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POWER SUPPLY CONTROLLER FOR FUTURE ACCELERATOR FACILITIES AT BINP

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Abstract

A design of a new power supply controller was initiated in BINP for upgrade of existing accelerator facilities and for demands of future projects. Any accelerator facility includes a set of diverse power supplies which controllers have different specifications: number and precision of DAC/ADC channels, speed and algorithm of operation. Therefore, the main idea is to elaborate a controller, which consists of common digital part including an interface with a control system and specialized analog frontend that fits to power supplies requirements. The digital part provides easy integration to control system by means of some standard network protocol and performing some data processing and analysis. Ethernet is used for communication with controllers, MQTT is under consideration as a high-level transport protocol in some cases and EPICS IOC was tested to be embedded into controller. The initial prototype of controller is developed and deployed at VEPP-3 storage ring. The status of the work and future plans are presented in the paper.

INTRODUCTION

Modern circular and linear electron accelerators, which are part of accelerator complexes, are used for synchrotron radiation generation or for physical experiments. They operate with high-density beams of charged particles, which are moving in strong magnetic fields and are very spatially restricted. The smallest and even momentary fields' fluctuations from the prescribed values cause particles death. Therefore, experiments with such beams need positioning of their trajectory or equilibrium orbit with high precision up to parts of micron. These conditions lead to following requirements for magnetic system control: relative stability precision and control of main magnetic elements should be 0.001 % and better, continuous measurement with frequency about 1 kHz of power supply main parameters is necessary at circular accelerators.

To solve mentioned problems a control system based on non-trivial power supply controllers of magnetic system elements is needed. Such controllers should synchronously process and measure specified output parameters with required precision. In addition, this control system should provide transmission and on-line processing of data streams from hundreds of devices for detecting abnormalities in power supplies operation. This paper considers a perspective approach for power supplies development for such control system.

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THE HISTORY

Evolution of accelerator control systems at BINP has the following history.

The first automation systems (in 1970s) based on computers and on dedicated in-house developed digital-analog electronics connected to them. Computers and electronics were concentrated in certain places. At that time, electronics did not have built-in processors and was connected to computers through in-house designed serial communication links with cascade connection. Analog signals between digital-to-analog electronics and controlled equipment propagated over long cupper cables, causing problems from noises, attenuation, and signal dissipation.

The next step of the BINP's accelerator controls development [1] was related with the use of modular crate electronics systems and, first of all, CAMAC. Creation of intelligent crate controller in BINP, in fact – a home-developed computer, as well as development of wide range of electronic modules for CAMAC satisfied all the requirements of control systems on accelerator complexes both in BINP and in the other accelerator centres of the USSR for many years [2]. While providing a relatively high data rate to the computer, this approach to control system design had the same disadvantage: electronic devices were located in crates in certain places; analog signals from the equipment were transmitted through long cable links.

Further (in 1990-2000s), both structural and functional evolution of control systems in BINP was based on the use of processors in analog-to-digital modules, as well as on using of serial communication links, and, first of all, CAN (Controller Area Network) [3]. A typical scheme of controllers of that period is shown on Fig. 1.

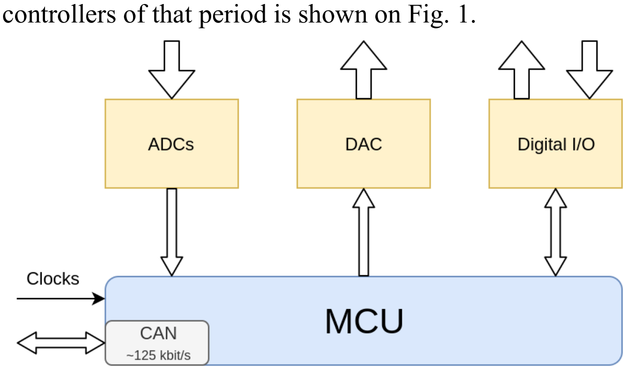

Figure 1: Power supply controller architecture based on MCU (Microcontroller Unit) and CAN.

This approach provided a possibility to develop distributed systems with control electronics located in close proximity or inside controlled devices [4] in order to reduce the lengths of analog signal wires. The use of

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processors provided some data processing operations within distributed controllers (interpolation between reference control values, averaging and filtering of measurements, calculation of various values) and opened new features for distributed control, and the application of CAN, for example, gave a possibility to interact with a control computer in active mode, transmitting data as it were ready. The main disadvantages of distributed control systems built on serial communication links are difficulties associated with connection of multiple modules to one line, as well as low data transfer rate. For example, it is not possible to provide continuous synchronous monitoring of parameters of a big set of controlled devices.

New approaches for design of distributed control systems are now possible due to the availability of components for construction of high-speed Ethernet networks (1-10 Gbps) and powerful compact processor modules (System on Module). These processor modules are capable to operate under Linux, as well as to perform real-time operations, and they are equipped with various interfaces for communication with computer and different peripheral devices (ADCs, DACs, etc.),

New approaches assume placing device controllers inside the devices, implementing device control logic, data processing and synchronizing of operations within the controllers, as well as fast communication with control computer via Ethernet to transfer measured data from all controllers (about 10 kB and more from each) in a short time interval.

PROPOSED APPROACH

Concept Description: Using SoM

At present time, highly integrated circuits so called SoC (System on Chip) are available for development of electronic devices. They include a full range of components that are vital both for power supply controller programming and for communication with upper level of control system and with A/D components of controller.

As an example lets review a NXP/Freescale i.MX7 chip. An important feature of this chip is that it contains two processor modules. The first one is a high-performance ARM Cortex-A7 with two cores working at 1.2 GHz. Another one is an ARM Cortex-M4 core operating at 200 MHz that it is typically used for real-time tasks. Communication between modules is available via RPMsg (Remote Processor Messaging) mechanism that is built into Linux kernel, and both modules have access to shared RAM. In addition the chip has many peripheral equipment such as DMA-controller, embedded memory, ADC, Ethernet-controllers, USB, SPI CAN, PCIe, external memory support including DDR2/3, NAND/NOR Flash, eMMC and so on.

This chip is frequently used on SoM (System on Module) – a small printed circuit board which may include in addition RAM, non-volatile memory and other necessary equipment and usually has a standard form-factor, e.g. SO-DIMM. As an example of such SoM we chose VAR-SOM-MX7 by Variscite, see Fig. 2.

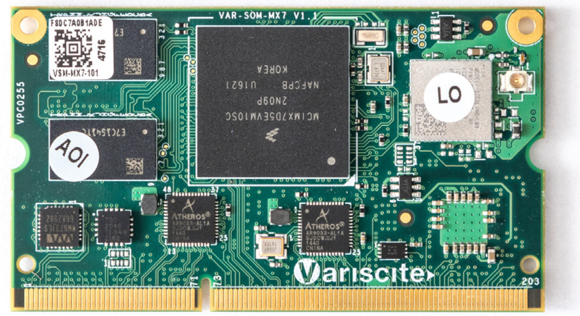

Figure 2: Variscite VAR-SOM-MX7.

NXP/Freescale i.MX7 is supported by GNU/Linux on main Cortex-A7 cores. Variscite provides prepared for use distributives Debian and Yocto Linux. Cortex-M4 core is supported by different RTOS (real-time operation system) and by FreeRTOS [5] in particular.

As a result, the logical scheme of power supply controller is shown on Fig. 3.

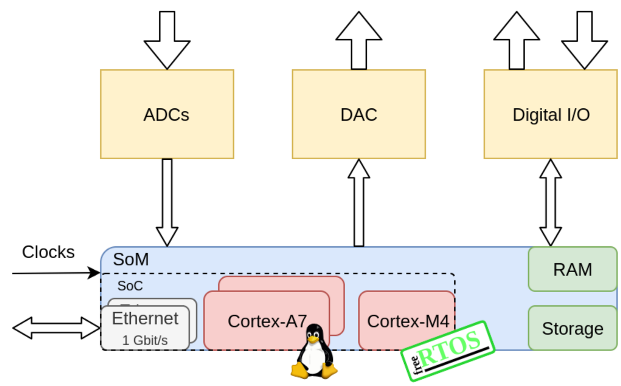

Figure 3: Power supply controller architecture based on SoM and Ethernet.

Real-time Tasks

A modern power supply controllers of accelerators' magnetic system should perform a number of tasks at real time.

Setpoint execution Usually controller should generate reference voltage for power supply using DAC by predefined table of setpoints with a frequency about 10 kHz. This frequency is limited by pair of power supply and its load (electromagnet) and is defined by operation pattern of accelerator and specific magnetic element. The size of a table is determined by acceleration cycle duration and is interrelated with a frequency. For example 10 kHz frequency corresponds to 10 000 points that is equivalent to 1 second cycle.

Measurements To monitor power supply it is necessary to measure a set of work parameters. Thus, a controller requires a set of ADC channels. For above-mentioned DAC speed numerical estimations, a

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sufficient ADC frequency would be 1-10 kHz. A sufficient number of ADC channels is defined by power supply type and typically is 4-6 channels total.

Measurements processing and transmission It is very important to guarantee power supply operation stability during an experiment and in case of some trouble to capture wrong parameters and inform facility operator. To monitor power supply stability it looks rationally to perform simple measurements analysis on-board and not transmitting all data to the upper level. In case of significant deviation, it is enough to alarm and send all relevant measurements. In that way a load to network and servers could be significantly decreased without losing a quality and performance of control system.

Besides the default operation mode, such controller should allow to operate in debug mode when all measurements are transmitted to the upper level for troubleshooting of particular controller or power supply.

Embedded EPICS

Due to relatively high performance of Cortex-A7 cores and thanks to the fact that they operated by Linux it is possible to integrate such controller into facility control system like EPICS directly without using intermediate gateways and special network protocols.

Tests with SoM VAR-SOM-MX7 running Debian GNU/Linux 9.9 (kernel version 4.9.88) and EPICS-base 7.0.2 shows sufficient performance reserve for planned usage of perspective controller. In particular while publishing PV containing 20 000 DOUBLE values to 256 clients the CPU load is 40-50 % for IOC and 40-60 % for ksoftirqd (with regard to the maximal load of two cores is 200 %). In case of 20 clients, the CPU load is 40-50 % for IOC and ~5 % for ksoftirqd. In that test the delay between sending array to IOC (caput) and receiving by all clients (camonitor) was measured. In the first case, it takes about 1 second that corresponds to 1 Gbps Ethernet bandwidth and in the second one it takes about 0.1 second.

INTEGRATION WITH LEGACY

When developing perspective systems it is important to ensure a smooth transition from legacy to future design. To deal with it a range of measures is foreseen.

Standardized Network Protocols

In a distributed control system with a heterogeneous hardware equipment, it is very desirable to come to common communication language of hardware with upper level of control system. In case of using Ethernet technologies for communication a choice and an implementation goes out easy. However, just so, this step has a fundamental nature and with a right protocol selection is able to simplify integration and support of hardware within control system.

As a kind of such language it is proposed to use MQTT family [6] of protocols or similar. In particular for simple devices based on low performance microcontroller and without (or with poor) TCP/IP it is recommended to use MQTT-SN over UDP.

MQTT-SN guarantees data delivery that is important for control commands and is quite simple in implementation. It has some drawbacks but because of the fact that it is a standardized protocol, it has a wide support in a various software and is a well-documented.

A prototype of power supply controller based on microcontroller with implemented MQTT-SN protocol was developed and deployed at VEPP-3 booster synchrotron. Its printed circuit board is shown on Fig. 4 and structural scheme is shown on Fig. 5.

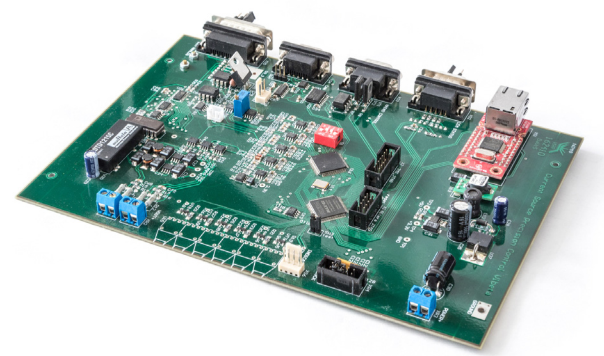

Figure 4: The prototype of power supply controller with MQTT-SN protocol.

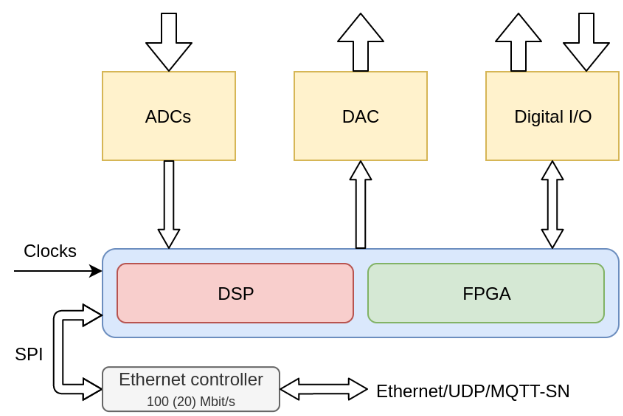

Figure 5: Recent power supply controllers design.

This approach has a few drawbacks:

- external Ethernet adapter has a low performance;
- network protocols and software are limited by MCU;
- programming is quite complex.

Therefore, this variant is not recommended for future developments.

SPI Bus Integration

Existing hardware design with a complicated analog-to-digital block or controllers where a specialized microprocessor for data processing and control is vital a special scheme of SoM integration via SPI bus is possible. This approach allows to have all SoM benefits (Ethernet, Linux with correct TCP/IP, capability to run specialized software like EPICS IOC and etc.) without significant

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modification of existent hardware design. This case is shown on Fig. 6.

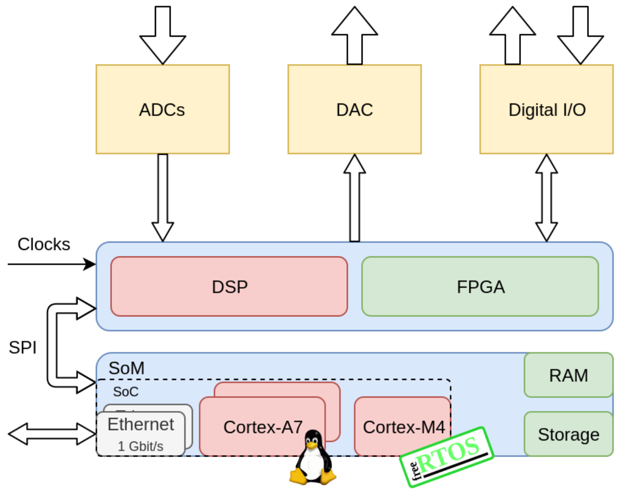

Figure 6: SoM-based design combined with legacy controller.

CONCLUSION

In this paper, an approach to developing future power supply controllers of distributed accelerator control system is described. Their functionality and performance meet the requirements to control modern accelerator facilities like 4-th generation synchrotron light sources. Universality of proposed approach is lies in possibility to create a common interface between hardware and upper level control system software and to ensure integration with legacy and future control equipment. It could be achieved by using SoM as basic component. All necessary A/D components are connected to it via available interfaces and are managed by it. Some SoMs are built around heterogeneous cores of different microarchitectures, have large amount of RAM, flawlessly run Linux, allow to operate with peripheral equipment in a real-time and finally provide powerful tool for data processing. Moreover, Linux presence allows to run control system servers directly on controller that simplifies integration of such controllers into distributed control system and increases reliability due to intermediate gateways exclusion.

The presented approach is planned to be used both for future accelerator facilities and for upgrading control systems of existing installations.

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[5] FreeRTOS, `https://www.freertos.org/`

[6] MQTT, MQ Telemetry Transport, `http://mqtt.org/`