Distributed Low Voltage Power Supply System for Front End Electronics of the TRT Detector in ATLAS Experiment

E.Banaś[a], P.Farthouat[b], Z.Hajduk[a], B.Kisielewski[a], P.Lichard[b], J.Olszowska[a], V.Ryjov[b], L.Cardiel Sas[b]

[a]Henryk Niewodniczański Institute of Nuclear Physics PAN, ul. Radzikowskiego 152 , 31-342 Cracow, Poland
[b]CERN, 1211 Geneva 23, Switzerland

elzbieta.banas@ifj.edu.pl, philippe.farthouat@cern.ch, zbigniew.hajduk@cern.ch , bartlomiej.kisielewski@ifj.edu.pl, peter.lichard@cern.ch, jolanta.olszowska@ifj.edu.pl, vladimir.ryjov@cern.ch, laia.cardiel.sas@cern.ch

Abstract

We present a low voltage power supply system which has to deliver to the front end electronics of the ATLAS TRT detector [1] ca. 23 kW of electrical power over the distance of 55 -106 m (which adds another 24 kW). The system has to operate in magnetic field and under radiation environment of the LHC experimental cavern. The system has ~ 3000 individual channels which are all monitored and controlled (voltage and current measurement). The hardware solutions are described as well as the system control software.

I. INTRODUCTION

A. TRT detector

The TRT (Transition Radiation Tracker) is a part of the Inner Detector tracking system of ATLAS experiment. It covers $|\eta|<2.5$ in pseudo rapidity at radii between 128 and 206 cm, allows for electron-pion separation at 97% level and provides continuous tracking with accuracy ~120 μm/point. The detector has three parts – barrel and two end-caps – which consist of arrays of the thin walled proportional counters – straw tubes. The barrel detector contains 96 parts called modules (3 layers of 32 modules). The end-caps consist of 20 'wheels' each, where wheel is functionally divided into 32 sectors. Each module and sector have its own individual electrical services (HV, LV, timing etc). The straw configuration gives ~36 space measurement points in whole TRT acceptance. The detecting elements act as drift tubes ensuring the tracking function and measure energy deposit in specially chosen active gas allowing for efficient detection of the transition radiation photons thus performing identification function. The detector contains ~350 000 detecting elements - straws.

B. Power requirements

The front end electronics of the TRT is based on two custom designed ASIC's: ASDBLR (amplifier-shaper-discriminator-base-line-restorer) which amplifies, shapes and discriminates the charge signal from straw anode and DTMROC (drift-time-measuring-read-out-chip) which measures the time-of-arrival of the signal with respect to the bunch crossing, encodes the charge value and serves as the read-out controller. Both chips are designed in radiation hard technologies. Total power consumption of individual channel is 40 mW/channel for ASDBLR and 21 mW/channel for DTMROC. From quoted numbers we find that whole front end (F-E) electronics consumes ~23 kW of power. Modern fast electronics requires very low voltage power supplies which results in high supply currents. Then a length of the cables, their cross-section and voltage drops are important factors for the power supply system design.

The F-E electronics of the TRT requires +/-3V (analogue part) and +2.5V (digital part). The auxiliary circuitry requires additional, supply of +5V with relatively low current.

The following table shows the current consumption in different detector parts.

Table 1: Power consumption in TRT detector (per side)

Sub-detector	Per stack/sector/side			Per subdetector/side		
	+3V	-3V	+2.5V	+3V	-3V	+2.5V
Barrel	13A	11A	13.5A	416A	352A	432A
Wheels A	18A	16A	19A	576A	512A	608A
Wheels B	12A	10.5A	12.5A	384A	336A	400A
Total	*43A*	*38A*	*45A*	*1376A*	*1200A*	*1440A*

Estimated power dissipation in the front end electronics is 22.66 kW. This requires careful design of the cooling system having in mind the confined space where electronics is positioned.

II. ARCHITECTURE OF THE SYSTEM

The TRT low voltage system consists of two basic parts - Figure 1:

- ✓ Bulk power supplies delivering power to distributors associated with detector geographically defined zones (in TRT case this are 32 sectors in Phi)
- ✓ Voltage distributors which supply individual loads (multiple in each sector) splitting the lines received from bulk power supplies

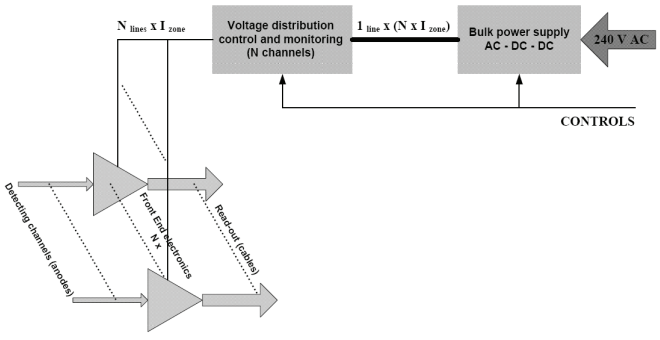

Figure 1: Architecture of the powering system

A. Bulk power supplies

To minimize the need for development, service and maintenance effort we have decided to use commercially available hardware. After market survey the WIENER MARATON [2] power system has been chosen. The system, developed originally for the needs of LHC experiments is able to operate in the moderate magnetic and radiation fields existing in the ATLAS experimental cavern during LHC operation. The principle of the system is shown on Figure 2:

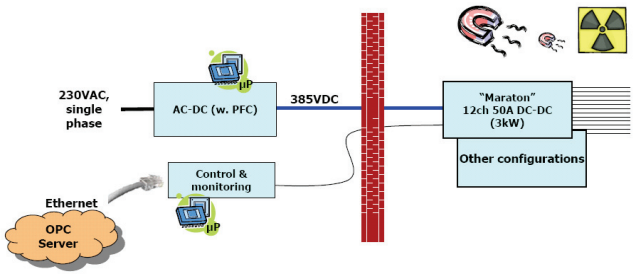

Figure 2: The MARATON power supply system (picture courtesy C.Parkman CERN)

Proper choice of the granularity allows for grouping into 'slices' (or 'wedges') the detector; a 1/32 phi segment of the detector is driven by four MARATON modules (one per each voltage used by the front-end electronics and one for the patch panel) delivering 8 V - 50 A. Control part of the system is placed in the control room. The bulk DC-DC converters are situated in the experimental cavern. Such a configuration allows for reasonably short low voltage cables requiring large cross-section of the Cu conductor and contributing to losses.

B. Voltage distribution

The voltage distribution has been based on the availability of radiation hard voltage regulators [3]. The granularity of the sub-detector front-electronics is such that each 'granule' consumes a current which can be delivered by 1 (or max. 2) voltage regulator i.e. ~ 3 A. The regulators together with control and monitoring electronics has been arranged onto boards which are housed in specially designed liquid cooled simple crates called Patch Panels 2 (PP2). These patch panels boards are placed within the volume of ATLAS at a 12 to 15-meter distance of the front-end electronics.

1) Radiation hard voltage regulators

The LHC(X)913 is a positive/negative voltage regulator family. Housed into power SO-20 slug-up, it is specifically intended for applications in rugged environments, subject to ionizing and neutron radiation. Input voltage ranges from (-)3 to 12(-9) volts. It is characterized by a low voltage drop (0.5 volt@ I_{out}=1A and 1.5V@I_{out}=3A). The over-temperature, and over-current protections guarantee robust operation. Output short circuit monitoring, signalled by TTL output allows for status detection. The regulator can be enabled/disabled by external TTL signal which in our application is going to be used for control of each output.

2) Low Voltage Patch Panels

Groups of regulators supplying geographically close parts of detector front-end electronics have been placed on a printed circuit board together with the control and monitoring electronics. One card of 440x200 mm size houses up to 36 regulators (positive and negative) delivering 6/8 voltage sets : +/- 3 V for analogue electronics and +2.5 V for digital part. Three boards are used to power a 1/32 phi slice of the detector: 1 for the barrel part and two for the end-cap wheels. Due to high power dissipation on the board (60 - 70 W) and to the requirement of being thermally neutral, it is equipped with an aluminium cooling plate which transports heat to the crate body where it is taken away by liquid cooling circuit. Thermal contact between regulators packages and cooling plate is assured by a layer of special thermo conductive rubber. Figure 3: presents the board photo (control side).

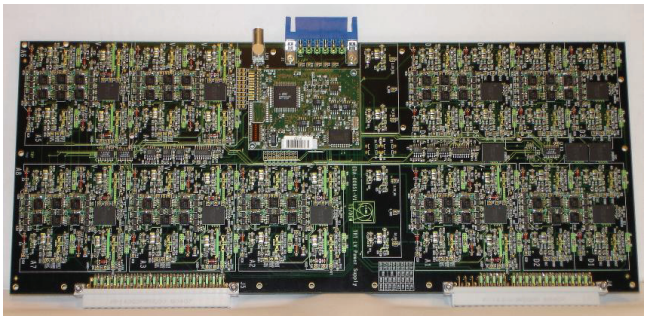

Figure 3: Low voltage 'patch panel' board

The circuits on the board perform the functionalities described in following paragraphs

3) Voltage regulation and setting.

The regulators used are of the adjustable version. Changing the voltage 'adjust' input allows output to be set at the value assuring the proper operation of the f-e electronics during life cycle of the experiment when semiconductor devices could change its characteristics due to radiation. The variable voltage is delivered by radiation hard DAC embedded in the DTMROC chip [8]. The settings of the DAC's are controlled over simple 3-wire serial protocol. The current swing of the DAC output allows for regulators output to be varied by ~0.5V up to 1.2 V, which is fully covering expected change of the voltage supplies of F-E electronics. Figure 4: shows basic schematic of the regulator control [4].

Some F-E parts draw current slightly exceeding the maximum one allowed for the regulators (wheels A). For these channels parallel operation of the regulators has been implemented. Carefully designed biasing network ensures correct sharing of current between the two regulators.

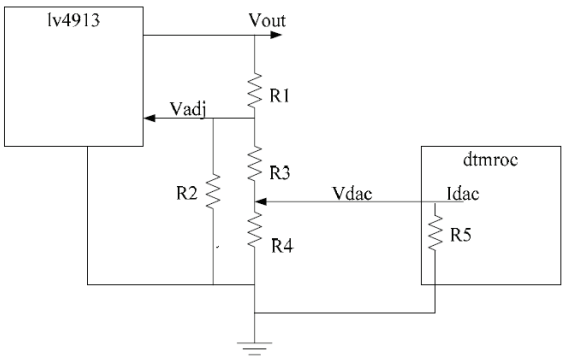

Figure 4: Positive voltage adjustment

4) Voltage and current measurements in each individual output line.

The board contains embedded controller – an ELMB (**E**mbedded **L**ocal **M**onitoring **B**oard), standard control unit designed for ATLAS [5]. All voltage outputs are connected to the ELMB's ADC allowing for output voltage measurements. The same ADC is measuring the output currents, by monitoring the voltage drop on 22 mOhms serial resistors inserted in output lines.

5) Over Current protection

The regulators have an over-current protection which, when current drawn exceeds designed value, operates the regulator in constant current mode. Such a state of regulator is signalled by a level on one of the pins. This signal is latched by board logic and can be read-out by ELMB and if enabled will switch the affected channel off.

6) Enabling and disabling individual output lines (on/off)

The DTMROC has an output which via the proper command can be set 'true' or 'false'. This output is connected to the 'inhibit' input of the pertinent regulator thus providing a mean to switch the regulator output on/off. The same input is as well accepting the signal from over-current-monitor circuitry.

C. Control and monitoring

The TRT power supplies control system has been build upon the commercial SCADA (**S**ystem **C**ontrol **A**nd **D**ata **A**cquisition) software package chosen by CERN as standard for control systems of LHC experiments – PVSSII. Detailed description of the available tools and methods can be looked at elsewhere [6].

1) CAN bus and ELMB

ELMB is a basic hardware unit of ATLAS detector control system which can operate in magnetic field and radiation environment of experimental cavern. It contains 64 channels multiplexed to the ADC input and several I/O digital ports. Its basic functionality and detailed description can be found elsewhere [5]. ELMB commands and monitoring readback values are send over the CAN bus - one of the CERN recommended commercial fieldbuses.

The CAN bus, designed and widely used in automobile industry, is a very robust communication layer and both hardware and software components are available from wide range of manufacturers.

Different autonomous actions can be taken when ELMB error condition was detected: node reboot, microcontroller firmware reload, disconnecting affected node from CAN bus. Merging the NodeID with MessageID codes to COBID (CAN Object ID) field allowed to set very efficient message oriented priority mechanism. A set of broadcast messages allows reducing bus load in complex systems.

2) DTMROC

The DTMROC is the digital front end chip for the TRT detector. This radiation hard chip contains four 8-bit DAC's which are used here to set the output voltage of the regulators.

Writing and reading of the DTMROC registers is performed over a 3-line serial protocol (data-in, data-out, clock) which is driven by the ELMB in this application.

III. SOFTWARE SOLUTIONS

A. Bulk power supplies

The MARATON power supplies are delivered with an OPC server package which serves for the remote control of the unit. The server operates via Ethernet.

1) OPC standard

One of the means to facilitate the equipment integration into complex control system is use of the standard interfacing methods to remove the need of device specific drivers. Industry cooperation with Microsoft has resulted in construction of the OPC (OLE for Process Control) standard. The device driver is hidden under the server software layer which when complying with OPC rules allows for easy integration into any SCADA system. The OPC standard has been adopted by CERN as one of the mandatory specifications for commercial equipment purchased for LHC experiments.

2) CERN FRAMEWORK

The effort needed for design and construction of the control system for LHC experiments in many cases surpasses the possibilities and available manpower of groups involved. This has resulted in wide use of commercial equipment and software tools making the tasks possible to achieve. CERN control group from IT department provides users with the skeleton software solution called FRAMEWORK. The package contains many useful tools serving for construction, integration and configuration of the complex multi-channel systems build of the standard, widely available equipment. The MARATON system has been included into FRAMEWORK which makes its integration very easy. Figure 5: shows typical PVSSII [6] control panel for MARATON system which can be tailored to specific user needs.

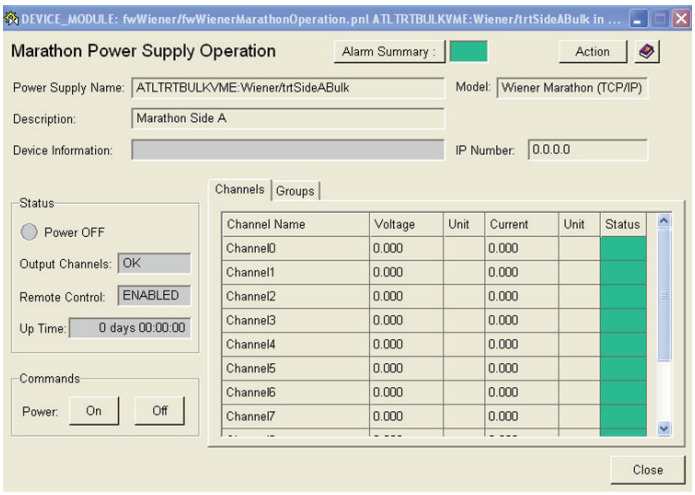

Figure 5: MARATON control panel as provided by CERN FRAMEWORK

The control commands of the MARATON system are limited. Basically the only important action which can be undertaken by user is switching the given output *on* or *off*. Such an action is triggered by clicking *ON* or *OFF* buttons on the panel.

B. LVPP boards

The main development effort spend on the TRT low voltage system has been directed into the design, programming and debugging of the Low Voltage Patch Panel boards (LVPP) containing the voltage regulators and main controlling/monitoring circuitry. As already has been mentioned the heart of the LVPP is an ELMB communicating with the host controller over the CAN bus. The read-out of the analogue values (current and voltage) is typical (and standard) for ELMB use and is based on the CANOpen [9] software layer where the OPC standard for data access has been implemented. The 'analogue' functionality of the ELMB has been included as well into CERN FRAMEWORK package so the integration and control is reasonably easy and straightforward. Fully custom made design was done for the control of the voltage regulators by DTMROC's. Figure 6: shows idea of the control.

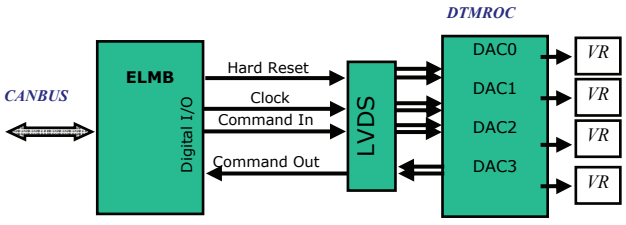

Figure 6: ELMB controls DTMROC

1) Possible solutions

The commands issued by control application to the DTMROC's via ELMB have to follow the mentioned control protocol i.e. ELMB has to send properly formatted data stream accompanied by clock pulses. This is done by proper control of the outputs of the ELMB digital ports. However correct sequence of bits and clock pulses on the output lines can be generated by programming in several places of the software layers. The expected performance is discussed on Figure 7:

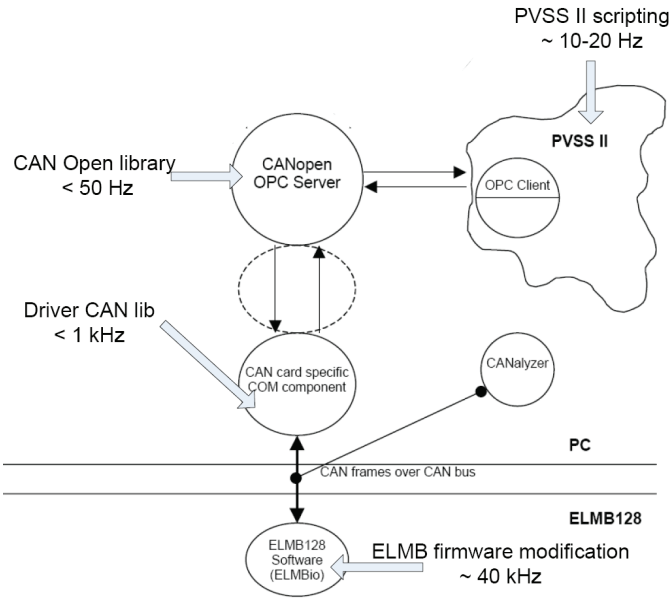

Figure 7: DTMROC control - possible places of the control software embedding

The easiest way would be to implement all algorithms simulating the DTMROC serial protocol in the PVSS layer. However this leads to slowest clock due to fact that scripting language of PVSS is interpreted and not compiled. The most performant solution would be to modify ELMB firmware embedding in its memory preset bits patterns send to DTMROC by single CAN message. Other, intermediate solutions would be to use modified software of CANOpen level or one acting directly on the driver by calls to its DLL classes. The attractive, firmware based solution has been dropped off since this would mean that our ELMB's become TRT custom equipment and have to be maintained, serviced and upgraded by us – which due to lack of manpower could not be realised right now. However this remains as possible upgrade for control system in future.

2) Custom DLL

We have decided to construct an extension to the standard PVSS CTRL scripting language [10], which allow for user defined functions to be interpreted by PVSS in the same way as PVSS functions. It consists of a set of class methods compiled into new shared library DLL, providing the input, output parameters and return value. The functions access directly the CANbus driver. The DLL contains following functionalities.

- Initialization of the CANbus, ELMB, DTMROC
- Operational:
  - Setting DAC's,
  - Reading back DAC's,
  - Setting *inhibits* in DTMROC's,
  - Reading back *inhibit* state,
  - Enable/disable and read out OCM state
- Diagnostics:
  - reset (soft and hard) of DTMROC's,
  - send given number of clocks to DTMROC's,

- get state of a given DTMROC,
- set ELMB in the requested state,
- read back ELMB state

- Closing connection,

IV. Performance and Results

The tests of complete system have shown that we achieved DTMROC clock frequency ~ 370 Hz (Figure 8:). The limiting factor appeared to be the ELMB firmware. When operating the CAN bus clock at 125 kHz, some messages have been randomly lost due to ELMB input buffer overflow. We had to operate the CAN bus at 50 kHz.

This results in ~ 5 sec. for setting one LVPP (1/32 of detector part – wheel A, B and barrel).

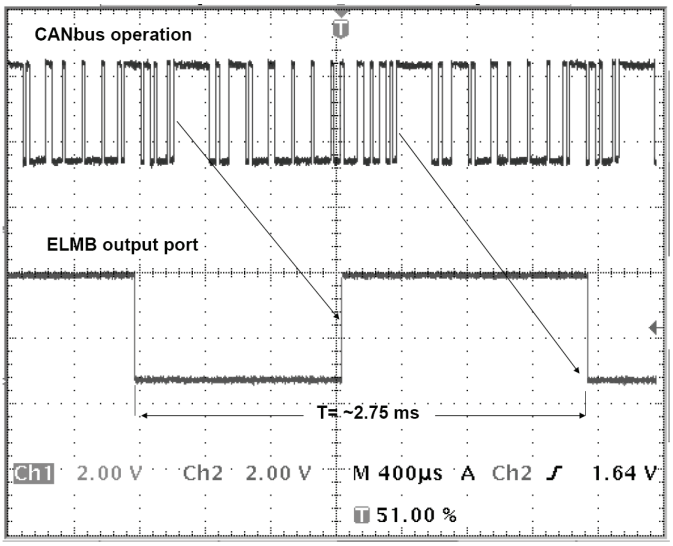

Figure 8: CAN bus messages and corresponding ELMB's digital port output (clock)

Thus the whole TRT can be set in ca. 90 sec's (taking into account topology of LV system, patch panels and configuration of CAN bus branches). If values written in are checked for correctness by read back, quoted time increases to 240 seconds. Since such an operation is foreseen only during cold start up of system (after detector shutdown) this time is deemed fully acceptable. Sequence of the control signals from ELMB is shown on Figure 9:

The plots of the regulators (8 channels) outputs for full range DAC (0-255) swing are shown on Figure 10.

V. Acknowledgements

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Furthermore we wish to acknowledge the valuable help of Francis Anghinolfi (CERN-Geneva) and Daniel Szymański (Jagellonian University Cracow student) for his contribution to the design of DLL.

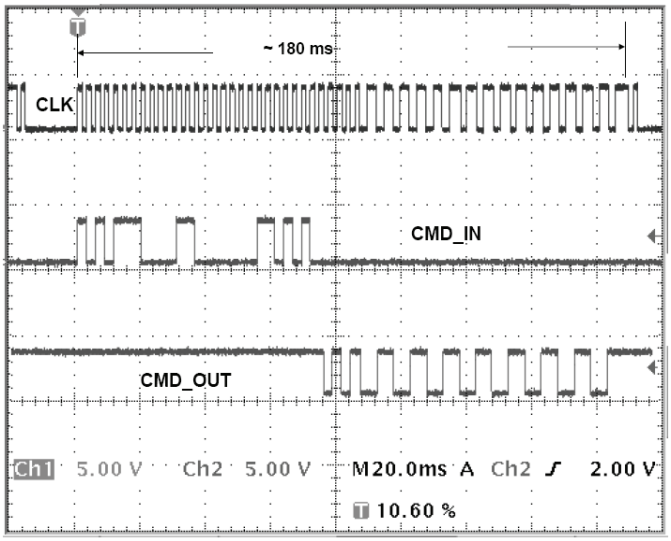

Figure 9: Exemplary scope plots observed on control lines during 'read' operation.

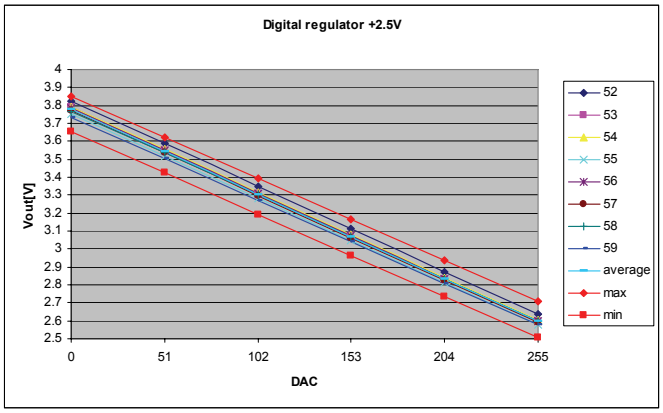

Figure 10: Output voltage of digital regulators

VI. References

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