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Distributed Embedded PC Based Control and Data Acquisition System for TESLA Cavity Controller and Simulator

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ABSTRACT

This paper describes an alternative approach for control and data acquisition system to be used in TESLA controller and simulator (SIMCON) boards [1]. The standard VME controller may be replaced with a cheap embedded PC to provide equivalent or even superior functionality. The new approach offers better cost/performance ratio, better scalability of the system and better testability of the SIMCON boards.

Keywords: TESLA, DESY, FPGA, embedded systems, embedded PC, simulator and controller boards

1. INTRODUCTION

The VME bus is a standard communication interface for controller and simulator (SIMCON) boards in HEP experiments. However, such a solution is expensive and suffers from some disadvantages. The system's VME controller can not service many boards simultaneously, which affects the performance.

The progress of technology allows putting more intelligence in the SIMCON board, and using other interfaces, better suited for communication between such "intelligent boards" - eg. the Ethernet network.

Another advantage of Ethernet is its wide use, which results in very low prices for Ethernet cables, switches and other accessories.

The Ethernet puts relatively high demands on the computational power of the board controller. In fact, it is necessary to put an embedded PC-like system on the board to use Ethernet efficiently.

However, this big computational power may be used to delegate more responsibilities to the boards' controllers themselves. They can work autonomously, in parallel, to boost the performance and responsiveness of the whole system.

2. TYPICAL VME BASED SOLUTION

In the typical VME bus based control and data acquisition system, all boards in a rack are connected to the VME bus (Figure 2 and 1).

The VME's relatively high bus throughput (40 MB/s with 32-bit bus) is shared between all the boards. VME bus uses many wires and requires multi-pin connectors, which makes the mechanical structure of the system more complex and less reliable. Each rack must be equipped with either a VME host (ca. 2500 USD) or a VME bus adapter (ca. 1500 USD), which increases total cost of the system. The VME bus allows fast register accesses and easy bit manipulations, however if the VME interface is connected indirectly (eg. via PCI bridge), such operations may introduce additional latencies.

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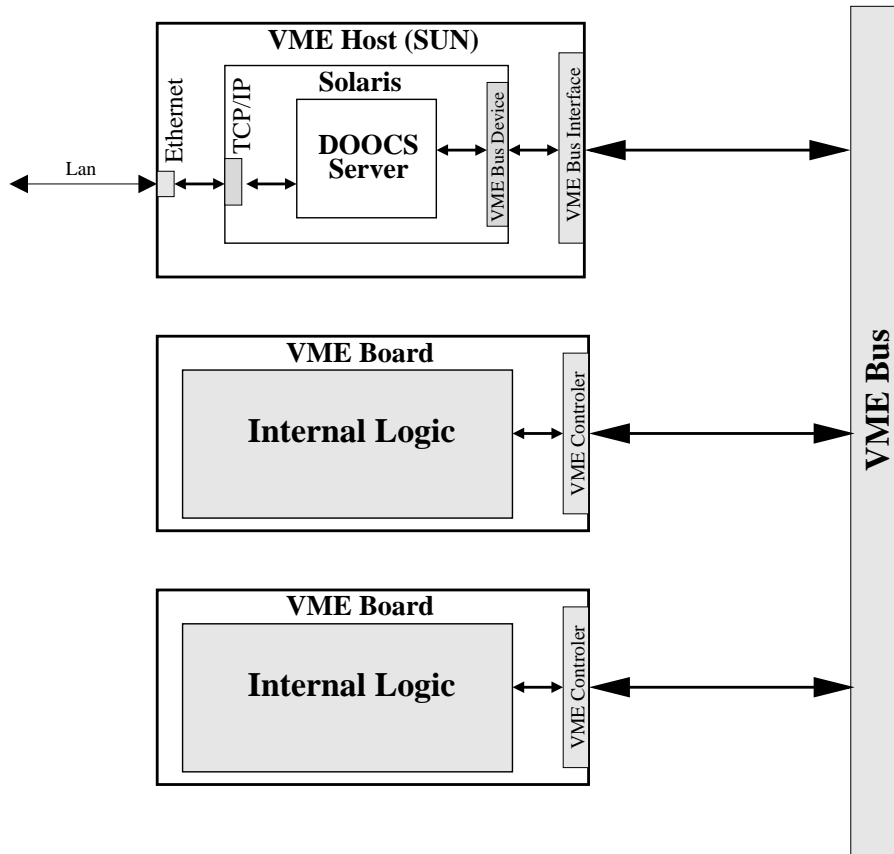


Figure 1. A typical VME based system with VME host.

3. REQUIREMENTS OF THE CONTROL AND DATA ACQUISITION SYSTEM

Typical tasks performed by control and data acquisition systems involve three basic classes of operations:

- Bits and register manipulations performed on hardware registers, often requiring reading of status registers to assure proper handshake. For this kind of operations the overhead introduced by a PCI or other bridge used in the VME host or bus adapter is barely acceptable. To boost efficiency, the CPU should as directly as possible drive the VME, or board's internal bus. Additionally the communication channel load may be lowered if the board's controller would perform such operations autonomously.
- Data processing operations, which may require sophisticated processing of complex data structures. These operation should be implemented in the high level language, and ideally should not absorb the managing host, but be executed by the board's controller autonomously.
- Data transfer operations, which should provide efficient transfer of control data or of acquired data. The communication traffic can be significantly reduced by appropriate preprocessing and sending the preprocessed data instead of raw data.

It is clearly visible that the use of intelligent embedded board controllers is desired to better match the requirements of control and data acquisition systems.

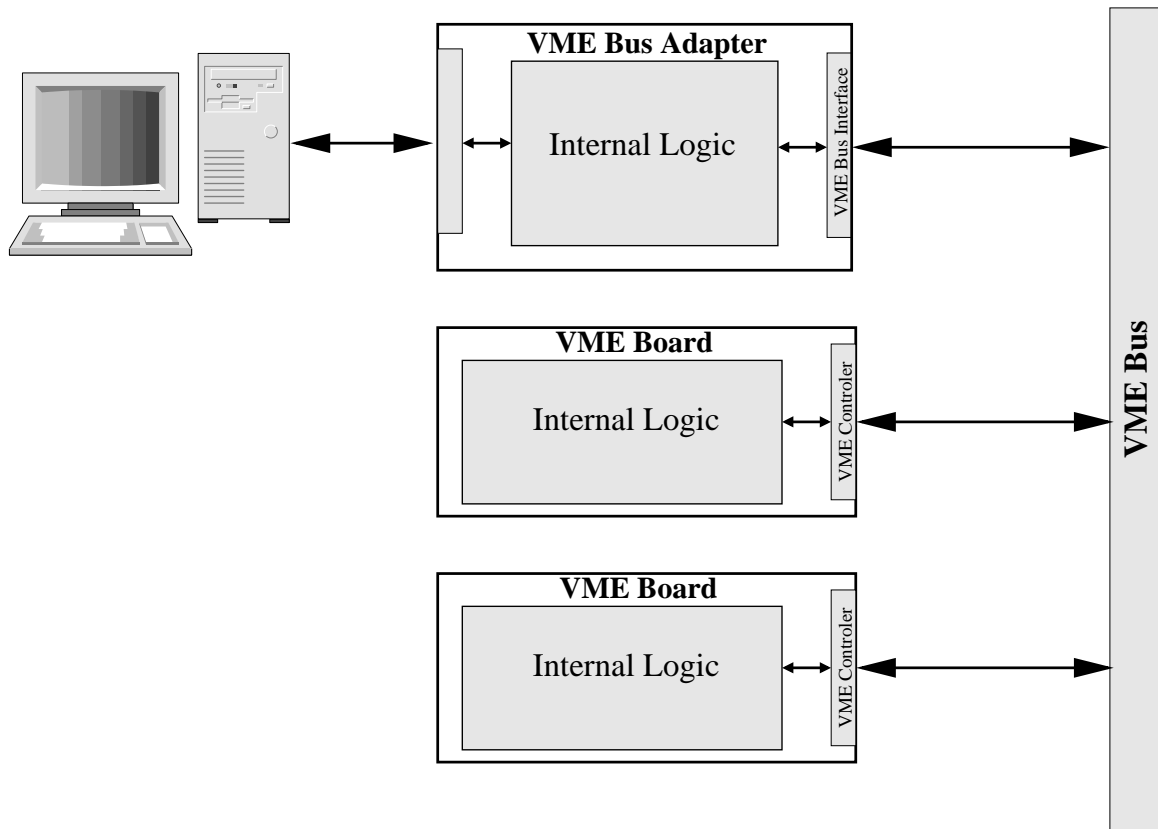


Figure 2. A typical VME based system with external computer and VME bus adapter.

4. STRUCTURE OF THE PROPOSED CONTROL AND DATA ACQUISITION SYSTEM

To provide the best efficiency of control and data transfer operations, an Ethernet interconnected system with embedded board controllers consisting of two basic components has been proposed (Figure 3):

4.1. Single chip microcomputer

The Single Chip Microcomputer (SCM) should be equipped with Ethernet interface to assure network communication with the managing host. It should also implement network protocols used for that communication and perform complex control, data processing and transfer operations.

The SCM should also be able to drive almost directly the VME-like bus used as board's internal bus.

4.2. Programmable FPGA chip

This component should provide a simple interface between the SCM bus and the board's internal bus. It may be used also to implement some additional hardware controllers, which could work autonomously decreasing the SCM load.

4.3. Modularity of the design

The whole Embedded Board Controller should be placed on a dedicated daughterboard with standardized connectors, to assure the technology independence. Such solution warrants that even if the currently used SCM and FPGA chips become obsolete, it will be possible to manufacture another, compatible Embedded Board Controller.

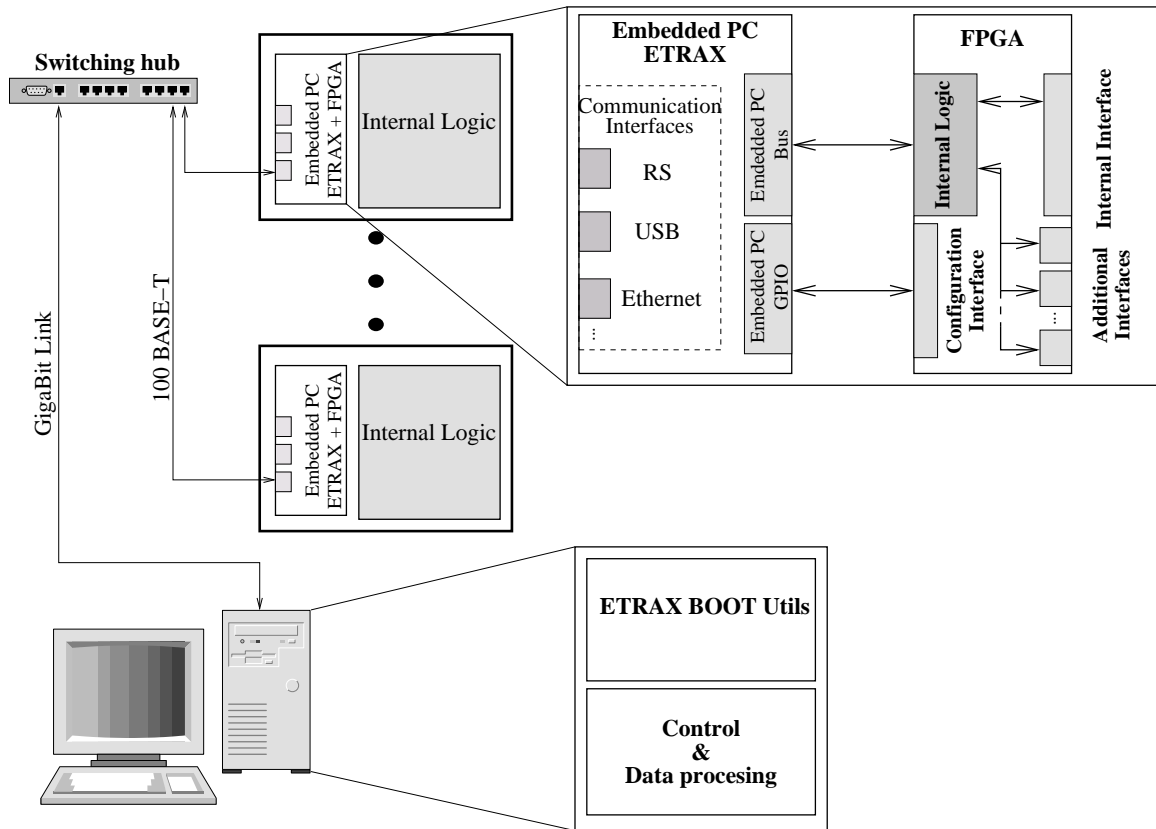


Figure 3. Proposed architecture of the control and data acquisition system.

5. DESIGN OF THE EMBEDDED BOARD CONTROLLER

The final design of the embedded board controller is based on the ETRAX MCM single chip computer and the Altera ACEX FPGA. These components have been chosen considering their availability, price and features.

5.1. ETRAX MCM chip

ETRAX MCM is a relatively cheap (currently 40 USD) single chip computer based on 32 bit 100 MIPS RISC CPU. It provides many peripherals and convenient extensibility possibilities:

- 10/100 MBit Ethernet controller
- 32-bit external memory and peripheral asynchronous bus
- 4 asynchronous serial ports
- 2 synchronous serial ports
- 2 USB ports
- 2 Parallel ports
- 4 ATA (IDE) ports
- 2 Narrow SCSI ports (or 1 Wide)
- 2 MB of FLASH and 8 MB of SDRAM memory
- Support for additional memories (SDRAM, Flash, EEPROM, SRAM, and others)

The ETRAX chip may work under the control of popular Linux OS. Many software tools (compilers, libraries and others) for Linux are freely available, which makes implementing of necessary software both easy and cheap. This

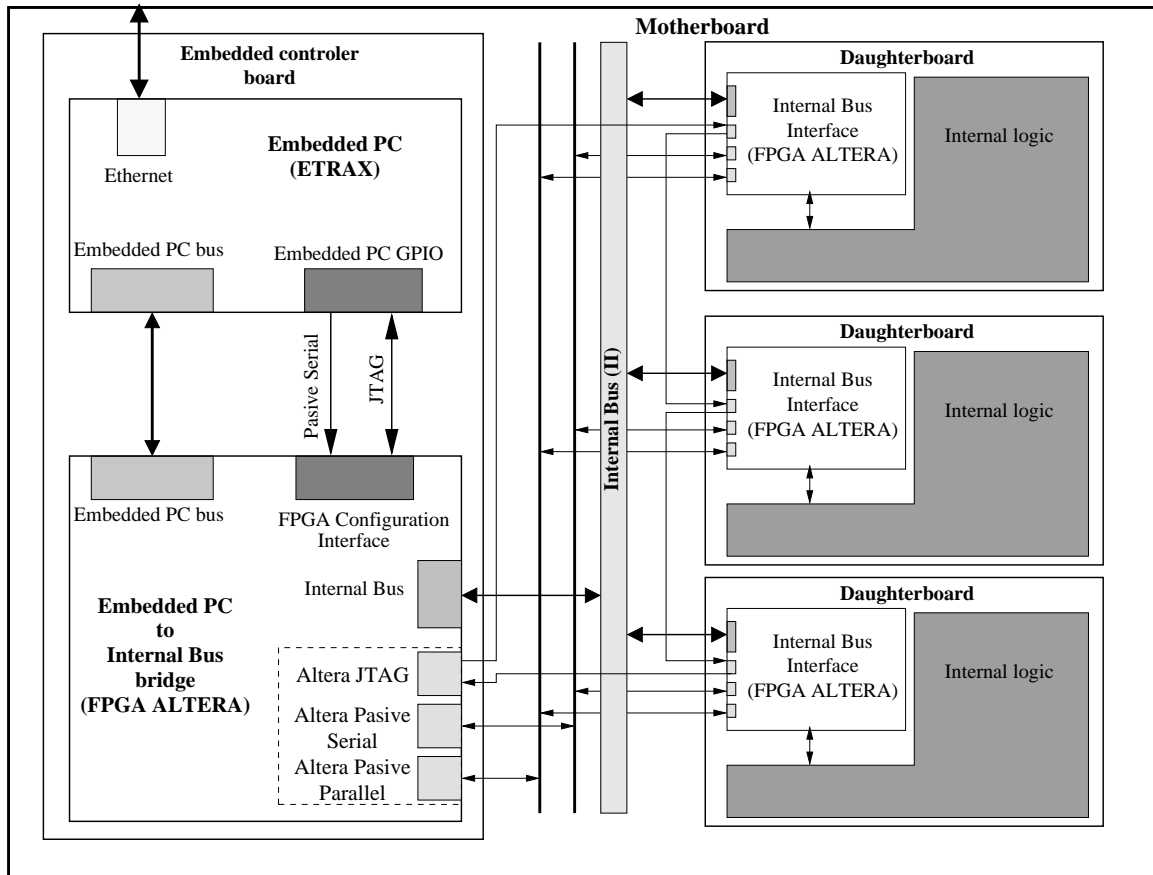


Figure 4. Block diagram of the Controller and Simulator (SIMCON) Board with the Embedded Board Controller (EBC).

system also offers good networking capabilities. Finally, the Open Source status of Linux allows to avoid problems with nondocumented bugs and features of operating system.

Block diagram of the SIMCON board with the Embedded Board Controller (EBC) is shown in the Figure 4.

6. NETWORK PROTOCOLS

The communication between the managing host and the embedded board controllers uses the TCP/IP protocol. This protocol is platform independent, so it doesn't put any limitations on the platform to be used in the managing host. Additionally it is efficient, reliable and well tested.

Because the control and data acquisition network is a private, well protected network, it is possible to use simple protocols. Particularly the RPC protocol will be used to provide communication between the software running on the managing host and programs running on embedded board controllers. However, if the network traffic should be encrypted for better security, it is possible to implement the cryptographical engine with the remaining resources of the FPGA chip.

6.1. Network throughput

The ETRAX chip offers 100 Mb/s Ethernet interface, which effectively should be able to handle 8MB/s data transfer. It's less than the VME throughput (40 MB/s for 32-bit bus), however the effective communication speed still may be better in the newly proposed architecture.

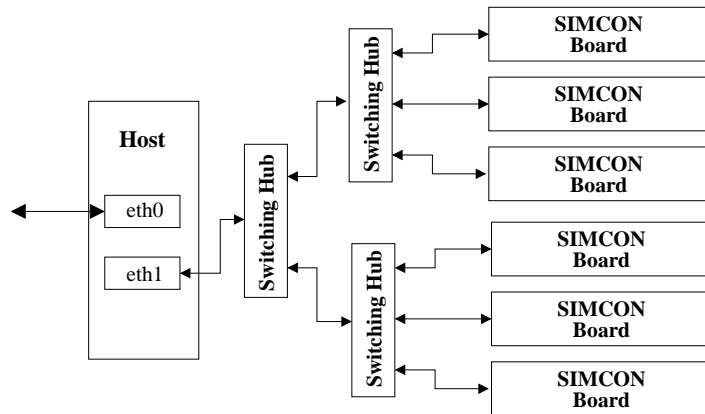


Figure 5. System architecture with multiple boards connected to single network.

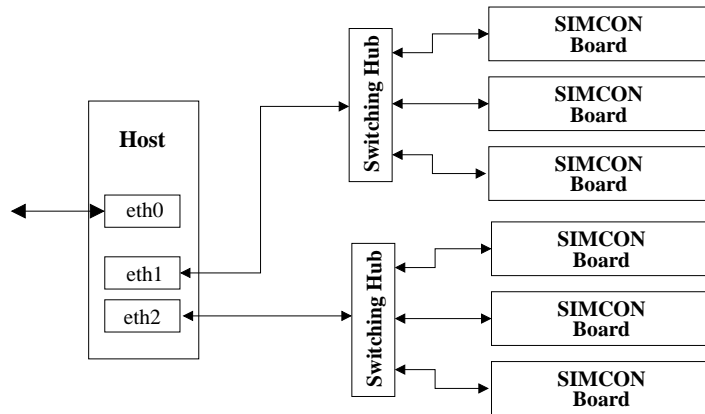


Figure 6. System architecture with boards divided between separate networks.

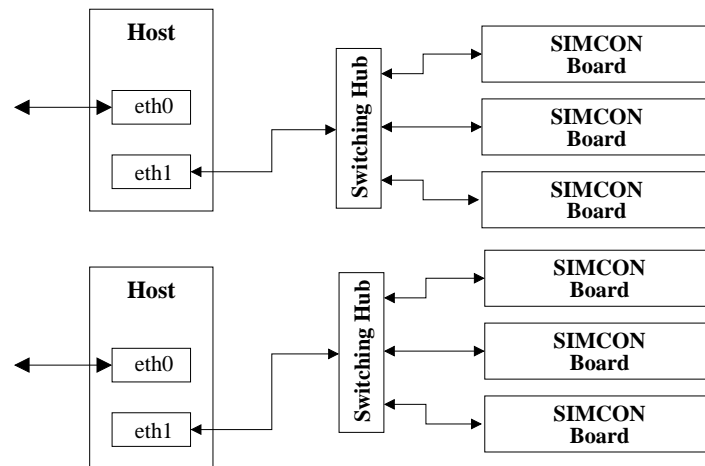


Figure 7. System architecture with boards serviced by separate managing hosts.

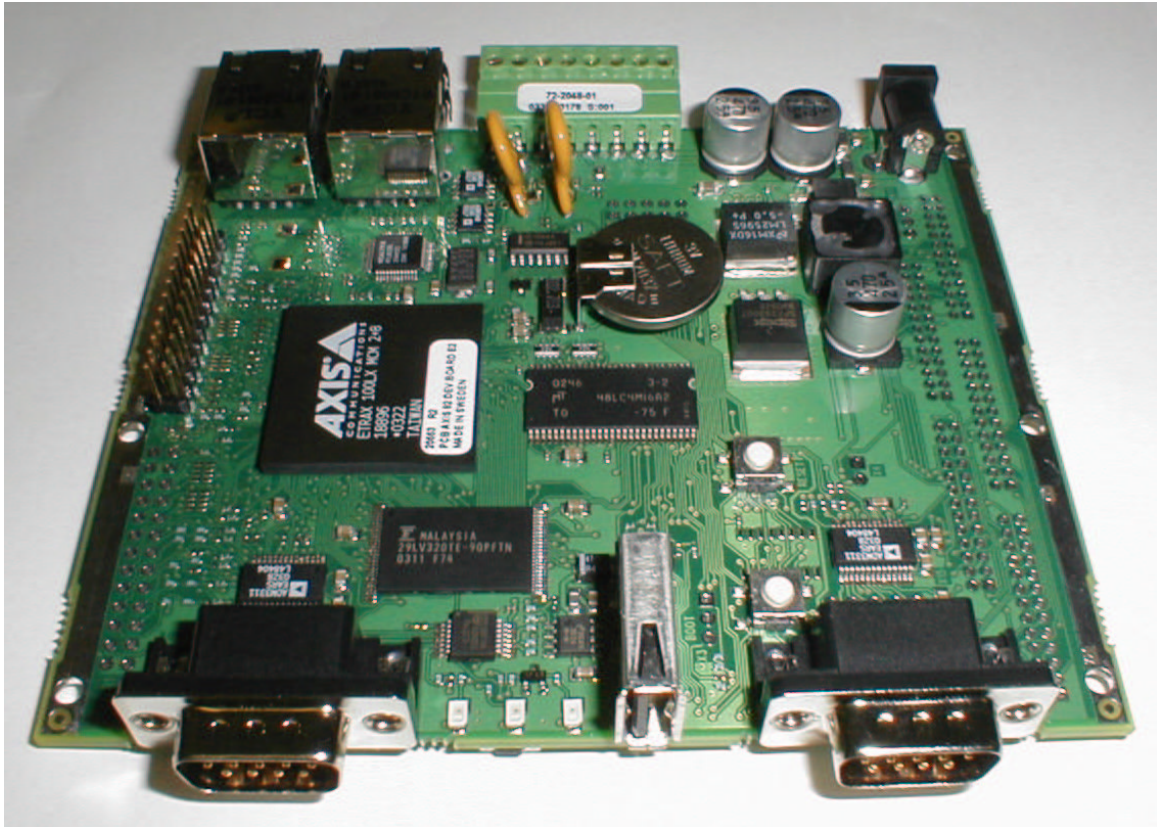


Figure 8. The commercially available ETRAX development board, used for software development and testing.

For example in the set of 8 boards connected to the single VME bus the effective throughput for a single board is only 5MB/s, for the same set of boards connected to the network switch with Gigabit Uplink (for ca. 150 USD) it is possible to maintain the throughput of 8MB/s for each board.

As it was mentioned previously, it is possible further to improve the communication performance, because a higher level protocol may be used to communicate with SIMCON boards. Instead of direct manipulating with the bits in board's hardware registers, the managing host can send only the commands' codes and parameters, and the commands will be performed by the board controller itself. An additional advantage is that many board controllers can work in parallel.

7. FLEXIBILITY AND SCALABILITY OF THE SYSTEM

The proposed solution offers easy reconfiguration of both the embedded controller firmware and the FPGA core. The ETRAX chip allows for remote update of its FLASH memory contents. Additionally, it is possible to test a new version of the software without writing it to the FLASH memory (eg. from ramdisk or from NFS mounted remote filesystem). The FPGA may be configured with the bitstream stored in the FLASH or received via the network.

Use of the standard TCP/IP Ethernet network allows to suit the system's architecture to the particular needs. It is possible to connect many boards to the single managing host, if main priority is to keep costs as low as possible (Figure 5). If the highest priority is to provide the best possible network throughput, it is possible to use multiple network interfaces in a single managing host (Figure 6). Finally, if the main goal is to achieve the best possible performance, it is possible to use more managing hosts servicing limited number of boards (Figure 7).

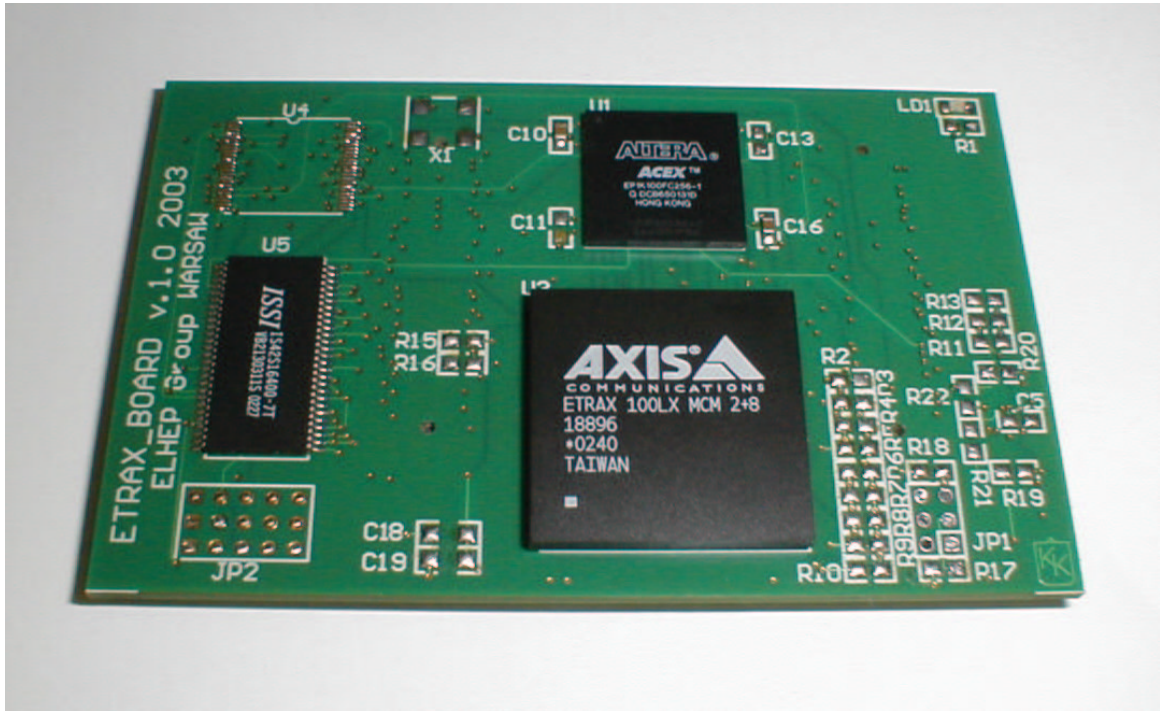


Figure 9. The Embedded Controller Board - top view.

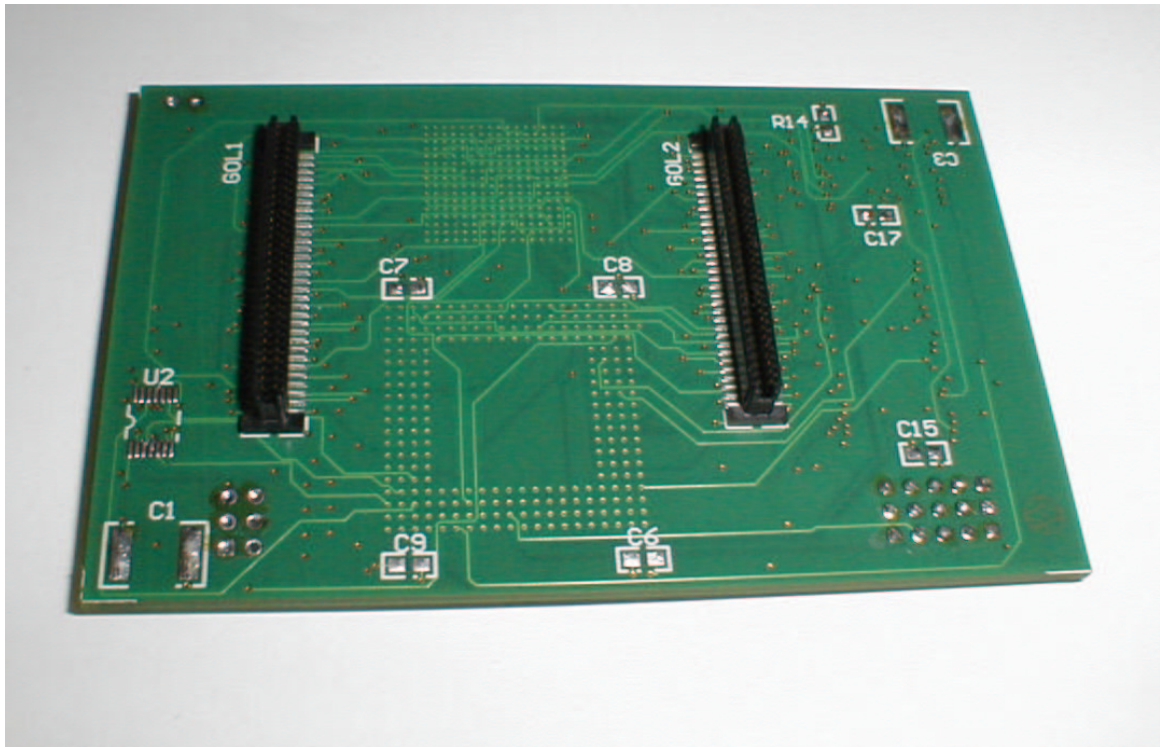


Figure 10. The Embedded Controller Board - bottom view. The standardized connectors visible in the picture.

8. THE SOFTWARE

The software for the Embedded Board Controller includes the dedicated device drivers for the SIMCON board's hardware and for additional hardware controllers implemented in the EBC's FPGA.

Next software layer is a set of servers accessible with the RPC protocol, which implement more complex algorithms and communicate with the client programmes running on the managing host.

Both above mentioned layers will be implemented in the C language to make effective use of small resources of the ETRAX SCM.

The client software running on the managing host may be written in C++ and should provide integration with the DOOCS system.

The ETRAX chip offers also a HTTP server, which can be used to provide a simple debugging and testing interface - significantly improving the testability of proposed control and data acquisition system.

9. HARDWARE

For development and testing of the software a commercially available ETRAX development board (Axis 82) has been bought (Figure 8).

The dedicated embedded controller board has been designed. The first manufactured prototype is being debugged (Figures 9, 10).

10. CONCLUSIONS

The proposed architecture of the control and data acquisition system offers better performance/cost ratio than the standard VME based solution. The system may be easily extended and tested. The control and data acquisition tasks can be performed by controllers of multiple SIMCON boards in parallel, resulting in overall performance boost. The modular structure of the system assures independence on the obsolescence of currently available chips.

REFERENCES

1. "Tesla cavity simulator and controller." TESLA Reports: 2003-28, 29, 30, 32.