THE LHC BEAM DUMPING SYSTEM TRIGGER SYNCHRONISATION AND DISTRIBUTION SYSTEM

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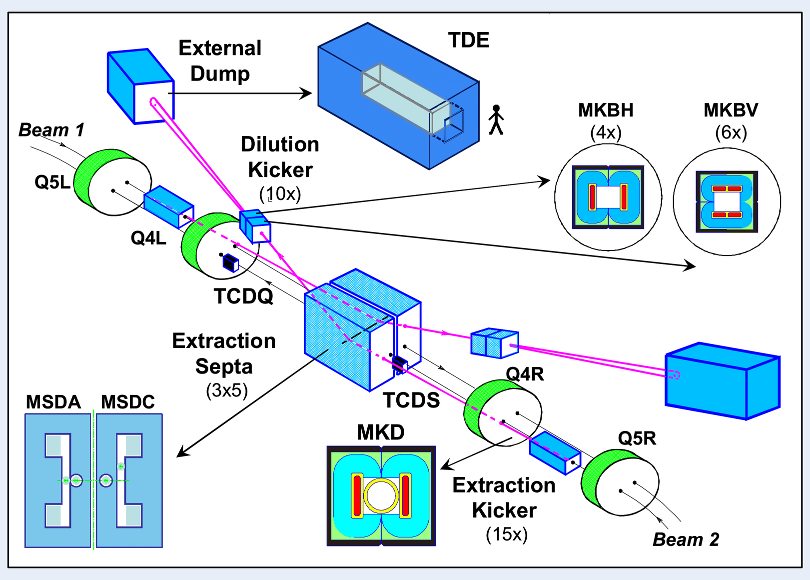
Abstract

Two LHC beam dumping systems (LBDS) are required to remove with a loss-free fast extraction the counter-rotating beams safely from the LHC collider during setting-up of the accelerator, at the end of a physics run and in case of emergencies. They consist of two groups of 15 fast pulsed magnets for beam extraction from the accelerator combined with two groups of 10 fast pulsed magnets for horizontal and vertical beam dilution. Dump requests come from 3 different sources: the machine protection system for emergency cases, the machine timing system for scheduled dumps or the LBDS itself in case of internal failures. These spontaneously issued dump requests are synchronized with the 3µs beam abort gap within a fail-safe trigger synchronisation unit (TSU) based on digital phase lock loop (DPLL) locked on the beam revolution frequency with a maximum phase error of 40ns. Afterwards, the synchronised trigger pulse is distributed to the fast pulsed magnet high voltage generators through a redundant fault tolerant trigger distribution system based on the domino effect strategy. The time of flight of the beam through the different magnets as well as the electronic and high voltage generator turn-on delays are individually compensated for each magnet through the trigger distribution cable length. This paper reviews the technical implementation of the LBDS trigger synchronisation and distribution system.

LHC Beam Dumping System

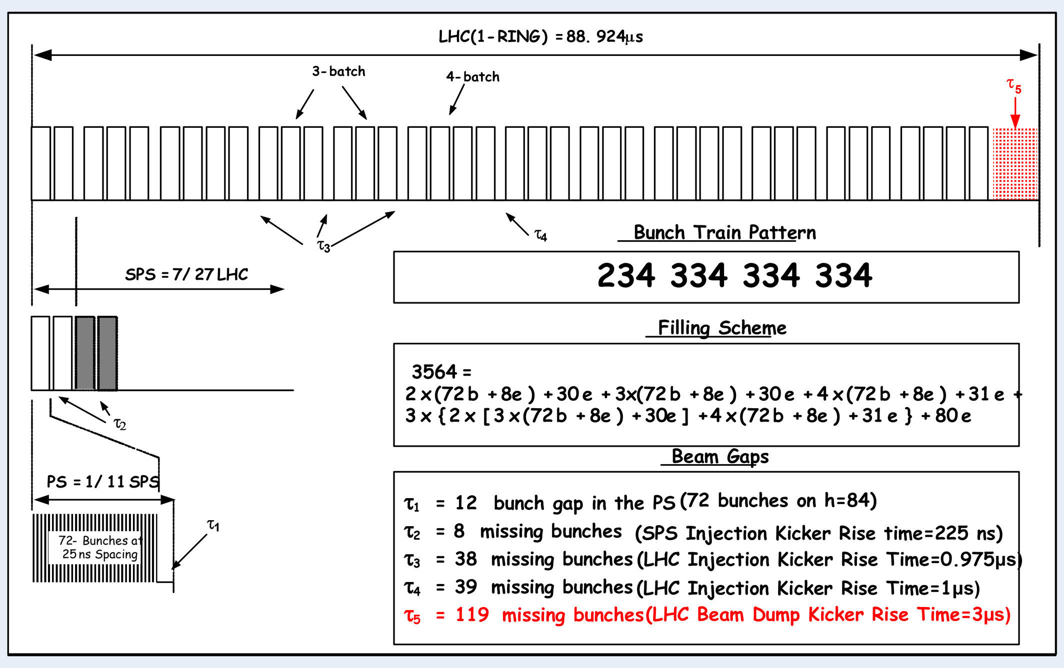


The function of the LHC Beam Dumping System, actually under test at CERN, is to fast-extract the circulating beam in a loss-free way from each ring of the collider and to transport it to an external absorber positioned sufficiently far away to allow appropriate beam dilution.

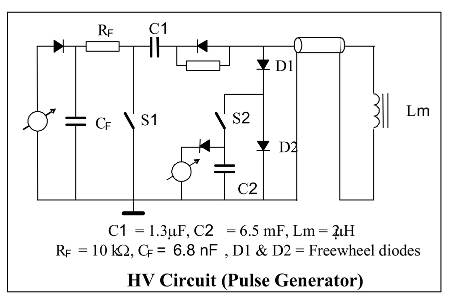
It consists, per ring, of 15 extraction kickers, followed by 15 septum magnets, 10 dilution kickers, and finally an external dump, mounted in a separate cavern some hundred meters away.

A loss-free extraction requires a particle-free gap in the circulating beam during which the field of the extraction kicker magnets can rise to its nominal value.

For a correct beam dump action, the 15 extraction kickers must all be fired at the same time with a precision better than 25 ns and the 2.8 µs kick rising edge must be synchronised with the 3 µs beam abort gap with a phase error lower than 40 ns.



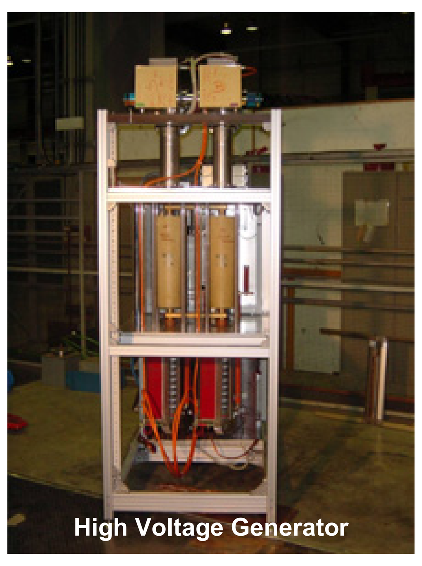
LHC Extraction Kicker



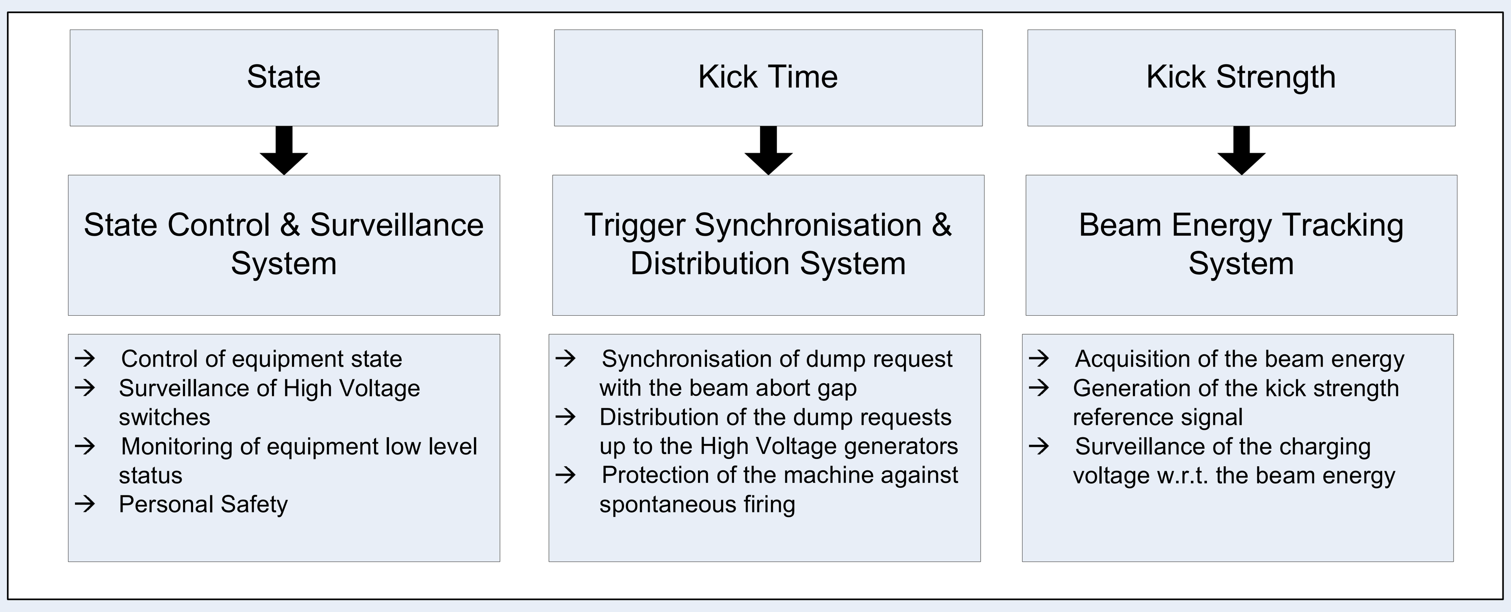
HV Circuit (Pulse Generator)

Number of magnets per system	15	
System deflection angle	0.275	mrad
Operating charging voltage range	2.2 to 30	kV
Operating magnet current range	1.4 to 20	kA
Magnet field overshoot	8	%
Field flat top duration	> 90	µs
Field rise time 0.5% - 100% per magnet	2.8	µs

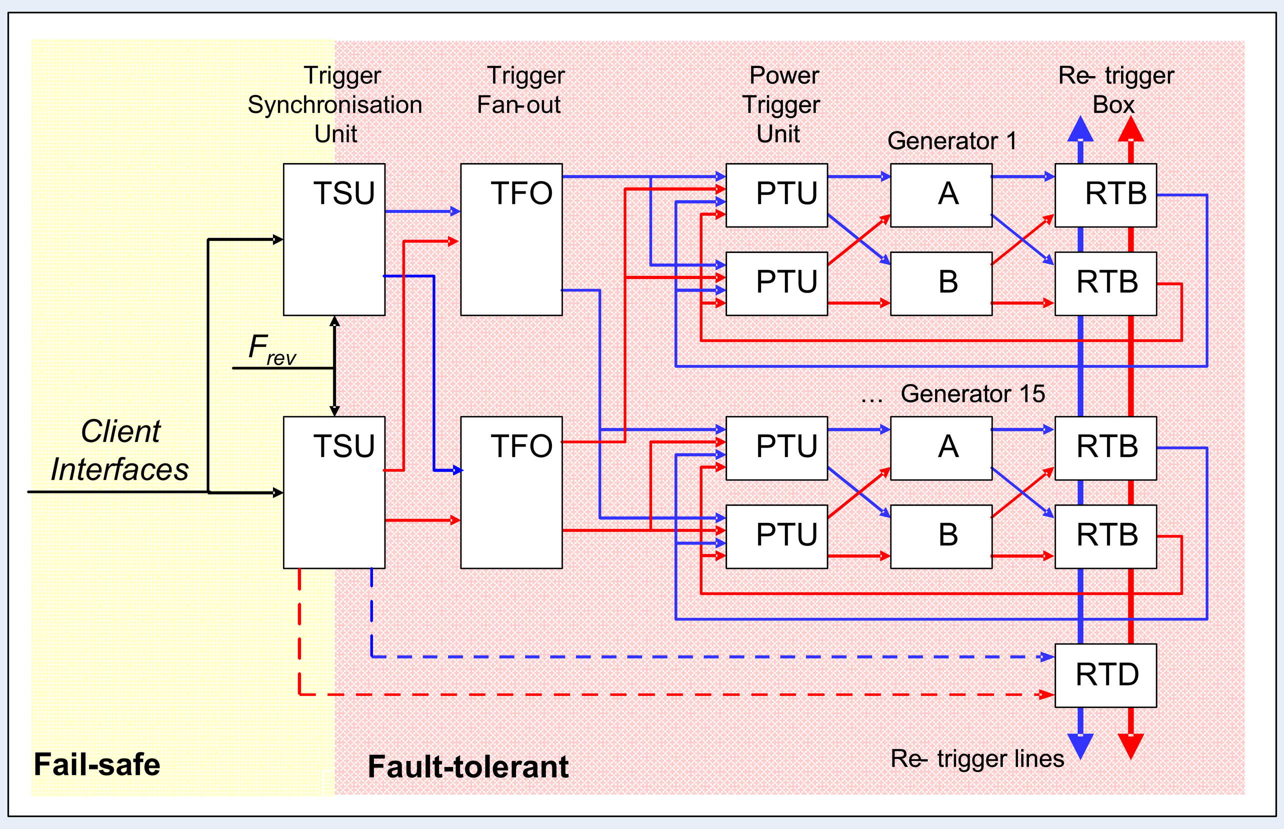
Kicker Magnet



High Voltage Generator



Trigger Synchronisation and Distribution

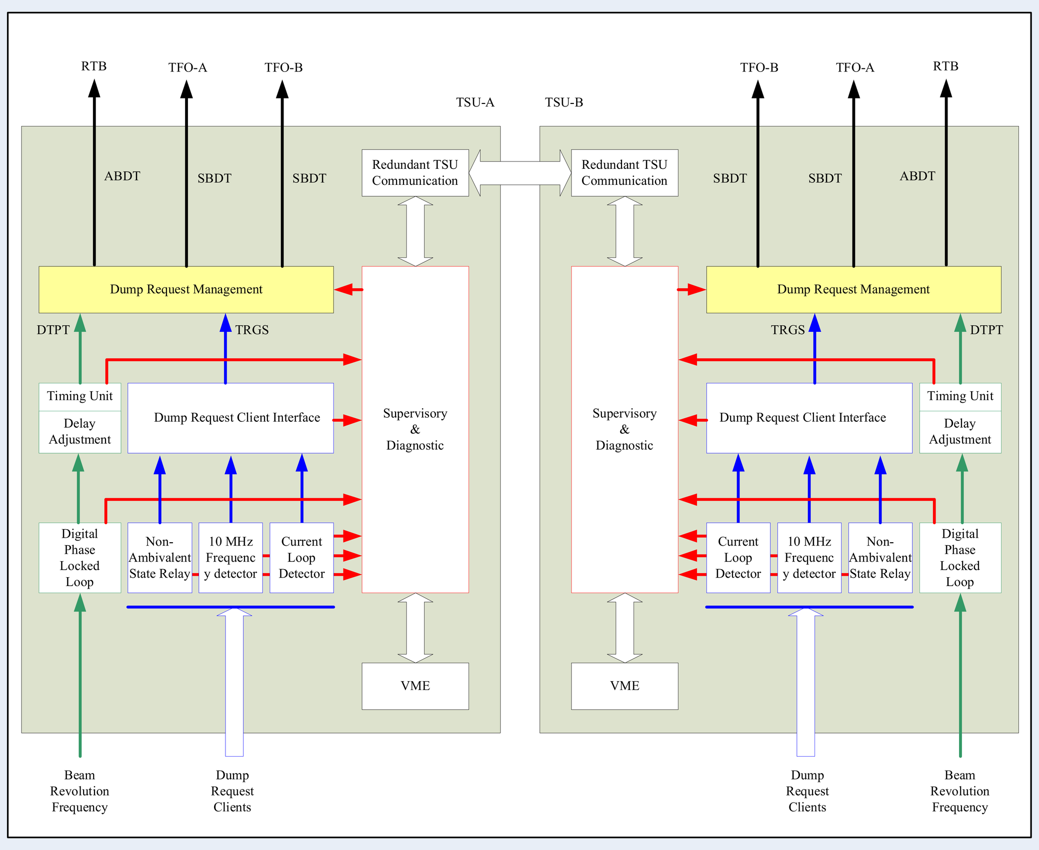


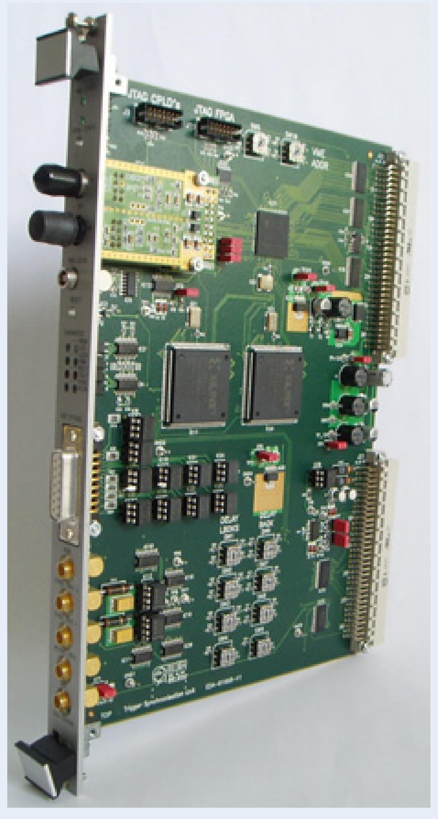
Dump requests come from 3 different sources:
- → The machine protection system for emergencies,
- → The machine timing system for scheduled dumps, or
- → The LBDS itself in case of internal failures.

These spontaneously issued dump requests are synchronised with the beam abort gap within the Trigger Synchronisation Units (TSU). Once synchronized, dump requests are distributed through the Trigger Fan-Out units (TFO) to the Power Trigger Units (PTU) for firing of the extraction kicker pulse generators. In addition, a redundant fault-tolerant Re-Trigger System is foreseen to re-distribute, as fast as possible, a trigger request issued from a spontaneous firing of one generator to the remaining 14 generators through redundant chains of re-trigger boxes (RTB).

Furthermore, any dump request will also send a dump trigger, delayed by more than one turn, via the Re-trigger Delay box (RTD) to all power trigger modules. This additional trigger path guarantees that at least an asynchronous beam dump is initiated, even when both TSUs fail.

Trigger Synchronisation Unit





A TSU consists of four independent sub-systems:

- →The **synchronisation** sub-system that consists of a DPLL oscillator unit and a timing unit for compensation of the phase error between the beam revolution frequency and the beam abort gap position at the extraction kicker location,
- →The **dump requests client interface** sub-system that consists of detection of the dump request issued by clients through redundant fail-safe 10MHz frequency detectors, current loop detectors and non-ambivalent state detectors,
- →The **dump request management** sub-system that re-phases the dump request with the beam abort gap and generates the synchronous beam dump trigger output pulse,
- →The **supervisory and diagnostic** sub-system that cross-checks the correct operation of the TSU with the redundant unit and interfaces the board to the VME interface for surveillance of all the operational parameters and post-mortem diagnostic.

The TSUI re-phases the spontaneous dump requests issued by the external clients with the circulating beam such that the rising edge of the magnetic field in the extraction kicker coincides with the beam abort gap in the circulating beam.

Locked to the LHC beam revolution frequency, two redundant TSUs produce continuously dump trigger pulse trains synchronised with the beam abort gap. The distribution of these pulse trains are inhibited until a beam dump is requested. The pulses which pass the inhibit stage are then sent via two redundant trigger fan-outs (TFO) to all the power trigger modules. In this way the first pulse after the reception of a dump request triggers synchronously the system.

In case the beam revolution frequency is lost during more than one turn, an internally synchronised direct digital synthesiser based on a Digital Phase Lock Loop (DPLL) implementing a numerically controlled oscillator, precisely locked on the beam revolution frequency, issues a dump trigger which is still synchronous with the beam abort gap. In addition, the two redundant TSUs cross-check continuously their DPLL synchronisation and a phase discrepancy greater than 40 ns between the two TSUs issues automatically a synchronous dump. This mechanism reduces the probability of non synchronised dumps to almost zero. If the synchronisation of only one of the TSU fails, a synchronous dump trigger is forced by the redundant system.

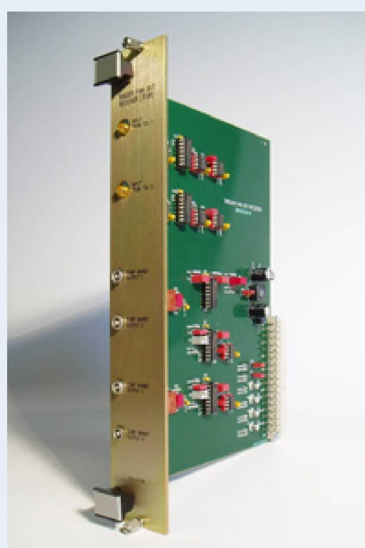
Trigger Fan-Out and Distribution

Dump request distribution uses the "**domino effect**"

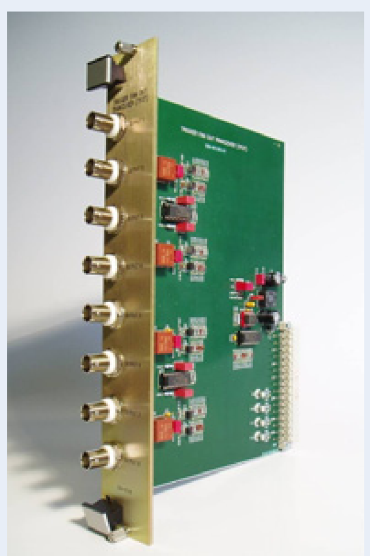
→ **Energy** required **to distribute** the **dump request** up to the kicker HV generator is
- **Pre-stored within capacitor** at each stage of the triggering chain,
- **Used to trigger the next stage,** and
- **Checked before a beam permit** signal is issued,

but, **somebody** has to **trigger the chain**… to **push** the **first domino stone!**

→ **Propagation** of the **trigger pulse** through the different stages of the triggering chain relies either on an **active fail safe logic** up to the synchronisation with the abort gap and on a **passive redundant fault tolerant logic** up to the HV generator in order to avoid asynchronous beam dumps.



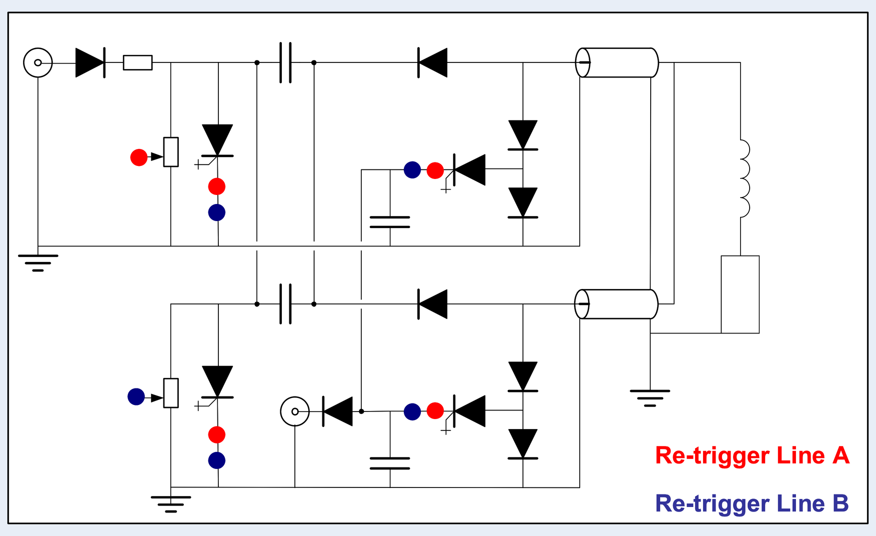
Trigger Fan-Out Receiver

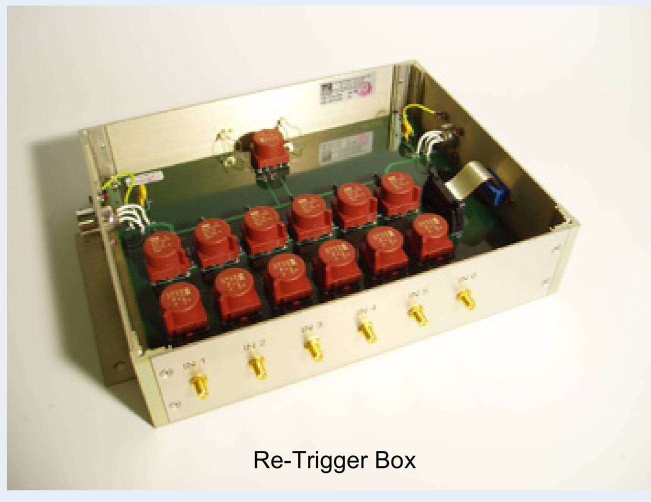


Trigger Fan-Out Transmitter

Two redundant TFOs are used to distribute the dump request coming from the TSUs to the PTUs. Each TFO is divided in three main circuits: the Trigger Fan-Out Receiver (TFOR), the Trigger Fan-Out Transceiver (TFOT) and a +/- 15V power supply.

Re-Triggering System

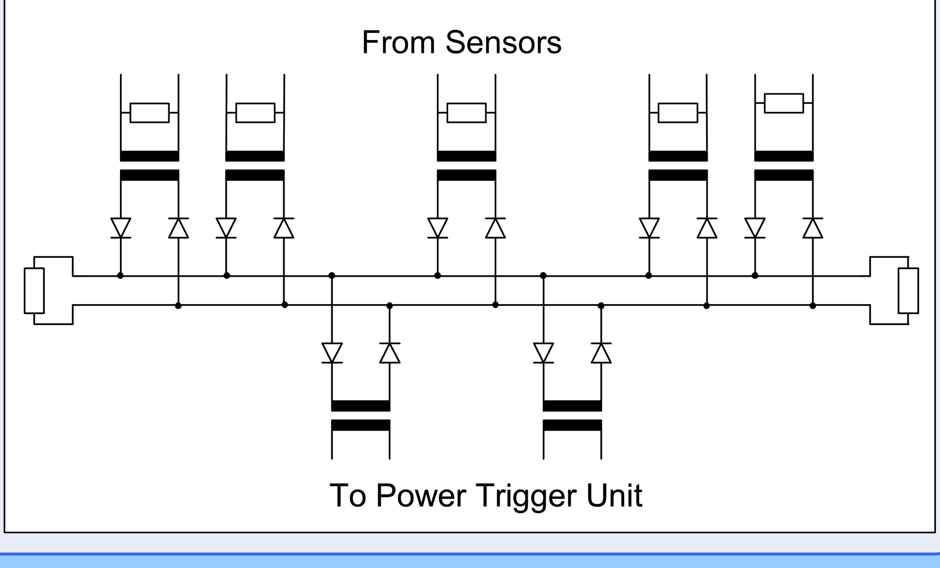




Re-Trigger Box

The main task of the RTS is to re-distribute, as fast as possible, a trigger request issued from a spontaneous firing of one generator to the remaining 14 generators.

A redundant chained input/output system has been chosen for the RTS. Each pulse generator has 5 re-trigger source sensors per chain with enough powering capabilities to trigger all the PTU of the remaining 14 high voltage generators. Due to the architecture of the system, an avalanche mechanism is started after a detection of a spontaneous firing.



Summary

The LBDS must remove both beams safely from the LHC to prevent any damage to the machine. A complete redundant path for the entire triggering system from the synchronisation unit up to the triggering of the generators has been designed to provide the required degree of safety. The high availability of the selected architecture and its redundant structure minimises the risk of an asynchronous beam dump.

The principal features of the system are:
- **1oo4** independent trigger channels can issue the dump trigger.
- **1oo2** Trigger Synchronisation Unit systems can synchronise the dump requests.
  - → Both systems are independent.
  - → The mission time for tests is 89 µs.
- Each generator has 10 re-trigger sources which feed 2 independent re-trigger distribution lines.
  - → Each source can deliver sufficient energy to trigger all the power triggers of all LBDS high voltage generators (Twice **1oo5)**
- Continuity of the re-trigger lines is continuously checked (pulse train).