R&D PROJECTS IN COLLABORATION WITH CERN

2000

Project CERN/P/FIS/15170/1999

Collaboration in the CMS Experiment

Final Report

20 November 2000

Project Title:

Collaboration in the CMS experiment at CERN

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General Introduction:

LIP is a member of the Compact Muon Solenoid (CMS) experiment at the Large Hadron Collider (LHC) presently in preparation at CERN. The experiment aims are the study of very high energy collisions of proton beams. Investigation of the most fundamental properties of matter, in particular the study of the nature of the electroweak symmetry breaking and the origin of mass, is the experiment scope.

The LIP activity is centered on the development of hardware and software for the calorimeter trigger and for the readout system of the electromagnetic calorimeter. The project is carried on in collaboration with INESC and involves the microelectronics company TECMIC.

The calorimeter trigger system of the CMS/LHC experiment at CERN is a high performance electronics and computing system which processes on-line the detector data, about one hundred thousand calorimeter channels, to select electrons, photons, taus and missing energy events, as well as, samples of jet events. The trigger system performs the first selection step in the search for new physics reactions, in particular the search for the Higgs boson. The scale of the problem is several orders of magnitude above the trigger systems developed so far, given the large number of channels to process and the very high repetition rate of the LHC collider (40 MHz). In short, the CMS calorimeter trigger system is a massive parallel processor, working in pipeline mode. State-of-the-art microelectronics and data links are used in the project. The calorimeter trigger is composed of four main systems: the Trigger Primitive Generators (TPG), the Regional Trigger, the Global Trigger and the Readout & Control System.

The Electromagnetic Calorimeter (ECAL) is an electron and photon detector composed by eighty thousand high purity PbWO4 crystals. The extremely fine granularity and the excellent energy resolution makes this instrument very well suited for the measurement of electrons and photons at the LHC. The crystal scintillation light is converted by avalanche photo-diodes (APD), digitized and transferred from the detector through high speed (1 Gbit/s) optical links. The readout system is responsible for collecting data from 80000 detector links, storage in pipeline memories, event formatting, data integrity checking and data transmission to the DAQ system. This system is composed by about 50 VME 9U crates. Each crate houses 17 Readout/Trigger Boards, 1 Data Concentrator Card (DCC) and one controller CPU.

The participation of LIP is concentrated in the following items (see figure 1):

- Development and construction of the ECAL Trigger Primitive Generators (in collaboration with LPNHE-Palaiseau), in particular the trigger primitives synchronization circuits and the trigger high-speed links (construction of 850 Synchronization and Link Boards).
- Development and construction of the ECAL Data Concentrator Card (construction of 50 DCC 9U VME boards).
- Development and construction of the calorimeter trigger readout and control system, both hardware and software. This system will use a simplified version of the ECAL Data Concentrator Card. Construction of 20 PMC trigger readout boards and 5 trigger DCC boards. Control software running of 20 trigger VME processors and one trigger back-end server.
- Development of software for the ECAL readout prototypes. Control software running on 50 ECAL VME processors.

The general planning of the ECAL and Trigger/DAQ projects foresees that the present prototyping phase will continue up to the year 2000-1 when the final design will be frozen. A pre-production will be made in the year 2002 and full production and installation in the years 2003-2004.

The following institutes participate in the project:

ECAL Readout/Trigger module (ROSE100)	CERN, Palaiseau, ETHZ, Lisbon
Synchronization and Link Board	Lisbon
ECAL DCC and readout software	Lisbon
Regional Trigger	Wisconsin
Global Calorimeter Trigger	Bristol
Trigger Readout and Control	Lisbon

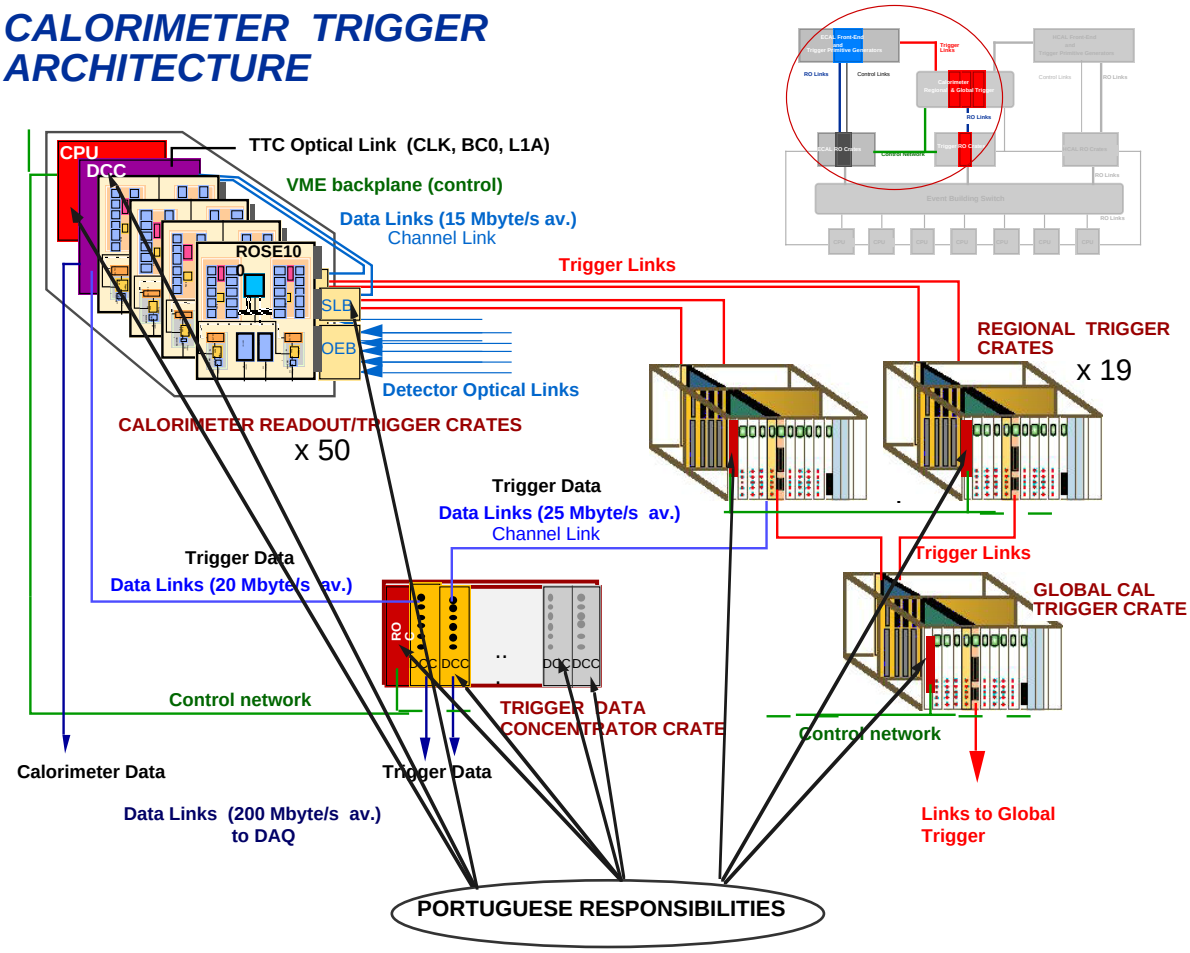

Figure 1. The CMS Calorimeter Trigger and the portuguese responsibilities.

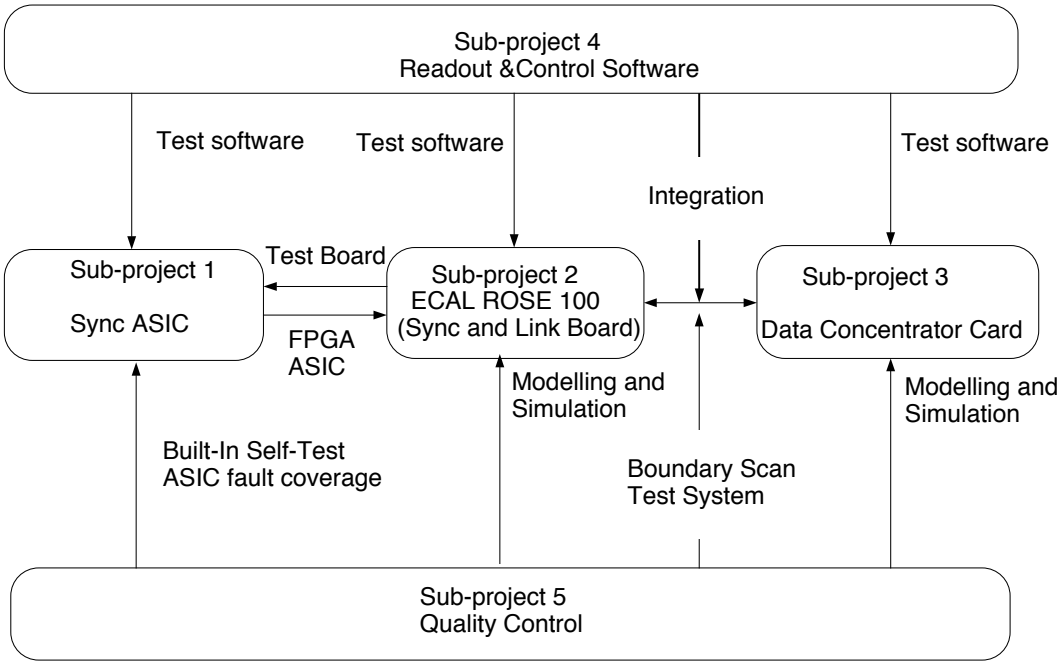

Figure 2- Interrelation between the sub-projects.

Summary of Activities

The LIP/CMS program for 2000 was divided in five inter-related sub-projects. Figure 2 shows in diagrammatic form the interrelations between the five sub-projects. An activity on the development of monitoring software for the ECAL test beam was also started. The participation in the development of the CMS object oriented simulation and reconstruction software was pursued in the areas of electron and photon reconstruction and trigger software.

During the year 2000 the Trigger Technical Design Report submitted to the LHC Committee (LHCC) was prepared. This extensive document (approx. 600 pages) describes in detail the first level trigger systems, as well as the interfaces to the subdetector front-end systems and the data acquisition system.

Most of the results obtained by the portuguese R&D effort in CMS in the last years are summarized in the TDR. The contributions of our group to this work are the following:

1) Chapter 3: Calorimeter Trigger Introduction

- Calorimeter trigger algorithms concepts, in particular the electron and photon fine grain algorithm.
- Simulation studies of the trigger algorithms.

2) Chapter 4: Calorimeter Trigger Primitive Generation

- Development of the architecture of the trigger primitives generator.
- Construction of prototypes of the Trigger Primitives Boards.
- Beam tests of the trigger and digital processing electronics for the electromagnetic calorimeter of the CMS experiment.
- Development of the trigger synchronization method; construction of the SyncRx and SyncTx circuits; development of the Synchronization Test Setup.
- Development of the SyncRx/Tx (2^{nd} version); construction of the Synchronization and Link Board prototype; construction of the SLB Tester.
- Implementation of Built-In Self-Test techniques in the SyncRx/Tx circuit.

3) Chapter 7: Calorimeter Trigger Readout and Control

- Development of the architecture of the trigger readout and control system; construction of Readout PMC prototype.
- Development of the ECAL selective readout concept; simulation studies of data reduction and physics impact.
- Design of the Data Concentration Card (DCC); simulation of DCC functionality.
- Development of the prototype of a Boundary Scan Controller in the VME bus.
- Architecture of the Trigger Control Software (CARDS); user requirements, software requirements, architectural design, development of the Front-End and TTC software.

4) Chapter 16: Trigger Control

- Architecture of the Trigger Control System: fast control and fast monitoring systems.

5) Chapter 17: Synchronization and Latency

- Principles and methods of synchronization of the overall trigger system.

Sub-Project 1

THE TRIGGER SYNCHRONIZATION CIRCUIT

Data synchronization is one of the most challenging tasks to be performed by the trigger and data acquisition system of the CMS experiment at LHC. The LIP group developed a method to achieve data synchronization in the context of the CMS synchronous and pipelined trigger system. The method is physically implemented by synchronization circuits associated to each trigger data link.

In 1997 LIP, in collaboration with the Portuguese microelectronics company TECMIC, has developed prototype versions of these circuits (SyncTx and SyncRx) as well as a test setup which demonstrated the performance of the synchronization method.

Based on this experience, in 1998-99 we have redesigned the circuit in order to integrate the two circuits in one (SyncTx/Rx), adding at the same time some test functions. The specification of the new circuit was written and the design of the functional blocks was done at TECMIC.

The design of the Built-In-Self-Test (BIST) of the SyncTx/Rx was done at INESC and implemented in 99-00.

The test of the proto-99 done at LIP during last year showed some instabilities that were traced back to limitations of the technology used.

Sub-Project 2

ECAL READOUT AND TRIGGER MODULE (ROSE100)

The prototype ECAL readout and trigger modules (ROSE100) developed in previous years consists of a motherboard (VME 9U) and a number of daughter boards that implement the various functions. The list of boards, functions and responsibility is the following:

Mother Board	Interfaces and Control	CERN, ETHZ
Receiver Board	Optical receivers, deserializer	CERN, Palaiseau
Pipeline Board	Data pipelines	CERN
TPG Board	Primitives generator and filters	Palaiseau
Sync/Link Board	Synchronizer, trigger and DAQ links	Lisbon

The SLB prototype built by LIP was successfully tested in a dedicated test system built on purpose (Figure 3). The present SLB prototype includes all the functionality except the trigger links, due to delays in the delivery of the Vitesse components.

The remaining daughter boards indicated above were developed by our collaborators and tested in standalone mode. Due to a problem with the high density connectors used in the Mother Board the integration test that was planned for this year was not concluded. Partial integration tests, namely the test of the Sync/Link Board together with the TPG Board, are planned for this fall.

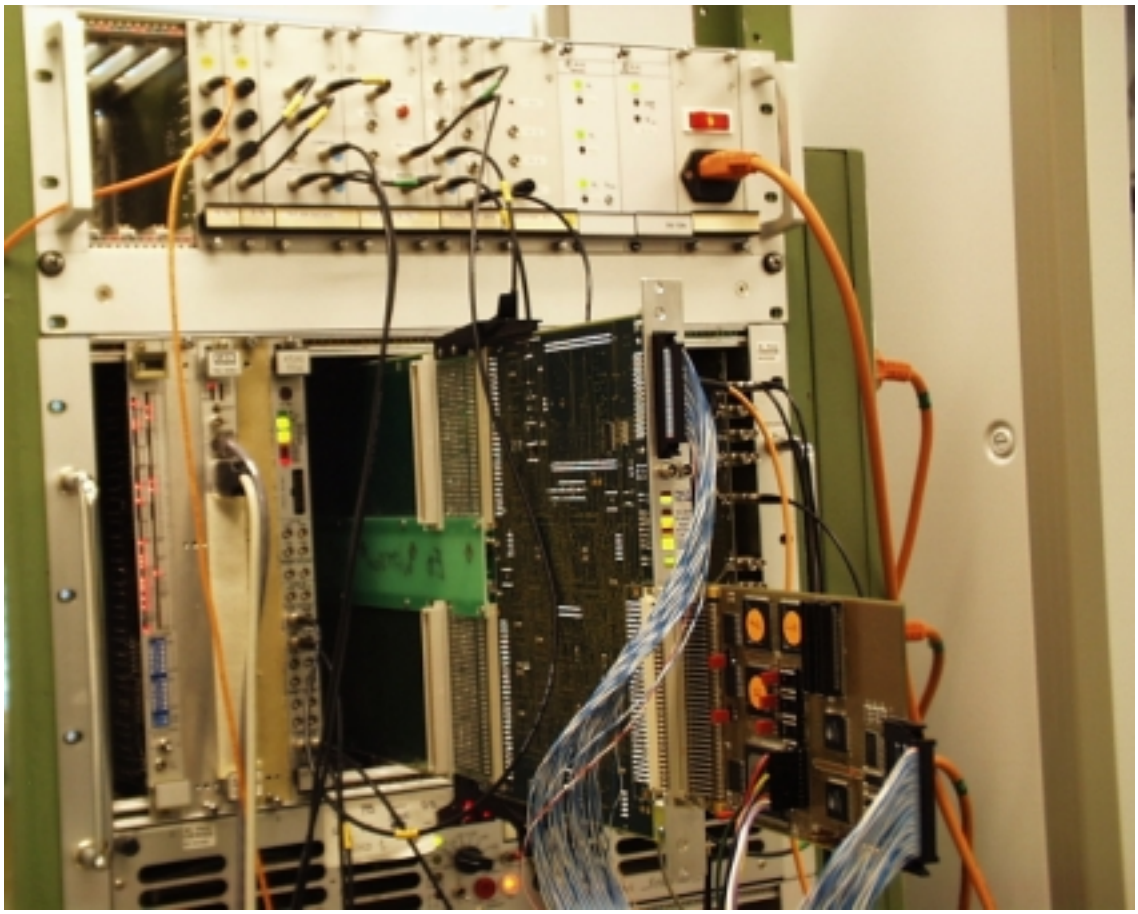

Figure 3. SLB Test Setup

Sub-Project 3

PROTOTYPE OF THE DATA CONCENTRATOR CARD

1.1 Trigger readout

We have built a first prototype of the Local Readout Unit (LRU) in the trigger. The LRU is implemented as a PMC (PCI Mezzanine Card) in the crate processor. Serial links connect the crate LRUs to the Trigger Data Concentrator Cards (TDCC). The TDCC is a simplified version of the ECAL DCC, which is also under our responsibility (see next).

The first prototype was used to evaluate different serial link technologies (IEEE 1394, Firewire and Channel Link, National). The final choice was made (Channel Link from NI).

1.2 ECAL readout

LIP is responsible for developing, prototyping and building the Data Concentrator Cards (DCC). The DCC is a 9U VME module responsible for collecting data from 20 sources, performing event formatting, data integrity checking, and transmission to the central Data Acquisition System. The final system will include 60 DCCs, one per ECAL readout/trigger crate.

Our group has developed the concept of ECAL selective readout for reducing the amount of data to be collected without damaging the physics. Simulation studies were performed in order to estimate data volumes and impact on physics.

A study of selective readout implementations and an architectural design of the data collection were performed. Preliminary system simulations were done in order to estimate buffer sizes and readout latencies.

The design of the DCC is now well advanced and a detailed document of specifications was produced.

Sub-Project 4

TRIGGER READ-OUT AND CONTROL SOFTWARE

The main objective for 2000 was to deliver a major version of the Calorimeter Trigger Readout and Control System. This release, an almost full functional experimental prototype for the Trigger Readout and Control System, should include:
a. all the functionality, identified so far, for operating an ECAL Front-end Sub-system;
b. all the functionality, identified so far, for operating the ECAL Trigger hardware prototypes, including prototype components for the readout, trigger primitive generation (TPG) and trigger primitive synchronization and transmission (SLB).

While the first part of this objective is still under way, the second was accomplished partially on time.
Hence, looking back to the past year we have planned for:

Sep. 1999 - Dec. 1999: the design, implementation and test of software for all the Front-end Calorimeter Trigger hardware components. This phase was intended to include the delivery of test software for all the Front-end Calorimeter Trigger hardware components, including the calorimeter read-out, the trigger primitive generation and its synchronization and transmission. In fact we have only delivered test software for the readout and the trigger primitive synchronization and transmission. The rest of the software is waiting for the availability of the remaining hardware components to be developed.

Sep. 1999 - Mar. 2000: the design, implementation, integration and test of the control and data transmission software component (DCP) for the Calorimeter Trigger Readout and Control System. The objective of this phase was to assess and solve the problems inherent to the data transfer and the inter-process communications in a distributed environment. Its outcome should be a standalone, single crate, Calorimeter Trigger Readout and Control System. But, as mentioned at that time, this task depended on finding a suitable partner for its execution. Since we haven't find such a partner, it was decided to continue it on our own using 'components off-the-shelf' (COTS). As a result, this task is still under way and is expected to last until the end of this year.

Apr. 2000 - Jun. 2000: the implementation, test, installation and deployment at CERN of a remote controlled Calorimeter Trigger Readout and Control System version including a dual-crate Front-end Sub-system. This phase depended on the previous one and therefore is now scheduled to the end of this year. Instead, during this period, we made a first attempt to integrate the current H4 Test Beam software with our own software.

Jul. 2000: the participation in the Pre-calibration of the first CMS ECAL Super-modules in the H4 beam line. This phase was postponed to July 2001 since the Pre-calibration of the first CMS ECAL Super-modules, itself, was postponed to July 2001.

Jul. 2000 - Dec. 2000: the design, implementation and test of software for the Calorimeter Regional Trigger hardware. This task depended on the availability of the Regional Trigger hardware prototypes. Due to the unavailability of those prototypes it was postponed also.

Dec. 2000: the implementation and test of a standalone Calorimeter Trigger Readout and Control System version including a single (or dual) crate Front-end Sub-system and a single crate Regional Trigger Sub-system. This phase also depended on the previous one and therefore is subject to the same delay.

Concurrently with these activities, we continued to:
- update the Calorimeter Trigger Readout and Control System User Requirements;
- update the system logical model;
- update the system architecture model.

Sub-Project 5

QUALITY CONTROL

During this year of 2000, INESC has developed one boundary scan controller board prototype, housed in the VME crate, intended to use the ANSI IEEE 1149.1 Standard (Boundary Scan - BS) to test the system at different levels. The corresponding software to perform the format translation needed to download the test stimuli and to recover the test response was also developed. This software establish a bi-directional link between the SVF format, generated by the commercial boundary scan software package VICTORY™, and the VME controller.

System-level modelling and specification using real-time, object-oriented modelling techniques have been used with the ECAL Front-End and Trigger Primitive Generators. A common CASE (Computer-Aided Software Engineering) platform is being used by LIP and INESC both for hardware and software model representation – Rationale-RT. Research has also been performed on valued characteristics and metrics for quality assessment of architectural solutions. The system-level modelling work is a critical factor of success for system integration and will become more significant in 2001.

The introduction of BIST in system ASICs, namely in the Tx_Rx synchronization IC, under development by TECMIC, has been implemented in a standard cell layout style, while TECMIC produced a alpha-version of a prototype Xilinx FPGA, tested at CERN (SubProject 1). Close cooperation between INESC QTHS Group, LIP and TECMIC is now a reality.

Test effectiveness validation, for classic single Line Stuck-At (LSA) and more realistic (defect-oriented) fault models is under way for the current structural description of the Sync Tx_Rx chip. Results show the usefulness of the approach, highlighting the need to verify how far pseudo-random test sequences, generated on-chip in the BIST solution, are able to uncover likely physical defects, and eventually the need to enhance the test pattern. Moreover, the design and test decisions on a possible, final FPGA-based product, incorporating two Sync Tx_Rx circuits, will be addressed during 2001, as a final decision has to be made by the end of next year.

Sub-Project 6

TEST BEAM ECAL MONITORING

Two senior members of the LIP/CMS group particpated during this year in the development of the monitoring system of the ECAL test beam setup. The ECAL barrel supermodules (structures with 1700 crystals) and the endcap Dees will be tested and calibrated in the H4 CERN electron beam during the next three years. 36 supermodules and 4 Dees will undergo this calibration process. A large experimental infrastructure, including readout electronics, data acquisition, trigger, cooling, test systems, etc. will be installed in the CERN North Area to allow the completion of this program. The size of this experimental setup is typical of any fixed target experiment. Many experimental aspects related to the physics behaviour of the CMS electromagnetic calorimeter will be studied in this environment.

Sub-Project 7

PHYSICS RECONSTRUCTION AND SELECTION

During 2000, the LIP group participated in the development of the CMS simulation and reconstruction software, the ORCA pachage. Our contributions were concentrated in the reconstruction of electrons and photons in the ECAL and Preshower endcaps and in the development of the calorimeter trigger primitive generation software.

Publications and Technical Documents:

CMS, The TriDAS Project, Technical Design Report, Volume 1: The Trigger Systems, CERN/LHCC 2000 - 38, CMS TDR 6.1, November 2000.

A System Level Boundary Scan Controller Board for VME Applications, Nuno Cardoso, Carlos Beltrán Almeida, José Carlos Silva, submitted to Journal of Electronic Testing.

A System Level Boundary Scan Controller Board for VME Applications, Nuno Cardoso, Carlos Beltrán Almeida, José Carlos Silva, in proceedings of IEEE European Test Workshop (ETW 2000), Lisbon, July 2000.

Timing and Synchronization in the LHC Experiments
J. Varela, invited contribution to the 6th Workshop on Electronics for LHC experiments, Kracow, September, 2000,

Technical Specifications of the ECAL trigger Synchronization and Link Board, S. Silva, J. Varela, CMS IN 2000/005

ECAL Data Synchronization, J. Varela et al., CMS IN 2000/006

Conferences

A System Level Boundary Scan Controller Board for VME Applications, presented by N. Cardoso at IEEE European Test Workshop (ETW 2000), Lisbon, July 2000.

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