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EMBEDDED LOCAL CONTROLLER FOR THE CS-30 CYCLOTRON*

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Abstract

The Embedded Local Controller is used for upgrading the old CS-30 cyclotron control system at King Faisal Specialist Hospital and Research Centre. It is installed inside the cyclotron vault and connected to the control room using CAN serial bus. This is to avoid adding more wires from cyclotron vault to the outside, because there is no room for extra wires in the feed through conduits. The system is carefully designed to be fault tolerant so that it can run in a radiation environment without failure. Details of the design and field test results are presented.

INTRODUCTION

Production of radioisotopes by CS-30 cyclotron at KFSHRC started in 1982 with seven targets, each positioned at the end of a beamline. In addition to these seven beamlines, it is also possible in this type of cyclotron to irradiate a solid target internally. A special ISO-RABBIT mechanical system connects the cyclotron with one of the hot cells to receive the target before irradiation and deliver it after irradiation. The internal target is located inside the cyclotron tank at the edge of the pole where the proton has gained full energy of 26.5 MeV [1, 2]. Table 1 illustrates the specification of the CS30 cyclotron

In our attempts to upgrade the control system of our old CS-30 cyclotron, we always face the wiring problem. The wiring channels are full of heavy gauge wires and there is no room to add more wires for our upgrade. This raised the need to add a part of this upgrade locally inside the cyclotron vault, and motivated us to design our robust embedded controller to use inside cyclotron vault. Cyclotron local controller is placed inside cyclotron vault to overcome the wiring problem, therefore, it is subjected to a high ionizing and non-ionizing radiation, and must be carefully designed to guarantee reliable operation for a long time [3].

A prototype of the system was produced and as a first try, it is used as a cyclotron vacuum system controller. It has been placed under actual field-testing for more than a year without any failure.

SYSTEM OVERVIEW

The control system consists of backplane, controller board, optional signal conditioning board, and power supply, all placed inside a 19”, 3U sub-rack (see Fig. 1). Figure 2 shows that system is placed inside the cyclotron vault and connected to the remote user interface computer though CAN serial bus.

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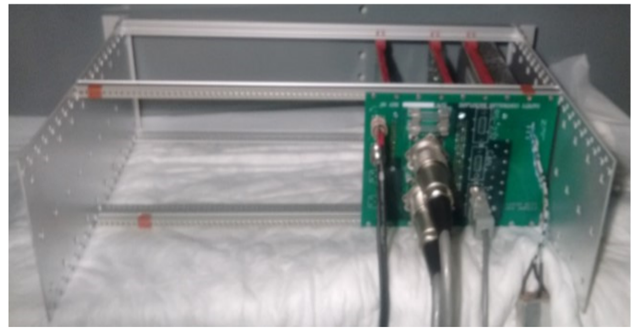

Figure 1: Embedded local controller system.

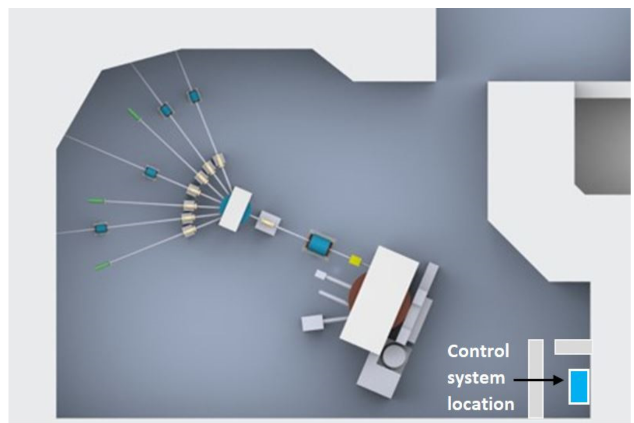

Figure 2: Control system location inside cyclotron vault.

CONTROLLER BOARD DESCRIPTION

Figure 3 shows the PCB of the controller and block diagram of this board is shown in Fig. 4. This board has all sub-circuits that allow it to be high reliability standalone controller. At the top is TMS570LS0432 safety microcontroller (Texas Instruments) that has many features, which make it very robust in the radiation environment [4]. There is a digital I/O sub-circuit, with 16 lines output (24 V, 0.5 A), 24 lines input (24 V), and four high-speed inputs (24 V) that can be used as quadrature encoder input. Additionally, there is an analogy I/O sub-circuit, with 8 analogy inputs (programmable range) and 8 analogy outputs (programmable rage). In addition, there are two CAN ports, one isolated and the other non-isolated, and one isolated RS-232 port. All sub-circuits power supplies are protected and can be on/off controlled, and can be monitored through the microcontroller, this feature is crucial to monitor current variation due to the effect of radiation.

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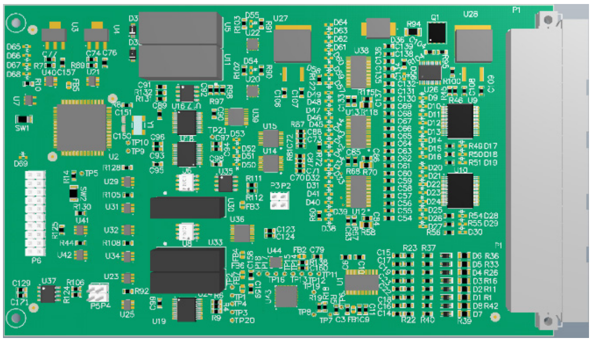

Figure 3: Controller PCB.

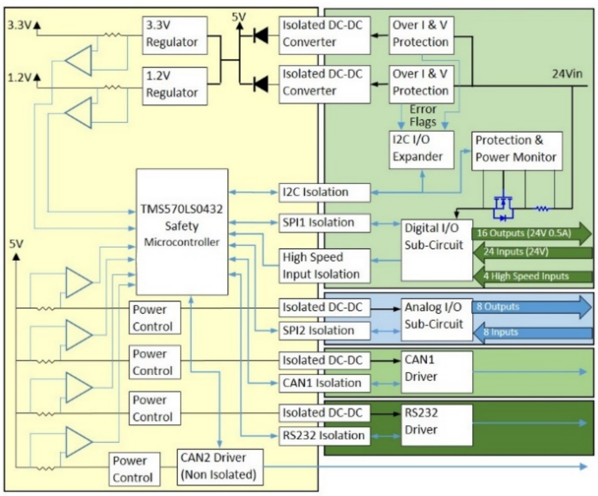

Figure 4: Controller block diagram.

Microcontroller Sub-circuit

Power supply of this sub-circuit utilizes two parallel connected DC-DC converters with two protection circuits. This ensures the operation of the circuit even with one DC-DC converter failure, thus increasing system reliability. The protection circuit provide flags to the microcontroller indicating over current or voltage.

LDO voltage regulators are used to generate 3.3 V and 1.2 V for microcontroller supply.

Current consumption of 3.3 V and 1.2 V supplies can be monitored by the microcontroller such that detect any abnormalities due to ionizing radiation.

Microcontroller used is Texas Instruments TMS570LS0432 safety microcontroller. It is a high-performance automotive-grade microcontroller for safety systems. The safety architecture includes dual CPUs in lockstep, CPU and Memory BIST (Built-In Self-Test) logic, ECC (Error Correcting Code) on both the flash and the data SRAM, parity on peripheral memories, and loop-back capability on peripheral I/Os. All these feature make it ideal for high reliability, fault tolerant system.

Digital I/O Sub-circuit

Figure 5 shows the block diagram of the digital I/O sub-circuit, which comprises digital output, digital input, and high-speed digital input. Digital output is implemented using two VNI8200XP (ST Microelectronics) high side driver which capable of driving up to 0.7 A, 32 VDC. It converts serial data at the SPI port into the parallel high current output.

Digital input is implemented using three SCLT3-8BT (ST Microelectronics) protected digital input with serializer. It accepts up to 35 VDC parallel input and convert into serial data that can be read by microcontroller SPI port.

Finally, the high speed input comprises two PCLT-2A (ST Microelectronics) that convert the high voltage signal to a low voltage logic signal that can be fed to the microcontroller. The high speed digital inputs can be used for quadrature encoder interface. This encoder interface can be used for motor speed measurement, flow sensor, or any other quadrature signal interface.

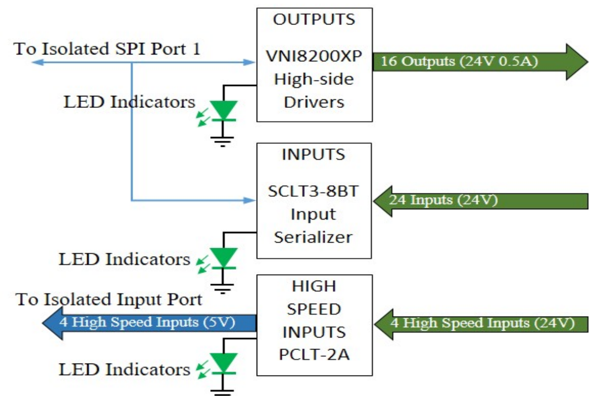

Figure 5: Digital I/O sub-circuit.

The power supply of digital I/O sub-circuit is controlled and monitored using TPS2483PW (Texas Instruments) by which we can turn the power on or off and can measure the voltage and current drawn by this sub-circuit. This can help in discovering the circuit abnormalities before complete failure.

Analog I/O Sub-circuit

The analog I/O sub-circuit (see Fig. 6) comprises ADS8688A 8 channels, 16 bits ADC (Texas Instruments) for analog input, and LTC2668 16 channels 16 bits DAC (Linear Tech) for the analog output.

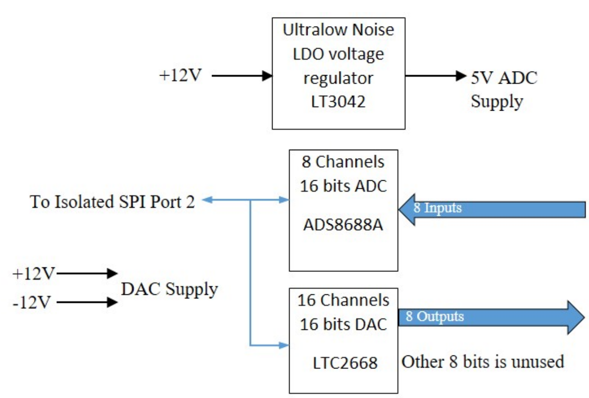

Figure 6: Analog I/O sub-circuit.

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Also, LT3042 Ultralow Noise LDO voltage regulator (Linear Tech) is used to generate the supply of the ADC. The power supply current of this sub-circuit is monitored by the microcontroller for any abnormalities to give early warning before complete failure.

Serial Communication

There are one isolated CAN port, one non-isolated CAN port, and one isolated RS-232 port. The supply of these ports can be on/off controller, and measured by the microcontroller to monitor the effects of radiation on the IC's. The isolated CAN port (CAN1) is used for communication with host computer at the control room. Non-isolated CAN port (CAN2) can be used for communication between modules on the same backplane, allowing the use of more than one controller board to increase the number of I/O, or to make a redundancy to improve the reliability of the system. The isolated RS-232 port can be used to interface with other external equipment that equipped with that port.

Software

The host PC at the control room is connected to the controller through CAN bus using Remote Procedure Call RPC [5]. It is a simple way to transfer control and data across a communication network (CAN bus). Figure 7 shows the components of the RPC system.

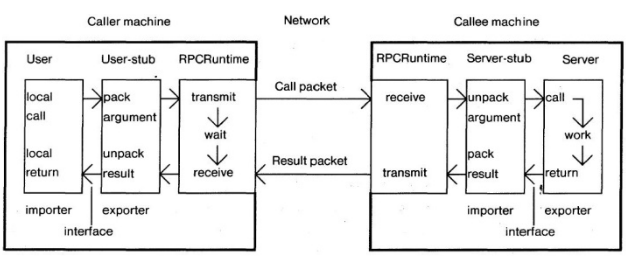

Figure 7: Components of RPC system and their interactions.

In this preliminary version of the software, we have the minimal number of RPCs that can work the system, and it can be extended to get more functionality. Table 1 lists the currently implemented RPCs.

BACKPLANE DESCRIPTION

The backplane is customized according to the requirements (see Fig. 8). At least, it contains connectors for the one power supply, and one Controller board. It may contain a connector for signal conditioning board that is used to interface with different sensors in the system (e.g. Vacuum sensor). Also, it contains the cable connectors that interface with different actuators and sensors of the system. The following figure shows the backplane used to control the cyclotron vacuum system.

Table 1: RPCs

Proc. ID	Procedure
0	void SetOutputBit(uint8_t OutputNumber, uint8_t Out-putState);
1	void SetOutputValue(uint32_t OutputValue);
2	uint32_t GetOutputValue(void);
3	uint32_t GetOutputInterlockValue(void);
4	uint8_t GetInputValue (uint32_t* InputData);
5	uint16_t GetAnalogValue (uint8_t ChannelNumber);
6	uint32_t GetFlowRate(void);
7	uint32_t GetErrorFlags(void);
8	uint32_t GetFirwareVe (void);
9	void SetAlarmHi(uint8_t Channel Number, uint16_t AlarmHiValue);
10	void SetAlarm Lo(uint8_t ChannelNumber, uint16_t AlarmLoValue);
11	Errors Get UcErrors (void);
12	void InjectError (uint8_t Index, uint8_t DualBit);

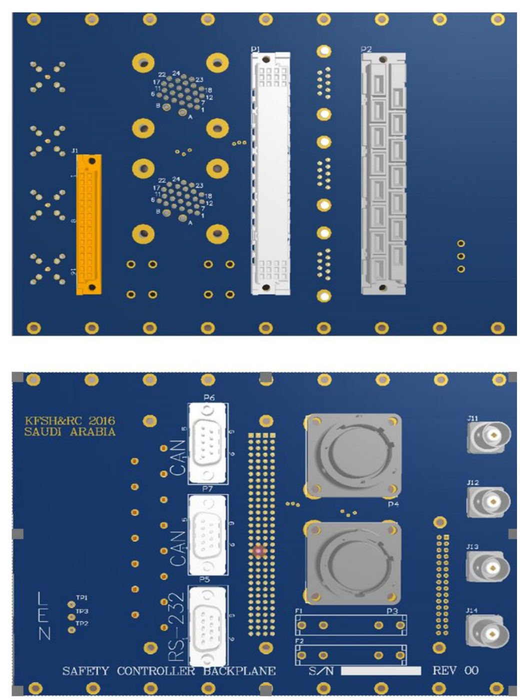

Figure 8: Backplane front (up) and back (down).

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FIELD TEST

The system was installed inside the cyclotron vault and was under full operation for more than one year. Table 2 lists the run history during this duration.

Table 2: Cyclotron Production Run

Isotope	Target	Run Time	Average Current (µA)	Number of Runs
^{123}I	Internal	3 Hr	18	39
^{81m}Kr	Line 5	1 Hr	13	34
^{13}N	Line 7	5 Min	10	34
^{67}Ga	Internal	7.5 Hr	45	6
^{201}Tl	Internal	5 Hr	80	5

During this duration, the microcontroller detected only one correctable error.

CONCLUSION

Embedded Local Controller is a way to place the control system inside the cyclotron vault. This has a great advantage to reduce the wiring complexity and cost. It also allows easy extend and modify the functionality. This raises the issue of semiconductor operation in the radiation environment. By carefully designing the system and using a powerful microcontroller with redundancy, we can achieve the required working time using COTS components.

ACKNOWLEDGEMENTS

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