TIMING SYSTEM AT SPring-8

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Abstract

In order to realize any beam filling pattern required by users in the storage ring, a timing system to control electron beam has been developed and constructed at SPring-8. The tools developed for the timing system are presented. Moreover, new synchronization method for the two rf's of a linac and a circular accelerators was invented and installed in the linac. The present timing system at SPring-8 including New SUBARU is briefly described.

1 INTRODUCTION

The SPring-8 had to be constructed to satisfy many users' requests such as various kinds of beam filling pattern including single-bunch, multi-bunch and their hybrids. In order to realize any beam filling pattern easily and quickly, we reached the conclusion that a very precise timing system for controlling a beam had to be introduced. The development of a synchronous universal counter (SUC) [1] is one of the most important elements in it. The main purpose of the SUC is to number all the rf buckets of the storage ring from 0 to 2435. The resulting advantage of this is as follows. An rf bucket in the storage ring is filled with a beam, and the beam intensity decreases with time. Beams can be reinjected into the same rf bucket for addition as long as the rf bucket number already filled is not reset. Beam intensity would be consequently recovered and could be kept almost constant. To number all the buckets in the storage ring, the SUC must work at 508.58 MHz. The required SUC must be equipped with the two main functions of a programmable divider and a cascadable universal counter. The former corresponds to the harmonic number of a storage ring, that is, the repetition rate is equal to the revolution frequency of the storage ring. The latter is to give a function as a digital delay device with a time interval of more than two seconds because the beam injection rate is almost 1 Hz at SPring-8. Furthermore, to transmit a timing pulse signal over a long distance, we developed a new signal transmission system using a phase stabilized optic fiber [2] to minimize transmission time jitters. A reference frequency of 508.58 MHz is also delivered to each station through the same kind of optic fiber. The assembly of the entire timing system was completed at the end of 1996, and a beam has been correctly injected into a targeted rf bucket of the storage ring since beam commissioning in March, 1997. It was verified that any beam filling pattern could be easily realized by using the precise timing system.

The beam commissioning of New SUBARU began in September, 1998. The timing system to control electron beam from the linac of SPring-8 adopted the same system as that of SPring-8. An electron beam can be anytime injected into a targeted rf bucket.

A single bunch is formed in the booster synchrotron by using rf-KO system [3]. To achieve a much better single-bunch mode operation required by users in the storage ring, we exchange the 1 ns-grid pulser with another pulser with a shorter pulse width of 250 ps FWHM [4]. There, however, is a very difficult issue which two rf's of the linac and the booster synchrotron ring should be synchronized. In order to keep the electron beam intensity constant even in the case of a grid pulser with a 250 ps-time width, the phase difference between both the 508.58 MHz and 2856 MHz rf's should be fixed. Thus, we invented a new synchronization method for the two rf's. A very important clue to solving the problem was the fact that the electron beam from a linac is generally not continuous, but pulsing. We therefore thought that an rf for a linac might be fed only in a short time during beam emission and acceleration. This idea is completely different from the general method: an rf continuously generated by a synthesizer. The new synchronization method was constructed this summer and works well.

Those new methods developed at SPring-8 are reported.

2 DEVELOPMENT OF TOOLS FOR TIMING SYSTEM

2.1 508 MHz synchronous universal counter

A synchronous 508 MHz universal counter (508 MHz SUC) was developed for beam handling and monitoring. The 508 MHz SUC works at 508.58 MHz rf and has a 30-bit width. Since beam injection rate is 1 Hz, we set long bit width. The circuit block diagram is shown in figure 1. The circuit is packed in a single span NIM module to protect from electromagnetic noise. One output indicated by '1/N out' is to output the revolution frequency of the storage ring. The other output indicated by 'M out' is to output a delay time signal which corresponds to a targeted rf bucket. A beam is injected into the rf bucket. The delay time from 'M out' can be changed manually or remotely. The 508 MHz SUC equips an input connector on the rear panel and the data of a delay time is latched in the memories by a VME. The users in experimental hall at SPring-8 use the 508 MHz SUC's to detect only the synchrotron radiation from electron beam stored in a specific rf bucket. The 508 MHz SUC is applicable in accelerator facilities, particle experiments and other environments.

2.2 Precise signal transmission system

To inject electron beam from the linac into a targeted rf bucket of the booster synchrotron, we developed a new signal transmission system. The required time jitters should be within ±100 ps at $\Delta P/P = \pm 1$ %. A developed signal transmission system has a time jitters less than 10 ps as a standard deviation. The system consists of a level converter, an electric-to-optic (E/O) converter, an optic-to-electric (O/E) converter, a phase stabilized optic fiber and a constant fraction discriminator (CFD) as shown in figure 2. The level converter is a module to convert a NIM pulse to a positive pulse of 0.8 volts with a rise time of less than 1 ns. The E/O and O/E converters used are models 3510A and 4511A by ORTEL Company, respectively. The purpose of a CFD is to compensate for a small amplitude fluctuation in output signal height from E/O, which has a solid state laser module. The ORTEC 935 was selected due to its small time jitters. The time jitters of the system was measured by using the electron gun system of the SPring-8 linac and obtained 7.4 ps as a standard deviation [1].

2.3 Distribution of rf reference

In the storage ring, there are four rf stations. A phase-stabilized optic fiber turns around the storage ring of about 1436 meters. The reference frequency of 508.58 MHz is transmitted through the optic fiber. In each rf station, 508.58 MHz rf is picked up through an optical coupler. The returned rf reference is compared the phase with the direct rf reference from a synthesizer. The phase difference is kept to be constant by PLL system. The measured phase variations is approximately less than 5 degrees in 508.58 MHz phase during one year. The PLL system keeps the phase difference within 1 degree. The rf reference system for the storage ring is shown in figure 3. On the other hand, the booster synchrotron ring is supplied the rf reference with another method. The method was developed in the LEP [5]. We adopted the same method, which is shown in figure 4. Total length of the optic fiber is almost 700 meters. Even if no PLL system is installed, the phase difference is kept to be less than 3 degrees during one year because of using a phase stabilized optic fiber. Thus, both rings are completely synchronized with the accuracy of less than 1 degree in phase.

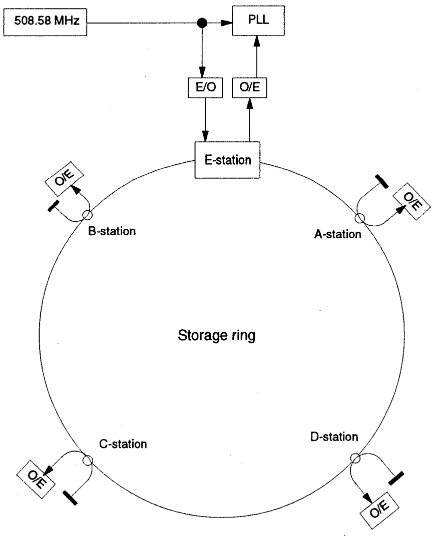

Figure 3: rf reference distribution for the storage ring.

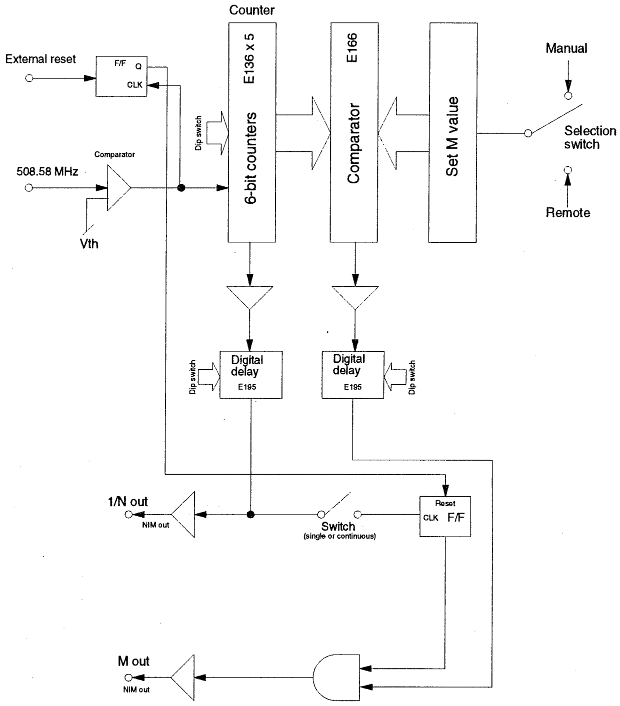

Figure 1: Block diagram of a 508 MHz SUC.

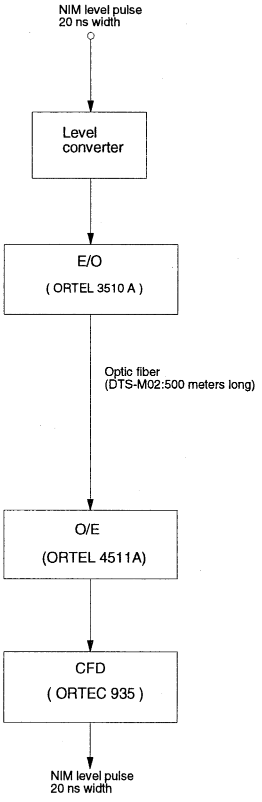

Figure 2: A signal transimission system with small time jitters.

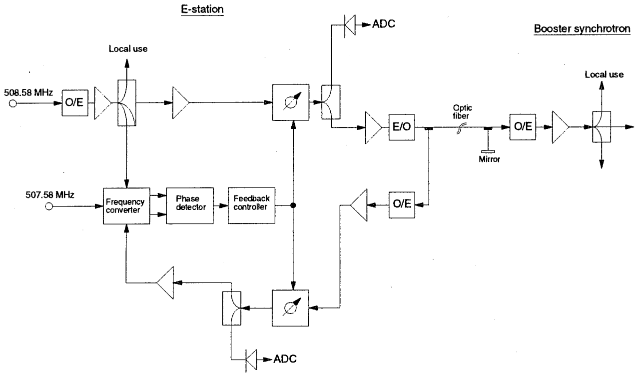

Figure 4: rf reference distribution for the booster synchrotron ring.

2.4 *Final pulse signal transmission system*

We had developed the signal transmission system with small time jitters mentioned in section 2.2. The final version for pulse signal transmission system, however, does not require such a precise signal transmission system. The system allows time jitters within one wavelength, for example, 1.97 ns for 508.58 MHz. To explain the reason, we first show the total system in figure 5. The phase of an rf reference is stable because of both a phase stabilized optic fiber and PLL system. A pulse signal is transmitted by the signal transmission system shown in figure 2. The pulse signal transmitted is introduced into a 508 MHz SUC, which is input 508.58 MHz, too. The pulse signal passing through the 508 MHz SUC is synchronized and the resulting time jitters due to signal transmission process are cured almost completely. The measurement of time jitters says that the time jitters with around 10 ps as a standard deviation decrease less than 3 ps only through a 508 MHz SUC. A gun trigger pulse signal transmitted from the storage ring to the booster synchrotron ring must pass through a 508 MHz SUC. Thus, time jitters as to serious pulse signal such as a gun trigger signal must be always suppressed less than 10 ps as a standard deviation. In the figure 5, a pulse signal is generated by using an rf reference and a 508 MHz SUC. A line A-B means a border between side A and side B, where is located in the distance. The phase of the rf reference is locked by PLL system. It is actually a combination of three tools shown in figures 1, 2 and 4, respectively. Thus, we could finally get a pulse signal transmission system with low time jitters. All pulse signals required low time jitters are transmitted by the system at SPring-8. The method is very useful for huge accelerator facilities. The method could be applied for the future project such as JLC (Japan Linear Collider) [6].

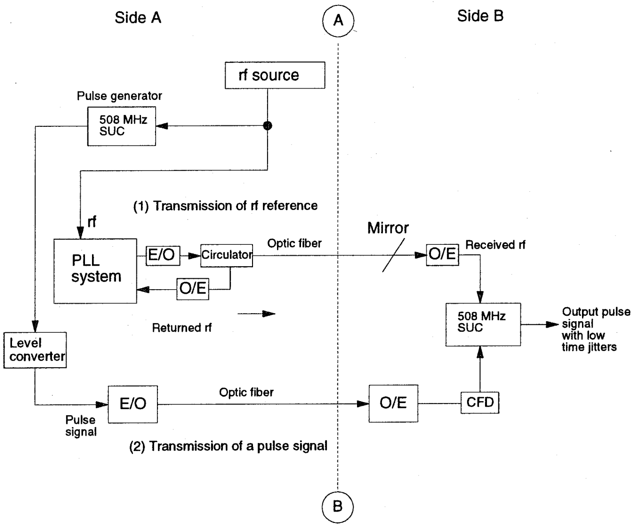

Figure 5: An ultimate pulse signal transmission system with small time jitters.

3 ELECTRON GUN TRIGGER SYSTEM

3.1 *SPring-8*

All the commands for accelerator operations are delivered from the central control room through a computer network. First, information on the address of the rf bucket into which a beam is injected is transmitted from the central control room to the timing control room, named E-station. The address of the rf bucket is written on the 508 MHz SUC by a VME. Second, a command of the linac gun trigger from the central control room is also received, and the gun trigger signal is produced at E-station in the storage ring. The signal is transmitted to the control room of the booster synchrotron through a phase stabilized optic fiber. Then the signal is divided into branches for various purposes such as triggers for septum and bump magnets and so on. The linac gun trigger signal is transmitted to the linac electron gun module from there. Total length of transmission line from the E-station to the location of the electron gun deck is about 1000 meters. The actual block diagram of the electron gun trigger system is shown in figure 6. There are two AND logic units (1 and 2) in figure 6. AND (1) has three inputs and one veto. Since the power supplies of the linac modulators are dependent on 60 Hz, the timing system must be synchronized with 60 Hz. For this purpose a 60 Hz pulse module is introduced in a NIM crate with a pulse width of 80 μs. Synchronization is realized as the following. An output signal from AND (1) logic is produced at the rate of revolution frequency. The 60 Hz timing is not as precise as the 508 MHz one. Simple coincidence between the 508 MHz SUC and the 60 Hz pulse may cause ambiguous output timing depending on the relative timing of the two inputs. In order to avoid the situation where a 60 Hz pulse determines the timing, the second coincidence output must be used by ignoring the first one. The output signal generated by AND (1) logic is introduced to AND (2) logic and at the same time the signal enters into a gate generator (1). The first signal from AND (1) logic never triggers the output signal from AND (2), but the second signal from AND (1) logic triggers it. Consequently, the timing signal for the linac gun trigger is determined by the 508 MHz SUC, and a beam is injected into the targeted rf bucket correctly. A correct signal including information on the rf bucket address in the storage ring is transmitted through a phase stabilized optic fiber. The signal from AND (2) logic is divided into two. One is transmitted to the linac and the other is further divided into two. Then the one signal triggers the gate generator (2), which generates a veto signal. The veto signal closes AND (1) and (2) logic units, and the third signal from AND (1) logic is not generated. The other signal stops the gate generator (1) and protects acceptance of the accidental third signal from AND (1) logic. A preset scaler counts the signal from the module generating 60 Hz. The preset scaler produces a signal after 60 counts and stops the gate generator (2). As a result, AND (1) and (2) logic units are reset, and then a new trigger signal for the linac gun is generated at the rate of 1 Hz.

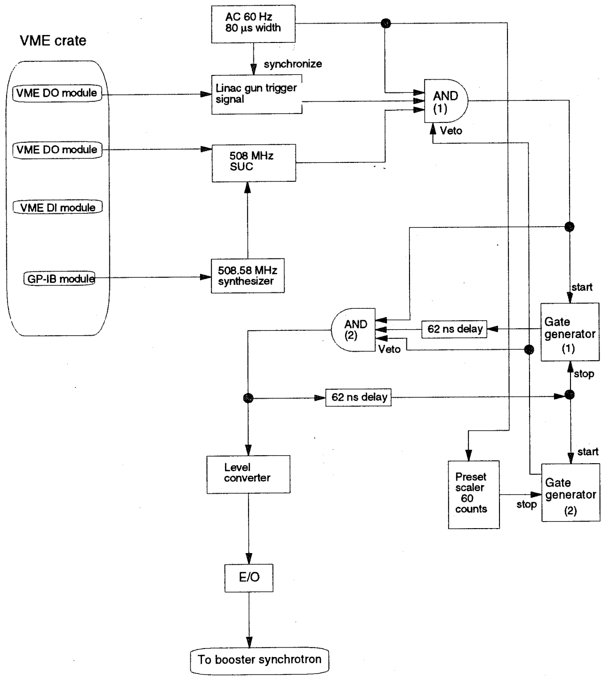

Figure 6: Block diagram for generation of the linac gun trigger signal.

3.2 New SUBARU

Total timing system including pulse magnets is much simpler for New SUBARU compared with that of SPring-8. Because New SUBARU directly accepts electron beam with the energy of 1 GeV from the SPring-8 linac. The gun trigger system is exactly the same as shown in figure 6, only exchanging 508.58 MHz to 500 MHz. Thus, another timing system such as pulse magnets and so on is shown in figure 7. It is, in particular, noted that the timing signals as for pulse magnets are generated by some 508 MHz SUC's.

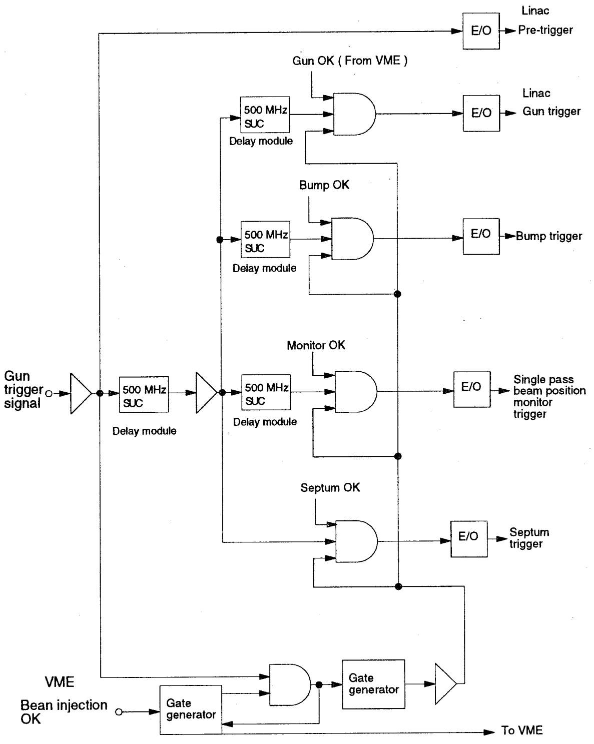

Figure 7: Timing system for New SUBARU.

4 NEW SYNCHRONIZATION METHOD BETWEEN TWO DIFFERENT rf's

To synchronize two rf's of 2856 MHz for the linac and 508.58 MHz for the storage ring, we invented a new synchronization method. A very important clue to solving the problem was the fact that the electron beam from a linac is generally not continuous, but pulsing. We therefore thought that an rf for a linac might be fed only in a short time during beam emission and acceleration. This idea is completely different from the general method: an rf continuously generated by a synthesizer. An electron gun trigger signal at SPring-8 is generated by using the 508.58 MHz rf of the storage ring. The gun trigger signal is divided in two. One is used as a pretrigger signal for klystron modulators and the other is a gun trigger signal. In the new synchronization method, the pretrigger signal triggers a 2856 MHz rf generator, which consists of an arbitrary waveform generator (AWG) and a frequency multiplier shown in figure 8. The time width generating the 2856 MHz rf is for a short duration of about 290 μs. With this method, two rf's are automatically synchronized [7]. The spectra obtained by the method is shown in figure 9. The 2856 MHz rf generated by a synthesizer

(HEWLETT PACKARD HP8664A) is also shown in the same figure. The difference of -18.719 kHz between the two 2856 MHz rf's can be seen, but this difference is too small to have any negative effect on the electron beam, because acceleration cavities in general have a Q-value ($Q=f/\Delta f$; f is the resonant frequency of a cavity and Δf is the full width at the half maximum). In the case of the linac at SPring-8, for example, the Q-value and Δf are 13,500 and 211.6 kHz, respectively. The difference of -18.719 kHz is small compared with 211.6 kHz and is not crucial in an actual beam operation. The merits of the new synchronization method of arbitrary different rf's are summarized as follows. This method is applicable to any electron beam facility consisting of linac and circular accelerators. The choice of rf's, which had been previously limited by klystrons, becomes flexible. The rf for a linac can be easily generated by using the rf of a circular accelerator. The method itself is very simple and can be easily constructed. Construction simply requires making a frequency multiplier and inputting the data information of an rf into an AWG. The phase between the two rf's is automatically synchronized by the new method.

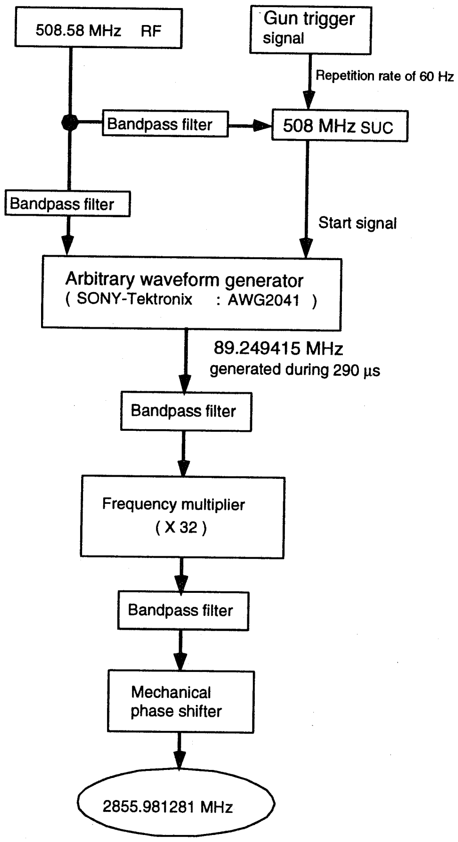

Figure 8:Block diagram of the new synchronization method between the 508.58 MHz and 2856 MHz rf's.

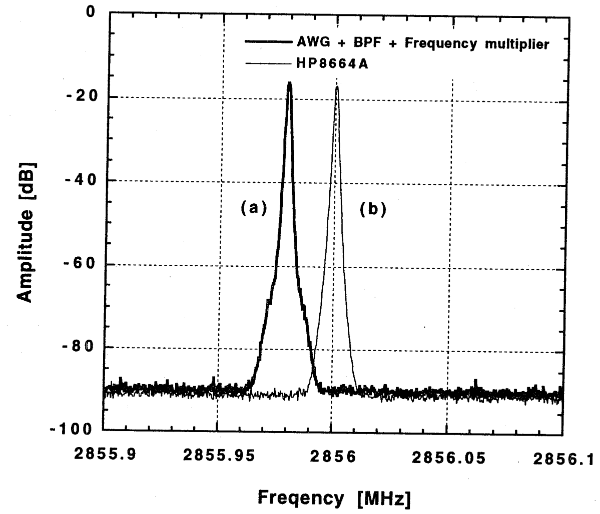

Figure 9: Obtained spectra of 2856 MHz rf's: (a) generated by the new method; (b) generated by a synthesizer.

5 PRESENT STATUS OF SPring-8

The 2856 MHz rf for the linac is completely synchronized with the 508.58 MHz rf of the storage ring. Beam intensity from the linac to the booster synchrotron was improved and became almost constant in case of beam with 1 ns-time width and even 250 ps-time width in a grid pulser. Thus, there is now only one synthesizer in the storage ring.

As for New SUBARU, the 2856 MHz rf is independently generated by the 500 MHz rf of New SUBARU by the new method. An electron beam with the time width of 250 ps emitted through the grid will be correctly injected into a targeted rf bucket of the New SUBARU storage ring from October, this year.

6 ACKNOWLEDGEMENTS

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7 REFERENCES

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