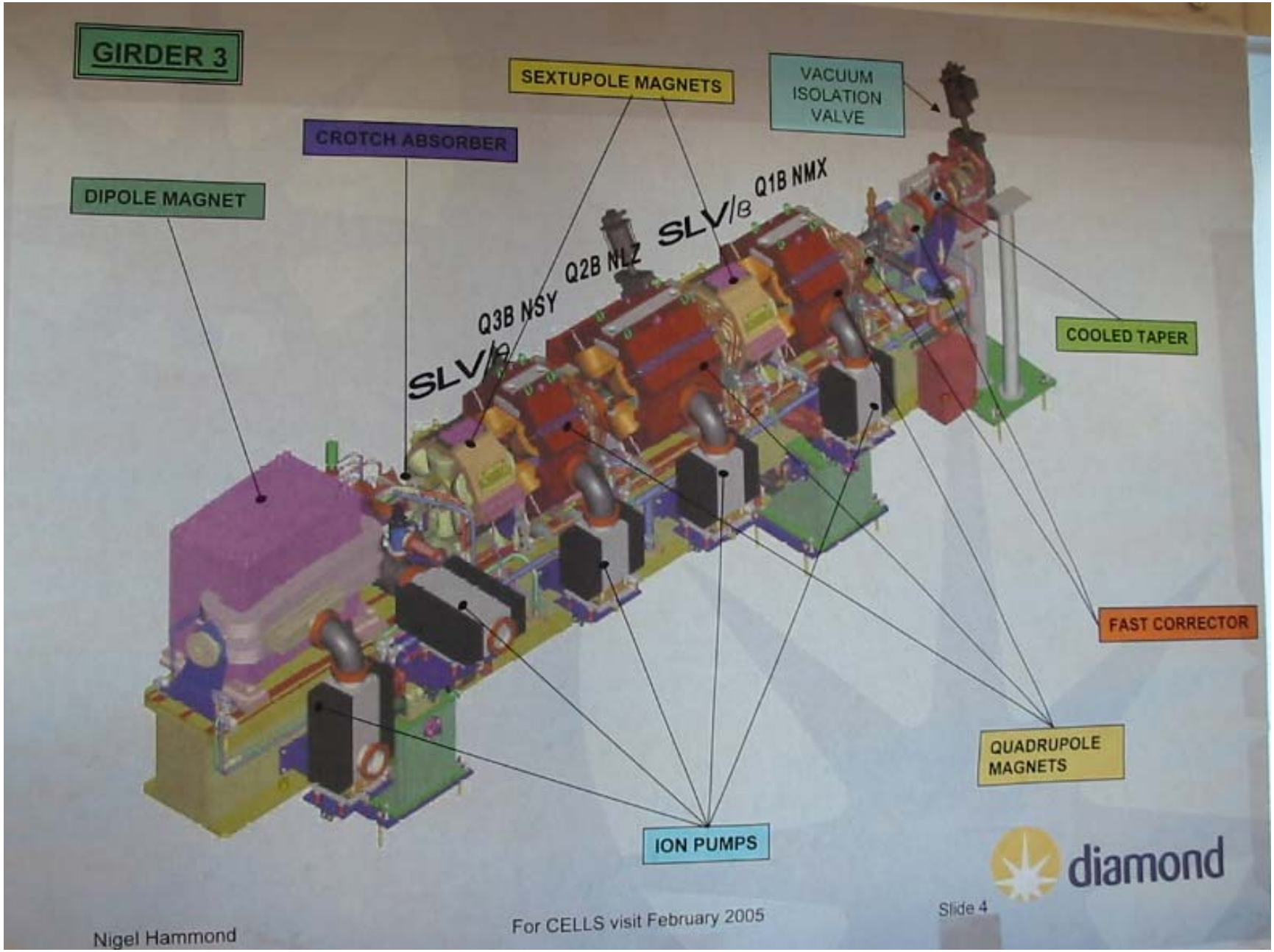
DIAMOND LIGHT SOURCE (DLS)
Didcot, UK

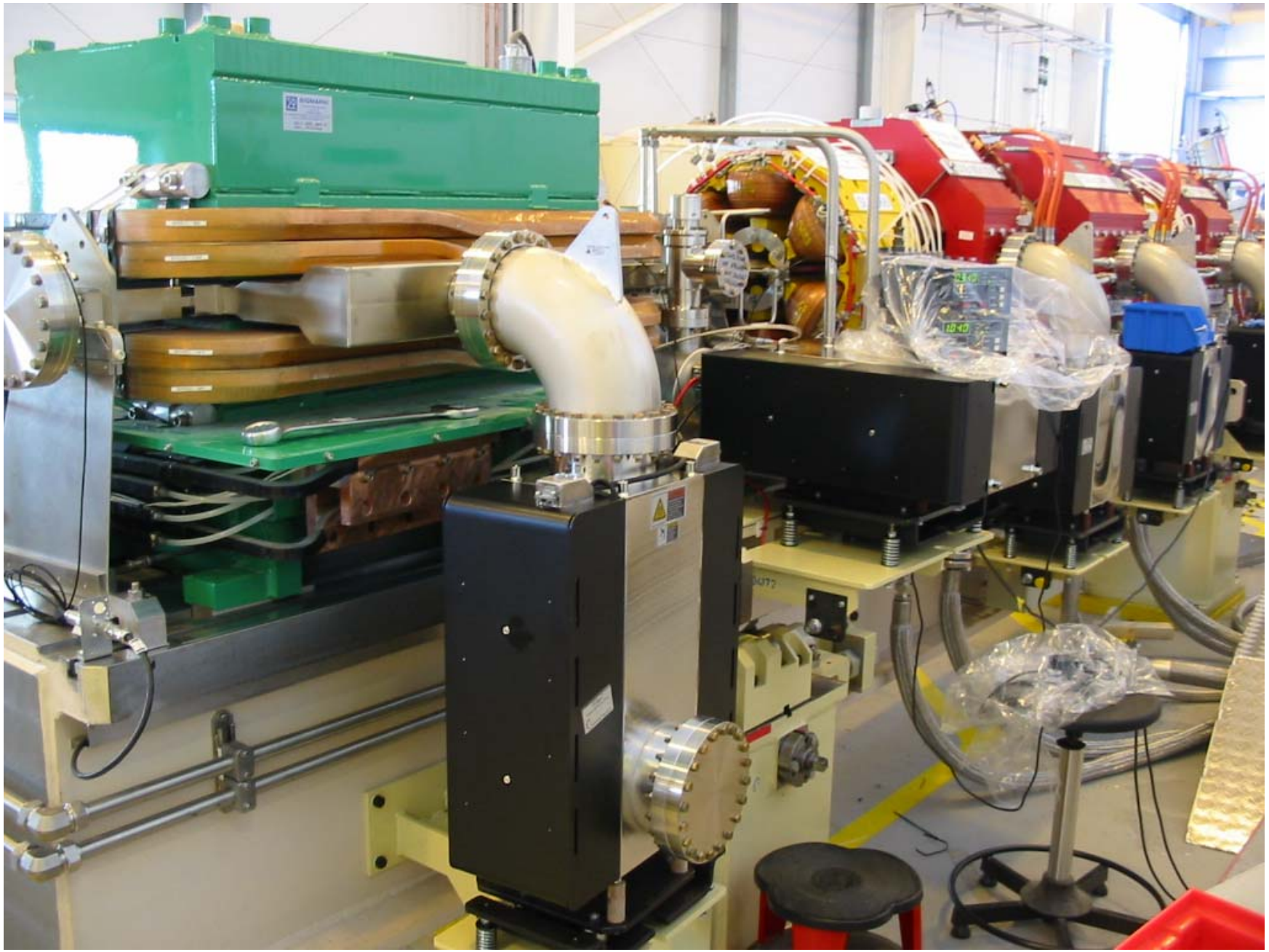
August 17 – 18, 2005

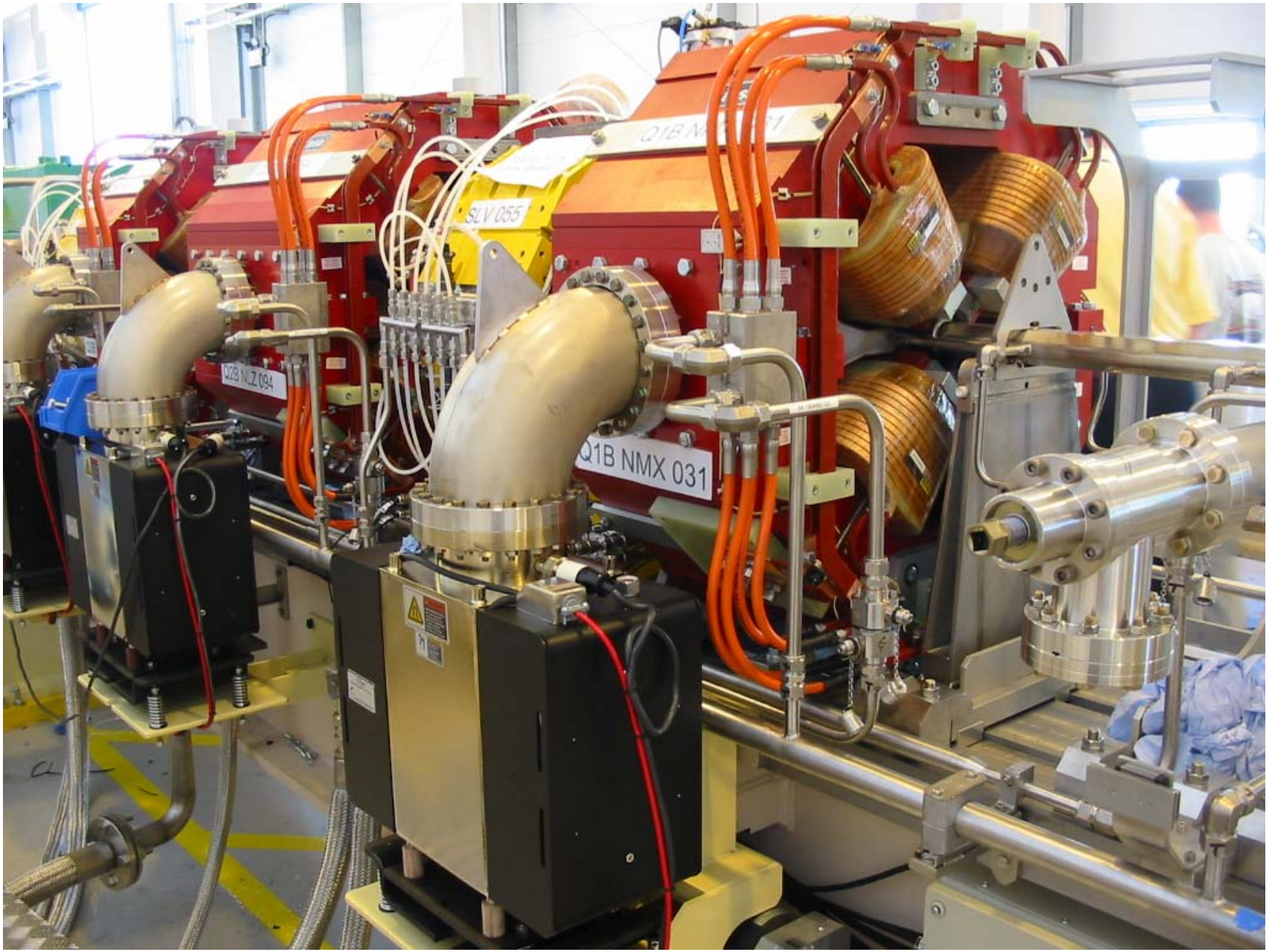
TRIP REPORT

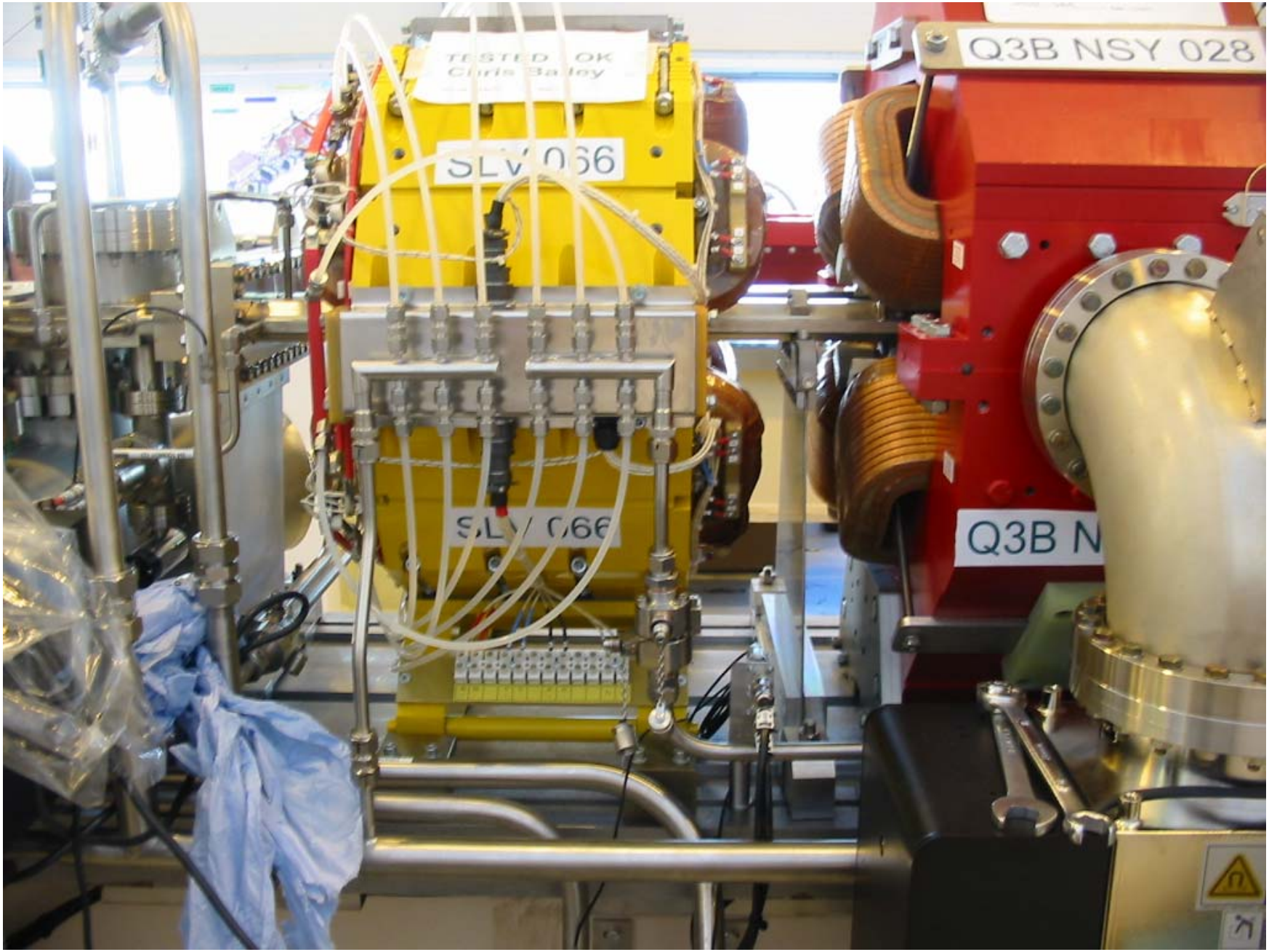
Antonio de Lira & Dave Mac Nair

Controls & Power Electronics Department -SLAC


GIRDER 3
SEXTUPOLE MAGNETS
VACUUM ISOLATION VALVE
CROTCH ABSORBER
DIPOLE MAGNET
Q3B NSY
Q2B NLZ
SLV/B
Q1B NMX
SLV/B
COOLED TAPER
FAST CORRECTOR
QUADRUPOLE MAGNETS
ION PUMPS
diamond
Nigel Hammond
For CELLS visit February 2005
Slide 4




SLV 055
Q1B NMX 031


Q3B NSY 028
Q3B N

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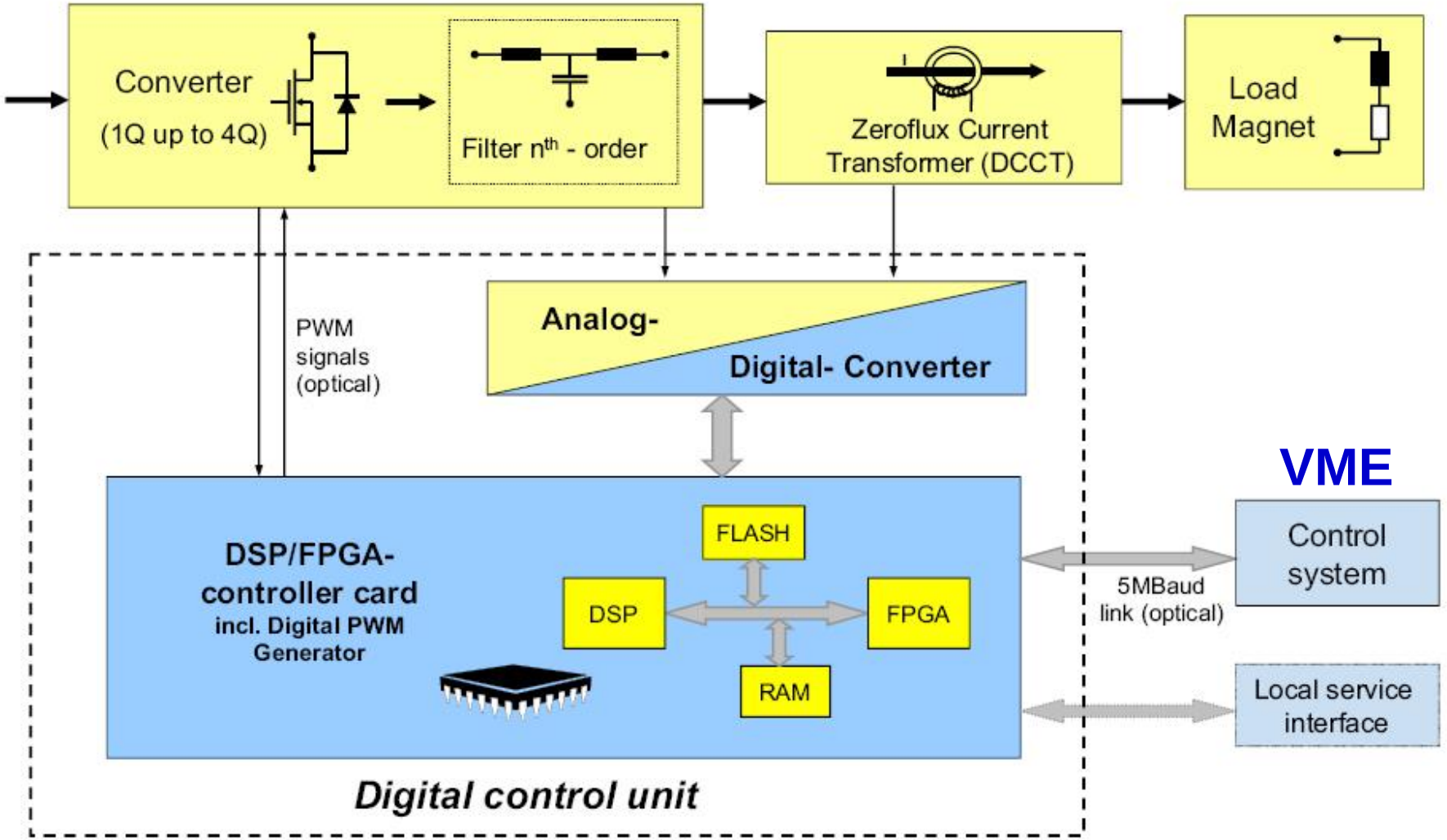
Power-Electronics

Basic hardware control structure for *digital controlled accelerator Power Supplies*



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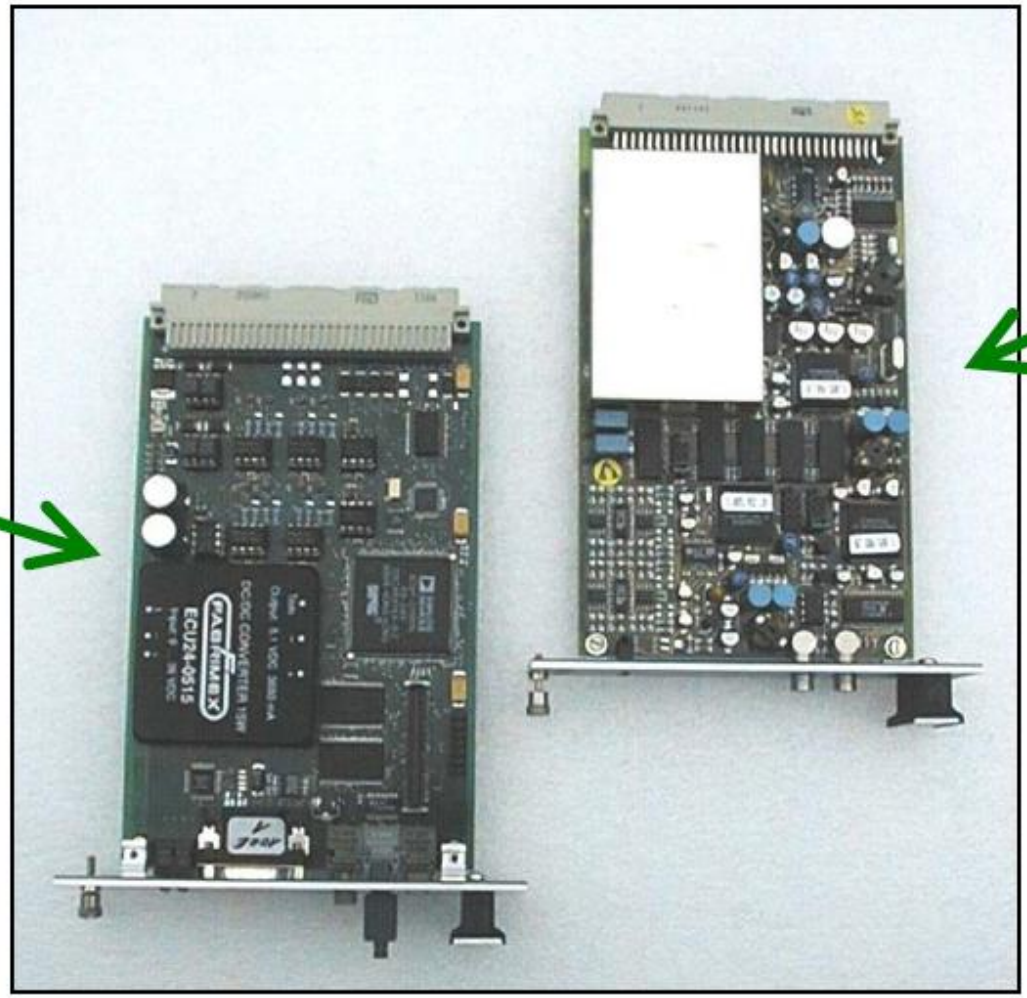
Power-Electronics

Digital control unit



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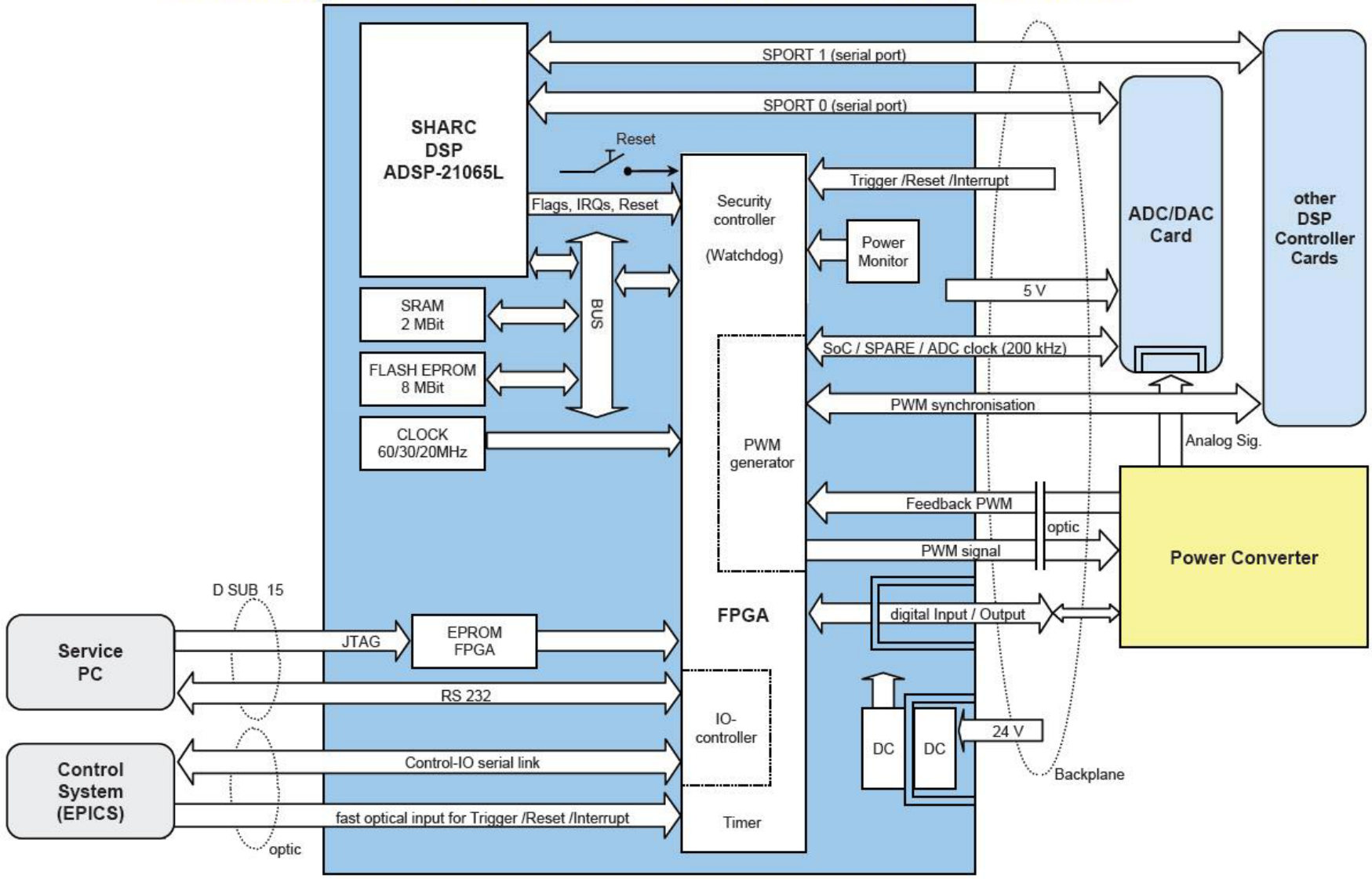
Power-Electronics

Block diagram of Controller Card without software functions



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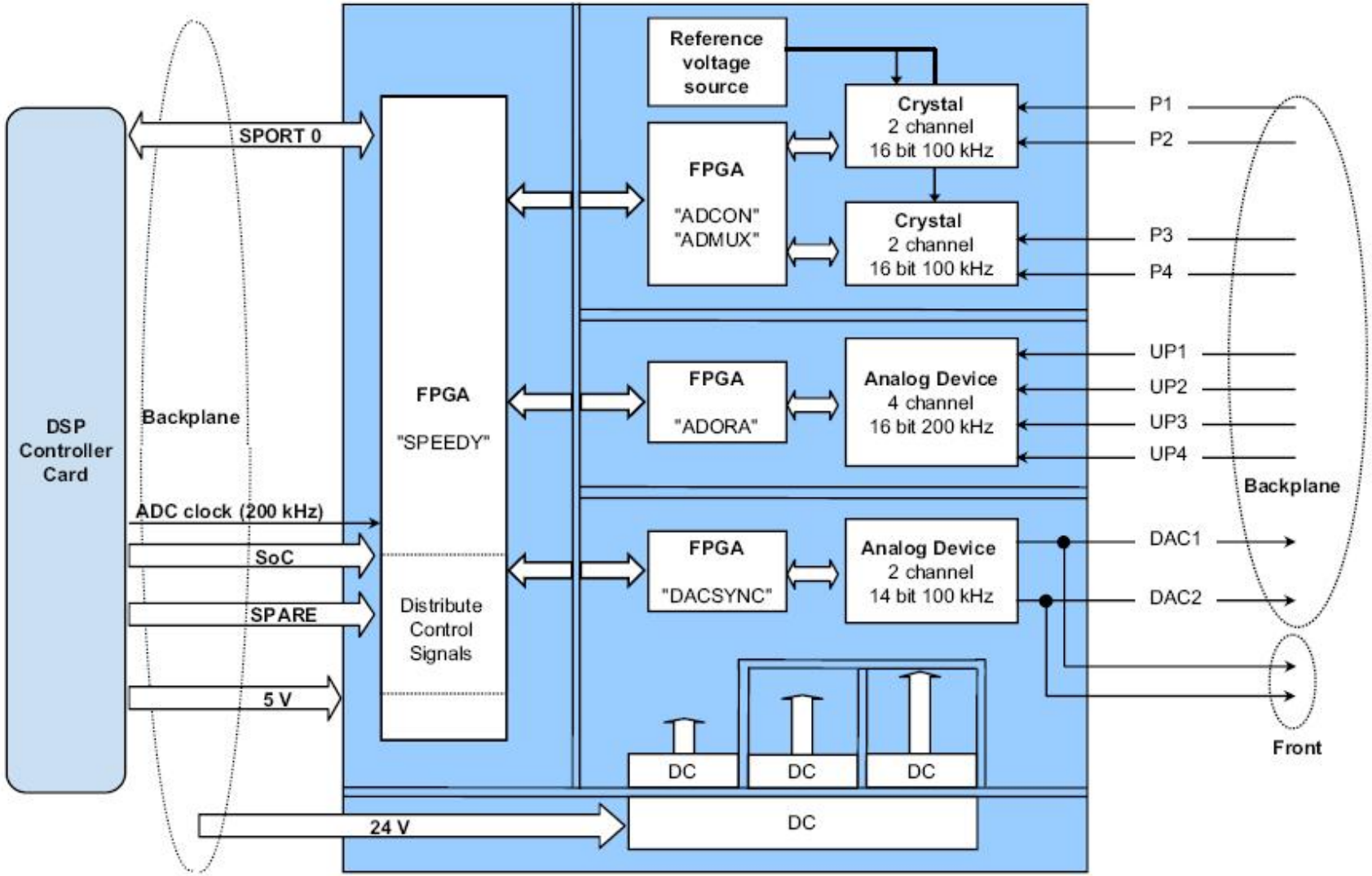
Power-Electronics

Block diagram of AD/DA Converter Card



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21-May-04

So far, Diamond has built:

- 1350 sets of controller cards
- 130 transition boards

Cost estimate:

£ 500 (US$ 900) controller set of 2 cards (DSP + ADC)
£ 250 (US$ 450) license fee (royalties)
£ 25k (US$ 45k) : 1-time license fee

Back planes are not included in the above cost estimate.

Diamond has spent around £ 300,000 (US$ 541k) in license fees to PSI

Advantages:

- Standardization
- Low cost to interface controls

PS configurations:

- 8 different types at DLS
- Controller cards are programmed for each application
  - A register in the controller card identifies the configuration

Examples of PS configurations

- Slow/fast correctors
- Medium PS
- Pulsed magnets
- SR booster
- Booster Dipole

Advantage: interface with control systems remains the same.

Infant mortality failures:

- 1% - “not too bad”, according to Tony Dobbing.

With Austen Rose:

Demonstration of the EPICS controls interface under development

Some details:

- 16 bits are associated with input digital signals
- The controller is also used for the pulsed magnets (no timing function)

Some of the software needed:

- Visual DSP++ version 4.0
- Analog Devices' Flexlink
- Visual ECS

DSP cards handle the interlocks.

There is no PPS associated to the PS.

Magnets are covered.

Qualifications needed to work with controller cards:

- C
- VHDL (Altera) for the FPGA's

Note: PSI offers a 2-day course as part of the initial license.

- Not enough
- Hands-on training needed

Notes:

1. DLS will be able to sub-license the PSI controller.

2. DLS is unable to provide much support right now.

3. Requisitions for controllers from DLS will be analyzed by DLS' upper management.

Presentation on the PS for DLS by Tony Dobbing

Highlights:

- Redundancy all over the spectrum of PS
- 2500 power modules procured from OCEM
- DLS does not intend to hot-swap OCEM modules
- OCEM modules were “cooked”
  No failures reported. “They will try harder”.
- Availability not yet set.
- Correctors 10 ppm.
- GND Fault Detection is done on the bulk PS only.

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
Fast Corrector Type	224	16.5	55	1000

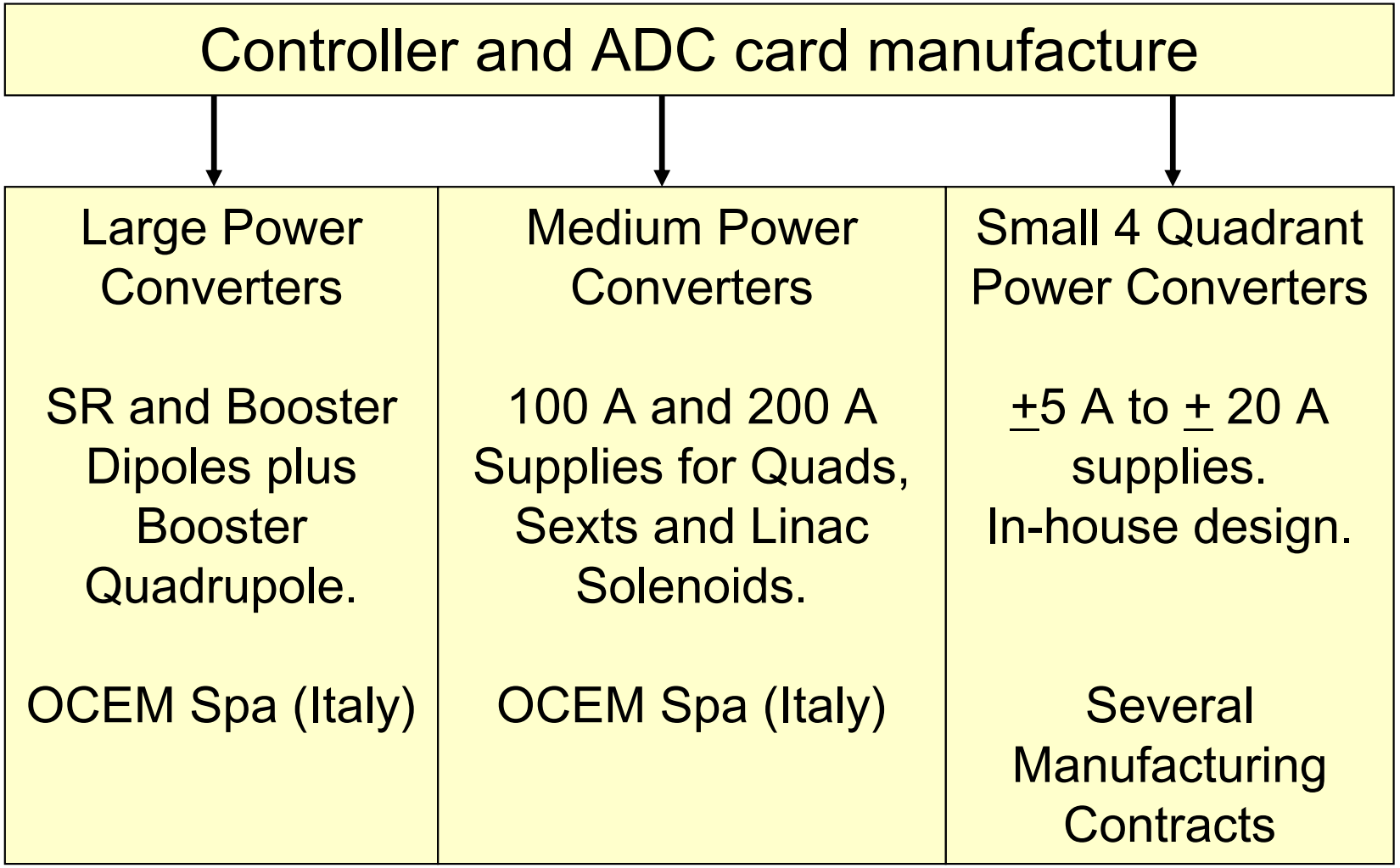
J A Dobbing March 2005

diamond

Diamond Power Converter Requirements

- Operational life of 30 years
- Modular architecture with:
  a) Trade-off: an N+1 redundancy vs. low component count.
  b) Identification of failed modules through Control System
  c) 'Hot Swap' replacement of failed modules

The Power Converter Procurement Contracts



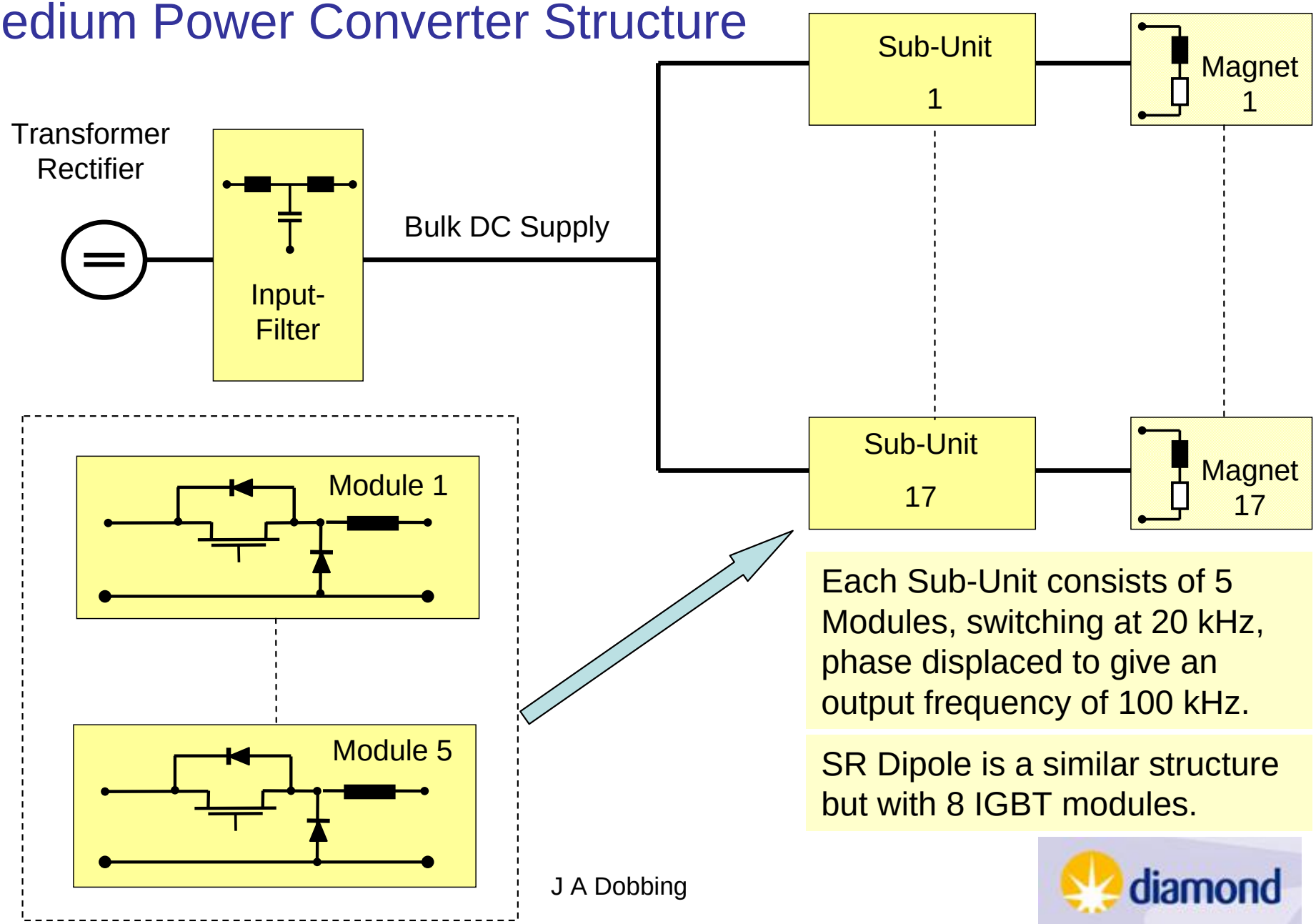
Diamond Power Converter Costs

"The total cost of the 3 large power supply contract was around EURO 500,000" (US$ 617k)

"The total cost for the medium supplies (100A/200A/350A) contract was around EURO 1,500,000" (US$ 1.85M)

DLS "free-issued the controller cards"

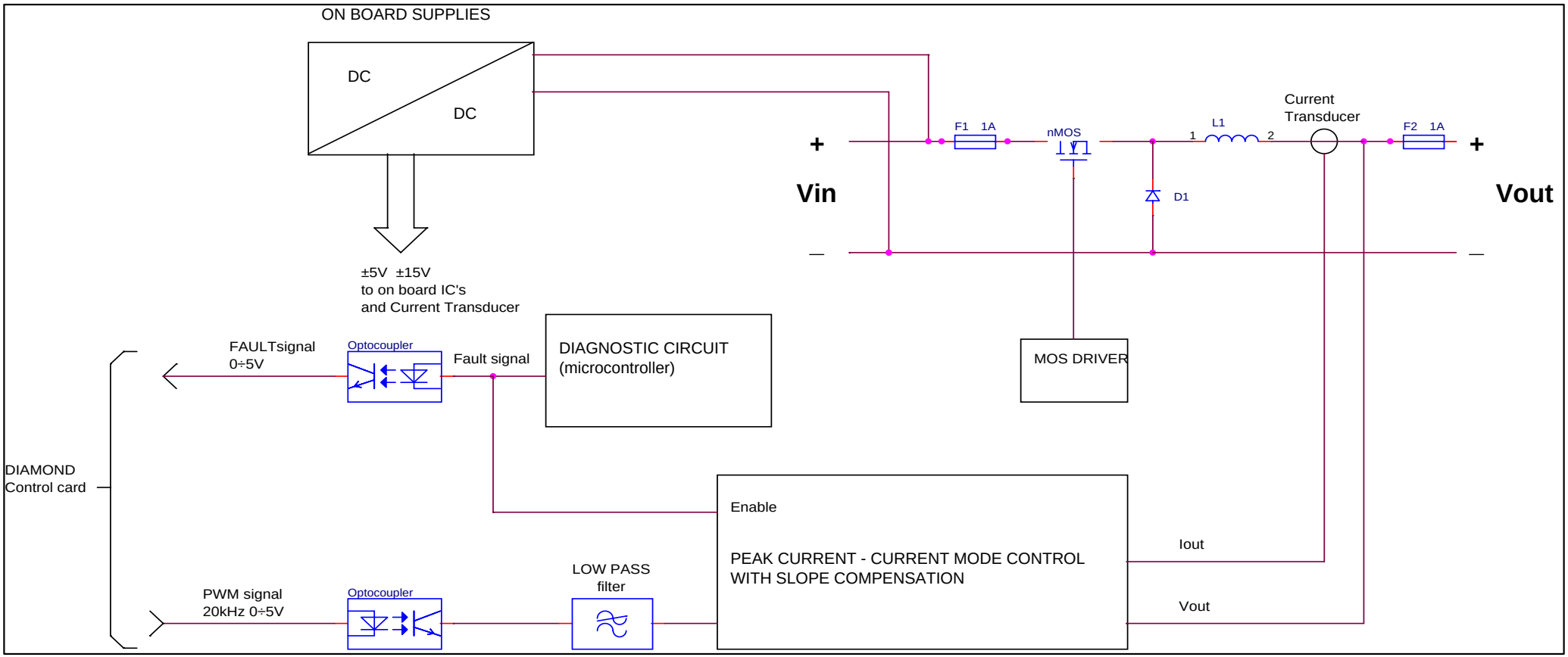
Medium Power Converter Structure

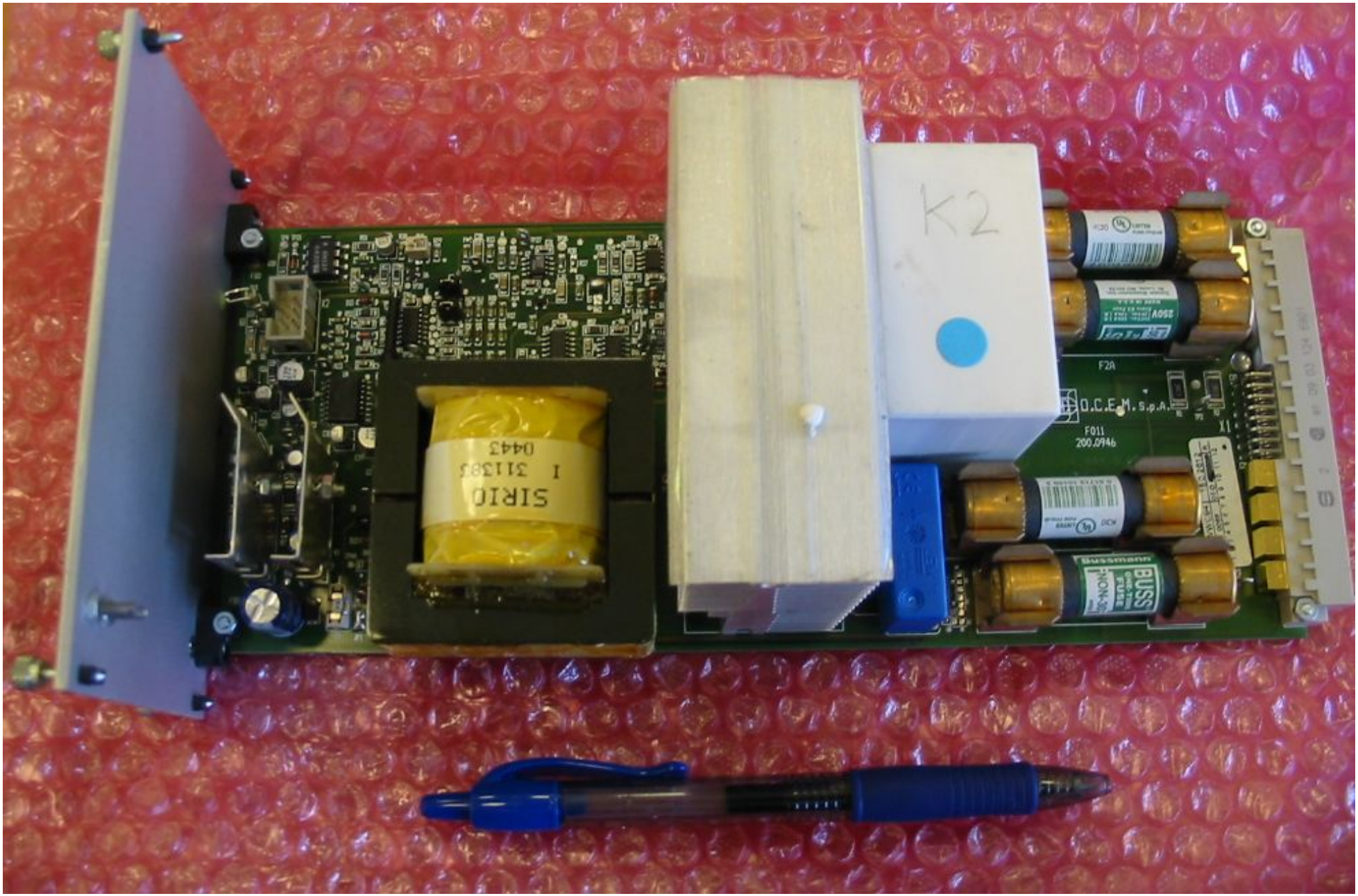


Each Sub-Unit consists of 5 Modules, switching at 20 kHz, phase displaced to give an output frequency of 100 kHz.

SR Dipole is a similar structure but with 8 IGBT modules.

J A Dobbing


ON BOARD SUPPLIES
DC
DC
±5V ±15V
to on board IC's
and Current Transducer
+
Vin
—
F1 1A
nMOS
L1
1
2
Current
Transducer
F2 1A
+
Vout
—
D1
MOS DRIVER
FAULTsignal
0÷5V
Optocoupler
Fault signal
DIAGNOSTIC CIRCUIT
(microcontroller)
DIAMOND
Control card
Enable
PEAK CURRENT - CURRENT MODE CONTROL
WITH SLOPE COMPENSATION
Iout
Vout
LOW PASS
filter
PWM signal
20kHz 0÷5V
Optocoupler


K2
F2A
O.C.E.M.s.p.A.
F011
200.0946
SIRIO
0443
Bussmann
BUSS

Costs:

- US$ 315 / module
  (on a production of 2040)

- US$ 408 / backplane (200A)
  (on a production of 408)

Visit to the Synchrotron building

Safety requirements:

- Safety shoes
- Visible clothes
- Hard hat

Locations visited:

- LINAC & Booster
- Injector PS room
- Storage ring

by Patrick Krejcik

by Patrick Krejcik

In the PS room:

- Medium PS from OCEM, mounted in racks
  - 17 PS / per bulk PS
  - Bulk PS has capacity for 18 medium PS

- Bulk PS characteristics:
  - o 3 x 400Vac ±10%
  - o 58kVA 50Hz
  - o Output: 15 x 200A 0-16V, 2 x 100A 0-9.6V


WARNING!

Potential problems detected:

- o Fiber optics on the front of the rack
- o Fiber optics can present problems
  (they are similar to the ones used in our chopper modules)

- No fuses on bus capacitors: 3 x 350,000µF
  connected to the output of the bulk PS.

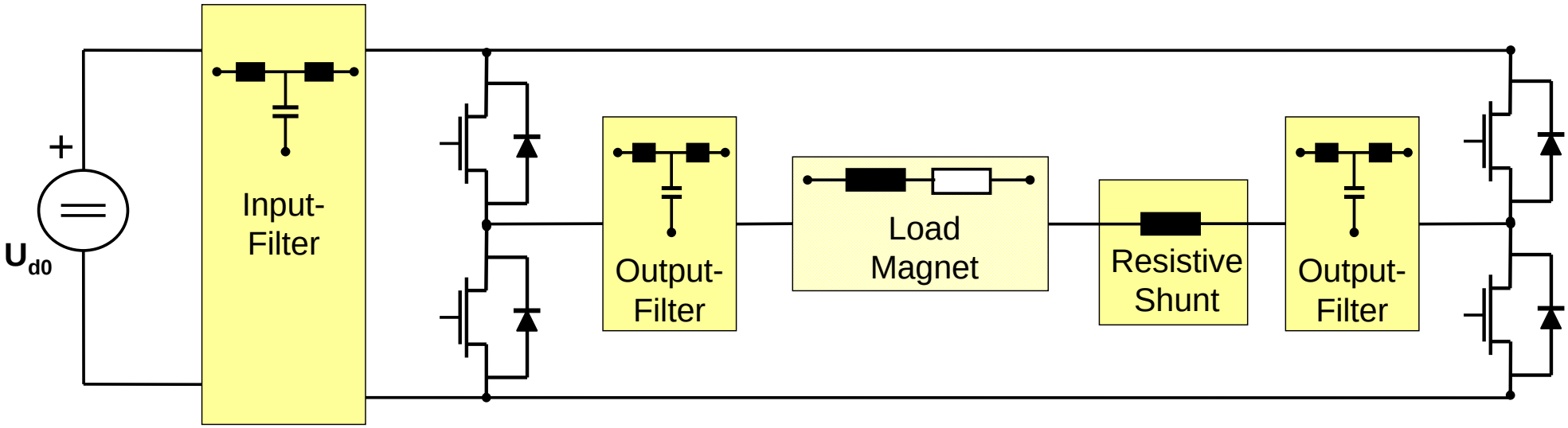
Wed, Aug 17, 2005 - 9:00 AM

Slow and Fast Corrector PS at DLS:

DLS went to a new design for their correctors:

- o Plug-in design
- o Redundancy on the bulk PS
- o Compactness
  - o 3 corrector PS / crate instead on 1 in PSI's design.

Fast and Slow Corrector Power Converter Structure



Switching frequency 100kHz.

Corrector PS at DLS with Mr. Bob Rushton

Corrector PS main features:

- Modules can be hot-swappable
- A bulk 24VDC bus provides DC power
- The H-bridge inverter runs at 100kHz
- Modules are 5A / 20V
- ADC cards have isolated (floating) inputs
- 0 – 5VDC on the transducer (shunt) card
- Overtemperature detector
- Designed for a 5A max due to thermal constraints

Corrector PS at DLS with Bob Rushton

Corrector PS configuration:

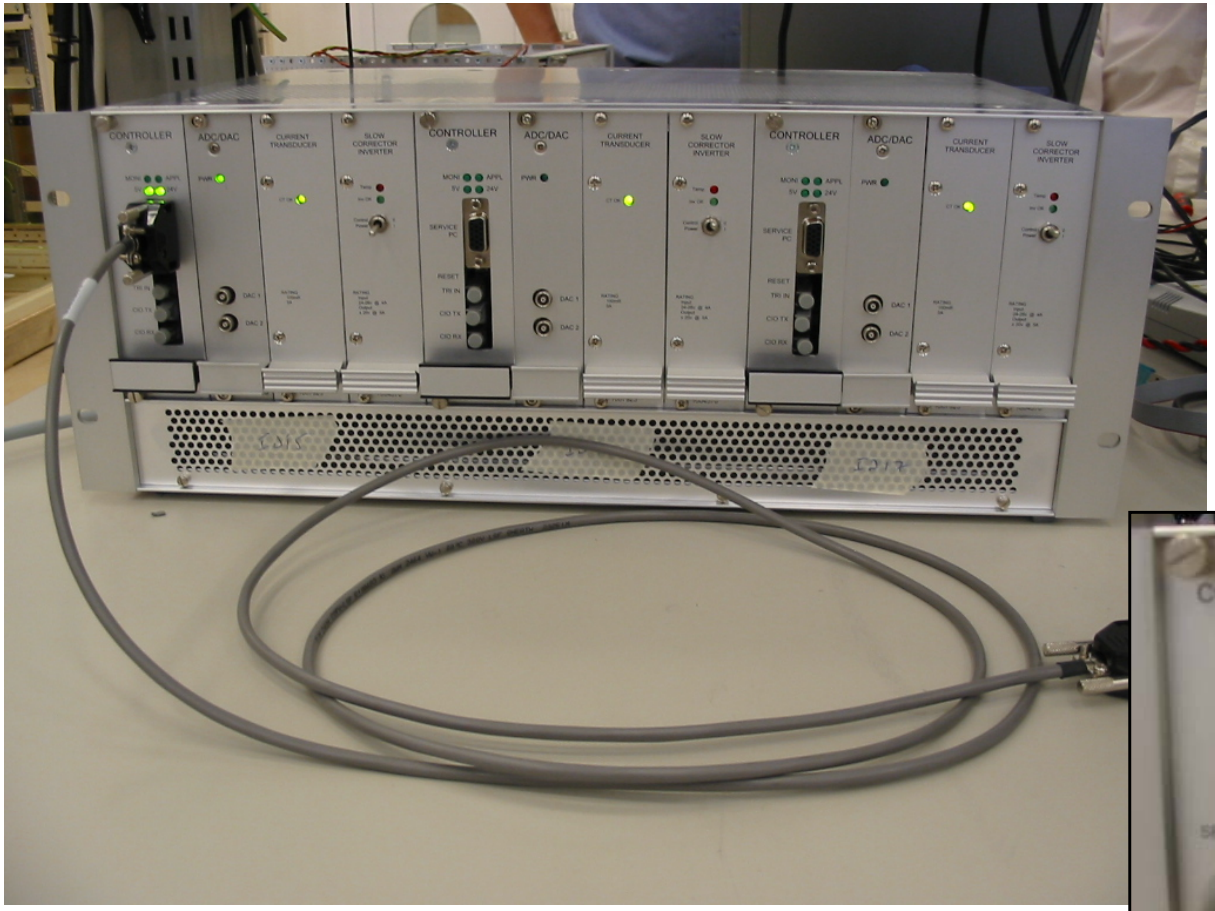
- 18 channels / bulk PS
- The bulk PS has a 2 over 3 redundancy scheme
- Extra capacitors are added to limit the overvoltage
- No ground fault protection
- The bulk PS are on all the time

Notes:

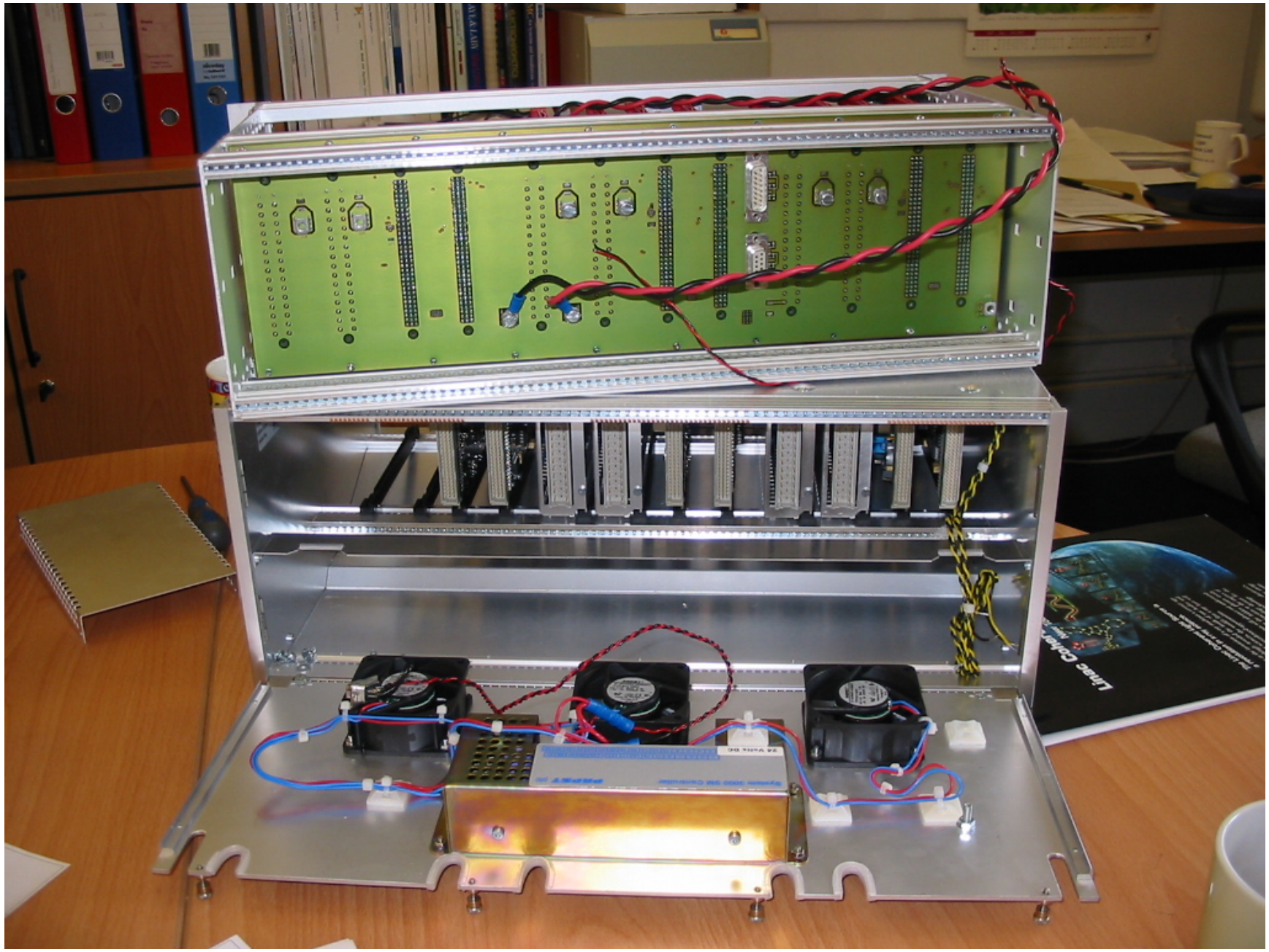
- Fans and electrolytic capacitors are the weakest link

Additional characteristics:

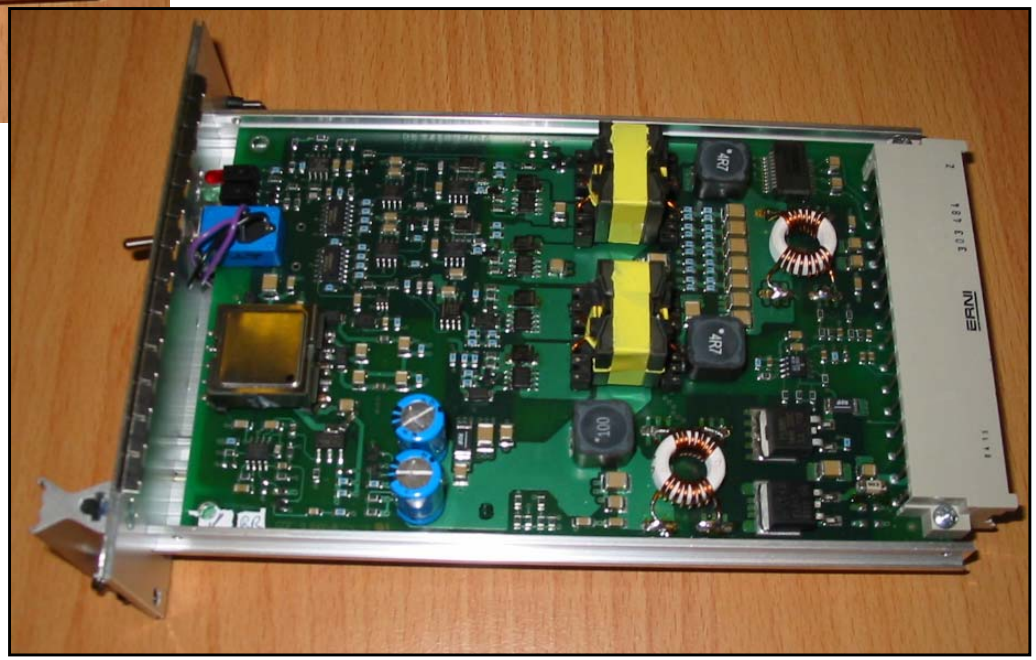
- No temperature control on the Transducer card
- Overall stability:
  - Shunt: 2 ppm
  - Shunt amplifier: 5 ppm
- Shunts by POWERTRON
- Total height: 4U
- Typical load
  - 400mH / 4A for the slow correctors


CONTROLLER
ADC/DAC
CURRENT TRANSDUCER
SLOW CORRECTOR INVERTER


CONTROLLER
ADC/DAC
CURRENT TRANSDUCER
SLOW CORRECTOR INVERTER
MON
APPL
5V
24V
PWR
CT OK
Temp
Inv OK
TRI IN
CIO TX
CIO RX
DAC 1
DAC 2




R100B S5
POWERTRON
USR 4-4020 D
TX 1
DLS/1007B38
ISS 1.0
ERNI


ERNI

by Patrick Krejcik

Costs to DLS:

- Inverter + Transducer: £ 150 (US$ 270) for 550 sets
- Back-plane: £ 75 (US$ 135)
- Fully assembled crate: £ 250 (US$ 451)
- Per channel:
  - £ 700 + £ 150 + 1/3 (back-plane + crate)
    ≈ £ 1000 (US$ 1800)

Fast Corrector Inverter

Main Features:

- Bulk PS bus: 24 VDC
- Booster section to 72 VDC
- ±16.5A / 55V (900 W peak)
- 200W max. input power
- 500 Hz bandwidth
- 4 shunt resistors used for current measurement
  - o 1 ADC/shunt
  - o same shunt as for the slow correctors

Fast Corrector Inverter

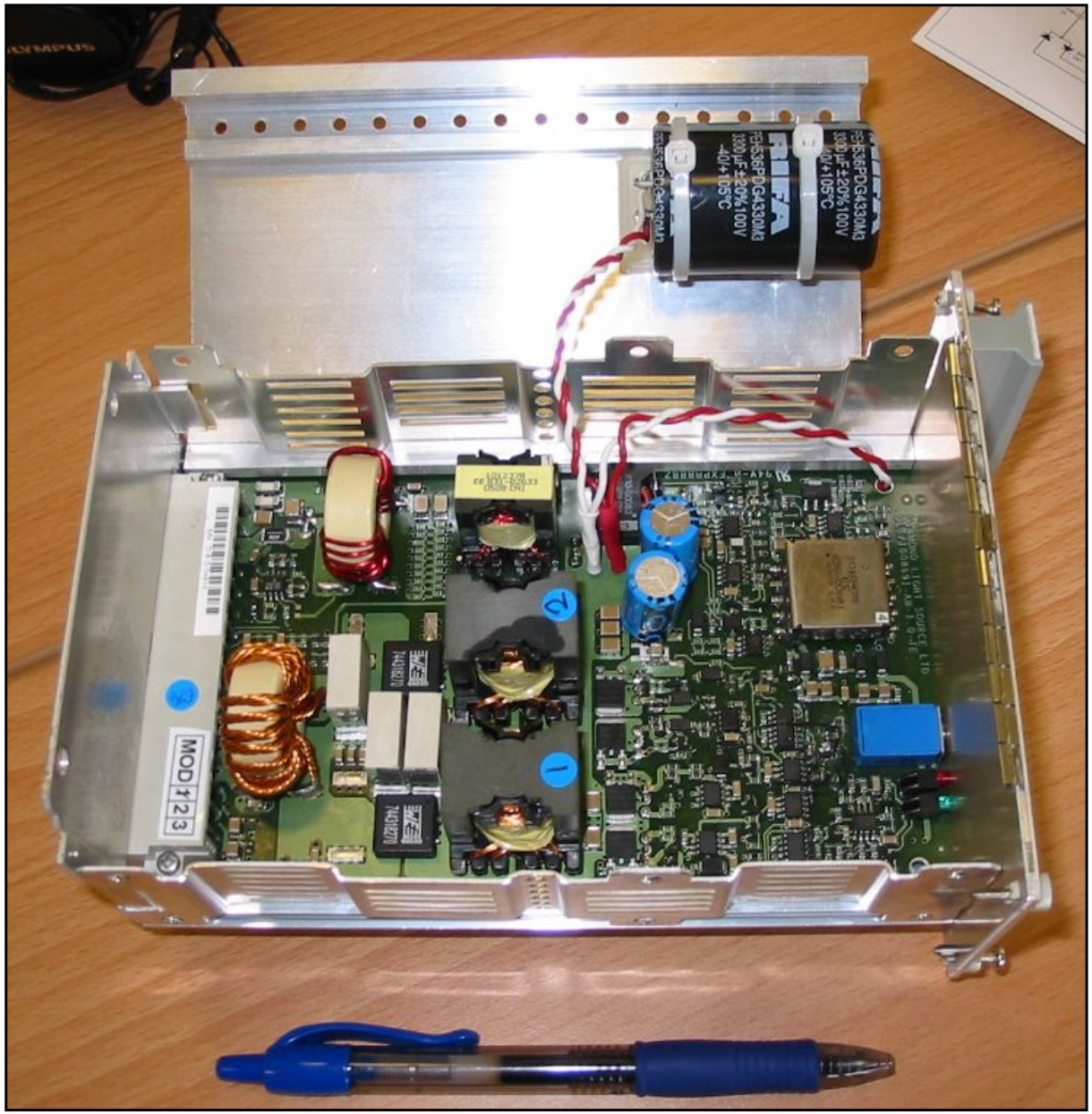
Designed in Diamond

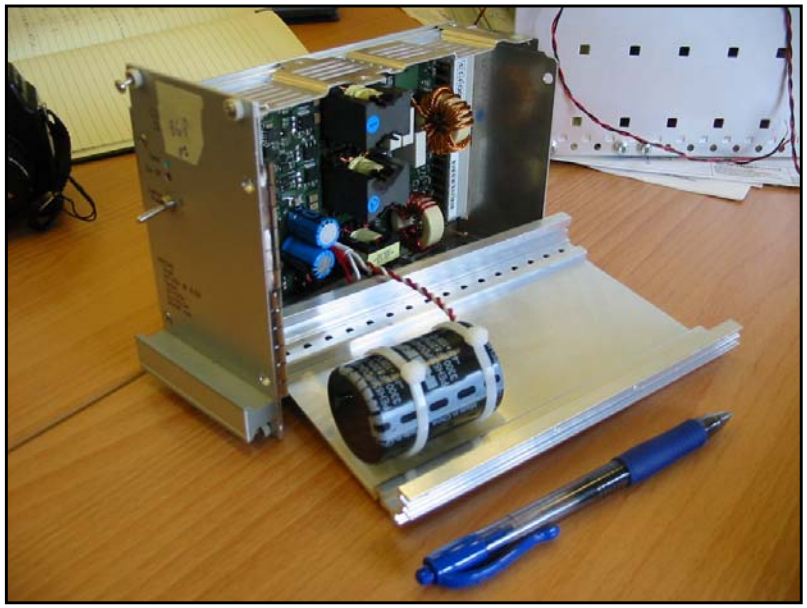
- PCB design + fabrication subcontracted

Note: ADC + Transducer card are matched

- They have to be swapped together

- Slew rate to the reference is limited in the DSP card.


MOD 1 2 3



With Mr. Colin Abraham

Exercise on the operating Visual ECS

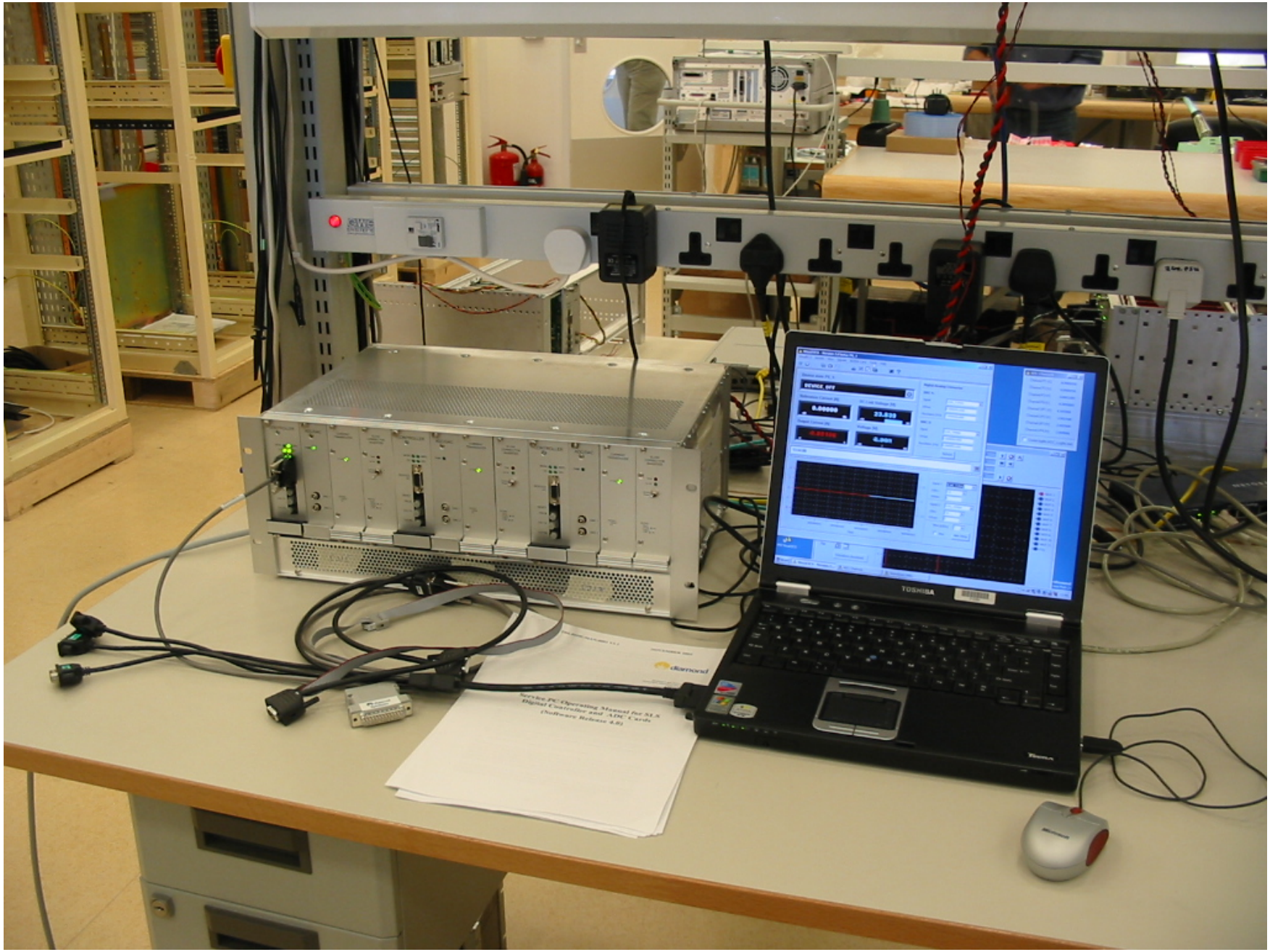
Configuring a slow corrector PS into a dummy load:

- 300mH / 3 Ω

Exercise on the Data Logger Utility

Visual ECS software:

- Good for initial conditioning only
- Not possible to use when running with EPICS controls

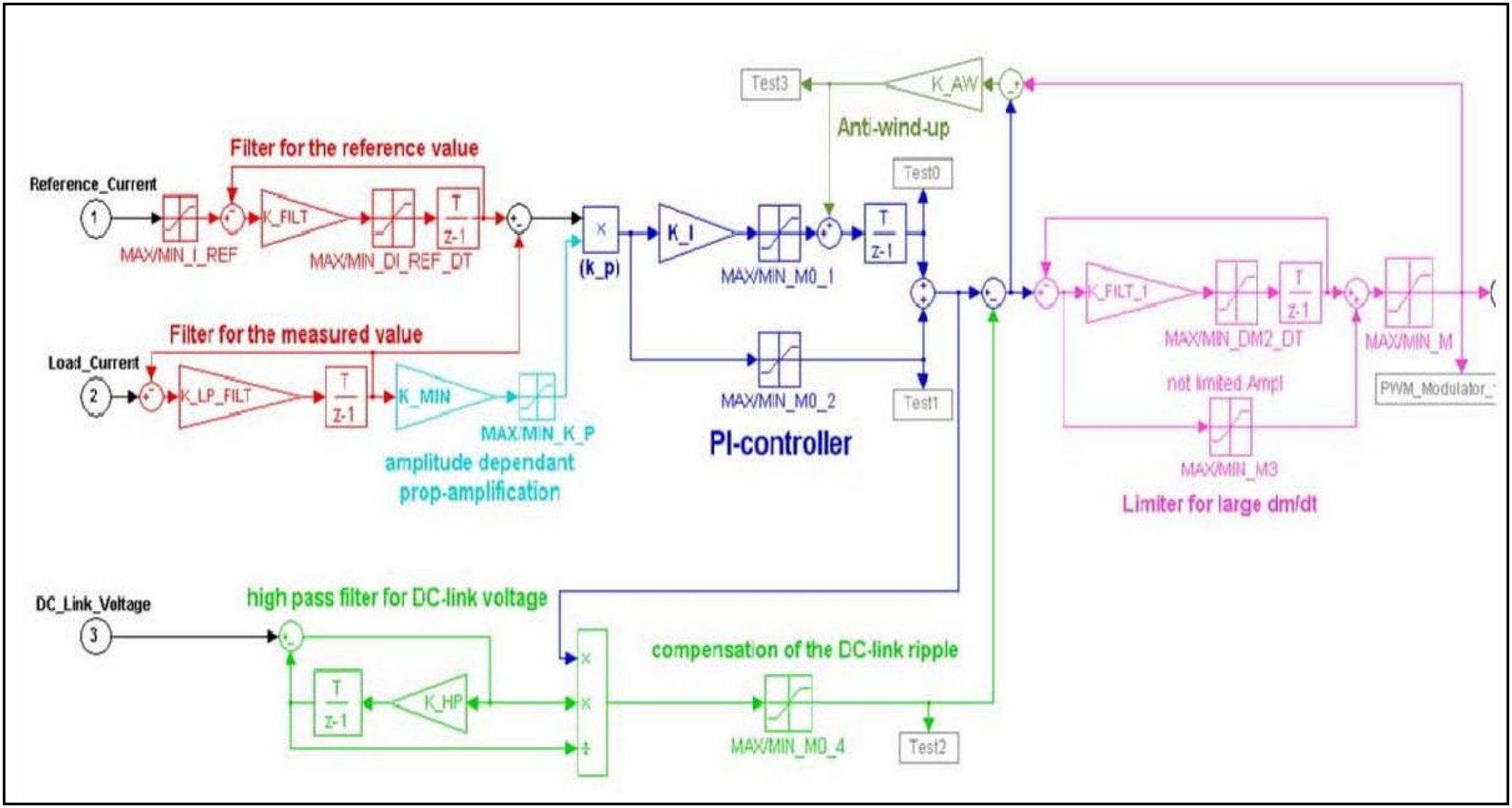

TOSHIBA
diamond

Visual ECS software:

- Possible to download waveforms into the DSP
  - o Very useful for commissioning

Basic procedure for tuning the PS controller:

- Get load parameters
- Run simulation into MATLAB
  - o There is a model (inside MATLAB) for the controller


Test3
K_AW
Anti-wind-up
Filter for the reference value
Reference_Current
1
K_FILT
T
z-1
MAX/MIN_I_REF
MAX/MIN_DI_REF_DT
X
(k_p)
K_I
MAX/MIN_M0_1
Test0
Filter for the measured value
Load_Current
2
K_LP_FILT
K_MIN
MAX/MIN_K_P
amplitude dependant
prop-amplification
MAX/MIN_M0_2
Test1
PI-controller
K_FILT_1
MAX/MIN_DM2_DT
MAX/MIN_M
not limited Ampl
MAX/MIN_M3
Limiter for large dm/dt
PWM_Modulator
DC_Link_Voltage
3
high pass filter for DC-link voltage
K_HP
compensation of the DC-link ripple
MAX/MIN_M0_4
Test2

The V-mode, feed-forward control loop has been disabled.

Output voltage monitoring → impedance measurement and interlock only.

During the commissioning phase there's a resistance calculation procedure:

- Running the PS at 50% of the nominal I_L
- Measures V_L
- Calculate R_L

If during operation, R_L deviates 10% off from the calculated values an interlock is activated.

Debriefing section with Tony Dobbing

Q1: How and where is PPS connected to the PS?

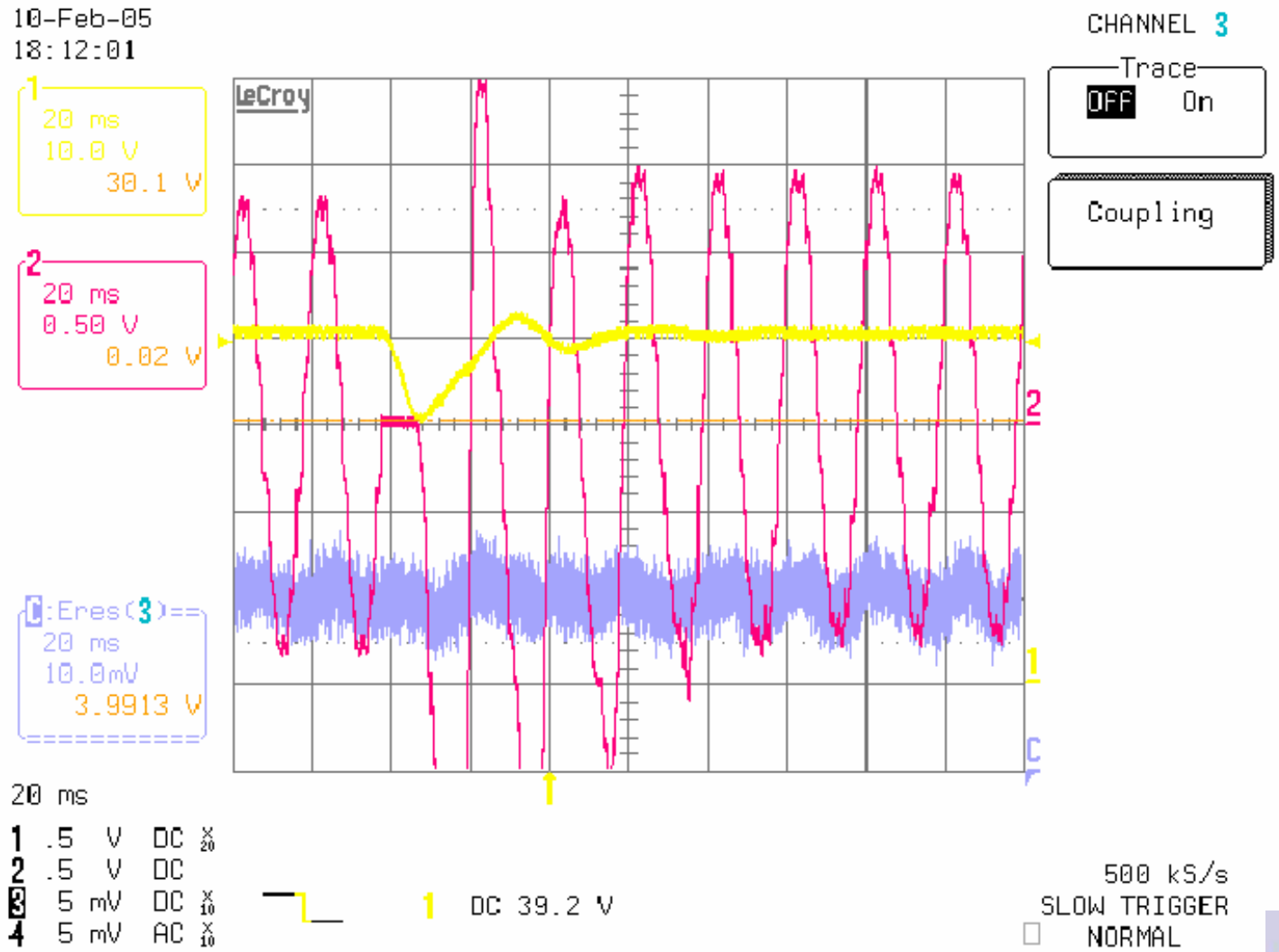
A1:

- No PPS on the PS.
  Only some dipole PS in the transfer line are turned off.
- MPS is connected to one of the 16 bit inputs of the DSP (software)

Q2: Output Voltage mode control loop?

A2: Big capacitor banks flattens the bulk voltage

Medium PC: Interruption of a Half Cycle of Mains Power



J A Dobbing March 2005

Debriefing section with Tony Dobbing

Q3: Is £ 250 the license fee for the set of cards (DSP + ADC) or is it per card?

A3: This is the cost of the set.

- Both cards are always used.

Debriefing section with Tony Dobbing

Q4: What's the bandwidth on the PS?
A4:

- Slow correctors: 50 Hz @ -3dB
- Fast correctors: 1 kHz @ -3dB

Q4a: How in the final BW determined (PS + load)?
A4a: Simulink

Q4b: How is the final frequency response measured?
A4b: Look at the step response. Must be critically damped.

Debriefing section with Tony Dobbing

Q5: Is it possible to buy corrector PS from DLS?
A5: "In principle, yes".
Depends on DLS time schedule.
They are very busy for the next 6 months.

Slow correctors: ≈ £ 2000 / channel (US$ 3600)
Fast correctors: ≈ £ 2500 / channel for fast correctors (US$ 4500)

Some Remarks on the PS Design:

- Highly customized solution
- Low variability between PS ratings in the synchrotron machine
- Redundancy topologies chosen by OCEM
- No time budget associated with PS Systems
    - Criteria: “not to be called in the middle of the night”
- No tests under short circuit conditions in the bulk PS, or on one of the free-wheeling diodes
- Only one DCCT per PS
- Air conditioning system defines overall stability

Some Remarks on OCEM's design:

- Redundancy was allocated within the money budget
- OCEM has Gov. incentives to design PS - ↓ NRC
- This is OCEM's first design of such PS systems
- OCEM prices very close to IE Power's
- Modularity design is a plus
- No single point failure analyzes
- Not truly hot-swappable

Some Remarks on the PSI controller:

- PSI controllers have a high initial price
- Requires software engineering support to program DSP and FPGA for a particular configuration
- Highly customized PS design
- Capability of paralleling controller sets (Dipole PS)

Some Remarks on the PSI controller:

- PWM signals to the switching devices generated internally to the DSP
- Visual ECS doesn't run in parallel with EPICS
- Allows for a variety of different systems by reprogramming
- Requires deep knowledge of C and VHDL for reprogramming