference signal is delivered to each control station of the present system and used for the generation of the 324 MHz RF. In the case of the 960 MHz reference, the number of optical transfer lines is 16×5 and each is delivered to the ACS station in order to generate the acceleration frequency of 972 MHz.

NEW LINAC MASTER OSCILLATOR

The block diagram of the new J-PARC Linac RF master oscillator, which was made by CANDOX Systems Inc. [5], is shown in Fig. 2. It has the input port of the optical 12 MHz signal and two kinds of outputs, 312 MHz and 960 MHz, with the phase locked loop (PLL) against the input. The 312 MHz and the 960 MHz output signals are used in the present and the ACS control stations, respectively. Moreover, there are the electrical outputs for the 12 MHz input and each RF reference due to the monitor.

This oscillator consists of a 80 MHz Oven-Controlled Crystal Oscillator (OCXO), 960 MHz and 936 MHz Voltage Control Oscillators (VCOs), a mixer, and PLL circuits. As the feature, the 80 MHz OCXO, which is generally used in many fields and has the precise and reliable system, is contained. The phase noise in the system with a OCXO can be suppressed in comparison with that composed of only VCOs and PLLs cicuit. Additionally, the Peltier cooling system is used for the temperature control.

MEASUREMENT OF PHASE NOISE

The phase noise of the new oscillator was measured using the signal source analyzer, which was called E5052B and made by Agilent Technologies. In the free oscillation without the 12 MHz input, the jitters estimated from the integration from 10 Hz to 10 MHz were 78 fsec for the 312 MHz RF and 41 fsec for the 960 MHz. However, those inputting the 12 MHz clock were about 250 fsec in both frequencies. It was considered to be effected by the accuracy issue of the 12 MHz master clock.

Therefore, the transmission path of the 12 MHz master clock from CCR to this oscillator was optimized. The 12 MHz optical signal was divided into 2 in Linac Klystron

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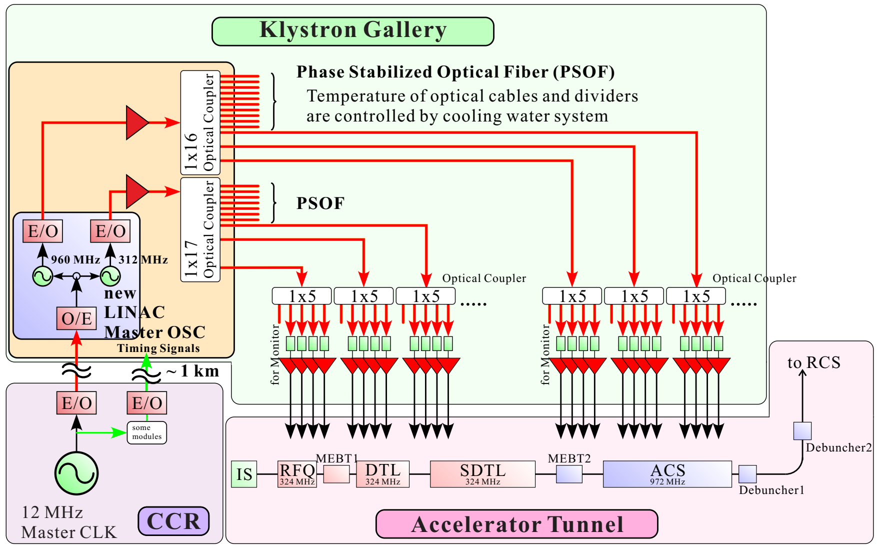

Figure 1: Upgraded J-PARC Linac RF reference distribution system. Two kinds of references, 312 MHz and 960 MHz, can distributed to each control station.

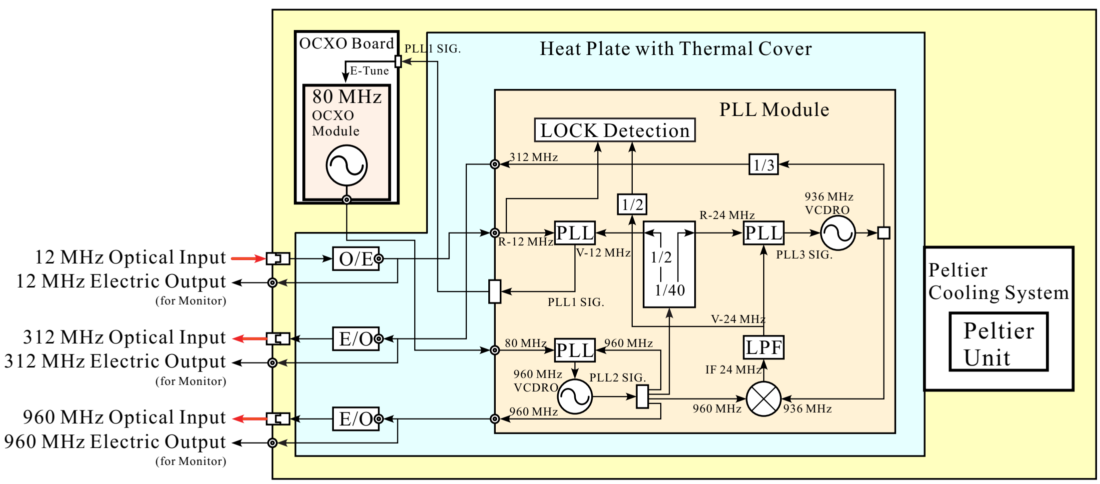

Figure 2: Block diagram of new J-PARC Linac master oscillator. It has the input port of 12 MHz optical signal and the 312 MHz and 960 MHz output signals in synchronization with the input.

Gallery. One was used in the previous distribution system and the other was as the timing reference (trigger) signal. The previous transmission path is presented in Fig. 1 as the green route. However, some modules are unnecessary for the RF system. Therefore, the path was optimized as through only electro-optical transmitter (E/O) module shown in Fig. 1. Additionally, the E/O in CCR and the O/E modules in Gallery were adopted to base on the least phase noise in the similar functions.

Figure 3 shows the distributions of the phase noise. The black line and the red dash line are represented as those before and after the optimization of the transmission path, respectively. It is clear that those in (a) the 312 MHz and (b) the 960 MHz RF were suppressed by the optimization in the lower region of the offset frequency. Moreover, the phase noise in the previous system is shown as the green dot line in Fig. 3 (a).

Table 1 shows the jitter estimated from the integration of phase noise from 10 Hz to 1 MHz (blue region in Fig. 3). It was estimated to be 41 fsec in rms at the 312 MHz signal and were expressed to be 0.005 deg. in phase. In the case of the 960 MHz signal, it was 35 fsec in time and 0.012 deg. in phase. The obtained results satisfy the required phase stability of less than 0.3 deg. for the RF reference distribution system. Moreover, it is can be confirmed that the jitter was suppressed to be one fifth when the transmission path of the 12 MHz master clock was optimized. This result indicates that the precision of a master clock play the important role for the phase stability. The jitter of the 312 MHz RF in the previous system was estimated to be about 1.7 psec. Comparing the new system with the previous, the phase stability is improved to be two order.

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Table 1: Jitter of new J-PARC Linac Master Oscillator

frequency	previous oscillator	new oscillator	
		before path optimization	after path optimization
312 MHz	1746 fsec	243 fsec	41 fsec
960 MHz	-	237 fsec	35 fsec

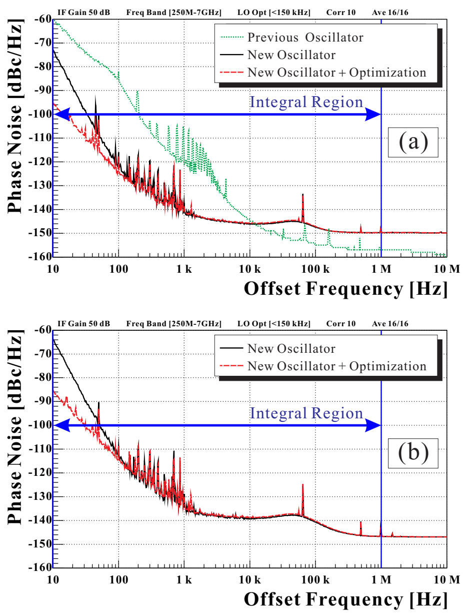

Figure 3: Phase noise of new J-PARC Linac master oscillator. (a) and (b) show the 312 MHz and 960 MHz output signals, respectively. The green line represent and the 312 MHz and 960 MHz output signals in synchronization with the input.

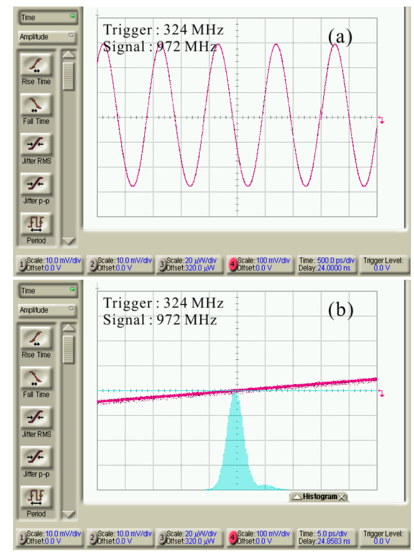

Figure 4: Acceleration frequency in synchronization. The trigger signal in the sampling oscilloscope is the 324 MHz RF and the 972 MHz RF signal is detected. The synchronization of 324 MHz and 972 MHz can be confirmed from (a). (b) shows the wide view. The width of the phase difference using zero cross method is 1.3 fsec in rms.

SYNCHRONIZATION

The acceleration frequencies, 324 MHz and 972 MHz, were generated using the practical modules. The synchronization of the acceleration frequencies were confirmed using the sampling oscilloscope (86100B, Agilnet Technologies). However, the optical amplifiers and the optical couplers in Fig. 1 were not used in this measurement.

Figure 4 represents the acceleration frequency by the sampling oscilloscope. The 324 MHz RF was used as the trigger and the 972 MHz was detected. The input signal with the frequency of 972 MHz could be confirmed to synchronize with the 324 MHz trigger from Fig. 4(a).

Figure 4(b) shows the zoomed view of (a). The distribution of time differences between the 324 MHz RF and the 972 MHz was measured using the zero cross method and is indicated as histogram. The width of the main peak was obtained to about 1.3 psec in rms. The resolution of the sampling oscilloscope in this condition was obtained as 1.2-1.3 psec. Therefore, this result satisfies the requirement for the RF reference distribution system which is less than 1 psec in 972 MHz.

SUMMARY

The new J-PARC Linac RF master oscillator was installed and the reference distribution system was improved due to the Linac upgrade. Therefore, not only 312 MHz but also 960 MHz signals are able to be distributed to each control station as the RF timing reference. The jitter of the those references was about 40 fsec after the installation of the new oscillator and the improvement of the transmission path of the 12 MHz master clock. It is one order less than the requirement of the phase stability. We could confirm the synchronization of the acceleration frequency between 324 MHz and 972 MHz.

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