

TOTEM**TOTEM Experiment****TOTEM ELECTRONICS SPECIFICATION***TOTEM Project Document No:***TOTEM EL SPEC***Institute Document No.*

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Created: **09/05/05***Modified:* **27/01/06***Page:* **1 of 11***Rev. No.:* **0.1****TOTEM****GENERAL ELECTRONICS SPECIFICATION***Abstract*

This document provides the full specification of the Electronics of the TOTEM experiment. It is meant as a working document during the development, fabrication and final commissioning of the electronics in the experiment. This document is complemented by documents which specifically treat the different subdetectors. This document is the result of many discussions with several people, in particular the physicists in TOTEM and the electronics designers on the project: P. Aspell, G. Anelli, K. Kloukinas, J. Kaplon, F. Regnier, P. Chalmet, H. Mugnier, G. Antchev and M. Sanchez.

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1 Introduction

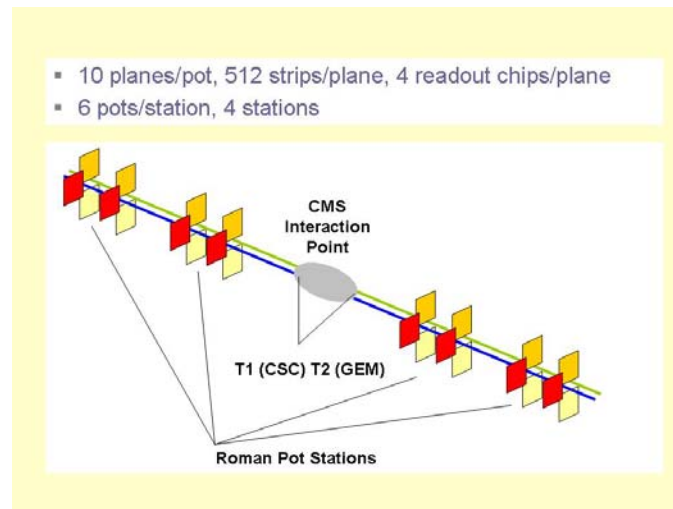


Fig. 1. The full TOTEM detector with 3 subdetectors.

The full TOTEM detector (Fig.1) (Ref. 1 TDR) consists of the Roman Pots housing silicon strips for tracking and triggering purposes, the T1 detector with Cathode Strip Chambers, and the T2 detector. The T1 and T2 detectors are located on each side of the CMS interaction point in the very forward region, but still within the CMS cavern. Two Roman Pot stations are foreseen on each side of the interaction point at 220 m and 150 m with the possibility to add a third station at 80 m. Each Roman Pot station consists of two groups of three Roman Pots at a distance of a few meters to obtain a sufficiently large lever arm to establish co-linearity with the LHC beam for the tracks prior to generating a level one trigger for the corresponding event. Three Roman Pots were foreseen in one group to approach the beam with detector stacks from three different sides (top, bottom and one side, the other side is impossible due to the presence of the second beam pipe).

General requirements are that the three TOTEM detectors should be able to operate as a subdetector of CMS. They need to provide trigger inputs which are in time to generate a global trigger for the CMS experiment, which is particularly difficult for the Roman Pots at 220 m from the interaction point. The detectors should be triggered by the general CMS trigger, and their data should be incorporated into the CMS data acquisition. In the following the electronics requirements will be detailed together with the architectural solutions taken.

2 Trigger partition and TTC system

TOTEM will be allocated one timing partition out of 32. It will receive its trigger and timing information for all three detectors from this partition. The Timing, Trigger and Control (TTC) system adopted is the one developed in common for all LHC experiments. The system is interfaced to the LHC machine signals, the global trigger processor, the front-end electronics controllers, the data acquisition, and status, calibration and test systems, and is based on the use of a few relatively high power laser sources which distribute the signals via a hierarchy of passive optical tree couplers to several thousand destinations each. Events are synchronized with the 40.08 MHz bunch-crossing clock of the LHC machine. TOTEM has one TTC crate in which an LTC card, TTC-ci card, and optical fanout will be placed. This TTC crate will be placed in the trigger rack allocated to TOTEM, which is in close proximity with the CMS global trigger to minimize the latency (see next section).

3 Trigger generation

Currently it is foreseen (see trigger note) that TOTEM provides 16 inputs out of 128 to the global trigger box of CMS. Of these 8 are allocated to the Roman Pots, 4 to the T1 detector and 4 to the T2 detector. The trigger signals are generated independently for the three TOTEM detectors and forwarded as such to CMS. Because of the stringent latency requirement on the trigger coming from the Roman Pots at 220 m a special rack was foreseen at an optimal location in proximity of the global trigger box of CMS. This rack will house the TOTEM TTC and trigger electronics and a part of the slow control and data acquisition. The other part of the electronics will be housed in the additional 6 TOTEM racks further removed from the global trigger box of CMS. The TOTEM trigger bits need to arrive at the global trigger box at or before bunch crossing 85. The trigger bits for T1 and T2 are transmitted optically (using the standard GOL optohybrid or GOH). For the Roman Pot system this was not possible as the optical signal propagation delay of 5ns/m precludes the in-time arrival of the signal in the counting room for the 220 m pots. There electrical signal transmission has been opted for using LVDS signalling with repeaters at regular distances to preserve signal integrity. The repeater chip has been designed and will be submitted together with the VFAT.

Since the trigger data for T1 and T2 will be transmitted optically, it made sense to use the same hardware as for the data readout. So, the GOL and optoreceiver mezzanine are used also for the trigger data. This minimizes the total hardware development.

The total number of trigger bits arriving from the TOTEM detectors in the counting room is distributed as follows:

Roman Pots	32 bits per pot	768 bits
T1 (CSC)	16 bits per detector	960 bits
T2 (GEM)	104 bits per quarter	416 bits

To generate these trigger bits the VFAT is equipped with eight trigger outputs, which can be programmed to correspond to certain groups of its 128 channels (the output equals one when one of the channels belonging to the group corresponding to this output detects a hit). The T1 detector will send these trigger outputs directly to the counting room for further processing, T2 and the Roman Pot detectors make use of programmable coincidence chip developed in parallel with the VFAT. This chip has also been designed to be radiation tolerant and to interface with the standard slow control token ring from the CMS tracker and ECAL detectors.

Figure 2 details how sectors on the detectors are allocated for trigger generation.

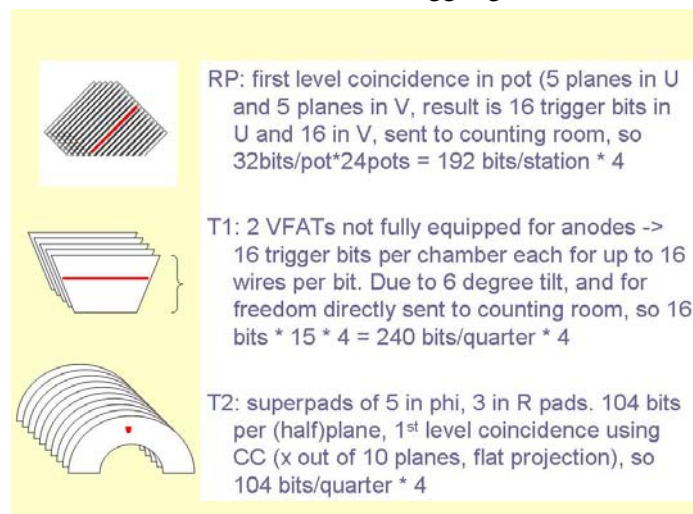


Fig. 2. Overview of sectors allocation for trigger generation

4 Data readout

The CMS data acquisition system contains 512 legs (Frontend Readout Links or FRL) of which some fraction will be allocated to TOTEM. Each of these FRLs is capable of taking a maximum average data rate of 200MByte/s, and a maximum of 2kByte per event (200MByte/s corresponds to this number for the maximum level one trigger rate of 100kHz). The data is fed into the FRL using an Slink-64.

All three TOTEM detectors will use the digital part of the VFAT chip for reading out the detectors. The T1 detector will normally use a CSC specific front end and only enter into the digital part of the VFAT. T2 and the Roman Pot detectors will use the analog front end of the VFAT. This means that the rest of the read out chain is completely standardized for the three TOTEM detectors.

The VFAT data is transmitted to the counting room by means of the GOL (Gigabit Optical Link) chip developed in the MIC group at CERN. This chip which serializes data and can operate at 800 MHz or 1600MHz (for effective data rates of 640 Mbit/s and 1280 Mbit/s) and can drive a laser for an optical link is also used in the CMS ECAL detector. Transmission rate for the Data Concentrator Card is limited to 640 Mbit/s, because the lasers equipping the GOL optohybrids are not sufficiently fast. For the readout of the ECAL detector a Data Concentrator Card was developed capable of receiving the data from 70 GOL chips, which is very close to the full GOL count for the Roman Pots (72) and about twice the GOL count of the GEM detectors. However, the information content of the TOTEM GOLs is much higher, and does not allow to fully equip one card (which only interfaces to one FRL).

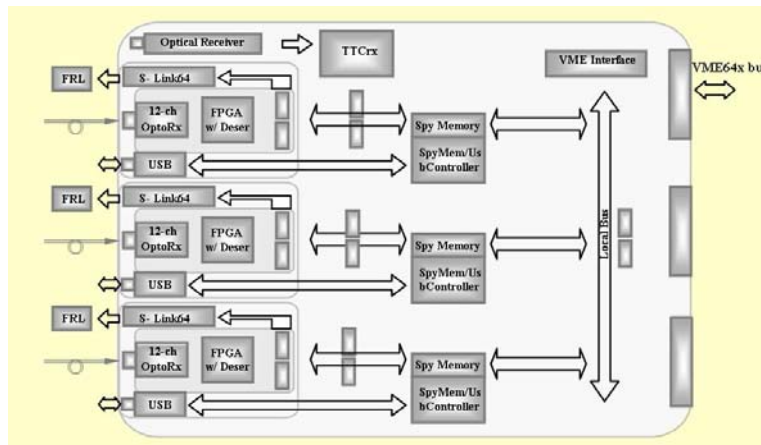


Fig. 3. Joint TOTEM – CMS Preshower FED card, carrying three optoreceiver mezzanines each driving an Slink for TOTEM.

A joint development with the CMS preshower team was started who could not use the standard DCC card because a more complex pedestal- and common mode subtraction could not be implemented in the FPGAs deserializing the transmitted data. The joint effort foresees a VME compatible card carrying three optoreceiver mezzanines which each can receive signals from up to 12 optical fibres. For the preshower the data from these three optoreceiver hybrids can be merged and further reduced prior to sending it over a single Slink to the CMS data acquisition for the three together. The optoreceiver mezzanines are equipped with a direct Slink output towards the CMS data acquisition, because in the TOTEM case one optoreceiver hybrid will receive sufficient data to fully occupy one Slink: If all 16 bits of the GOL carry VFAT data, eight GOLs will provide the maximum amount of data that can be absorbed by the CMS data acquisition.

The 21 Frontend Readout Links foreseen for TOTEM are distributed as follows:

Roman Pots	1 FRL/3 Roman Pots	8 FRLs
T1 (CSC)		6 FRLs
T2 (GEM)	3 FRLs/GEM side	6 FRLs
Spare		1 FRL

5 Full custom integrated circuits

TOTEM is designing 3 new full custom chips: the VFAT II, the Coincidence Chip and the LVDS repeater chip, all designed to be radiation tolerant. The VFAT contains 128 channels each with an analog front end and a comparator of which the threshold can be adjusted. The data is written into a first memory every clock cycle where it is kept for 256 cycles. Within this time a level 1 signal has to be applied to the chip to transfer the data from the event corresponding to the level 1 trigger to a second memory which automatically transfers its data to the counting room. The chip is equipped with internal biasing, testing and system features, and with an I2C interface providing extensive configuration features. The chip also has 8 configurable trigger outputs (see section 3). Further documentation can be found in the VFAT specification (see references).

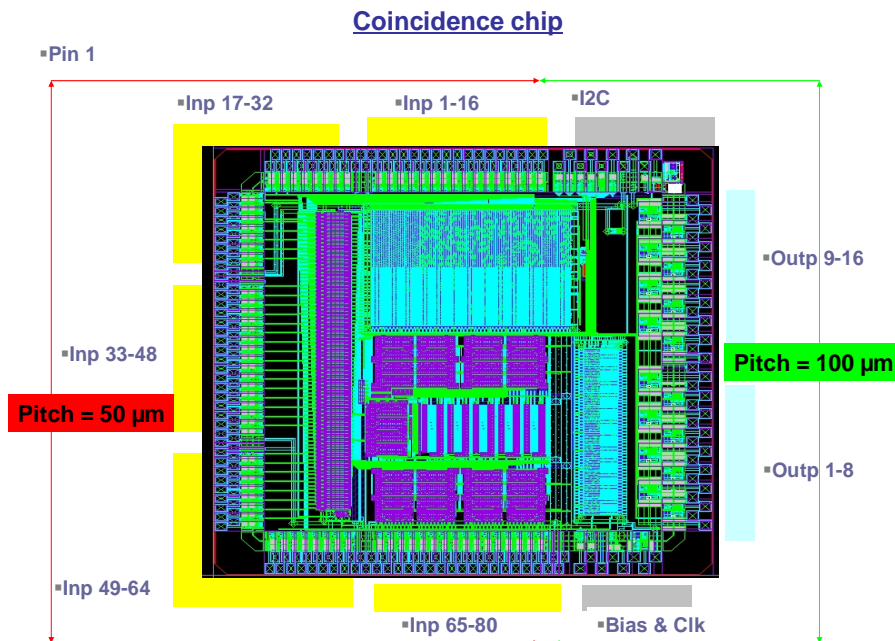


Fig. 4. Floorplan of the Coincidence Chip (CC chip).

The Coincidence Chip (figure 4) is used in the GEM and in the Roman Pot detectors to perform a first level coincidence of the trigger bits generated by the VFAT. This reduces the number of trigger bits to be transmitted to the counting room by an order of magnitude. Also this chip has been equipped with an I2C interface to allow reconfiguration using the slow control system. The chip can receive 80 LVDS inputs and has 16 configurable outputs. More information on this chip can be found in its specifications.

The LVDS repeater chip (figure 5) is used in the Roman Pot system to buffer the trigger bits sent from the detector to the counting room at regular instances along the electrical cable. This is required to preserve signal integrity. Latency considerations imposed electrical trigger bit transmission (delay about 4.2ns/m compared to 5ns/m for optical fiber). The chip has been equipped with more robust protection at input and output as it is linked to long cables. More information on this chip can be found in its specifications.

6 VFAT emulator card

The three TOTEM chips will be submitted together for fabrication very soon. However, the tight schedule imposed to work on the data acquisition in parallel. Therefore it was required to make a system capable of emulating the VFAT datastream. Therefore a VFAT emulator card was designed which is now in the final stages of fabrication. It contains an FPGA linked to 12 GOH hybrids. The FPGA can be configured to provide an arbitrary signal to the 12 GOH which drive 12 optical fibers.

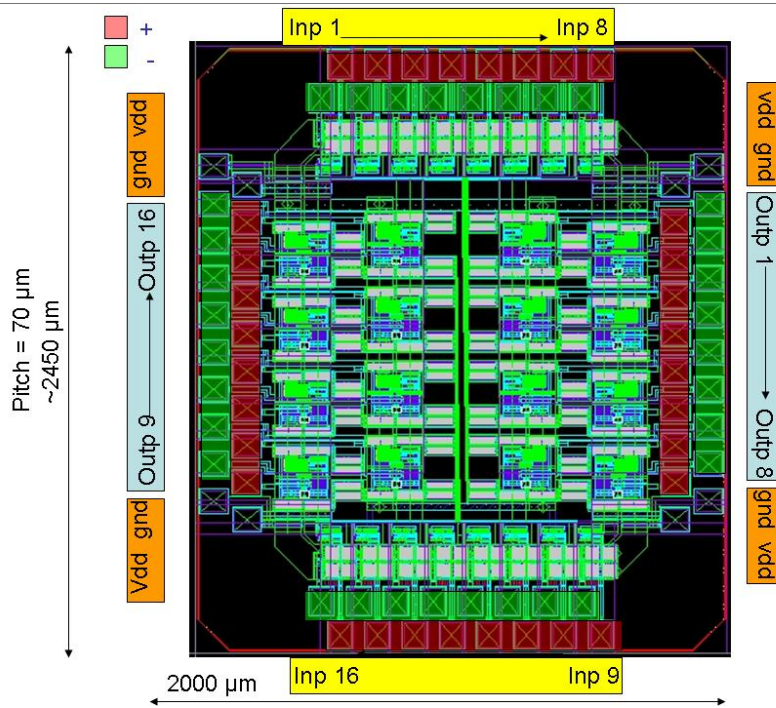


Fig. 5. Floorplan of the LVDS repeater chip used for the Roman Pot trigger bits.

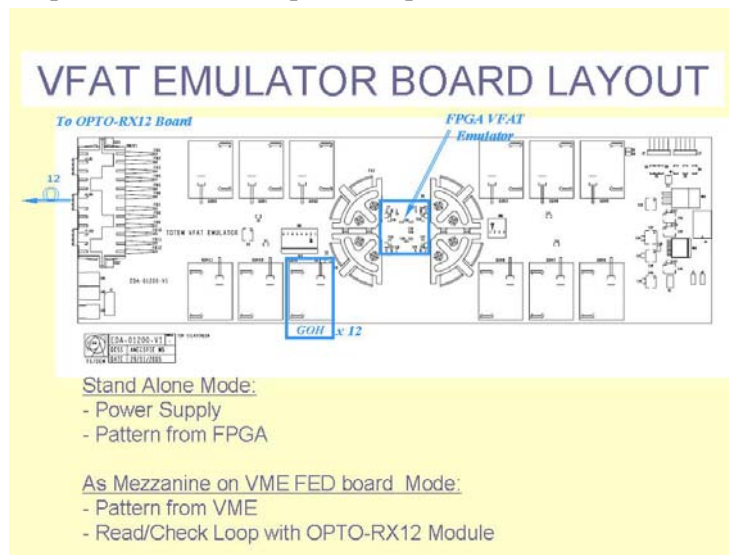


Fig. 6. VFAT emulator card driving 12 optical links in parallel.

7 Slow control for detectors and electronics

The slow control for the TOTEM detectors are based on the standard CMS FEC-CCS card and the optical control loop followed by an electrical token ring of CCU chips. The CCU chips interface with the front end chips by means of an I2C interface which is implemented on all chips used in the front end part of the detector. 4 control loops are planned (1 per station) for the Roman Pots, and 2 or 4 for the T1 and T2 detectors. The adoption of this slow control standard also allows the DCU chip with built-in temperature sensor to be used for monitoring purposes. This fully eliminates additional cabling for temperature monitoring. Following the CMS standard a separate power supply of the slow control system will be used to allow monitoring of certain parameters prior to power-on of the readout chips.

Note that cooling systems, Roman Pot Motion and Interlock systems are another part of the slow control system. These are being developed by specific specialized groups, and will not be further discussed here.

8 Overall detector electronics system

Figure 7 gives an overview of the full electronics setup. In the counting room the TOTEM TTC crate receives machine timing information, local triggers, and triggers from the CMS Global Trigger. It is a VME crate equipped with a controller with an optical interface, the LTC card (Local Trigger Controller) and the TTCci card. The latter generates from the information it receives from LTC and CMS global trigger the optical TTC signal which is distributed using an optical fanout to data acquisition and control cards of the experiment.

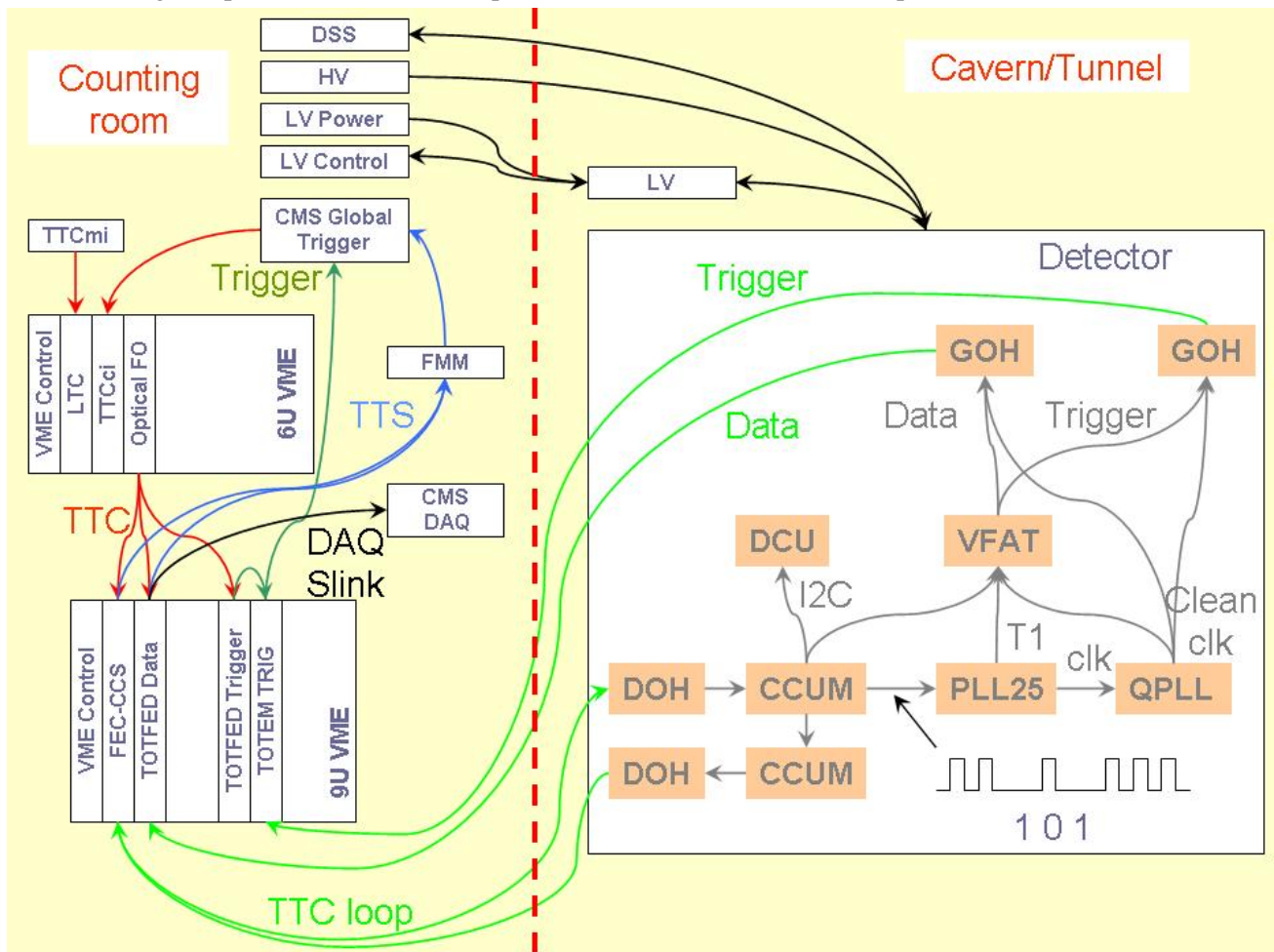


Fig. 7. General overview of the TOTEM detector electronics system. For simplicity coincidence chips and signal buffers have been omitted on the detector. For the Roman Pots the trigger signals will be transmitted electrically to deal with the severe latency requirement.

The rest of the electronics system in the counting room is based on three cards with VME interface:

- 1) The FEC-CCS card contains the FEC mezzanines which provide the interface for the TTC token rings on the detector which provide timing (clock), fast commands like trigger and sync, and slow control.
- 2) The TOTFED (see fig. 3) is the VME card which receives three optoreceiver mezzanines, which each contain an optical receiver and FPGA. The data is processed inside the FPGA and presented to the CMS DAQ through the on-board Slink, so there are 3 Slink connections per TOTDCC.

The TOTFED will also be used for trigger generation: for T1 and T2 the trigger signals will be sent optically to the counting room. The optoreceiver mezzanine's firmware will be adapted to provide trigger signal processing. The Slink connector can be reconfigured to output a very limited number of trigger bits. For the Roman Pots the FPGAs on board of the TOTDCC can be used to implement the trigger algorithm.

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A small adaptation mezzanine card which receives the LVDS signals and transforms them to CMOS is necessary to feed the Roman Pot trigger signals to the TOTDCC. T1 will need 5-6 optoreceiver mezzanines and 2 TOTDCC, T2 3 optoreceiver mezzanines and 1 TOTDCC, and the Roman Pots 2 TOTDCC for trigger generation.

- 3) A final trigger coincidence card. This might be implemented using a TOTDCC or not, this is still under study. This card will contain the LVDS outputs to the CMS global trigger.

In CMS each detector can indicate to the trigger system that it detected a problem (for instance a synchronization error or that the data buffers are filling up). This is done using the Trigger Throttling System or TTS. This system allows to take action to remedy the problem. For instance if a detector notifies that its buffers are filling up, the trigger rate can be artificially lowered (hence the name...). For this signal outputs are foreseen on the TOTDCC towards the FEC-CCS which combines the signals and sends them to CMS. In the TOTEM case the buffers on the VFAT are quite large, so the probability is quite small that a buffer overflow will occur – normally other CMS detectors will saturate sooner. However, the TTS signals are required to deal with other problems like synchronization errors.

On the detector the TTC signals are received by the Digital OptoHybrids. The system is based on a loop where signals have to be returned to the counting room to verify proper functioning of the system. In addition the return of the loop can be used to transmit slow control data to the counting room (e.g. temperature readings...). Fast commands (sync, level 1 trigger...) are coded onto the clock by missing pulses (see the figure), and the PLL separates clock and fast commands. The clock is sent to the QPLL to reduce its jitter. This is required because optical transmission of trigger and readout data. In case of Roman Pots and T2 (GEM) a first coincidence of the trigger signals sent by the VFAT is carried out on or near the detector using the full-custom coincidence chip, which can be controlled using the slow control system via its I2C interface.

Power needs to be provided to the detector and to its electronics. This is further described in the next section.

9 Power supplies, racks and cables

The power system is separated into a low voltage and a high voltage part. The low voltage part has to provide a large current (many Amperes) to the detector and to reduce the voltage drop in the cables, the power is brought to near the detector using a 380 V DC power supply. The power is converted to the required voltage using power supplies which are foreseen to stand the radiation and in case of T1 and T2 the magnetic field near the detector.

The low voltage supply needs are summarized in the following table:

Roman Pots	2.5 V	<5 A	1 channel/Pot	analog
	2.5 V	<5 A	1 channel/Pot	digital
	2.5 V	<5 A	1 channel/Station	slow control
	2.5 V	<5 A	1 channel/Station	repeater
	3.3 V	<5 A	1 channel/Station	optocoupler
			⇒ 15 channels/Roman Pot station, or 30 per side	
T1 (CSC)	+10 V	<5 A	1 channel/Quarter	bulk bias
	- 5 V	<5 A	1 channel/Quarter	bulk bias
	5 V	<150 A	4 channels of 55 A/Quarter	analog
	2.5 V	<12 A	1 channel/Quarter	digital
	2.5 V	<5 A	1 channel/Quarter	slow control
T2 (GEM)	all 2.5 V	<10 A	2 channels/Quarter	analog

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<10 A	2 channels/Quarter	digital
<5 A	1 channel/ Quarter	slow control

For the low voltage Wiener supplies will be used, of which each unit contains up to 12 channels. From the table above it can be concluded that for the Roman Pots 2 fully equipped and one partially equipped module is sufficient per side. For the T1 (CSC) 1 module per quarter (15 out of 60 detectors) is sufficient, and for T2 1 module is sufficient per side (the two quarters on the same side can share the module, the detectors are powered in groups of 5 (20 detector (half)planes per side). The power supplies for the Roman Pots will be placed in the racks QYC02 of alcoves of RR53 and RR57, and will be air cooled. The power supplies for T1 and T2 will be placed in the racks near these two detectors, but will be subject to a magnetic field sufficiently large to require the maximum magnetic shielding (up to 120 mT). They will be water cooled.

The low voltage system is integrated with the CMS low voltage system and is supplied via an uninterruptible supply which in case of a power failure can sustain power delivery for about 2 minutes sufficient to bring down the power on the detectors gracefully.

The high voltage system needs to provide up to 3.5 kV for T1, up to 4.5 kV for T2, and up to 0.5 kV for the Roman Pots, but the current to be delivered is very small normally without significant fast variations. This allows TOTEM to place the high voltage power supplies in the counting room with cables to the detector with proper on-detector filtering. To avoid powering these power supplies from the counting room supply, a special power line linked to the detector power system will be provided.

10 Electronics Racks

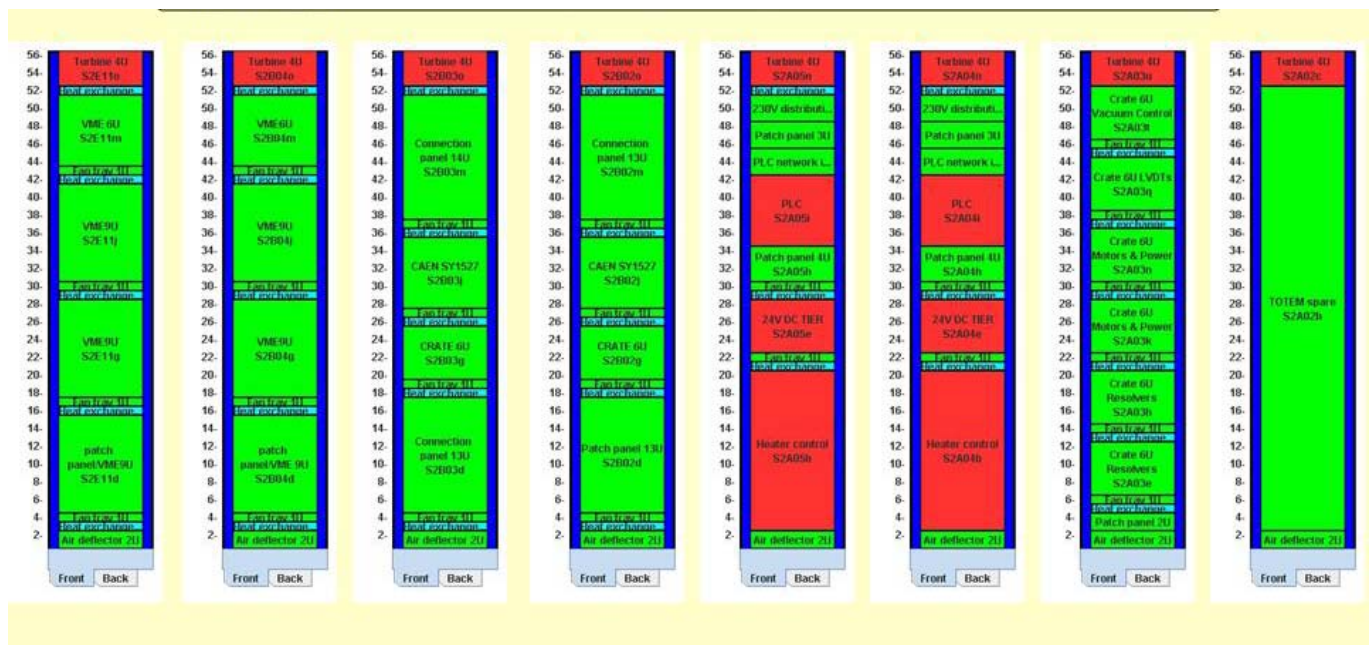


Fig. 8. TOTEM racks in the counting room

Figure 8 gives an overview of the racks for TOTEM in the counting room. One rack (S2E11) is located right above the CMS Global Trigger to minimize the latency for the trigger signals. The other TOTEM racks are located on the same floor. Eight racks are foreseen for TOTEM in the counting room:

- S2E11 data acquisition, TTC and trigger
- S2B04 data acquisition
- S2B03&4 power and safety*

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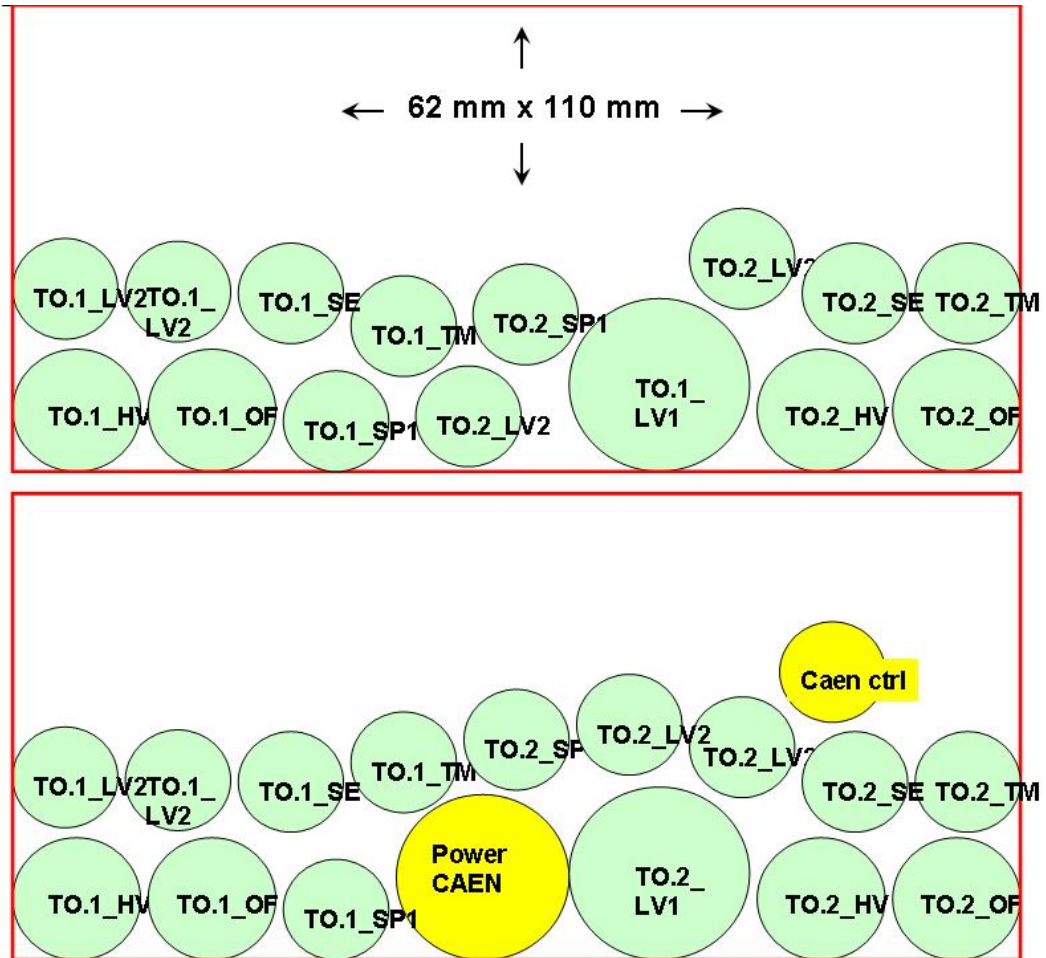


Fig. 9. Overview of the cables for the T1 and the T2 detector in the cable chain. The cable in yellow is for the power of the CMS BCM.

In one of the two compartments on each side 2 cables are put for power supply of the CMS BCM. It is planned to wire a certain number of cables for T1 to the T2 rack first to allow exchange of spare cables between T1 and T2. An overview is shown in figure 9.

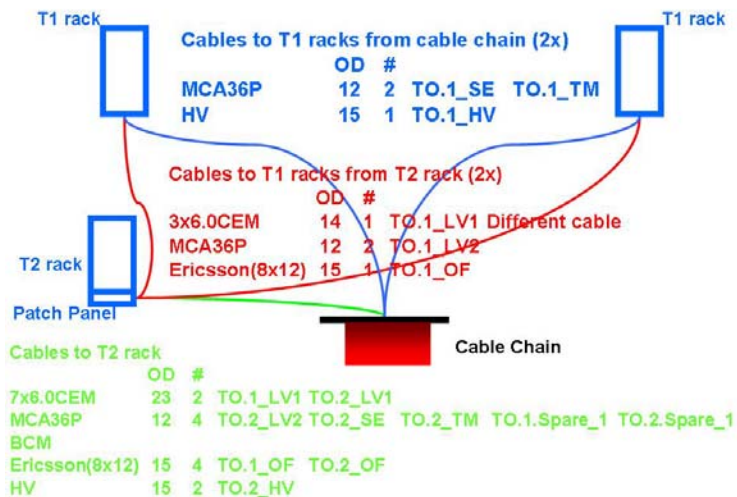


Fig. 10. Overview of cabling on the HF platform.

The cabling for the Roman Pot system is currently being finalized.

12 Detector safety

CMS has foreseen a detector safety system which is used to verify all conditions are met for the detector to operate safely. If this is not the case, some action is taken as for instance to take power away from the detector. Note that this system is different from the detector control system where typically a much larger amount of signals are controlled and measured. Here the idea is to measure a few parameters as temperature for instance and react on those. TOTEM has to provide the signals to the rack S2E15, and has to specify the margins between which these signals should remain. Currently it is planned to have a few PT100 per detector for T1 and T2 which should be monitored. In addition overcurrent and overvoltage are already taken care of by the power supplies. For the Roman Pots a special interface for interlock for the machine is foreseen.

13 References

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6. P. Chalmet & W. Snoeys : Repeater Chip specification