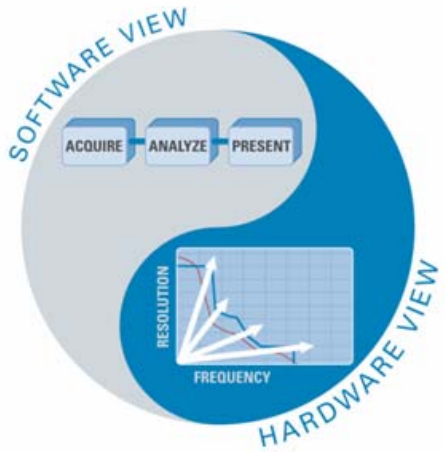
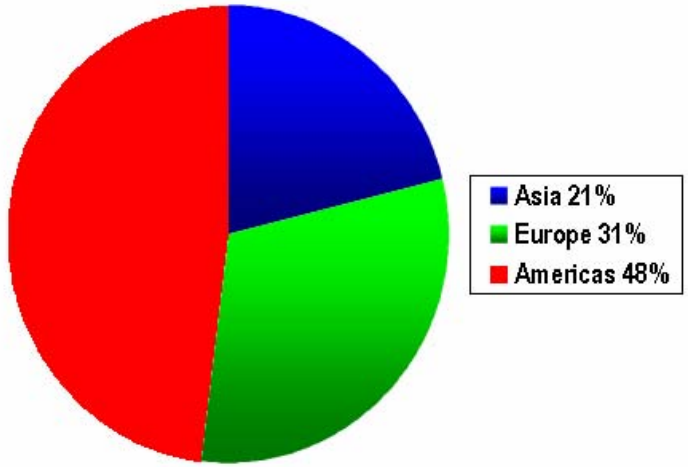


It's all about time

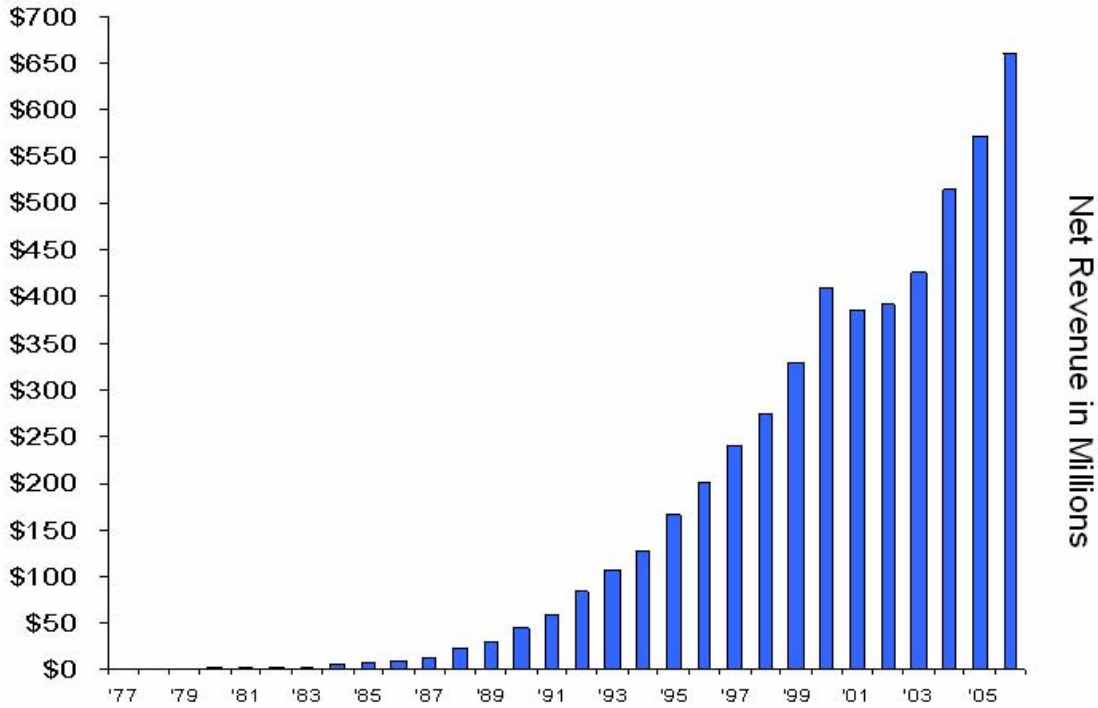
Software and Hardware Timing Elements

Jacob Kornerup, Ph.D.
LabVIEW R&D
National Instruments

National Instruments

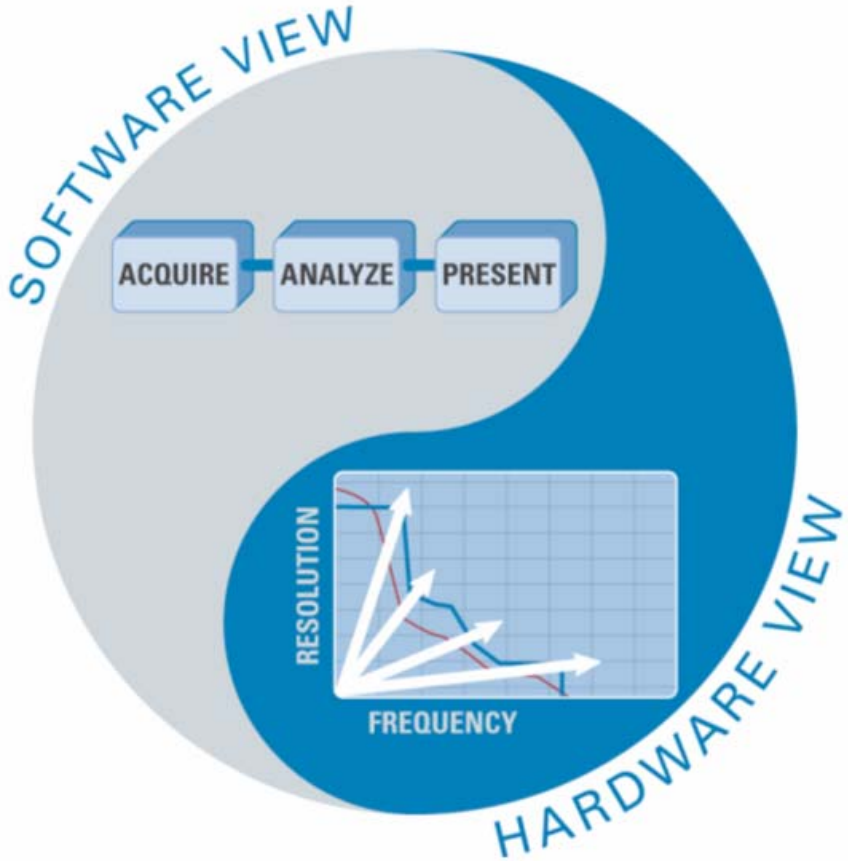


- *Leaders in Computer-Based Measurement and Automation*
- Founded in 1976
- Based in Austin, Texas
- More than 4,000 employees; operations in 40+ countries



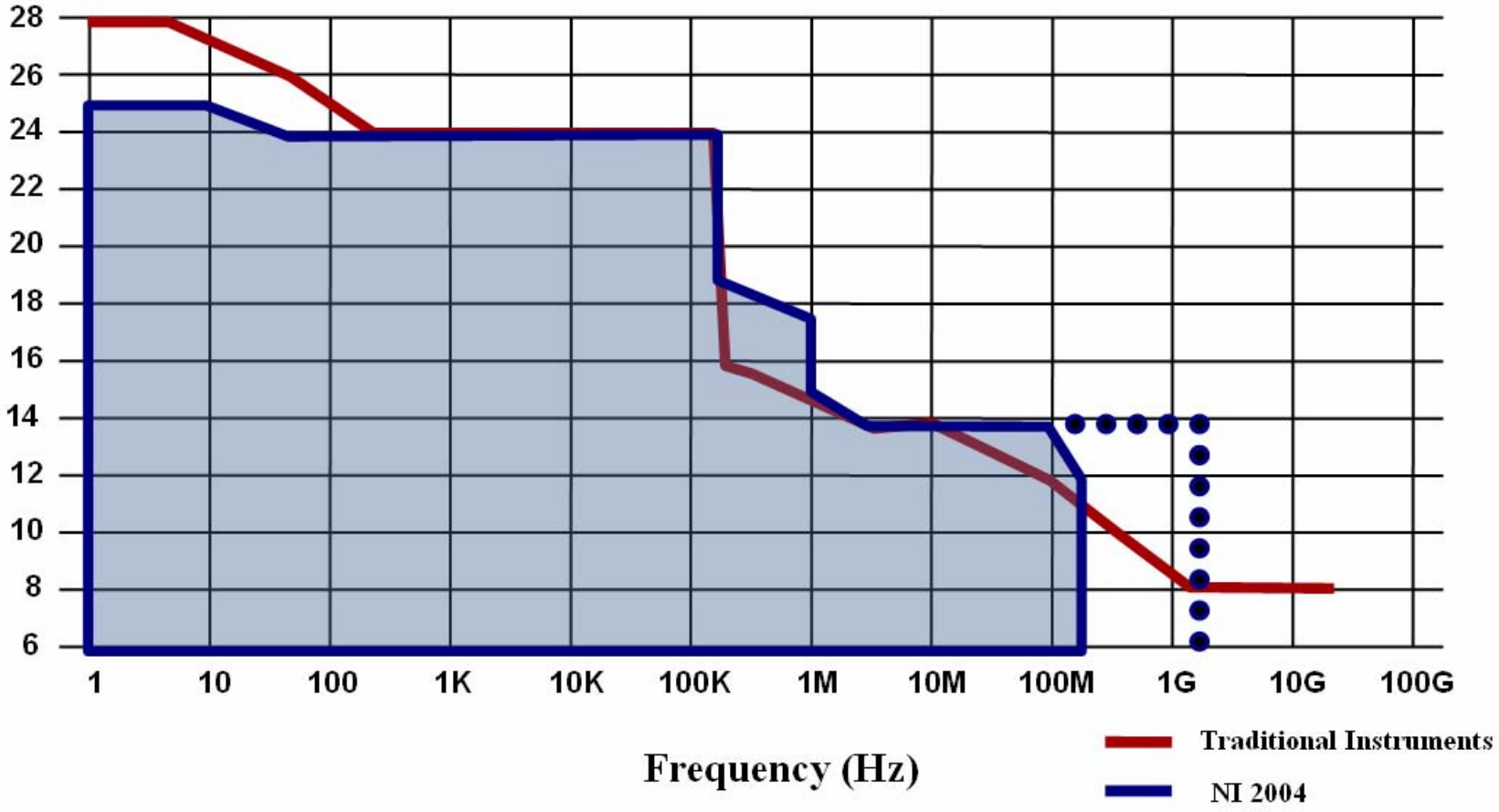
NATIONAL INSTRUMENTS

National Instruments Vision

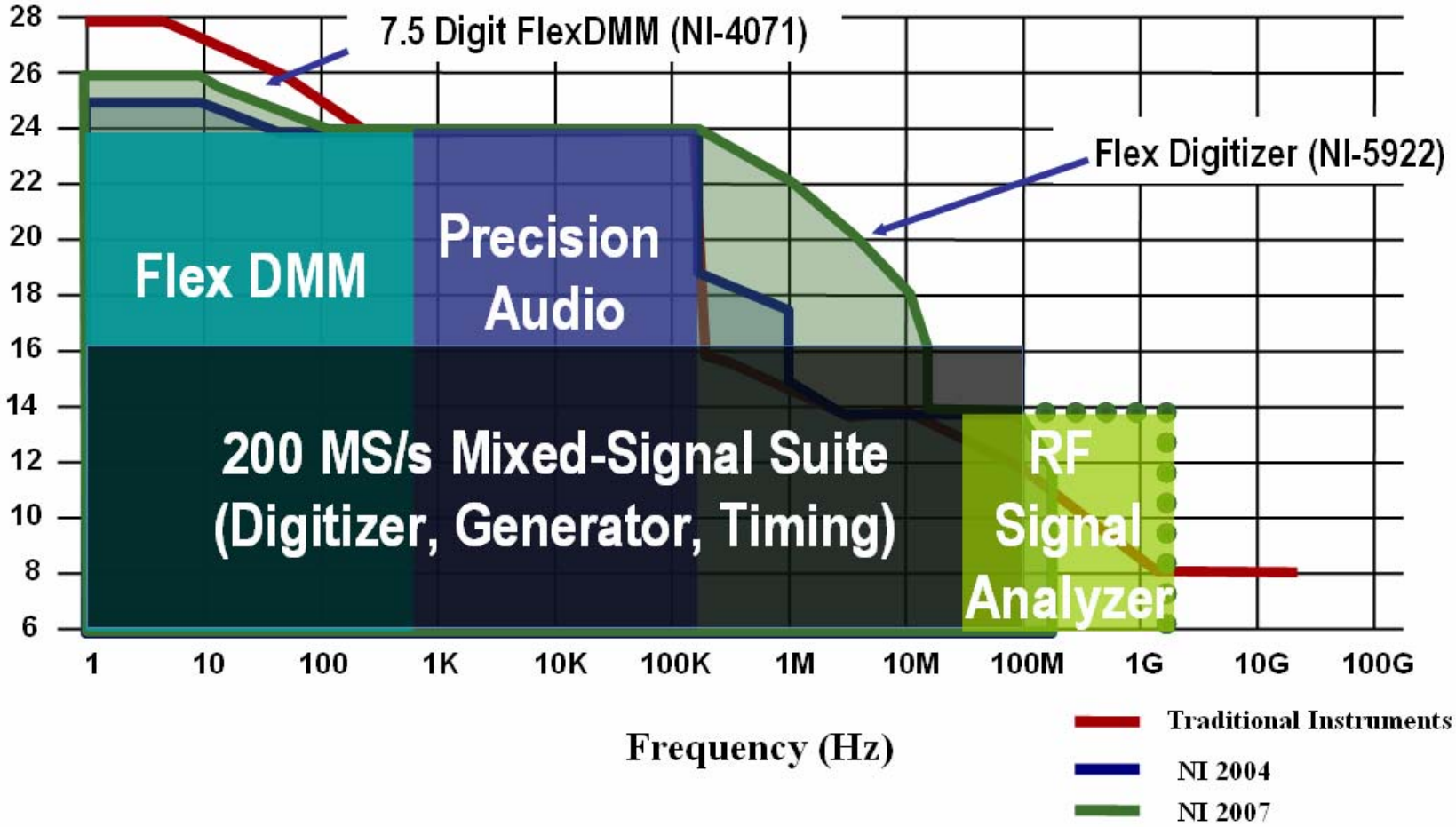


Graphical System Design

Leveraging Semiconductor Technology

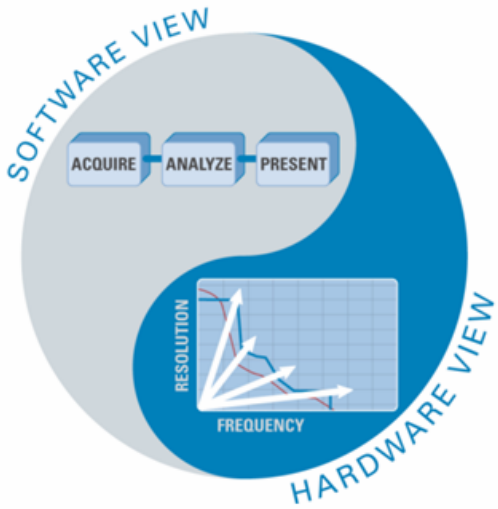


Leveraging Semiconductor Technology



Agenda

- Importance of Timing
- Role of Time in Measurements
- Role of Time in Concurrency
- Timing Technology Enablers

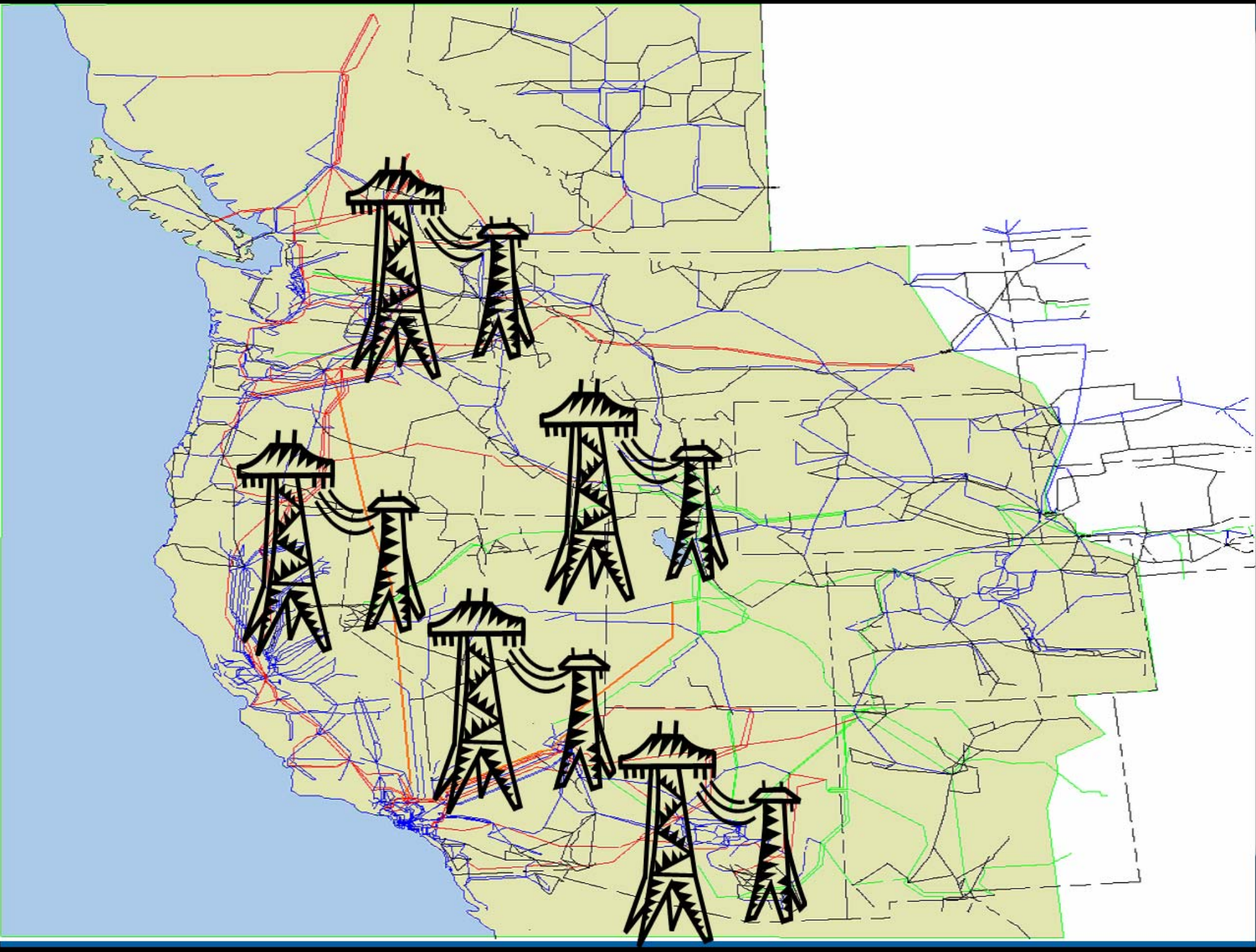


The world without timing

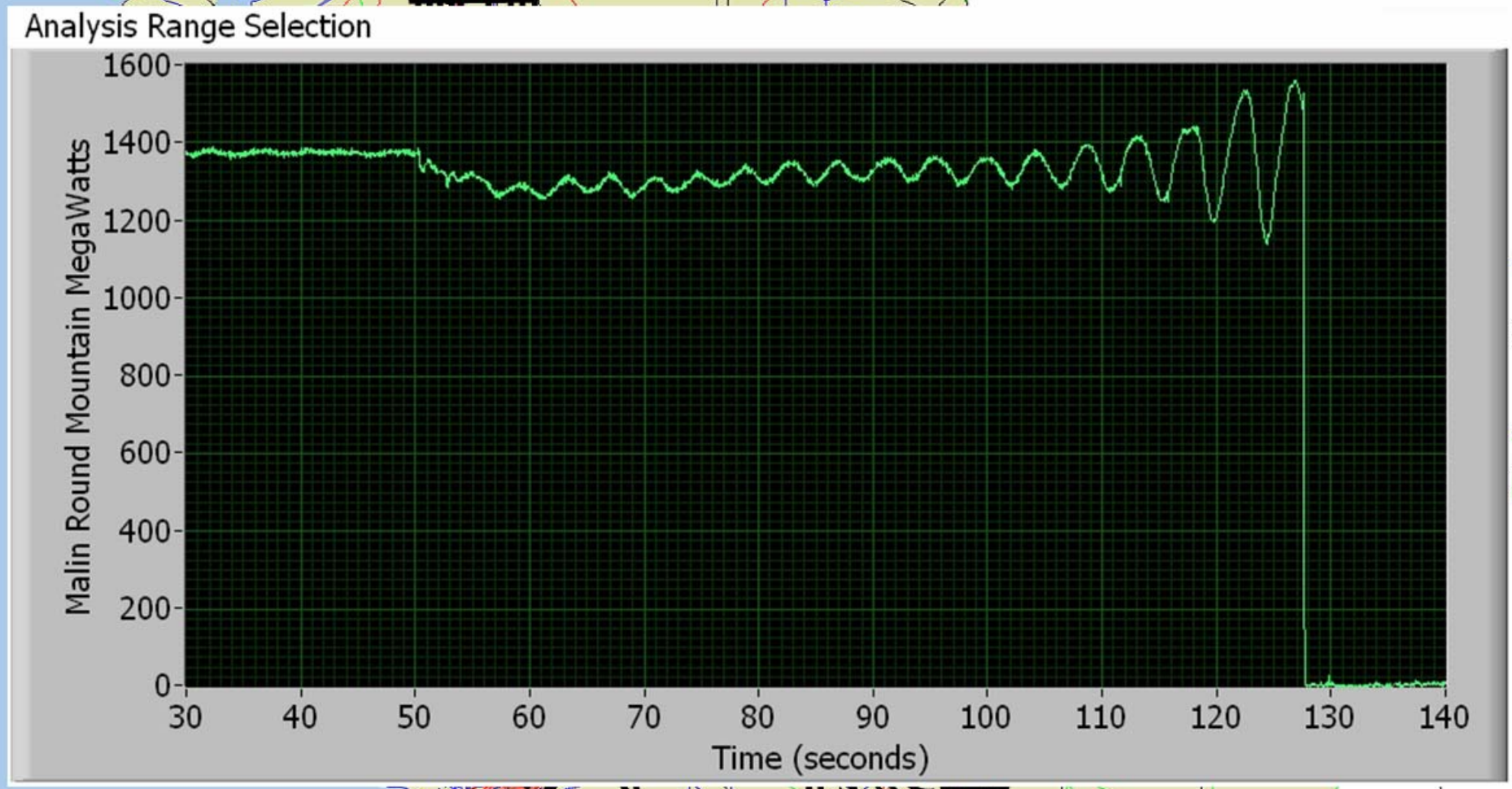
Functionality

Accuracy

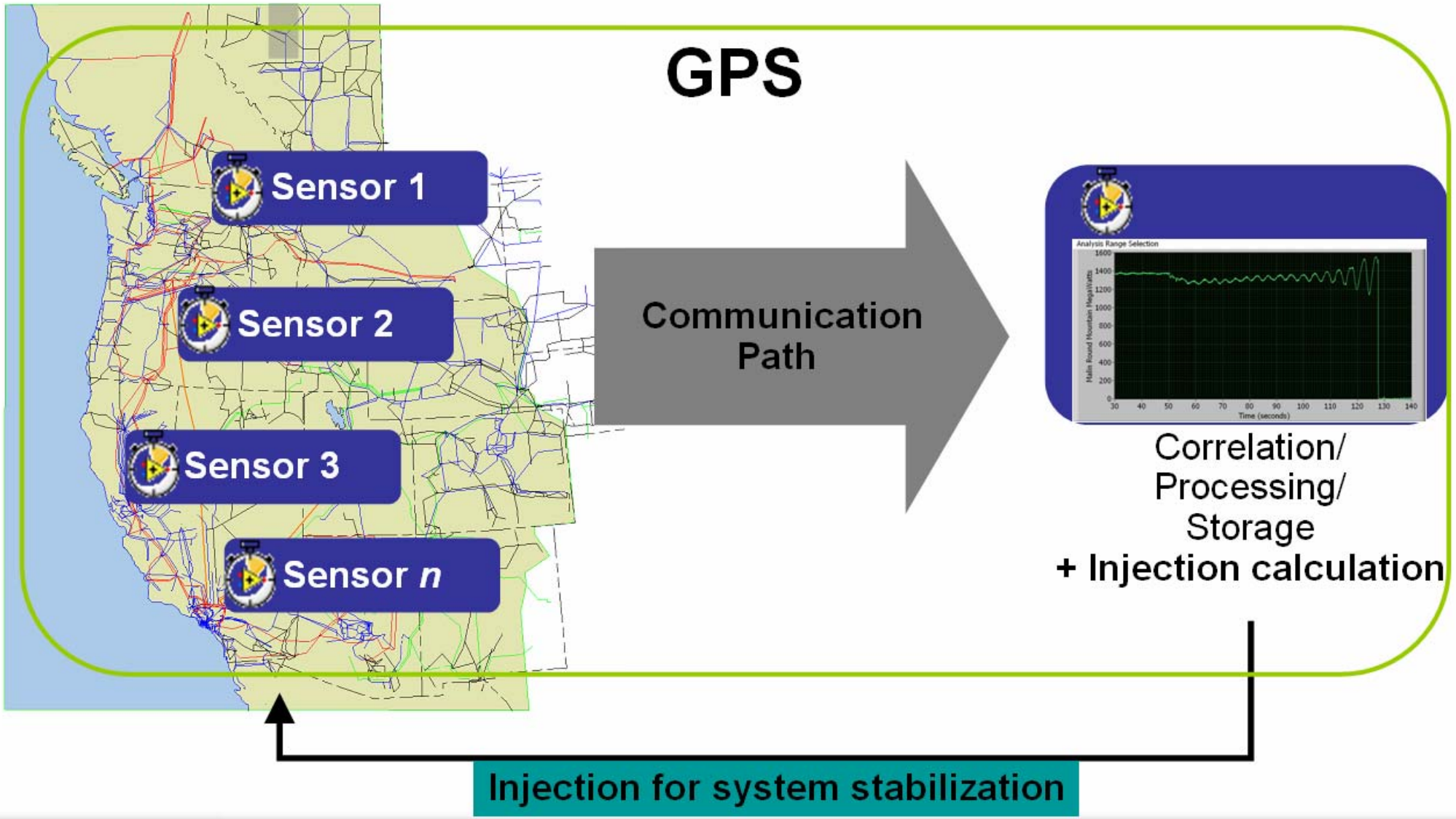
Safety



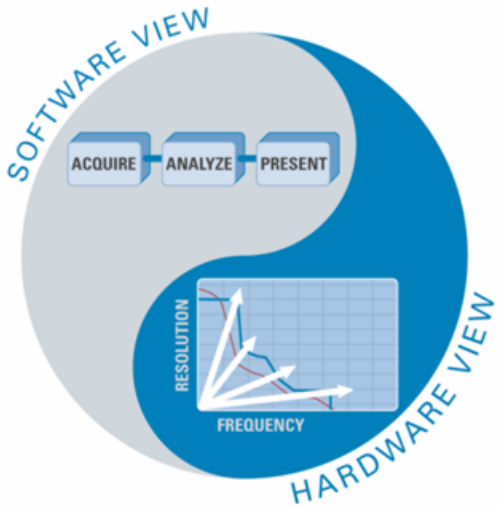
Actual Data from August 10th, 1996 Blackout



GPS Enables Stabilization System



The Role of Time in Measurements



Timing Considerations for Measurements

- Sample rates determined by physical phenomenon
- Triggers from external events
- Timed stimulus/response measurements
- Global triggers and clocks for synchronizing multiple measurement devices
- Buffers and FIFOs for storing acquired data
- Interrupts for transferring data

Technologies for Time and Concurrency

Time Scale

Nanoseconds

Microseconds

Milliseconds

Backplane timing

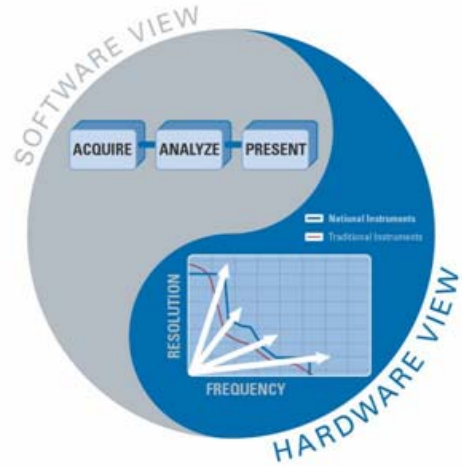
IO synchronized with a global clock

Software programmed FPGAs

Timed Loops

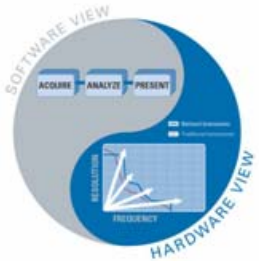
Software constructs: FIFOs and Queues

Structured dataflow



Flexibility

30 Years of NI Timing and Synchronization Innovation



GPIB Group Execute Trigger

Real-Time System Integration (RTSI) Bus

System Timing Controller ASIC(STC)

Timing I/O ASIC (TIO)

PXI Platform

PXI Slot 2 System Timing

Synchronization and Memory Core (SMC)

LabVIEW Programmable FPGA devices

PXI Express, IEEE-1588

1978 1986 1987 1994 1998 2003 2006

Timing Primitives

Occurrences

Events

Synchronization Primitives

Profiler

LabVIEW Real-Time for Deterministic Timing

State Diagram

Nanosecond Timing Engine

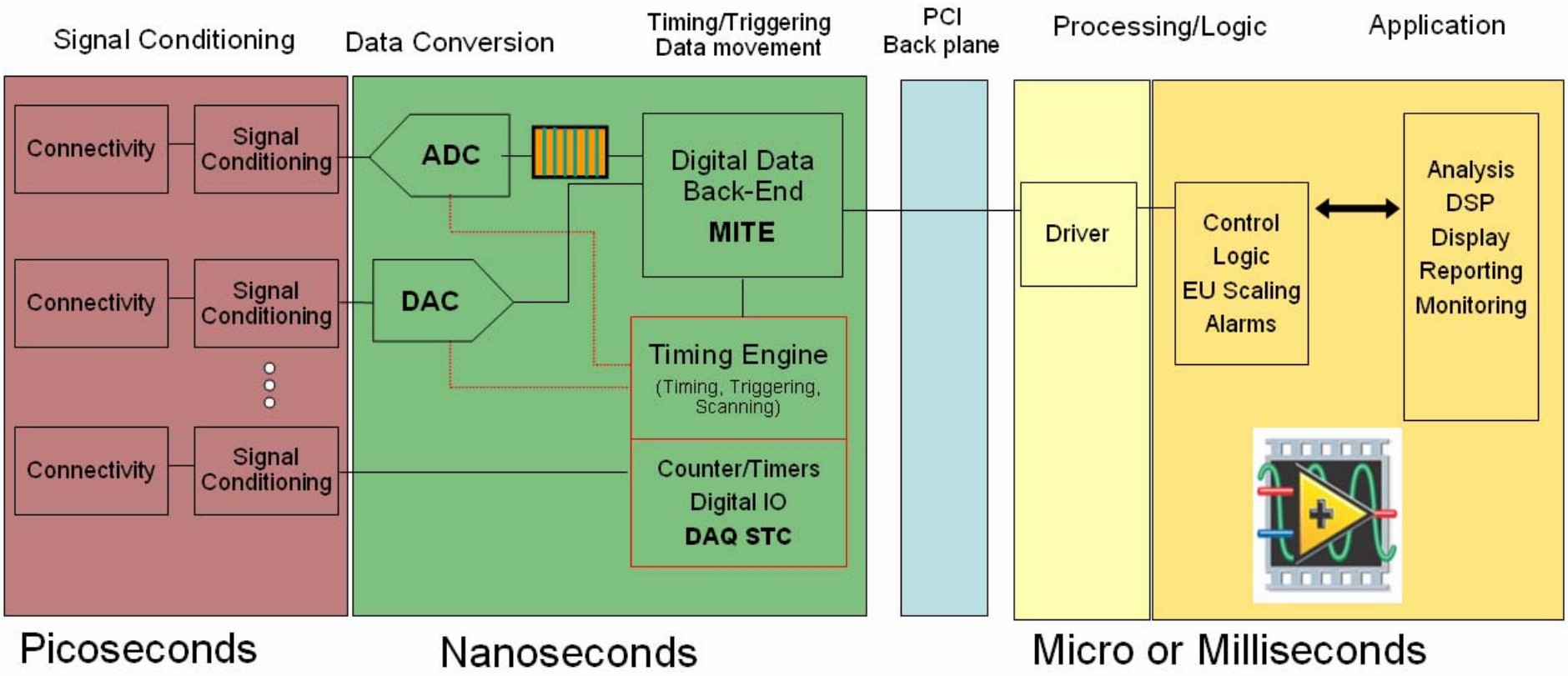
Elemental I/O

Timed Loop

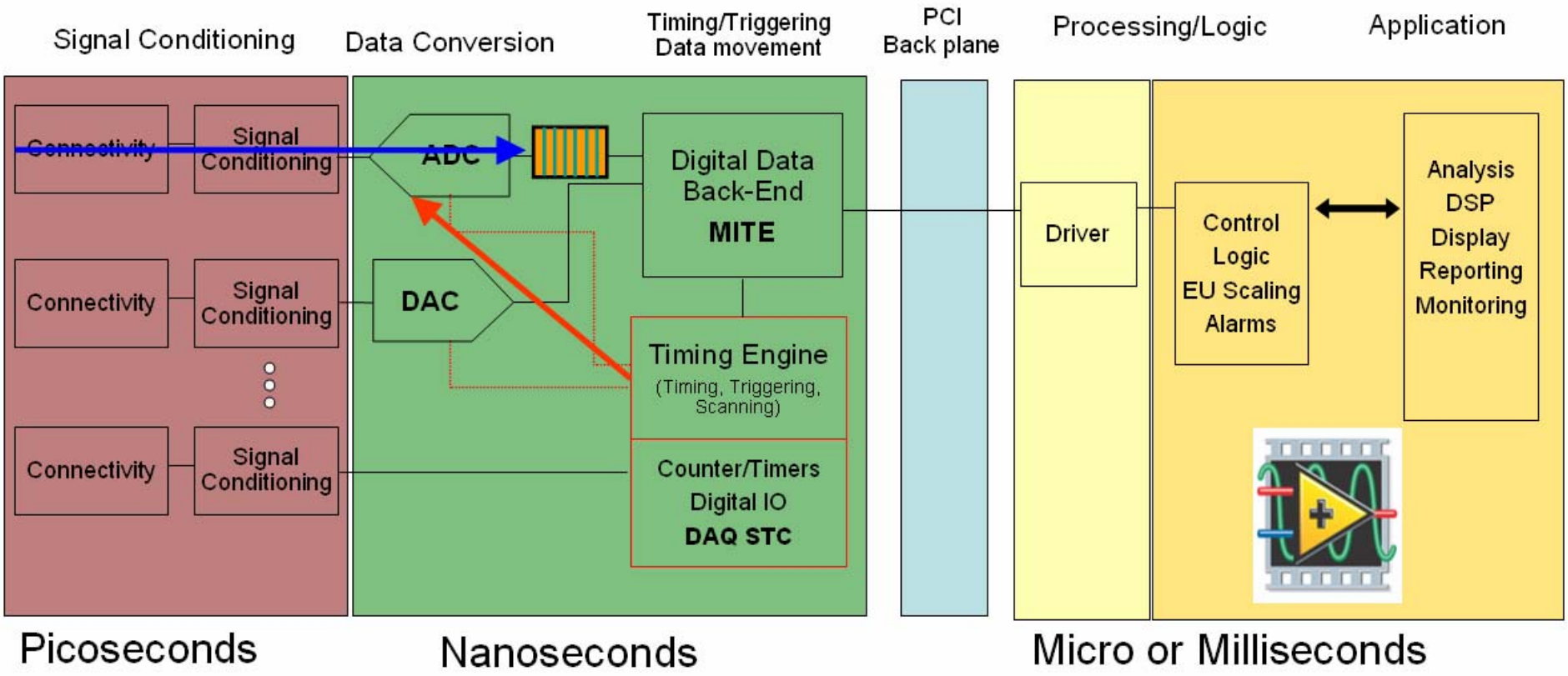
Distributed Time-Triggered Variable

LabVIEW FPGA for Defining Hardware Timing

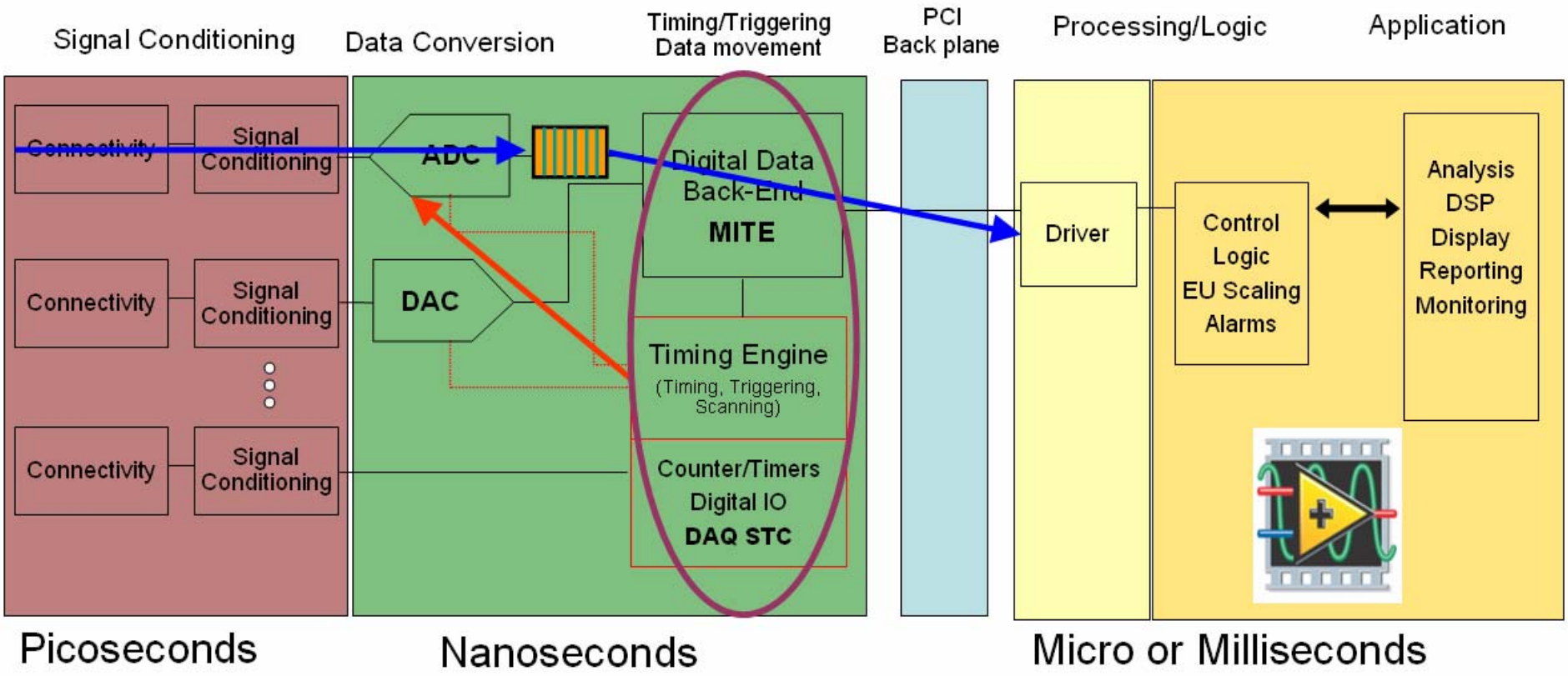
Data Acquisition



Data Acquisition

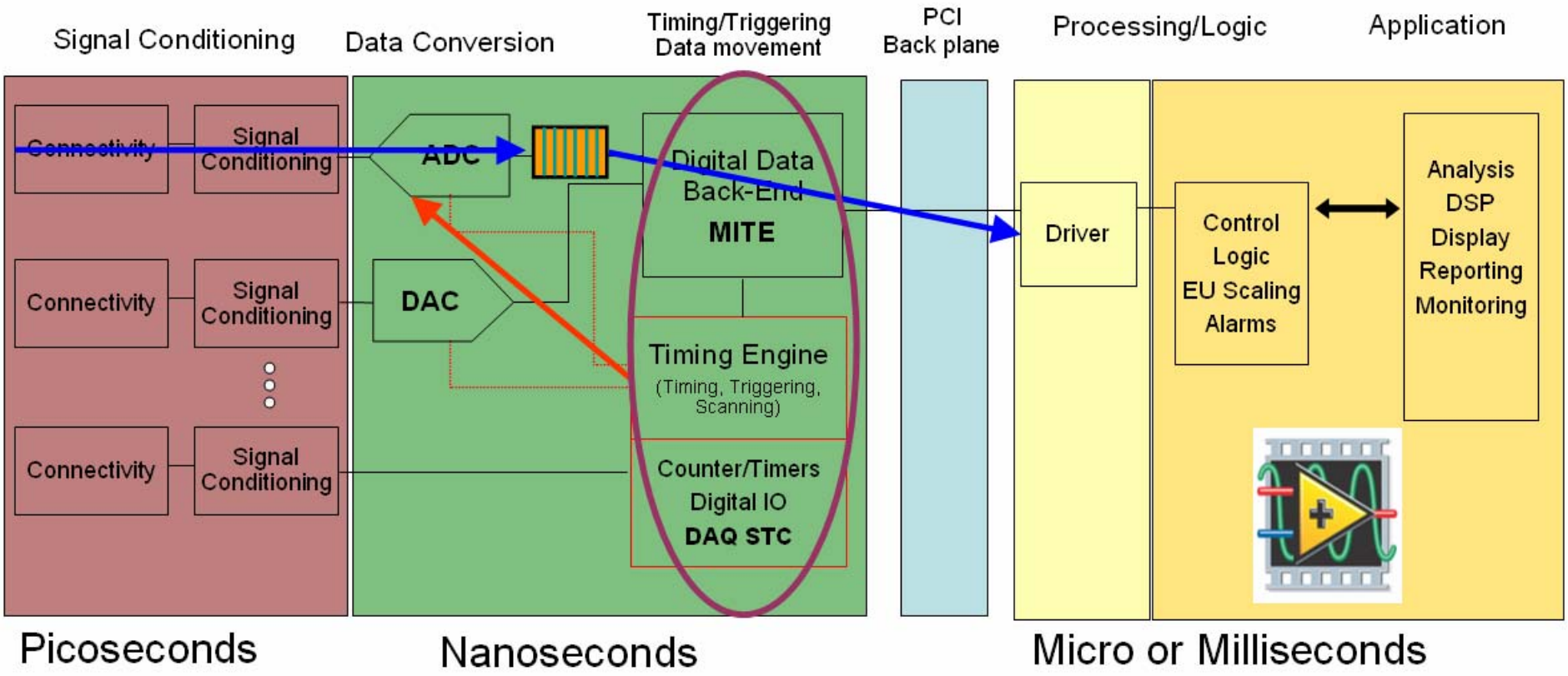


Data Acquisition



- IO "Operating System" implemented in

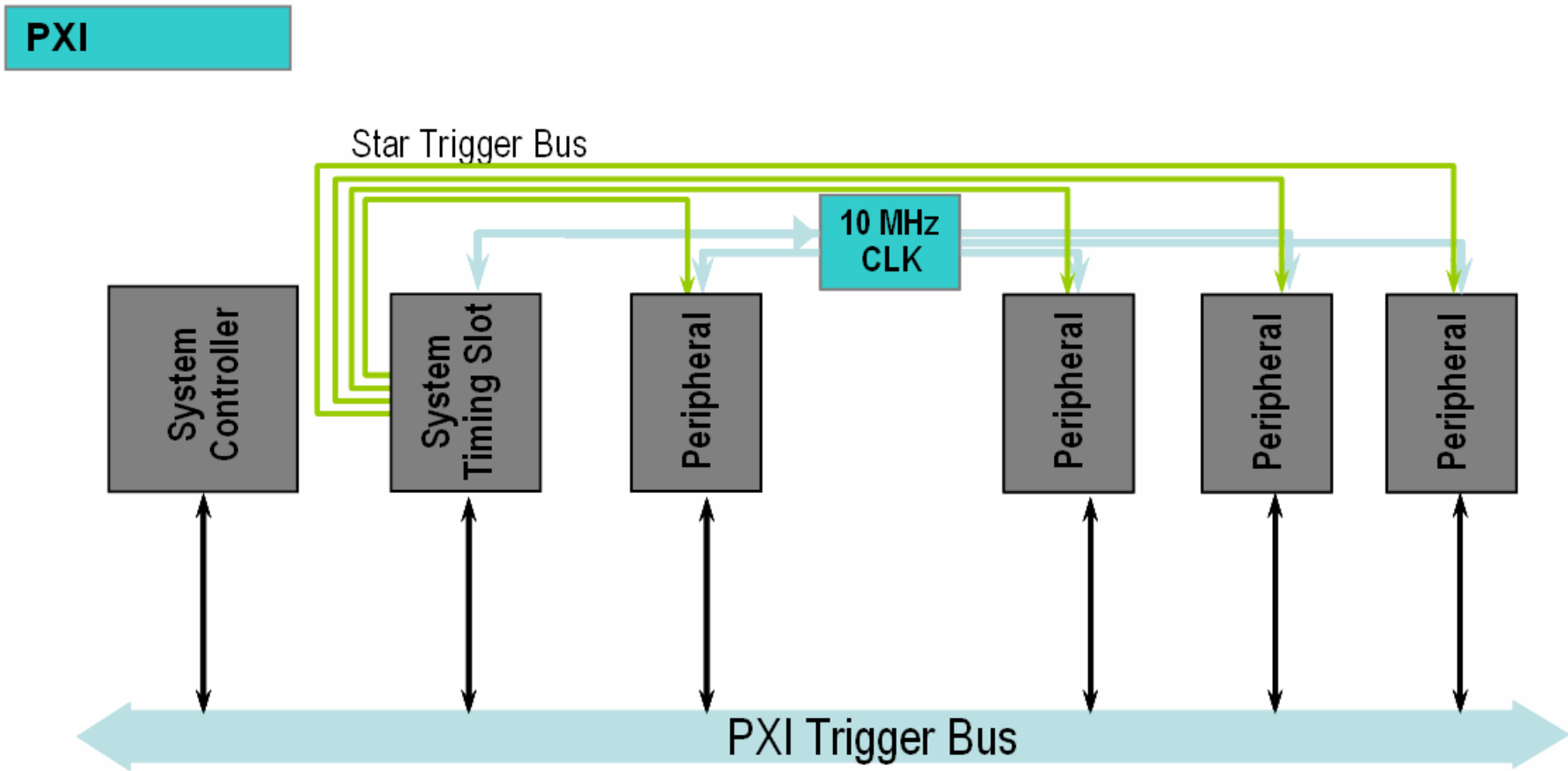
Data Acquisition



- IO "Operating System" implemented in hardware
- Continuous or finite, hardware-timed acquisition
- Host application does not need to be real-time

Considerations for Distance and Delay

- The delay of a signal is proportional to its travel distance
- PXI platform provides Star triggers
  - all trigger signals have the same delay (<1 ns PXI, <150ps PXI Express)



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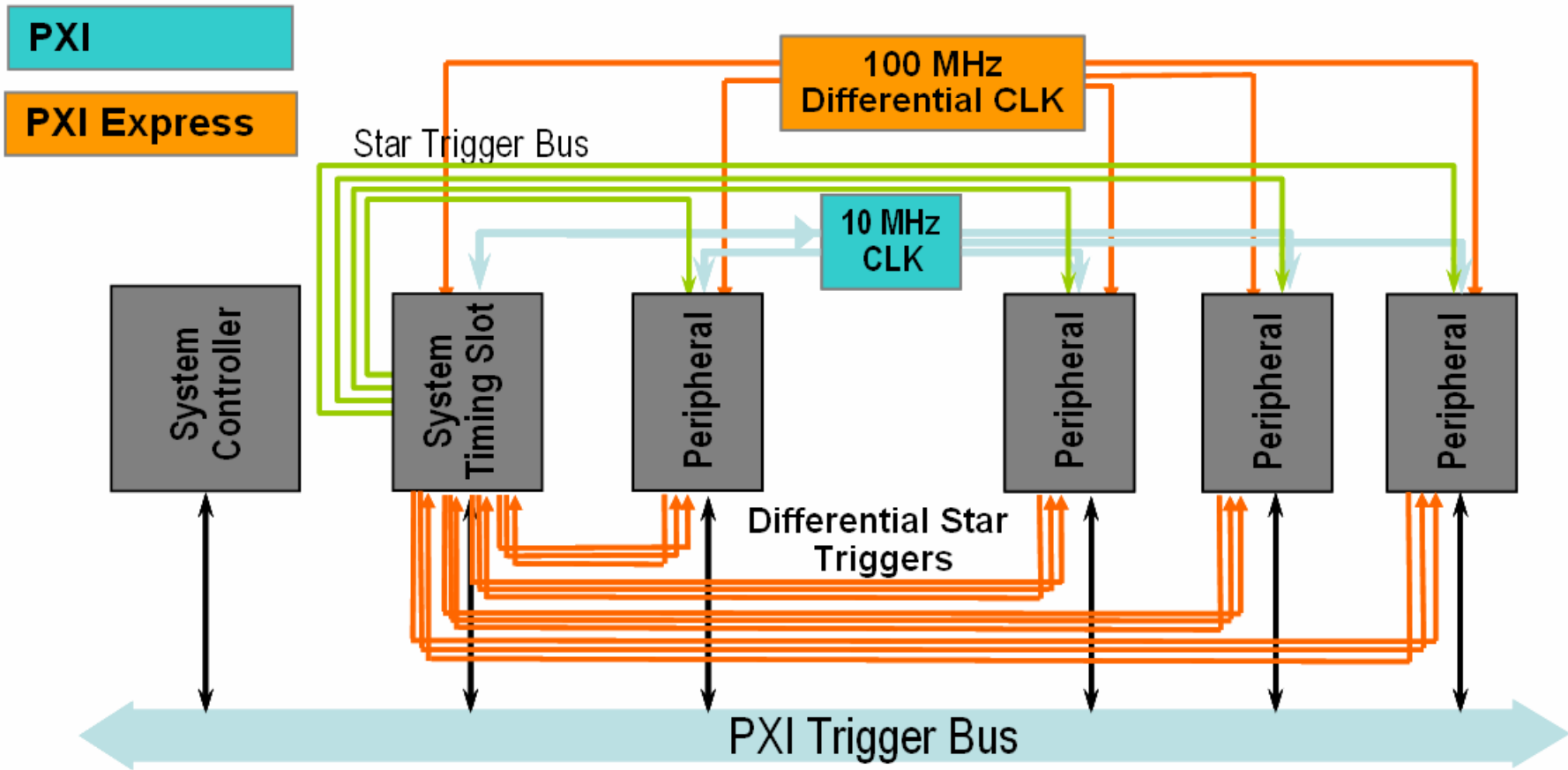


PXI Combines Standard Technologies

PXI controller
•OS Technology
•ADEs

Chassis

PXI backplane
•Bus Technology
•Timing
•Synchronization

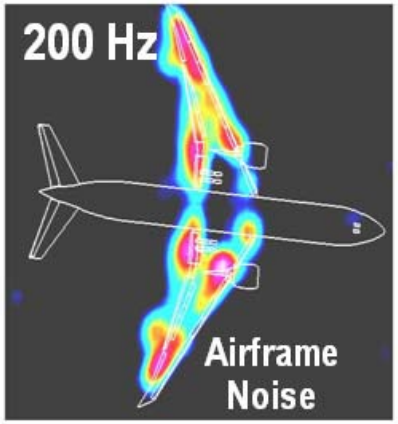
Peripheral Slots

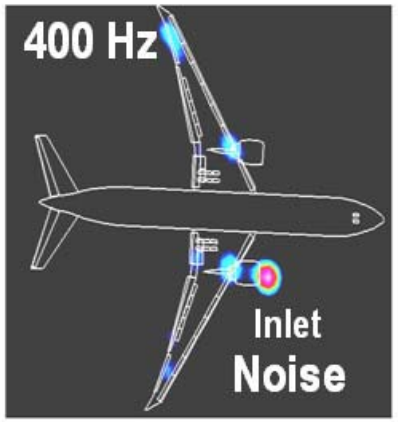
PXI Systems Alliance

Over 1500 PXI Products from over 70 Vendors

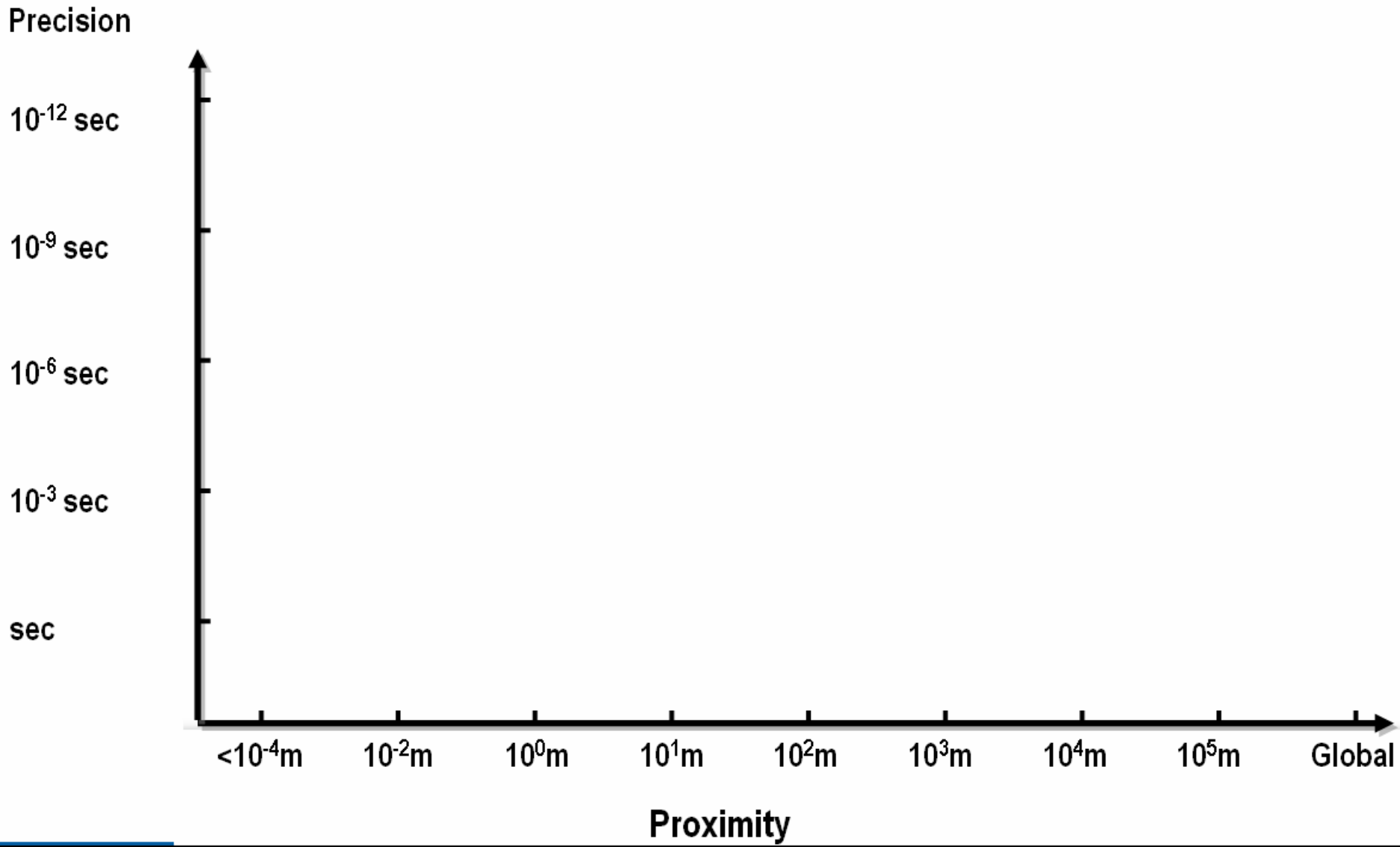
Flyover Test

Signal-based, synchronous and Distributed System

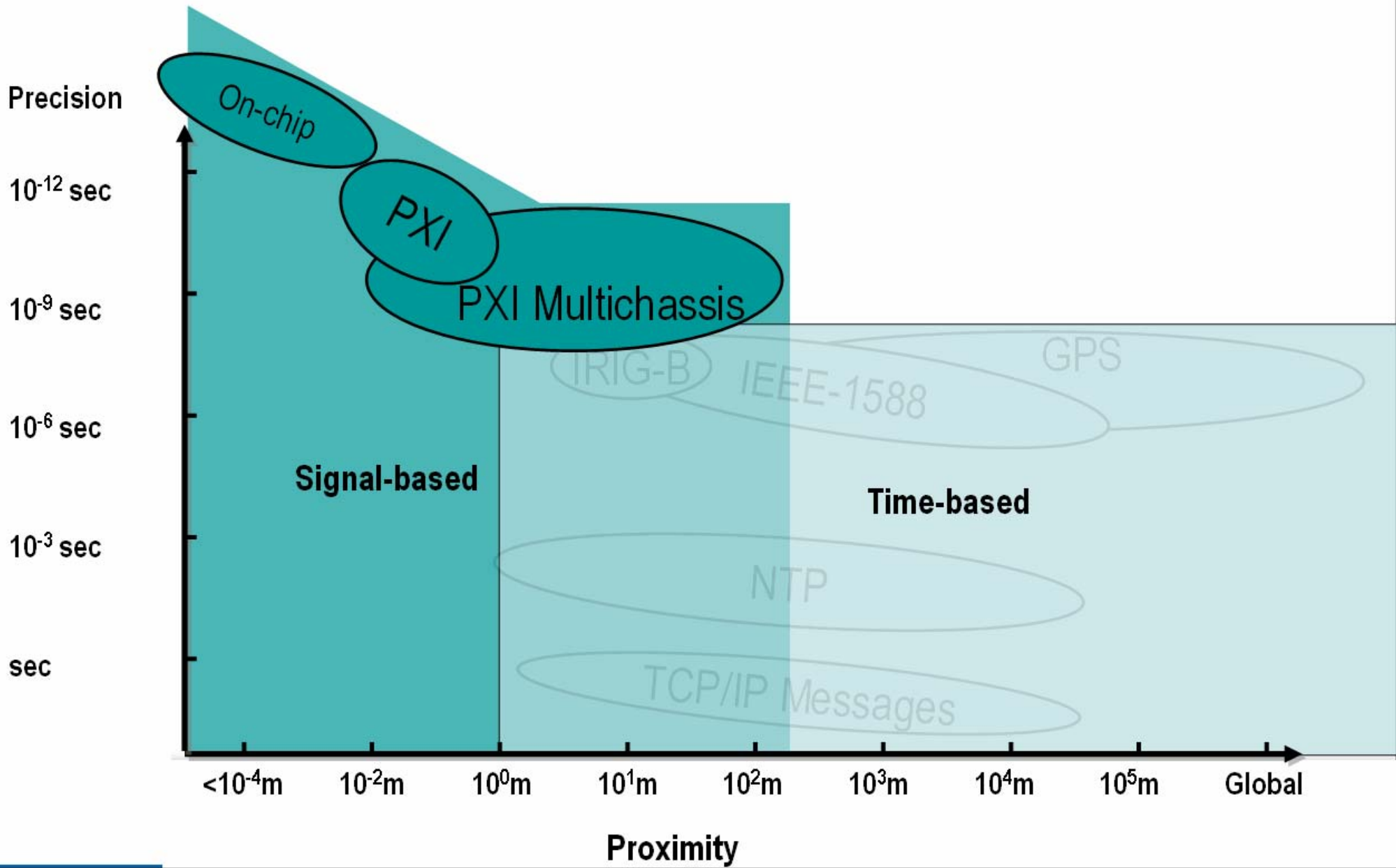




Comparing Synchronization Technologies



Comparing Synchronization Technologies



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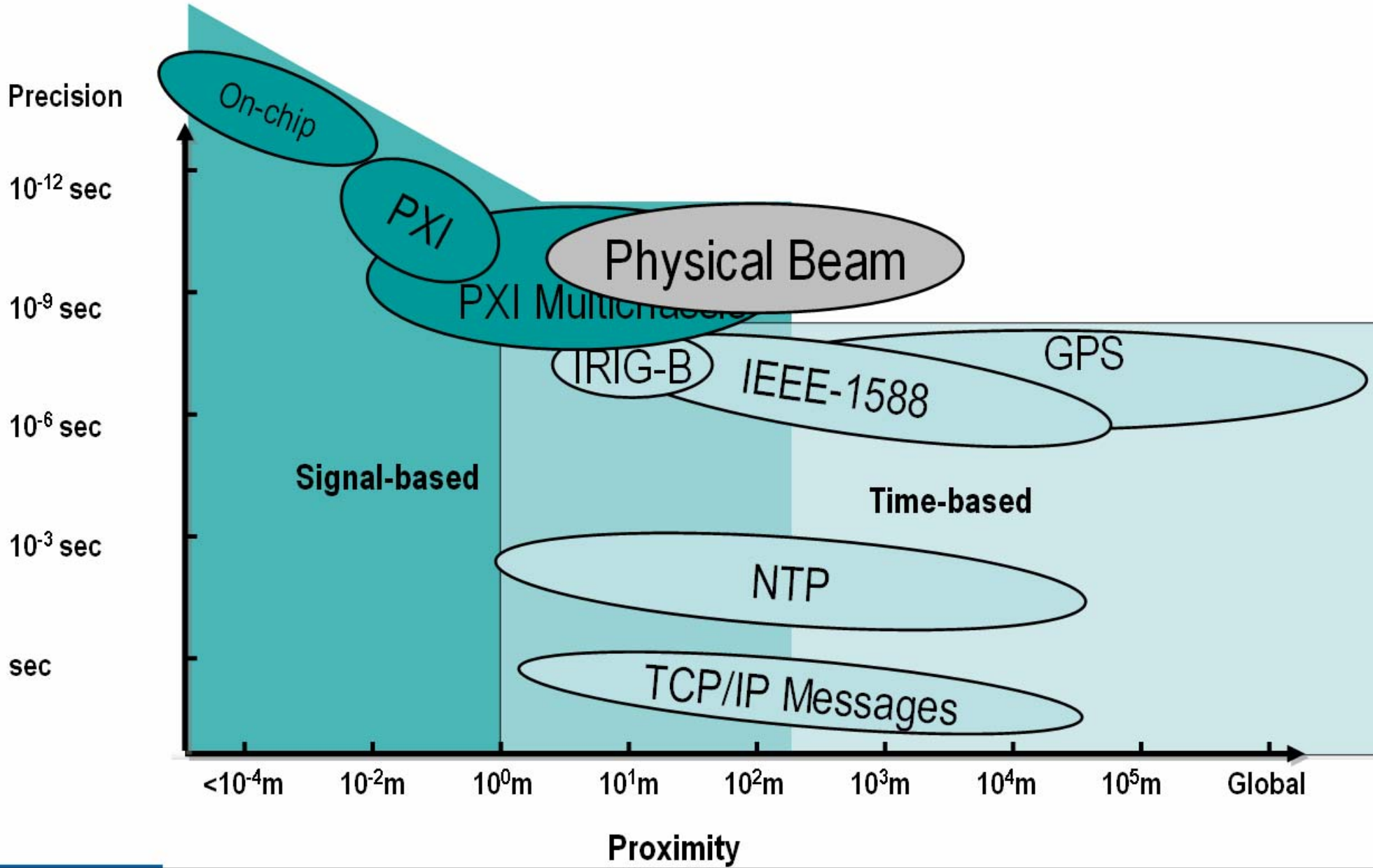
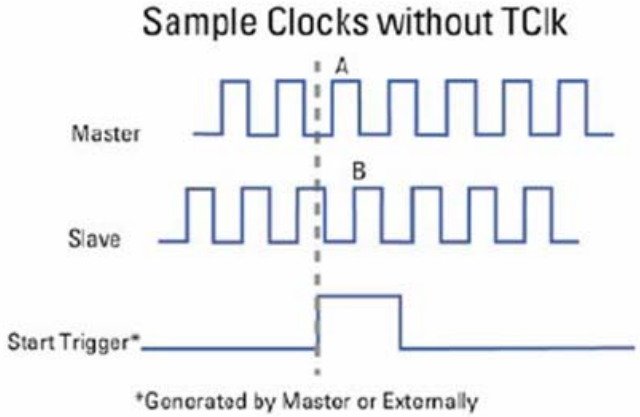
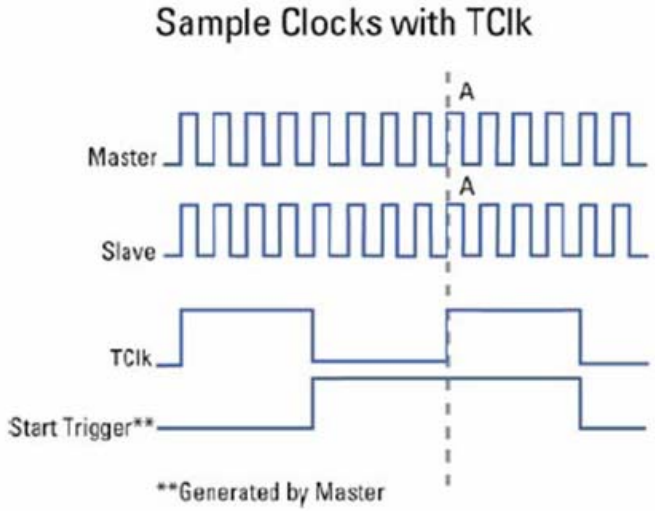


Picosecond-Level Synchronization

with NI TClk Technology

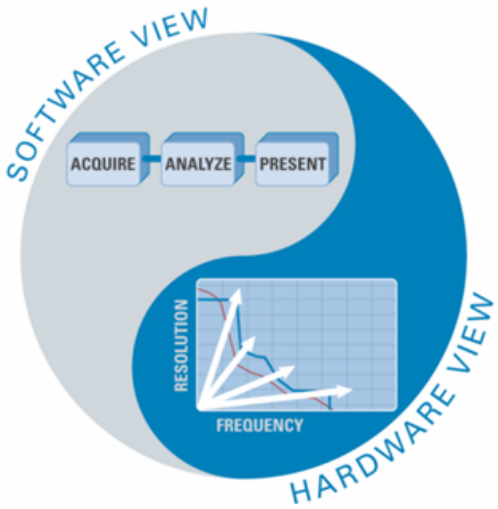




Trigger Clock (TClk)

- Modular Instruments
- Synchronization and Memory Core (SMC)
- Typical skew < 1ns, jitter < 10ps
  - Less skew with calibration
- Aligns sample clocks that may not be aligned initially despite being phase locked

The Role of Time and Concurrency



The Free Lunch Is Over

Multi-core is here

"The concurrency revolution is likely to be more disruptive than the OO revolution…"

Herb Sutter

Microsoft

The Free Lunch Is Over

Traditional Development Tool Challenges

Priority Inversion

Deadlock/Livelock

Thread Synchronization

Processor Cache Effects

Race Conditions

Scalability to Multiple CPUs

Sequential Performance

Lock Contention

Flow of Data

Non-Determinism

Load Balancing

Thesis

- *Embedded software* is not just software on small computers.
- *Time and concurrency* are essential in embedded software.
- *Platforms* are essential in the design of embedded software.
- Platforms need good modeling properties (*model-based design*).
- *Object-oriented design* cannot provide these modeling properties.
- *Actor-oriented design* offers better concurrency and time.
- *Behavioral types* offer a truly practical form of verification.

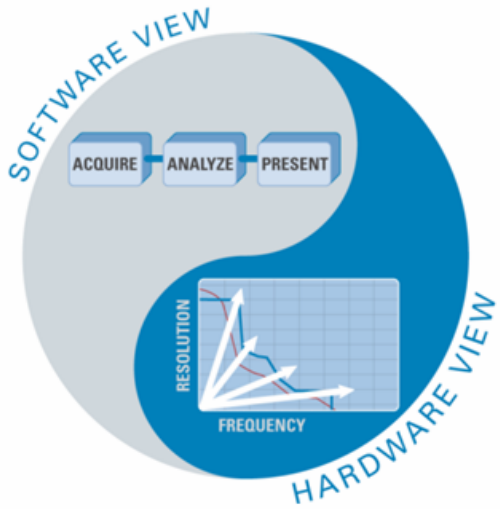
Source : An Overview of the Ptolemy Project and Actor Oriented Design Presentation

Traditional Programming Languages

Ignore both time and I/O and have problems dealing with concurrency

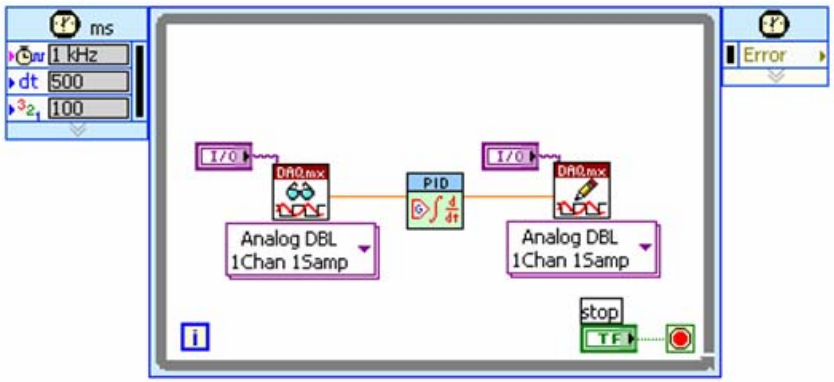
- I/O has been managed by a driver with no presence in the language
  - I/O should be an integral part of the language
- Time is not a part the language
  - Add time to the language to reduce the complexity for both computation and I/O
- Sequential nature of threads adds complexity to I/O processing
  - An actor-oriented approach is inherently concurrent

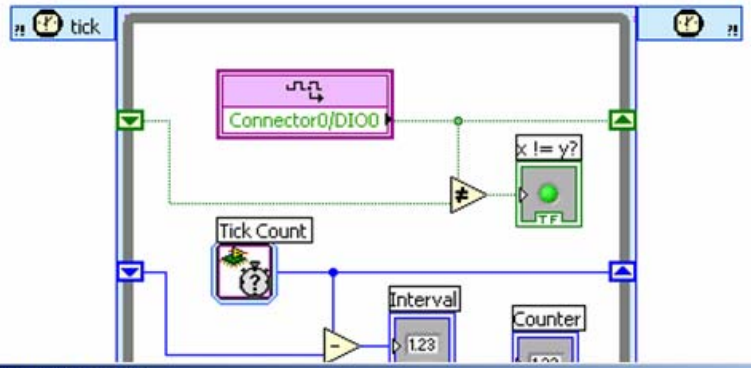
Timing Technology Enablers

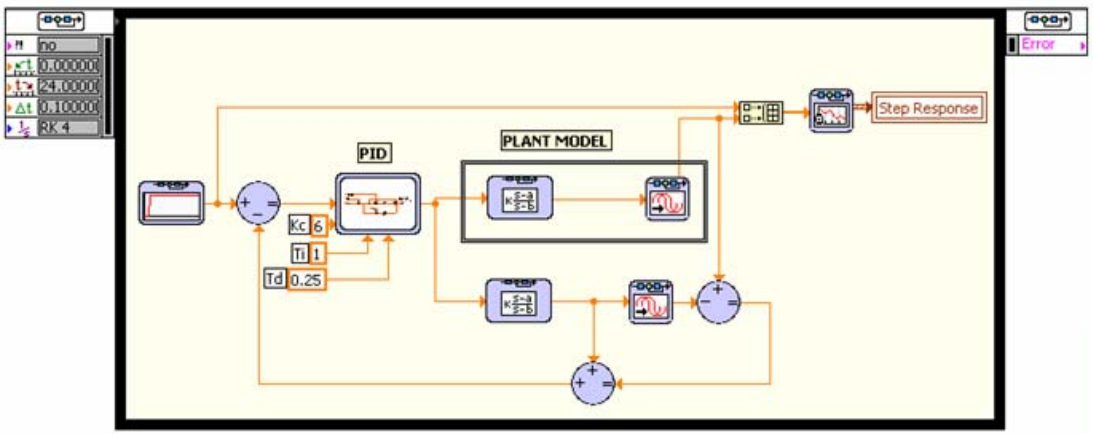


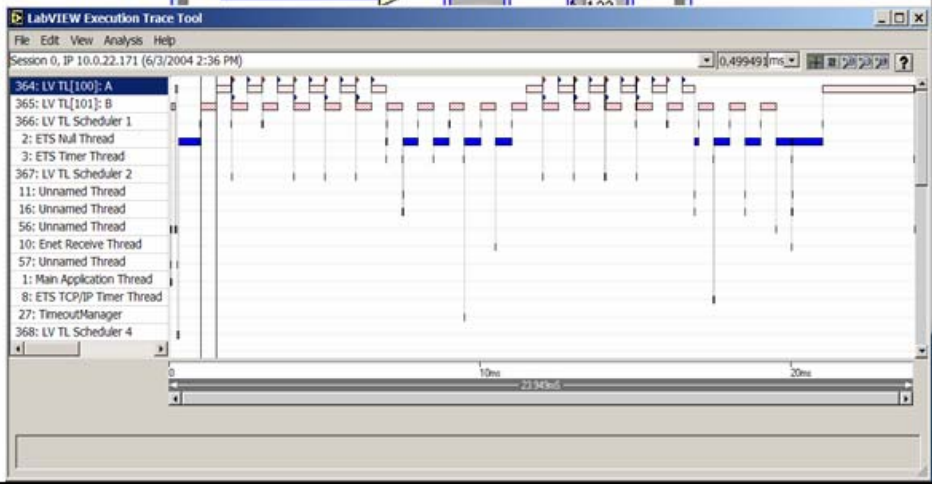
Graphical Timing Options

- Multi-rate time-critical loops
- Microsecond timing
- Single-cycle FPGA timing
- Simulation loop structures
- Real-Time trace tool

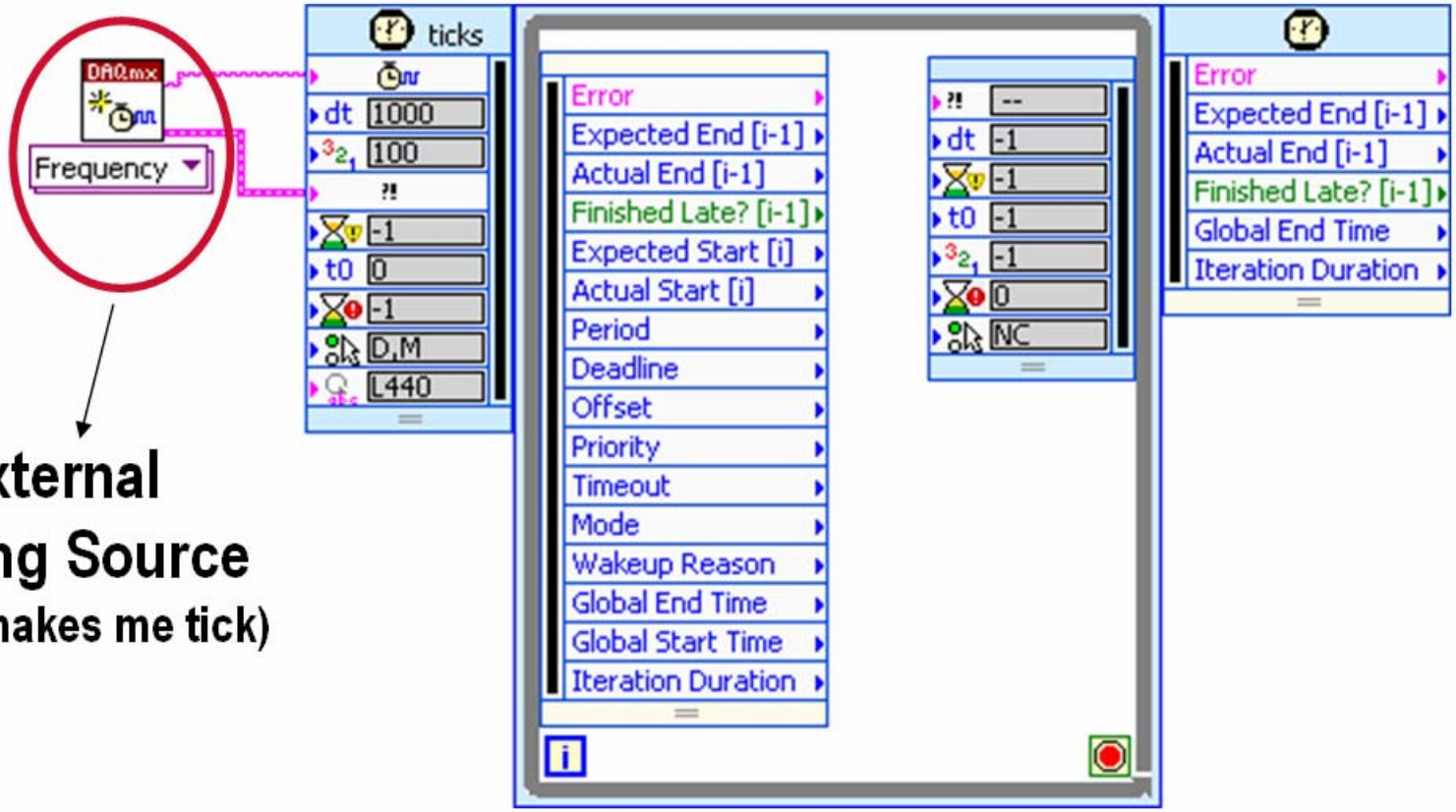






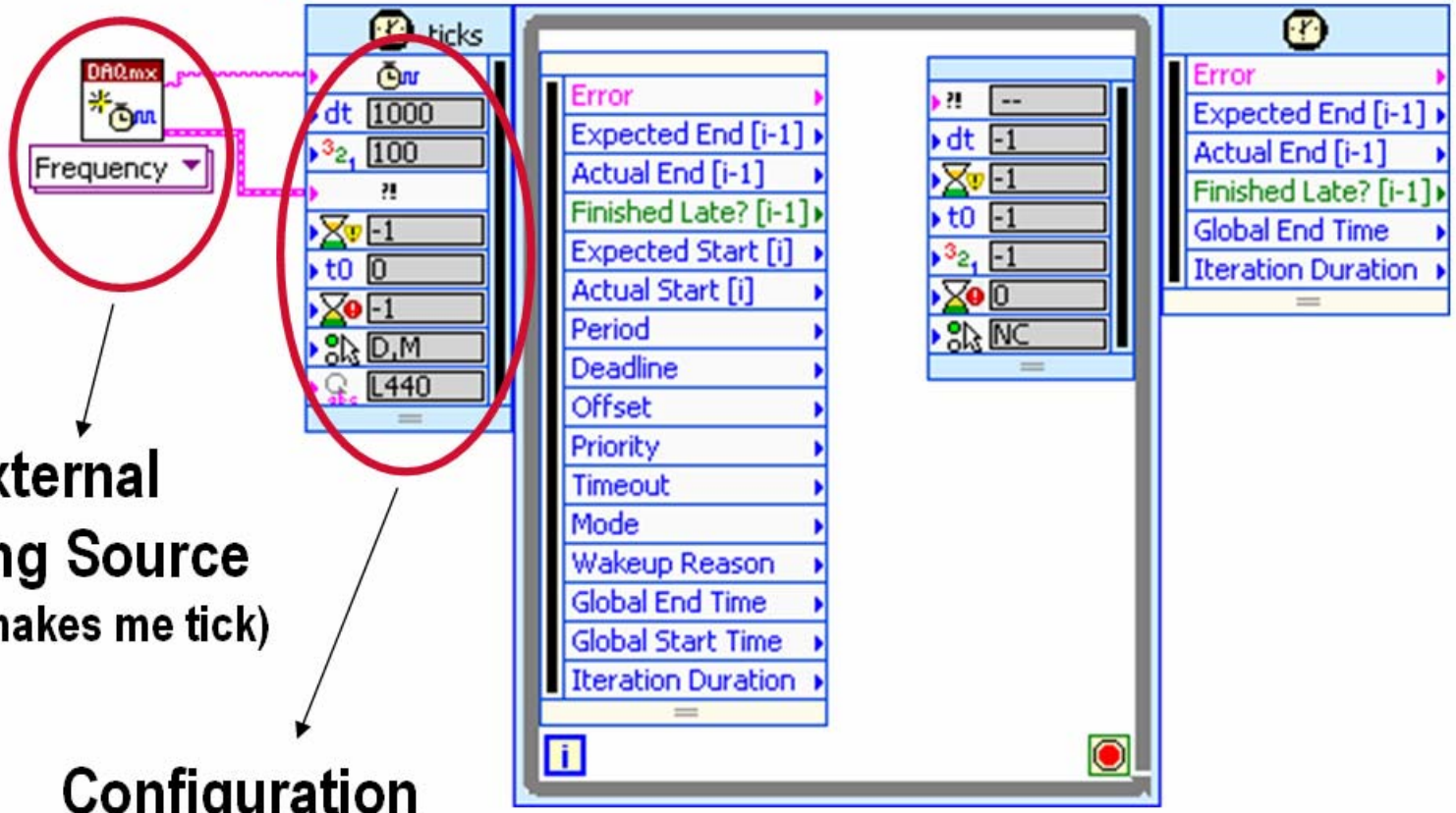


Timed Loop in LabVIEW



External Timing Source
(What makes me tick)

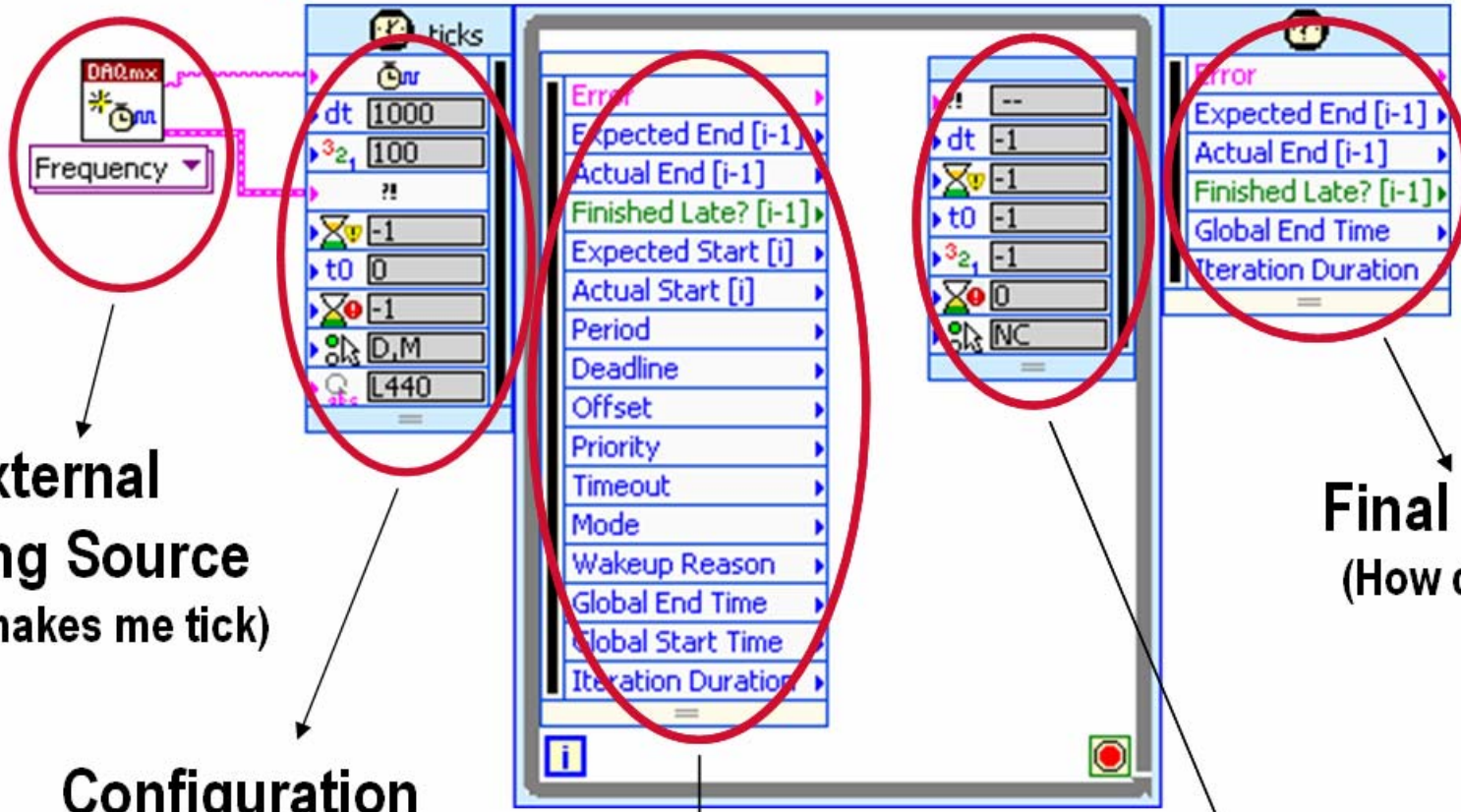
Timed Loop in LabVIEW



External Timing Source
(What makes me tick)

Configuration
(What can I do for you)

Timed Loop in LabVIEW



External Timing Source
(What makes me tick)

Configuration
(What can I do for you)

Run Time Status
(How am I doing)

Run Time Configuration
(How can I serve you better)

Final Status
(How did I do)

Multicore Process Control for Plasma Control

- Max Planck Institute (Munich, Germany)
- Plasma control in nuclear fusion tokamak with LabVIEW on an 8 core real-time system

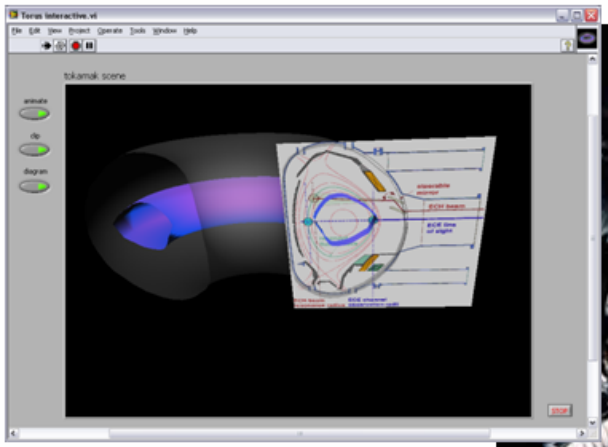
*"…with LabVIEW, we obtained a **20X processing speed-up** on an octal-core processor machine over a single-core processor…"*

Louis Giannone

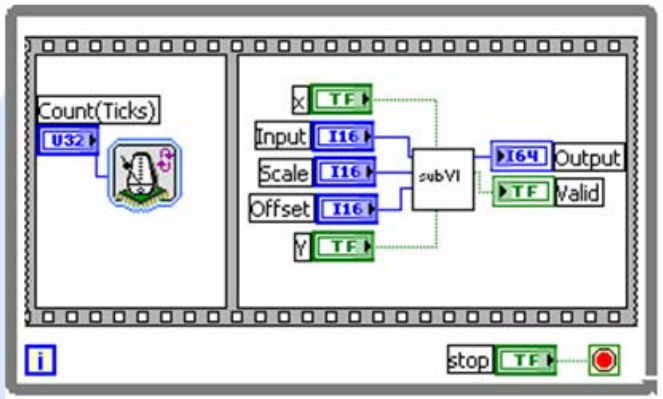
Lead Project Researcher

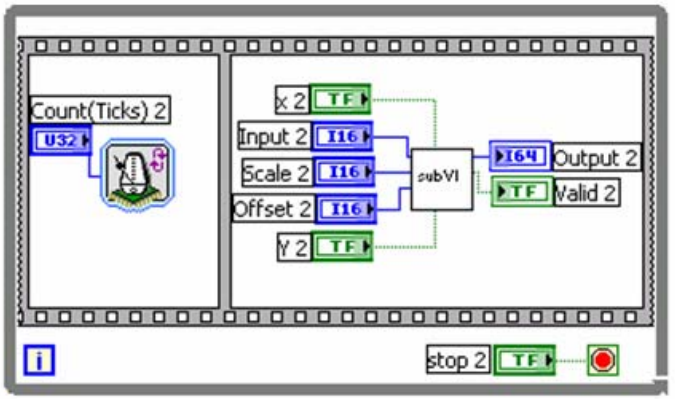
Max Planck Institute

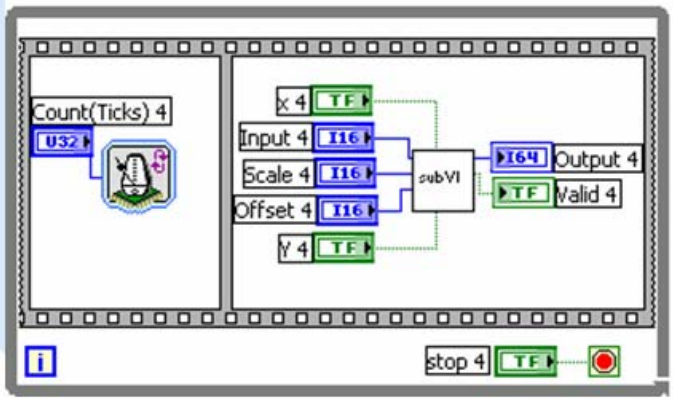
IPP Max-Planck-Institut für Plasmaphysik

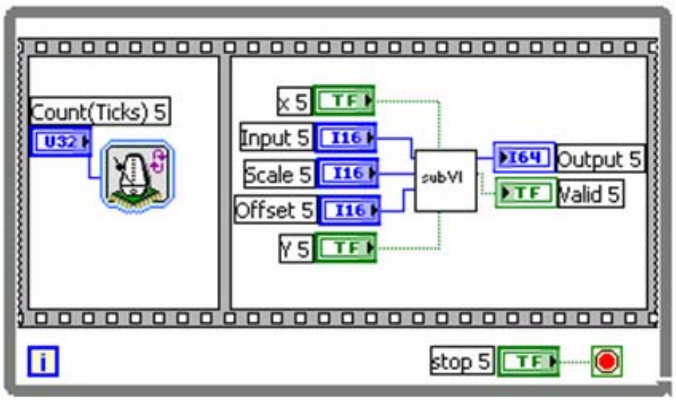


FPGA Programming: The Ultimate in Multicore, Multiprocessor Development

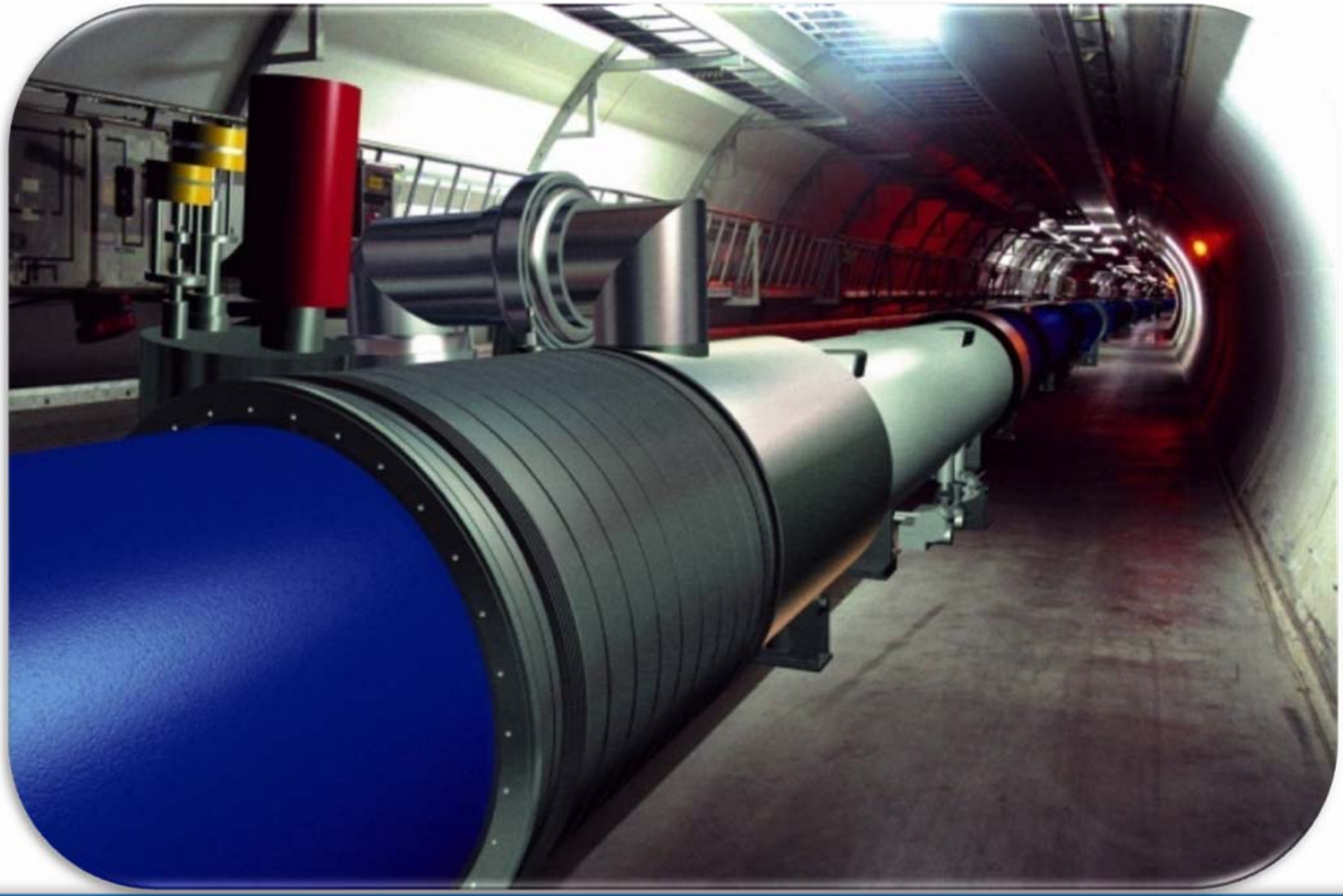






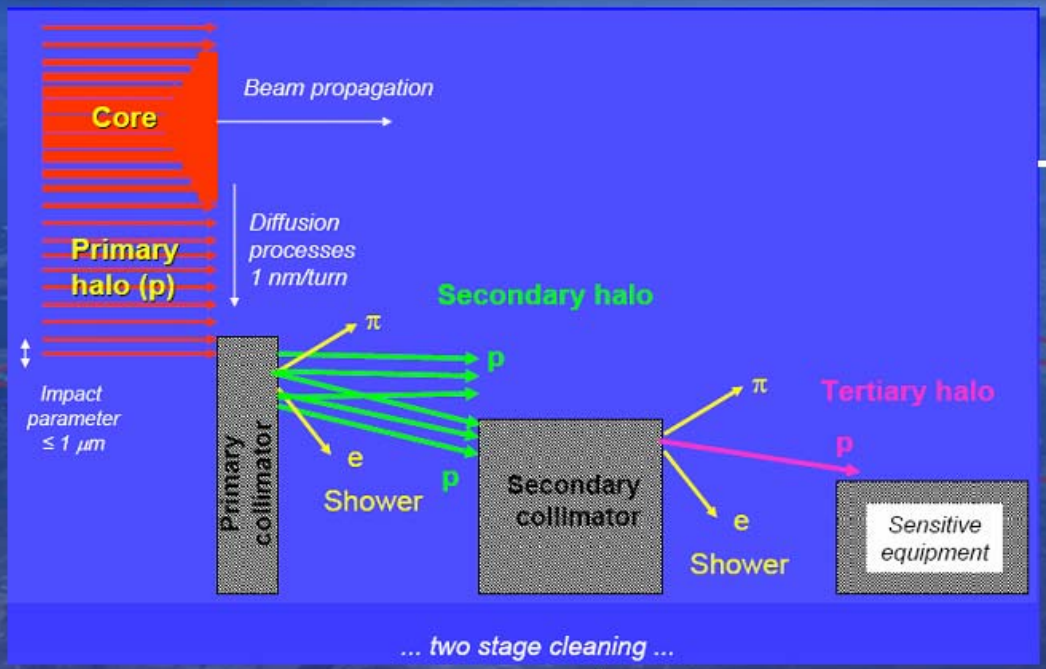


CERN Large Hadron Collider



The LHC collimators system

Road Map

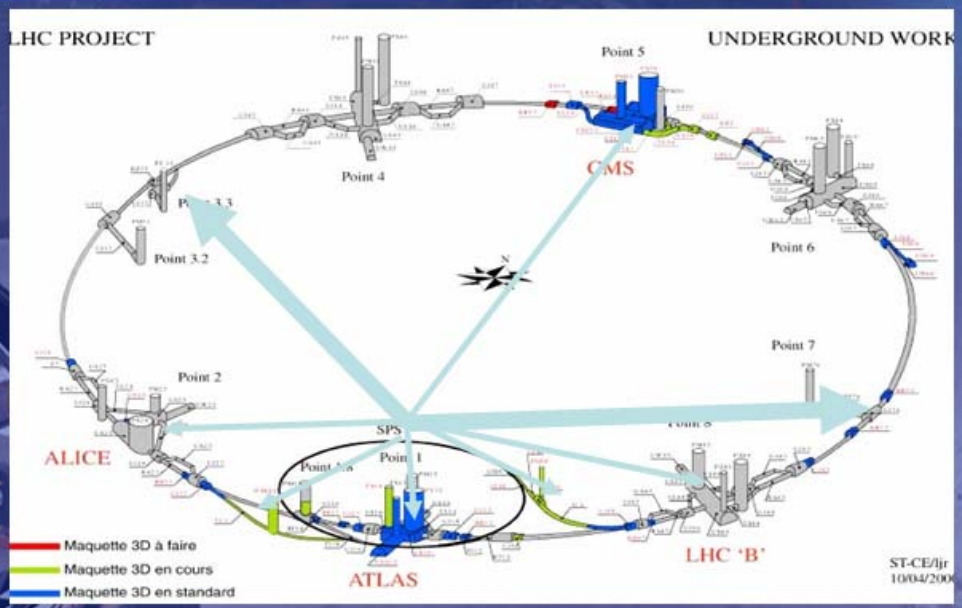


The collimation system is based on different collimators types and

up to 108 collimators distribuited over 6 points in the machine

Jaw positions are correlated primary – secondary– tertiary

Also during movements they have to stay in sync



Road Map

The RT platform used

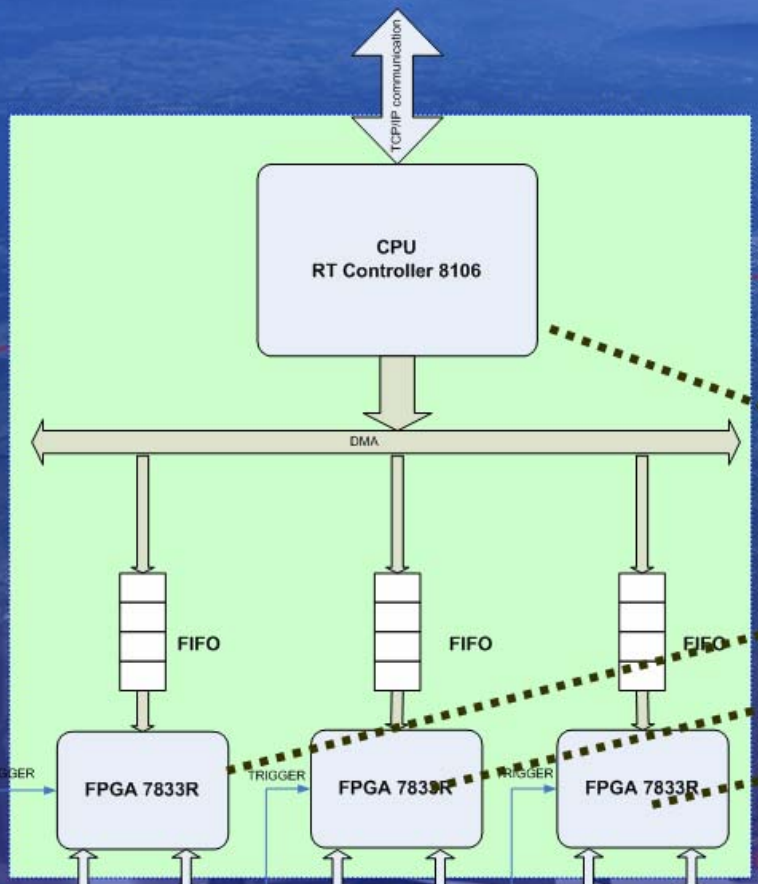
PXI systems by National Instruments have been used as RT platform because of:

- **their robustness and compactness**
- **the new RT controllers based on Intel Dual Core processors with solid state disk are powerful and reliable**
- **the built-in 10 MHz signal architecture allows easy daisy chaining of a synchronization clock across multiple chassis through BNC connectors on the back of the chassis**
- **3 Mgate FPGA cards with integrated digital and analog I/O are available**
- **A wide variety of cards is available and provided with LabView RT drivers. This allows saving manpower on the drivers' development**

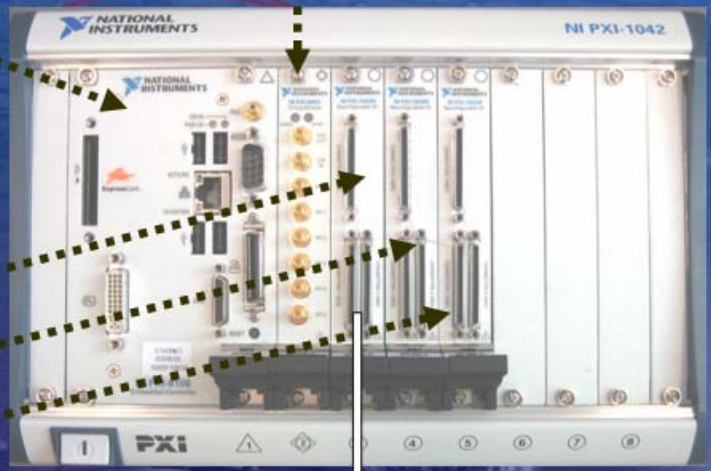
MDC hardware architecture

Road Map

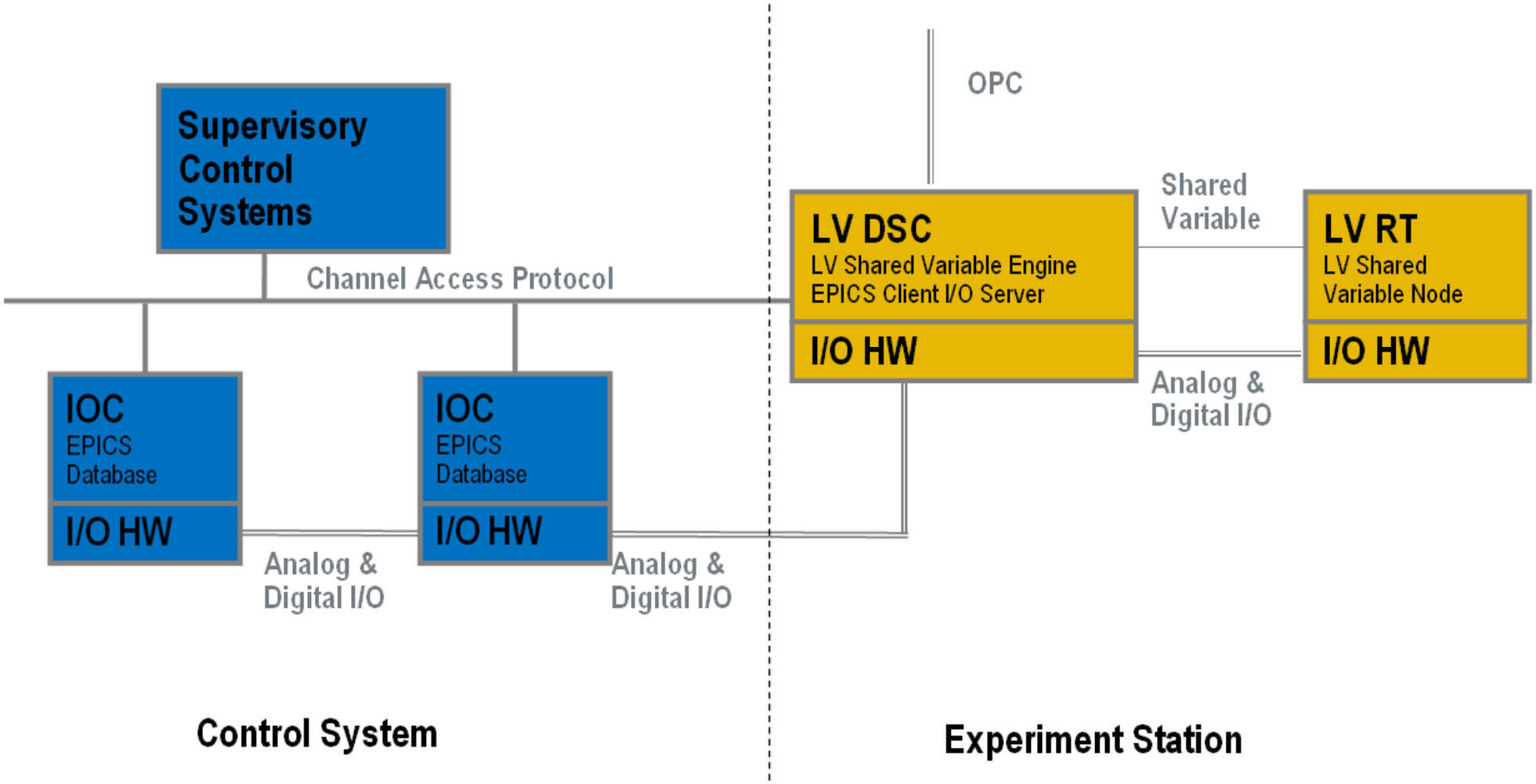
- The LHC collimators system
- Control requirements
- Control system layout
- The RT platform used
- Control system software architecture
- The MDC
- The PRS
- Conclusions



Timing Card 6653 with 45 ppb clock stability

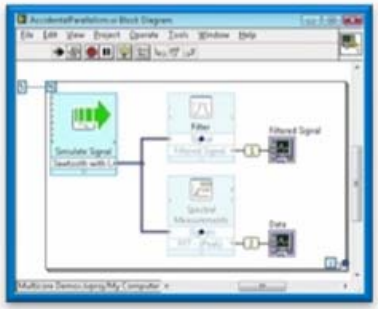


EPICS and LabVIEW



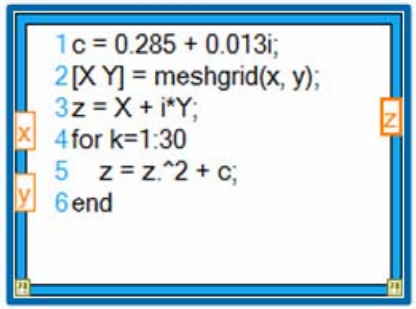
High-Level Design Models

Data Flow

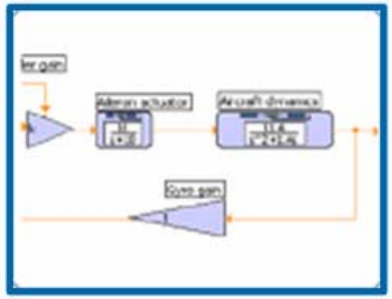


C Code

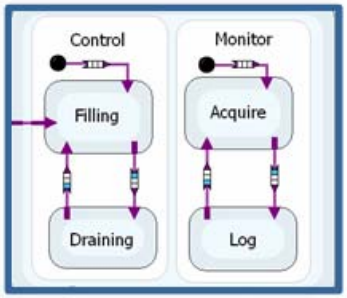
Textual Math



Simulation



Statechart



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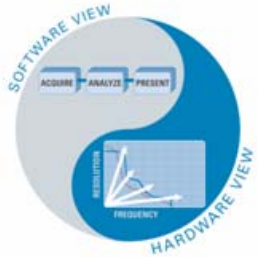
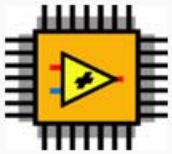
Graphical System Design Platform



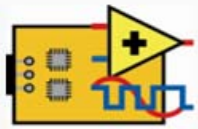
Desktop

Real-Time

FPGA

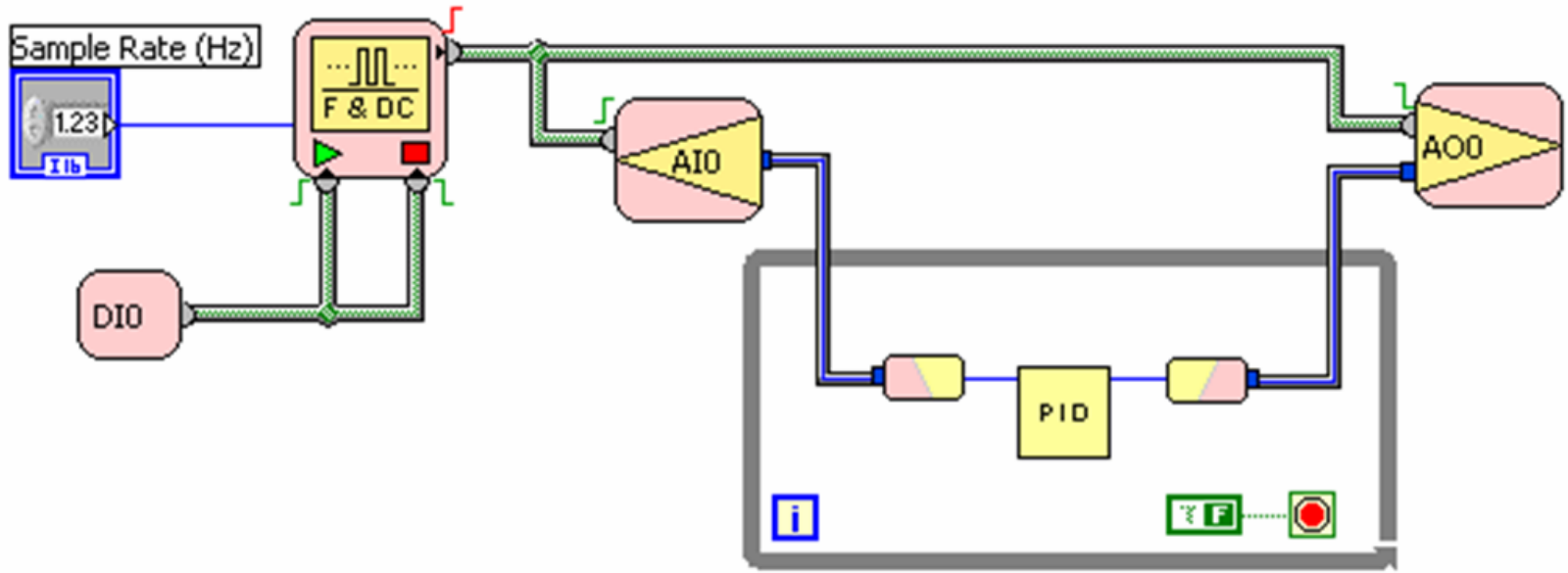


Microprocessors



The Future of Timing and Synchronization

- Focus on the particulars you care about
  - Hide the details you don't care about
- Introduce a "Timing Wire"
  - Since time is an integral part of the system



Graphical System Design

It's all about time

LEGO MINDSTORMS NXT
"the smartest, coolest toy of the year"

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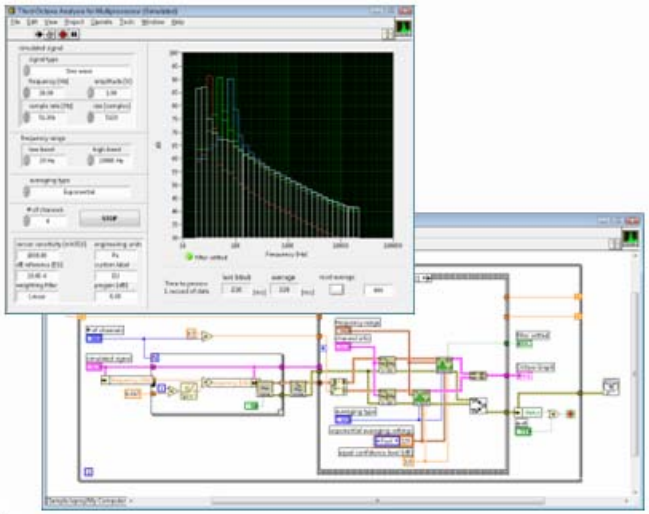

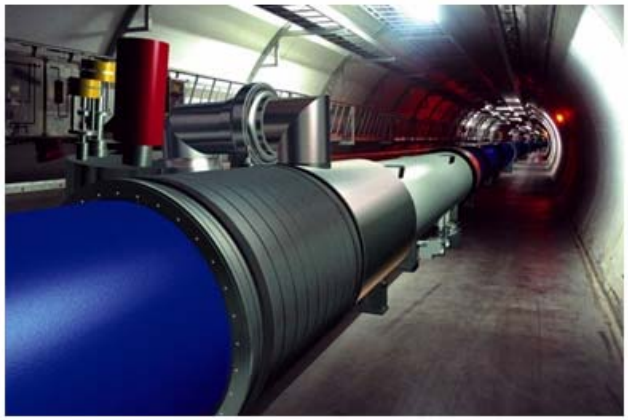

CERN Large Hadron Collider
"the most powerful instrument on earth"