



October 12-16, 2009, Kobe Japan
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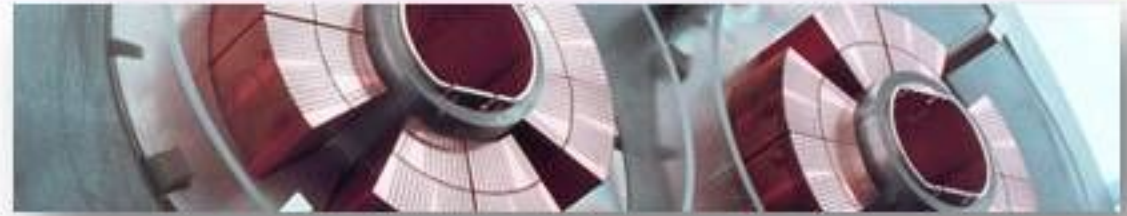
Status of the LHC power converter* controls

* A CERN "power converter" = everyone else's "power supply"

Quentin King
Converter Controls
Electrical Power Converter Group
CERN



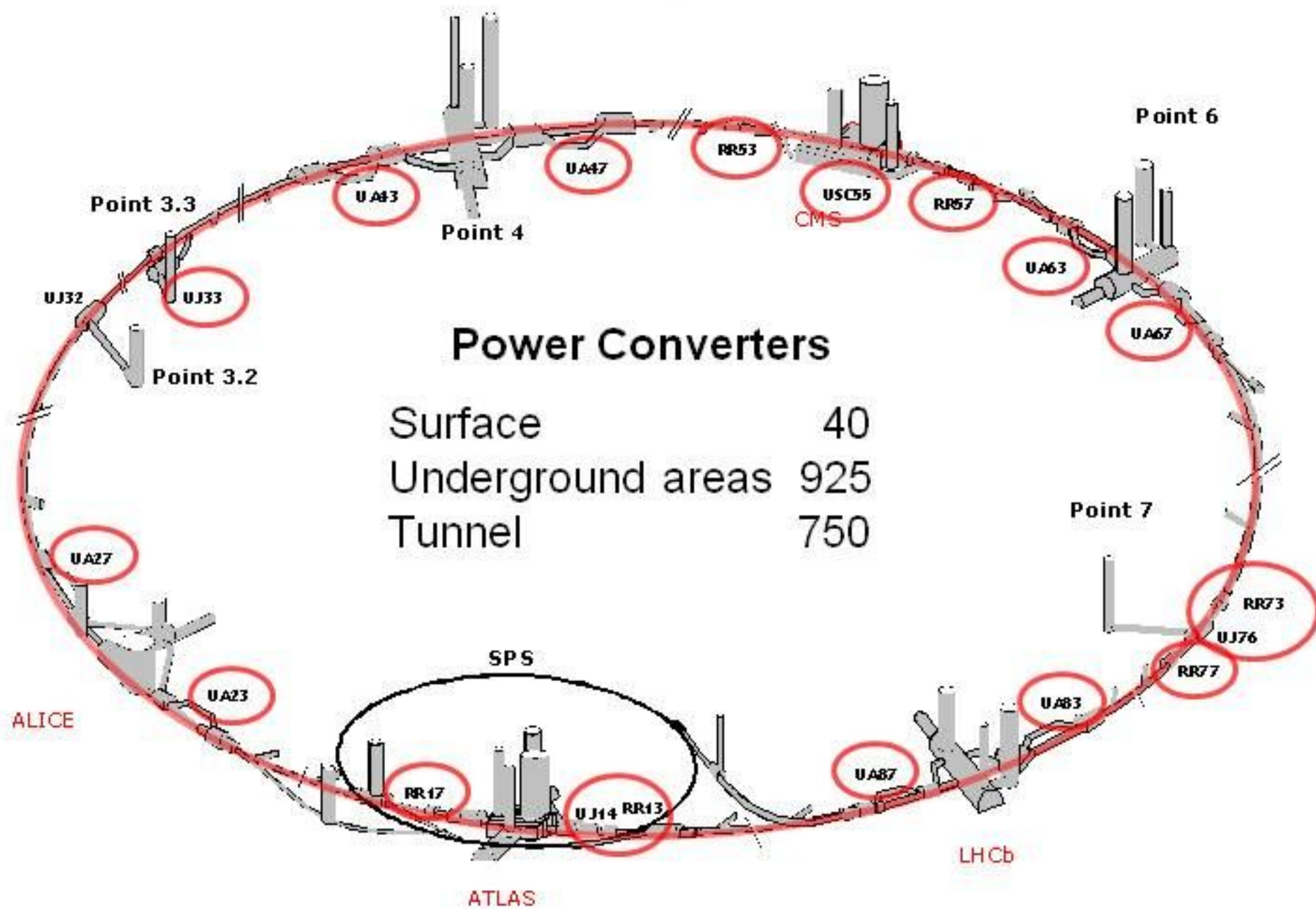
Context



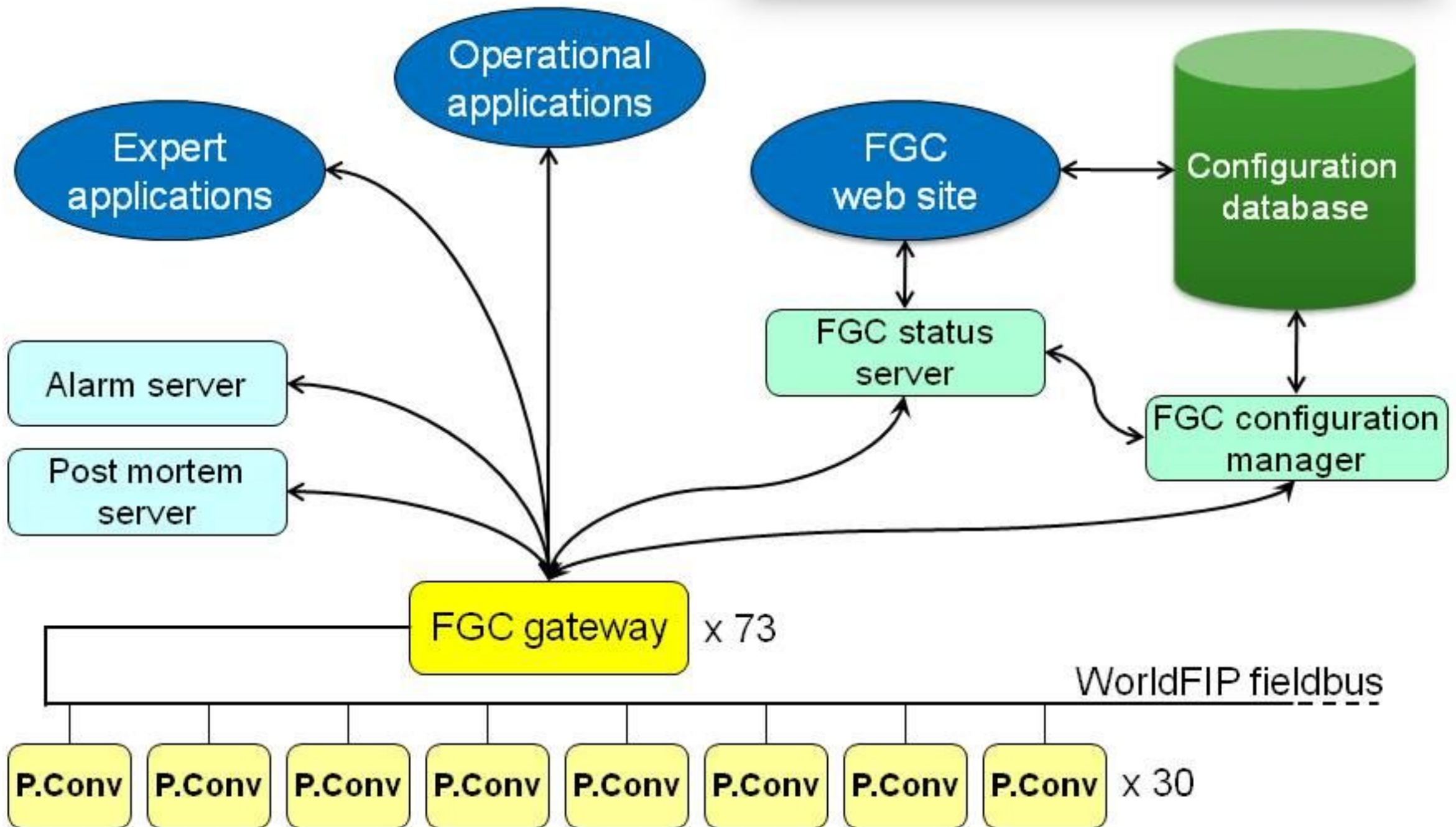
- The LHC has ~1700 magnet circuits, each driven by a power converter
- Each power converter is controlled by an embedded computer called a Function Generator/Controller (FGC)
- The complete powering system cost 86 MSF + 280 FTE years
- The controls cost 7 MSF + 50 FTE years (8% + 17%)
- 2000 FGCs have been produced and 1700 have been installed in the LHC since 2007
- The LHC experiments also use FGCs to control their magnet power converters



LHC powering



System Architecture

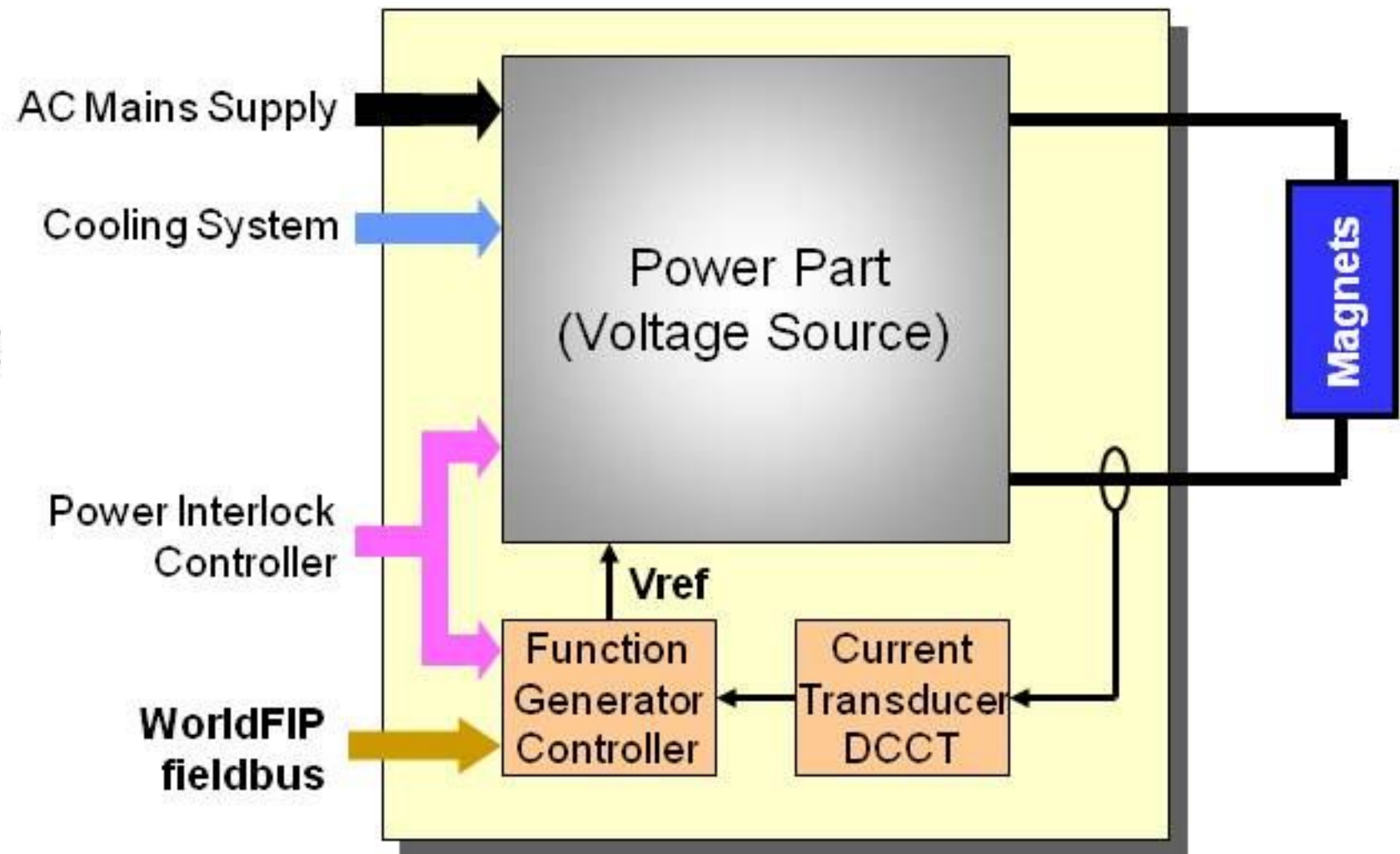


Power Converter



- LHC power converters are current sources
- They are made from a voltage source, current transducer and a Function Generator/Controller (FGC) running a digital current regulation loop

- Application defines:
Current vs. Time



FGC



- Embedded computer designed specifically for LHC power converters
- Microcontroller + Floating point DSP
- Error corrected memory
- 2 ADC channels to measure the current
- 1 DAC to send the voltage reference to the voltage source
- Digital inputs and outputs to control and monitor the voltage source
- Metal cassette to protect the circuit boards



Power Converter Types



$\pm 120A \pm 10V$ 1.2kW
300 Units



$\pm 600A \pm 10V$ 6kW
400 Units



$\pm 600A \pm 40V$ 24kW
40 Units



$\pm 60A \pm 08V$ 480W
730 Units



Power Converter Types



4/6/8kA 8V 32/48/64kW
200 Units

13kA 18V 234kW
16 Units



13kA ±190V 2.47MW
8 Units



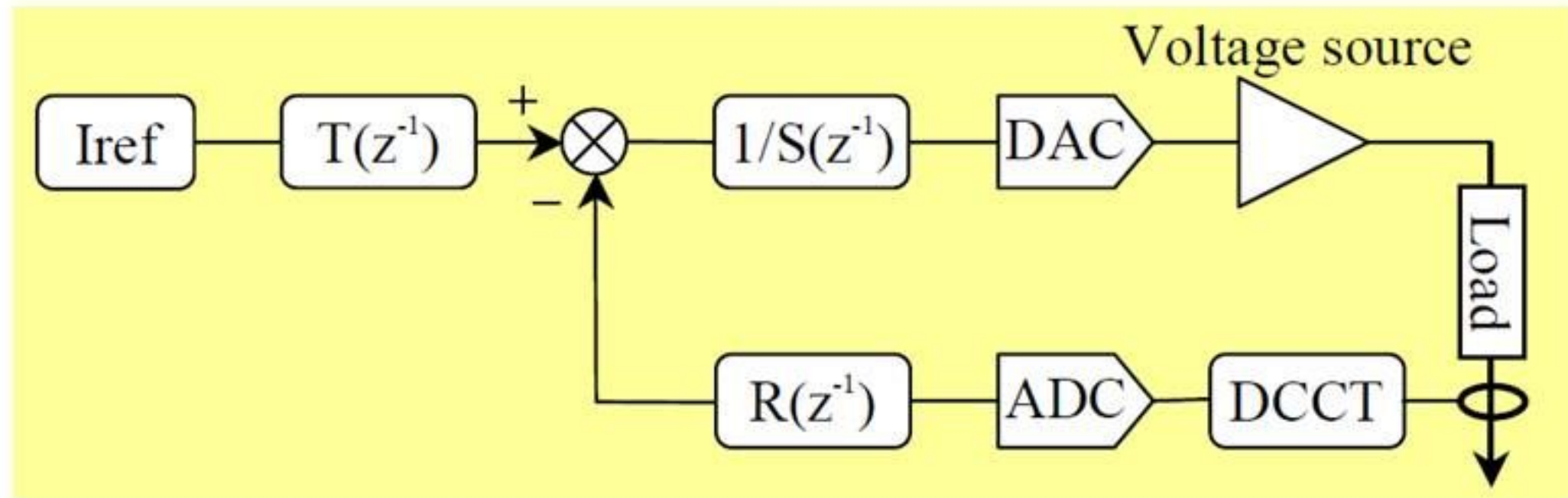
WorldFIP



- Presented at ICALEPCS 2005
- 2.5 Mbps real-time fieldbus
- Supports:
 - Time and events distribution
 - Commands and responses
 - Real-time publication of status
 - Real-time control of current
 - Software updates
 - Remote Terminal access
- Low throughput per FGC but WorldFIP supports parallel communications, so an application can send commands to all 1700 FGCs simultaneously (120ms for most commands)
- CERN now owns the Alstom WorldFIP intellectual property



Current Regulation



- Digital Regulation uses a proportional-integral-integral controller (PII)
- Implementation uses an RST tri-polynomial algorithm
- Excellent results – no overshoot and no tracking errors during the ramps

Status web pages



The image shows three overlapping browser windows displaying different status pages from the FGC (Front End Computer) system:

- FGC System Status:** A matrix showing status for SR1 and SR2 across rows 0-30. Legend: UNSCHEDULED (cyan), OFFLINE (black), OFF (grey), ON (UNKNOWN) (yellow), ON (ON) (blue), ON (SOFT) (magenta).
- Powering Status:** A matrix showing status for SR1-SR7 across rows 1-30. Legend: UNSCHEDULED (cyan), OFFLINE (black), OFF (grey), ON (UNKNOWN) (yellow), ON (ON) (blue), ON (SOFT) (magenta).
- FGC Status:** A detailed table for RPLA24LBCB23L01.

CHANNEL	DATA_STATUS	CLASS_VALID
STATE_R	OK	DATA_VALID
STATE_PL	LOCKED	STATE_OK
STATE_DP	NORMAL	STATE_OK
LEAKY_PUMP	START_STOPPED	START_STOPPED
LEAKY_VAL	START_STOPPED	START_STOPPED
LEAKY	START_STOPPED	START_STOPPED
LEAKY2	START_STOPPED	START_STOPPED
FT_FAULTS	FT_WARNINGS	
FT_ERRORS		LOG_CURRENT NORMAL_LONG
FT_WARNINGS	FT_WARNINGS	FT_WARNINGS
FT_ERRORS		LOG_CURRENT NORMAL_LONG
V_WARNINGS		V_WARNINGS
FT_ERRORS		FT_ERRORS

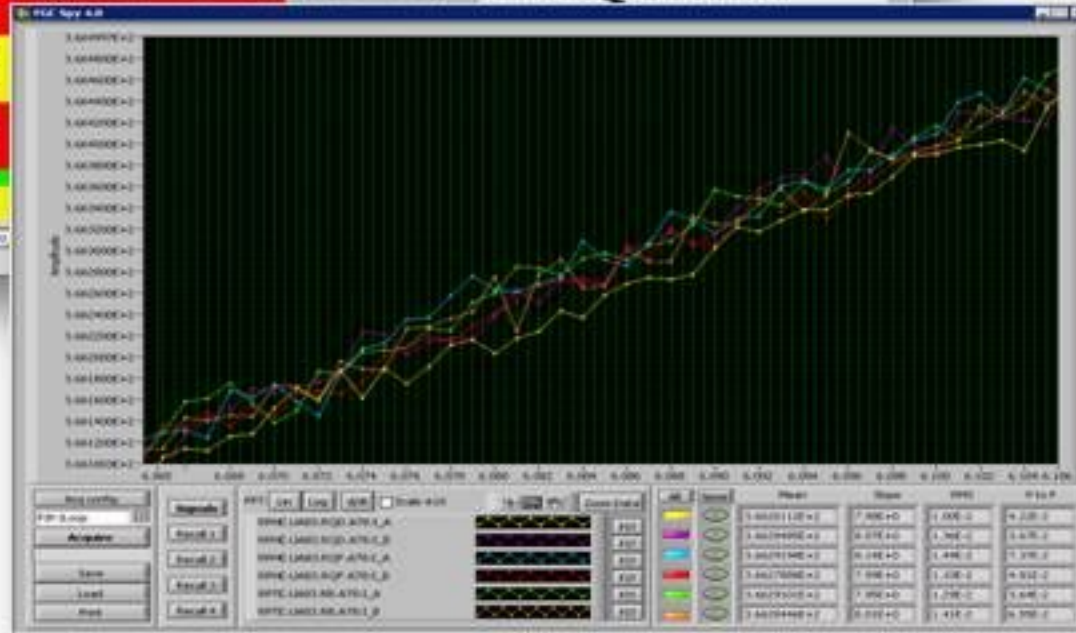
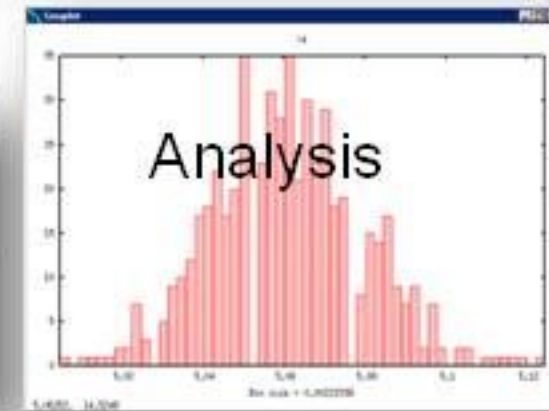
Content by Cometto! Thu Oct 8 16:41:43 2009 TSP 3072 3347

Expert tools



The screenshot shows a software window with a table of data. The table has columns for various parameters and a list of identifiers. The data is color-coded by row.

PL_ID	YS_PO	E_REF	E_P0A0	V_REF	V_P0A0	SN	SN / ID#	Username	Group	Password
LA_20_17_17	0.00	-0.00	0.00	0.00	0.00	001	001	g1_group		*****
LA_20_17_17	0.00	-0.00	0.00	0.00	0.00	002	002			
LA_20_17_17	0.00	-0.00	0.00	0.00	0.00	003	003			
LA_20_17_17	0.00	-0.00	0.00	0.00	0.00	004	004			
LA_20_17_17	0.00	-0.00	0.00	0.00	0.00	005	005			
LA_20_17_17	0.00	-0.00	0.00	0.00	0.00	006	006			
LA_20_17_17	0.00	-0.00	0.00	0.00	0.00	007	007			
LA_20_17_17	0.00	-0.00	0.00	0.00	0.00	008	008			
LA_20_17_17	0.00	-0.00	0.00	0.00	0.00	009	009			
LA_20_17_17	0.00	-0.00	0.00	0.00	0.00	010	010			
LA_20_17_17	0.00	-0.00	0.00	0.00	0.00	011	011			
LA_20_17_17	0.00	-0.00	0.00	0.00	0.00	012	012			
LA_20_17_17	0.00	-0.00	0.00	0.00	0.00	013	013			
LA_20_17_17	0.00	-0.00	0.00	0.00	0.00	014	014			
LA_20_17_17	0.00	-0.00	0.00	0.00	0.00	015	015			
LA_20_17_17	0.00	-0.00	0.00	0.00	0.00	016	016			
LA_20_17_17	0.00	-0.00	0.00	0.00	0.00	017	017			
LA_20_17_17	0.00	-0.00	0.00	0.00	0.00	018	018			
LA_20_17_17	0.00	-0.00	0.00	0.00	0.00	019	019			
LA_20_17_17	0.00	-0.00	0.00	0.00	0.00	020	020			
LA_20_17_17	0.00	-0.00	0.00	0.00	0.00	021	021			
LA_20_17_17	0.00	-0.00	0.00	0.00	0.00	022	022			
LA_20_17_17	0.00	-0.00	0.00	0.00	0.00	023	023			
LA_20_17_17	0.00	-0.00	0.00	0.00	0.00	024	024			
LA_20_17_17	0.00	-0.00	0.00	0.00	0.00	025	025			
LA_20_17_17	0.00	-0.00	0.00	0.00	0.00	026	026			
LA_20_17_17	0.00	-0.00	0.00	0.00	0.00	027	027			
LA_20_17_17	0.00	-0.00	0.00	0.00	0.00	028	028			
LA_20_17_17	0.00	-0.00	0.00	0.00	0.00	029	029			
LA_20_17_17	0.00	-0.00	0.00	0.00	0.00	030	030			



The screenshot shows a terminal window with the following code:

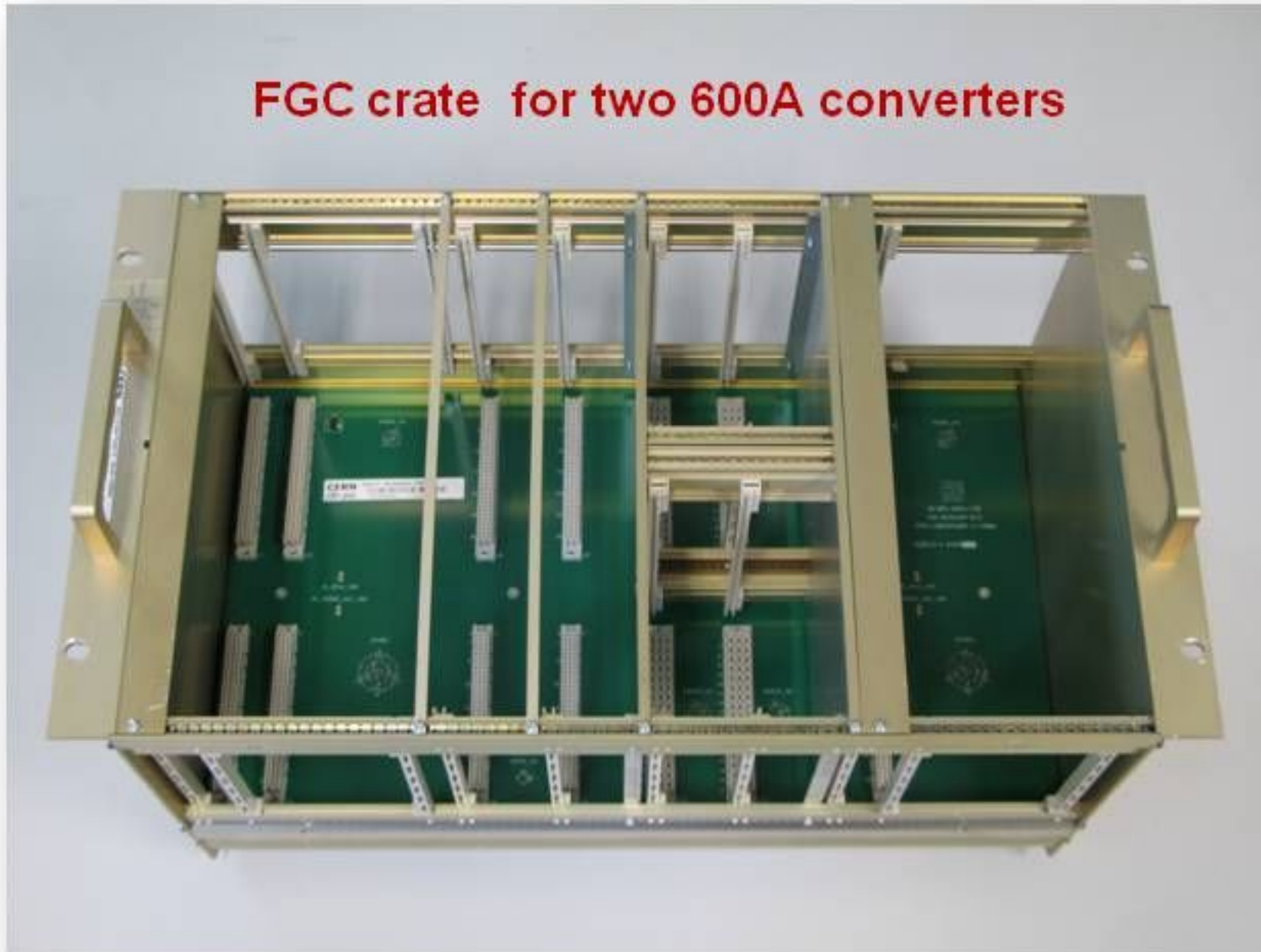
```
PLD VERSION: 5
CODE (BOOT): 110
CODE (MP): 175
NAME: RPLA_20L5_RCBV27.LSB
LABEL: 50W 5V 42 converter (arc orbit connectors)
FIP_ID: CFC-SES-08.04.13
```

Below the code, the text 'FGC Terminal' is overlaid.

FGC Crate


HCRFMCA__-JT000176

FGC crate for two 600A converters



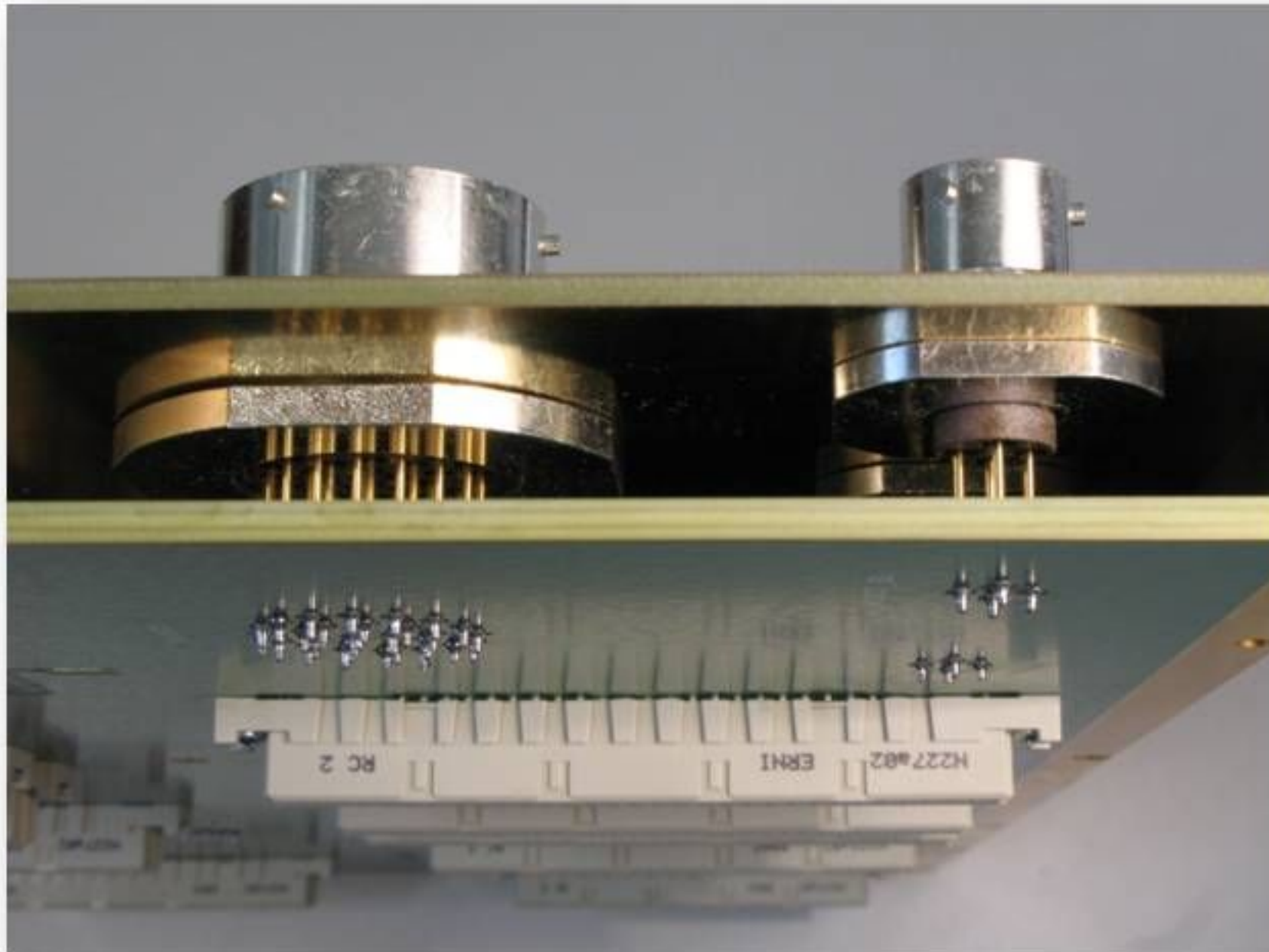
FGC Crate


HCRFMCA___JT000176



FGC Crate


HCRFMCA__JT000176



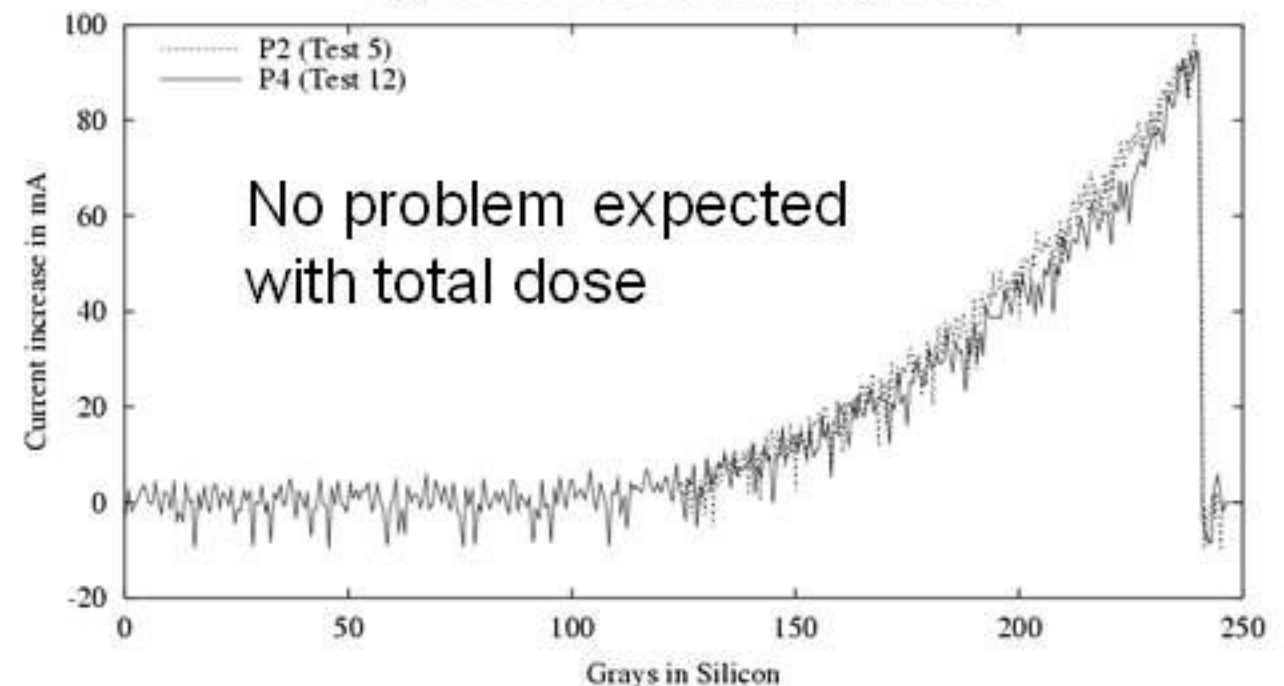
Radiation



- 750 converters are in the tunnel with $\sim 10^{10}$ particles/cm²/year ($E > 20$ MeV) expected for nominal LHC operation
- Another 200 converters are in underground areas that will have lower but still significant radiation levels
- The FGCs were designed to tolerate this level and were tested at a 60 MeV cyclotron

- Single event upsets were seen
- Error corrected memory
- Use flash based CPLDs rather than RAM based FPGAs

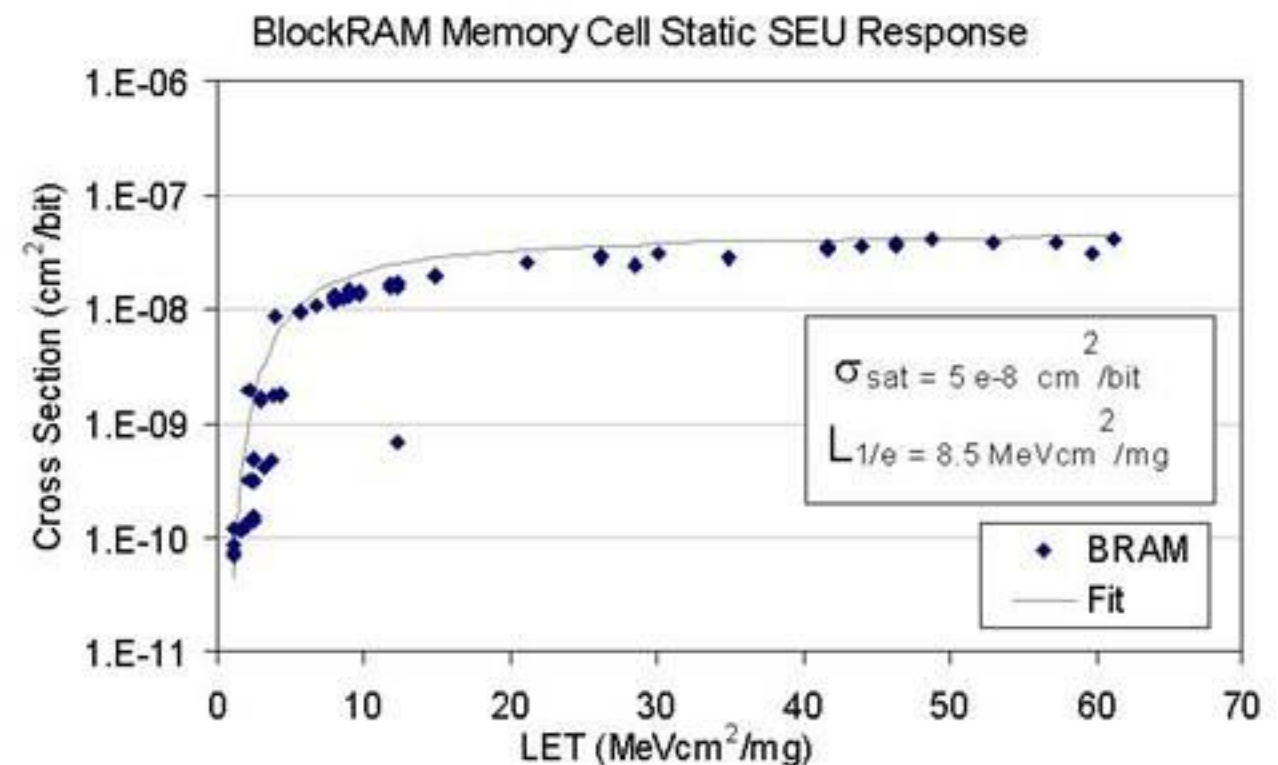
Figure 9: CPU CPLDs current increase against dose



Single Event Latch-ups



- Latch-ups require a power cycle to clear and none were seen because 60 MeV protons were not sufficiently energetic – we should have used a 250 MeV beam instead
- Tests using the CERN SPS accelerator have now shown that the Xilinx 95 series CPLDs **do** latch-up and even burn out
- Converters in the tunnel are redundant so a power cycle won't lose the beam
- Converters in the underground areas are not redundant so latch-ups **will** lose the beam
- Tests are on-going and all options are being considered



Summary



- ☺ Metal cassette for the FGC
- ☺ Wiring free backplane
- ☺ WorldFIP Fieldbus
- ☺ XML definition files with a Perl parser
- ☺ AJAX based status web pages
- ☺ Perl-Tk expert interface
- 💣 Radiation tolerance

Conclusions



- The LHC power converter controls are working very well – but the radiation tolerance of the FGCs is still being studied and may be a problem for a small number of converters
- Overall it is a huge system and the effort spent on automatic configuration and diagnostics was well invested

Thanks to:



- My colleagues in TE-EPC-CC
 - Stephen Page, Philippe Fraboulet, Philippe Semanaz, Alex Frassier, Gilles Ramseier, Daniel Calcoen

- The excellent collaboration from my colleagues in TE-EPC, BE-CO and BE-OP

- To you for listening!