# CONTROLLER FOR RF STATIONS FOR BOOSTER OF NICA PROJECT

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*Abstract*

Intellectual Controller for RF stations based on CPU module SAMA5D31-CM for Booster of NICA Project is presented. Controller measures magnetic field using induction coil and provides corresponding real-time tuning of frequency according to non-linear law with 20 µs period and better than $2 \cdot 10^{-4}$ accuracy. Controller also allows setting up and monitoring parameters of RF stations. The tester module that generates a sequence of events and signals imitating acceleration cycle is alo presented.

## INTRODUCTION

RF System for Booster of NICA Project (JINR, Dubna) [1] are created at Budker Institute of Nuclear Physics [2]. It consists of two resonators, two RF stations including power amplification cascades and low-voltage electronic, intellectual controller and tester module. RF system provides ~10 kV acceleration voltage in required frequency range (0.5-5 MHz) on cavity gaps.

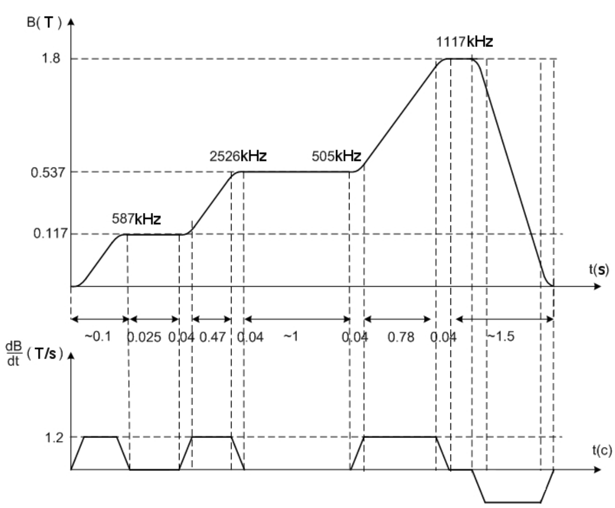


Figure 1: Booster magnetic field and acceleration frequencies.

This article describes the intellectual controller and tester module. Primary function of controller is generation of master frequency depending on the current value of magnetic field. Inaccuracy of frequency setting must not be worse than $2 \cdot 10^{-4}$. The graphic of magnetic field in booster and corresponding acceleration frequencies for nuclotron injection mode are presented at fig. 1. Magnetic field increase rate in this mode is around 1.2 T/s. Several other acceleration modes are planned including autonomous mode (rising frequency from 0.5 to 5 MHz in 2 s).

Controller also manipulates low voltage electronics, measures and generates all signals necessary for the functioning of RF sections (see tab. 1). Controller must also have means to be integrated in booster control system.

Table 1: Main controller signals

| Signal | Channels | Sample Rate | Resolution |
|---|---|---|---|
| Input Signals | | | |
| Master frequency | 2 | 50 kHz | 24 |
| V resonator | 2 | 50 kHz | 12 |
| I anode | 2 | 1 kHz | 10 |
| Synchronization | 7 | N/A | N/A |
| Output Signals | | | |
| Field sensor | 1 | 50 kHz | 18 |
| V resonator | 2 | 50 kHz | 12 |
| V preamplifier | 2 | 5 kHz | 12 |
| I anode | 4 | 1 kHz | 12 |
| V rectifier | 6 | 1 Hz | 12 |
| V filament | 2 | 1 Hz | 12 |

Currently most of booster elements are in design and manufacturing stages. That is the reason why tester module is created. It imitates signal from magnetic field sensor and necessary synchronization pulses in different acceleration modes. Tester module is intended to allow regular RF system checks at the installation. Both developed devices are 19" 3U modules and are placed in RF stations electronics rack.

## CONTROL ARCHITECTURE

The scheme on fig. 3 shows interaction of controller and tester modules with booster instrumentation and RF stations electronics.

Signals from magnetic field sensor and synchronization pulses are provided to the tester module Tester module allows to interchange between imitation and through-pass modes. Signal from magnetic field sensor is integrated and resulting magnetic field value B is used to calculate frequency according to the following formula:

$$F(B) = \frac{c^2 / L \, Z / A_n \rho \, 1/10^6 \, B}{\sqrt{m_n^2 + (Z/A_n \rho c / 10^6)^2 B^2}} \quad (1)$$

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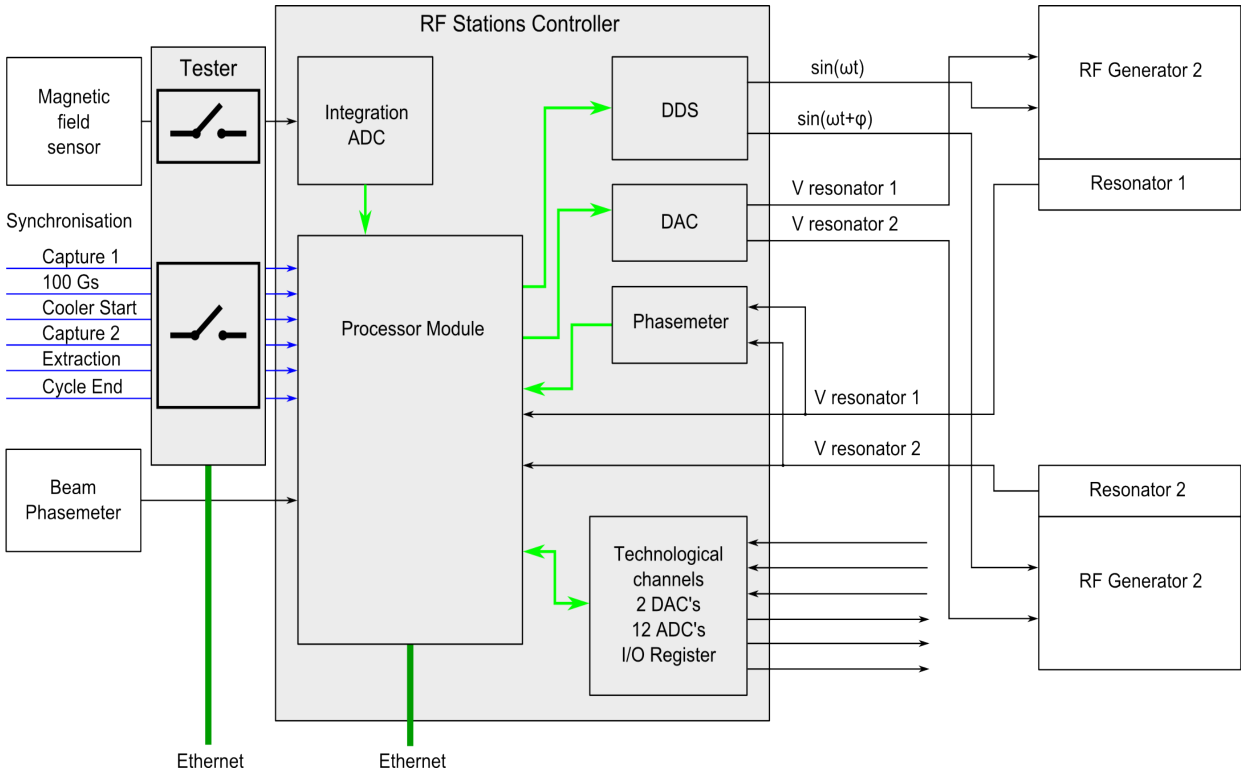


Figure 2: Control architecture.

In (1), B – is the resulting field value and all other symbols represent static parameters of installation. Calculated value is used to generate two master frequency sinusoidal signals. These signals are generated with specified phase difference defined by distance between resonators. In future it is intended to provide suppress synchrotron oscillations by variation of this phase according to signal from designed beam phase measurement system.

## SOFTWARE

Both tester and controller modules are managed over the Ethernet interface using text-based command protocol over telnet. RS-232 interface is provided for reprogramming and debug.

Apart from adequate embedded programs, testing software was developed. This software will also serve as a reference for implementation of corresponding modules in NICA booster control system.

## CONTROLLER MODULE

Observing tab. 1 one may conclude that controller module must supply 3 high rate (50 kHz) output channels and measure 6 output channels with same rate. Most calculations and data conversions require floating-point arithmetic. It is also necessary to arrange data interchange between several independent measurement and control devices. E.g. to generate master frequency controller must receive data from measuring ADC, convert, correct and integrate the resulting value to attain field value then calculate frequency according to formula (1), convert it again and finally send this data to DDS. At the same time a lot of other signals must be changed and measured: resonator voltages, cathode currents, preamplifier voltages etc.

Two main approaches are used for creation of such complex high rate systems: FPGA and high-end micro-controllers. The reasons for choosing micro-controller approach were following: need of floating point arithmetic, complex logic with different modes of operation that will require expansion and finally variety of interfaces (I2C, SPI, Ethernet, RS232).

Controller structure is shown on fig. 3. It is based on Atmel SAMA5D31 micro-controller. Availability of on-board 1 MHz 12 bit 8-channel ADC was a significant advantage. Usage of SAMA5D31-CK SO-DIMM board allowed to significantly accelerate and simplify PCB design.

It must be noted though that we had to give up usage of any (even real-time) operational system to provide necessary reaction rate (20 μs cycle). Apart from such bare-metal approach we had to significantly optimize our program code. Another restriction we had to establish is following: interaction with booster control system using Ehternet protocol is available only between cycles, while in-cycle Ethernet controller is turned off.

Apparently an ideal approach is using SOC with FPGA and ARM kernel e. g. CYCLONE V SOC. But when we started this work, boards like MITYSOM-5CSX on SODIMM were still unavailable. And PCB layout of

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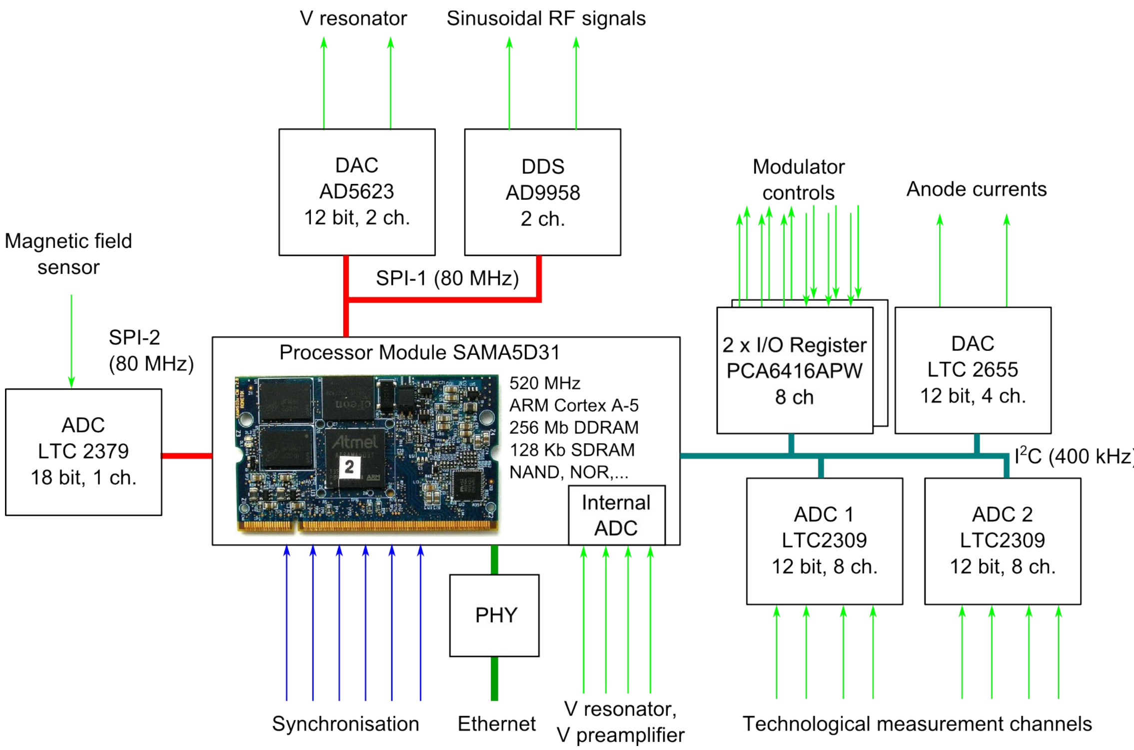


Figure 3: Controller module structure.

CYCLONE V SOC is quite problematic in itself and was considered more tedious than program optimization.

## TESTER MODULE

Imitation of the signal from induction magnetic field sensor and generation of synchronization pulses sequence according to the booster mode is the main task of this auxilary module. Resulting imitated signal and it's integral (magnetic field) is shown or fig.3.

For the operational check of RF stations tester has a multiplexor that allows to disconnect controller module from booster systems and check it's operational capability. Generally, tester will be in through-pass mode when real signals from booster are provided to the controller inputs.

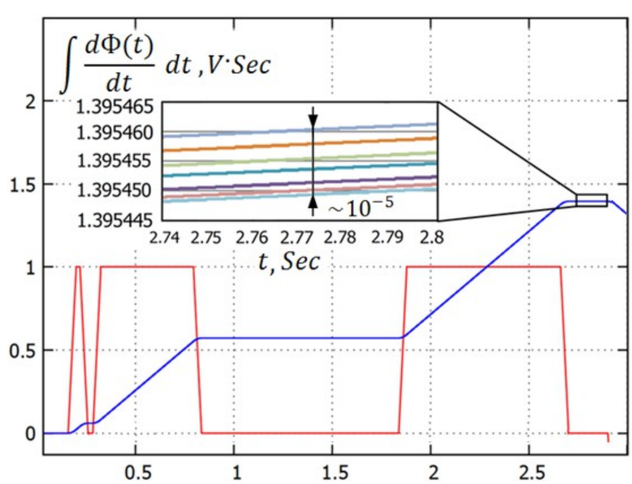


Figure 4: Imitation of magnetic field sensor signal.

Particular attention was paid to precision of imitation circuit design. Resulting noise of integral (magnetic field) at the end of acceleration cycle is shown on fig. 4. This resulting noise is $\pm 5\cdot 10^{-6}$, attained signal noise is $\pm 5$ μV and temperature stability is 5 ppm/°C. Imitator circuitry is based on DAC8331.

Intellectual part of tester module is based on LPC2478 processor and provides control of DAC, synchronization pulses generation, multiplexor control and Ethernet interface for inter-operation with booster control system.

## CONCLUSION

Controller and tester modules were designed manufactured and tested in work with RF stations. Usage of SAMA5D31-CK board allowed to achieve necessary speed and algorithm modification easiness. Processor had almost reached it's performance capacity though. And bare-metal programming is not very comfortable. In future similar works it is more appropriate to use more powerful multi-core processors like TI AM355x or CYCLONE V SOC chips. This will allow to use real-time operational system and further ease software development.

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