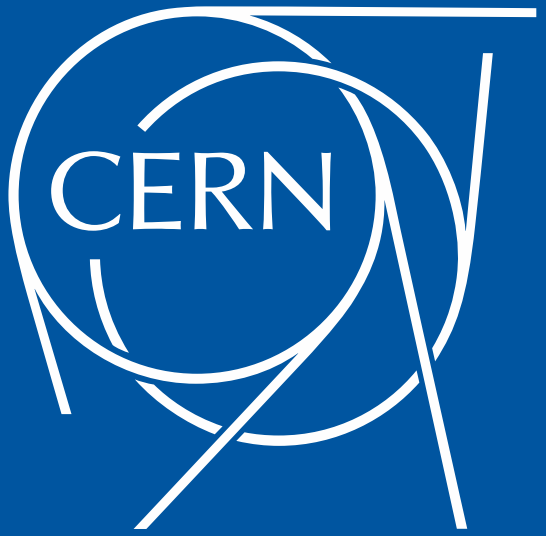

CERN

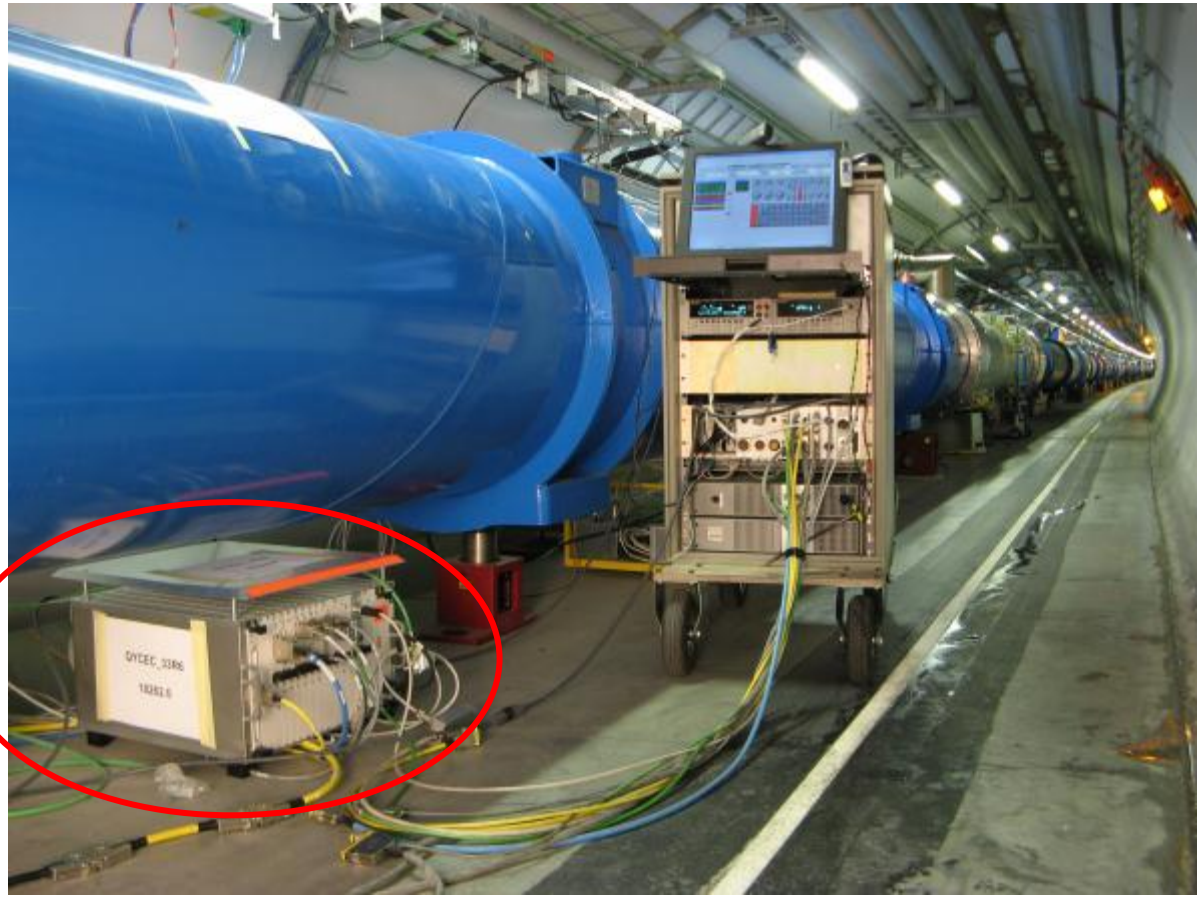
Nikolaos TRIKOUPIS TE-CRG-CI

Design and prototyping of the heater supply board

Contents

- The cryogenics crate
- Data flow
- Heater board - Theory of operation
- Comparisons: Existing design & Consolidations
- Prototyping

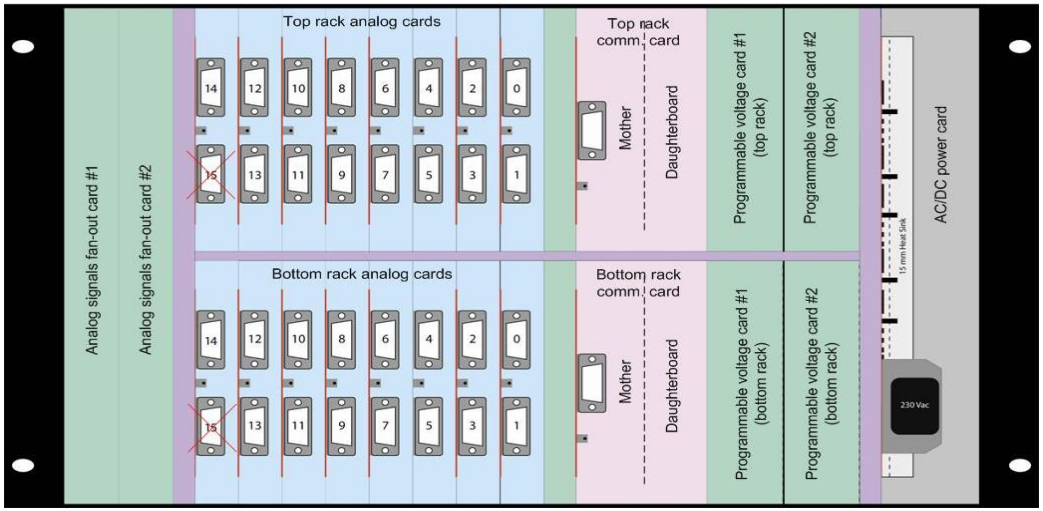
The cryogenics crate



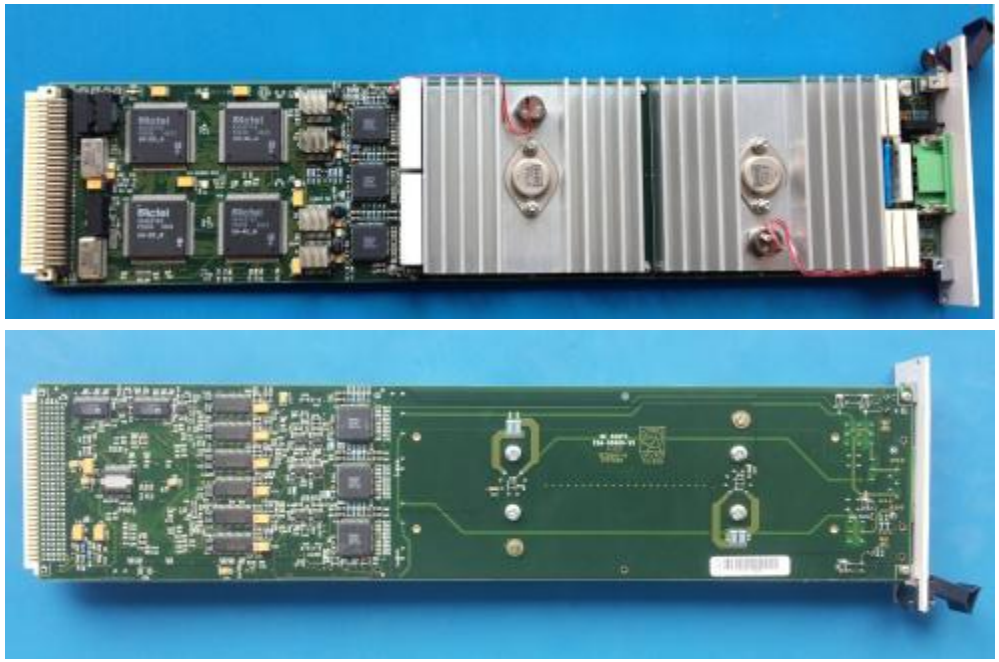
The cryogenics crate

The cryogenics crate

The Electrical Heater (EH) card



The electrical heater card



The Electrical Heater (EH) card

Purpose

- Deliver power to resistive loads by 0-60 VDC or 230 VAC PWM (Pulse Width Modulation).
- Provide measurements of V_{DC}, I_{DC} and thermocouple protection.

PLC - EH card communication

PLC

FEC

Ethernet

RT

CM

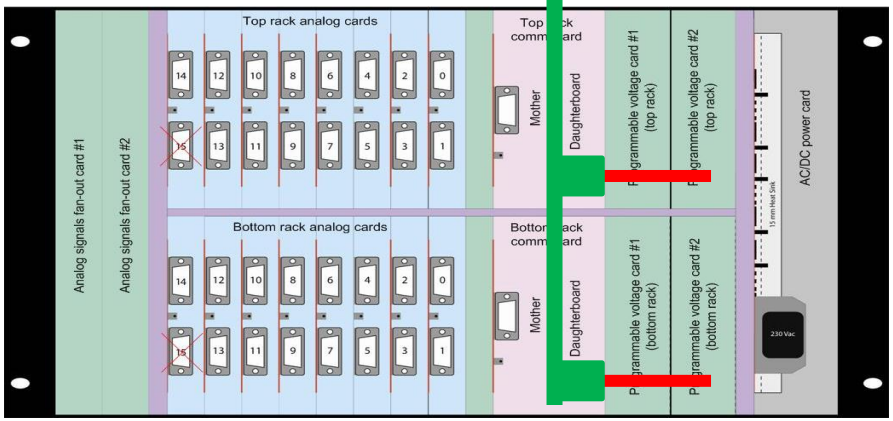
SECT

EN/ICE
BE/CO

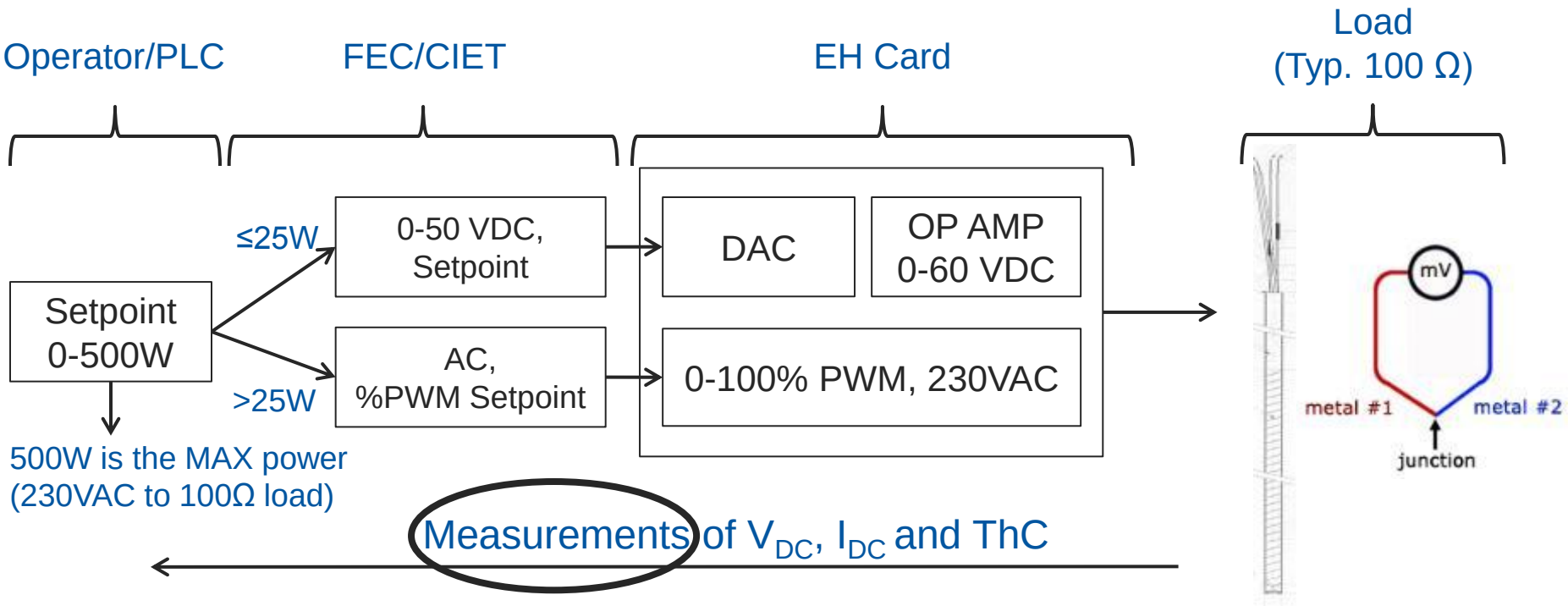
Control loop logic

W-FIP

W-FIP update rate: 2 Hz



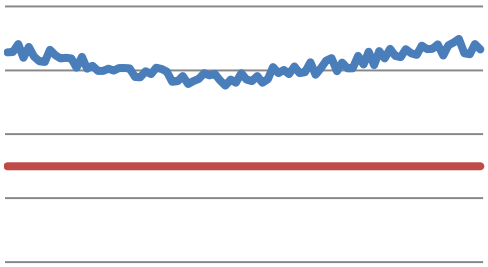
Theory of operation - Existing

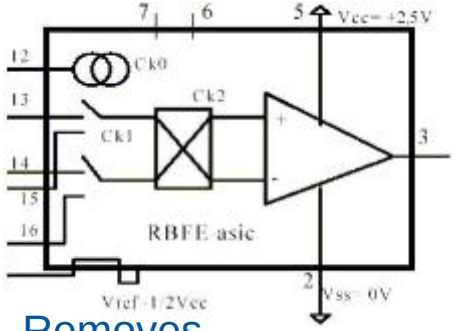


- Provide DC/AC power
- Calculate ThC, V_{DC} and I_{DC}
- 2 Identical channels (Top/Bottom)

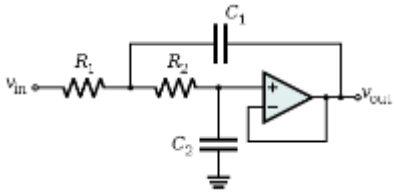
Theory of operation - Measurements

Input voltage
Reference voltage





Sallen-Key
Low pass filter
Fc:159Hz, Q=0.5, ζ =1



ADC

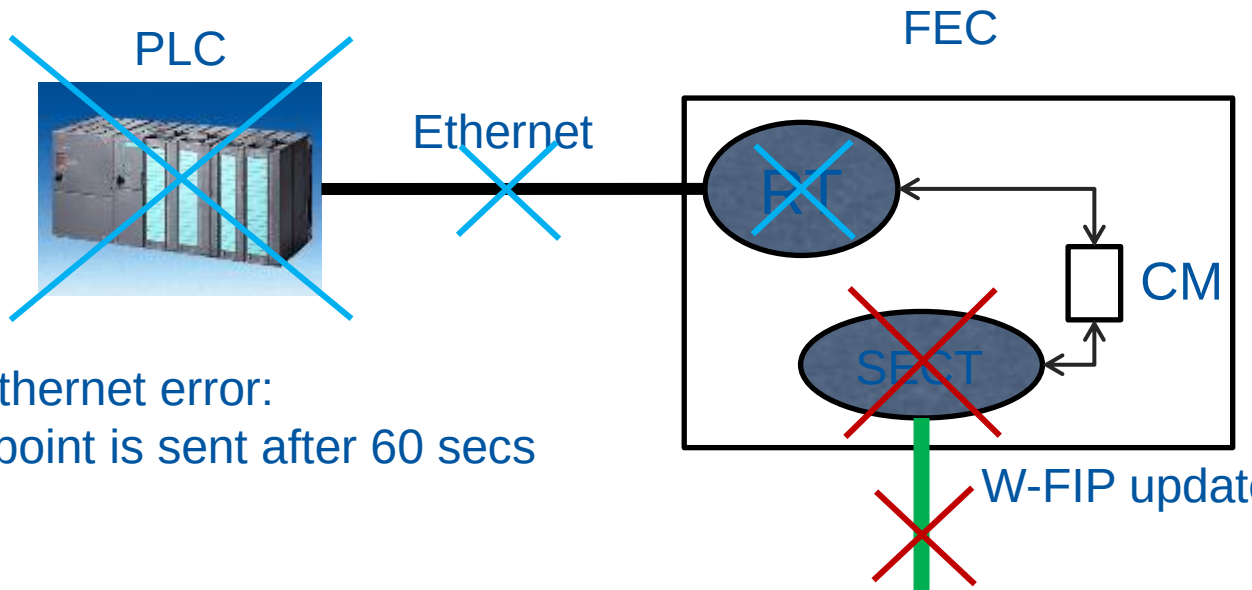
1024 samples
per position (40msec)

Removes
1. Offset, common mode errors
2. Gains & gain errors
3. % of radiation effects

Simultaneous measurements of ThC, V_{DC} and I_{DC}

Existing design issues & Consolidations

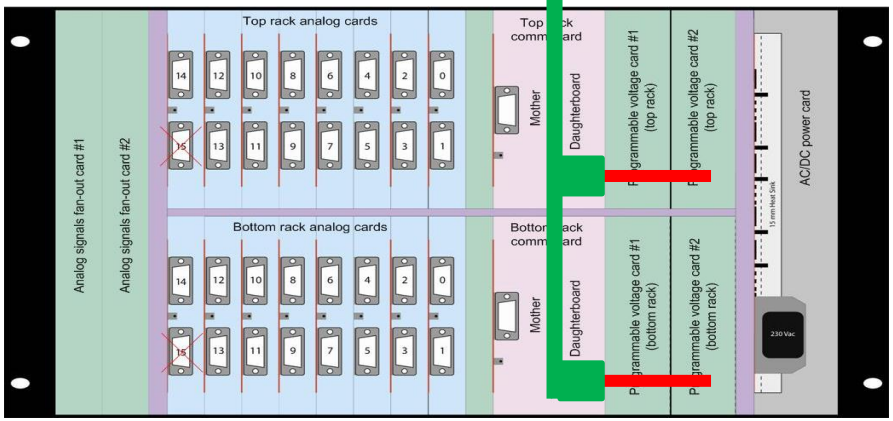
Communication lost - Existing



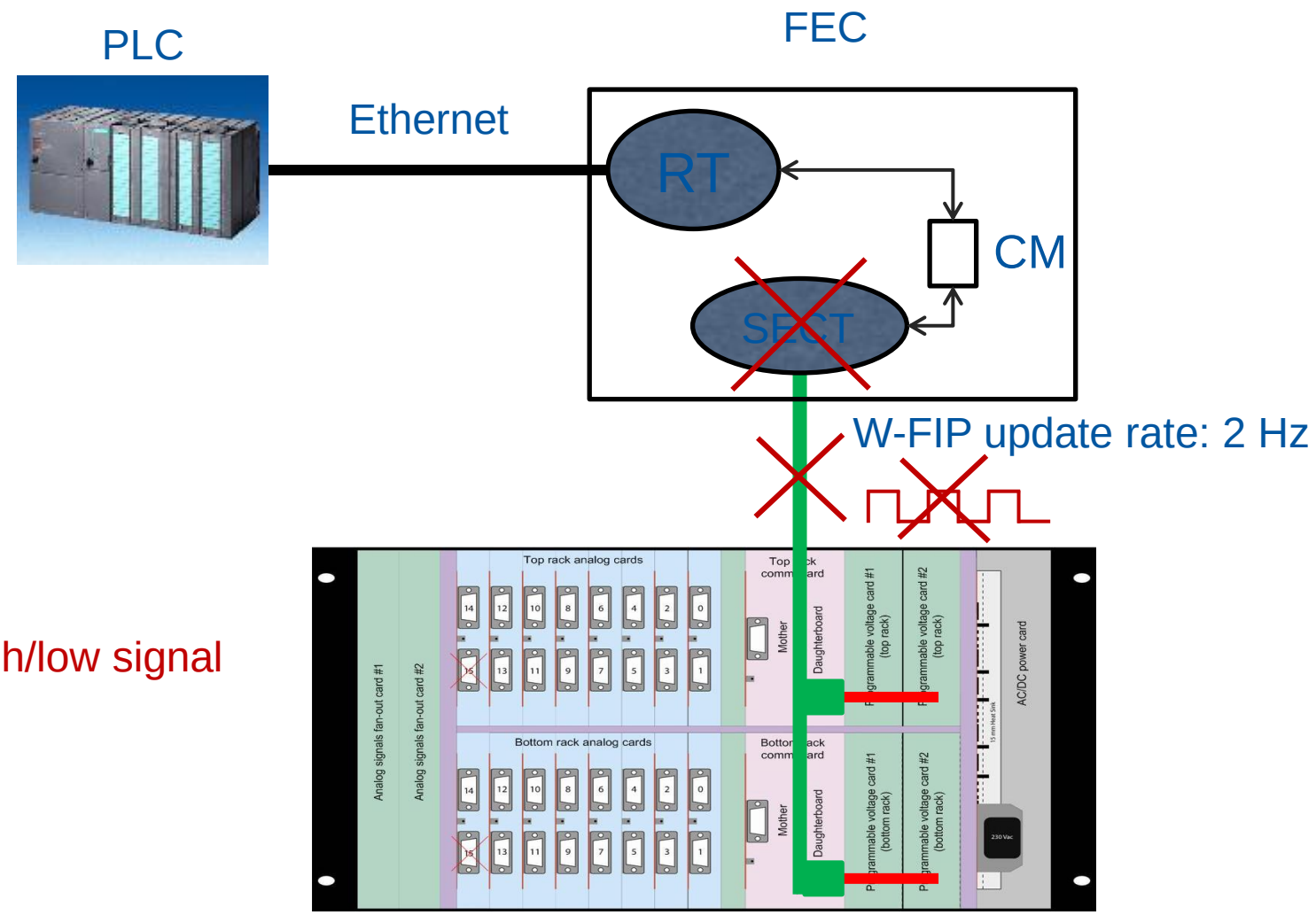
On PLC/Ethernet error:
ZERO setpoint is sent after 60 secs

W-FIP update rate: 2 Hz

In case of failure,
The EH cards operates
with the latest setpoint

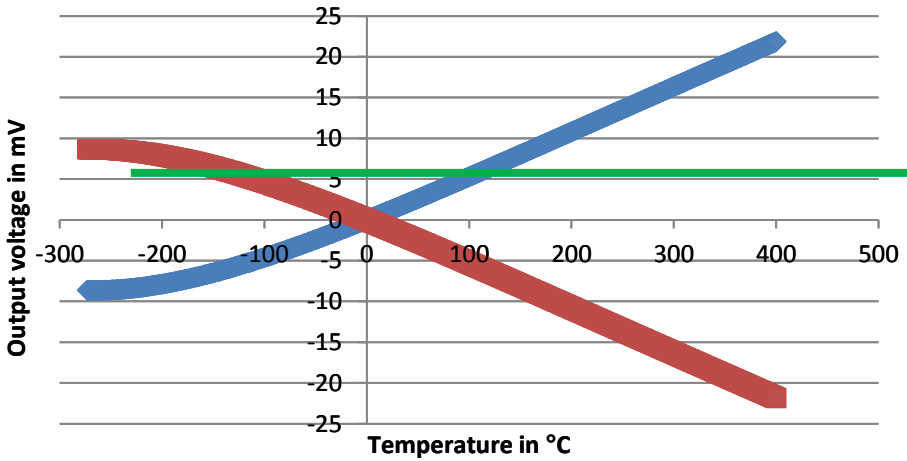


Communication lost - Consolidation



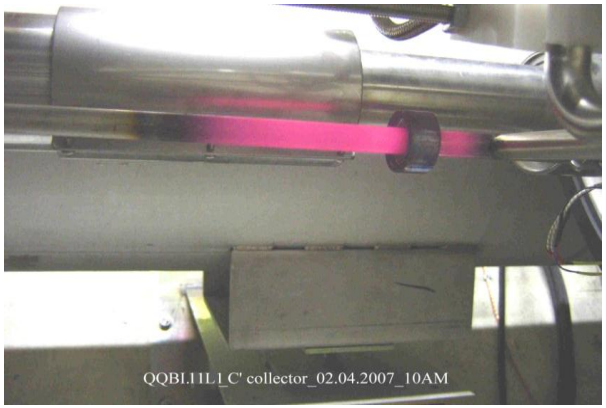
A watchdog high/low signal to the EH card

Thermocouple - Existing



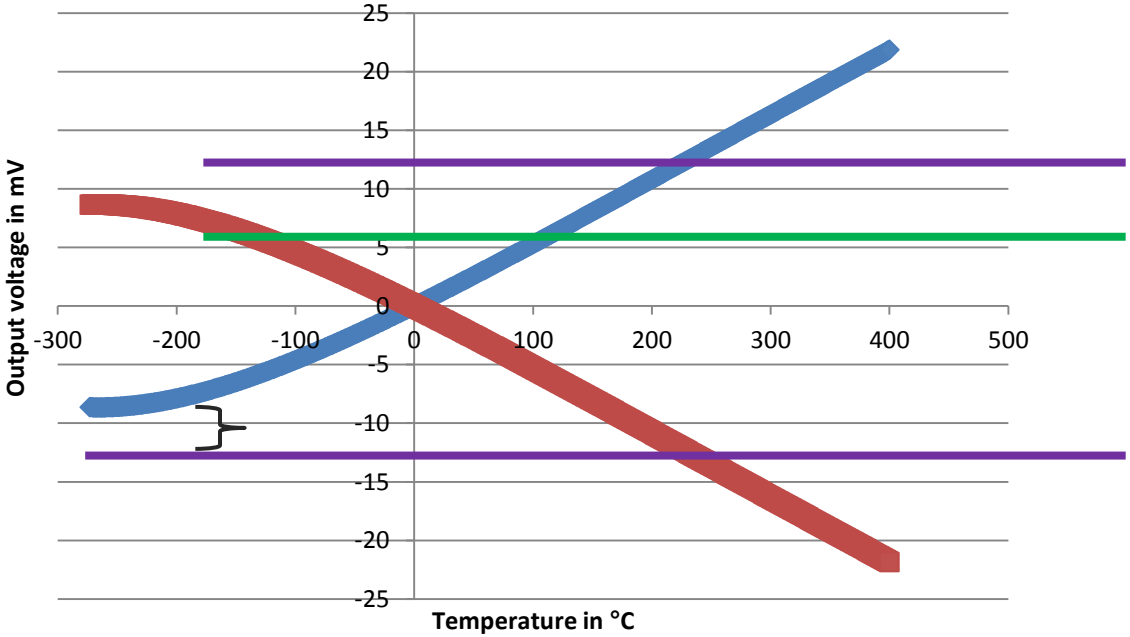
Soft interlock (Instrument specialist)

Blue: ThC correct polarity
Red: ThC inverse polarity



- Uncontrolled heating during LHC installation (April 2007)
- Due to a combination of tests on the CIET-FEC and not properly wired thermocouple protection (inverse)
- Not attributed to a problem of the communication

Thermocouple - Consolidation



Upper hard interlock (On EH card)

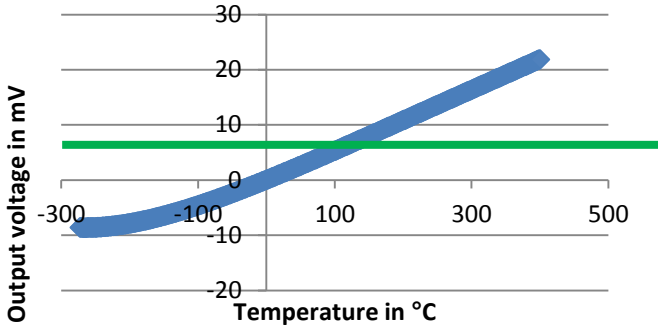
Soft interlock (Instrument specialist)

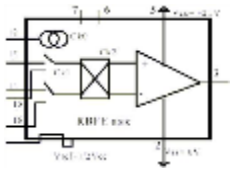
Lower hard interlock (On EH card)

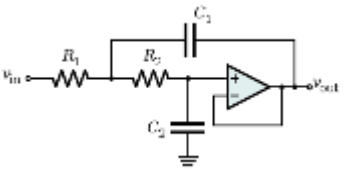
Blue: ThC correct polarity
Red: ThC inverse polarity

- The soft interlock is set by the instrument specialist through the communication card
- The hard interlocks are set on the EH card

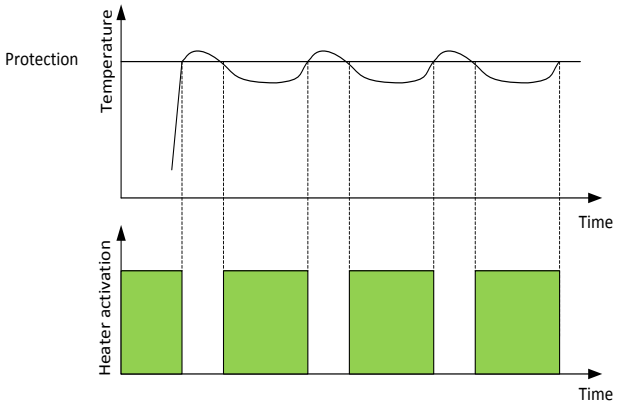
Auto Enable Mode - Existing

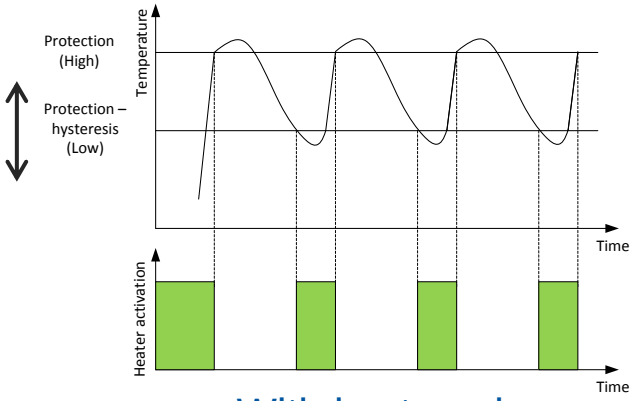






ADC





With hysteresis
(Feature not used)

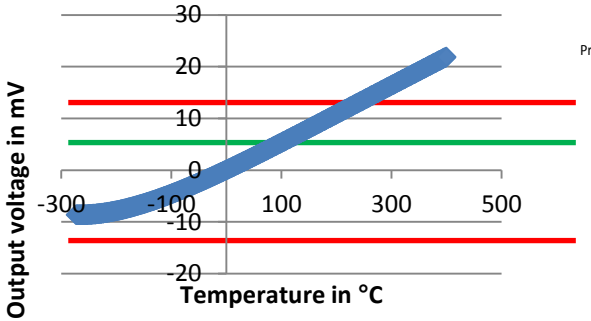
Consolidation request:

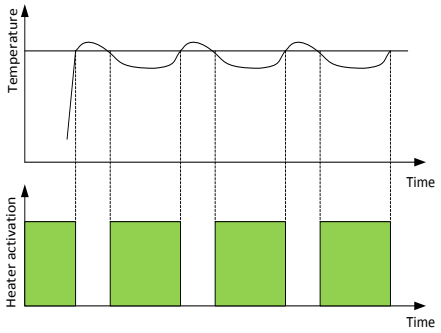
- Provide INTERLOCK functionality
- Provide ENABLE/DISABLE functions

Interlock – New

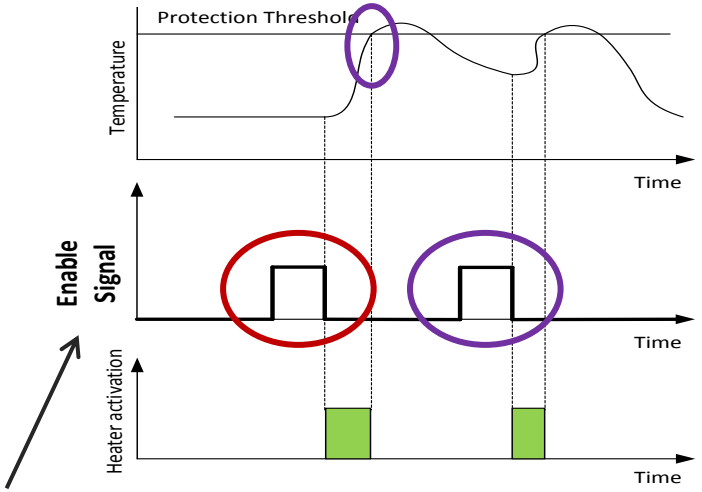
EH card to support 2 modes of operation:

Auto Enable

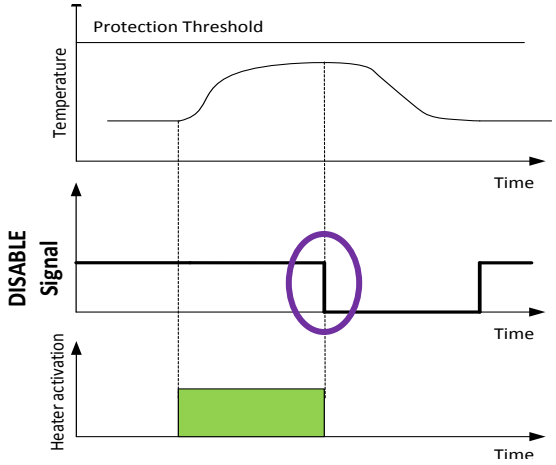




Manual Enable



Manual Disable



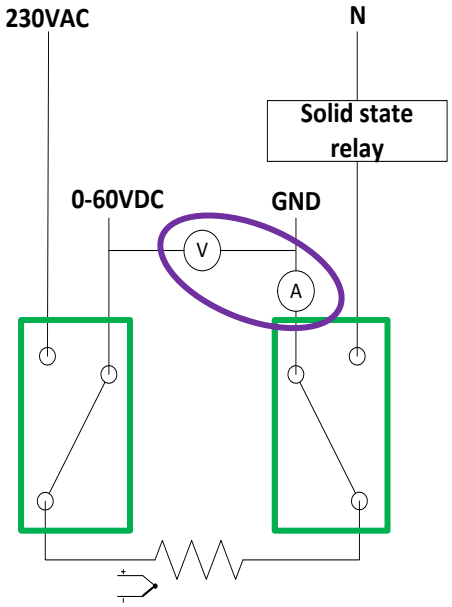
Operator ENABLE command after a reset/startup and interlock protection

Operator DISABLE command to deactivate and disconnect the load

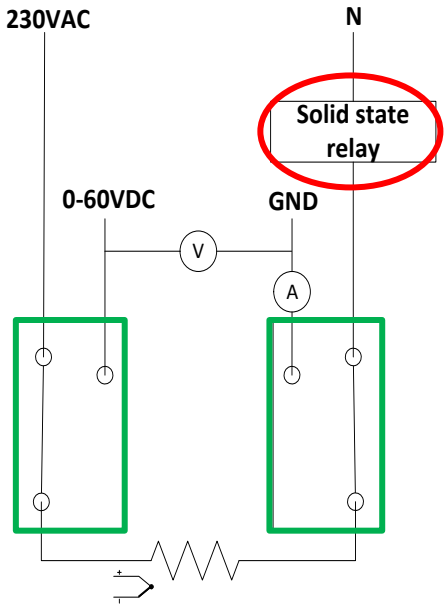
AC/DC mode - Existing

**Per channel*

DC mode



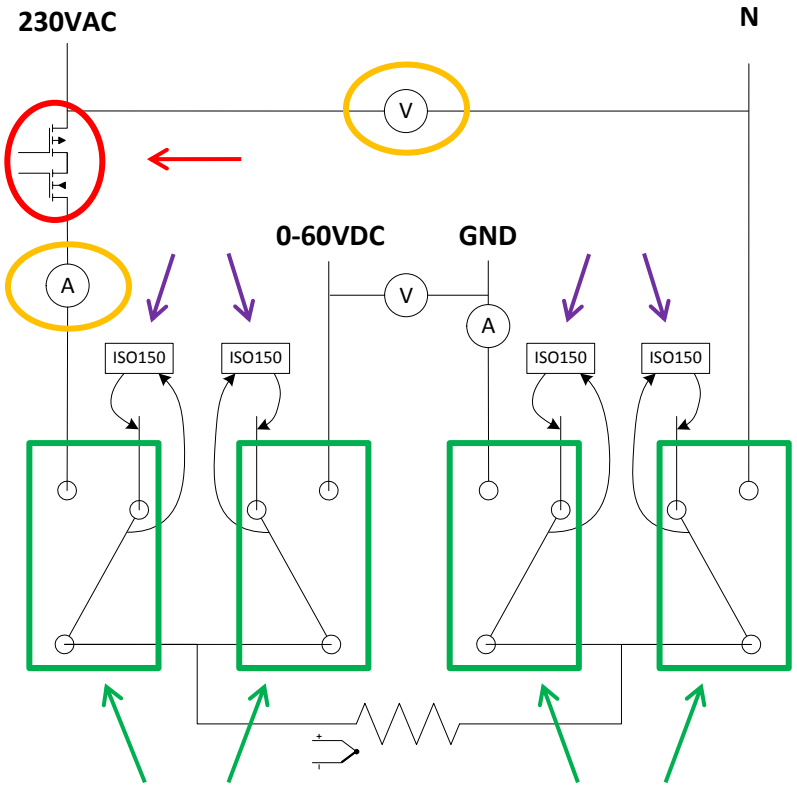
AC mode



- No relay failure identification exists. On failure, card destruction may occur.
- Load is connected to either **DC** or AC.
- Power calculations only in DC.
- Solid state relays are not rad-tol and will stop operating (be always OFF) after dose accumulation.
- Works without problem in protected areas.

AC/DC mode - Consolidation

**Per channel*



Contact positional monitoring

- Use of isolation digital couplers

PCB Relay with forcibly guided contacts according to EN 50205 type B

- Double connection is not possible

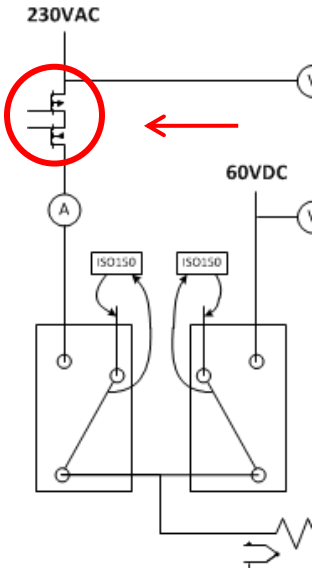
AC mode is rad-tol

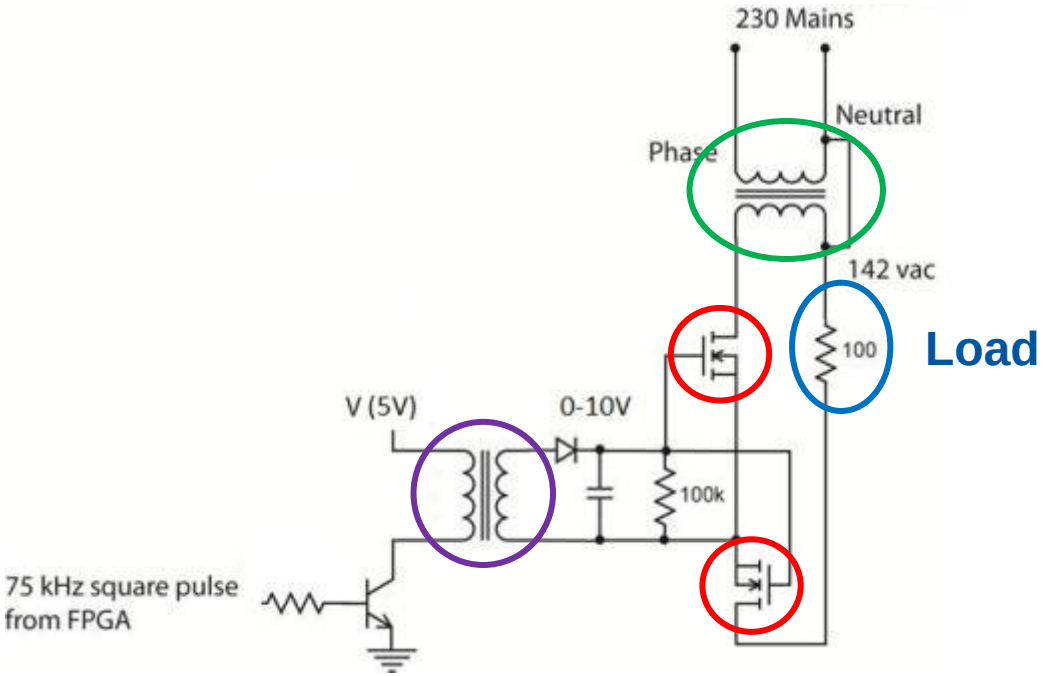
- Use of rad-tol NMOS power MOSFETS

V_{AC} & I_{AC} measurements

Requirement for Beam Screen Heaters:
provide AC power up to 200W with beam OFF
(Provide DC power up to 25W with beam ON)

Rad-tol AC mode

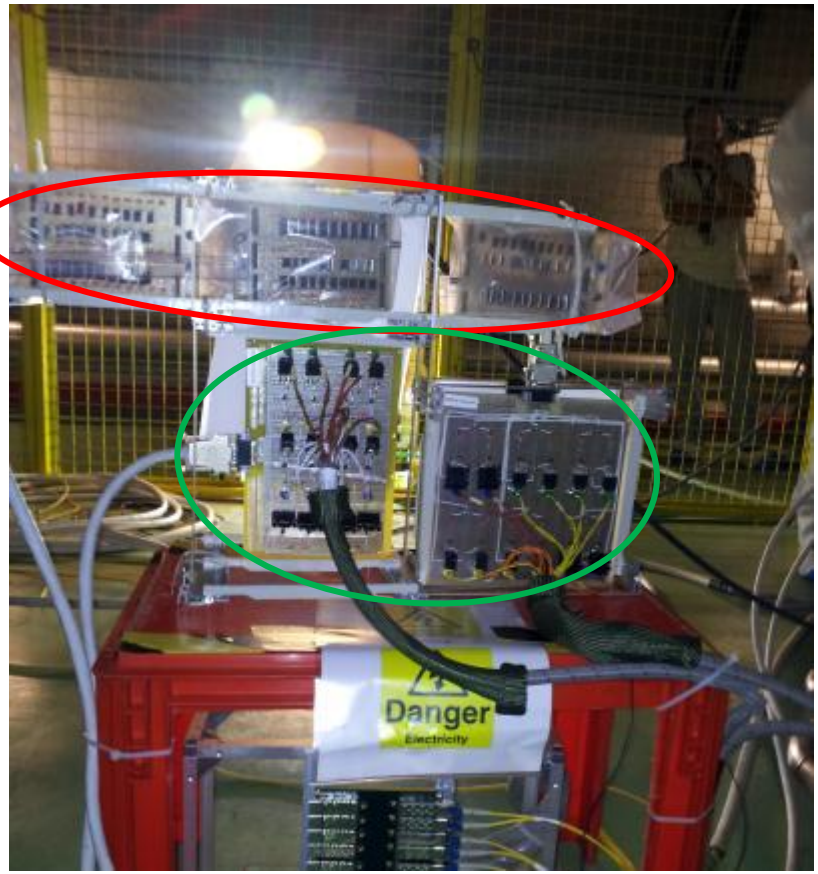




*AC/DC relays not shown

- 2 power MOSFETS for AC mode
- Isolation from the EH card digital circuitry using a PCB transformer (5V to 10V)
- A step-down transformer will be used to reduce the AC voltage (142VAC -> 200W max)

Rad-tol AC mode – Qualification (1)



MOSFET Types Tested

T1: FCA36N60NF	**600V,**	**36A,**	**0.095 Ω**
T2: STFI10NK60Z	600V,	10A,	0.65 Ω
T3: FDP7N60NZ	600V,	6.5A,	1.25 Ω

From each type:

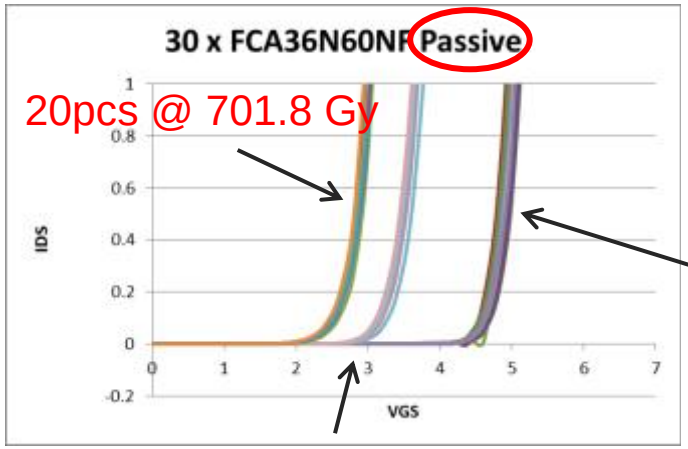
- 30 in passive mode
- 8 in active mode (connected to 230VAC & 130Ω)

T1, T2, T3: No failures in passive mode
T1 only: No failures in active mode

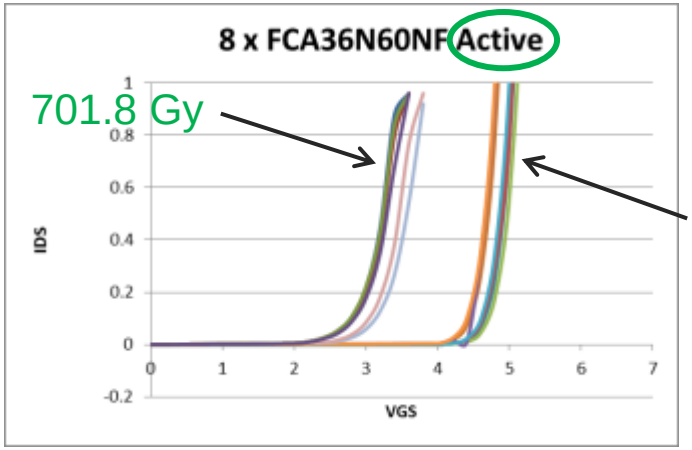
LHC conditions:
AC mode to be used with beam OFF
MOSFETs to be operated at 142VAC

CNRAD: 701.8 Gy, Neutrons: 6.94 e^{12}, Hadrons: 4.89 e^{12} LHC at crate locations 2-100 Gy/y

Rad-tol AC mode – Qualification (2)



T1



CNRAD: 701.8 Gy,
Neutrons: 6.94 e^{12}, Hadrons: 4.89 e^{12}

AC supply to load - Consolidation

Existing

230VAC

The 230VAC of the load is common to the crate AC supply

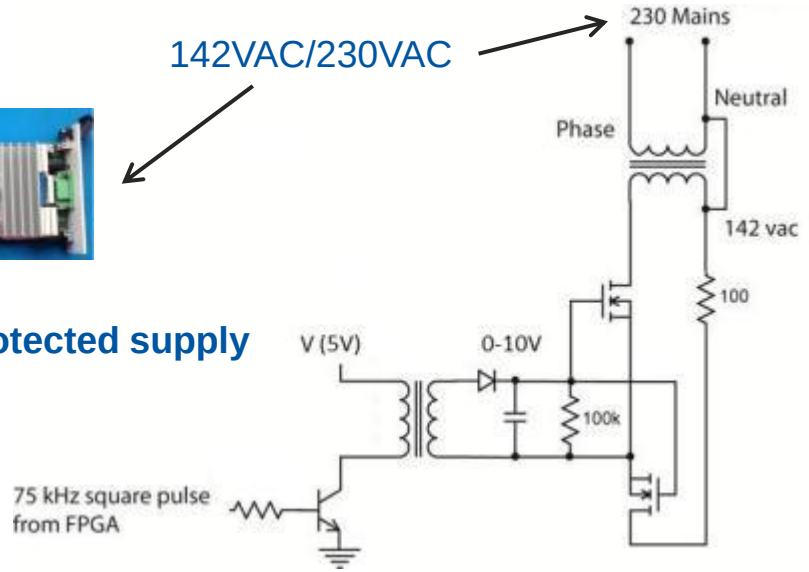
In the past, overcurrent of 230VAC has led to:

- Crate and full rack (3 crates) power loss

Consolidation

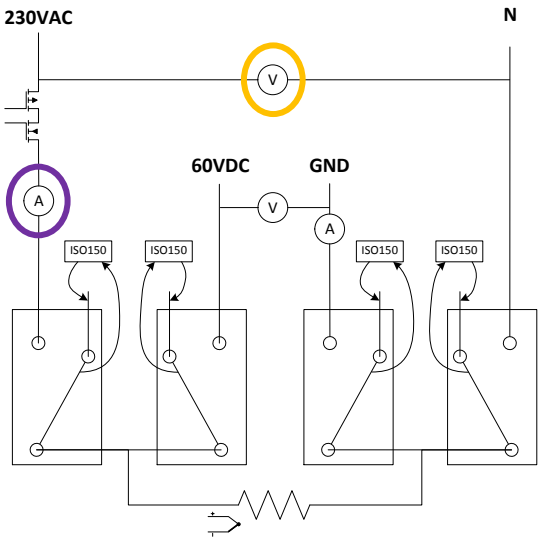
142VAC/230VAC

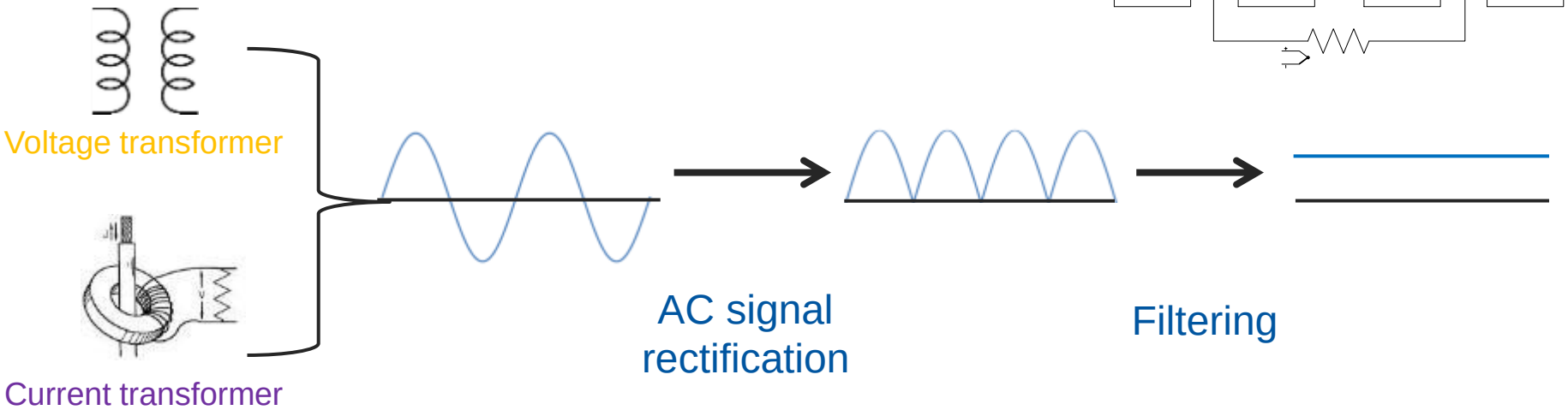
The 142VAC/230VAC from an **independently protected supply**



Measurements on AC - New

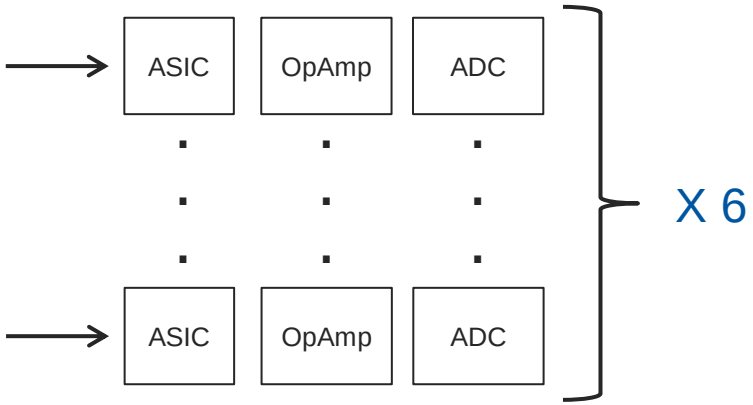
To support V_{AC} and I_{AC}



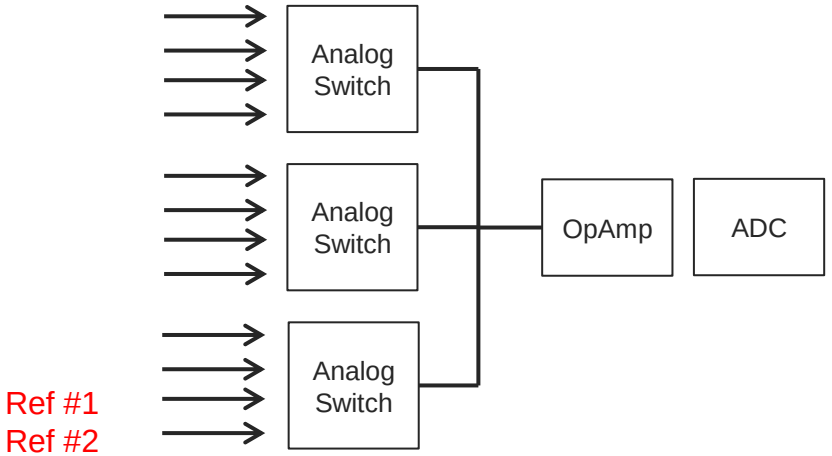


Analog switches – In evaluation

Existing version
6 simultaneous measurements
(V_{DC}, I_{DC}, ThC) x 2 Channels



New version
10 circular measurements
(V_{DC}, I_{DC}, V_{AC}, I_{AC} , ThC) x 2 Channels



Use of analog switches:

- Component reduction: (approx. 9 ADC, Op amps, …)
- Reduced power consumption, thermal dissipation, space, ...
- ADC weakest point (up to 500 Gy, 10 fold current increase)

Analog switches - Qualification

Name/Manufacturer	SW06 (Analog Devices)	HS-201HSRH (Intersil)	RHD 5920 (Aeroflex)
Type	Quad SPST JFET analog switch	Quad SPST CMOS analog switch	16-Ch analog mux
RadHard Tech	No	Yes	Yes
Cost per card	7.5$ (3 x 2.5$)	234.9$ (3 x 78.3$)	340$ (1 x 340$)
Dose	---	3000 Gy	10.000 Gy

CNGS: Testing the Analog Devices SW06

18 in active mode (72 channels)
6 in passive mode (24 channels)

Dose: 347.5 Gy, Neutrons: 3.44 e^{12}, Hadrons: 2.42 e^{12}

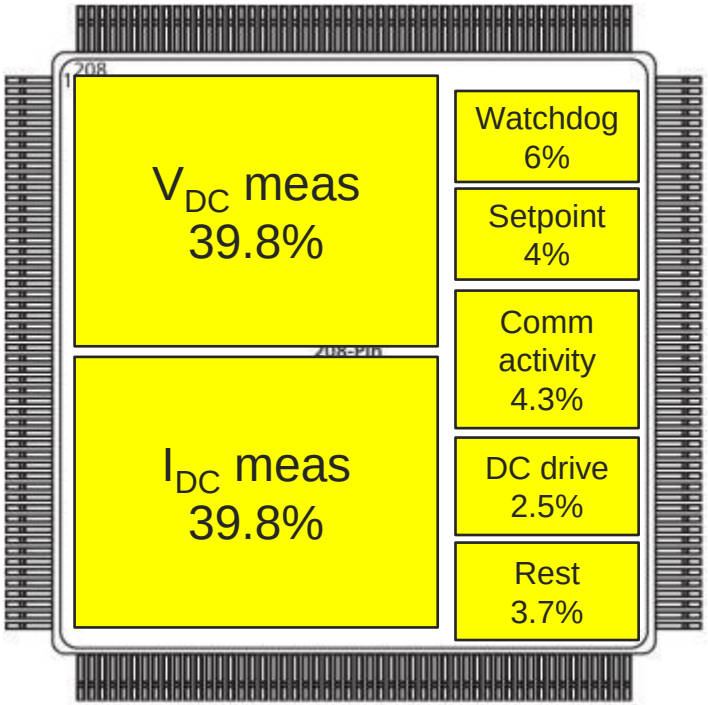
CNGS: SW06 Seems to be OK.
Tests planned at PSI, Zurich (24th FEB 13)

Use of COTS SW06 switch will result in savings of ~450CHF

FPGA utilization – Existing (1)

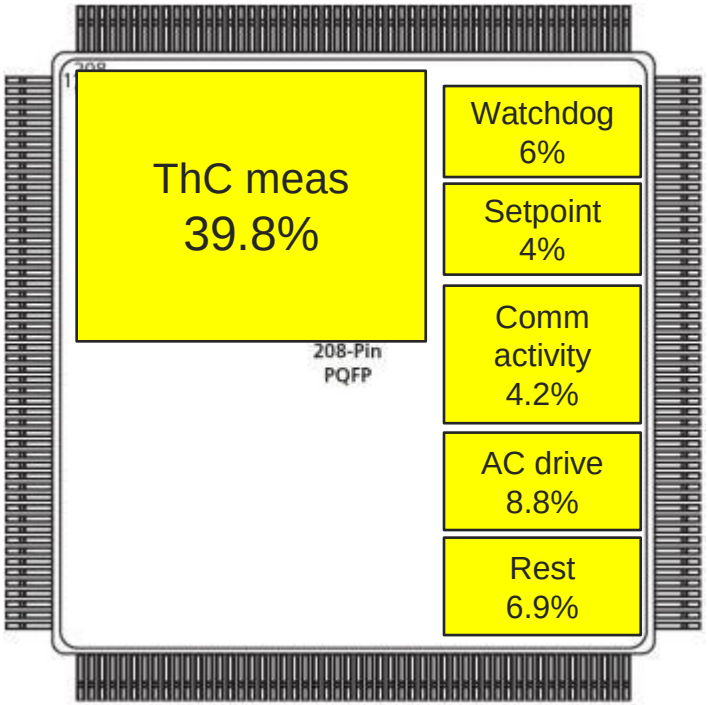
2 FPGAs per channel
Part: Actel/Microsemi antifuse A54SX72A-PQ208

FPGA #1



Utilization
100% FFs, 75% gates

FPGA #2



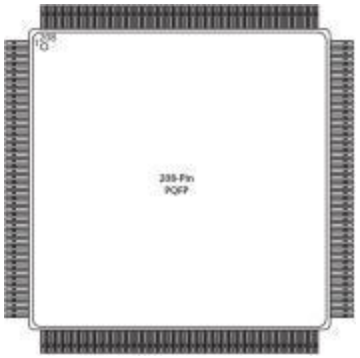
Utilization
69.7% FFs, 53% gates

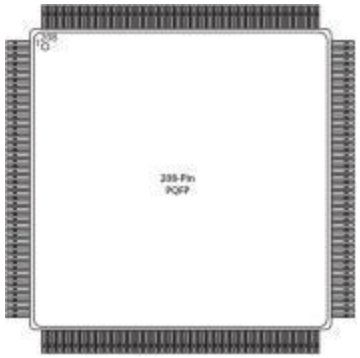
FPGA utilization – Existing (2)

FPGA #1

FPGA #2

TOP channel

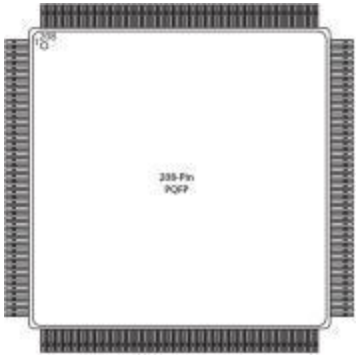


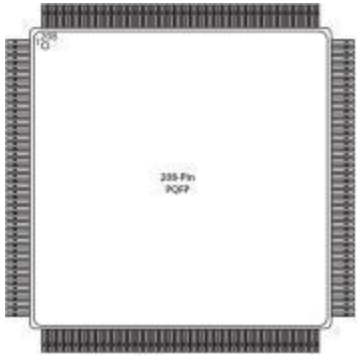


FPGA #3

FPGA #4

BOTTOM channel



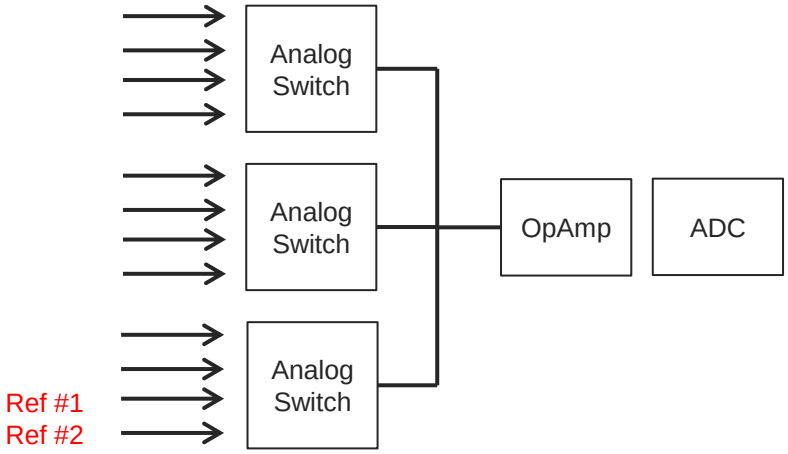


Utilization
100% FFs, 75% gates

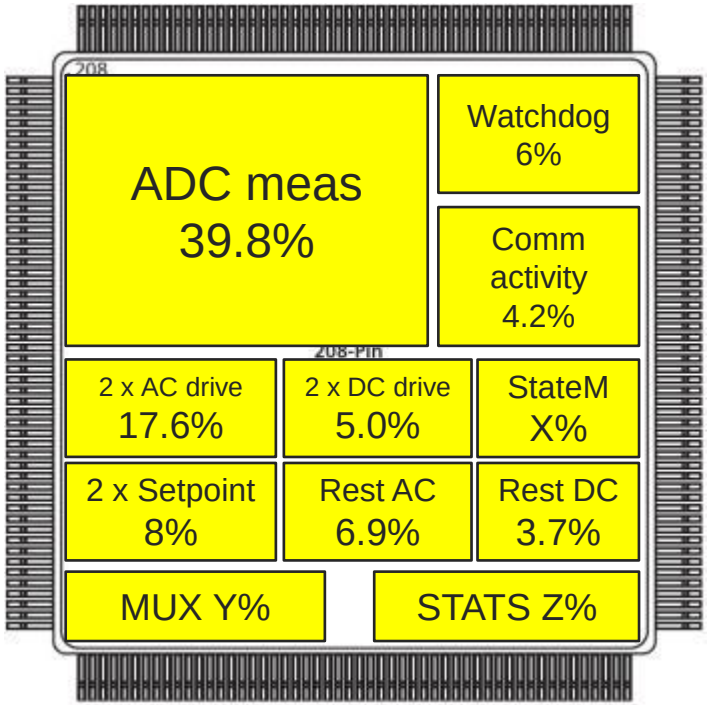
Utilization
69.7% FFs, 53% gates

FPGA utilization – New

with analog switches



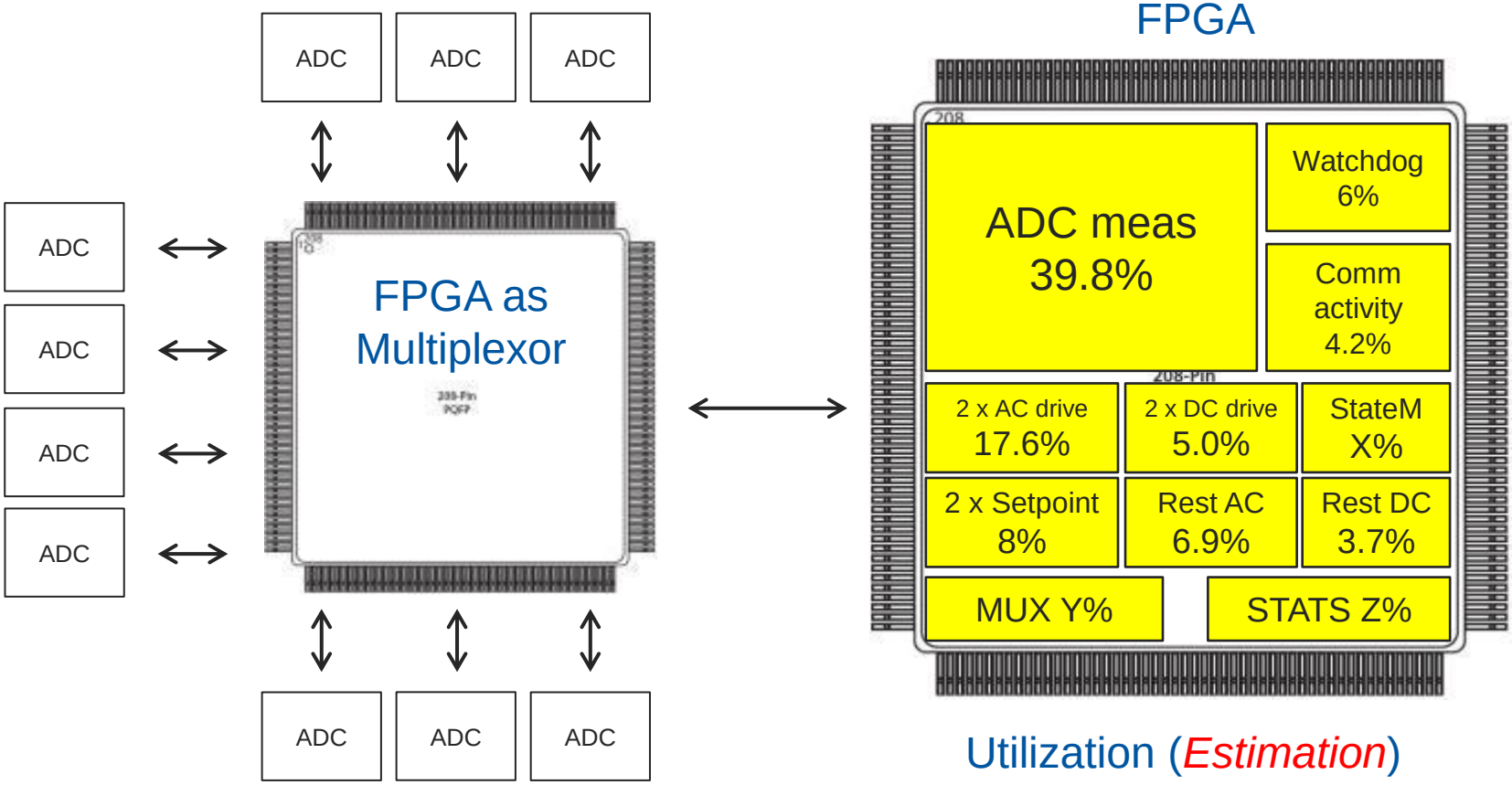
FPGA



Utilization (*Estimation*)
91.2% FFs, 80% logic +X,Y, Z%
A small-size FPGA might be needed

FPGA utilization – New

without analog switches



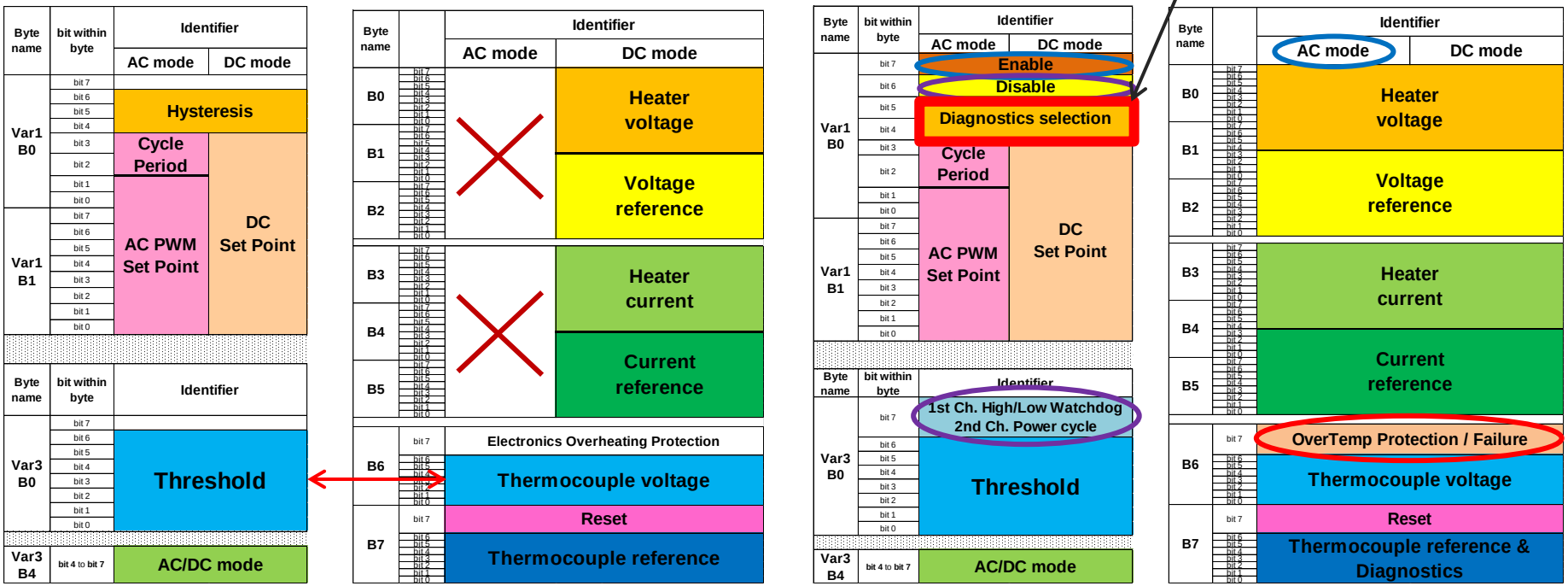
Utilization (*Estimation*)

91.2% FFs, 80% logic +X,Y, Z%

Data exchange with comm. card

**Data per channel*

Available commands



Data sent to an EH channel
Limited signals

Data received from an EH channel
No ThC protection feedback

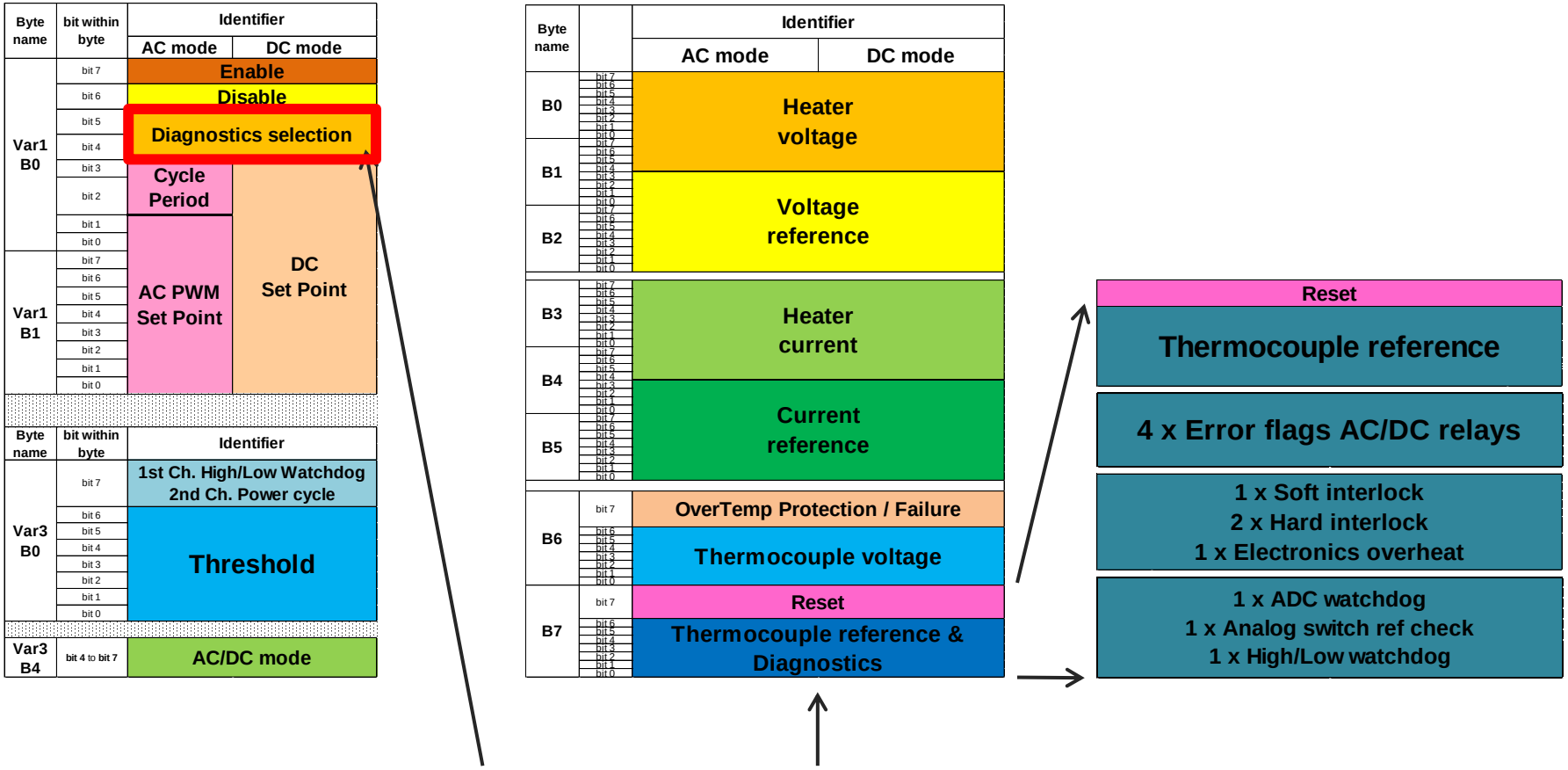
Data sent to an EH channel

Data received from an EH channel

Existing

Consolidation

Data exchange – Diagnostics (firmware)

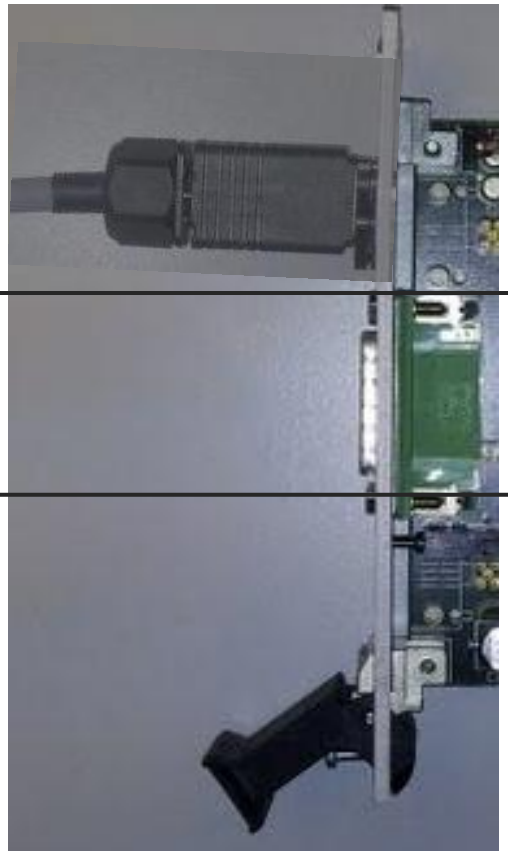


Diagnostics selection can be used for cycling/multiplexing diagnostics data

Diagnostics (hardware)

Existing front panel

Diagnostics connector



New front panel

Other features

PARAMETER	PRIOR CONSOLIDATION	AFTER CONSOLIDATION
Temperature sensor	Thermocouple	Thermocouple or Resistive (PT100)
Short-circuit protection (AC mode)	None	Fuse
AC driver over-temperature protection	No	Yes
Soft reset	Yes	Yes
Power cycle (Disconnect 9V)*	No	Yes
AC power start/stop options	Zero crossing	1. Random 2. Zero crossing 3. V_{AC} peak
Additional DC supplies	DC/DC converter	Linear conversion

**** Relay driven by communication card***

Prototyping

- Climate chamber for ambient tests
- Cards to be tested in our laboratory
- Cards to be deployed in cryo facilities (SM18)
- Automatic testbench to be modified and support the new EH card

Summary

The new EH card:

- Provides operational backwards compatibility
- Tackles problems of incorrect protection connections
- Rad-tol AC mode, I_{AC} and V_{AC}
- Lost W-FIP communication – no thermal overrun
- Interlock and Enable/Disable commands
- Extensive diagnostics available
- Consolidates several issues (Front AC connection, AC/DC relays, fuse protection)

Questions?

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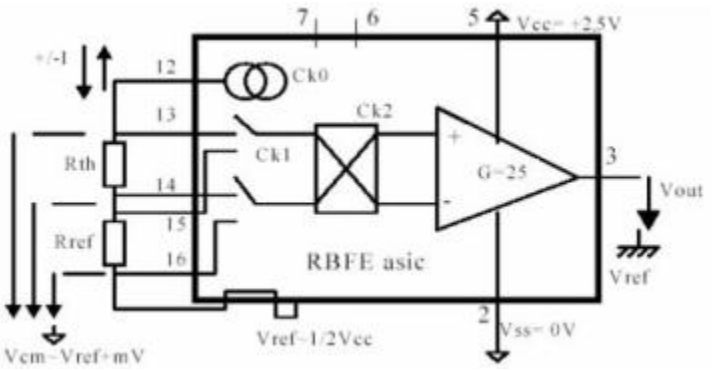
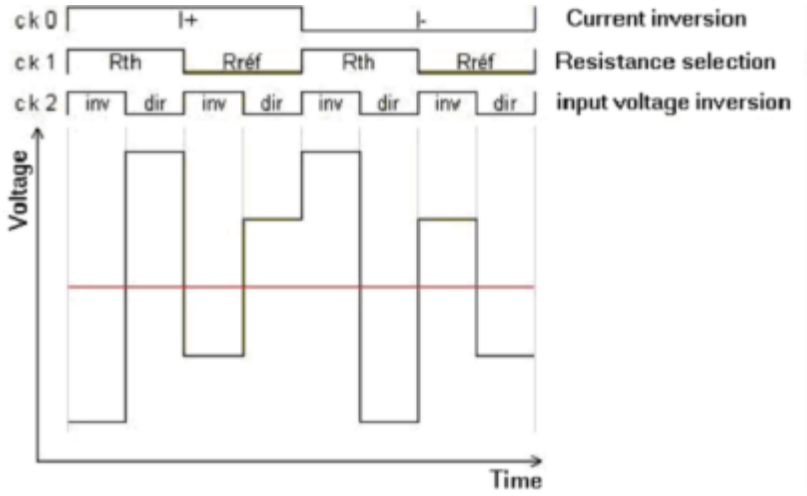
Theory of operation - Measurements





RBFE ASIC

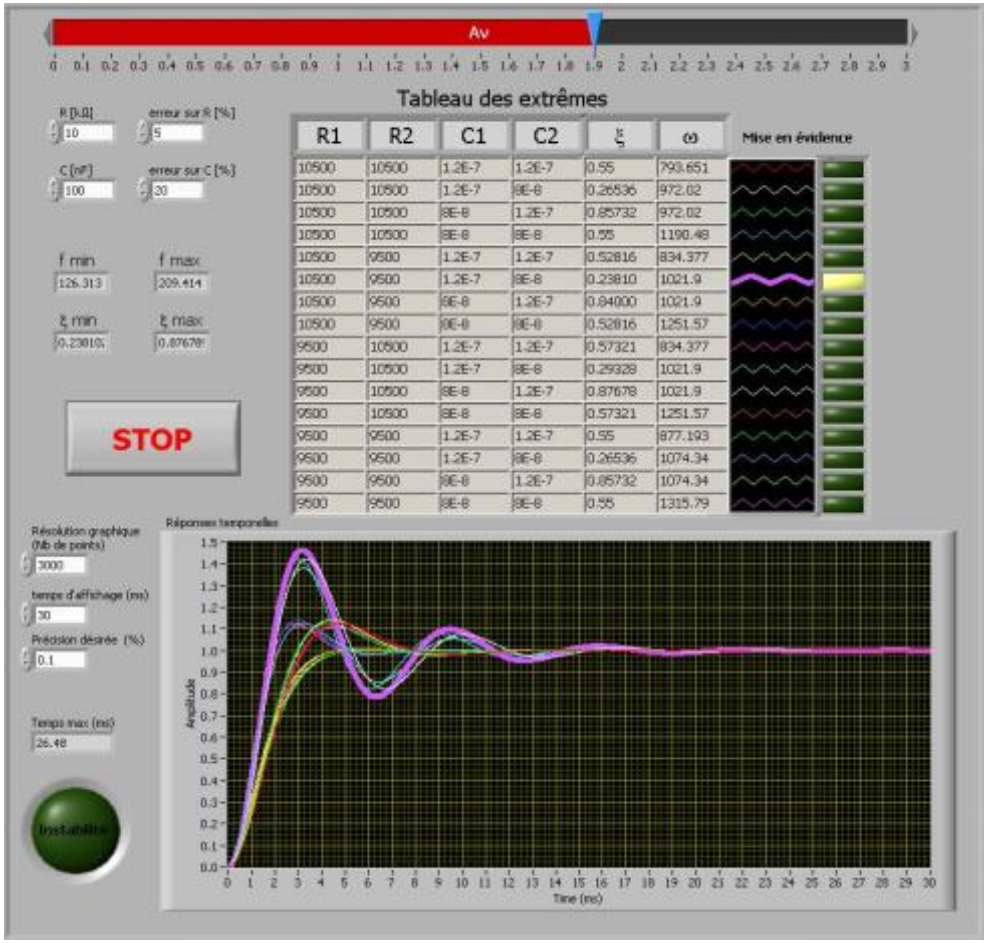
1. Direct/Inverse connection
2. Signal/Reference selection
3. Current inversion

Removes

1. Offset errors, Common mode
2. Gains & gain errors
3. Thermoelectric potential
4. % of radiation effects

Result depends on ADC measurement and reference

Sallen-Key simulations



Safety relays

finder

50 Series - Forcibly guided contacts relay 8 A

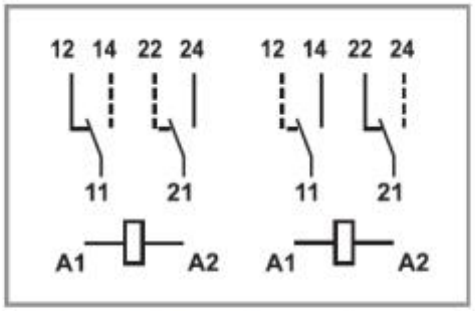
Features

PCB Relay with forcibly guided contacts according to EN 50205 type B
2 CO contacts *

- High physical separation between adjacent contacts
- Cadmium Free contact materials
- 8 mm, 6 kV (1.2/50 µs) isolation, coil-contacts
- Flux proof: RT II

50.12...1000

50.12...5000



Alternative selection of NO and NC contacts to provide Forcibly guided (mechanically linked) contacts, in accordance with EN 50205 (type B).

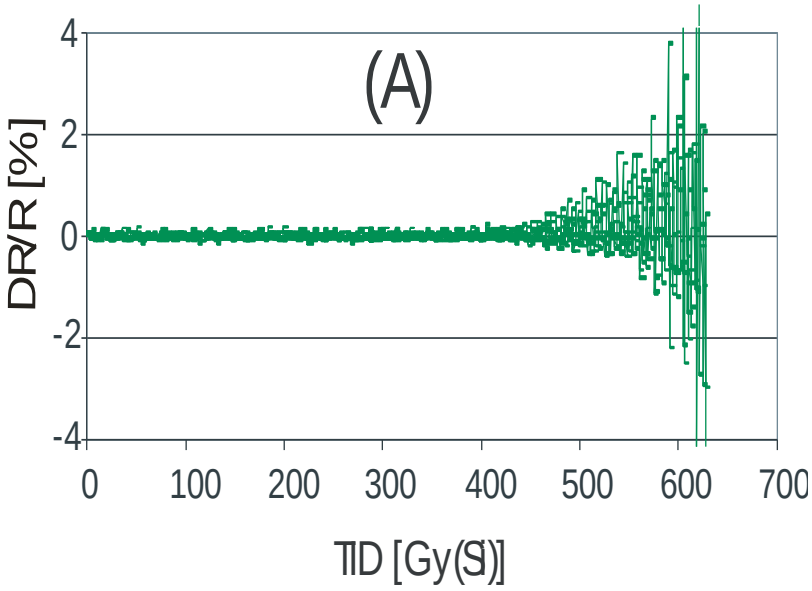
ADS7807 Electrical specs

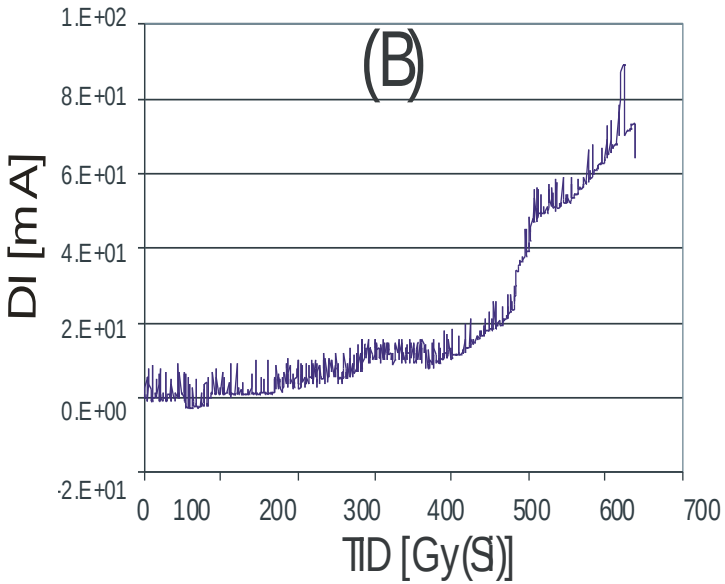
ELECTRICAL

At T_A = –40°C to +85°C, f_S = 40kHz, V_{DIG} = V_{ANA} = +5V, using internal reference and fixed resistors shown in Figure 7b, unless otherwise specified.

PARAMETER	CONDITIONS	ADS7807P, U			ADS7807PB, UB			UNITS
		MIN	TYP	MAX	MIN	TYP	MAX	
DIGITAL TIMING								
Bus Access Time	R_L = 3.3kΩ, C_L = 50pF			83			*	ns
Bus Relinquish Time	R_L = 3.3kΩ, C_L = 10pF			83			*	ns
POWER SUPPLIES								
Specified Performance								
V_{DIG}	Must be ≤ V_{ANA}	+4.75	+5	+5.25	*	*	*	V
V_{ANA}		+4.75	+5	+5.25	*	*	*	V
I_{DIG}			0.6			*		mA
I_{ANA}			5.0			*		mA
Power Dissipation	V_{ANA} = V_{DIG} = 5V, f_S = 40kHz		28	35		*	*	mW
	REFD HIGH		23			*		mW
	PWRD and REFD HIGH		50			*		µW
TEMPERATURE RANGE								
Specified Performance		–40		+85	*		*	°C
Derated Performance		–55		+125	*		*	°C
Storage		–65		+150	*		*	°C
Thermal Resistance (θ_{JA})								
Plastic DIP			75			*		°C/W
SOIC			75			*		°C/W

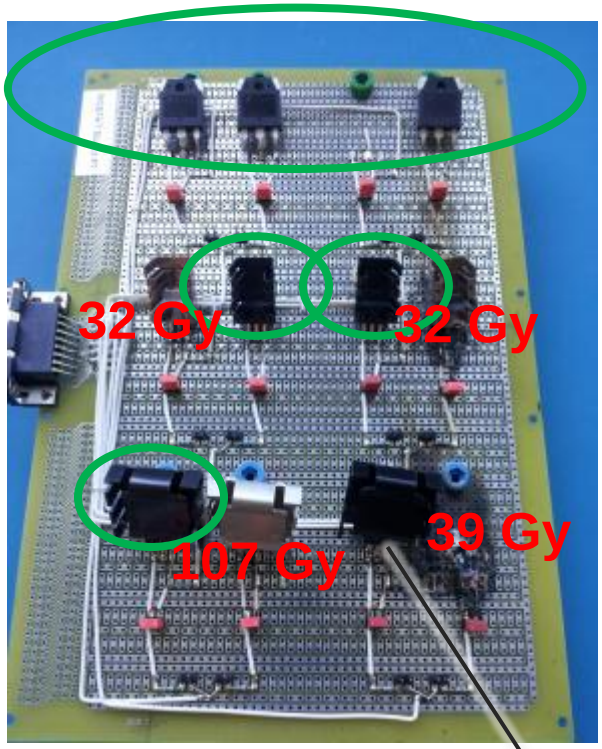
ADS7807 rad data





PSI 60MeV proton beam

CNRAD results – Power MOSFETS

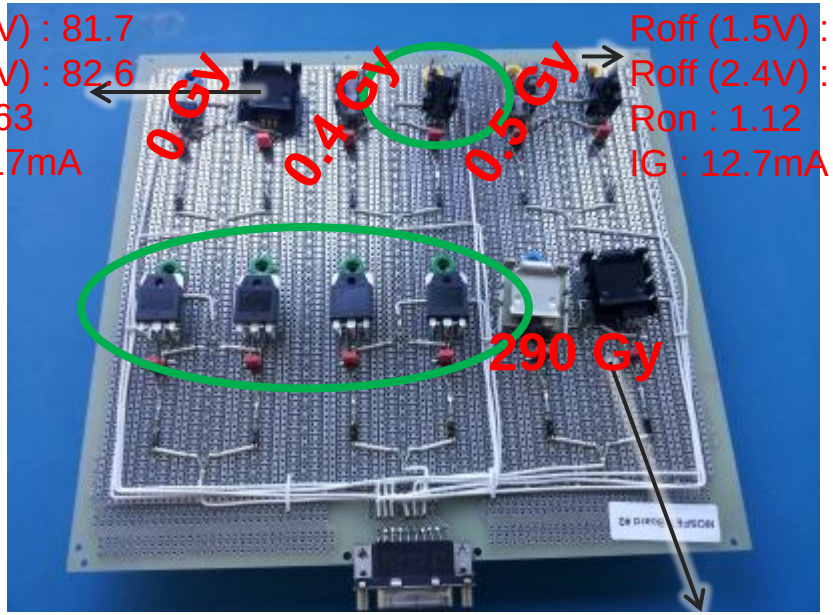


Dose: 701.8 Gy
Neutrons: 6.94 e12
Hadrons: 4.89 e12

Active board #1

Roff (15V) : 100
Roff (20V) : 15
Ron : 1.74
IG : 72.5mA

Roff (15V) : 81.7
Roff (20V) : 82.6
Ron : 1.63
IG : 26.17mA



Roff (1.5V) : 12.5
Roff (2.4V) : 8.03
Ron : 1.12
IG : 12.7mA

Roff (15V) : 170
Roff (20V) : 154
Ron : 1.12
IG : 25mA

Active board #2

CNRAD results – Power MOSFETS

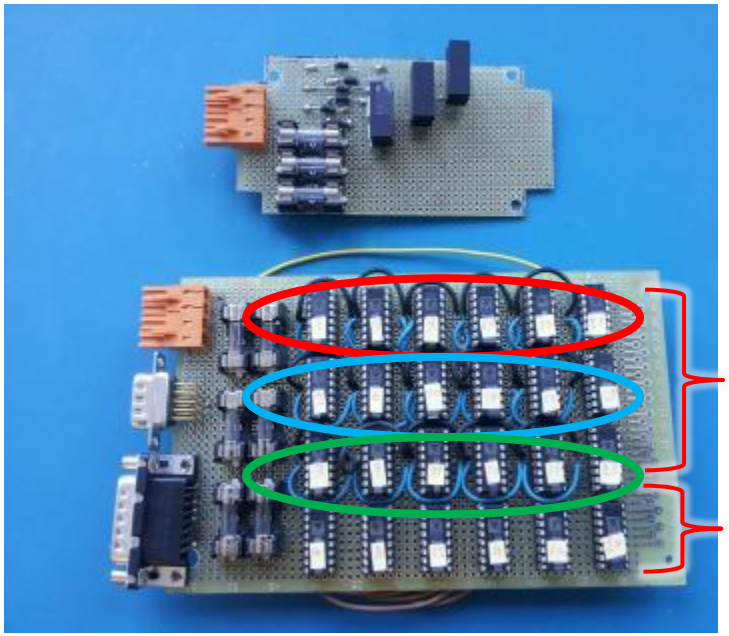
Threshold voltage Vgs

Before Radiation	354Gy	702Gy Passive	702Gy Active
T1: 4.1	T1: 2.6	T1: 1.6	T1: 2/2/2/2.4/2.6
T2: 4	T2: 2	T2: 1.4	T2: 1.8/3/1.6
T3: 4.4	T3: 2.4	T3: 1.6	T3: 2.2

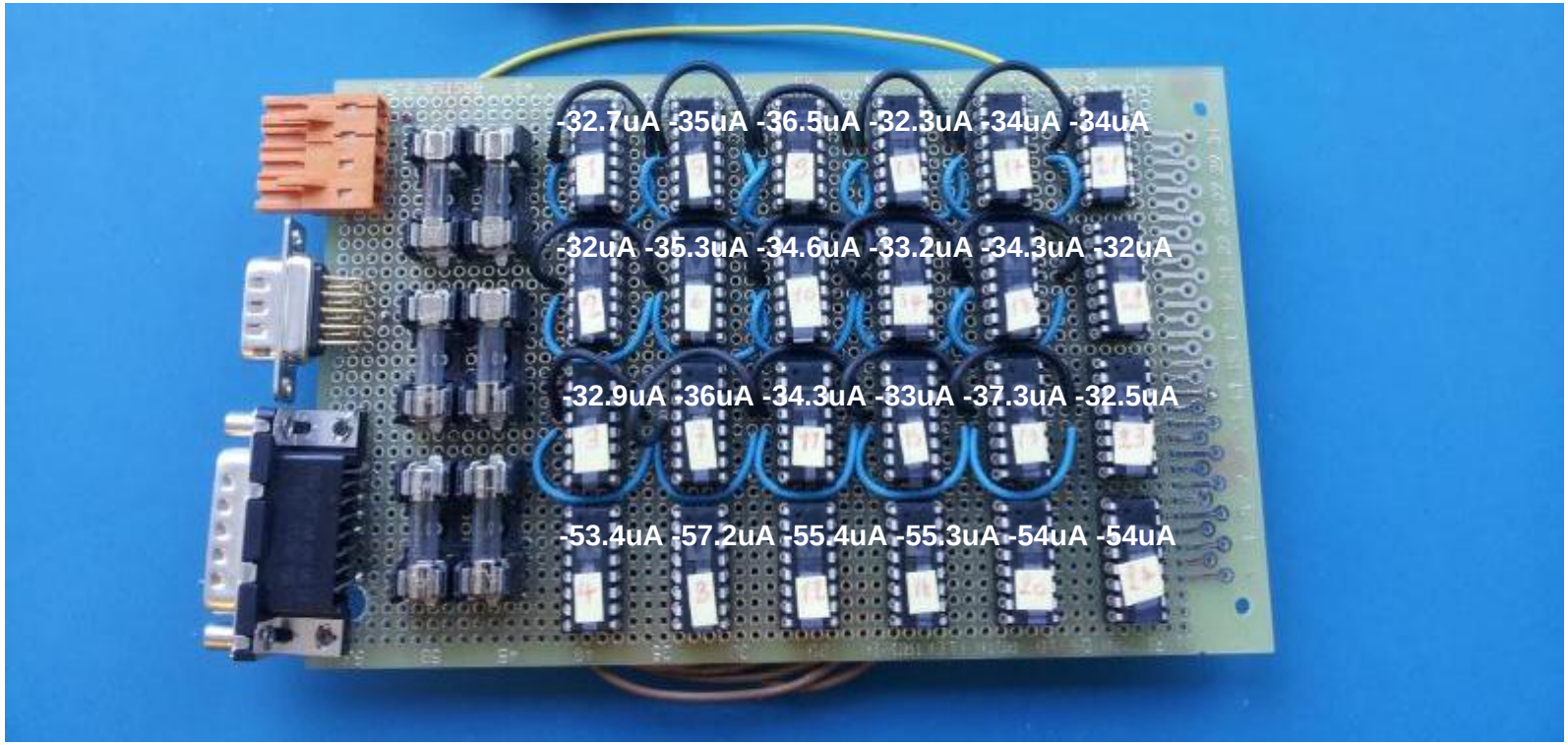
Installed on 27/06/12

CNRAD results – Analog Switches

Triplicated 5V to ±12V
Power supplies with fuses



CNRAD results – Analog Switches



Typical input current: -2uA

No increase in power supply

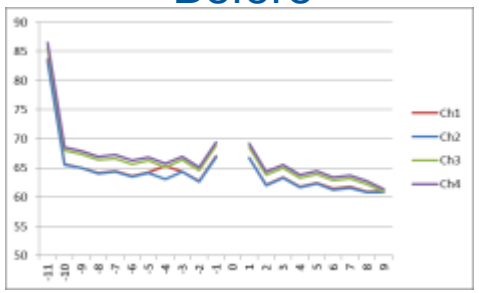
Dose: 347.5 Gy
Neutrons: 3.44 e12
Hadrons: 2.42 e12

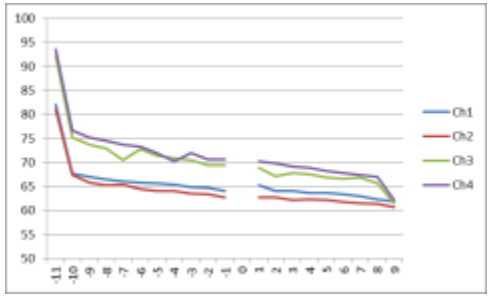
CNRAD results – Analog Switches

Before

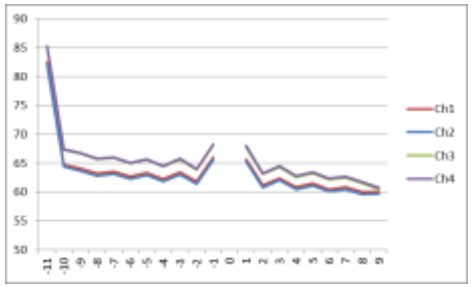
After

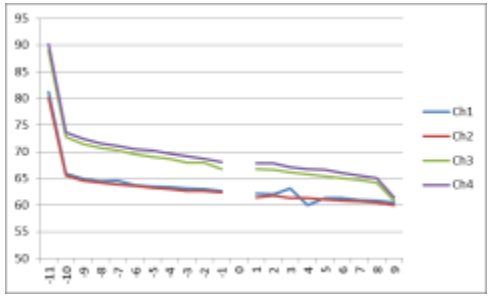
SW#1 Active



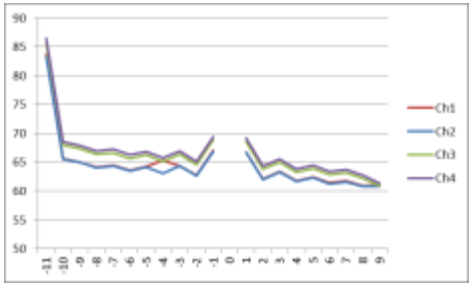


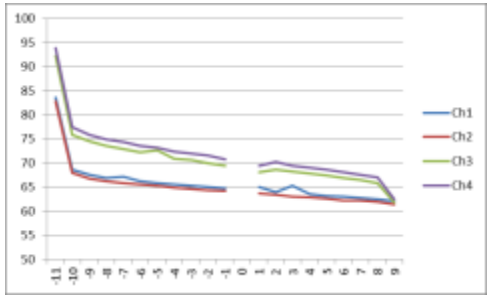
SW#2 Active





SW#4 Passive





EH card specifications prior and after consolidation

EH Specs
Page 1/2

OPERATIONAL ENVIRONMENT

(To meet all specs)

PARAMETER	PRIOR CONSOLIDATION	AFTER CONSOLIDATION	UNITS
Operating temperature	0 to +40	0 to +40	°C

GENERAL SPECIFICATIONS

PARAMETER	PRIOR CONSOLIDATION	AFTER CONSOLIDATION
Load	Non-reactive	Non-reactive
Number of channels	2	2
Modes of operation	AC/DC	AC/DC
DC mode of operation	Programmable DC voltage	Programmable DC voltage
AC mode of operation	Pulse Width Modulation (PWM)	Pulse Width Modulation (PWM)
Feedback on delivered power	DC only	DC and AC
Temperature sensor	Thermocouple	Thermocouple or PT100
Over-temperature setpoint resolution	Approx. 14°C	~10°C
Over-temperature soft setpoint (FEC, CIET)	Yes	Yes
Over-temperature hard setpoint (Jumpers)	No	Yes

DC/AC ELECTRICAL CHARACTERISTICS

PARAMETER	PRIOR CONSOLIDATION	AFTER CONSOLIDATION	UNITS
AC input/output voltage	20-230	20-230	V_{RMS}
AC input/output frequency	50 or 60	50 or 60	Hz
DC output voltage	0-60	0-60	V
DC output current	0-2	0-4[1]	A
AC output PWM duty cycle	0-100	0-100	%
AC output PWM period	1.25, 2.5, 5 or 10	1.25, 2.5, 5 or 10	s
AC output current	0-6	0-6	A_{RMS}
Minimum AC output pulse	Half grid period	Half grid period	
Power start/stop options[2]	Zero crossing	1 Random 2 Zero crossing 3 V_{AC} peak	

Notes:

1. For DC output current >2 A, active ventilation is required.

2. Option selectable by hardware setting.

POWER INTERLOCK CONDITION[1]

CONDITION	PRIOR CONSOLIDATION	AFTER CONSOLIDATION
Start-up	None	Enabled
Over-temperature (temperature rises over "high"[2] threshold)	Enabled	Enabled
Over-temperature (temperature drops below "low"[2] threshold, after having passed the "high" threshold)	Disabled	N.A.
Sensor disconnection	Enabled	Enabled
Thermocouple reversal	None	Enabled > 300°C[3]

NOTES:

1. In the consolidated EH Card, if interlock is enabled it can only be disabled by an external command.
2. The "high" threshold is identical to the equivalent soft or hard over-temperature setpoints. The "low" threshold is a calculated lower setpoint if the hysteresis option is used.
3. Typical value for type J thermocouple.

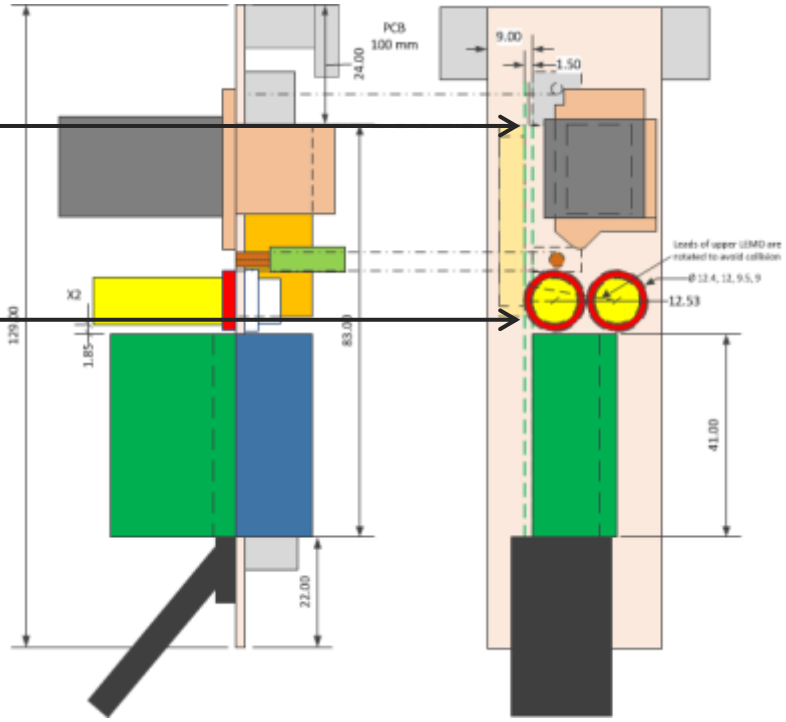
OTHER FEATURES

PARAMETER	CONDITION	PRIOR CONSOLIDATION	AFTER CONSOLIDATION
Short-circuit protection	DC mode	2.2A	4.4A
Short-circuit protection	AC mode	None	Fuse
DC driver over-temperature protection		Yes	Yes
AC driver over-temperature protection		No	Yes
AC mode is rad-tol		No	Yes

Front panel & Diagnostics (hardware)

Existing front panel

Diagnostics connector



New front panel

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