Modern Accelerator Control Systems

Kazuro Furukawa, KEK

for KEKB Control Group

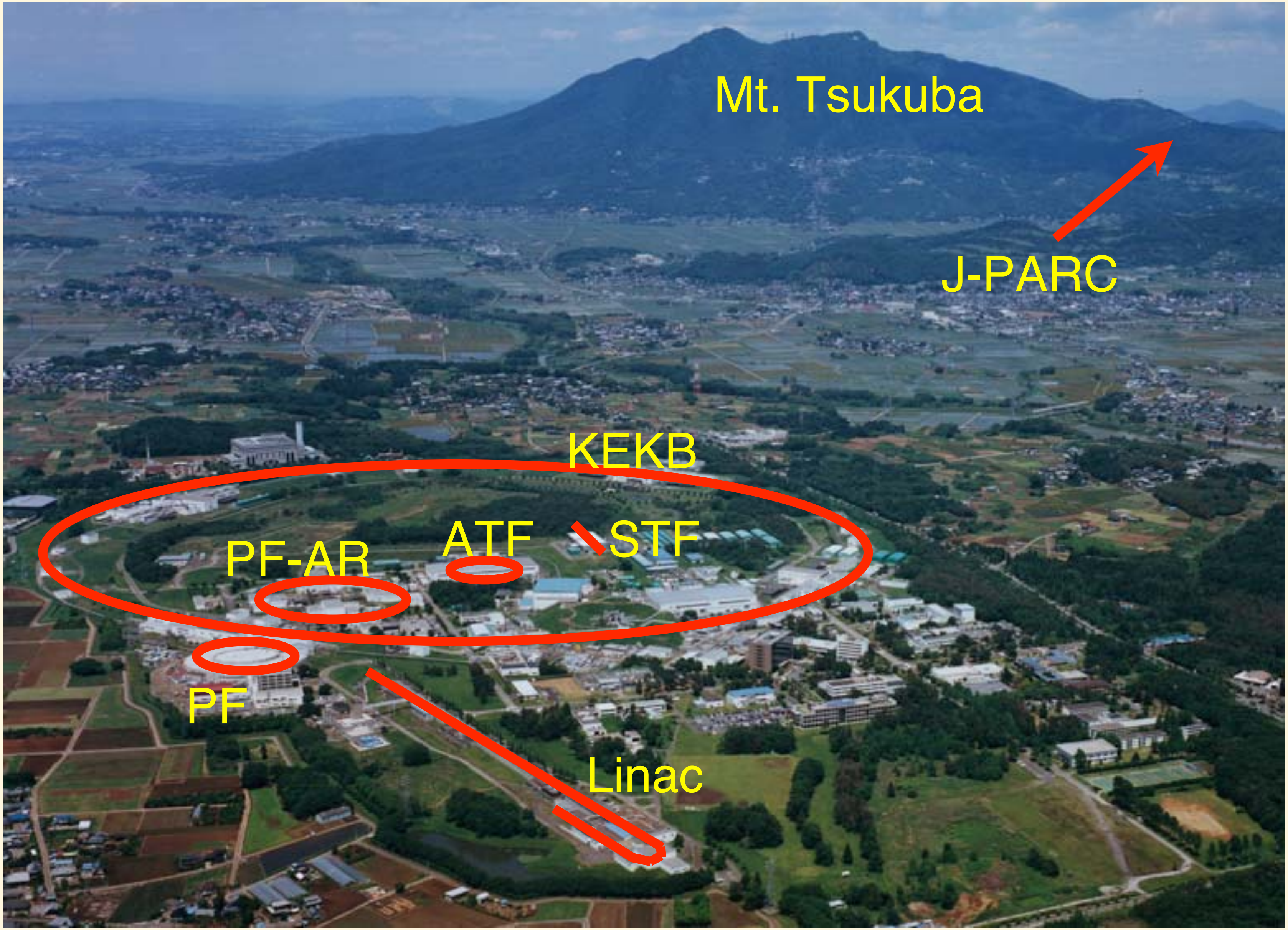
and Linac Control Group

<kazuro.furukawa@kek.jp>

Jun. 26. 2007.

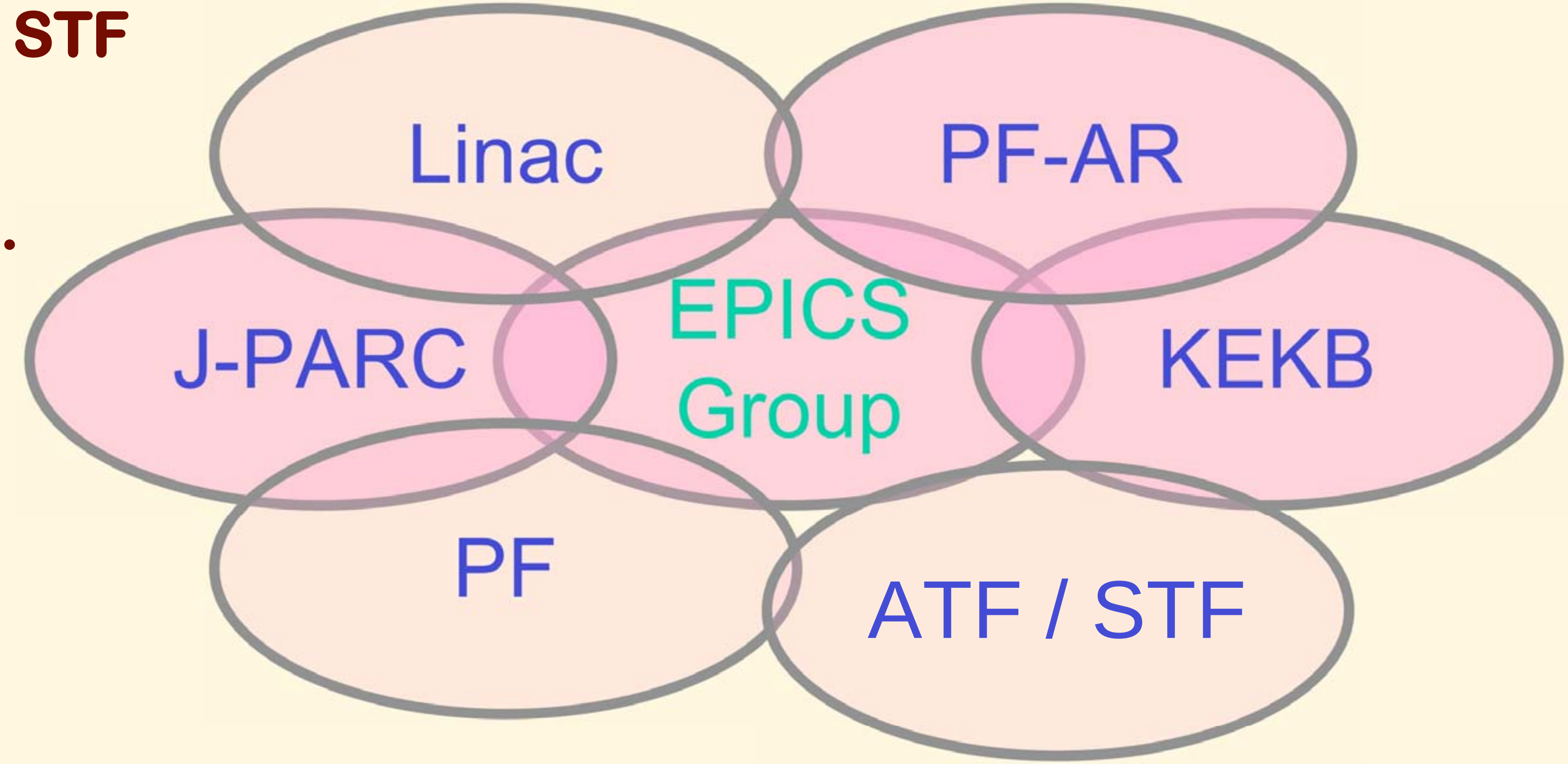
- **Accelerator Controls at KEKB and Linac**
- **Operational Software**
- **Considerations on Accelerator Controls in General**
- **Available Technologies**
- **Adaptive Reliabilities**
- **Summary**

KEKB and Linac

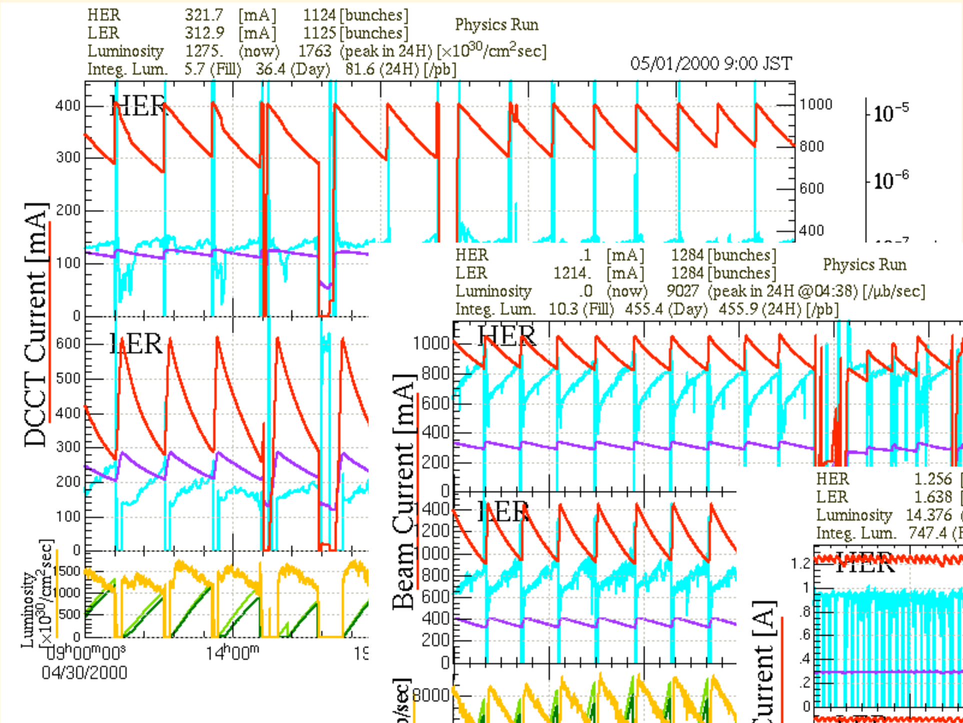

Mt. Tsukuba
J-PARC
KEKB
ATF
STF
PF-AR
PF
Linac

Control Systems in KEK

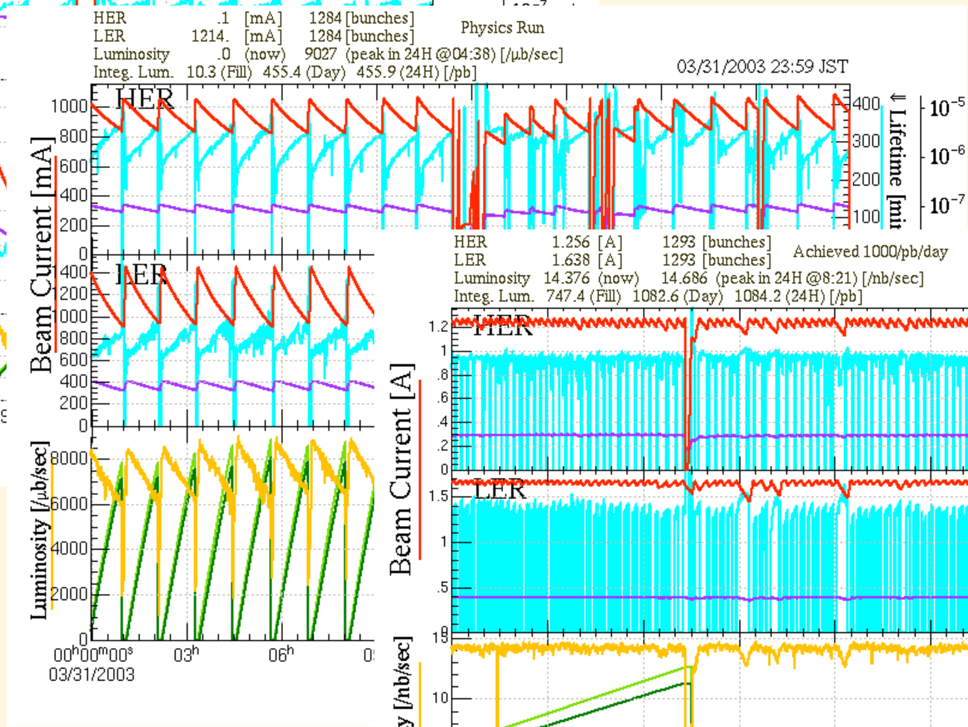
- **Operational Presently**
  - **Linac, PF, PF-AR, ATF, KEKB**
- **Under Construction**
  - **J-PARC, STF**
- **EPICS**
  - **KEKB, ...**



Increase of the Luminosity



May.2000



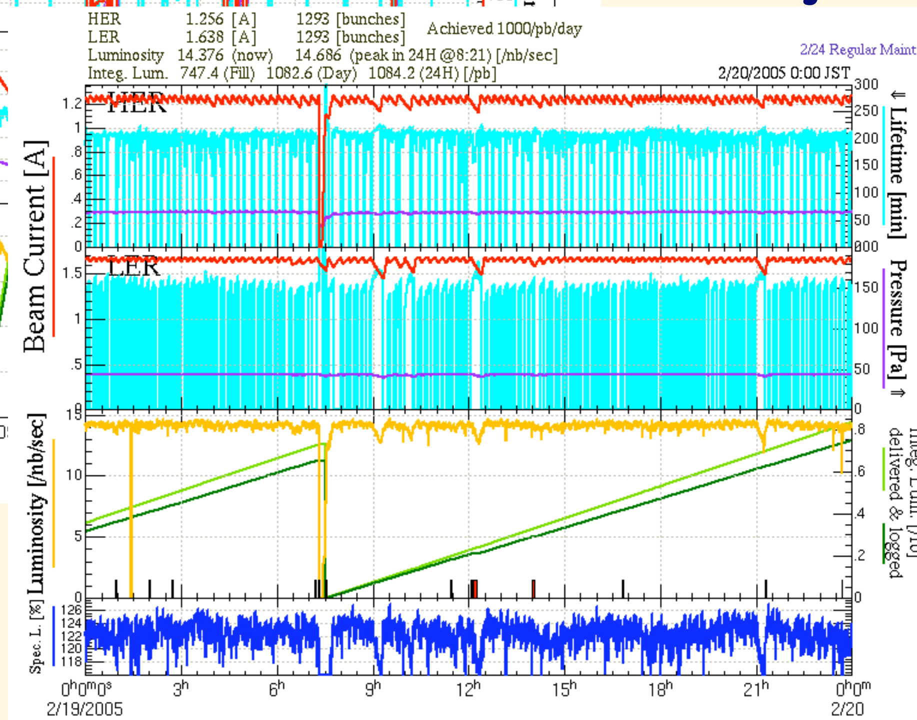
Apr.2003

Dual Bunch e⁺

Feb.2005

Continuous

Injections



Now

Collision with

Crab Cavities

KEKB Control System (Hardware)

- **GbE Fiber Optic Networks**
  - **Single Broadcast Domain**
  - **Central Control Room and 26 Local Control Rooms**
- **VME/IOC**
  - **~100 VME/IOC mostly with PowerPC CPU**
- **Field bus**
  - **~200 VXI thru MXI for BPM Instrumentations**
  - **~50 CAMAC for rf and Vacuum (inherited from TRISTAN)**
  - **~200 ArcNet network segments for Magnet Power Supplies, and other field Controllers**
  - **GPIB for Instrumentations, RS232C, Modbus+ for PLCs**
- **Host Computers**
  - **HP-UX/PA-Risc, Linux/x86 Controls Server**
  - **3 Tru64/Alpha with TruCluster**
  - **Several Linux**
  - **Many MacOSX**
  - **(Solaris/Sparc for VxWorks)**

KEKB Control System (Software)

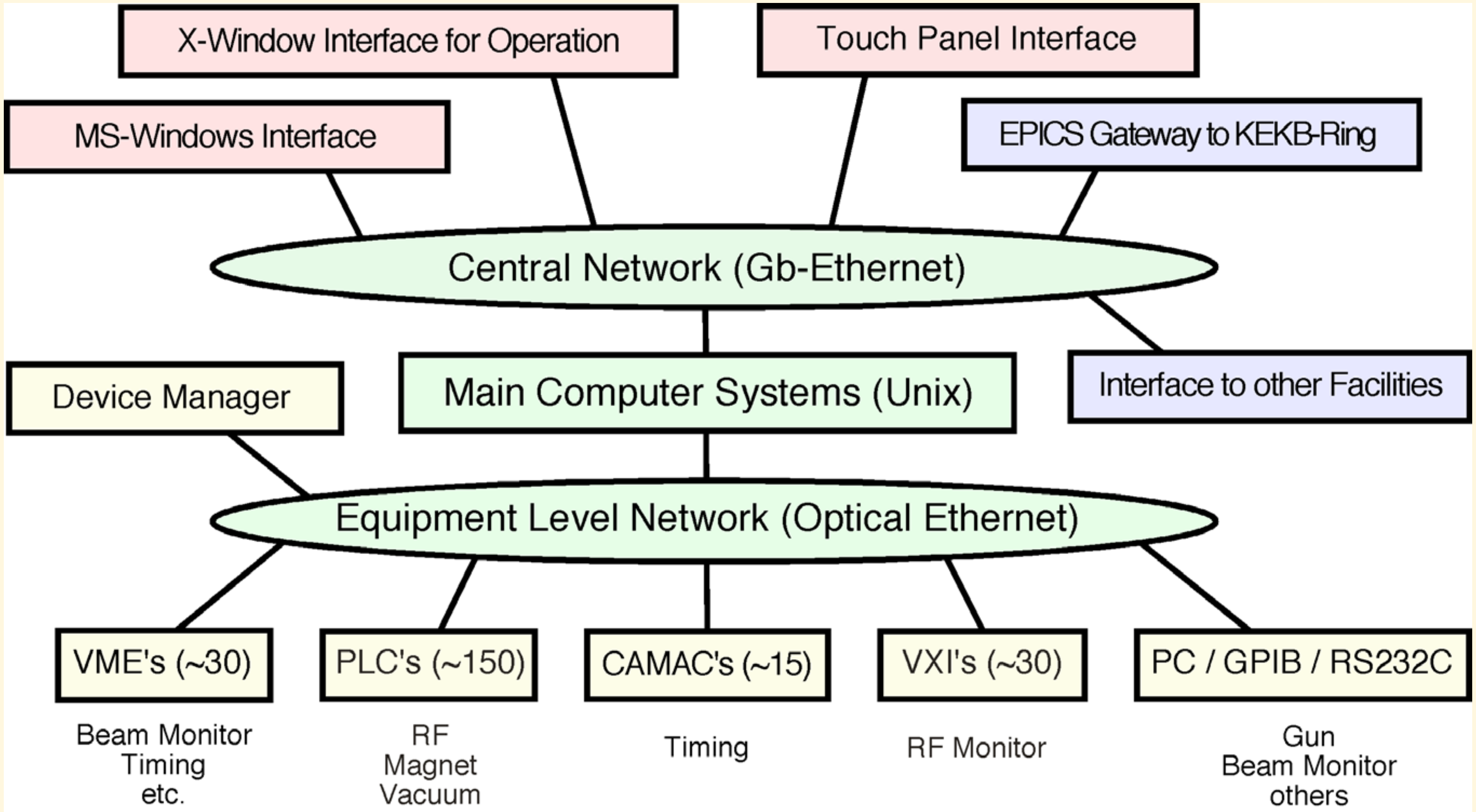
- **EPICS 3.13.1 and 3.14.6,8**
- **VxWorks 5.3.1 mainly, and 5.5.1**
  - **Hope to upgrade EPICS/VxWorks Shortly**
- **IOC Development**
  - **CapFast, (VDCT) Perl, SADscript for Database Configuration**
  - **Oracle as a backend Database Management**
    - **Migration towards Postgresql**
- **Operational Application Development**
  - **MEDM(DM2k) for Startup**
  - **Python/Tk for Equipment Controls**
  - **SADScript/Tk for Beam Operation, etc**

KEKBLOG and ZLOG

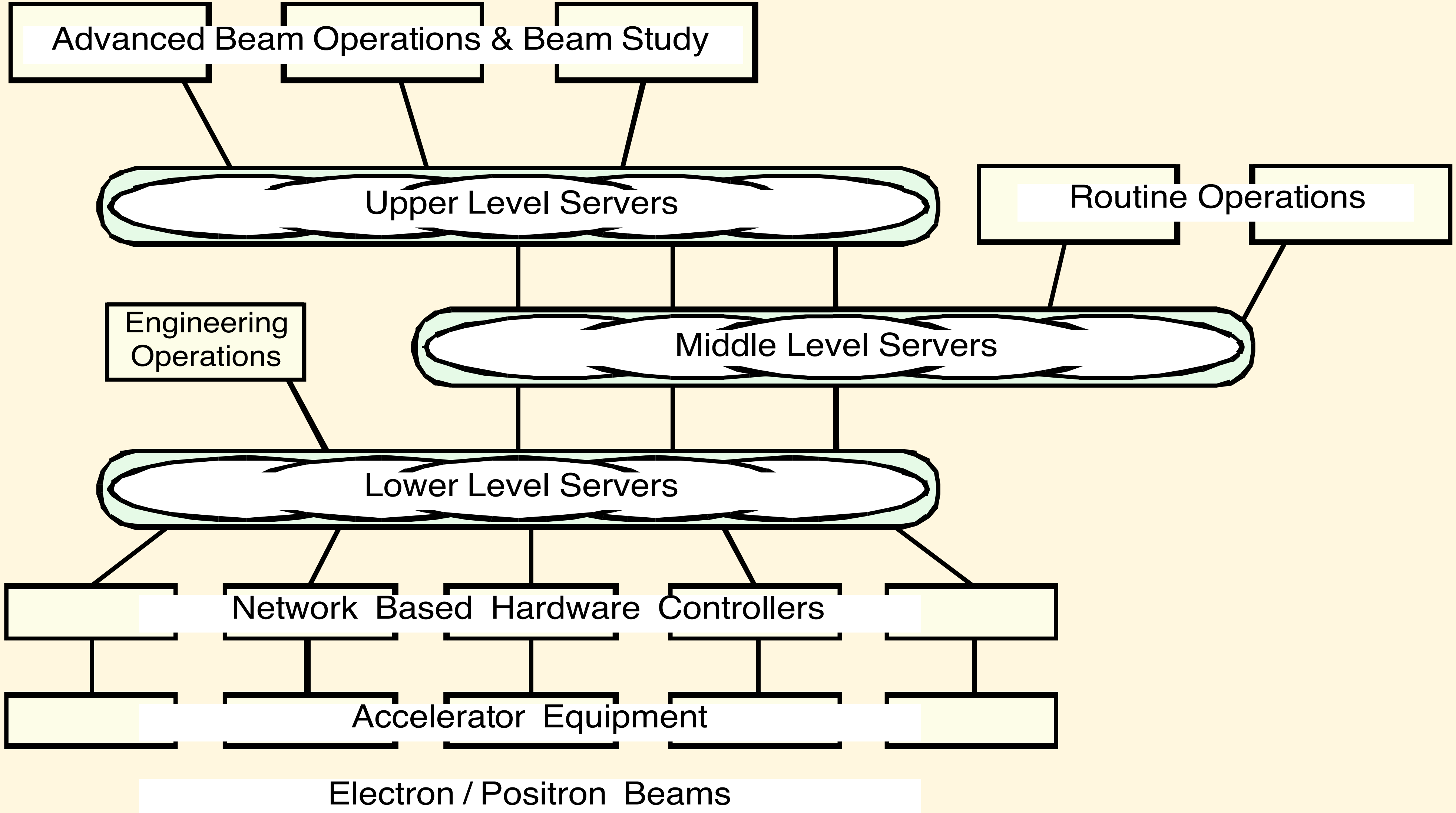
- **KEKBlog/kblog Archiver is Used from the Beginning of the Commissioning**
  - **Just less than 2GB / day**
  - **Several Viewer Tools**
    - **Very often Used to Analyze the Operation Status**
- **Zlog Operation Log**
  - **Zope, Python, PostgreSQL**
    - **Most of the operation logs**
    - **In Mostly Japanese**
    - **Figure Storing Integration**
      - **ex. Screen shot of operational Panels**

Linac; Physical Structure

- **Multi-tier, Multi-hardware, Multi-client, ...**



Linac; Multi-tier Logical Structure



Software Architecture

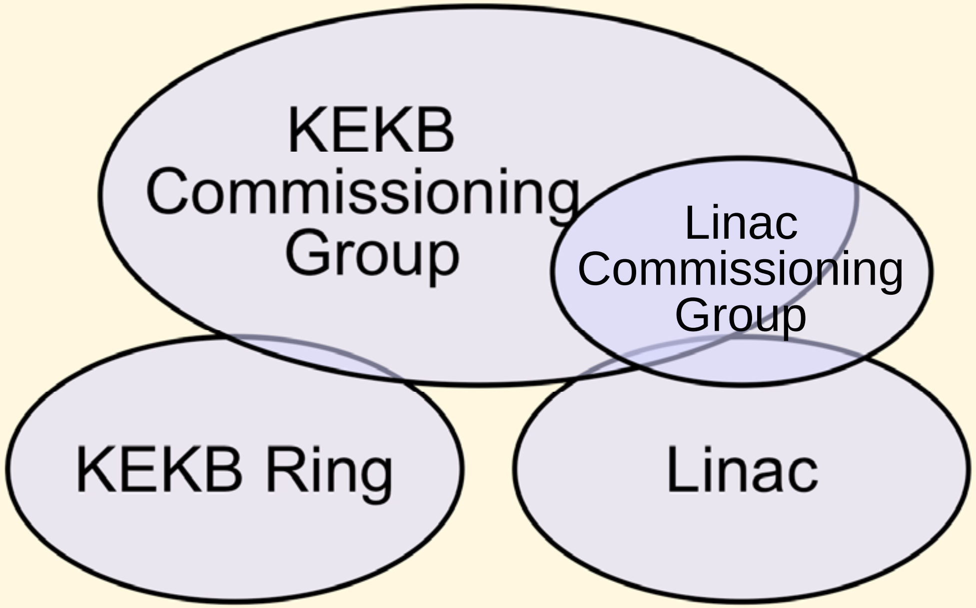
- **Base control software structure for Multi-platform**
  - any Unix, OS9, LynxOS (Realtime), VMS, DOS, Windows, MacOS
  - TCP - UDP General Communication Library
  - Shared-Memory, Semaphore Library
  - Simple Home-grown RPC (Remote Procedure Call) Library
  - Memory-resident Hash Database Library
- **Control Server software**
  - Lower-layer servers (UDP-RPC) for control hardware
  - Upper-layer server (TCP-RPC) for accelerator equipment
  - Read-only Information on Distributed Shared Memory
  - Works redundantly on multiple servers
- **Client Applications**
  - Established applications in C language with RPC
  - Many of the beam operation software in scripting language,
    - Tcl/Tk
    - SADscript/Tk

Operation

KEKB Commissioning Groups

- **Formation of Commissioning Group (KCG)**
  - **Linac Commissioning (LCG)**
    - **7 from Linac**
    - **~10 from Ring**
  - **KEKB Ring Commissioning Group (KCG)**
    - **All LCG**
    - **~20 from Ring**
    - **Several from Detector (BCG)**
  - **Commissioning software base was formed during Linac Commissioning (1997~)**

Tcl/Tk , Python/Tk, SADscript/Tk



SADScript

Mathematica-like Language

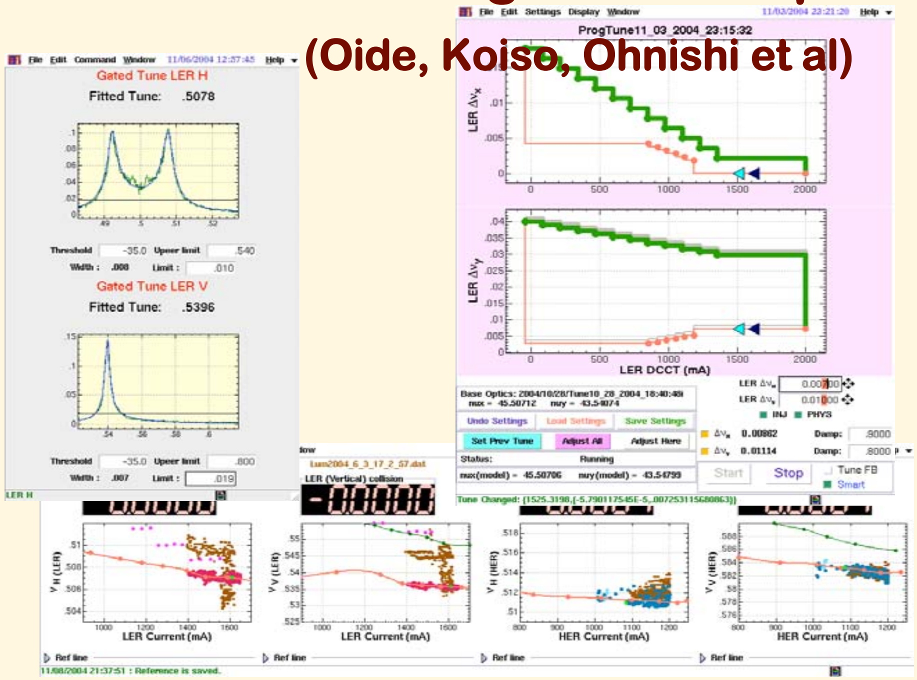
- Not Real Symbolic Manipulation (Fast)
- EPICS CA (Synchronous and Asynchronous)
  - CaRead/CaWrite[ ], CaMonitor[ ], etc.
- (Oracle Database)
- Tk Widget
- Canvas Draw and Plot
- KBFrame on top of Tk
- Data Processing (Fit, FFT, …)
- Inter-Process Communication (Exec, Pipe, etc)
  - System[ ], OpenRead/Write[ ], BidirectionalPipe[ ], etc.
- Greek Letter
- Full Accelerator Modeling Capability
- Also Used for non-Accelerator Applications
- Comparable to XAL, but very different architecture

Virtual Accelerator in KEKB

◆For Example in KEKB

- ❖most Beam Optics Condition is maintained in the Optics Panel
- ❖Other Panels Manipulate Parameters Communicating with the Optics Panel

(Oide, Koiso, Ohnishi et al)



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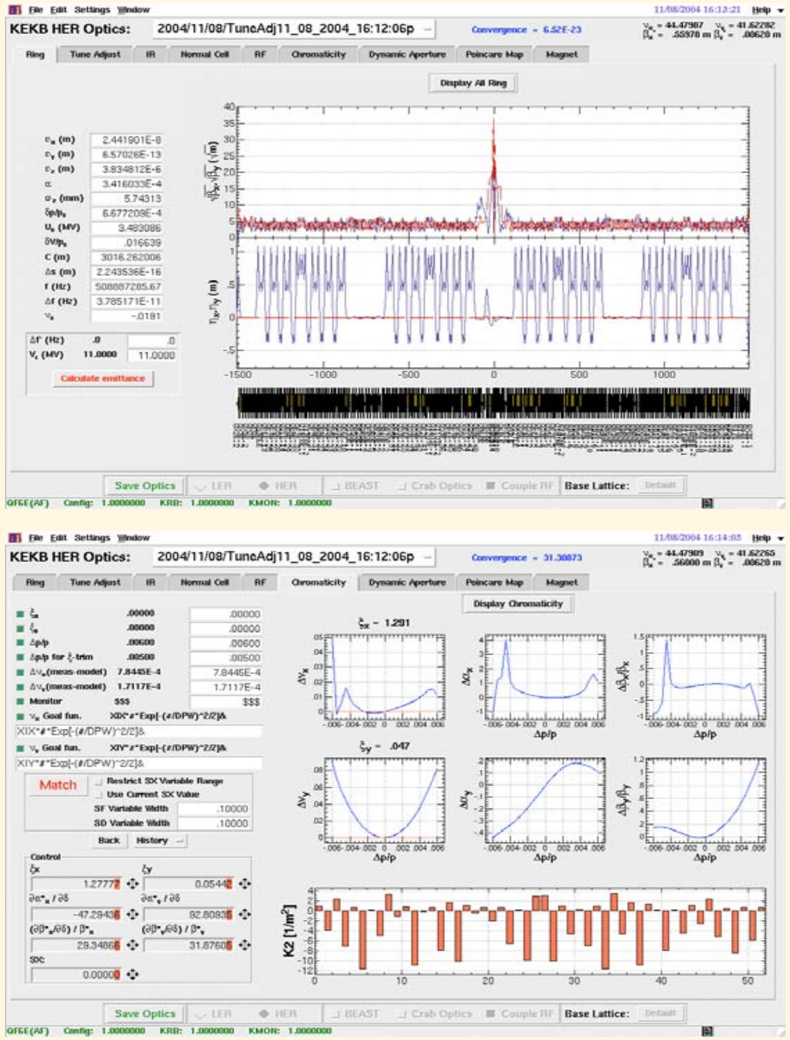


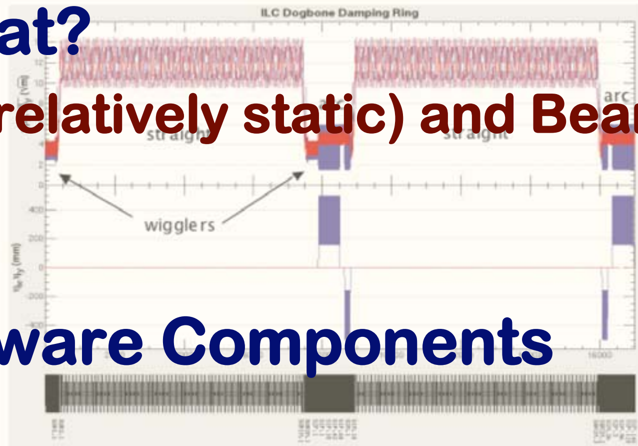
Tune Measurement/Changer

Optics Panel

Beam Optics Database

- **Repository of Inputs to Simulation Codes?**
- **XSIF Extended Standard Input Format**
  - **Many Simulation Codes utilize it**
  - **SAD does not**
  - **Currently a Conversion Tool is Used to for These Input Formats**
  - **XSIF (LIBXSIF) inclusion in SAD?**
- **Yet another Generalized Input Format?**
  - **Separation between Beamline Geometry (relatively static) and Beam Optics (more varying)**
  - **Could be structured into XML**
- **Relational information to each Hardware Components**
  - **We do not prefer complicated relations**

The Dogbone lattice was reproduced on SAD successfully.



- MAD to SAD conversion by Koiso.
- Class library: acsad0.kek.jp:/users/oide/ILC/DR/DB.n
- CVS repository by Ohnishi.

by Oide

Accelerator Controls

Accelerator Controls

- **Definition and goal**
  - **Specified only after technical details of the accelerator is decided**
    - **Of course the final goal is the science achievement**
  - **Often change after commissioning**
    - **Many prefer to flexibility as well as to robustness (depending on the purpose)**
    - **Should support rapid development to realize novel ideas immediately**
  - **Unfortunately we don't have general accelerator controls**
    - **We may have to make something**

History

- **Discussion of accelerator controls**
  - **At ICALEPCS conferences**
    - **After some success of NODAL at SPS/CERN**
    - **Needs for more general software tools**
  - **NODAL was chosen at TRISTAN**
  - **SLC/SLAC used Micros + VMS**
  - **Standard model**
    - **Field-network + VME + Unix + X11**
  - **Software sharing**
    - **Definition of a Class to represent whole accelerator**
      - **Which was impossible**
  - **More common control system with extended API**
    - **ncRPC/CERN, TACL/CEBAF, ACNET/Tevatron, etc**
    - **EPICS got popular maybe because of the selection at SSC, APS, CEBAF, BESSY, …**
  - **Then more object oriented software (naturally after RPC)**
    - **More computer aided development possible**
    - **CICERO/CERN, TANGO, CORBA+Java, CERN, …**
    - **Windows/Microsoft, …**

No common controls yet

- Balance between many available technologies
- **Object-oriented vs. Channel-oriented**
  - Object-oriented technology
    - More support benefits from software engineering
    - Extendable, clearer definitions
    - Different people have different ideas on control objects
  - Channel-oriented technology
    - Flat (one-layer structure), simple, scalable
    - Not much support from software engineering
    - Easy to make gateways

More balances

- **Compiled language vs. interpretive language**
  - **Two level languages**
    - **Interpretive language for rapid prototyping**
    - **Compiled language for established algorithms**
  - **After too much success of NODAL**
  - **Compiled languages programmed by expert**
    - **Documentation, maintenance, policy-driven**
    - **Manageable, then reliable**
  - **Interpretive/scripting languages**
    - **Rapid development**
      - **Realization of novel ideas in hours**
    - **Everyone attends the construction of operation environment**
    - **Another level of management/maintenance required**

More balances

- **Best & aggressive vs. moderate & conservative**
  - **New technology is attractive**
    - **But can be a “fad”**
    - **Can we justify the choice?**
  - **For longer life-span, which is better?**
    - **Life of accelerator is often very long compared with**
      - **User facilities**
      - **Commercially available software/communication technologies**
    - **Operational performance continuously advances**
  - **Accumulation of operation knowledge base**
    - **Stored mainly as software and database in the control system**
      - **Beam stabilization algorithms, hardware startup procedures, etc**
  - **It is valuable treasure**
    - **There should be mechanism to keep such resources**
      - **With longer life-span**

More balances

- **International vs. de-facto standards**
  - **International organizations pursue ideal solutions**
    - **Sometimes they don't become de-facto standards**
    - **Selection of one of many standards is difficult**
  - **Watching the market**
    - **TCP/IP network, Unix/Windows operating system, VME boxes**
  - **Advantages of de-facto standards**
    - **Economical advantage to select products out of markets**
    - **Save man-power avoiding proprietary development**
    - **Solutions will be provided for the old standard in the next generation**
    - **As a whole, it is good for long life-span**

Available Technologies

PLC

- **Programmable Logic Controllers (PLC)**
  - **Rule-based algorithms can be well-adopted for simple controls**
  - **IP network for the both controls and management were preferable**
    - **Especially at KEK/Linac which has a policy of IP only field network**
  - **~150 PLCs at Linac since 1993, and also many at J-PARC**
  - **Isolated/separated development becomes easy**
    - **Outsourcing oriented**
  - **Equipment developer oriented**
    - **Many maintenance capabilities were implemented**
  - **IEC61131-3 Standards**
    - **5 languages, with emphasis on naming**
    - **Not so popular in Japan**
    - **Effort to make common development environment**
    - **XML representation of resources**
    - **Should be paid more attention**
  - **Redundancy**

Network with only IP/Ethernet

- **The policy chosen when we upgrade Linac in 1993**
  - **Make network management simpler**
    - **Faster switches, routing, network-booting, etc.**
  - **Avoid Hardware failure and analysis effort with old field network**
    - **Home-grown field networks need much dedicated man-power**
  - **Cost for optical Ethernet went down at around 1995**
    - **Linac has high-power modulator stations, noise source**
  - **Nowadays many facilities have this policy with GbE**
    - **J-PARC controls basically followed this**
  - **More and more intelligent network devices**
    - **ex. Oscilloscopes with Windows/3GHz-Pentium built-in**
    - **Even EPICS IOC, MATLAB, or others can be embedded**
  - **Network components can be replaced one-by-one**
  - **Security consideration will be more and more important**

FPGA

- Another “everywhere” after IP network
  - Digital circuit and software can be embedded in to one chip
    - Even CPU core is embedded
    - Flexible and robust, wonderful platform for local controls
      - Sometime terrible source of bugs
  - Nano-second level timing
  - More and more gates, memory, pins, etc
  - More software support

ATCA and μTCA

- **Advanced telecommunications computing architecture**
  - Accommodate several 100ohm serial buses
  - GbE or PCI-express, 10GbE, etc
  - Typically 14slots in 19" and 12-unit height
  - Shelf manager manages healthiness of the system
    - through Intelligent Platform Management Interface (IPMI)
  - Many reliability improving facilities, redundancy, hot-swap, etc
- **MicroTCA**
  - More recently defined in 2006, based on AdvancedMC Mezzanine Card defined in ATCA
  - Begin to have many facilities from ATCA

EPICS

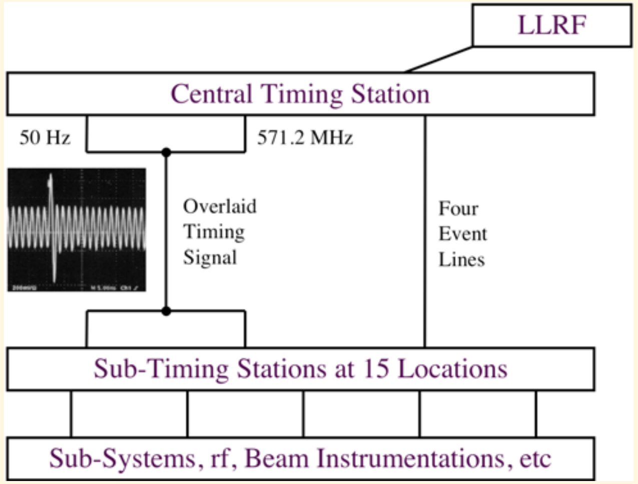
- Now is a kind standard, but …
- Object-oriented design support
  - Naming scheme, and/or design of new record
  - More software-engineering support favored
    - Several different efforts to provide better environment
      - Java IOC (M. Kraimer), Control system studio (M. Clausen), Data access (R. Lange)
- Security mechanisms
  - User, Host-based protection available
  - More security
    - Dynamic controls of security
    - Access logging
- Dynamic configuration of database
  - Dynamic creation / loading of records
  - Dynamic removal of records
    - Maybe some part of the codes can be shared with redundant-IOC project

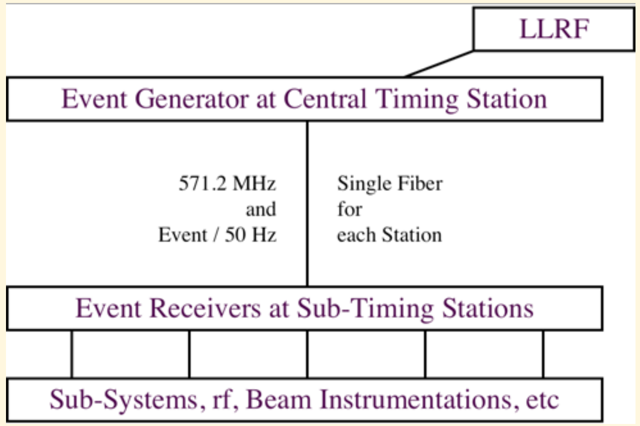
Magnet Controls

- **It is typical controls and still many things to do**
- **Many magnets and many power supplies**
    - **No one-to-one correspondence**
  - **Which hardware interface to use**
- **Procedures**
  - **Interlock status, on/off, analog with some precision, etc**
  - **Energy, kick - field - current conversions**
    - **How to represent those conversion curves**
  - **Timing synchronous operation**
    - **for tune change, orbit correction, etc.**
  - **Standardization**

Timing Event System

- **Present Timing System**
  - **Provides ~3pico-second Timings to ~150 Devices**
  - **Only 4 Events can be Distinguished**
  - **VME(x6) and CAMAC(x10)**
- **Diamond Event System**
  - **Single Fiber can Transfer Clock, Delayed-Timings, Events (256), Data Buffers (2k-bytes)**
- **New IOC**
  - **MVME5500**
  - **RTEMS (developed at BNL)**
    - **(May migrate to VxWorks if KEKB upgrades Vxworks)**
  - **EPICS Driver/Device Support from SLS/Diamond/SLAC/LANL**





Reliability

Reliability

- The end user expect rigid reliable operations
- Inner layers need flexibilities
  - Because of daily improvement
- Compromise between
  - Practical or ideal solutions
  - Aggressive and conservative
  - Under restrictions of
    - Time, safety, budget, man-power
- Here we think about

  adaptive reliability

hardware
hardware Interface
equipment controls
beam controls
linac
ring
accelerator physics
beam delivery
detector
data acquisition
computing
physics, chemistry,
medical treatment

Reliability Increase without much Cost

- **There should be "right way"**
  - **We hope to have it some day, but for now we need interims**
- **Surveillance for everything**
  - **Well-arranged system does not need this, but…**
- **Testing framework**
  - **Hardware/Middleware tests just before Beam**
  - **Software tests when installed**
- **Redundancy**
  - **In Many Hardware/Software components**
  - **Of course some of them are Expensive, but…**

Surveillance for everything

- **We have written too many pieces of software**
  - **which assume certain circumstances unfortunately**
    - **which will fail some day**
  - **in scripting languages too rapidly and too easily**
    - **without documentations**
- **We manage too many computers**
  - **If only one, I'm almost sure I can make it stable**
    - **But in reality even hostname can be mis-labeled**
- **We installed too many network components**
  - **without good network database etc**
    - **which sometimes has bad routing information, etc**

Surveillance for everything

- **If certain installation of (software/hardware) was not ideal**
  - **Find out**
    - **What is the most important feature of the installation?**
    - **What is the easiest test for its healthiness?**
  - **Routine test is carried automatically**
    - **by cron or continuous scripts**
    - **If an anomaly found,**
      - **Alarm, e-Mail to the author, make error log**
      - **Restart related software, if not critical**
      - **Report to the human operator, if critical**
  - **Not ideal, but effective under limited human resources**

Software Testing

- **Moving operating environment**
  - **For better resource performance**
    - **We tend to do it because of the pressure from budget restrictions**
  - **May lead to malfunctions**
    - **We knew they may happen**
- **Automatic software (hardware) tests preferable**
  - **Under new environment (machine, compiler, network, etc)**
    - **Many kinds of important free software does them**
    - **Language systems, Linux Test Project**
- **We do some tests**
  - **But sometimes not enough**
  - **More thoroughly prepared tests needed**

Testing Framework

- **When we introduce new environment**
  - **Unit test**
    - We don’t do it much yet
    - EPICS began to have it, “make runtests”
      - Collecting existent test cases
      - User can provide tests in Perl/Test framework
    - Hope to have for SAD and SADscripts
  - **Regression tests**
    - We have something, but not thorough, not exhaustive
    - Difficult to collect cases
  - **Stress tests**
    - We do it during operation (?)
    - We know computers rarely fail, but network/network-devices do
      - Find solution
      - Development of surveillances
      - Installation of failure-recovery or failover procedures

Testing Framework

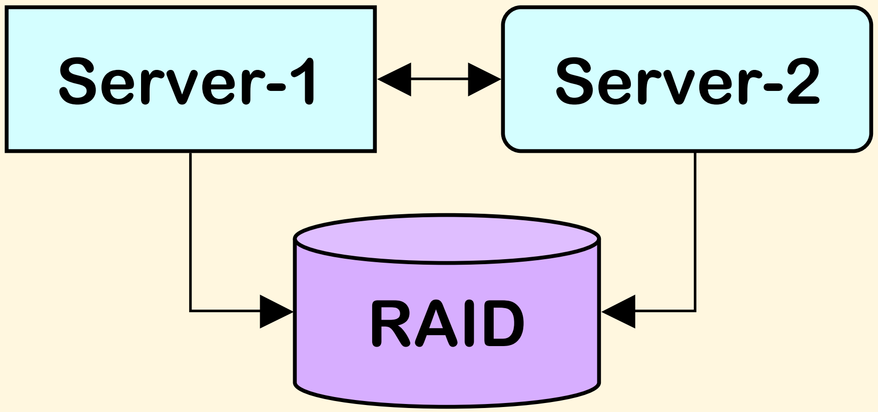
- **When we start new run**
  - **New software/hardware**
    - **We test unit by unit**
    - **But not through operational tools prepared**
  - **Maintenance works**
    - **We often forget to restore/initialize cables, switches, variables**
    - **Power-stop may bring another annoyance**
- **We need routine procedures which include**
    - **Hardware tests**
    - **Name/ID matching**
    - **Database tests**
    - **Software component tests**
    - **Software/Hardware simulation tests**
  - **Before beam operation**
  - **We do it mostly by operator observations based on written procedures**
  - **CERN did some efforts**

Redundancy

- **Do we need redundancy?**
    - Redundancy may be the last-resort measure
    - It may cost
  - Centralized facilities are easier to manage
    - If I have only one server, my life is much easier
  - But they become complicated monsters
    - Nobody understand everything
- **Especially useful for maintenance**
  - Not only for failure-recovery
    - Redundant systems of complicated system; $(\text{complicated})^2$
- **Anyway we may have to prepare backups**
  - Then automatic failover is just around the corner
    - And ...

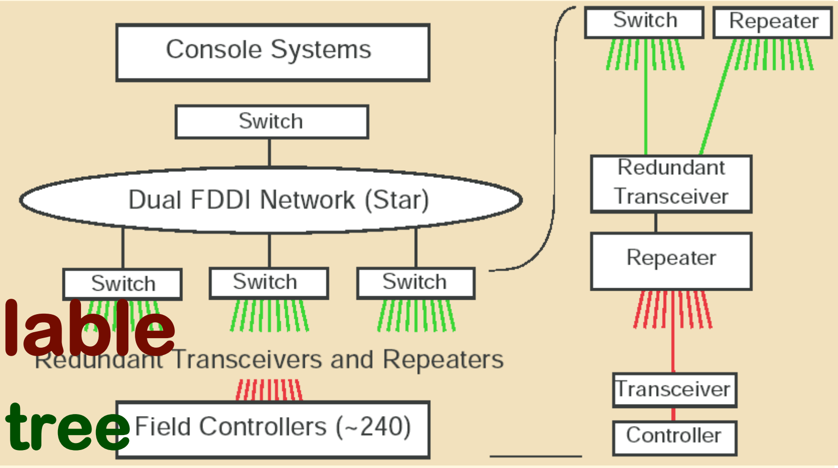
File server redundancy

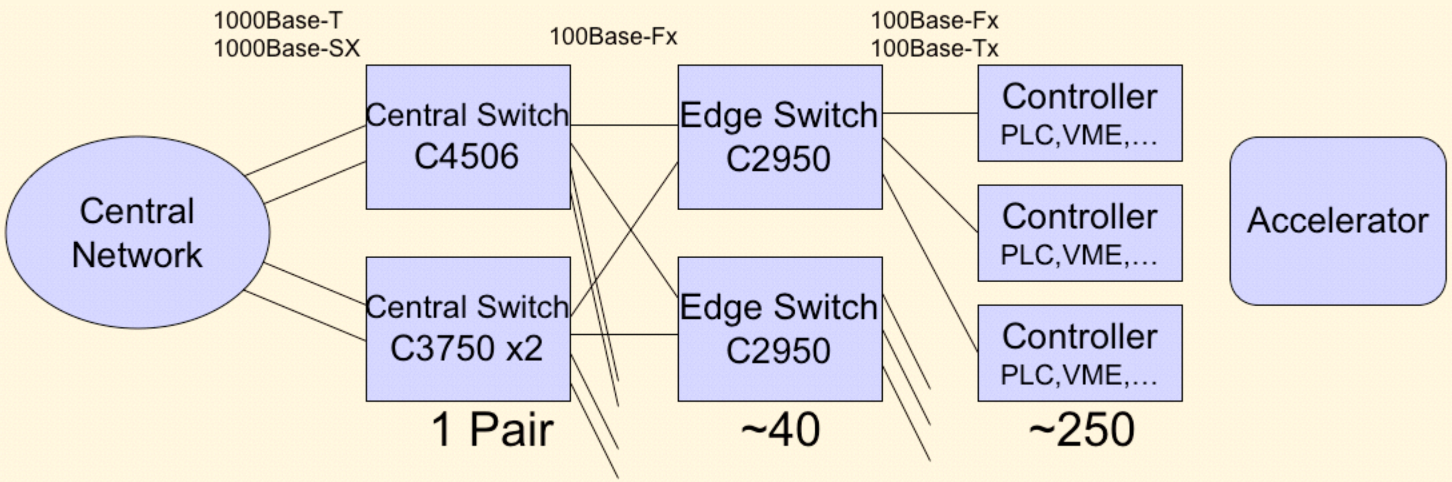
- RAID and Mirror-disks are used everywhere now
- We began to use Cluster software before KEKB
  - DECsafe, TruCluster for Unix
  - LifeKeeper, Redhat-AS, Rose-HA for Linux
  - NetApp
- It works at least for Hardware troubles; but sometimes for Software troubles
- Maintenance and Scheduling became easier



Network Redundancy

- **Mostly established technologies**
  - **Wide acceptance of Ethernet and IP**
- **> 10 years ago**
  - **Redundant Transceivers**
- **More recently Standards available**
  - **Hsrp or Vrrp and Rapid spanning tree**





Redundant PLC's

- CPU built-in redundancy is already used in several vendors
  - Dual main memory with checksum at every-cycle
  - ROM as well as flash memory
    - Bad circumstances at field forced them to implement it
- We just started to evaluate redundant CPU's
- Redundant PLC's are used at CERN
  - Siemens S7, slightly expensive
- Several possibilities in architecture
  - Single vs. dual backplane
  - Power-supply, CPU, Network-interface
  - I/O (?)

Redundant EPICS IOC

- **Redundant controllers are favorable**
    - as in PLCs
- **The project was started at DESY (M. Clausen)**
    - Redundancy monitor task (RMT)
        - Monitors healthiness of controllers
        - Manages primary redundancy resource (PRR)
    - Continuous control executive (CCE)
        - Synchronizes internal states
    - Modifications for several others PRR's
        - Scan tasks, Channel access server tasks, Sequencer, Drivers
        - Possibly user tasks
- **KEK joined in for wider applications**
    - Linux (OSI) port
    - Gateway applications
- **ATCA implementation possible**
    - For ILC (?), microTCA (?)

Software redundancy

- **EPICS IOC redundancy is slightly complicated**
  - **Since it has name resolution facility**
  - **More advanced**
- **Linac/KEK controls is simpler**
  - **Normally we run several middle-layer control servers**
    - **on separate machines**
  - **For EPICS gateway**
    - **We need redundant IOC technology**
- **Other existent servers**
  - **Recently more careful in redundancy**
    - **Like dchpd**
    - **Redundancy and replications**

Summary

Phronesis

- **Aristotle's view of wisdom.**
- **Contrary to Sophia; the ability to understand the universal truth**
- **Phronesis is the ability to find a way to achieve an overall goodness**

Summary

- **EPICS and SAD made KEKB a great success, but other accelerators have different criteria**
- **Accelerator controls design needs a balance between many aspects**
- **There are many good technologies waiting to be utilized**
- **Also more reliability features needed**
- **Share more experiences**
- **Phronesis**

Thank you