Synchronization Device of the Specialized Source of Synchrotron Radiation «Sibir-2» of the Kurchatov Institute

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***Abstract*—The purpose of the work is to design a schematic diagram and develop a printed circuit board, develop configuration for fpga of the injection and synchronyzation control unit for the specialized source of synchrotron radiation «Sibir – 2» of the Kurchatov Institute. According to the modernization plan the Main storage ring Sibir-2 and Booster ring RF System will operate on the same frequency of 181.139 MHz. In this connection it is required to create a control unit for synchronization of injection of electron bunches from the electron gun to Booster with an accuracy of 0.2 ns and from any separatrix of Booster into any separatrix of the Main ring; to form «Pre-Start» and «Solution» pulses which are required for synchronization of «slow» deflection systems for injection. As a result, a printed circuit board and internal fpga logic was designed according to the design specification. Measurements showed that the device meets the basic requirements.**

***Keywords*—accelerators, synchrotron, control systems, synchronization of acceleration systems, FPGA, circuit design**

I. Introduction

The Kurchatov Specialized Synchrotron Radiation Source «KISI-Kurchatov» in Moscow is currently being prepared for comprehensive modernization. The design and main characteristics of the synchrotron are presented in [1]. It is the only specialized source of synchrotron radiation in our country. The complex requires synchronization of the electron gun, kickers, deflecting magnets and diagnostic equipment . The perimeter of the Booster ring is 110.8 m, and perimeter of the main ring 124.1 m. Since they operate at the same frequency of the accelerating RF system 181.139 MHz, different number of bunches circulate in the accelerators. For the Booster ring, the number is 67, and for the main ring it is 75. The Fig. 1 shows a schematic representation of the complex

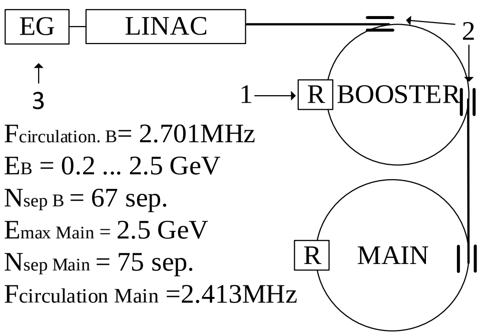


Fig.1 1 — Rezonator; 2 — Kiker; 3 — Electron gun.

Schematic of the modernized synchrotron-accelerator complex.

with its main parameters. The complex consists of an electron gun (EG), a linear accelerator (LINAC), the Booster, and the Main ring. Linac energy 200 MeV, repetition rate 1 Hz with beam length from 2 to 18 ns.

The signal that is used to synchronize the logical units of the device is a frequency obtained by dividing the RF frequency 181.139 MHz / (67×75) ≈ 36 kHz. Each time this pulse arrives, the location of the bunches in the main ring and in the booster is repeated so their position may be predicted and to one of these moments prepare an act of injection. The Fig. 2 shows a graphical representation of the Reference RF voltage pulses (181.139 MHz), the rings circulation frequencies and the main synchronous frequency of 36 kHz.

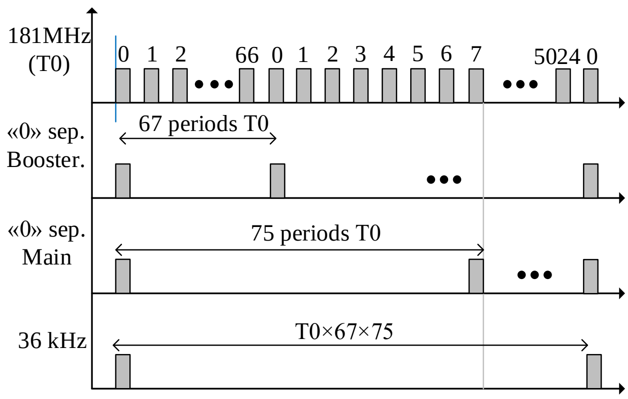


Fig.2 Main and booster ring pulse graphs.

Properties of synchrotron radiation and peculiarities of its production are presented in [2-8].

More information on the structure and parameters of synchrotron radiation can be found in [9].

II. Theory

Assuming that the RF voltages at the accelerating gaps of the resonators of both rings are rigidly phased with the Reference RF voltage, we must use this voltage as the main clocking signal for the logic blocks.

To control the injection of electron bunches from the Electron Gun to the Booster and from Booster to Main Ring we need to transmit a programmable delay via SPI. It is necessary to generate «Pre-Start » pulses to start preparation of «slow» deflecting elements (bending magnets in transfer line, etc.) (up to 5 ms) and then by the «Solution» pulse to perform the injection (Fig. 3).

The injection from the electron gun into the booster is determined by a 14-bit binary code. The upper 7 bits of the code determine the number of the booster separatrix to be filled, and the lower 7 bits determine the injection of the bunch into the equilibrium phase of the selected separatrix.

To ensure the accuracy of 1/10th of the beam length, the programmable delay circuit AD9500 must be at the output of the Booster separatrix selection block, and the output pulse from it should be generated only by the «Solution» pulse. Parameters of the AD9500 is described in [10]. The delay is set via a digital 7-bit interface. The range and the resolution are set via a variable resistor. The setting of the device done by setting the maximum delay via the fpga and adjusting the resistor until the maximum delay is equal to the period of the reference voltage T0. The resolution is defined as T0/128 = 0.043 ns. The «Booster Separatrix Select» register and the AD9500 register are combined to make 14 bits. The lower 7 bits assigned to the AD9500 delay, the higher 7 bits to the Booster separatrix selection block delay.

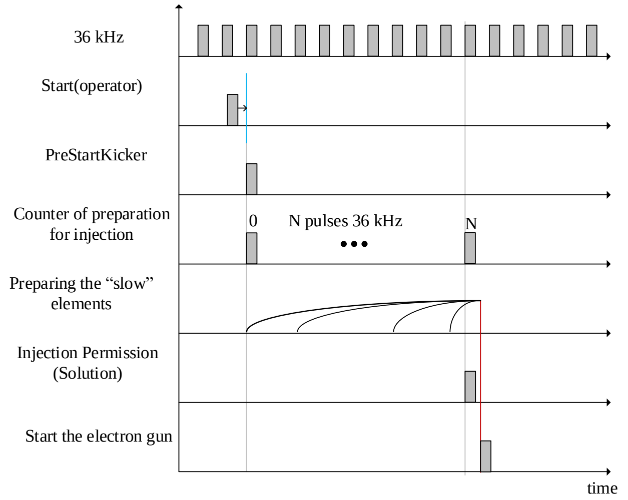


Fig. 3. Graphical representation of the signals when electron bunch injecting from Linac to Booster.

The injection from the booster to the Main ring is made on the similar principle, only there is no block with programmable delay circuit at the output.

Fig. 4 shows a schematic of the device with all the internal structure of the fpga.

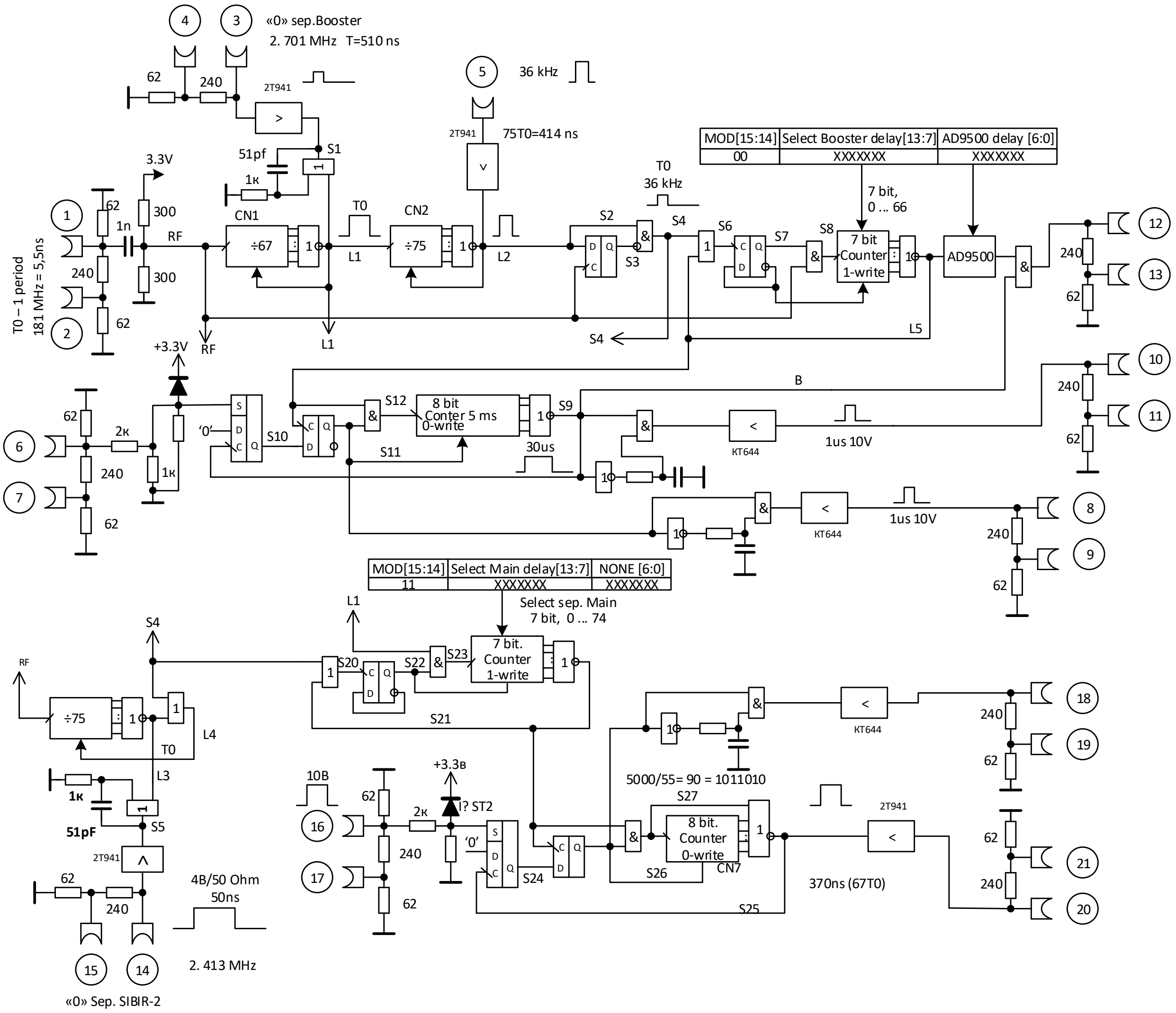


Fig. 4. Device schematic with inner part of the fpga.

The RF reference voltage is applied to input 1 and then to the divider by 67. The output pulses of the divider mark the position of the bunch of "0" - separatrix in Booster ring (output 3). Further these, pulses come to divider by 75, forming frequency 36 kHz (wire S4). This signal is then used to start the delay block for filling the selected separatrix of Booster. Signal 36 kHz (L4) is used also for synchronization of another divider by 75 of the generator of “0” – separatrix of the Main Ring (output 14).

Injection into Booster is triggered by the “Start (operator)” pulse from the complex Control System (input 6 in Fig.4) (see Fig.3). The first pulse of 36 kHz after “Start (operator)” is used as the “Prestart” to trigger “slow” elements of the injection system. The “Prestart” pulse starts also the "Counter for preparation for injection". It delays the “Prestart” by constant N periods 36 kHz. The N-th pulse is the “Solution” (output 10 in fig.4). It is used to trigger the input kiker of the Booster. The "Solution" pulse also opens the "AND" switch to transfer one of 36 kHz pulse to trigger the electron gun (output 12).

For injection from Booster to the Main ring the phase of accelerating voltage of the Main ring in relation to the reference RF voltage is adjusted so that the bunches arrive from Booster into the equilibrium phase of the selected separatrix. In another respect, the synchronization of injection into the Main Ring does not differ from injection into the Booster. Input 16 is the input of the signal "Start (operator)", output 18 is the "Prestart" and output 20 is the "Solution" pulse to trigger output kiker of Booster and input kiker of the Main ring. To determine the separatrix number of the Main ring to be filled, the signal L1 ("0" sep. of Booster) is delayed by the "Select Main delay" counter.

Table I shows all inputs and outputs that are required in the device. In addition to the main inputs and outputs, which are directly used to control the complex, there are also outputs, which allow you to monitor the amplitude and duration of the pulses.

RP — Inputs and outputs output to the rear panel of the rack, used only for triggering injection electron beam from Linac to Booster and from Booster to Main Ring.

FP — Inputs output on the front panel of the rack are for signal monitoring.

An ALTERA EPM240T100C3 FPGA was chosen as the main control chip with a maximum operating frequency of 304 MHz and 240 logic cells. Parameters of this fpga are provided in the [11]. The Verilog hdl language was chosen to program the fpga logic circuit because of its ease of learning and debugging individual blocks.

TABLE I. NUMBERING OF INPUTS AND OUTPUTS AND THEIR PURPOSE PLANNED SIGNAL PARAMETERS

№	Description	Purpose
1	reference voltage input 181.139 MHz 1.4V/50 Ohm	RP
2	Input pulse monitor	FP
3	Output «0» sep. Booster 4V/50 Ohm 50 ns	RP
4	Output «0» sep. Booster monitor	FP
5	Output 36 kHz 4V/50 Ohm 420 ns	FP
6	Input start injection LINAC to Booster 10V/50 Ohm	RP
7	Input injection electron gun to Booster monitor	FP
8	Output «Pre-Start», start Time Pulse Generator 10V, 1 us. Injection LINAC to Booster	RP
9	Output «Pre-Start» sensor	FP
10	Output «Solution», 10V/50 Ohm 1us, Start Delayed Pulse Generatlor, kikers's trigger	RP
11	Output «Solution» 10V/50 Ohm monitor	FP
12	Output «Start the electron gun» 10V/50 Ohm, 50 ns	RP
13	Output «Start the electron gun» monitor	FP
14	Output «0» sep. Main Ring 4V/50 Ohm, 50 ns	RP
15	Output «0» sep. Main Ring monitor	FP
16	Input Start injection form Booster to Main Ring 10V/50 Ohm	RP
17	Input Start injection form Booster to Main Ring sensor	FP
18	Output «Pre-Start», start Time Pulse Generator of Main Ring	RP
19	Output «Pre-Start» monitor	FP
20	Output «Solution» 10V/50 Ohm	RP
21	Output «Solution» monitor	FP

The amplitude of the output trigger signals up to 20V at a load of 50 ohms, so we need to install amplifier stages. The number of these stages is 8 pcs. For this purpose, we use bipolar npn and pnp transistors in the common emitter connection. Parameters of all output amplifier stages represented in the Table II.

TABLE II. PARAMETERS OF THE OUTPUT AMPLIFIER STAGES

№	Output Transistor	I Out, mA	U Out, V/50 Ohm	Rise Time, ns	Purpose
3	2T941	100	5	<2	«0» sep. Booster
5		100	5		Sync Pulse (36kHz)
10		200	10		«Solution» Booster
12		200	10		Start Electron gun
14		100	5		«0» Main Ring
21		200	10		«Solution» Main Ring
18	KT313	200	10	<20	«Pre-Start» Main Ring
8		200	10		«Pre-Start»Booster

III. EXPERIMENTAL RESULTS

The designed board is shown in Fig. 5. The fpga was then programmed according to Fig. 4. The experimental values of the output signals of the device were measured and are presented in Table III.

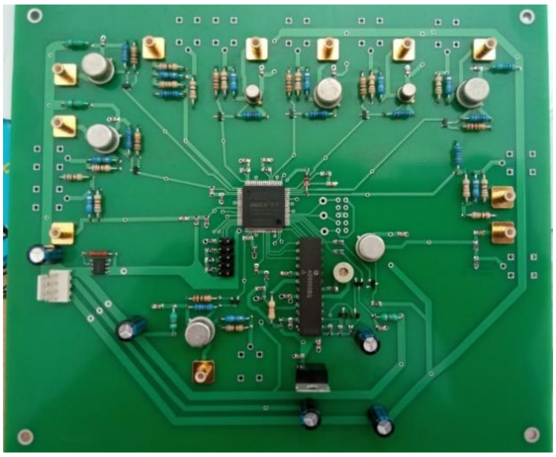
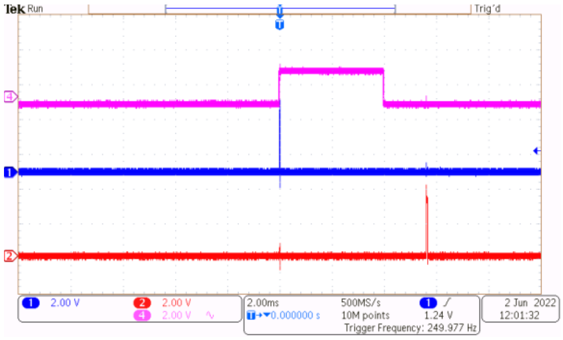


Fig. 5. Device printed circuit board.

TABLE III. EXPERIMENTAL PARAMETERS OF DEVICE OUTPUT SIGNALS

№	Amplitude, V	Duration, ns	Rise Time, ns	Fall Time, ns
3	5	520	1.5	20
5	5	510	1.5	30
12	10	25	1.5	28
10	10	1030	1.5	30
8	10	1025	14	25
14	5	80	1.5	20
18	10	1030	15	30
20	10	400	1.5	20

Fig. 1 shows the oscillograms of the «Pre-Start», «Solution» and the pulse start from the operator.



1 — Pre-Start; 2 —Solution; 4 — Start(operator)

Fig. 6. Oscillogram with the pulse «Solution» and «Pre-Start-Kicker», formed after the arrival of the pulse «Start(operator)».

In Fig. 7 shows the operation of the output stage with the AD9500 programmable delay unit.

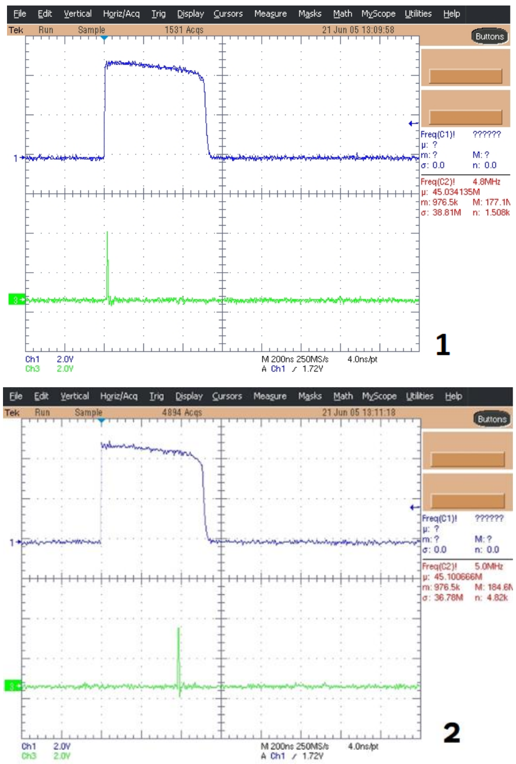


Fig. 7. Oscillograms of electron gun trigger pulse at the AD9500 output and synchronous pulse with «zero» delay (1); with maximum delay(2).

IV. CONCLUSION

As a result of the work was made a device that is able to form a synchronization and triggering pulses with adjustable delay.

You can contact us for details.

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