Power Converter Controls

Lecture for the
CERN Accelerator School
on Power Converters

Warrington May 16 2004

1.1 Global Controls Environment

- **Accelerators:**
  - The Advanced Photon Source (ANL)
  - The Tesla Test Facility (DESY)
  - The Continuous Electron Beam Accelerator Facility and IRFEL (TJNAF)
  - The Bates Linear Accelerator (MIT)
  - Next Linear Collider R&D (SLAC)
  - RF and feedback for PEP-II "B-factory" (SLAC)
  - The HERA cryogenic plant (DESY)
  - The Intense Pulsed Neutron Source (ANL)
  - Free Electron Laser (Budker INP)
  - The Tesla Test Facility Injector (SACLAY)
  - Racetrack Microtron (U Alabama)
  - The Free Electron Laser Program (Duke)
  - The Advanced Free Electron Laser (LANL)
  - The Average Power Laser Experiment (LANL)
  - LAMPF/LANSCE PSR (LANL)
  - LEDA (for APT) (LANL)
  - The Heavy Ion Fusion Test Stand (LBNL)
  - Advanced Light Source *(partial)* (LBNL)
  - National Laboratory for High Energy Physics B-factory (KEK)
  - Berlin Electron Synchrotron Light Source (BESSY II)
  - Microtron (U Athens)
  - RF (PSI)
  - Swiss Light Source (PSI)
  - Neutron Therapy Cyclotron (U Washington)
  - ISAA Radioactive Beam Facility (TRIUMF)
  - Magnet test facility and Accelerator R&D (Sync Lab Barcelona/IFAE)
  - SSRF synchrotron and BTCF e+/e- collider (IHEP)
  - NSRL (U Science/Tech, Hefei, China)
  - IPHI (SACLAY)
  - Spallation Neutron Source (ANL/BNL/LANL/LBNL/ORNL)
  - The National Spherical Torus Experiment (PPPL)
  - Linac Test Bed for APT (SRS)
  - Holifield Radioactive Ion Beam Facility (ORNL)
  - Cyclotron(s) Controls Upgrade (MSU)
  - DELTA Controls Upgrade (Dortmund)
  - Pohang Light Source: Longitudinal Feedback System (PAL/POSTECH)
  - Steady State Tokamak-1 (Inst. for Plasma Research, India)
  - Longitudinal Feedback for DAFNE (INFN/Frascati)
- **Detectors:**
  - Halls A, B, and C Slow Controls (JLab/NMSU)
  - Advanced Light Source Beamlines *(partial)* (LBNL)
  - Gammasphere (LBNL/ANL/ORNL)
  - Advanced Photon Source Beamlines (ANL)
  - The PHENIX detector system for RHIC Slow Controls (BNL/LANL/NMSU)
  - The STAR detector system for RHIC Slow Controls (Creighton/U. Wash/Kent State/UCLA/LBNL)
  - The Intense Pulsed Neutron Source Instruments (ANL)
  - The Biotechnology Beamline (SSRL)
  - The BaBar detector for PEP-II Slow Controls (SLAC/LBNL)
  - Structural Biology Research Group (Riken)
  - Wind Tunnels (NASA/Langley)
  - PRISMA and GARFIELD demonstrations (INFN/Legnaro)
  - D0 (FNAL)
  - High Acceptance DiElectron Spectrometer (GSI/Darmstadt)
- **Telescopes:**
  - The Gemini 8-M Telescope (AURA)
  - Kitt Peak Observatory (NOAO)
  - The United Kingdom Infrared Telescope upgrade (JAC)
  - The William Herschel Telescope/WFFOS instrument (RGO)
  - The William Herschel Telescope/ELECTRA instrument (U Durham)
  - The Keck II Telescope (CARA)
  - Canada-France-Hawaii Telescope Upgrade
  - LIGO (CalTech)
  - INTEGRAL instrument/Instituto de Astrofisica de Canarias (IAC)
  - Potsdam Multiaperture Spectrophotometer (Astrophysical Inst)
  - Sloan Digital Sky Survey/Telescope Performance Monitor (SDSS)
- **Commercial:**
  - The High Power Laser Experiment (Boeing)
  - Wafer Fabrication Plant (AMD)
  - Liquefied Nature Gas Plant (Baltimore G&E)
  - Tunnel Fire Ventilation Test Program (DOT/Bechtel-Parsons-Brinkerhoff)
  - Flexible Manufacturing Facility (Allied Signal)
  - Wastewater Treatment (Western Lake Superior Sanitary District)
  - Potable Water Distribution (St. Louis County)
  - Compressor Control (Baltimore G&E)
  - GM Fuel Cell Program (LANL)
  - Plant Simulation (Knolls)
  - Flight Simulation (JPL)
  - Fuel Depots (US Navy)
  - Product Storage/Movement Facility (Citgo)
  - Ground Tracking Station (NASA Canberra)
  - Well Head/Extraction (Saphania Oil Field)
  - Superconducting Magnet Test Facility for KSTAR (Samsung Adv. Inst. of Tech.)

1.2 Global Controls Environment

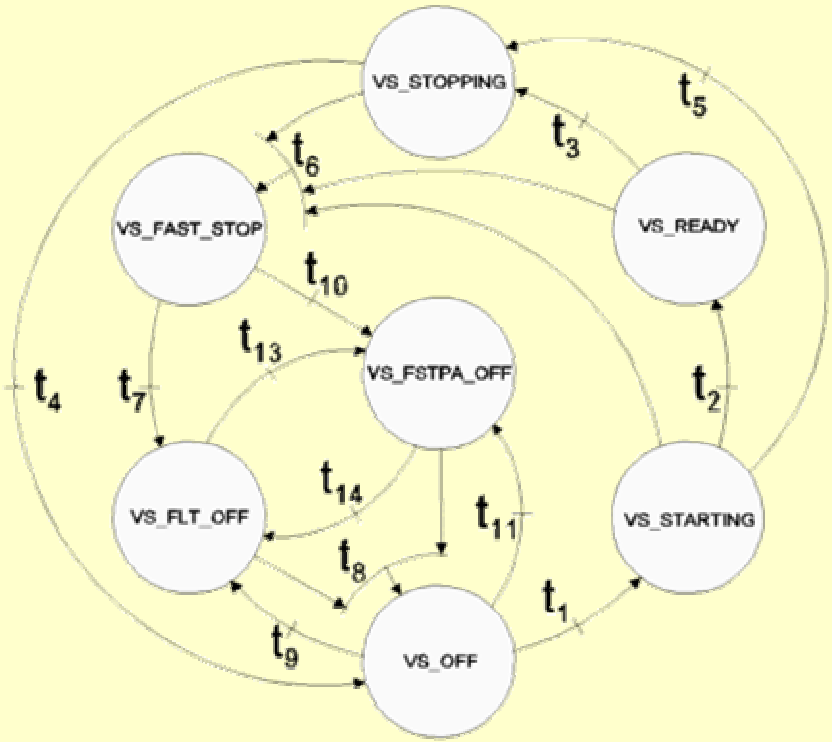
- Normally imposed by project
- EPICS
  - Many major projects worldwide
  - Excellent for new projects
  - All or nothing so difficult with existing projects
- Other SCADA systems - not really suitable

2.1 Homemade verse COTS

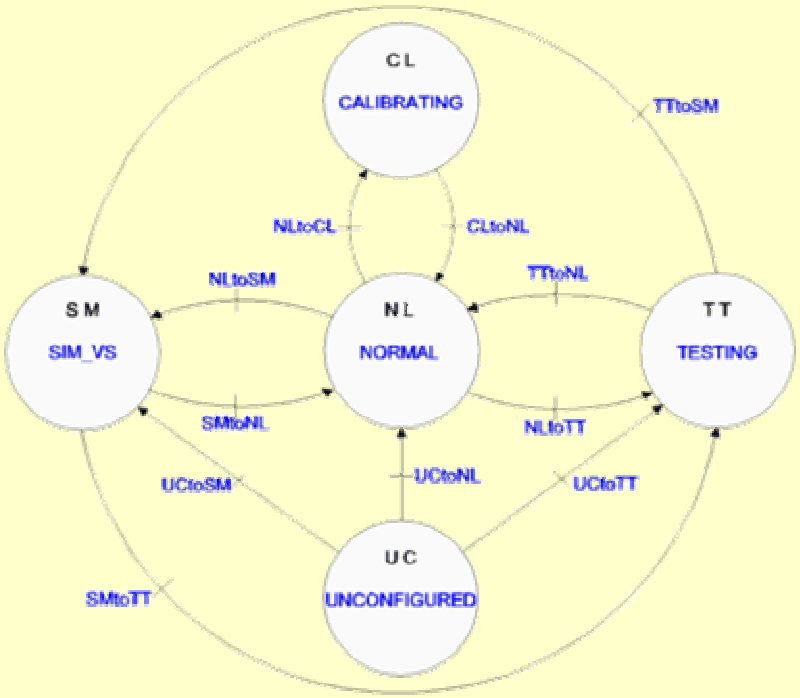
- Work out your requirements
- Identify your priorities
- Consider constraints
- Consider options:
  - PLCs
  - Mixed system based on COTS bus
  - Dedicated home made system
- Make your decision and good luck!

3.1 Power Converter State Management

Voltage Source State

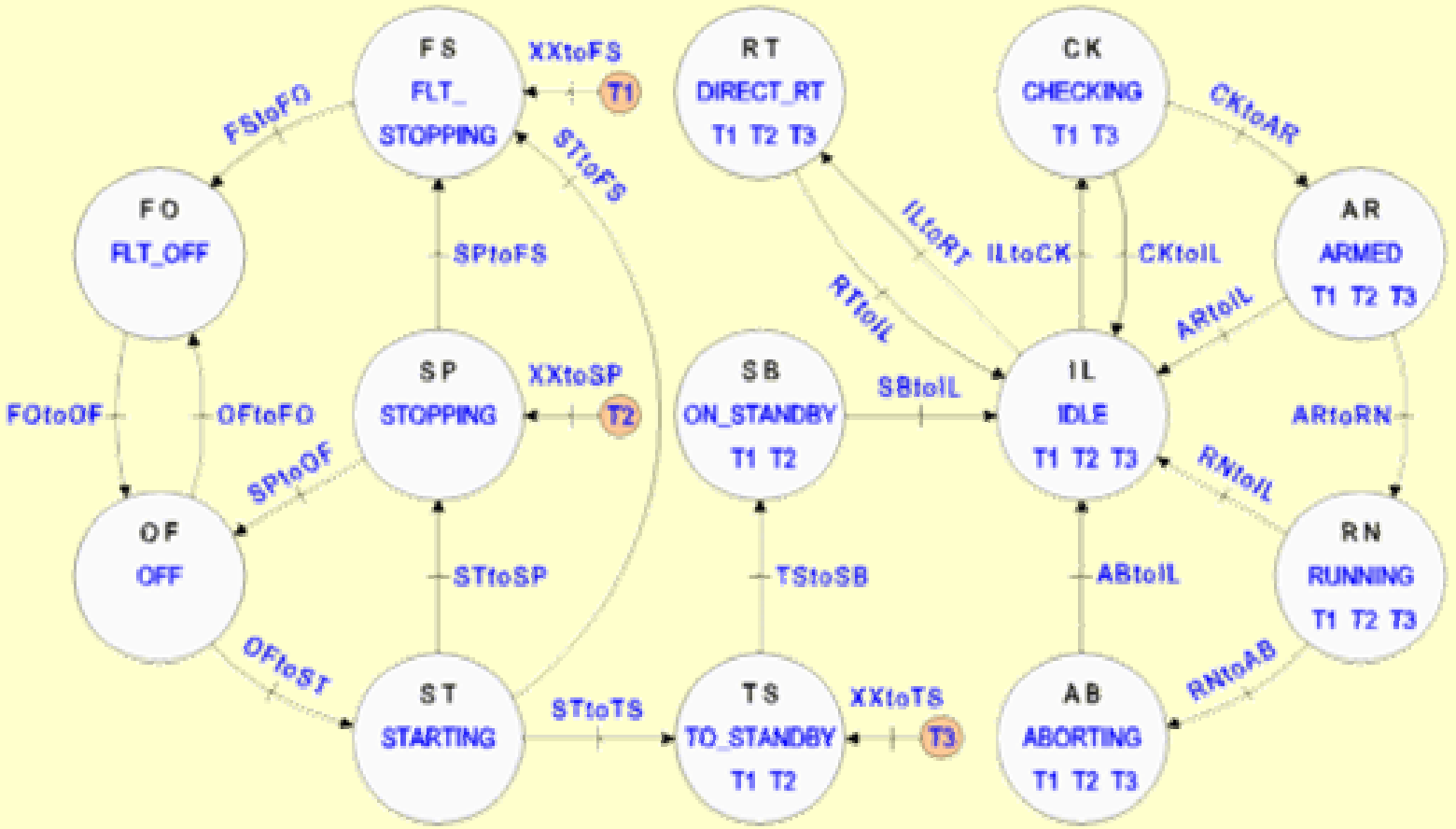


Operational State



3.2 Power Converter State Management

Power Converter State



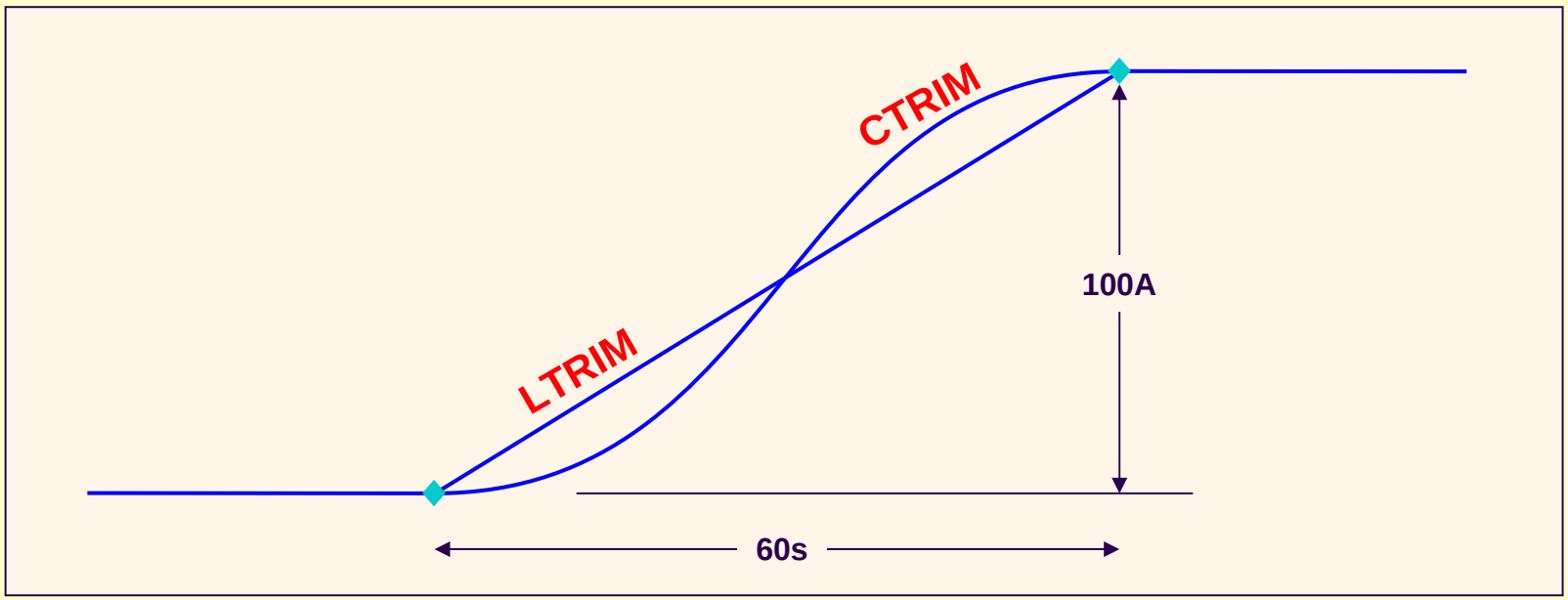
3.3 Power Converter State Management

- Design your state machine(s)
- Identify status and command signals required for each transition
- Choose you signal types
  - < 500mV CM – direct connection
  - < 10V CM – differential connection
  - < 1500V CM – Opto or capacitive couplers or relays
  - > 1500V CM – Fibre
  - Ensure safe behavior if the cable is removed

4.1 Function Generation

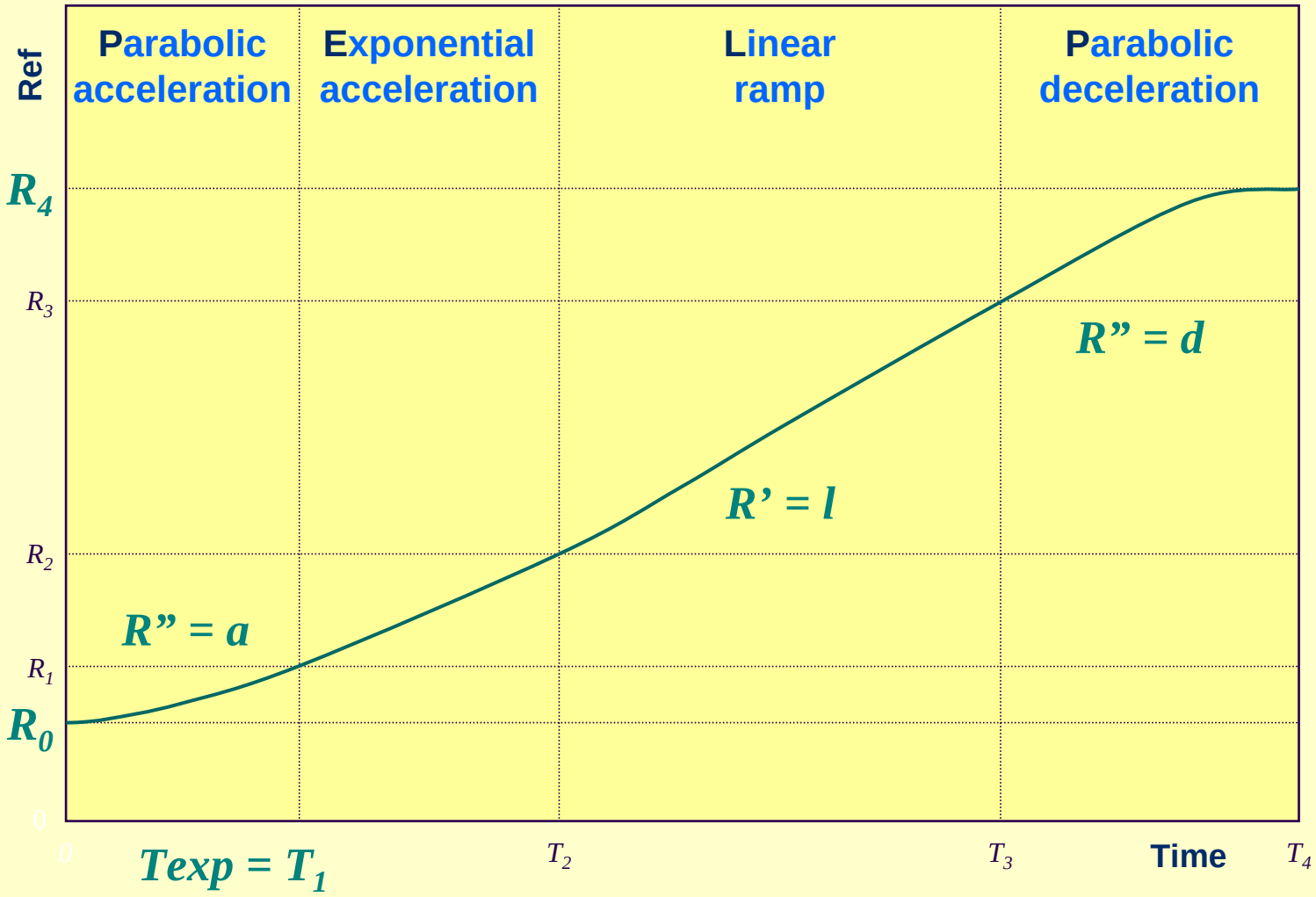
Parametric functions

Linear Trim and Cubic Trim



4.2 Function Generation

Parametric functions: PP, PLP, PEP, PELP, PLEP



4.3 Function Generation

Real-time control: NONE, SUM, GAIN, RT ONLY

$$ref = R(t)$$

$$ref = R(t) + R_{rt}$$

$$ref = R(t).(1 + R_{rt})$$

$$ref = R_{rt}$$

4.4 Function Generation

- Identify your requirements
- Use linear interpolation
- Use parametric function
- Support real-time control
- Use engineering units (Amps or Volts)

5.1 Network

- Define your overall architecture (2 or 3 layers?)
- Choose your media: Ethernet, Profibus, WorldFIP, etc…
- Considering:
  - Chipset cost/complexity
  - Software overhead – IP or private protocol
  - Cabling and connector costs
  - Performance: max length, number of nodes, repeaters, through put
  - Radiation tolerance if required
  - Real time support (control, publishing, synchronisation)

6.1 Synchronisation

- Identify your requirements
- Review your timing environment
- Use data network for timing if possible
- Use a digital PLL to generate RT clock in embedded systems

7.1 Regulation

- Use digital current regulation unless the requirements are very undemanding
  - Software can control the loop parameters
- Have an independent measurement of the current
  - Two DCCTs, two ADCs

8.1 Analogue Acquisition

- Precision analogue electronics is hard
- Don’t try it unless you have the right competence and lots of patience
- COTS can be crap – believe nothing - test everything
- The whole design matters: Vrefs, ADCs, layout
- Filter appropriately - know your noise environment

9.1 Mechanical Issues

- Very important to reliability – don’t underestimate the problem
- Casings should be robust, provide EMC protection
- Check thermal behaviour – avoid fans if possible
- Choose connectors very carefully
- Avoid ambiguous connectors
- Avoid intermediate cabling

10.1 Inventory Management

- Barcode
  - Materials are complex – choose carefully
  - Printer is a specialised (expensive) device
  - Scanners – wide choice – Serial, USB, Wireless, Laser, CCD
- Dallas 1-wire bus
  - Identity and optional temp sensors available
  - Separate bus using 2 wires (data/power and ground)
  - No position information

11.1 Remote Management and Diagnostics

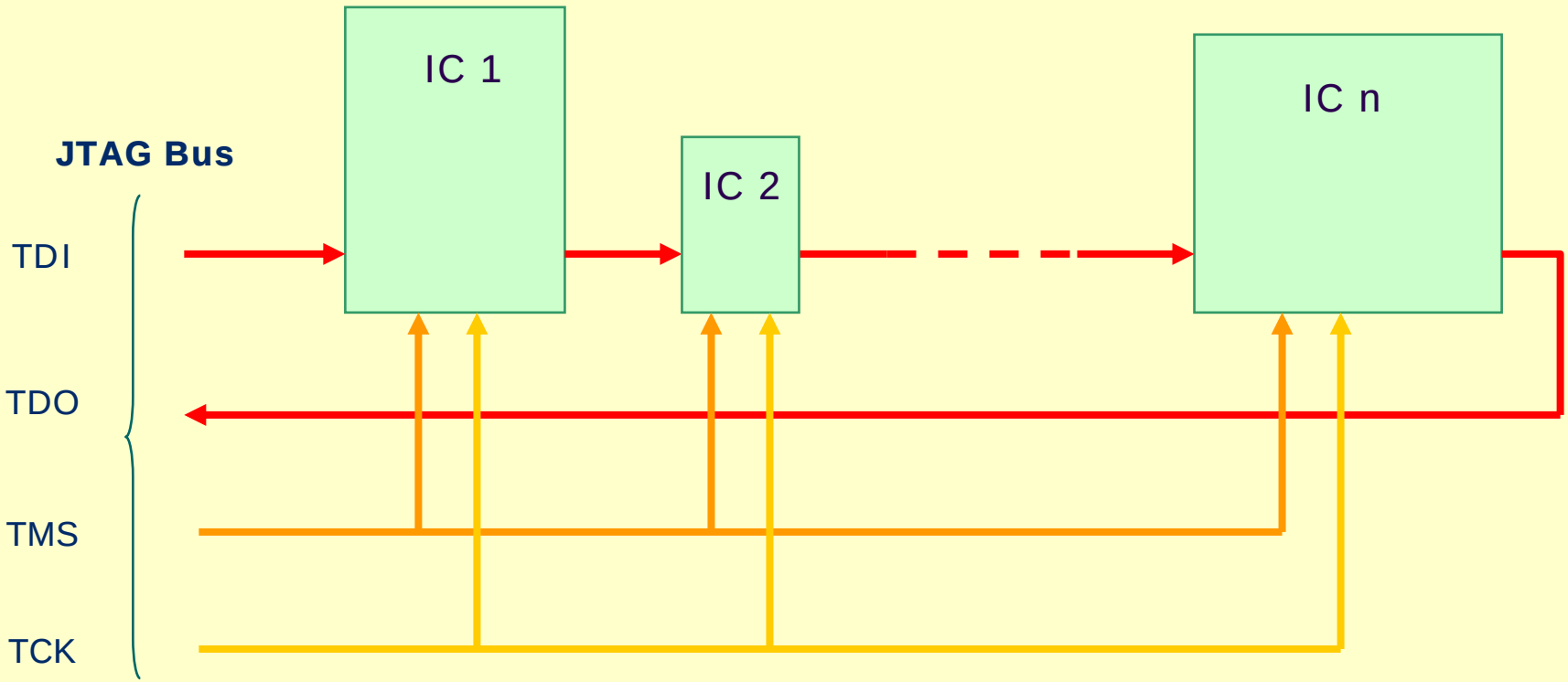
- Invest according to scale and remoteness
- Validate controller – then diagnose power converter
- First fault detection is very important
- Consider remote logic download
- Include remote code download
- Include remote parameter download

12.1 Power Supplies

- Work out all your requirements
- Consider your powering environment
- Decide on your topology
- Remember to add a switch and status signals

13.1 Testing

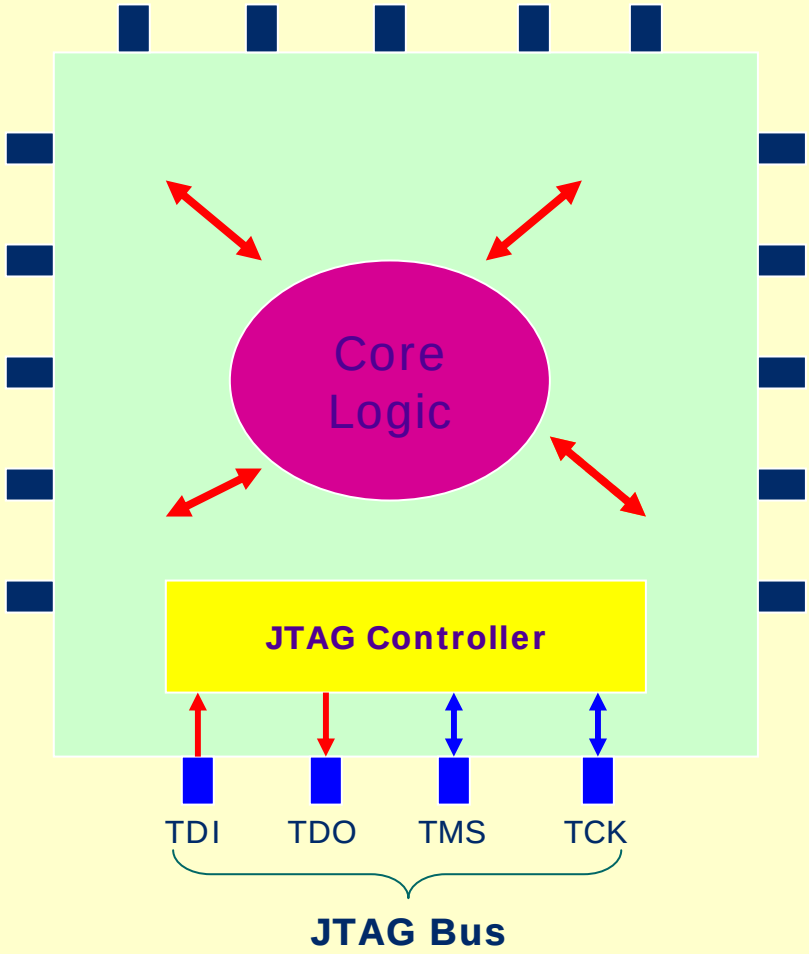
JTAG Boundary Scan: The JTAG bus



13.2 Testing

Normal device operation:

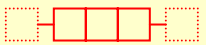
- Core logic controls pins
- JTAG controller is passive



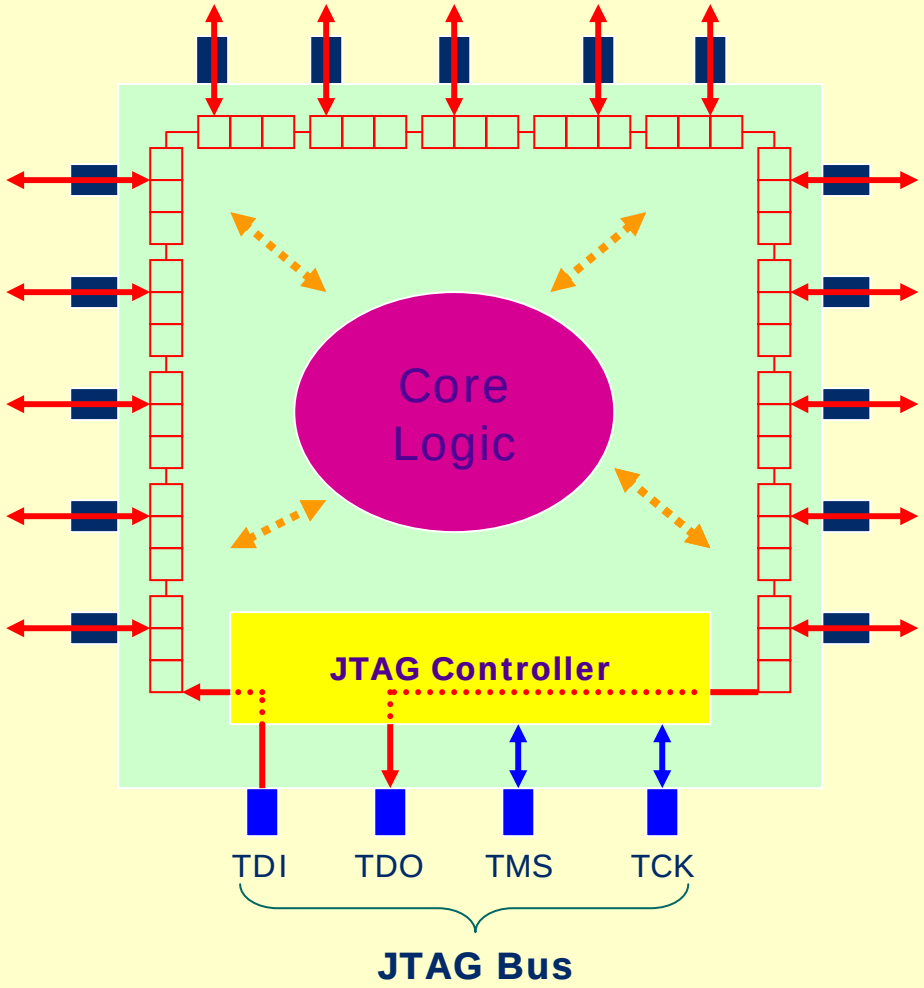
13.3 Testing

Boundary Scan Mode:

- Core logic disconnected from pins
- JTAG controller controls pins via daisy chain of boundary scan registers

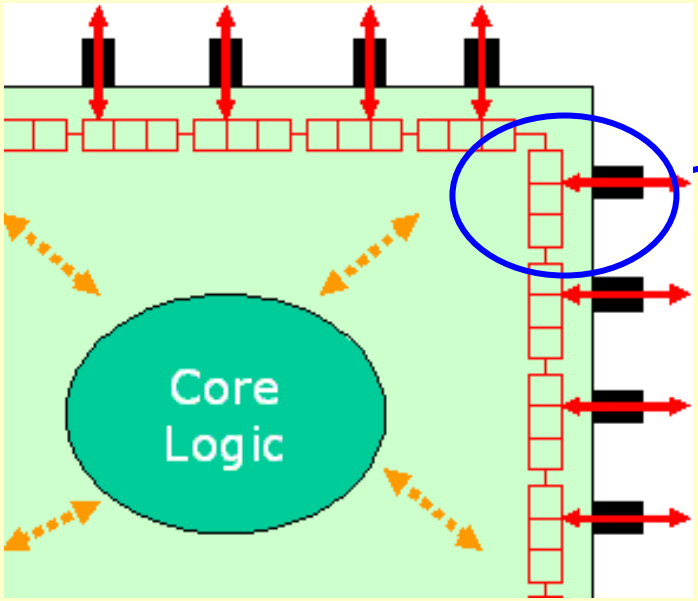


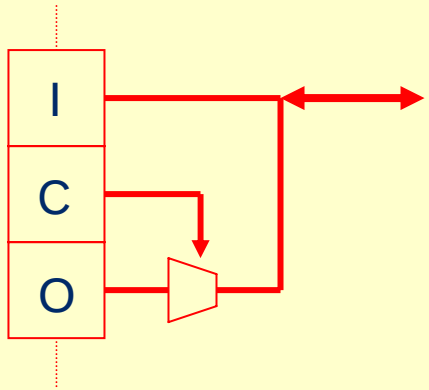
Boundary Scan Register



13.4 Testing

JTAG Boundary Scan Registers





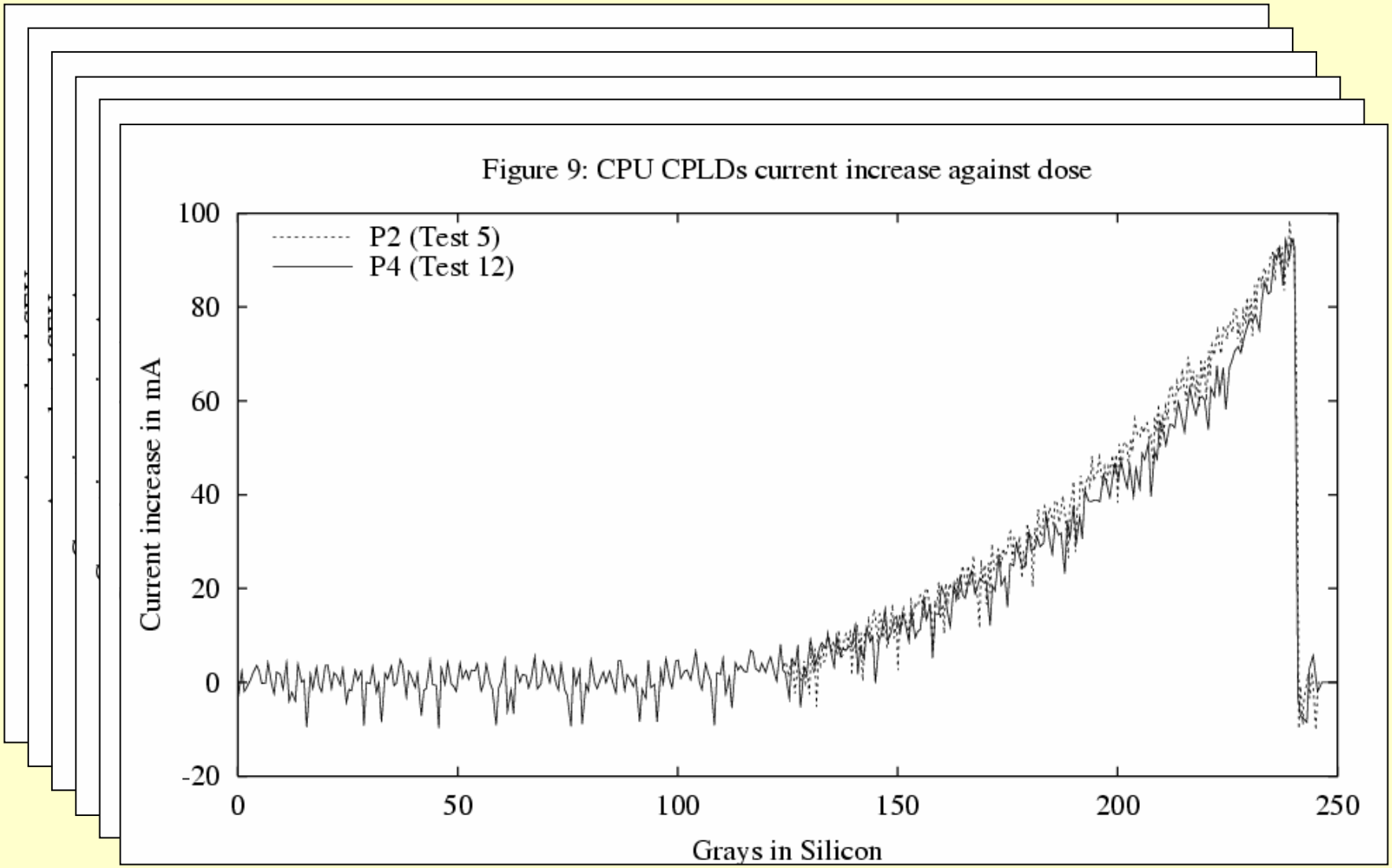
3 Boundary scan registers per pin:

- 1 bit per registers (0 or 1)
- I = Input register
- C = Control register (Input or output)
- O = Output register

13.5 Testing

- Make automatic test equipment for production and repair – lots of work
- Three levels of testing – DLI
- Design for Test – DTF
- Use JTAG boundary scan for in-situ testing
- Anticipate obsolescence

14.1 Radiation



14.2 Radiation

- <100 Grays is relatively easy with COTS
- 100-200 Grays still feasible with careful choice of COTS components
- Above 200 Grays is difficult
- Above 1000 Grays is VERY expensive
- EDAC memory works
- Crashes inevitable and must be managed
- Latch-ups require a power cycle

15.1 Protocols

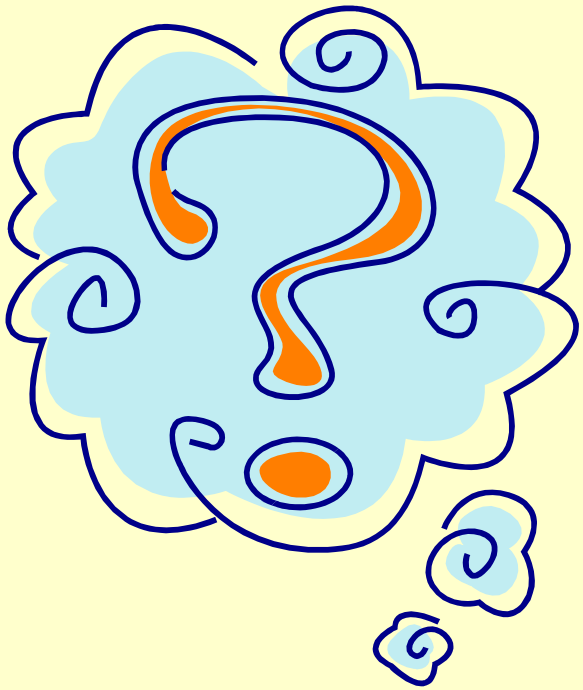
- Use ASCII for commands and responses
- Allow low level access with dumb terminal
- Allow non-blocking communication
- Acknowledge all commands
- Support Set and Get only
- Avoid JAVA and C++ in embedded systems

16.1 Documentation

- Golden rule of Data: define everything only once
- Use XML syntax
- Parse your XML into everything you need including documentation
- Exploit the web
- Remember to archive all your datasheets

The End

Thanks for listening!



Any questions?