A Burn-in test station for the ATLAS Phase-II Tile-calorimeter low-voltage power supply transformer-coupled buck converters

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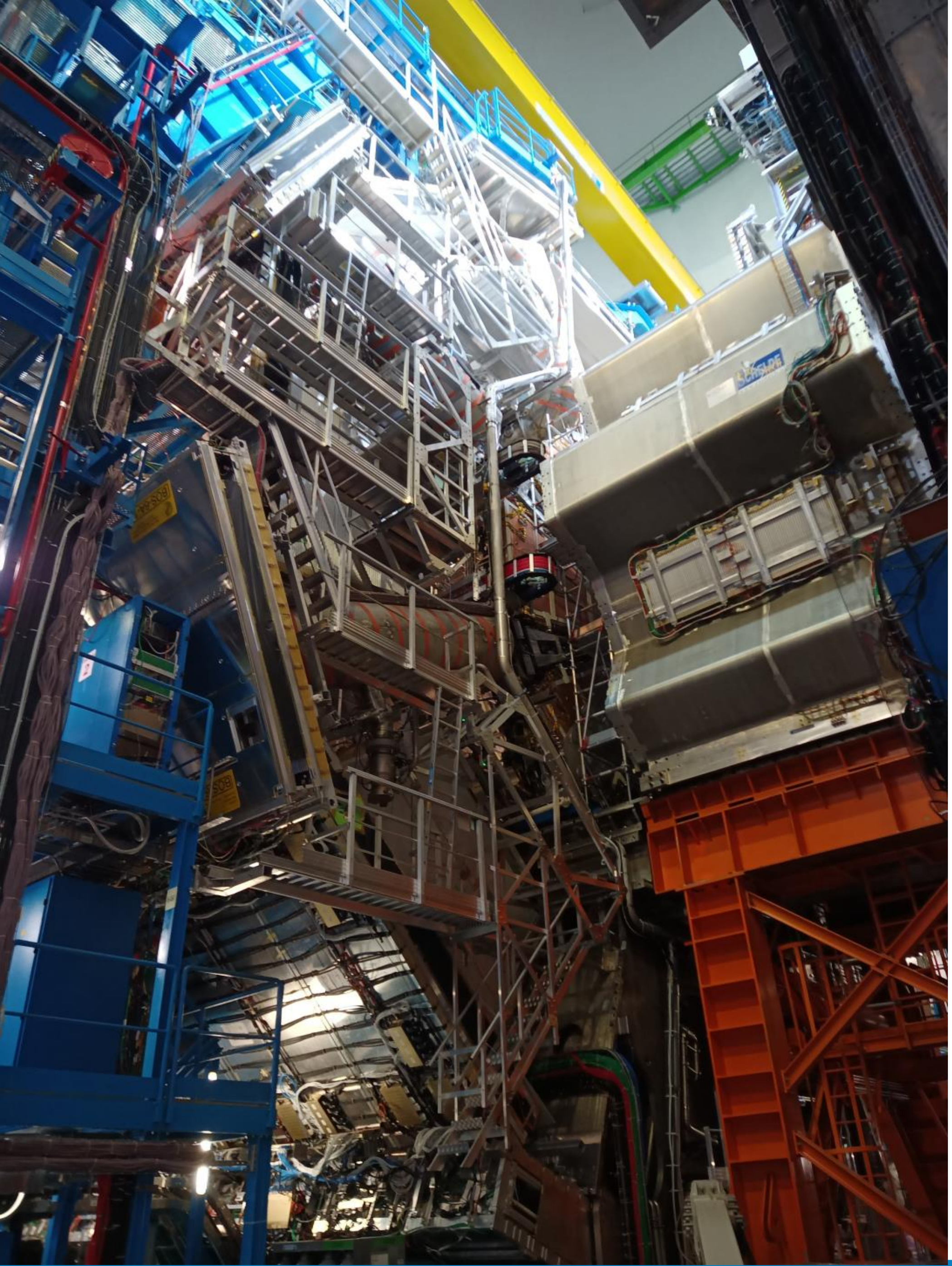
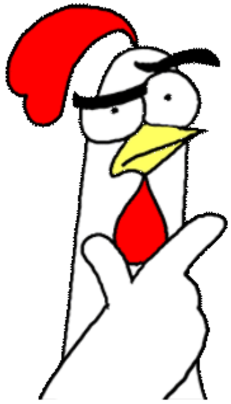


Talk Outline

- The ATLAS Tile-calorimeter
- TileCal Phase-II Upgrade
- Low-Voltage Power Supply Brick
- Quality Assurance testing
- Burn-in testing and its motivation
- Burn-in Test Station - Overview
  - Hardware
  - Software
  - First Burn-in
- Conclusion



The ATLAS Tile-Calorimeter

- The Tile Calorimeter (TileCal) is a sampling calorimeter which forms the central section of the Hadronic calorimeter of the ATLAS experiment.
- TileCal performs several critical functions within ATLAS such as: the measurement and reconstruction of hadrons, jets, hadronic decays of τ-leptons and missing transverse energy. It also participates in muon identification and provides inputs to the Level 1 calorimeter trigger system.
- The detector is located within the region $\eta < |1.7|$ and is partitioned into four barrel regions. Each barrel region consists of 64 wedge shaped modules which cover $\Delta\phi \sim 0.1$ and are composed of plastic scintillator tiles, functioning as the active media, inter-spaced by steel absorber plates.
- On-detector electronics located in extractable “drawers” at the outermost part of the module.
- Light produced by a charged particle passing through the plastic scintillating tiles is read out via wavelength shifting fibers to Photo-Multiplier Tubes inside the drawer

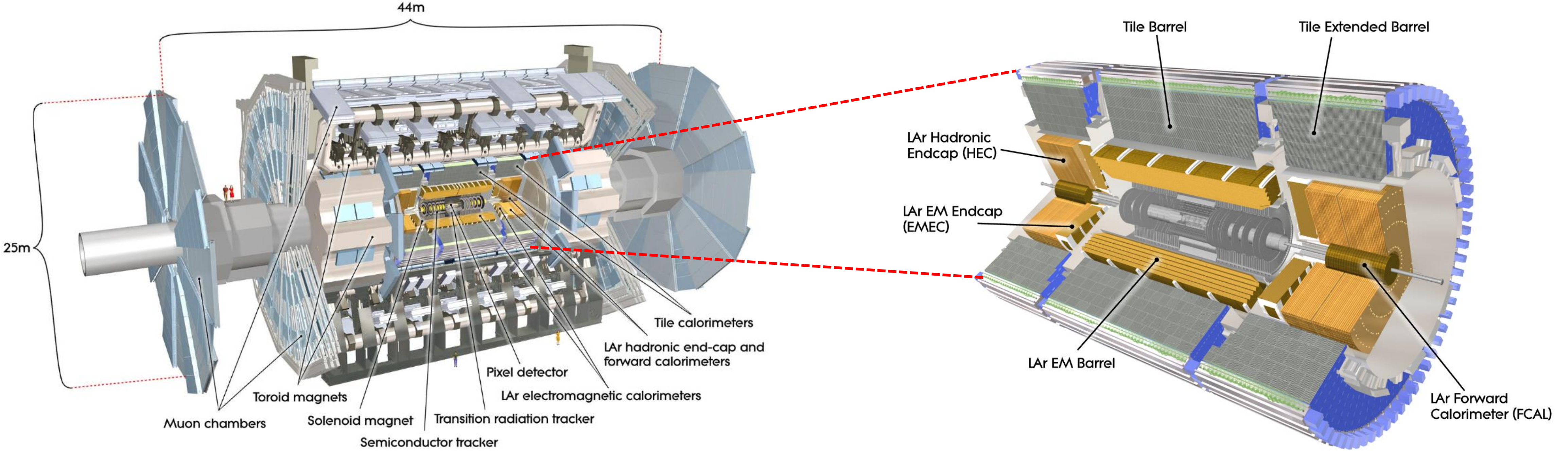


Fig. Left - The ATLAS detector, Right - The ATLAS inner Barrel, Right *J. Pequenao, Computer Generated image of the ATLAS calorimeter,(2008), https: // cds. cern. ch/ record/ 1095927*

TileCal Phase-II Upgrade

- In the year 2029 the start of the operation of the High-luminosity Large Hadron Collider(HL-LHC) is planned .
- The resulting HL-LHC environment has necessitated the development of **new electronics, both on and off detector**, in order to ensure the continued peak performance of TileCal.
- The new electronics need to meet the requirements of a 1 MHz trigger for the Level 1 trigger system, higher resistance to ambient radiation exposure and improved performance under pileup conditions.

See link for summary of the entire Phase-II upgrade

[Link: Upgrade of ATLAS Hadronic Tile Calorimeter for the High Luminosity LHC]

MD: Mini Drawer
SD: Super Drawer
PMT: Photo multiplier Tube
FELIX: Front-End Link eXchange
TDAQi: Trigger and Data Acquisition Interface
FPGA: Field Programmable Gate Array
PPr: Pre Processor
ADC: Analog To Digital Converter
HVAD: High Voltage Active Divider
DCS: Detector Control System
ELMB: Embedded Local Monitoring Board
ELMB-MB: Embedded Local Monitoring Board Mother Board
HV: High Voltage
LV: Low Voltage
FR: Front End

Upgrade LV power distribution system.

- A new three-stage system is being implemented.
- New LVPS Brick (Crux)

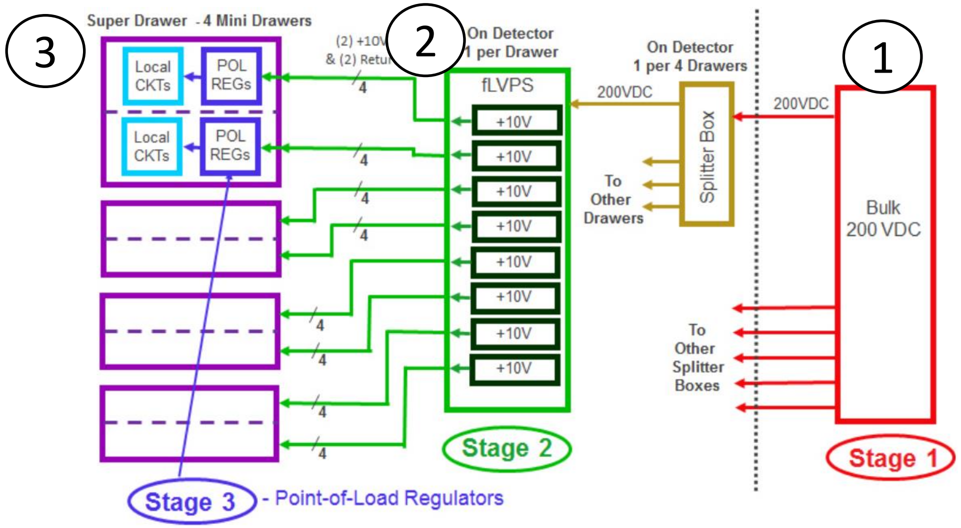


Fig. A Block diagram of the Phase-II upgrade 3-stage low-voltage system.

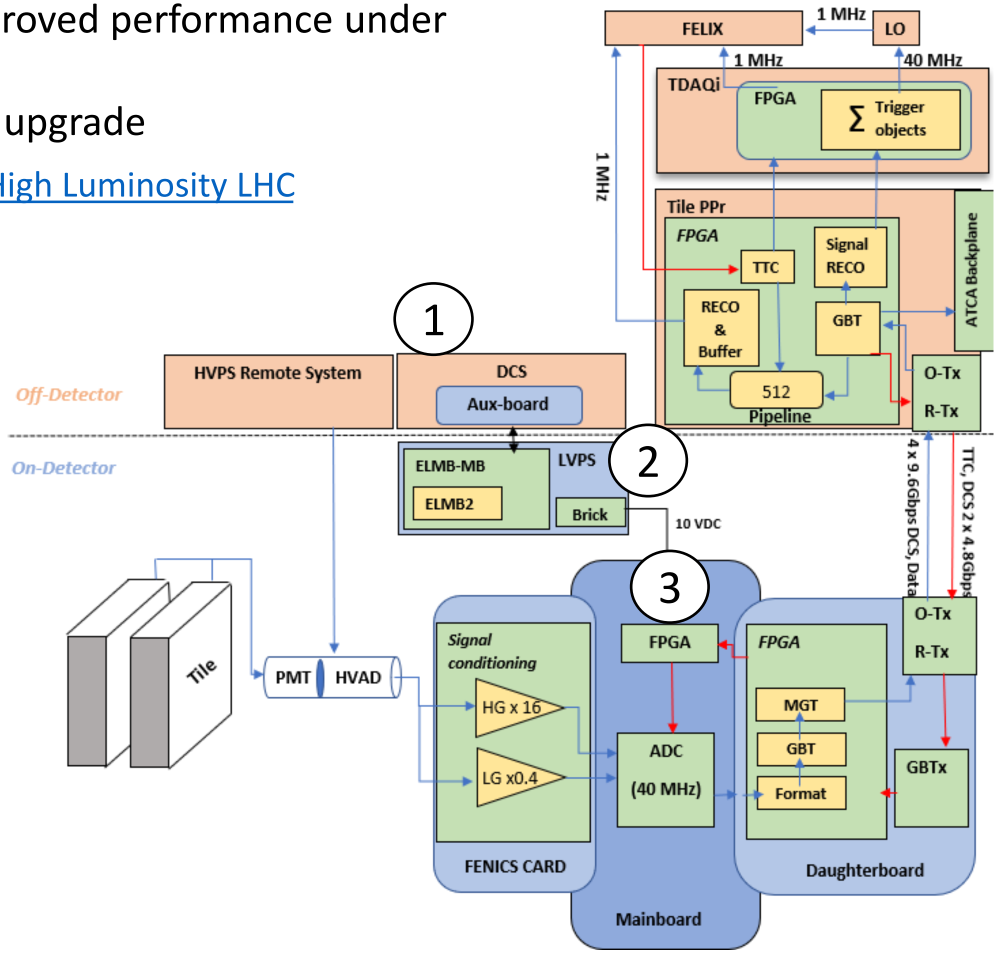


Fig. The upgraded readout chain and power distribution of TileCal.

Low Voltage Power Supply Brick

- Topology: A transformer-coupled buck converter.
- Converts bulk 200 VDC power received from off-detector to the 10 VDC which is then distributed to the Front-end electronics.
- Makes use of inbuilt protection circuitry – Over voltage protection, Over current protection and Over temperature protection.
- 1136 new LVPS Bricks to be locally produced by SA-CERN over the next two years.
- The required lifetime of a Brick within TileCal is ~ 20 years.
- Access to the LVPS Bricks is on the order of once per year.

Locally produced elements:
- ✓ Printed circuit boards
- ✓ Ceramic posts
- ✓ Production of final product

<u>Current Brick Version - V8.5.0:</u>

- New radiation hardness requirements.
- Single output voltage
- Increased efficiency
- Reduced operating temperature

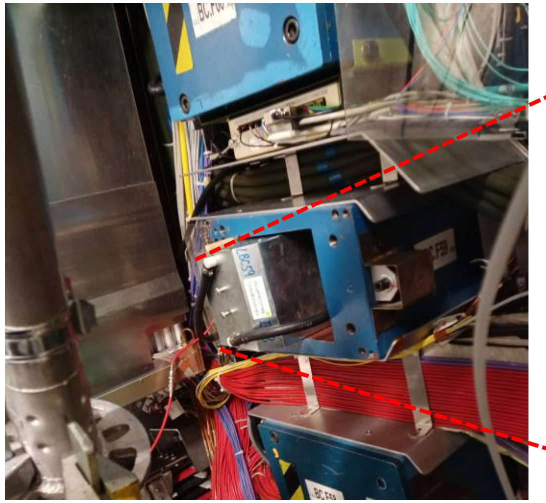


Fig. *An LVPS inside TileCal.*

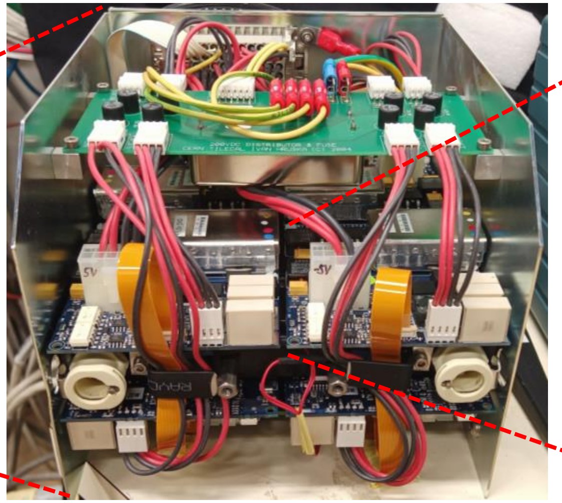


Fig. *Inside an LVPS.*

Primary side MOSFETs *Output inductor.*

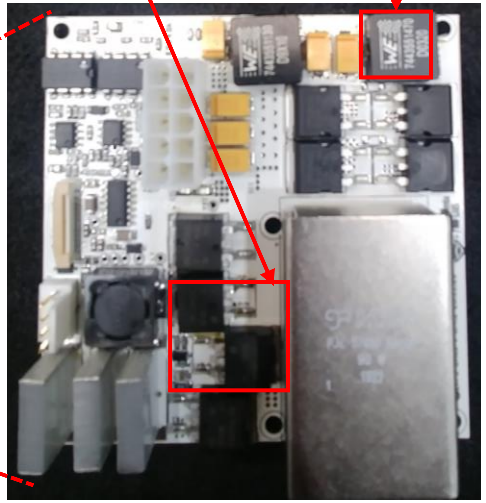


Fig. *High efficiency LVPS Brick top view .*

Ceramic post

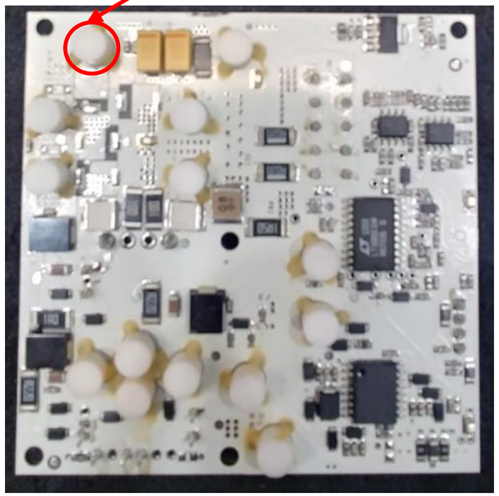


Fig. *High efficiency LVPS Brick bottom view .*

What is Burn-in and why should we do it?

τ_o = Equivalent operating time at T_o
MTTF – Mean Time To Failure

- Burn-in is a form of accelerated aging of electronic components.
- We make use of Burn-in as we want to age components out of the infant mortality region so that the normal operation period coincides with the Bricks installation within the TileCal.
- Improves LVPS Brick reliability once on detector by encouraging failures, associated with the infant mortality region, before installation.

Brick version	MTTF (Years)	Predicated failure rate (Bricks/year) No correction factor	Observed failure rate (Bricks/year)	Predicated failure rate With correction factor
V6.5.4	165	~ 12.4	~ 5	5
V7.5.0	406	~ 5	~ 2.4	2.4
V8.4.2	1198	~ 1.7	-	0.8

Table: V8.4.2 LVPS reliability study 20 October 2020.

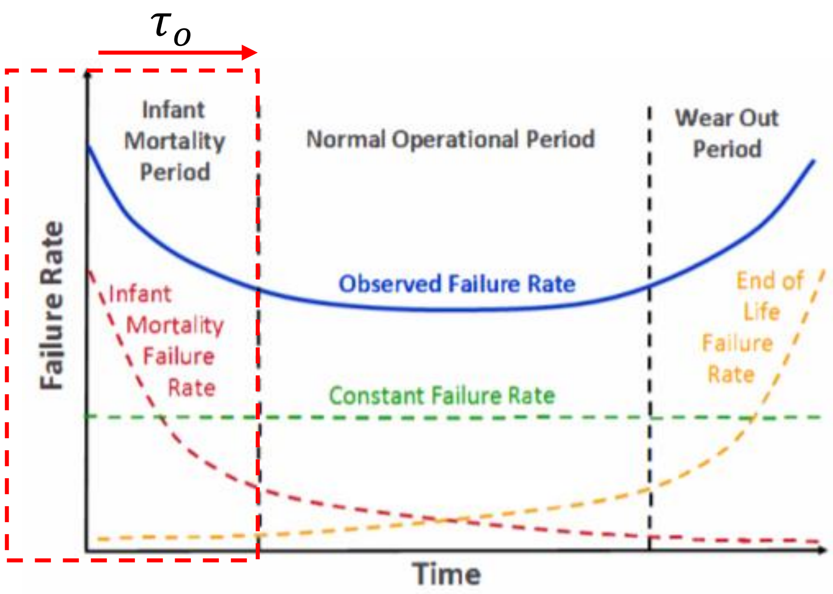


Fig. *Generalized bathtub curve of electronics failure rate.*

- The operation of the LVPS bricks at a higher load and operating temperature should cause the components to fail within the Burn-in station as opposed to prematurely within ATLAS.
- The Burn-in parameters allow for accelerated aging. That is, the Burn-in Run-time of the Bricks is multiplied by an acceleration factor.

Parameter	Burn-in	Nominal	Protection circuitry trip points
Operating temperature	60	35 ° C *	70° C
Load	5 A	2.3 A	6.9 A
Run Time	8 hours **	-	-

Table : V8.5.0 Brick Burn-in parameters, nominal Brick operating parameters and protection circuitry trip points.

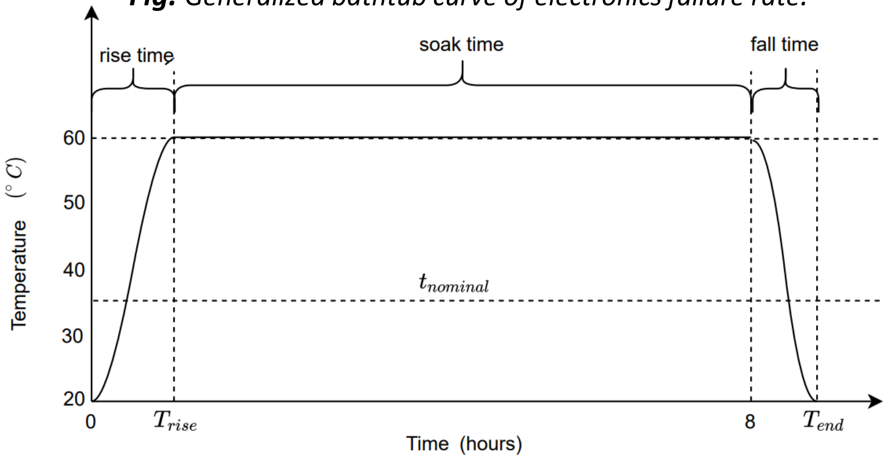


Fig. Generalized Phase-II Brick burn-in procedure thermal profile..

*The nominal operating temperature is heavily influenced by the primary side MOSFETS. ** The Burn-in run time is currently undergoing additional research. 8-hours is a legacy parameter.

PC = Personal Computer
GUI = Graphical User Interface

Burn-in Test Station

The Test station is composed of 4 elements which work together to facilitate the Burn-in of 8 Bricks per test cycle:

- **Test bed** – Required to contain the Burn-in station electronics, provide thermal and electrical insulation.
- **Cooling system** – Provides active cooling of the Bricks as well as the Dummy-Load boards. Allows for the control of the Bricks operating temperature.
- **Electronics** – Allow for control and monitoring of the Bricks as well as the applied load.
- **Software** – Allows for the control of the custom electronics, the HV power supply as well as the storage and real time viewing of data.

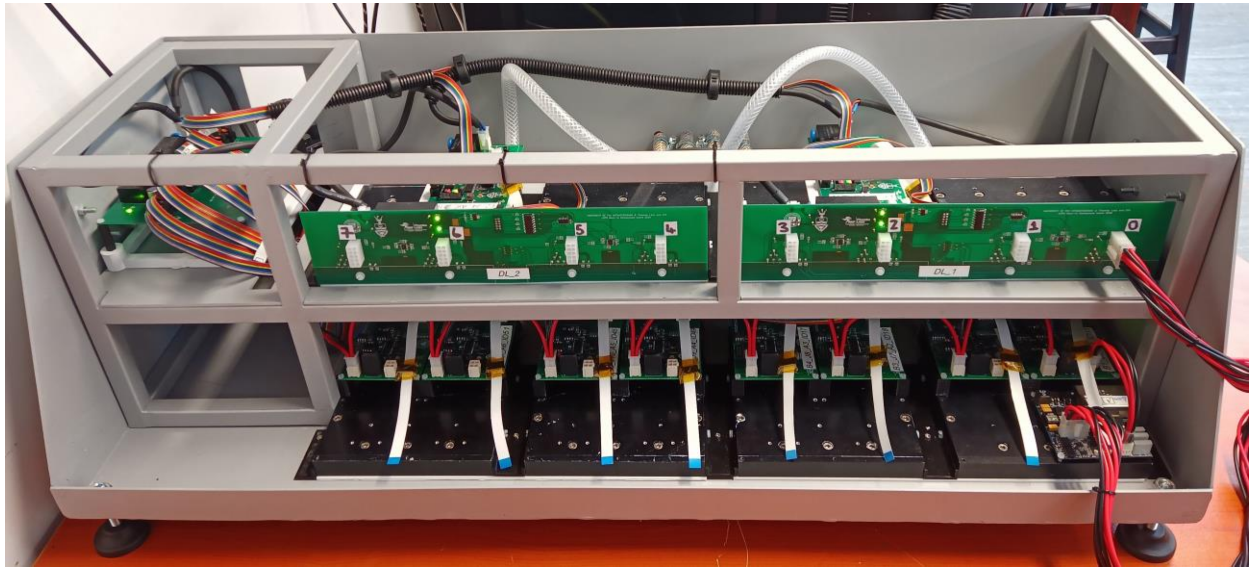


Fig. *Burn-in station test-bed.*

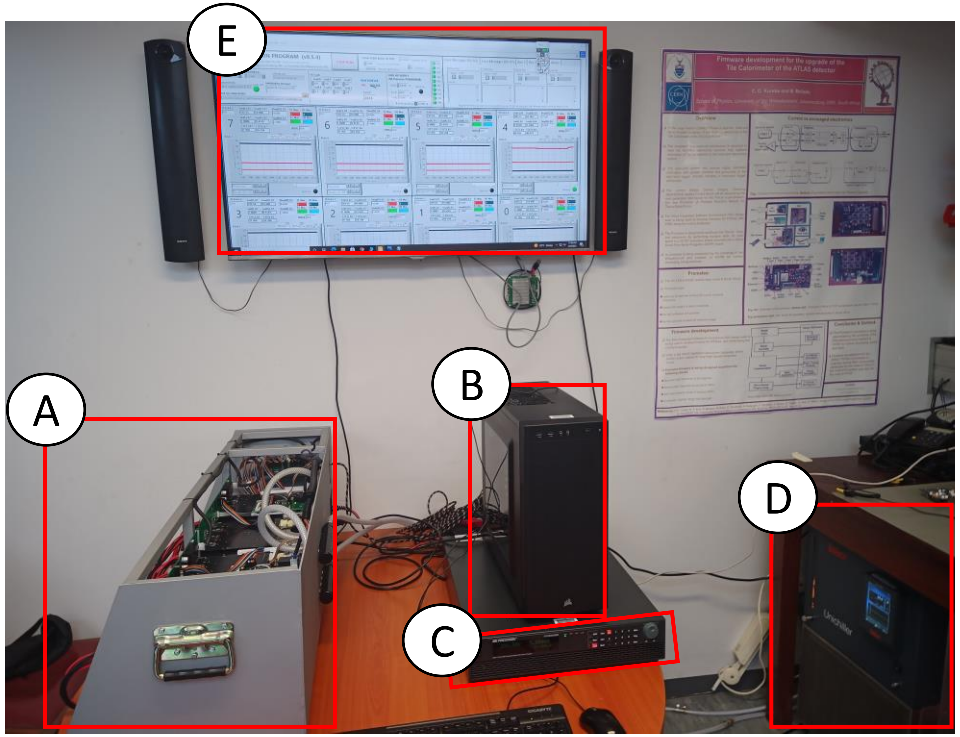


Fig. Burn-in test station.

(A) Test-bed (B) PC (C) DC power supply (D) Water chiller (E) GUI

Burn-in Test Station Hardware

BIB = Burn-in Interface Board
LIB = Load Interface Board
MB = Main Board
DL = Dummy-Load
HV = High Voltage
AC = Alternating Current
CP = Cooling Plate
PC = Personal Computer
APP = APPlication

- Based on the legacy designs developed by ANL, the Burn-in station PCBs have been redesigned by the University of Texas Arlington (UTA) and tested by the University of the Witwatersrand (Wits)

  There are four types of custom PCBs within a Burn-in station:

- **Main Board (X1) -** is responsible for communicating to the Brick and load interface boards through an application-specific control and monitoring program developed in LabVIEW. It does this by operating purely as a Demultiplexer to each of the Interface boards.
- **Brick Interface Boards (x8) -** provide control and data acquisition functions to their associated Brick. These included the on/off control of the Bricks, the on/off control of the High-voltage input to the Bricks and the digitization of analog performance signals received from the Bricks.
- **Load Interface Board (X2)** provide control and data acquisition functions to its associated **Dummy-Load**. It controls the load applied by the DL to the Bricks and digitizes analog performance signals received from the DL.
- **Dummy-Loads (x2)** - are responsible for the application of a load to the Bricks. A DL converts the electric power into heat which is then removed by the cooling system.

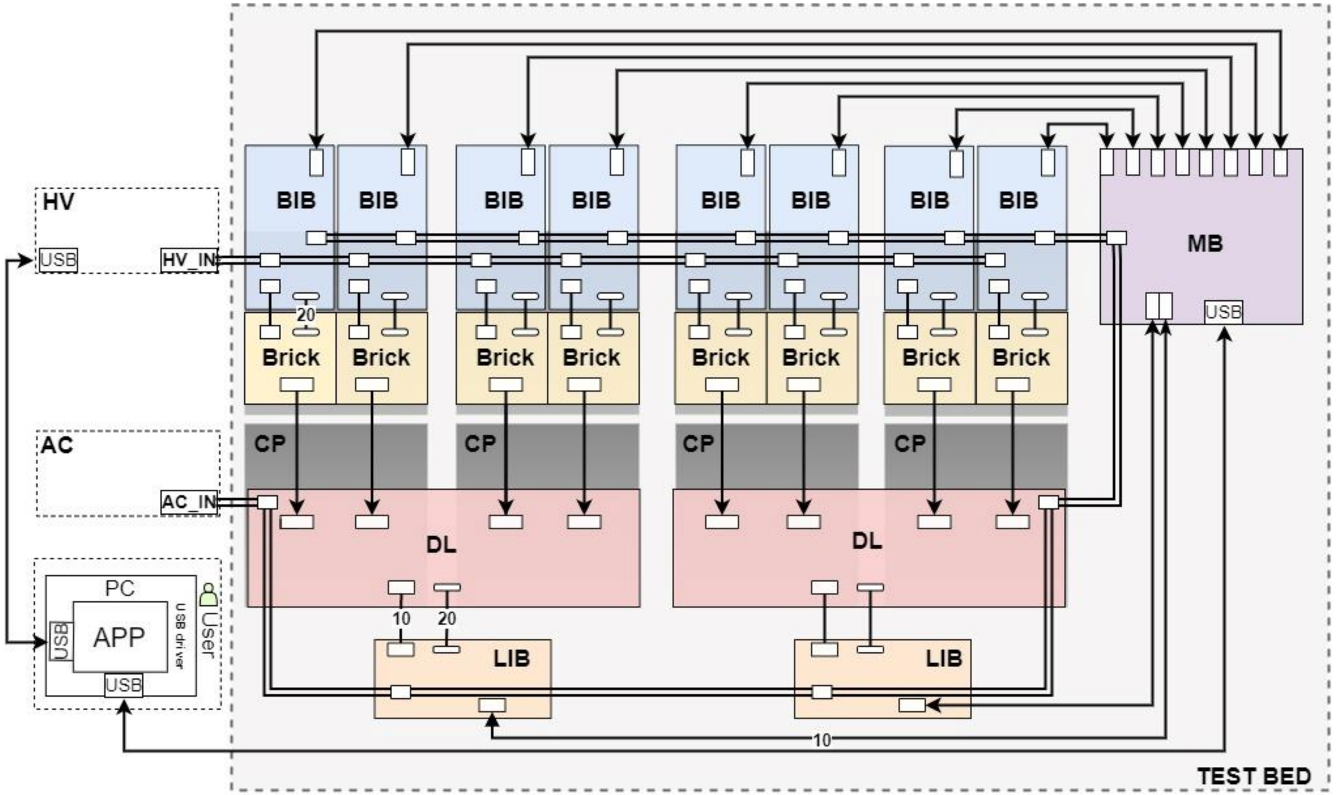


Fig. Block diagram of the burn-in station hardware..

Burn-in Test Station Software

BIB = Burn-in Interface Board
LIB = Load Interface Board
MB = Main Board
DL = Dummy-Load
HV = High Voltage
PIC = Programmable Integrated Circuit

- The Burn-in LabVIEW Application (BLA) and PIC firmware were originally developed by Argonne National Laboratory (ANL) in 2006 for the V6 Brick.

Software required for the operation of a Burn-in station can be divided into three categories:

- **BLA** provides control and monitoring of the Burn-in station and communicates via a PC over USB to the MB and PVS60085MR HV power supply. A PC runs the BLA responsible for Brick identification, Brick selection, Brick control (starting, stopping and load current), Brick and load performance measurements, HV control and monitoring, Brick trip detection and automatic restart, Burn-in time management and data logging.
- **PIC firmware** The MB embeds PIC firmware responsible for addressing and communicating from the BLA to the Interface boards of the Burn-in station.
- **Power supply instrumentation driver -** software routines that control the programmable instrument.

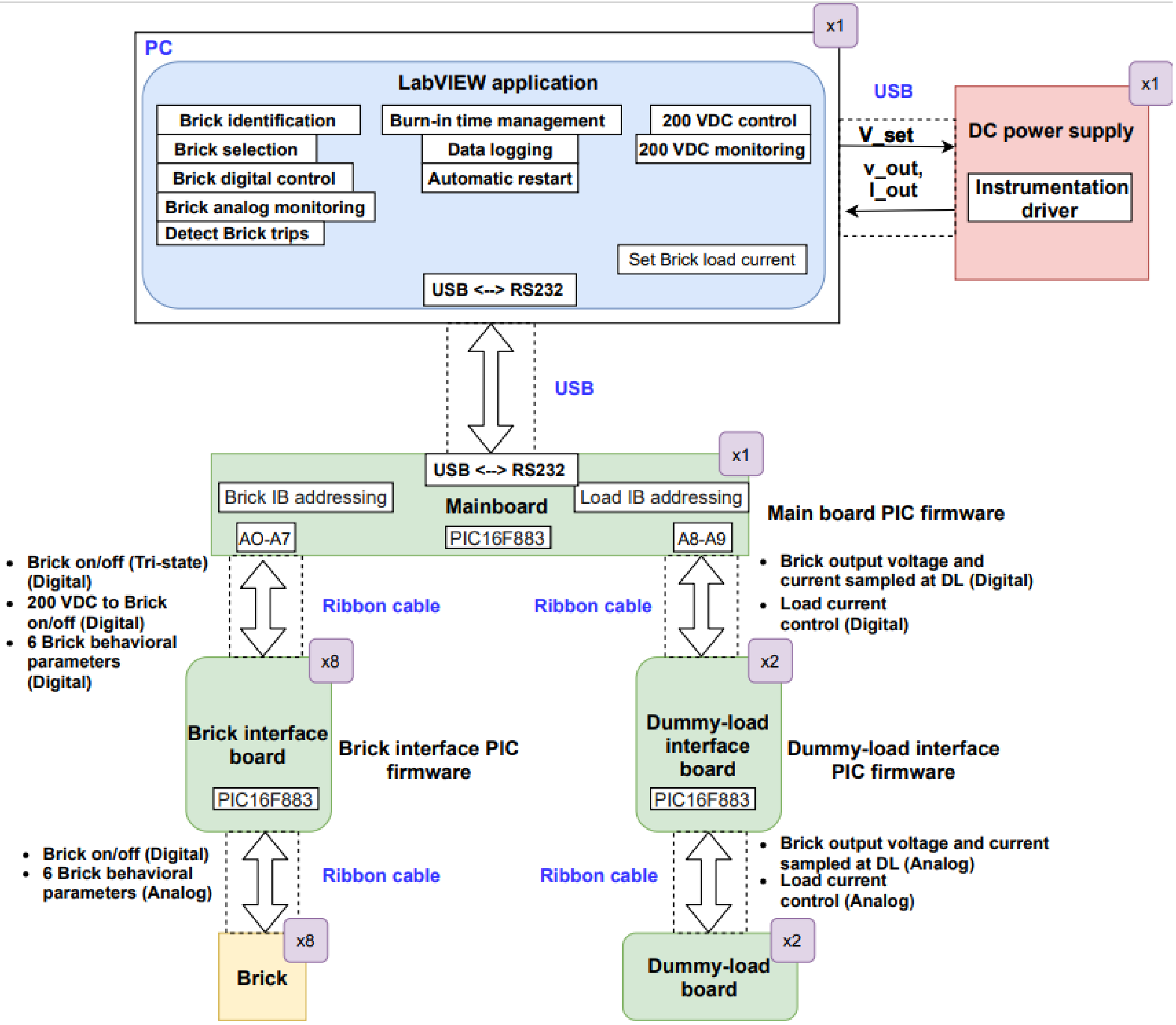


Fig. A simplified block diagram of the Burn-in station communication system..

Burn-in Test – The First Burn-in

Water chiller set to 18 °C
Load set to 5 A
V_In = 200 V
V_Out – 11 V

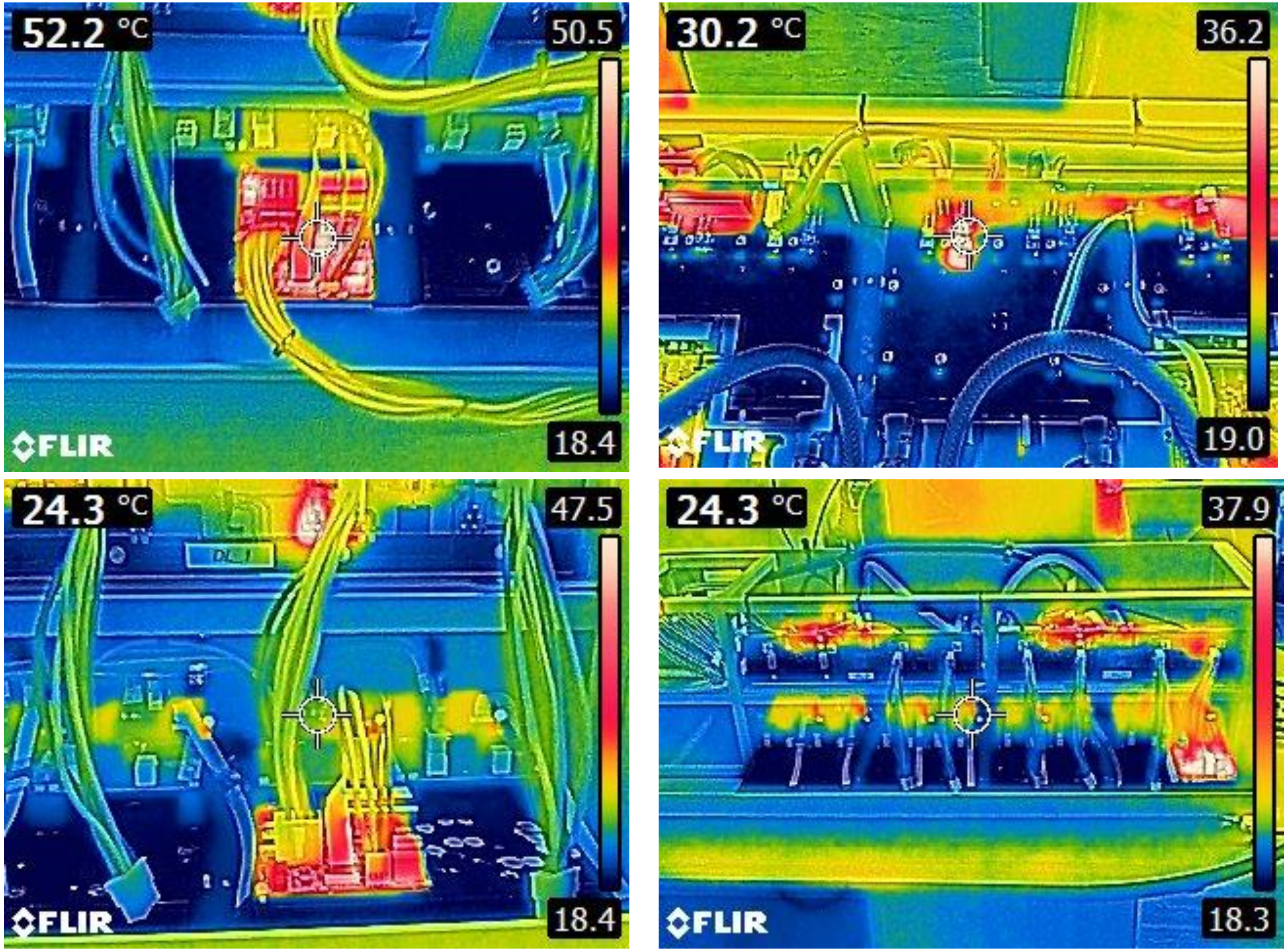


Fig. *Top and bottom left –Thermal imaging of LV Brick undergoing Burn-in. Top-Right – Thermal imaging of a Dummy-load MOSFET operating in the ohmic region. Bottom Right – Thermal imaging of an entire Burn-in station with the position 0 LV Brick undergoing Burn-in.*

Burn-in Test – Data collection

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**************** LVPS BRICK - WITS UNIVERSITY BURNIN STATION TEST REPORT ****************

3/17/2022 12:34:34 PM        PRG:MAIN_PRG_BURNIN_V8.vi
BrickID:    BRICK 1          Operator:    Ryan Mckenzie
TransformerID:
Comments:
```

TIME	TS	T2[°C]	T3[°C]	VinHV[V]	VinBrick[V]	IinBrick[A]	VoutBrick	IoutBrick[A]	VoutLoad[V]	Iload[A]	Iset[A]	Eff[%]
3/17/2022 12:34:41 PM	111	25.131539	25.289492	200.000000	201.375034	0.289751	11.000167	5.066141	11.646533	5.117871	5.000000	NaN
3/17/2022 12:34:43 PM	111	25.997043	25.779322	200.010000	201.375034	0.292397	11.000167	5.064786	11.646533	5.115890	5.000000	NaN
3/17/2022 12:34:45 PM	111	27.389086	26.310384	200.010000	201.375034	0.295074	11.000167	5.062967	11.646533	5.119821	5.000000	NaN
3/17/2022 12:34:47 PM	111	28.904854	26.780939	200.010000	201.375034	0.293738	11.000167	5.059792	11.645895	5.113904	5.000000	NaN
3/17/2022 12:34:49 PM	111	30.381551	27.209512	200.010000	201.375034	0.296387	11.000167	5.057515	11.645895	5.109936	5.000000	NaN
3/17/2022 12:34:51 PM	111	31.782637	27.600664	200.010000	201.382579	0.300412	11.000167	5.055710	11.645895	5.107934	5.000000	NaN
3/17/2022 12:34:53 PM	111	33.068251	27.949160	200.010000	201.375034	0.301749	11.000167	5.053435	11.646533	5.111917	5.000000	NaN
3/17/2022 12:34:55 PM	111	34.275537	28.281716	200.010000	201.382579	0.303089	11.000167	5.051626	11.646533	5.105948	5.000000	NaN
3/17/2022 12:34:57 PM	111	35.408149	28.592477	200.010000	201.375034	0.305739	11.000167	5.049805	11.647174	5.107934	5.000000	NaN
3/17/2022 12:34:59 PM	111	36.454639	28.878534	200.010000	201.375034	0.304402	11.000167	5.047530	11.646533	5.103961	5.000000	NaN
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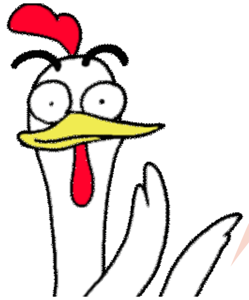
3/17/2022 12:35:39 PM	111	48.349971	32.372271	200.010000	201.375034	0.333763	11.000167	5.037099	11.653566	5.092074	5.000000	88.289507

Fig. *Burn-in test data output after preliminary calibration.*

Conclusions



- TileCal & Phase II upgrade.
- LVPS Brick
- Reliability and Quality assurance testing.
- Burn-in testing
  - Hardware
  - Software
  - The first “burn-in”
- What next?
  - Calibration of Burn-in station.
  - Production of Bricks.
  - Testing and Burn-in of Bricks.

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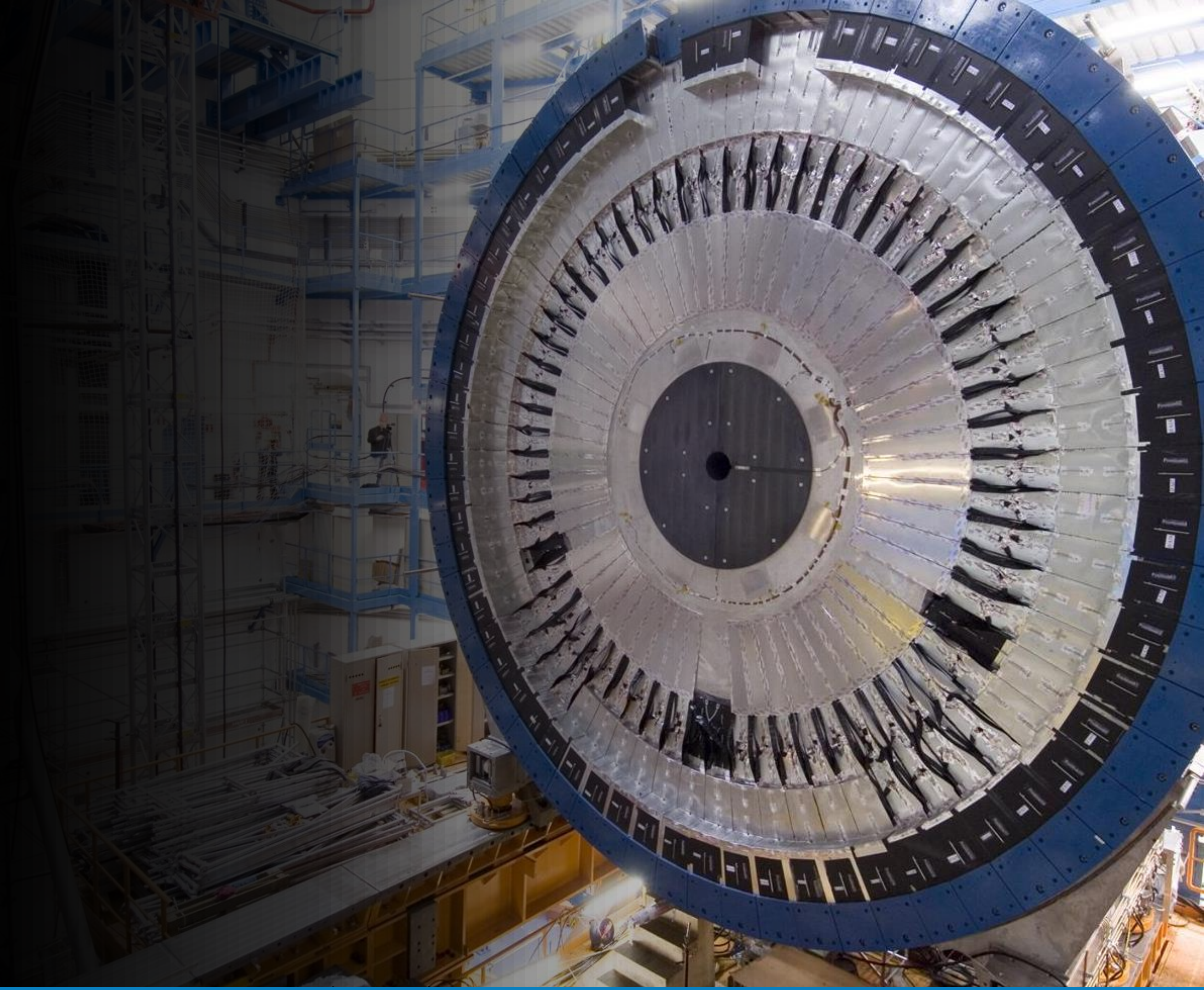
Reference slides



The ATLAS detector

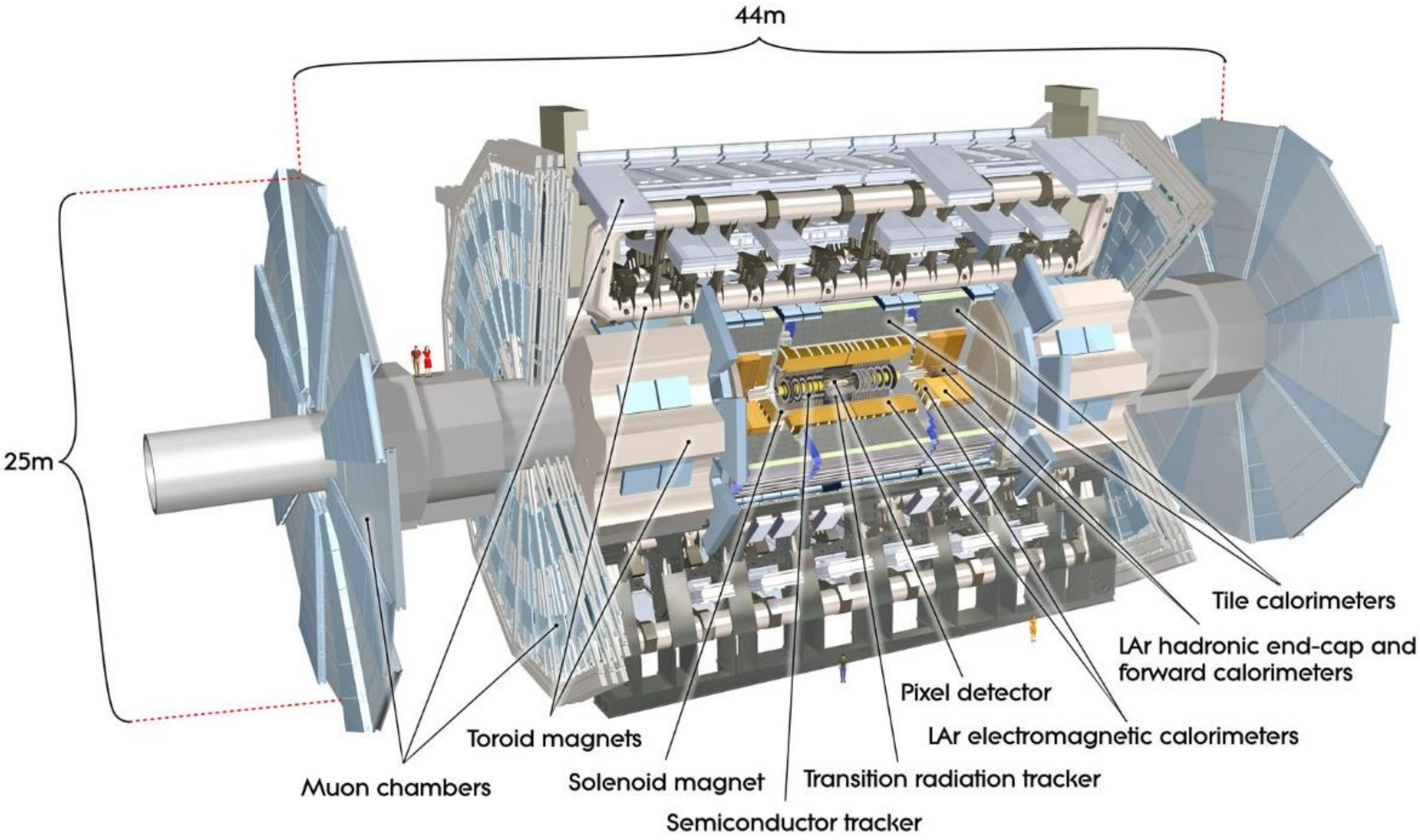


Fig. Left - The ATLAS detector, Right - The ATLAS inner Barrel, Right *J. Pequenao, Computer Generated image of the ATLAS calorimeter,(2008), https: // cds. cern. ch/ record/ 1095927*

Legacy Low-Voltage System

- A **2-stage system** in which Bulk 200 VDC power is converted to the voltages required by the FE electronics by different types of Brick.
- **Provides ON/OFF control** (Via Aux-boards) of the bricks in two groups which start successively.

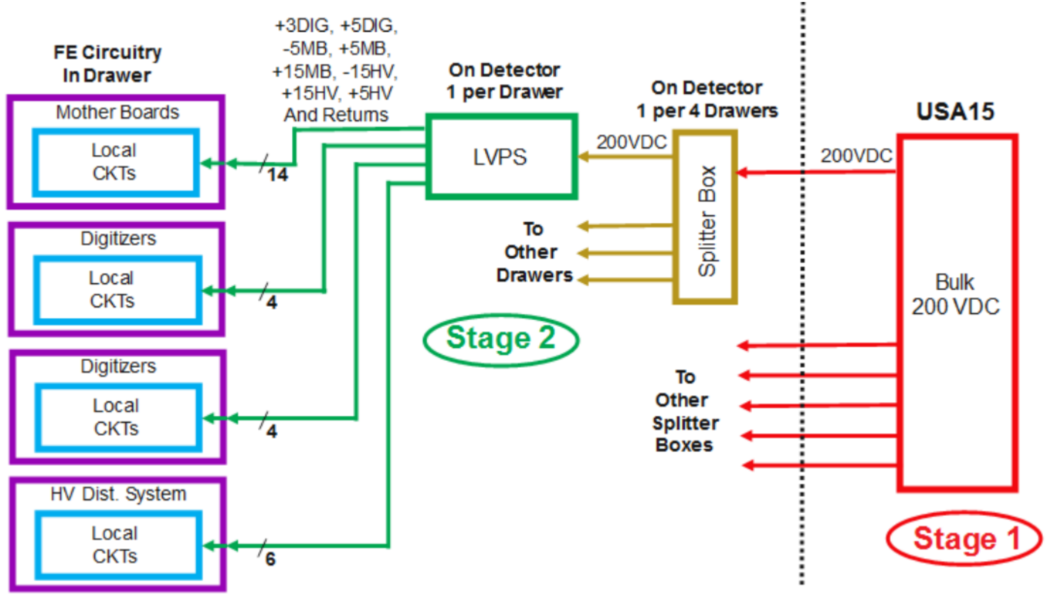


Fig. A Block diagram of the legacy 2-stage low-voltage system.

LV System Upgrade

- **Conversion to a 3-stage system** which makes use of Point-of-load regulators (POLs). POLs function to step-down the 10 VDC received from an LVPS Brick to the voltage required by local circuits. This allows for the use of a single type of brick with a standardized 10V output;
- **Tri-state functionality** is being introduced which allows for individual Bricks startup/shutdown. This functionality is so named due to the Aux-boards ability to send 3 different state signals to an LVPS Brick;

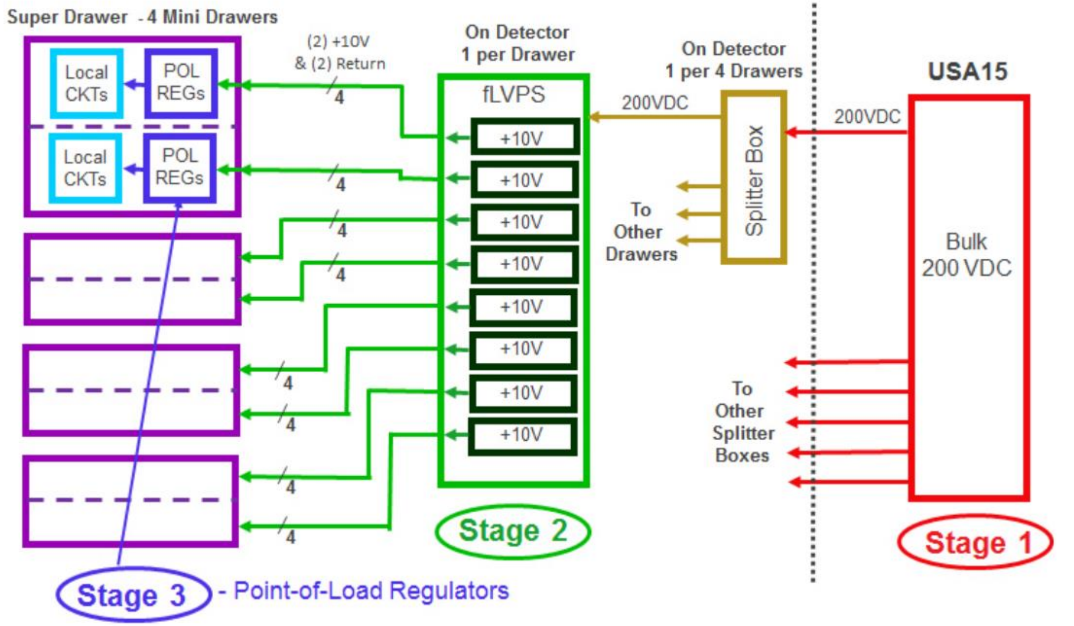


Fig. A Block diagram of the Phase-II upgrade 3-stage low-voltage system.

Low Voltage Power Supply Brick

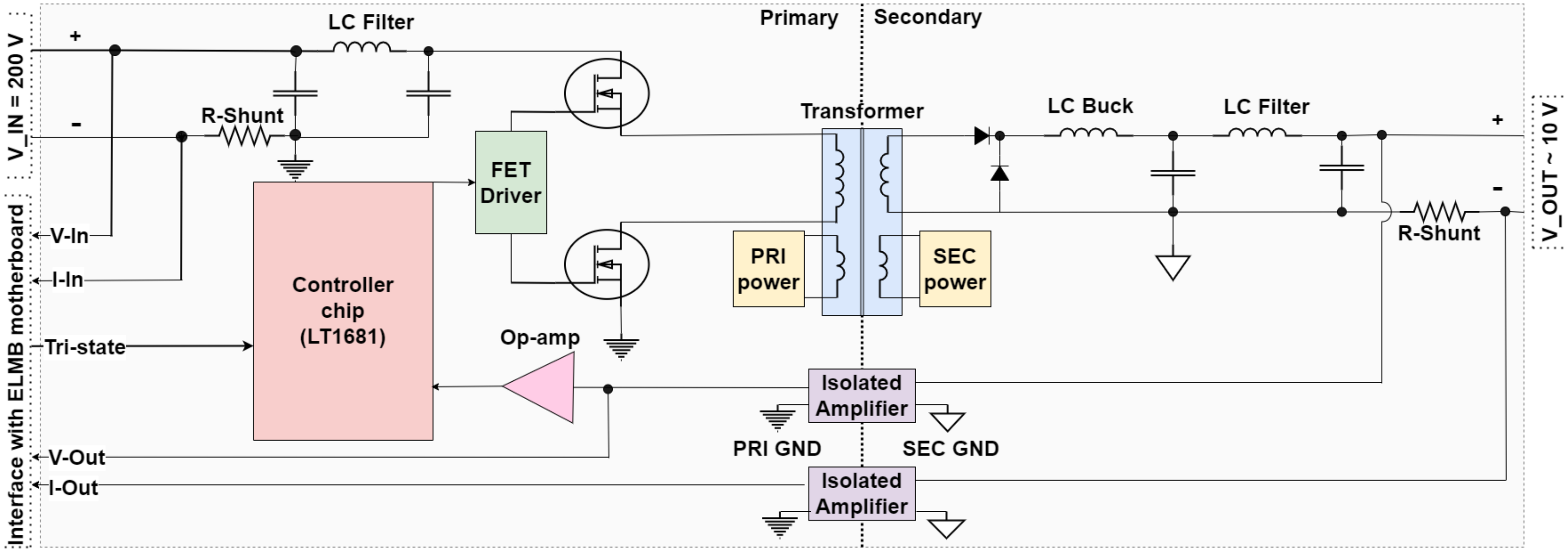
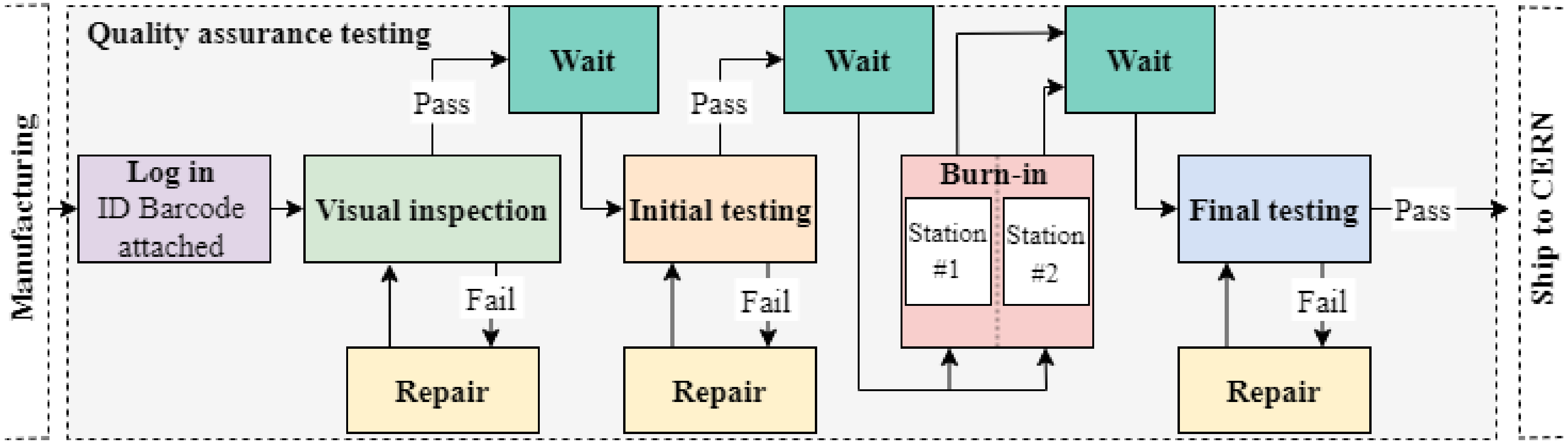


Fig. *LVPS Brick functional block diagram.*

Quality assurance testing



Burn-in Test Station GUI

Fig. *The Burn-in Test-Station LabVIEW GUI*