

Operational Experience with the Diamond Magnet Power Converters and Pulsed Power Supplies



Tony Dobbing
Head of Power Supplies Group

Operational Experience with the Diamond Magnet Power Converters and Pulsed Power Supplies

- Design features to maximise power converter availability
- Power converter fault statistics
- Conclusions

Diamond Power Converter Parameters

Type	Number	Current (A)	Voltage (V)	Bandwidth (Hz)
SR Dipole	1	1500	530	DC
Booster Dipole	1	1000	2000	5
Booster Quadrupole	2	200	421	5
Booster Sextupole	2	20	60	5
Medium Power Supplies	437	350/200/100	41/28/17	DC
Slow Corrector Type	544	5	20	50
LTB Quads.	10	20	55	1000*
Pulsed Power Supplies	10	85-15,000	100-23,000	Pulse

* Required for Fast Correctors, which are not fitted.

Diamond Power Converter Design Features to Maximise Availability

- Component Standardisation
- Digital Controller of proven design
- Plug-in modularity to minimise repair time
- Redundancy
- Minimised component count
- Component de-rating and stress analysis
- Highly Accelerated Stress Screening (HASS)
- MTBF Calculations

Diamond Power Converter Features

Component Standardisation

- 1,250 Controller and ADC cards common to all PC's and Pulse Power supplies
- 2,500 Power modules for all medium PC's (two types).
- 544 Inverter and current transducer modules for slow correctors
- 300 PULS 24 V, 20A/10A DC supplies for corrector PC's and control power.

These eight building blocks represent the majority of the components in the power converters.

Diamond Power Converter Features

PSI Digital Controller and ADC Cards

Advantages

- Proven design, working on an accelerator.
- Flexibility – easy to change parameters for different magnets. Change code for different types of power supply.
- Single type of interface to control system, which means easy commissioning, one set of interface software, one set of panels for operators.

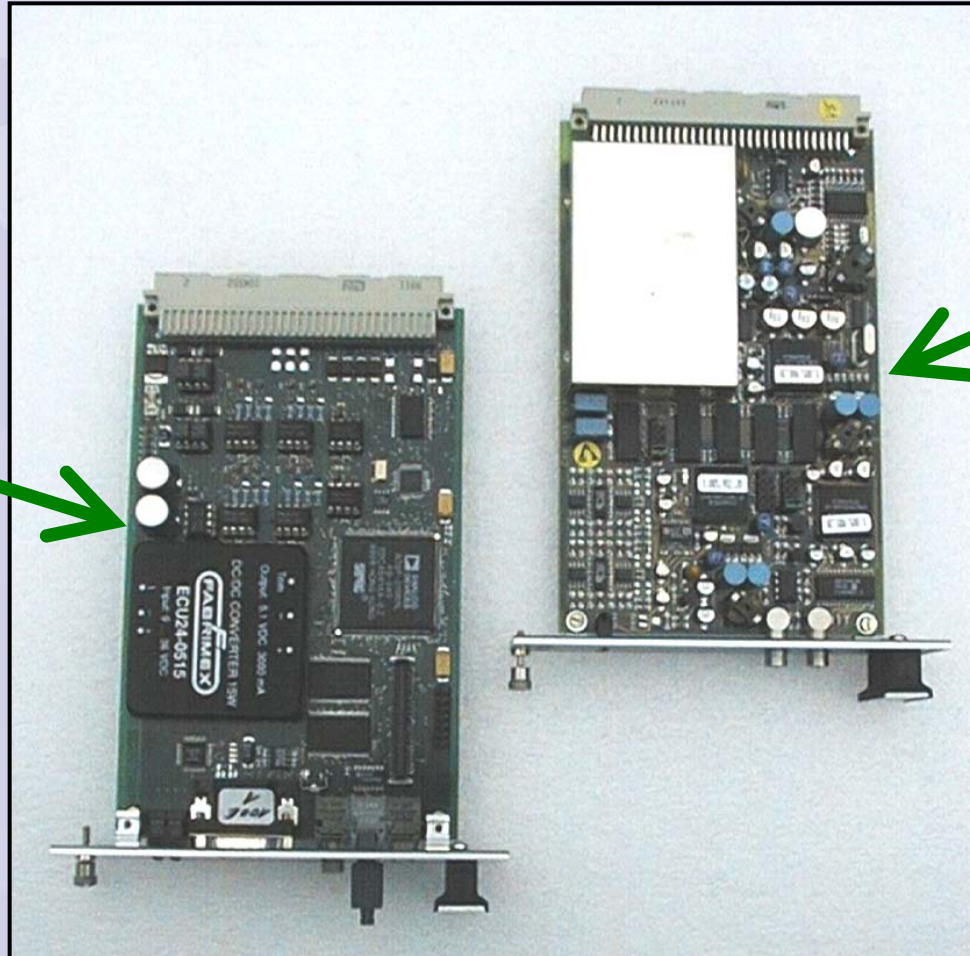
Disadvantages

- Responsibility for performance is not clear when free issued to a power supply manufacturer.
- Modification of someone else's software.

Diamond Power Converter Features

PSI Digital Controller and ADC Cards

DSP Controller
incl. PWM generator



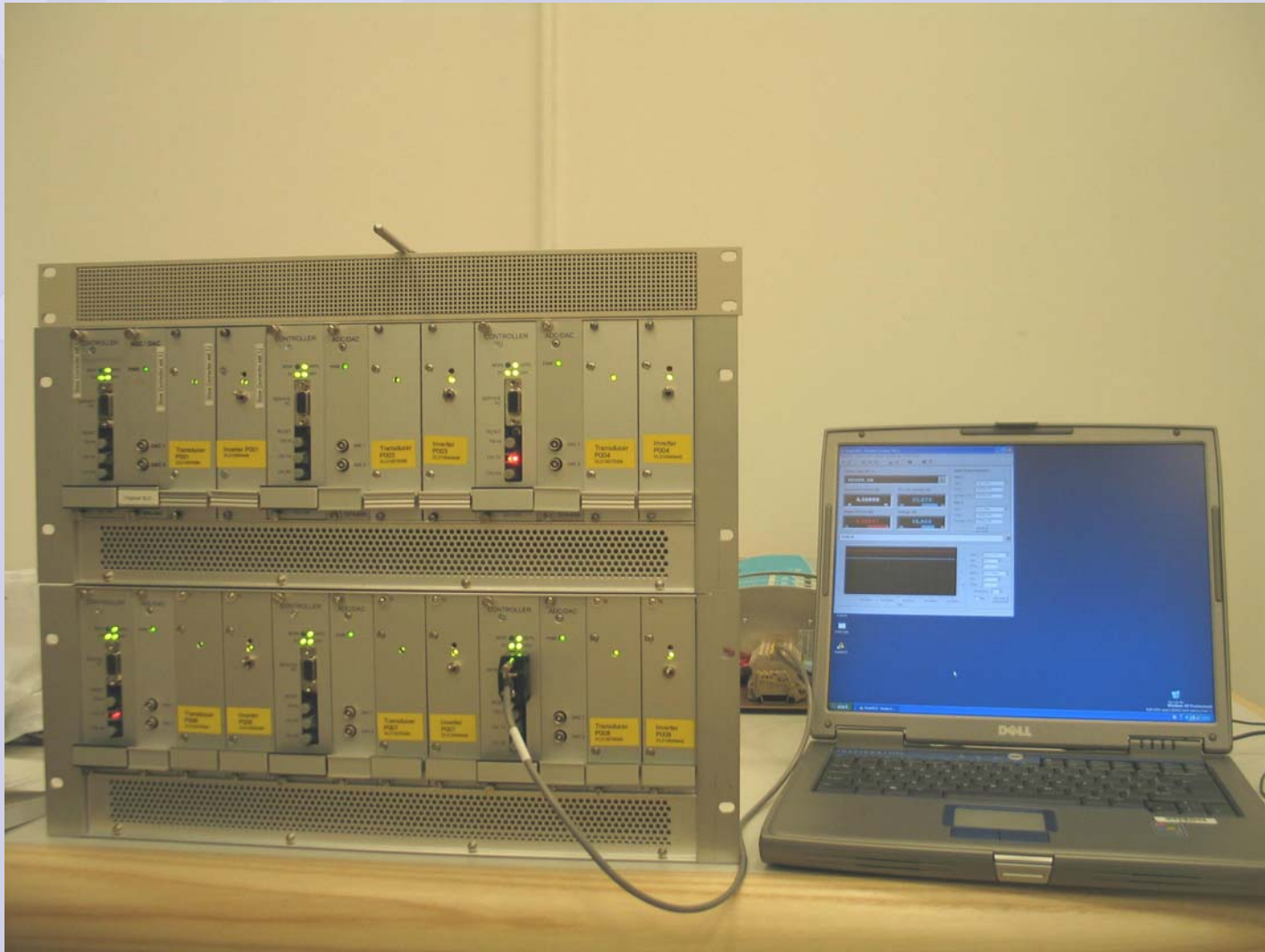
Analog/Digital
Converter

Diamond Power Converter Features

Plug-in Modularity

- Medium PC's built with:-
 - 'Hot swappable' plug-in power modules
 - Plug-in Controller and ADC cards
 - Plug-in fan trays
- Corrector power supplies built with plug-in modules:-
 - Controller card
 - ADC card
 - Current transducer
 - Inverter module
- Large PC
 - Power semi-conductors in open frame plug-in modules
 - Plug-in control cards

Six Slow Corrector PC's Under Test



SR Dipole PC



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Diamond Power Converter Features

Redundancy

Corrector PC's

- Share three parallel connected 24V supplies to feed the inverters, two of which are sufficient to provide full power.
- Share 24V control power using three supplies fed from independent mains feeds, whereas only two are necessary.
- Three fans are provide per sub-rack for cooling, whereas only two are necessary.

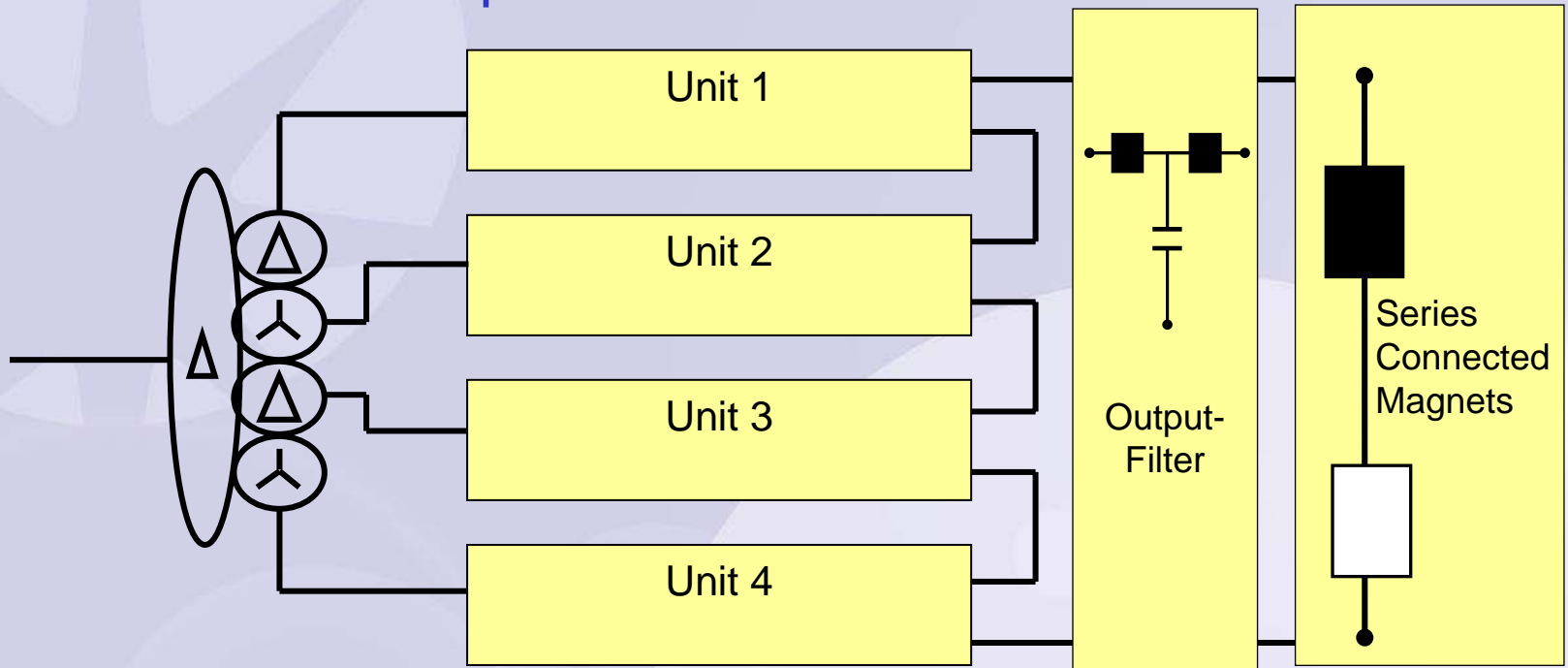
Medium and Large PC's

- Have redundant 24V control power supplies.
- Have redundant power modules.

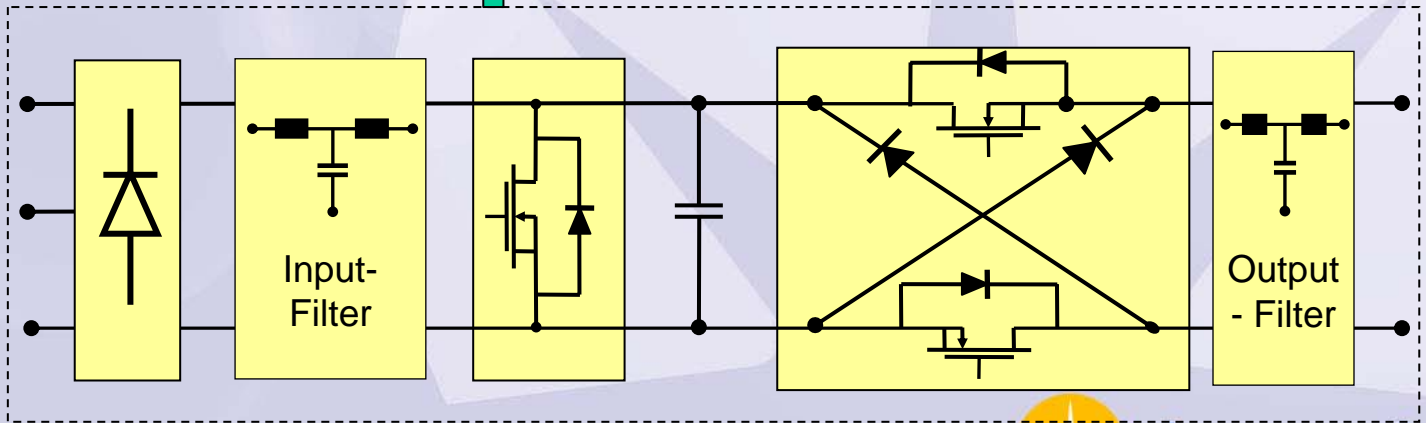
Factory Tests on Linac Medium PC



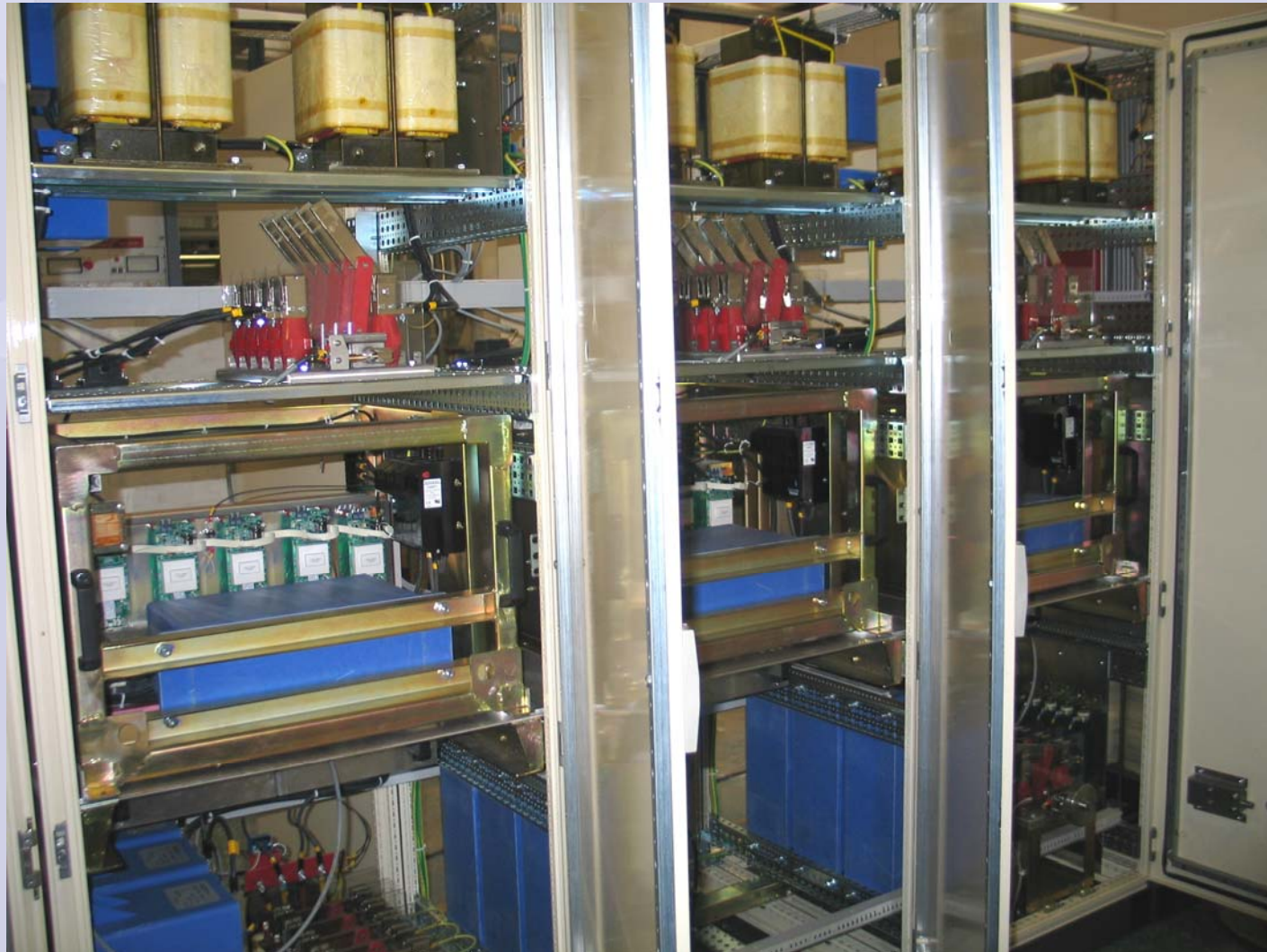
Booster Dipole Power Converter Structure



Unit switching frequency 4 kHz giving 16 kHz at output.



Booster Quadrupole PC's



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Diamond Power Converter Features

Reduced Component Count

All Power Converters

- Local controls are on a laptop that plugs into the controller card.

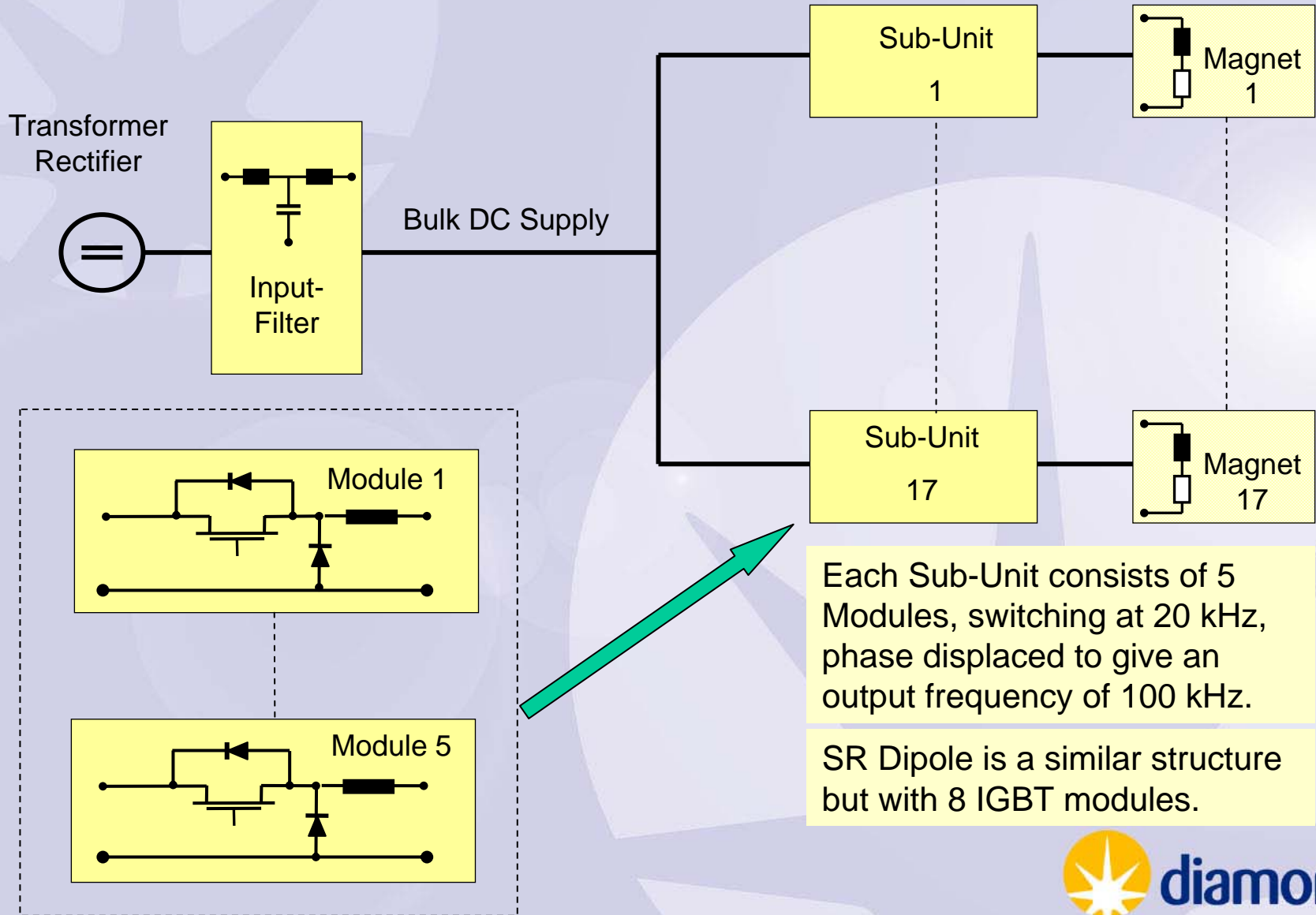
Medium PC's

- Up to 17 supplies have a common DC bus from a common transformer rectifier, reducing the number of transformer rectifiers from 437 to 26.

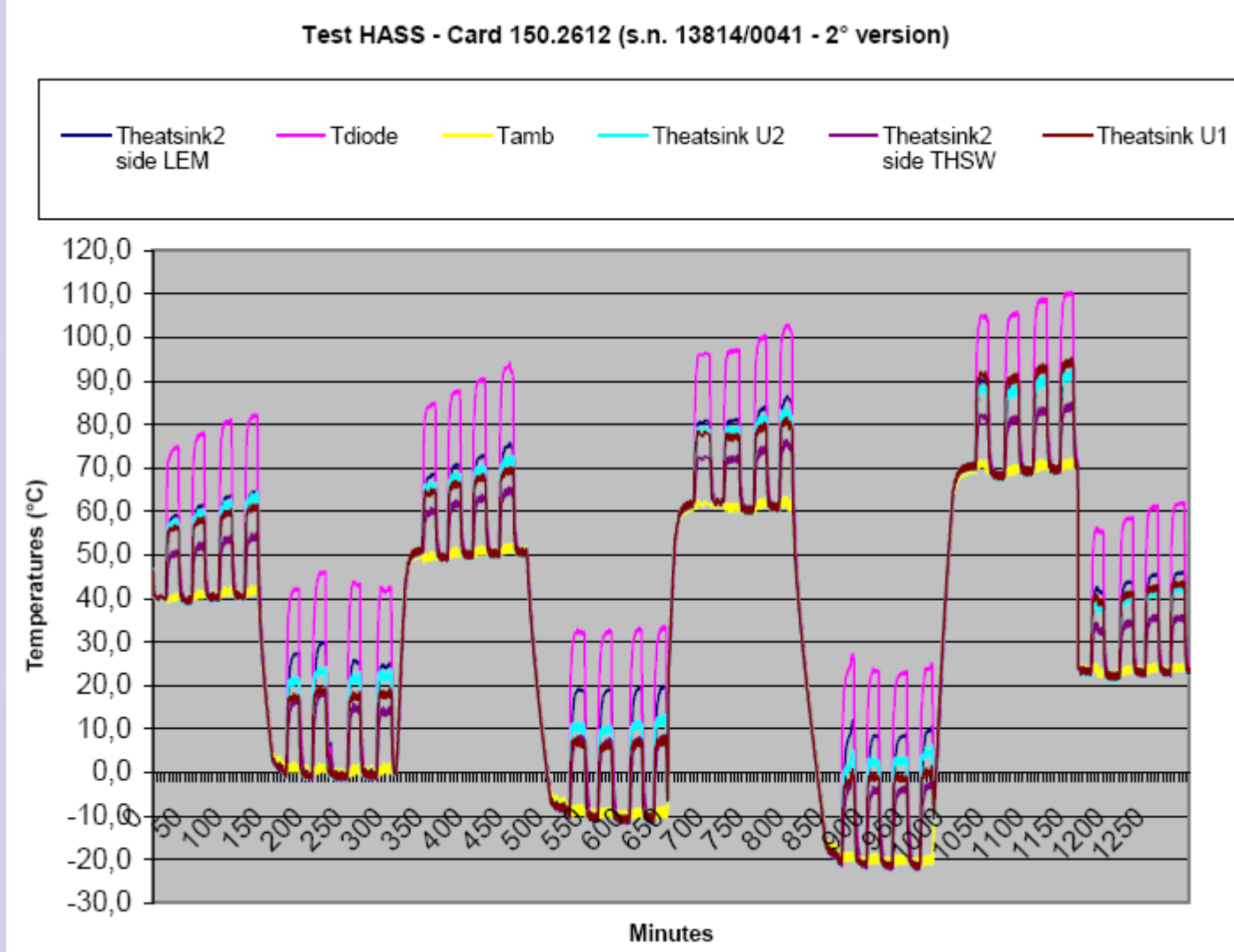
Corrector power supplies

- Up to 18 share three 24V,20A power supplies for the inverters and three 24V,10A power supplies for controls.

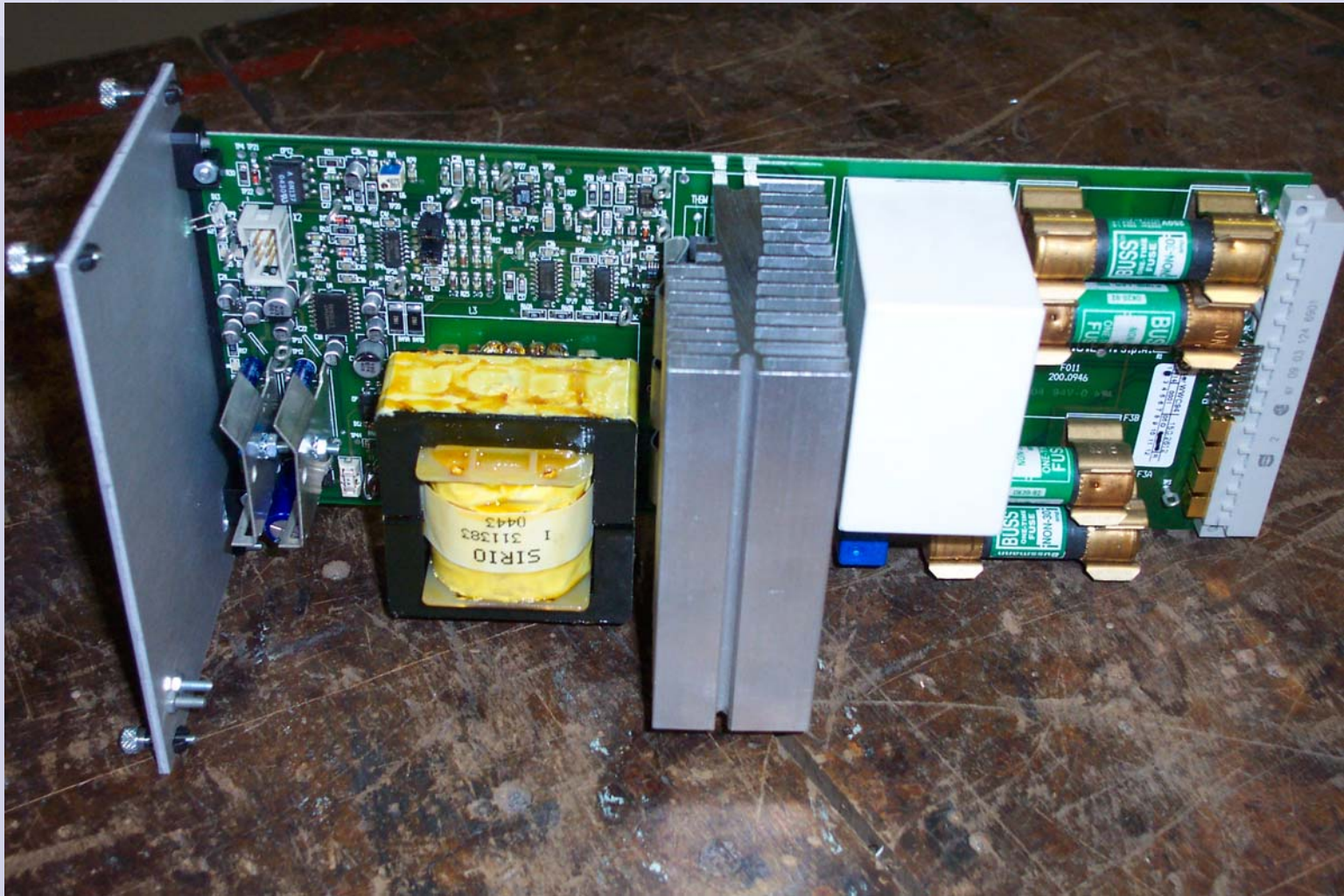
Medium Power Converter Structure



Power Module Highly Accelerated Stress Screening (HASS)



40 A Power Module



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Diamond Power Converter Features

MTBF Calculation

Medium power supply power modules

Using MIL-STD 217 F Notice 2

- Calculated Ground Benign failure rate - 700,000 hours
- Actual failure rate under operating conditions - 4.5 million hours

Difference attributable to power supply operation below rated level.

Diamond Power Converter Features

Component De-Rating

- Pulse Power Supplies power semiconductors voltage rating 3 times operating level due to the radiation environment.
- Generally power semiconductor voltage rating 2-2.4 times operating level.
- Power semiconductor junction temperature below 110°C.
- Electrolytic capacitors avoided where possible and where used ripple current de-rated for a 30 year lifetime.
- De-rating of control electronic components was also specified.

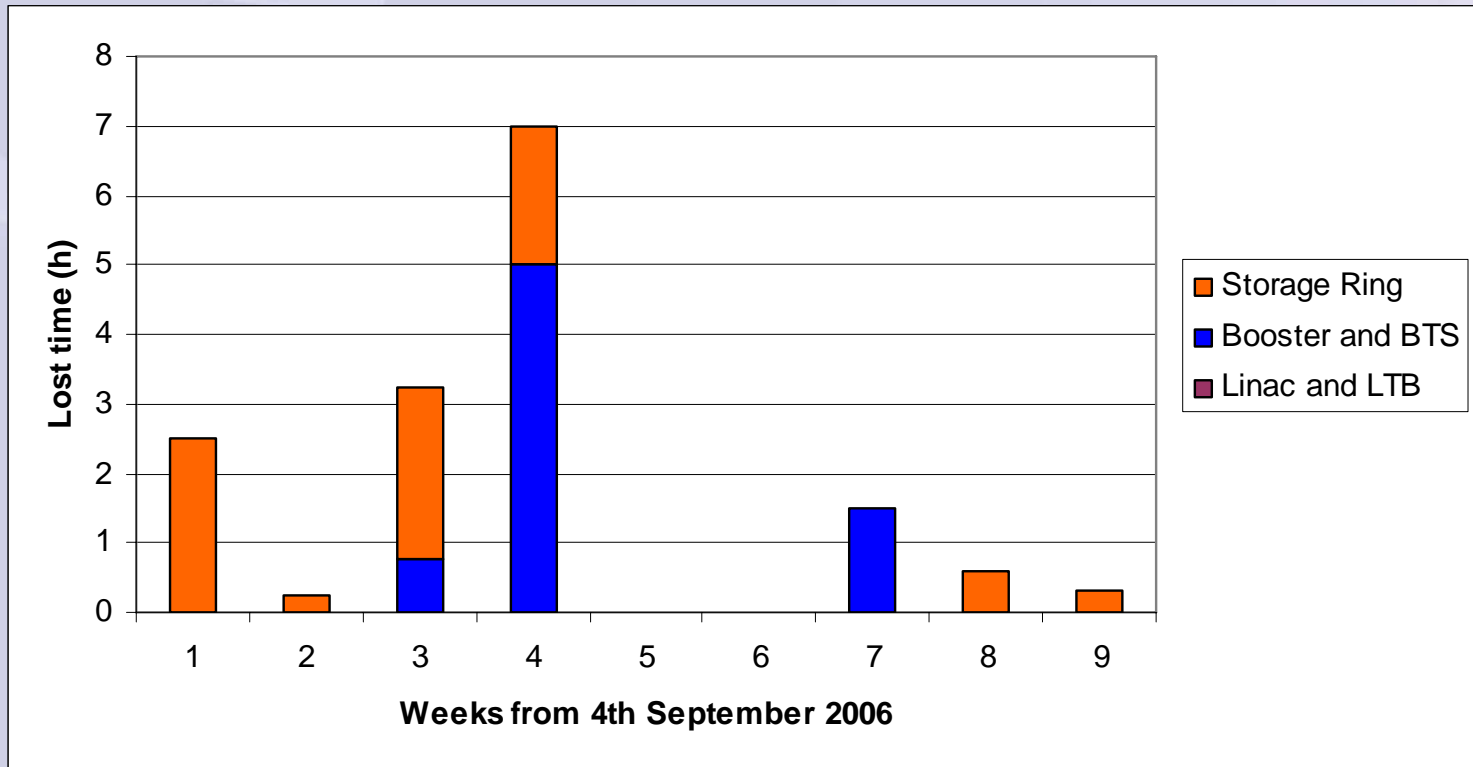
Two Booster Dipole Modules



Diamond Power Converter Fault Statistics

- During Storage Ring Commissioning
- During 1st year of operation (2007)
- During first four months of 2008

Down Time Attributable to Power Converter and Pulsed Power Supplies During Storage Ring Commissioning

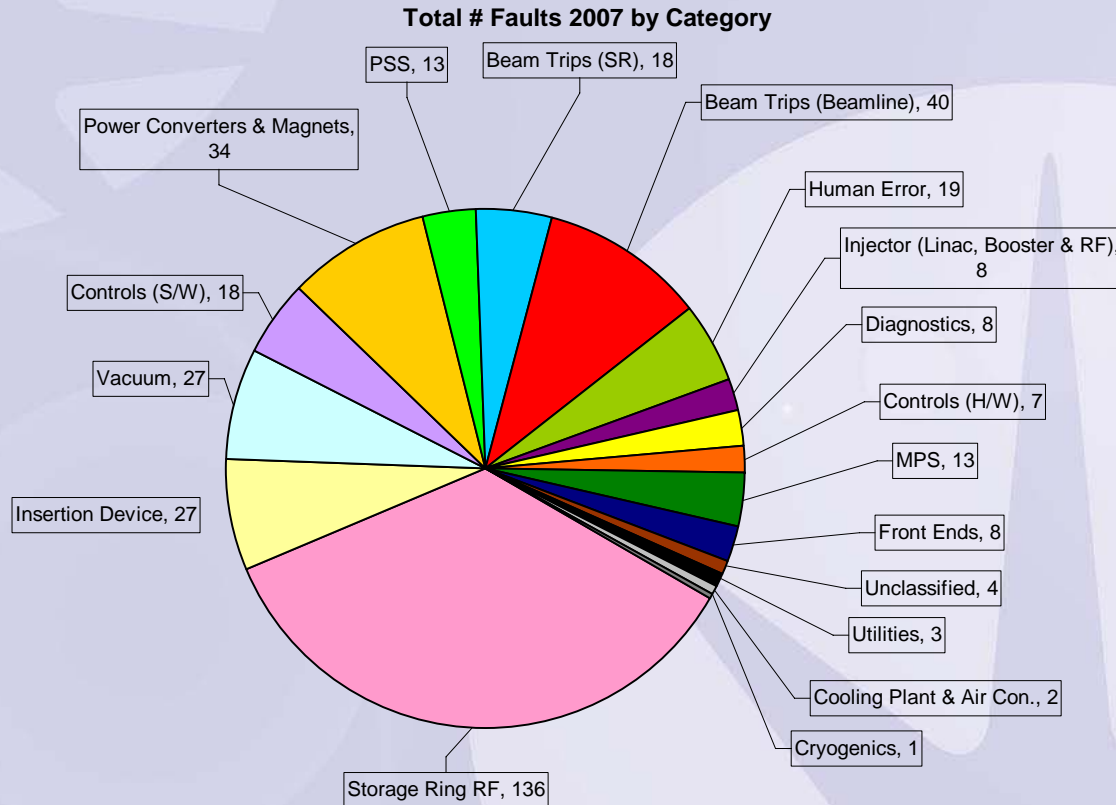


Average lost time over 9 weeks – 1.5%

Power Converter and Pulsed Power Supply Faults During 9 Weeks of Storage Ring Commissioning.

Number of Faults	Power Supply	Comment	Down Time (Hrs)
1	SR Dipole	Parameter set incorrectly	2
6	Medium	Power Module interlock design fault, causing fault on power up – software change required.	2
7	Correctors	Inverter failed – Feedback changed reference too fast.	3.2
1	Medium	ADC failed	0.5
1	Medium	DSP failed	1
16	Total		8.7

Categorisation of Faults Causing Beam Loss During User Mode Operation in 2007



Power Converter and Pulsed Power Supply Faults in User Time: 2007 Runs 1to 10

Number of Faults	Type	Comment	Down Time (Hrs)
5	Misallocated	Trip by external signal, not a fault or Controls fault.	2.4
7	Pulsed Power Supplies	More operating errors than faults.	0.33
6	Intermittent	Suspected poor solder joints. Interlock channels disabled due to high redundancy.	2.63
5	Auxiliary Supplies	PULS 24V PSU batch fault.	6.37
1	DSP/ADC	ADC card fault.	0.57
2	Set Up	Parameter error.	1.92
1	Wiring	Loose connection.	2.75
7	Unrepeatable, Unexplained	Random resettable trips.	2.33
34	Total		19.3

0.62% of User Time Lost to Power Converter Faults (92% overall availability)

Power Converter and Pulsed Power Supply Faults in User Time: 2008 Runs 1to 3

Number of Faults	Type	Comment	Down Time (Hrs)
2	Pulsed Power Supplies	Incorrect start up – controls/operator problem	0.44
1	ADC	ADC card voltage reading became unstable – reset.	0.35
2	DSP	Intermittent fault traced to a dry joint.	1.32
2	Pulsed Power Supplies	Booster Extraction Kicker - intermittent fault	0.27
1	Pulsed Power Supplies	SR Injection Kicker misfired	0.15
8	Total		2.53

Conclusions

- The Diamond power converters were commissioned with relatively little trouble. OCEM, who built the medium and large power converters, have never visited Diamond.
- To date, the power converters are a minor contributor to lost operating time on the machine.
- The trend in availability is improving as repeated faults are addressed and infant mortality decreases.
- The design features built into the power supplies for high availability have been worthwhile, in particular:-
 - Redundancy reduces the number of faults requiring an immediate intervention.
 - Plug-in modularity and operator training to replace modules reduces repair time. It also gives the Power Supplies Team a better nights sleep, with few call-outs!