# The experiences from the production of the ELMB

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## *1.0 Introduction*

The Embedded Local Monitor Board (ELMB), see Figure 1, is low-cost plug-on board, which was originally developed for a range of control and monitoring tasks in the MUON detectors of the ATLAS experiments. Later it has found many applications in other subdetectors and experiments. It is radiation tolerant and can operate in a magnetic field. The CAN fieldbus and the CANopen protocol are used. The latest version of the ELMB (ELMB128) consists of the ATMEL microcontroller ATmega128L and the INFINEON CAN controller SAE81C91. The ELMB has been specially designed to be remotely powered and has optocouplers for ground loop isolation. The ELMB is a collaboration between NIKHEF, (responsible for the embedded software) and CERN (responsible for the hardware design and production). More details of the project can be found in [1], [2].

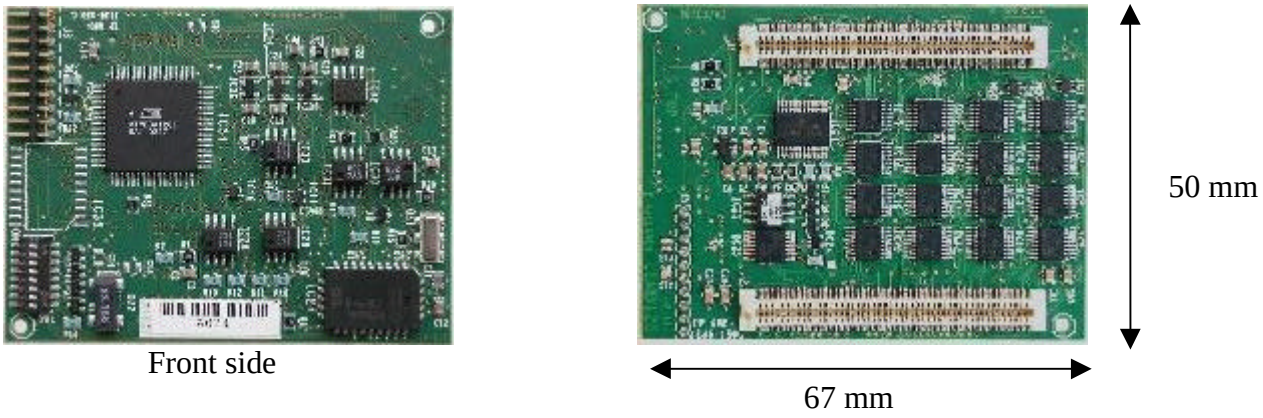


Figure 1 The Embedded Local Monitor Board ver 128 (ELMB128) with the ADC on backside.

## *2.0 First production series*

Several versions of the ELMB have been produced.

### 2.1 Prototypes

The CERN EP/PES group designed the PCB of the ELMB during spring 2000 and the first 5 prototypes were produced in June 2000. In October another 20 ELMB cards were produced and. distributed to the ATLAS subdetectors starting from November 2000.

### 2.2 1st series production

After consulting with the users it was decided to produce a new version of the ELMB with 3.3V power supply for the microcontroller as opposed to 5V on the prototype. Fortunately this required no PCB changes but only changes of two components. The total demand was for 300 ELMB, 200 with ADC and 100 without ADC. The largest request (>60 units) and most urgent request was from the EP-ESS group for their Generic Rack Prototype. Therefore collaboration between ATLAS and the EP-ESS group was started to produce the ELMB. The EP-ESS wanted to take the responsibility for the overall organization of the project, the purchase of the

components, the PCB production and the mounting of the components at a company in Geneva. The testing was made by the EP-ESS with a test system designed by ATLAS.

The first ELMB of this production was distributed to an ATLAS user on the 1 June 2001, which were several months later than the promised target date of mid-February. One reason for this was that the yield of the PCB manufacturing was only ~65% due to a layout flaw. The total yield of the production was finally 95%, which could have improved to 98%, if enough components had been bought. The price of the ELMB complete with ADC was CHF 250 while a simplified version cost CHF 150. The operational experience of the test system supplied by ATLAS was not good. The hardware required too many manual operations and the software PVSS-II and OPC server was difficult to get working reliably. No test results of the production were available.

### 2.3 The ATLAS Production Readiness Review (PRR) of the ELMB

In March 2002 an ATLAS Committee composed of members from the subdetectors performed a thorough production readiness review of the ELMB. They concluded on: "The ELMB basic concept is very good as is demonstrated by the number of users. These success and experience must be used to improve the functionality (when needed) in integrating software or hardware developed by users. The ELMB is a very versatile device which has been proven to be able to work in radiation and for which there is no commercial alternative. Hence it is a very important device for ATLAS."…

"The review committee recommends that some extra months are used before launching the production to:

1. Validate the SEE recovery procedure;
2. Study the new micro-controller (128);
3. Clarify the production strategy with the new ESS management;
4. Get more solid requests from the sub-systems.

In the meantime, some additional unqualified ELMBs can be produced to allow work to continue."

Organizational and manpower changes were made in during the first half of 2002 in both the groups EP/PES and EP/ESS, which had supported the ELMB design and production. The EP/PES group was transferred to the EST division and was integrated with other groups from other divisions to become the EST/DEM group with increased resources and competence gathered from several CERN divisions. The EP/ESS group was downsized.

### 2.4 ELMB becomes ELMB128

EP/ESS organized a meeting that was held in April 2002 between ESS/ATLAS for an intermediate production of ELMB. In this it was decided to make a production of 500 unqualified ELMB boards with EP/ESS in charge. No major changes were going to be made in the ELMB.

Meanwhile ATLAS started to make a detailed technical analysis of the ELMB taking into account the PRR but also the detailed suggestions from one of the ATLAS MUON detectors. The result was that many major and minor components changes and improvements were

identified. The modifications were so comprehensive that the name of the ELMB was changed to ELMB128. It was also clear that design documentation had to be put in the EDMS system. After discussing with the ATLAS Technical coordination it become obvious that the production of the ELMB128 needed to be transferred to the EST/DEM group. The group negotiated a contract with a European firm for the manufacturing. In the contract was included that the company tested the boards on a test system provided by CERN. Only cards that passed all the tests could be invoiced.

### *3.0 Production of the ELMB128*

The production of the ELMB128 was done during November 2002. Two versions were made. One complete with a 16-bit ADC with 64 differential inputs ELMB128-A and one simplified version called ELMB128-D without the ADC. The cards were tested as part of the manufacturing process with an automatic ELMB128 test system, see Figure 2 controlled by special developed test software running on a PC supplied by CERN. The tests consisted of readout of the serial number (bar code) of the card, DC measurements, the programming of the microcontroller ATMEGA128L and the calibration of the on-board ADC for the ELMB128-A. The test program decided if a card a passed the test or not. The result of the test was written on the hard disk of the PC for each card. Different formats were used for failed respectively good cards. Also the number of times a card has been tested was indicated in the file name. It was therefore possible to analyse in detail the production of the ELMB128 and draw conclusion for the future productions.


Figure 2 ELMB128 Test system

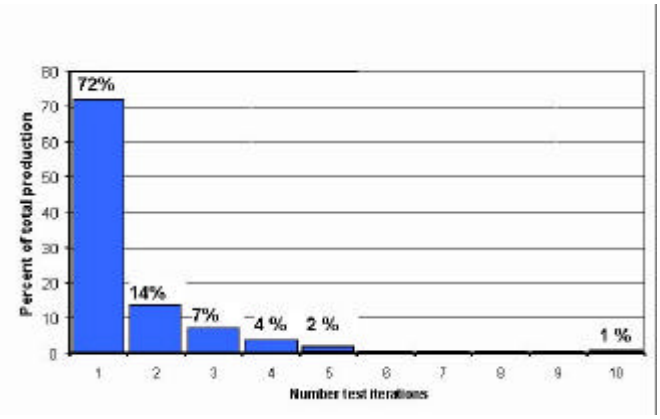


Figure 3 Yield per test iteration for ELMB128-A

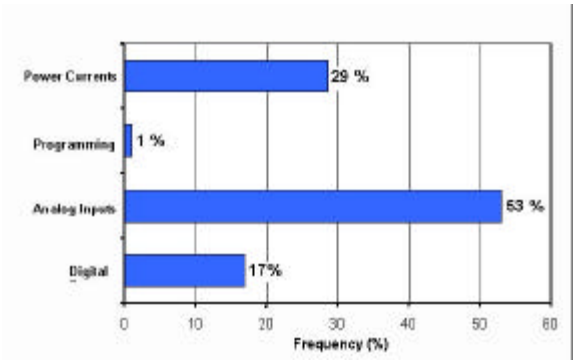


Figure 4 Error type found in the tests

## 3.1 Analysis of the production of ELMB128

The total number of ELMB128-A tested at the production was 471. From Figure 3 it can be seen that 72% of them passed all tests immediately. 14 % of the total number cards passed after one more test, while 7% required a third iteration etc. The type faults found were mostly in the analog inputs (53%). The total test time and repair time invested by the manufacturer was 1140 min or 2.4 min per card. The number of cards produced and could not repaired by the manufacturer was 4. This corresponds to a manufacturing yield of >99%.

As seen from Figure 5 more than 82% of the ELMB128-D cards did pass the tests immediately. Figure 6 show that the most common error was the programming of the microcontroller. This is however in most cases caused by mechanical problems in programming connector of the test box. The total number of cards tested was 186. The total test and repair time is estimated to 320 min or 1.7 min per card. All produced ELMB128-D could be repaired thus the manufacturing yield was 100%.

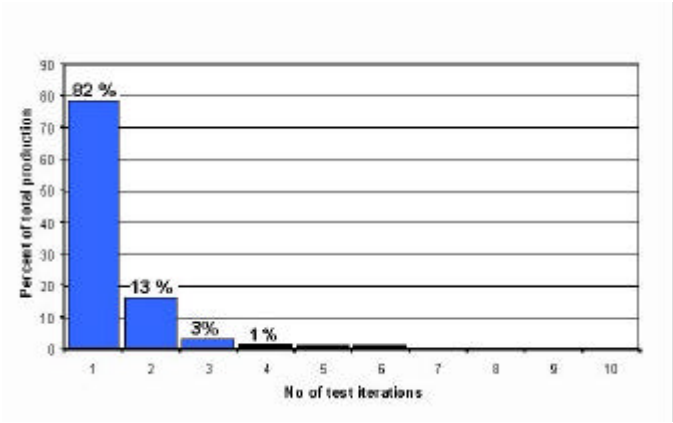


Figure 5 The yield for ELMB128-D

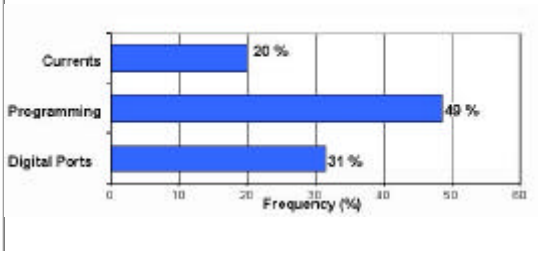


Figure 6 Type of faults found in the tests

### 3.2 Conclusions concerning ELMB128 production

The ELMB128 2002 production was organised in an excellent way by the CERN EST-DEM group. The ELMB128 cards were delivered fully tested and on schedule. The price per unit has been reduced to 55% of the previous production. This is very important because the price of the first ELMB version was such that at least one sub-detector said it was unable to complete their system within its budget.

The ELMB128 test system performed satisfactory even in an industrial environment of the manufacturer. However the mechanical construction, general robustness and the wiring must be improved before the next production. The present version of the ELMB128 test box can not check that the calibration has been done correctly i.e. that the gain factors stored in the EEPROM are correct. To do this the accuracy of the test box must be enhanced to better match that of a 16-bit ADC. The testing of the digital ports should be more complete.

## *4.0 What have we learned?*

For a good production yield it is important that the same company makes the tests and the production. Most faults are trivial solder faults, which can easily be repaired on-line.

The present test software written in C is performing very well. Much effort should be put on the test system design because this pays itself many times in the production as shown in by the ELMB128 tests. It is proposed that a series of 5 units test systems should fulfill the ATLAS applications, with each of the big MUON subsystems having one, while also the manufacturing can made at several places at the same time.

More than 1000 ELMB cards have been produced. This in itself motivates the decision that an ELMB lab is organized within the central ATLAS electronics group in which any user could test both the ELMB hardware but also develop ELMB embedded software. This will increase the credibility of the CERN ATLAS group when the question of long term support and maintenance during the next coming 15 years of the ELMB is raised.

When using standard integrated circuit in a design there is always a risk that the manufacturer stops the production of a component for any reason. It is therefore very important to have good reliable relations with the manufacturer and his representative to know any change of production far in advanced. This requires competence in electronics design.

[1] Hardware information see http://cern.ch/ELMB/elmb128.html

[2] In formation on the comprehensive software support is available on:
http://www.nikhef.nl/pub/departments/ct/po/html/ELMB128/ELMB128resources.html