Synchrophasors: Anomalies in the Past and a Look to the Future

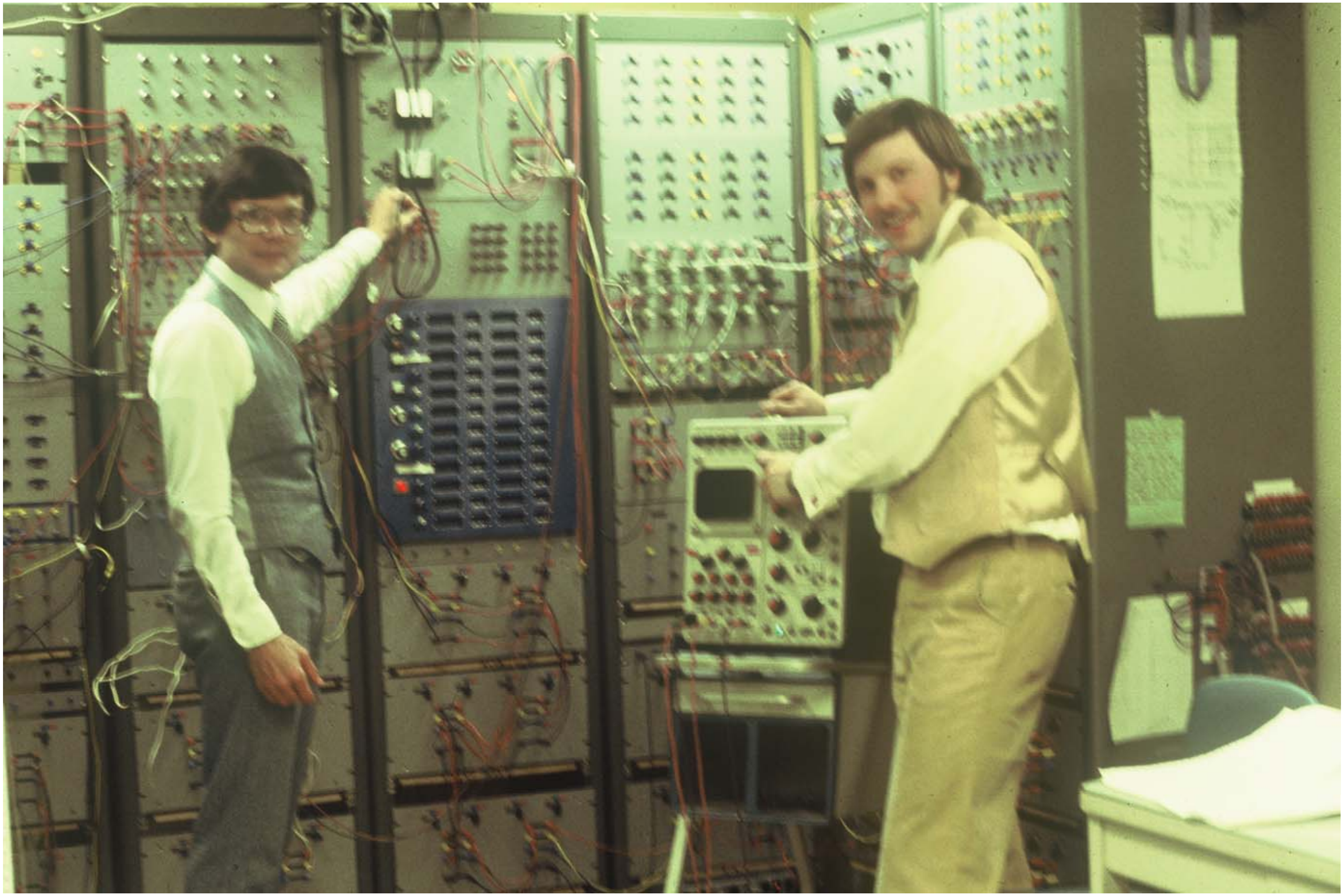
Mark Adamiak

GE Multilin

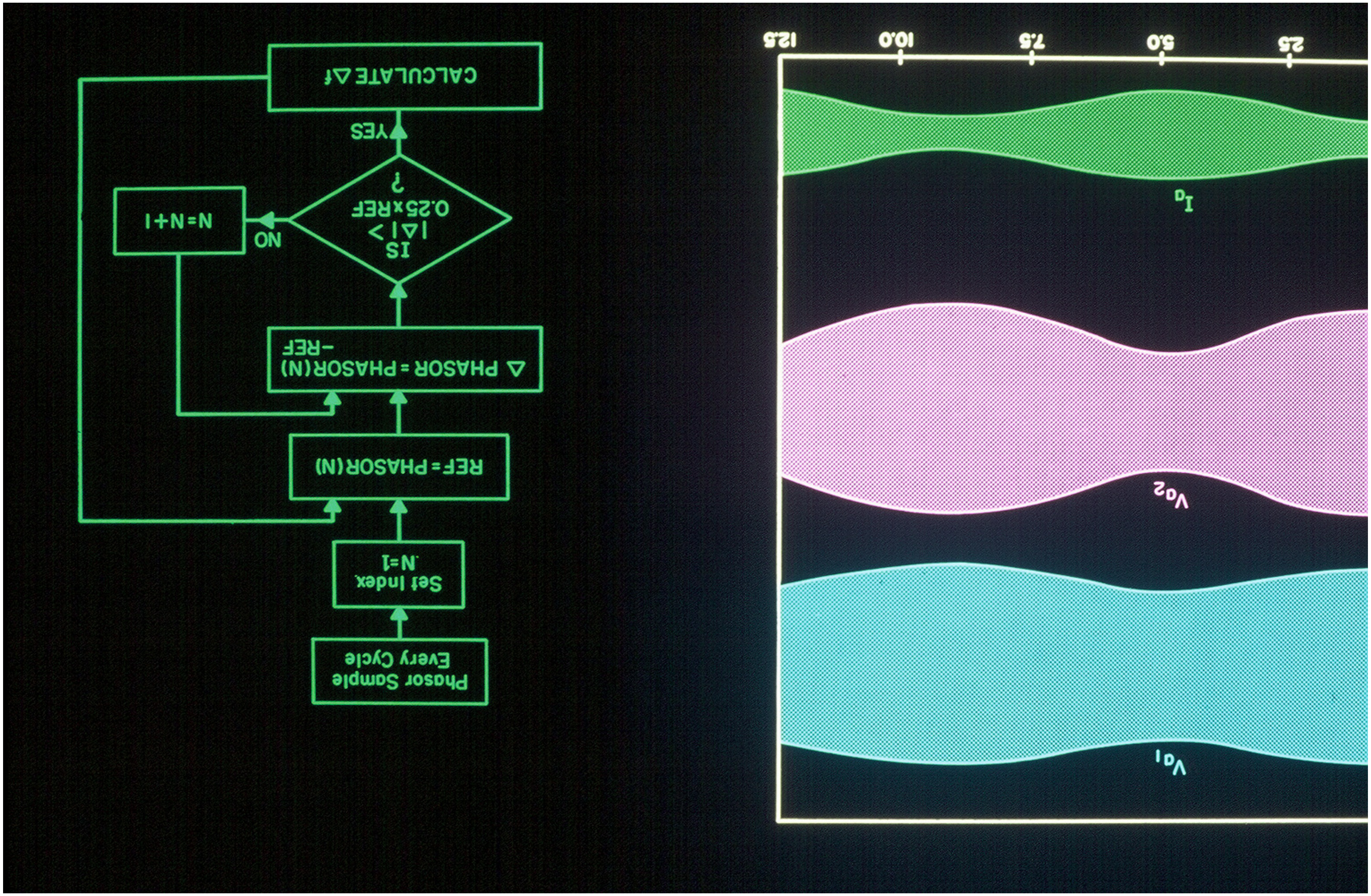
AEP Development of a Digital Relay

- Introduced the Fourier Transform for the calculation of Voltage & Current Phasors
- Memory Voltage was used for close-in faults
- It was noted that the phase angle between the stored voltage and the voltage some time later would rotate in angle
- Coordinating the calculation to absolute time resulted in the Synchrophasor

AEP Model Power System – circa 1978



Early Test Waveforms



…and the results were published

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A NEW MEASUREMENT TECHNIQUE FOR TRACKING VOLTAGE PHASORS, LOCAL SYSTEM

FREQUENCY, AND RATE OF CHANGE OF FREQUENCY

A. G. Phadke
Fellow, IEEE
VPI & SU
Blacksburg, VA.

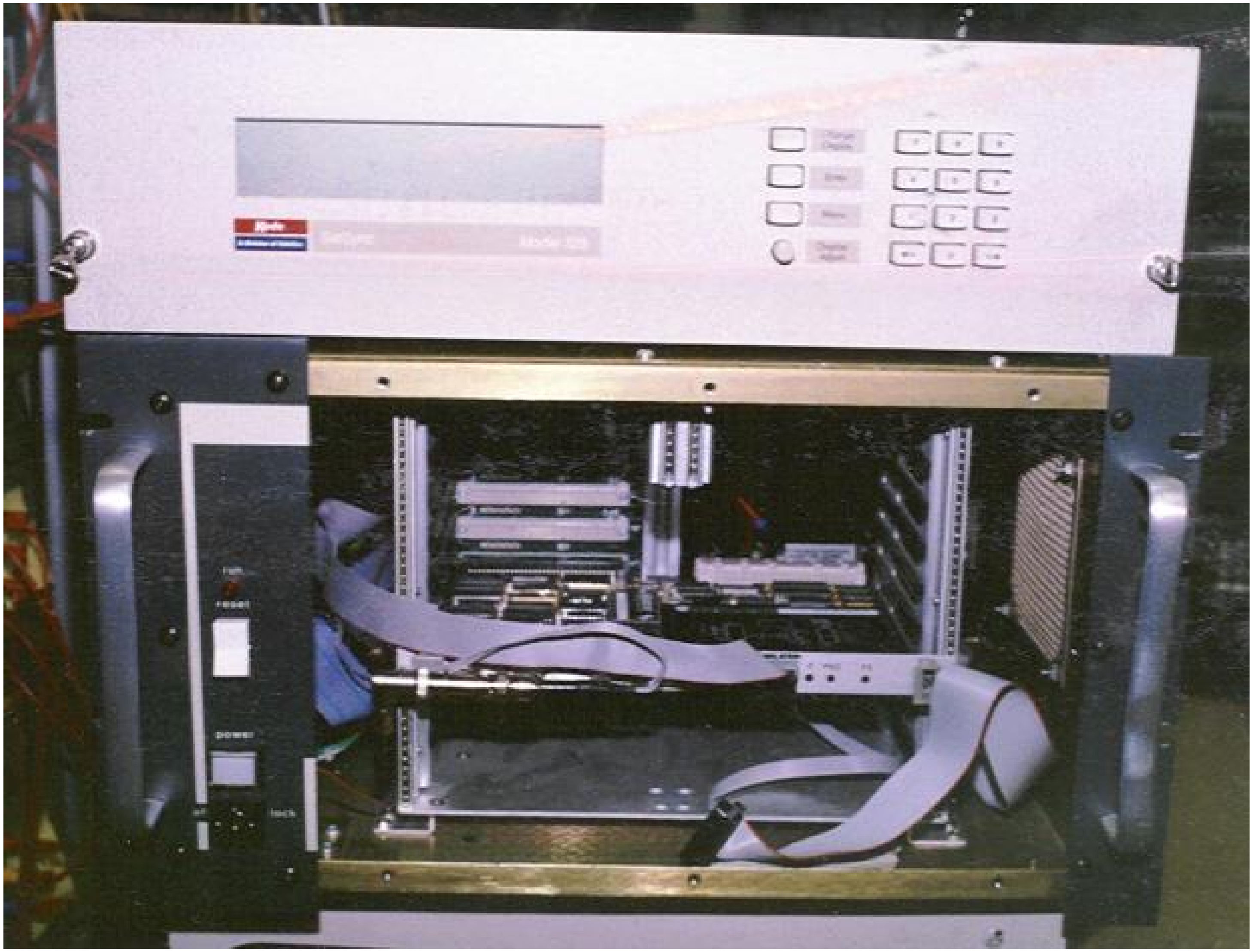
J. S. Thorp
Senior Member, IEEE
Cornell University
Ithaca, New York

M. G. Adamiak
Member, IEEE
AEP Serv. Corp.
New York, N.Y.

Primary Issue: Absolute Time

- First looked at WWVB
  - Too much time error (1ms)
  - Too much time variance
- LORAN
  - Limited availability
- GOES Evaluated
  - Accuracy & availability not good enough
- GPS Becomes available
  - First satellite launched – 1978
  - Opened to commercial enterprise - 1983
  - Initial units very expensive ($10k to $20k)

And Trial PMUs Were Installed…



Marysville 765kV Substation

AEP’s Rockport Plant

First Installations on the AEP System

World’s First PDC

- DEC MicroVax
- Communication via 2 serial comm lines
- Data streamed at 12 phasors sets per second
- Data stored on a 70MB hard drive
  - 30 day data storage
- Reported Magnitude & Angle difference

Issues in the Communication Design

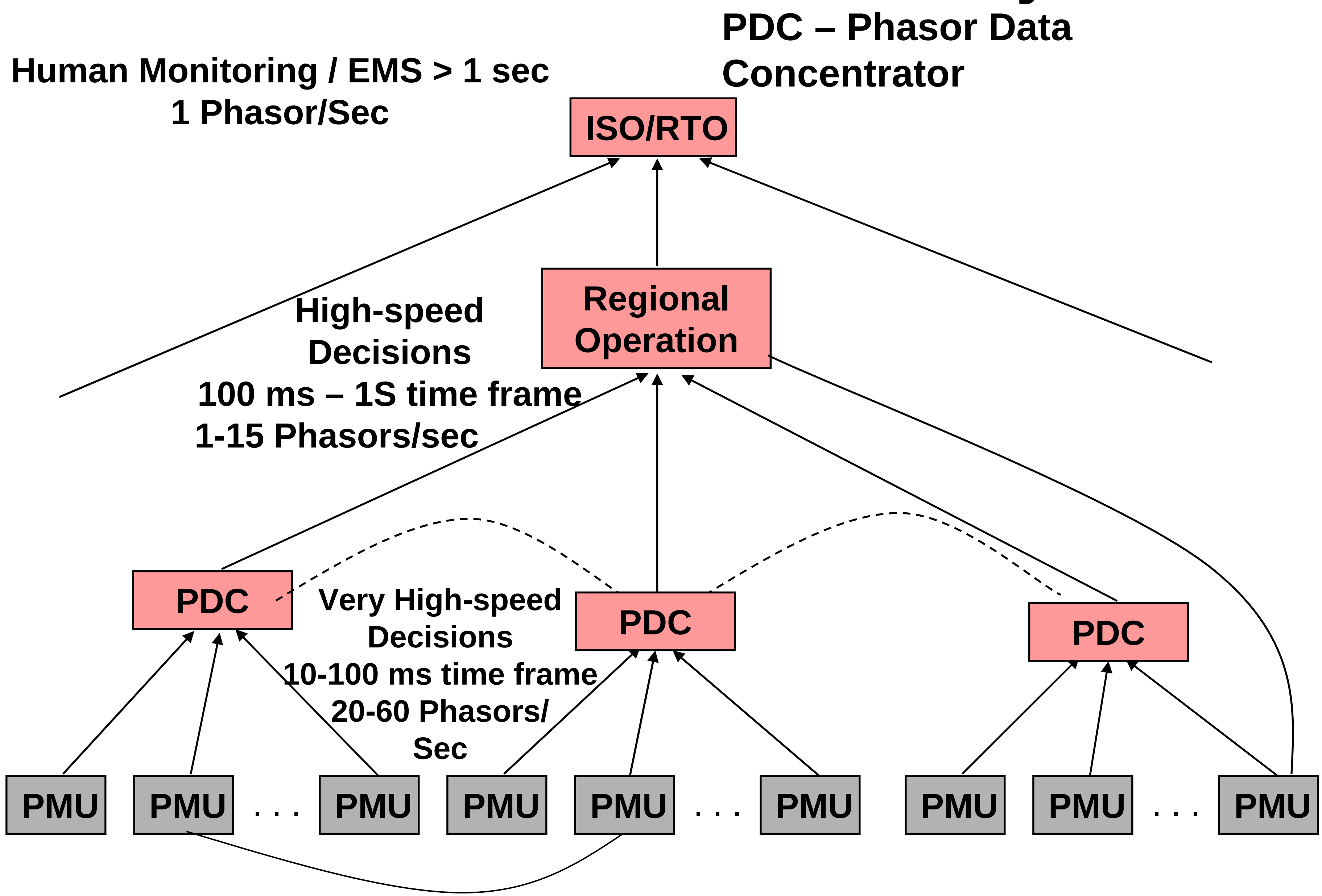
- Communications
  - Only 4800 bps links available
  - Binary data transfer used for efficiency
- Time Stamp
  - Original format was YYYY:MM:DD:HH:MM:SS:Sample Count
  - Modified to 4-byte NTP Second-of-Century
    - Originally referenced to 1900
    - Changed to 1970 in IEEE C37.118
    - Added Fraction of Second in C37.118

Synchrophasor Work Codified in IEEE 1344 - 1995

- Focused on “how” to compute a synchrophasor – not what the result should be
- Did not address when to report nor standardized reporting rates
- Did not address accuracy under different frequencies and harmonics
- Did not address “Front-End” magnetic and filter delays

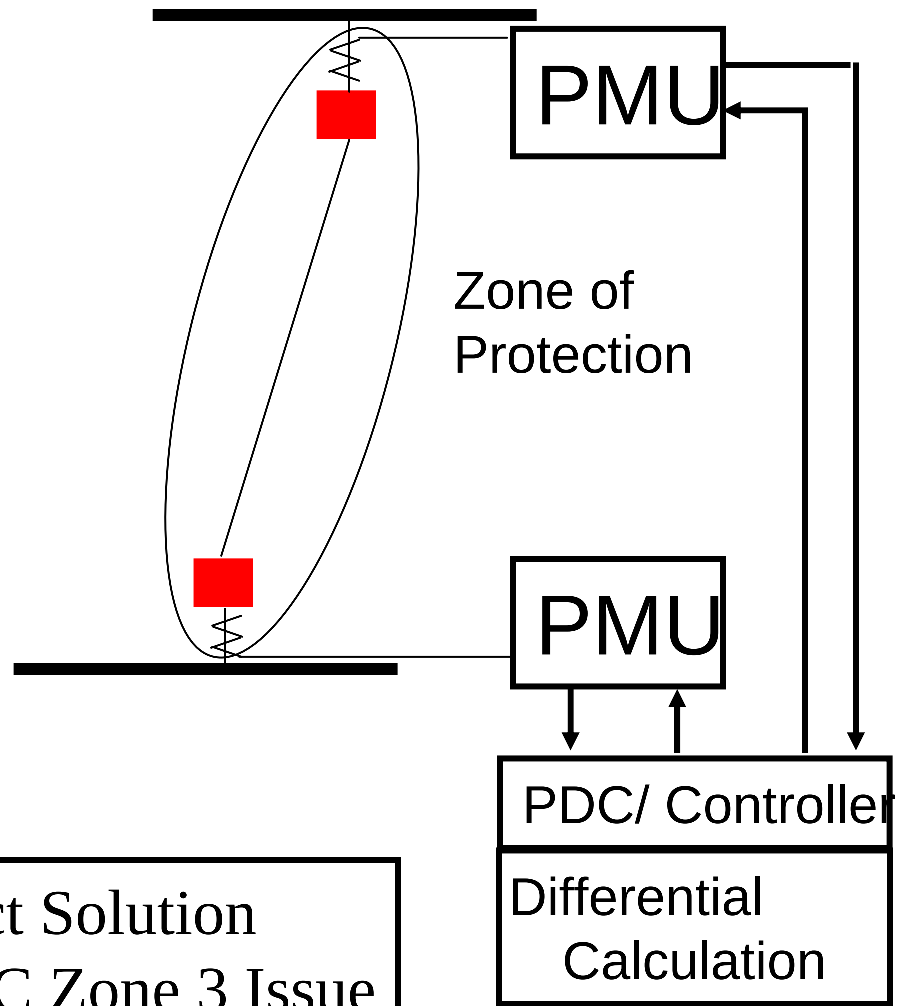
These Issues Resolved with C37.118-2005

Architectural Hierarchy



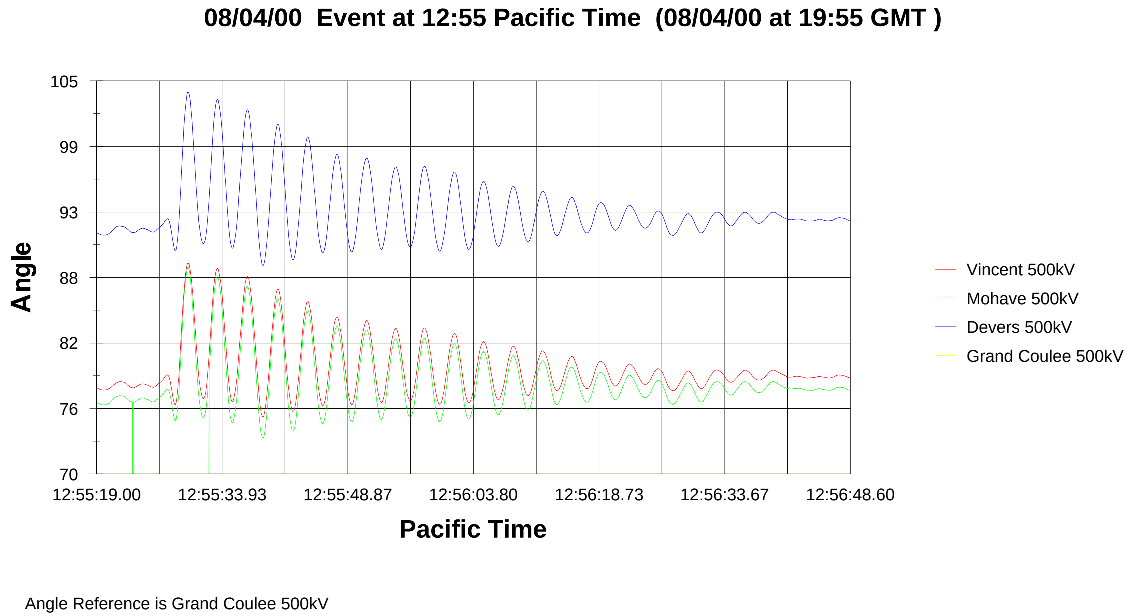
Synchrophasor Based Backup Current Differential

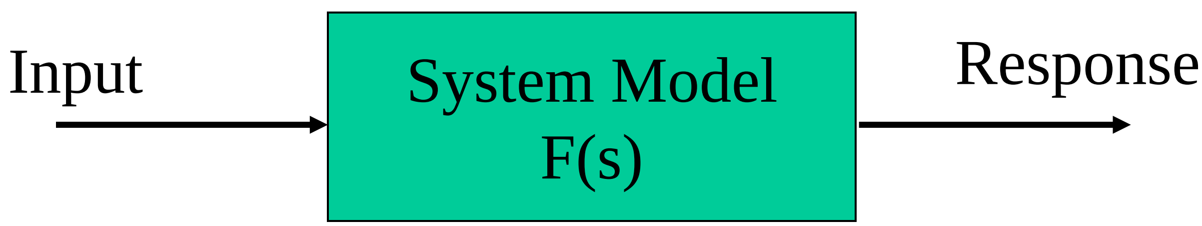
- Hi-Speed data streaming standardized (30 phasors/sec per standard)
- Low Communication latency available (7ms measured)
- Precise Zone isolation through current differential protection



High Impact Solution
Addresses NERC Zone 3 Issue

Power System Model Validation





Use System Disturbances to Create/Validate/Correction F(s)

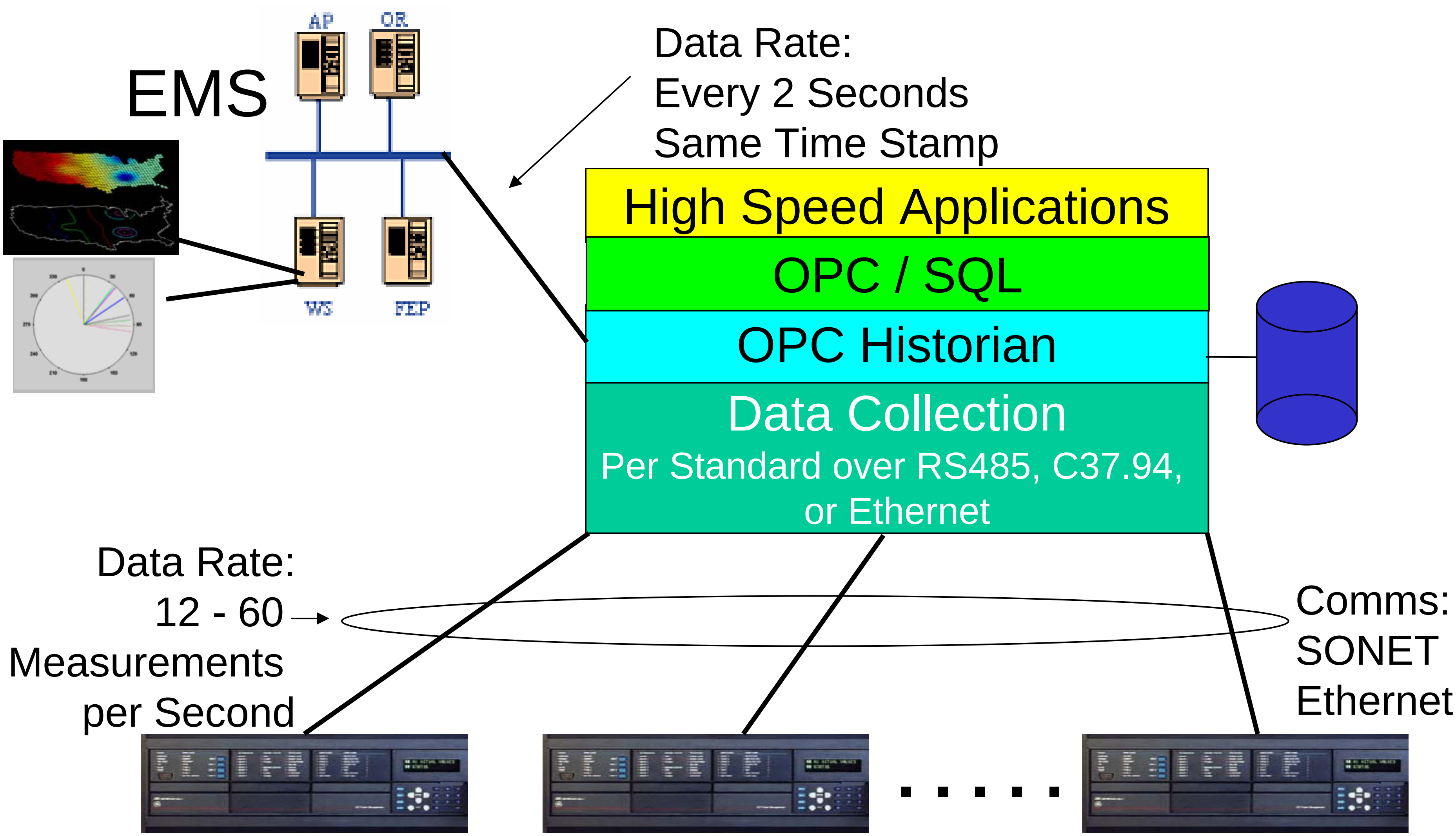
Obstacles to Implementation - 1

- Economic Justification
  - Still viewed as a “lab” experiment
  - Business case for both manufacturers and users needs to be strengthened

Obstacles to Implementation - 2

- Standardized PDC Functionality & Interoperability
  – PDC to PDC Communications
  – Database schema
  – Data Recovery
  – Multiple reporting rate requirements
  – TCP vs. UDP vs. IP Multicast
  – Data Stream Security
  – Mapping into IEC 61850
  – Standard Application Interface

PDC/Gateway Architecture



Visualization Applications

- Frequency and rate-of-change of frequency
- Positive, negative, and zero sequence plots of system voltage
- Damping constant calculations
- Power flow / change in power flow / general change detection
- Oscillation Identification / frequency calculation
- Historical Trends
- Event Signature Analysis

Challenge: Getting Operators to buy-in to the Visualizations

Analysis & Control Applications

- Situational Awareness
- Under-Voltage Load Shed
- Angle Check
- System-wide Automatic Voltage Control
- Control room alarm triggers
- MW/MVAR oscillation viewing/detection
- Oscillation damping
- State Estimation Enhancement
- State Measurement
- Contingency Analysis
- Oscillation Pattern Analysis and alarm
- Load Duration plots
- Dynamic Voltage Nose Curve creation
- Out-of-Step Block/Trip
- Back-up protection
- Phasors in F60 to look at device isolation from the system
- Under-voltage/Under-frequency load shed built into the appliance
- Multi wind-farm coordination

Communication Network Requirements

- Guaranteed bandwidth
- Adjustable bandwidth
- Settable priority
- High-availability (99.99%)
- Low latency
- Standards based
- Scalable
- High noise immunity
- Support for other functions
- Automatic Configuration
- Network monitoring/management

Obstacles to Implementation - 3

- Communication Infrastructure
  - Functional requirements drive communication needs
  - Architectural requirements must be based on functional requirements
  - Functional requirements must be fleshed out from the applications
  - The applications must be identified and prioritized

Wide Area Monitoring and Control