Quality assurance for CMS Tracker LV and HV Power Supplies

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Abstract

This work describes the quality assurance measurements that have been carried out on about 2000 Power Supply Units produced in CAEN technology for the CMS Silicon Tracker Detector. The automate procedure and the characteristics of the dedicated Test Fixture developed for this activity are described in details. Magnetic field tolerance and radiation hardness of Tracker power supply units is also discussed at length.

I. Introduction

The CMS Tracker Power system is made out of about 2000 complex units (PSU) able to provide, independently, 2 low voltage lines to the front-end electronics and 2 HV lines for the silicon strip detector bias. A Power Supply Module, commercially labelled CAEN A4601H, is made out of two PSUs and contains then 4 LV and 4 HV channels.

The specific ranges for LV and HV channels are listed in Table 1

Table 1: PSU channels nominal values

PSU Channel	Voltage	Current
LV0	2.5 V	0 – 13 A
LV1	1.25 V	0 - 6 A
HV0	0 – 600 V	0 – 10 mA
HV1	0 – 600 V	0 – 10 mA

They consist of :

- 2.5V and 1.25V regulators:
  - I2.5 max = 13 A ; I1.25 max = 6 A
  - Remote sensing to compensate up to 4V drop on each line:

    V2.5 max= 6.5 V, V1.25 max= 5.25 V
  - noise: Vpp (20 MHz bw) ≤ 10 mVpp
  - Efficiency: ε>70% at 90% of the maximum power.
- 2 independet HV regulators:
  - 0 - 600 V
  - IMAX = 10mA /ch
  - noise: Vpp (20 MHz bw) ≤ 30 mVpp
- Current limiters and trip procedure
- LV comparators: hardware Over Voltage protection
- Isolation: ZCM > 50 Ω at 5 MHz
- external alarms: Interlocks, Reset and mains faults

The A4601Hs will be placed underground close to the detectors, in an area where relevant fluxes of charge and neutral particles and not negligible residual magnetic field are expected.

The radiation levels foreseen in the underground area for the CMS experiment are described in detail in [1] and they strongly depend on the particular location where the device will be placed. At the A4601H's location (R =10m, z=0-6m), we expect to integrate in 10 years, running at nominal LHC luminosity, a neutron flux of 0.3×10^{10} n/cm^2 (E_n>20MeV) Charge particle contribution is lower by 2 orders of magnitude, resulting in an integrated dose of only 0.40 Gy over the same running period..

The magnetic field at the PSU location in the cavern is expected to be around 400 Gauss [2]: to have same safety margin the A4601H have been designed to have less than 10% reduction in efficiency at 1kGauss .

II. Test Fixture for CAEN A4601H Quality Control

In order to provide an efficient and stable quality control procedure during the production of A4601H and taking into account the large number of boards to be tested, a joint project between INFN Torino and CAEN spa developed a dedicated low noise, electrically floating test fixture module able to check the PSU specifications listed above in an automate way. The goal of the project was to provide a measurement device capable to condition each single channel of the PSU at different working points and measure its performances. Moreover, the device should allow to verify that the PSU channels follow sequences of operations causing a transition to a defined status like ITrip, Overcurrent, Overvoltage, etc., with a simultaneous cross-check of the slow control system reaction.

The Test Fixture, as shown in Fig.1, has 4 independent channels covering the PSU modularity: 2 channels dedicated to LV lines and 2 channel for HV lines. Each channel has its own microcontroller (ST10F269) with embedded ADC's and high performance 40MHz CPU with DSP function.

Figure 1: The Test Fixture developed by Torino-INFN and CAEN for the quality control on A4601H production

The experimental setup used in the measurement is shown in Figure 2: it consists of an EASY crate capable to host up to 9 A4601H, connected to the Main Controller SY2527.

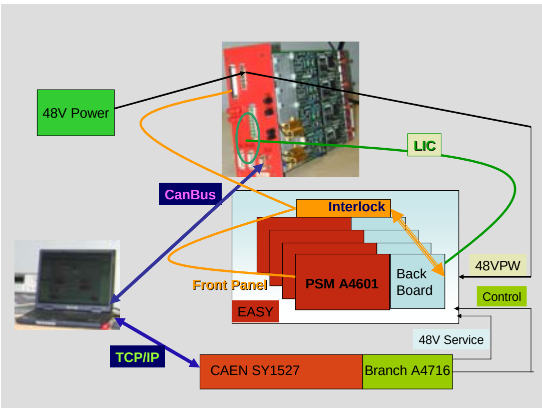


Figure 2: Quality control measuring setup

The SY2527 is a slow control system that allows to monitor PSM's current and voltage values and channel status with a refresh time of 1 s.

The output of the A4601H is connected via the CMS Low Inductance Cable (LIC) [3] to the test fixture loads that simulates the detector.

Two independent 48 V lines are present: the first one is the so called "48 V Power", that provide the power input to the PSMs and is monitored by the test fixture, the second one is the "48 V Service" that is used to maintain communication between the Control System and the Easy Crate in any condition even when the main power is off.

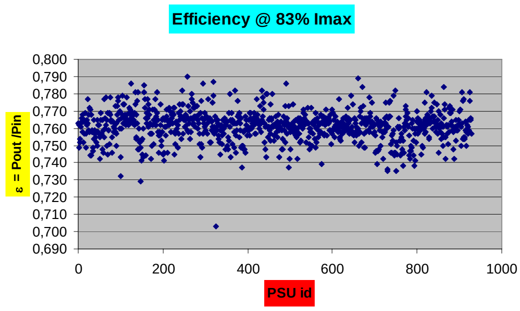
A PC communicates in parallel with the Test Fixture and with the SY2527 controller: this allows to change the PSM working point by terminating it to different resistive loads, to measure the reaction of the power supply with the Test Fixture and to compare it with the SY2527 response.

The development of such Test Fixture started in summer 2004 and was commissioned during spring 2005 using the production pre-series. Three of these experimental setups have been running since may 2005 without breaks both at CAEN directly on the production lines and in Torino for the quality acceptance validation.

III. MEASUREMENTS AND RESULTS

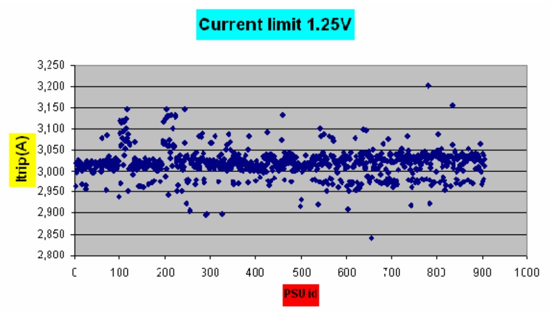
The quality assurance protocol consists of the following steps:

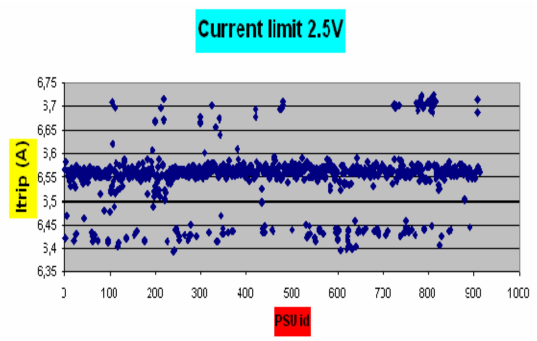
1. Switch on procedure: after a global clear alarm all channels should reach nominal voltage values at 25% of maximum current. Communication between Main Controller and the PSM should run properly.
2. Efficiency: by measuring the 48 V power input the system calculates the ratio ε=Pout/Pin as (Vcon *Imon) / (48Vmon*48Imon) where Vcon is the voltage output at the connector monitored by the SY2527 while Imon is the current measured at the load with the test fixture. A PSM is rejected if ε is less than 0.7 at 83% of maximum deliverable power. As can be seen in the following picture CAEN PSU's efficiency is always above the experimental cut.



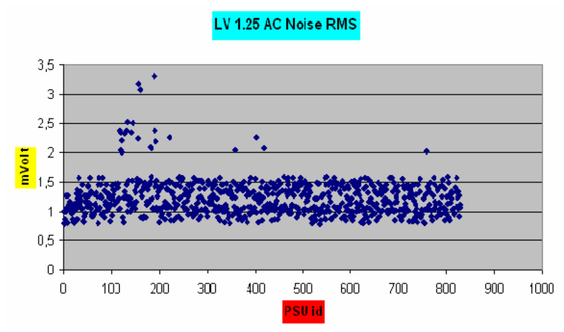
3. Power delivery tolerance: LV and HV channels should deliver nominal voltage values over the full power range with a tolerable variation of 5%. Three points at 5%, 50% and 95% of maximum current are chosen to verify this item for LV channels, while for HV ones two different reference voltages (400 V and 600 V) are tried. This test allows also to implicit check the sense compensation of 4V drop on the cable lines.
4. Current limit: each channel should not stay in a over current status more than set time (500 ms). After that it should turn off following a Trip procedure: a LV Trip switch off the entire PSU while a HV Trip switch off that specific channel only. The implemented test verify this protocol

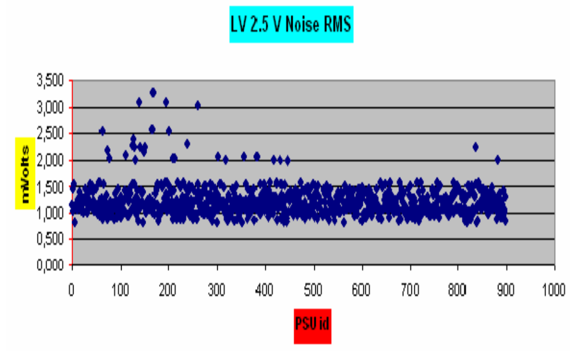
choosing as the working Iset the 50% of maximum current deliverable by the channel under test and also measure the Itrip value to be compatible within ±5% with the Iset value. In the following pictures the Itrip value is shown respectively for the 1.25V channel (Iset= 3 A) and for the 2.5V channel (Iset = 6.5A). The trip intervention is always in the wanted 5% limit.



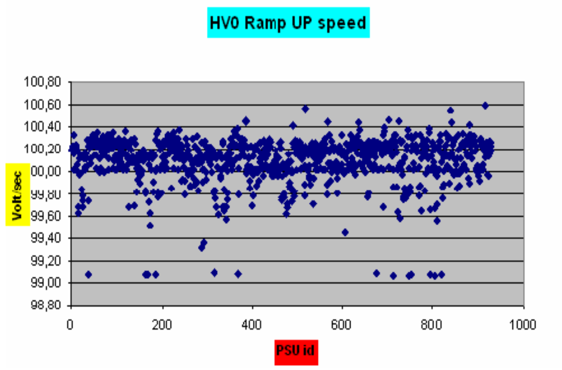


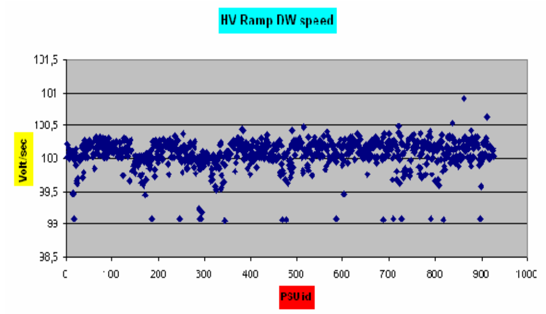
5. Transient load: by simultaneously commuting (10 ns commute time) finite resistive loads on both LV lines, corresponding to a ΔI = ±3A, the system registers and analyzes the under voltage or over voltage reaction at the output. The implemented test verifies that LV channel does not ever switch off and that the recovery time is less than 2 ms (nominal value).
6. AC Noise: for each line the AC noise at the load is measured using a 12 bit ADC acquiring 32000 samples with 20MHz bandwidth. The raw data are analyzed and voltage rms is extracted. The implemented test reject a PSM when 4 *Vrms is greater than 15 mV (LV channels) or 30 mV (HV channels). In the following plots an rms noise of 1 to 3 mV is appreciable.





7. Sense functionality: by forcing each sense line to short circuit to its ground the system checks the proper channel switch off procedure.
8. High Voltage ramp up and ramp down should proceed at 100 V/s. The test system accept a PSM if its HV lines show this feature with a tolerance of ±10%. As can be seen in the following distributions the PSU responses are in the limits.





9. Control Panel: the procedure checks that specific status like Trip, OVC, OVV etc. are measurable at the test points on the PSU front-panel.
10. Interlock: all the PSM in a crate should switch off as soon as an Interlock signal is received by the main CMS safety system. This is simulated by moving the interlock line on the EASY crate bus: channel should then switch off properly and turn back on when the interlock signal is removed.

The mean failure rate we have experienced during the last 2 years production is of the order of 5%, with an evenly distributed source of failure among the 10 different measurements listed above. Details about all the measurement results are retrievable at the page

http://cmstk.to.infn.it/PowerSupply/results.php

All the failed PSMs are sent back to CAEN for repairs and are check back again in Torino before being delivered to the CMS experiment,

IV. Hostile Environment Test

In order to check that the electronic components used to assemble CAEN A4601H are suitable to survive 10 years LHC in the CMS cavern environment several tests have been done to validate CAEN technology during the first phase of the A4601H production, following the experience gained in the prototyping phase [4]. The following sections describe how this has been pursued.

Neutron Irradiation Test

The radiation tests discussed in this paper have been carried out using the T2 neutron beam line facility at UCL (Louvain-la-Neuve) (see Figure 3).

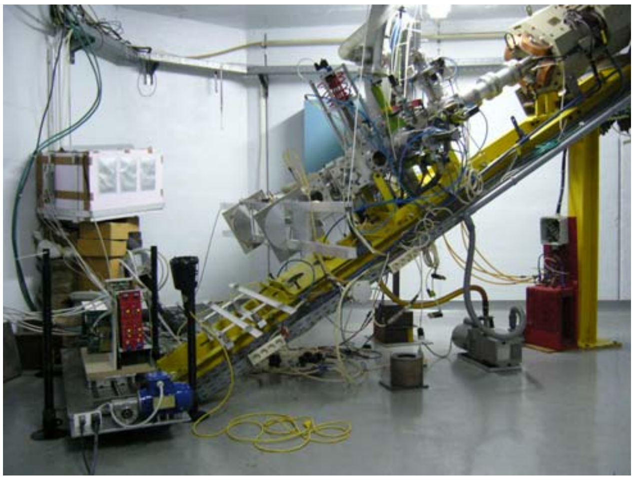


Figure 3: The experimental setup used in Louvain-la Neuve.

Neutrons are obtained converting 50 MeV deuterons on a berillium target. A study [5] has been done on the comparison between the measured Louvain neutron spectrum and the simulated CMS cavern one: 10 years LHC correspond to an integrated "Louvain" flux of 2.17 x 10^10 n/cm2.. The power supply units were mounted transverse to the beam at a distance of about 85 cm from the target..on a movable table. The beam cone radius at the board locations was about 10 cm, with an 85% level of neutron flux homogeneity. By moving the boards back and forth at a speed of about 1cm/s we guarantee homogenous exposure of all the board components. This introduces a correction factor that has been taken into account in the following flux calculations

The irradiation was done in sequential steps having the possibility of tuning the primary deuteron beam current I_b:

Step 1)2.5hours @ I_b =100nA (2.5*10^10 n/cm2)

Step 2)2.5hours a I_b =500nA (1.5 x10^11 n/cm2)

Step 3)0.5 hours a I_b =2500nA (2.7x10^11 n/cm2)

Step 4)0.5 Hours a I_b= 5000nA (0.8 x 10^12 n/cm2)

The first step, corresponding, to 10 years LHC was passed without any problem, and in fact the power supplies survived almost 100 years LHC without failures.

The PSM's output were terminated to resistive loads, placed in a safe room, by using 50 m long LIC cables and communicated as well with a system controller SY2527 that was used to switch on and off the low voltage and high voltage channels and to monitor the outputs with 1 Hz refresh frequency. Moreover it also allowed to check the communication status with the remote branch and to verify the 48 V supply of the remote crate.

The PSU channels were continuously monitored at the loads using a 1MHz digitizer board developed at Torino INFN [6] used in a triggered mode with 50 mV threshold and 2 mV resolution. The idea was that if a Single Event Upset occurred at the PSU level, some instability could appear at the DC output. One example is shown in Figure 4.

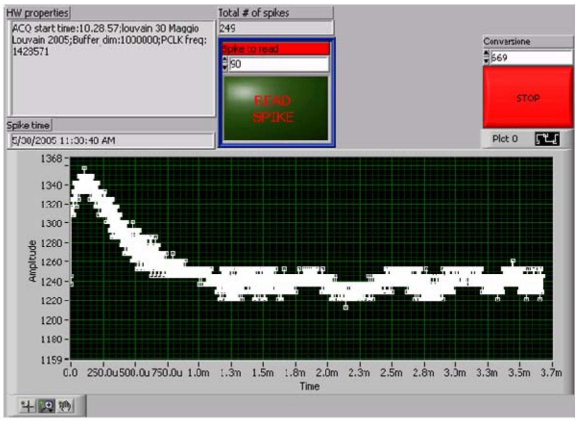


Figure 4: SEU effect on the 1.25V line

Typical amplitude is of the order of 150 mV (see Figure 5) with a recovery time of 0.5 ms (see Figure 4) related to the 2kHz bandwidth of the crowbar circuit used on the CAEN A4601H board to limit voltage instabilities.

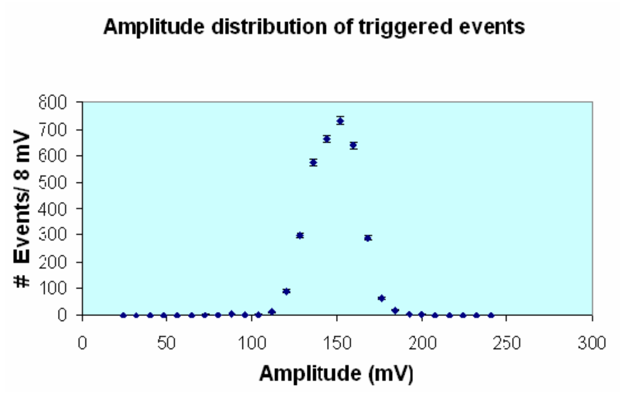


Figure 5: Amplitude distribution of SEU effects as measured at the loads on 4 LV lines using Torino made digitizer. Statistics corresponds to 500 years LHC.

Such instabilities have been proved to be not a problem for the operation of the CMS Tracker front-end electronics. This has been obtained by connecting a real CMS Tracker silicon detector at the PSU output during irradiation and verifying that this kind of oscillations did not affect the detector performances in terms of noise, pedestals and pulse height. The rate of such events was found directly proportional to the beam current and corresponds to 10 events/PSU in 1 year of LHC run at nominal luminosity. Integrating "Louvain" neutron beam current up to 500 years LHC equivalent running period several hundreds of such events have been recorded. However, the PSU's were always able to recover the nominal output values without any external intervention and no switch off was observed.

V. MAGNETIC FIELD TEST

The CAEN A4601H underwent a complete magnetic tolerance test at CERN-Prevessin facility.

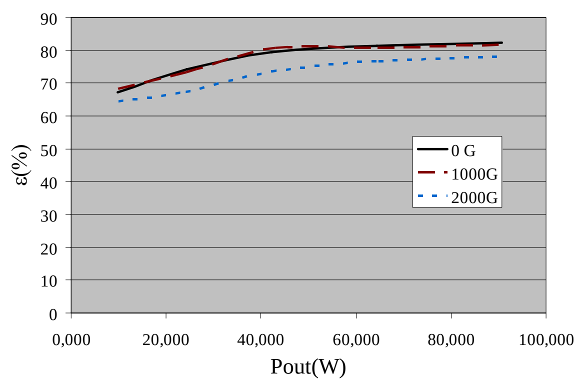


Figure 6: The A4601H board efficiency vs. the output power. Different lines correspond to different values of the magnetic field.

A4601H have been designed to limit the reduction in the efficiency at 1000 Gauss below 10%. For this purpose the range between 0 and 2000 Gauss was explored. The power efficiency of the A4601H board is plotted in Figure 6 as a function of the output power at different B field. The curves correspond to an interpolation of experimental data. Crate auxiliaries and control board dissipate a fix amount of power that have been measured to be 25 W and is not included in these plots. It can be seen that the efficiency is always very good with values of the order of 0.75 and that the external magnetic field has marginal effects on the performance of the power supply. We appreciated a 5% reduction at 2000 G.

VI. CONCLUSIONS

The CMS Tracker Power Supply System includes about 2000 complex units, with both LV and HV channels, produced in CAEN technology. A dedicated Test Fixture, developed by INFN-Torino together with CAEN, has been used to validate each PSU during the production. The results of the measurements described in the paper show a very satisfactory quality with a yield greater than 95%.

CAEN technology has proved to be also very robust for what concerns radiation hardness and magnetic field tolerance.

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VII. REFERENCES

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