Time Synchronization Accuracy Issues and Mitigation Measures

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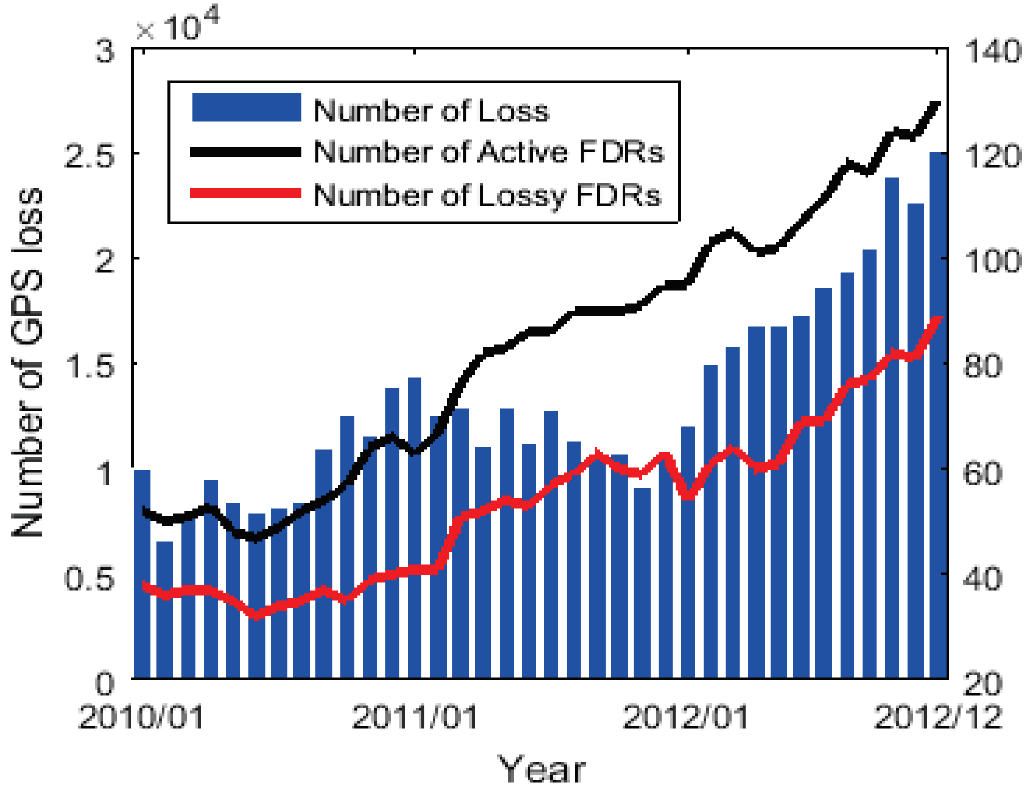
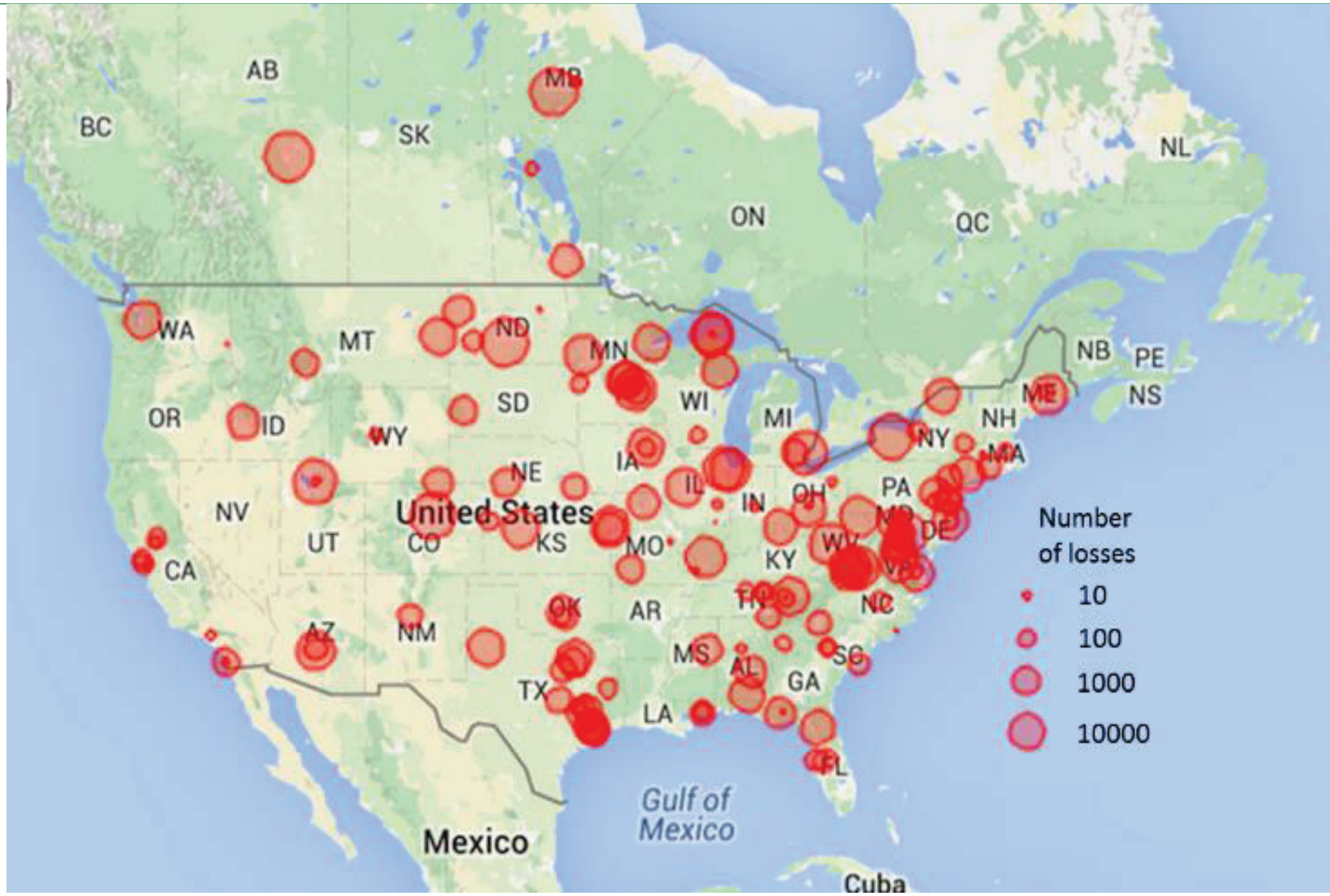
GPS Timing Signal Loss in FDRs and commercial PMUs

- Historical data of 80 PMUs and 100 FDRs from 2010 to 2012
- Over 50% of FDRs and PMUs sampled experienced GPS loss



Number of FDR GPS losses from 2010 to 2012

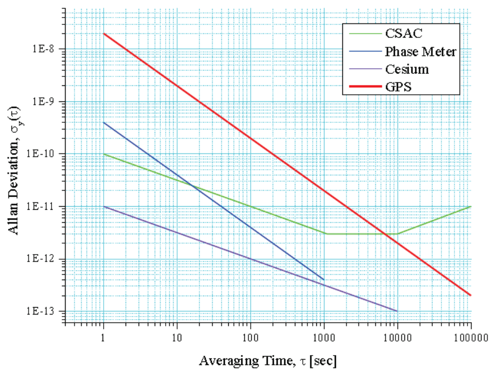
GPS Loss Location Statistics

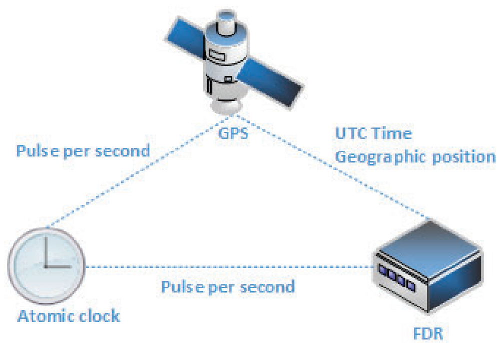


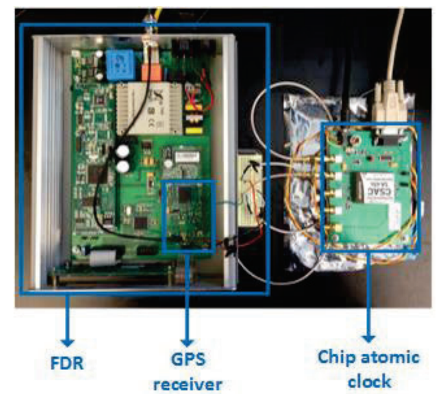
Timing Assistance by Chip Scale Atomic Clock

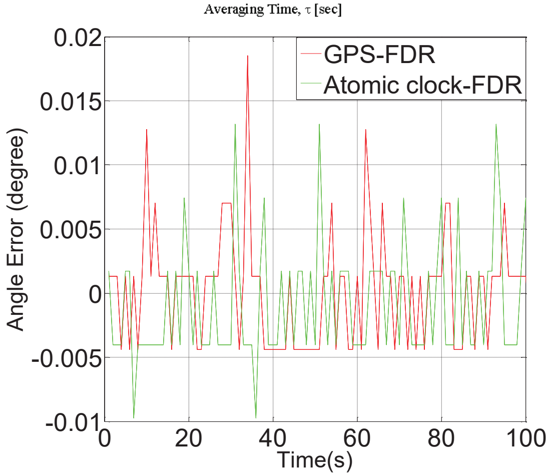
SA. 45s Chip-Scale Atomic Clock

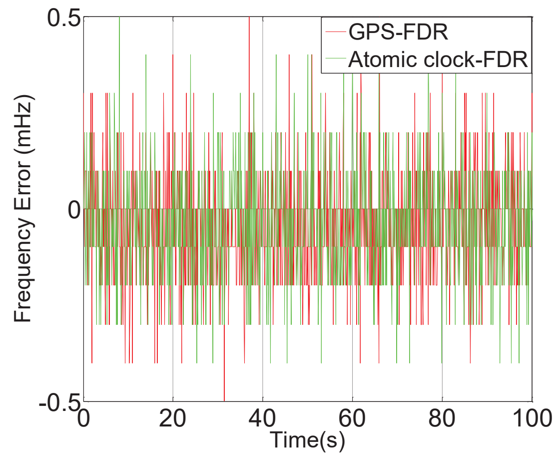
- World's first commercially available chip scale atomic clock
- GPS is noisier than CSAC for averaging time < 5000 seconds









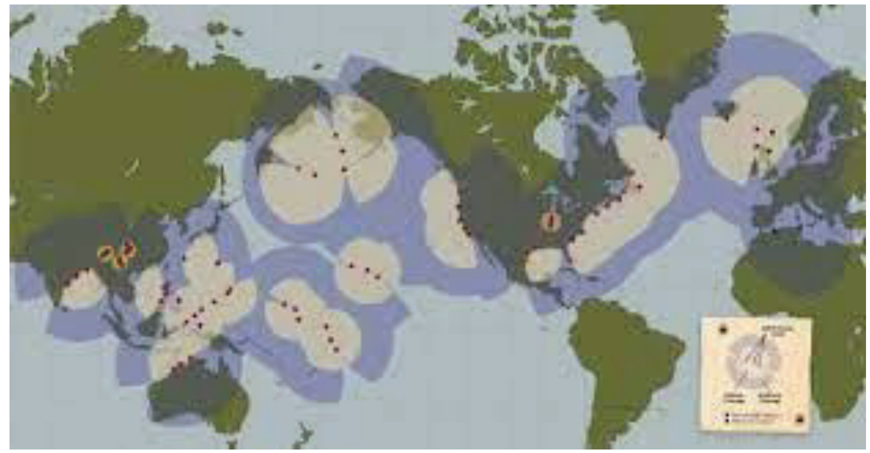


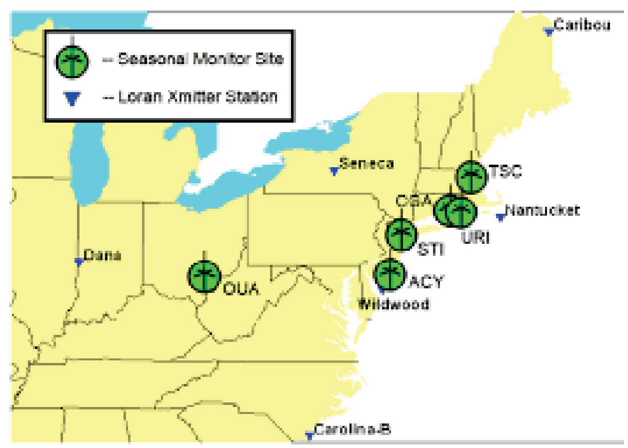
Standard deviation of frequency and angle errors

	GPS-FDR	Atomic clock-FDR
Angle	0.0041	0.0046
Frequency	1.45e-4	1.42e-4

e-Loran Navigation System Test New York => Knoxville

UTK FDR Test Bench Set-up





GPS vs. Cesium

Std of zoomed data is: 13.443977467
Max of zoomed data is: 38.598620893
Min of zoomed data is: -36.401379107

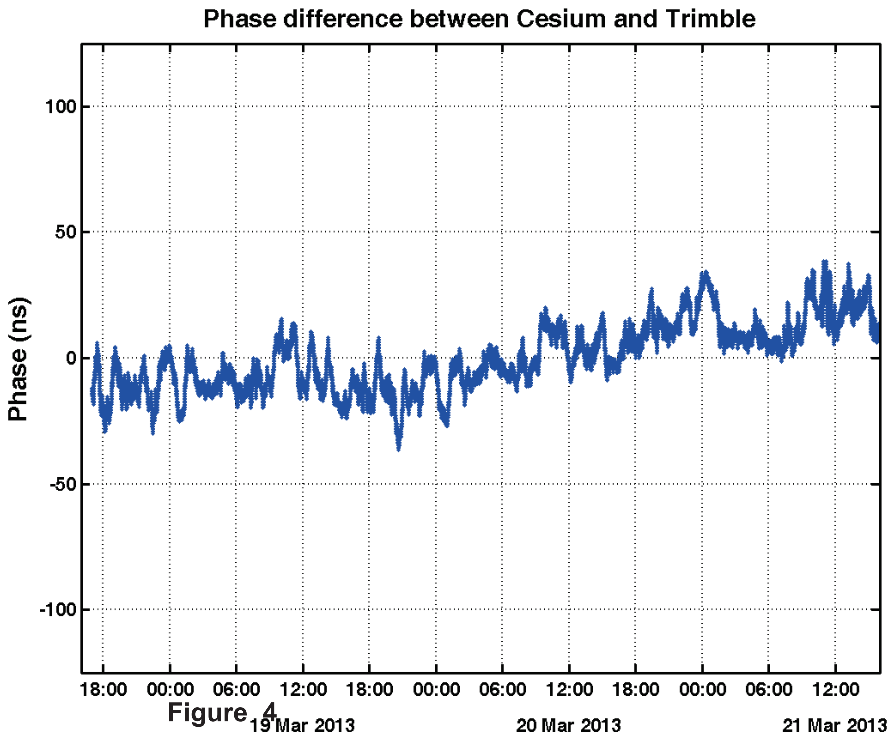


Figure 4

Cesium vs. UN152A (eLoran)

Std of zoomed data is: 17.782285425
Max of zoomed data is: 61.828816511
Min of zoomed data is: -73.671183489

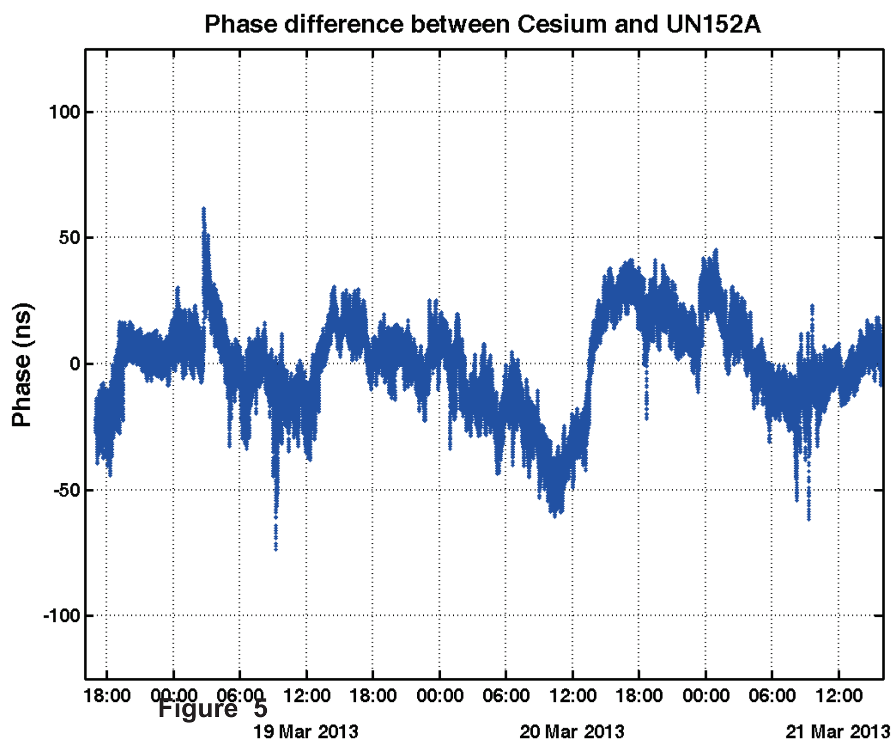
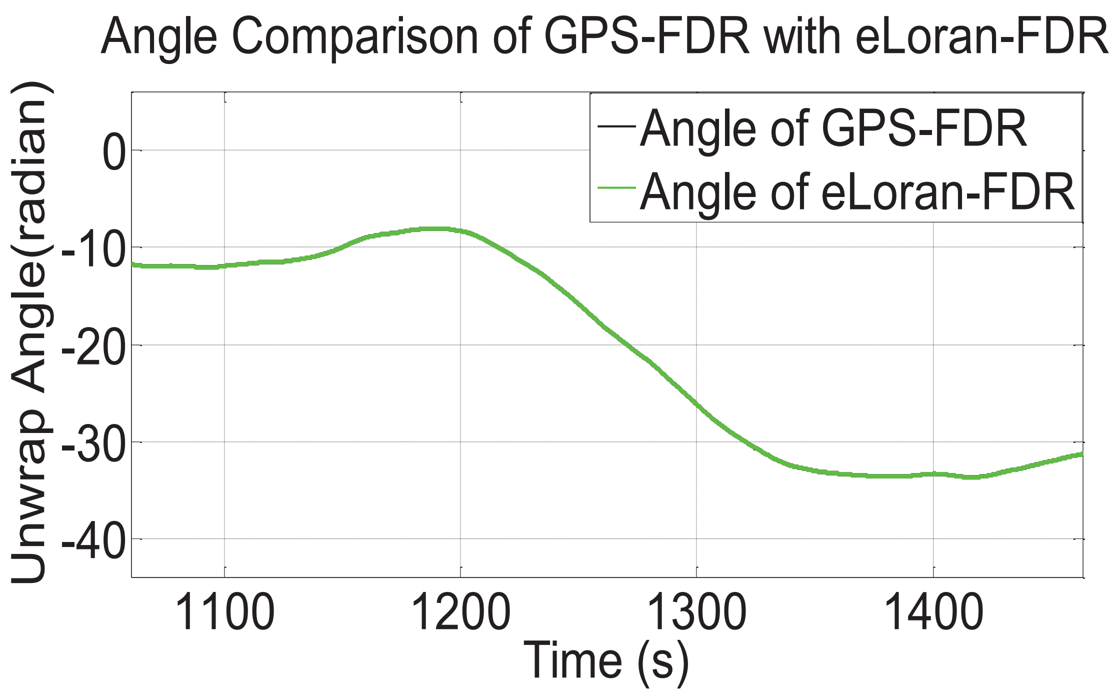
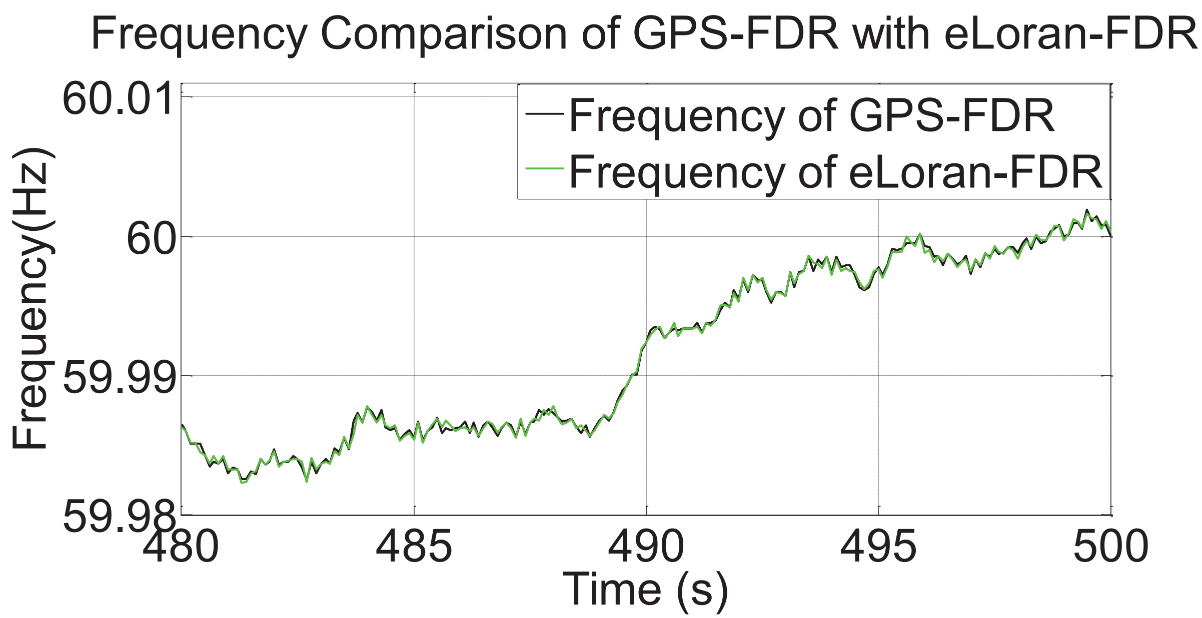


Figure 5

Comparison of Angle

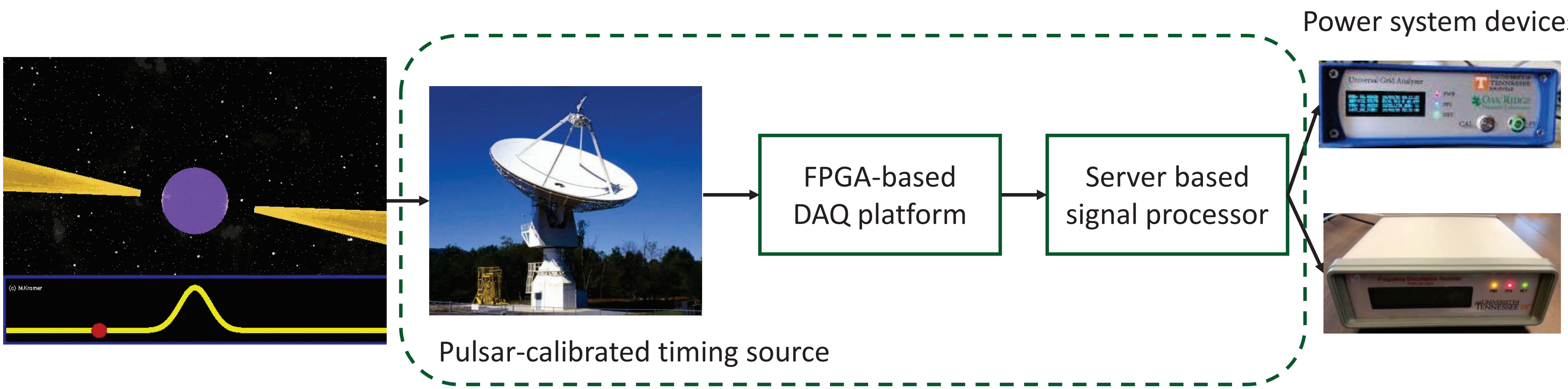


Comparison of Frequency



Hybrid Pulsar and GPS Timing System

- Pulsar-calibrated timing source (PTS)
  - Timing signal received from **precise millisecond pulsars**
  - Signal processing: folding, de-dispersion, filtering, etc
  - Generated PPS: **highly precise but not synchronized**

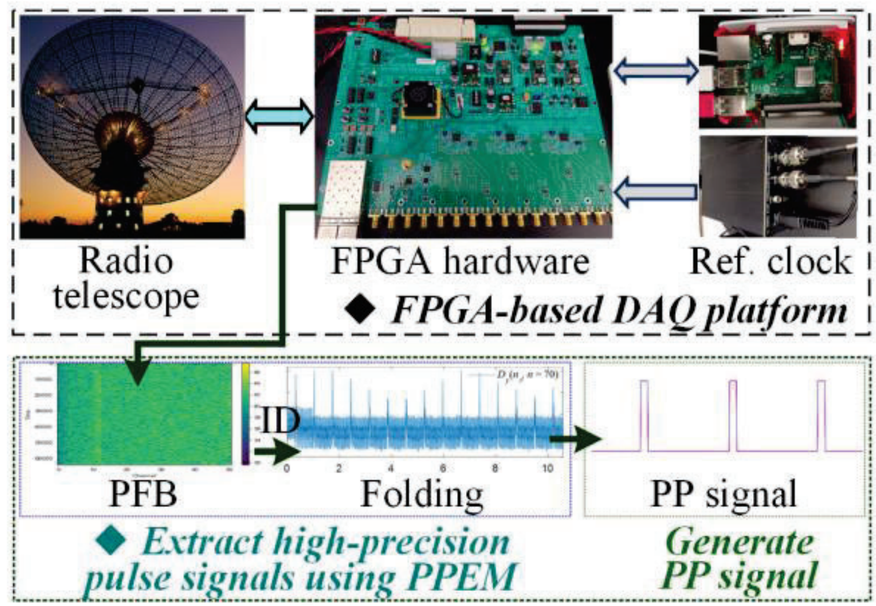


Hybrid Pulsar and GPS Timing System

Hardware design

- FPGA-based DAQ platform
  - Signal sampling from radio telescope
  - Timing signals generation
- Server-based signal processor
  - Folding, de-dispersion, filtering, etc
- Timing signal generation

Setup of Pulsar-calibrated timing source

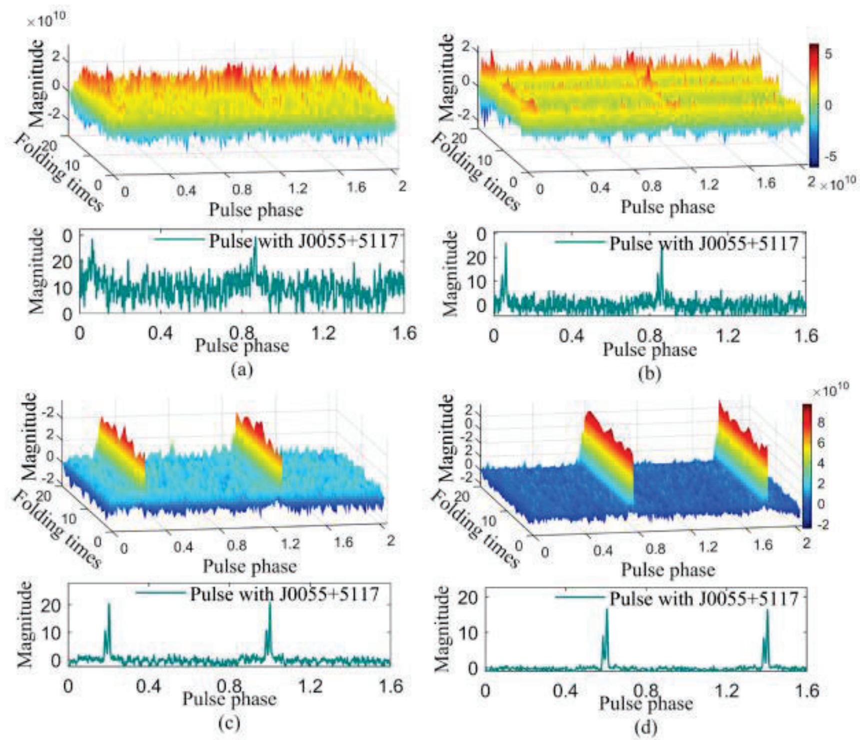


Hybrid Pulsar and GPS Timing System

- Software design
  - Automatic folding-based pulsar period estimation
  - Searching-based de-dispersion algorithm design

- Work in progress
  - AI-based period adjusting algorithm
  - Multiple pulsar switching algorithm

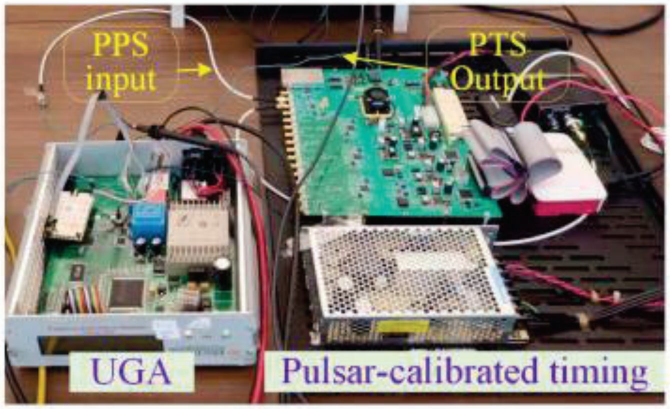
Generated PPS from PTS



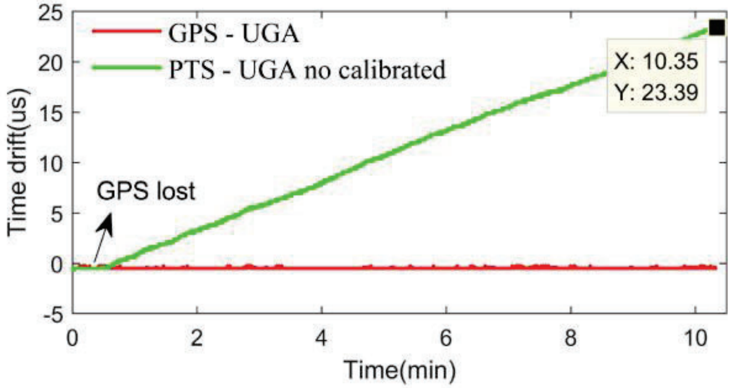
Hybrid Pulsar and GPS Timing System

- Hybrid timing system
  - PTS: backup timing source
  - GPS: synchronize PTS
- Applications on an Universal Grid Analyzer (UGA)
  - Calculate time drift from frequency and phase angle measurements

Setup of Pulsar-calibrated timing source with UGA



Time drifts for PTS with and without GPS calibration



Conclusion

- Accurate and reliable timing source is crucial for power grids wide area monitoring and measurements of **today.**

- The dependency on accurate and reliable timing source is even more critical for operating a fast moving grid dominated by IBRs of **tomorrow.**

Thank you!