Virtual-Instrumentation-Based PMU Calibrator for IEEE C37.118.1-2011 Compliance Testing

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Key Takeaways

- The differentiated PXI platform enables a rapid prototyping of automated, multi-functional, accurate PMU calibrator
  - Full coverage of the tests in IEEE C37.118.1 – 2011
  - Output uncertainty within the error limits in IEEE C37.242 – 2013
  - Graphical system design software platform is customizable enough to quickly respond to future standard evolvement

Agenda

- Specification overview
- Key components
- How to calibrate the PMU calibrator
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Uncertainty of Nominal Value

		Requirement in IEEE C37.242 - 2013	PXI-Based PMU Calibrator
Steady state	TVE (%)	0.1	0.05
	FE (mHz)	0.1	0.05
	RFE (mHz/s)	1	0.2
Dynamic, modulation	TVE (%)	0.2	0.1
	FE (mHz)	0.5	0.5
	RFE (mHz/s)	10	0.5
Dynamic, ramp	TVE (%)	0.2	0.1
	FE (mHz)	0.5	0.5
	RFE (mHz/s)	10	2

Other Advantages

Items	Traditional Implementation	PXI-Based PMU Calibrator
System setup	Complex	Simple and small size (all in a 3U chassis)
Execution	Requires proficient operator	Fully automated
Time consumption	6~10 hours per configuration	1.5~2 hours per configuration
Customization	Unchangeable hardware and closed software	Modular hardware and open-source software
Upgrade flexibility	Difficult	Easy
Cost	High	Low

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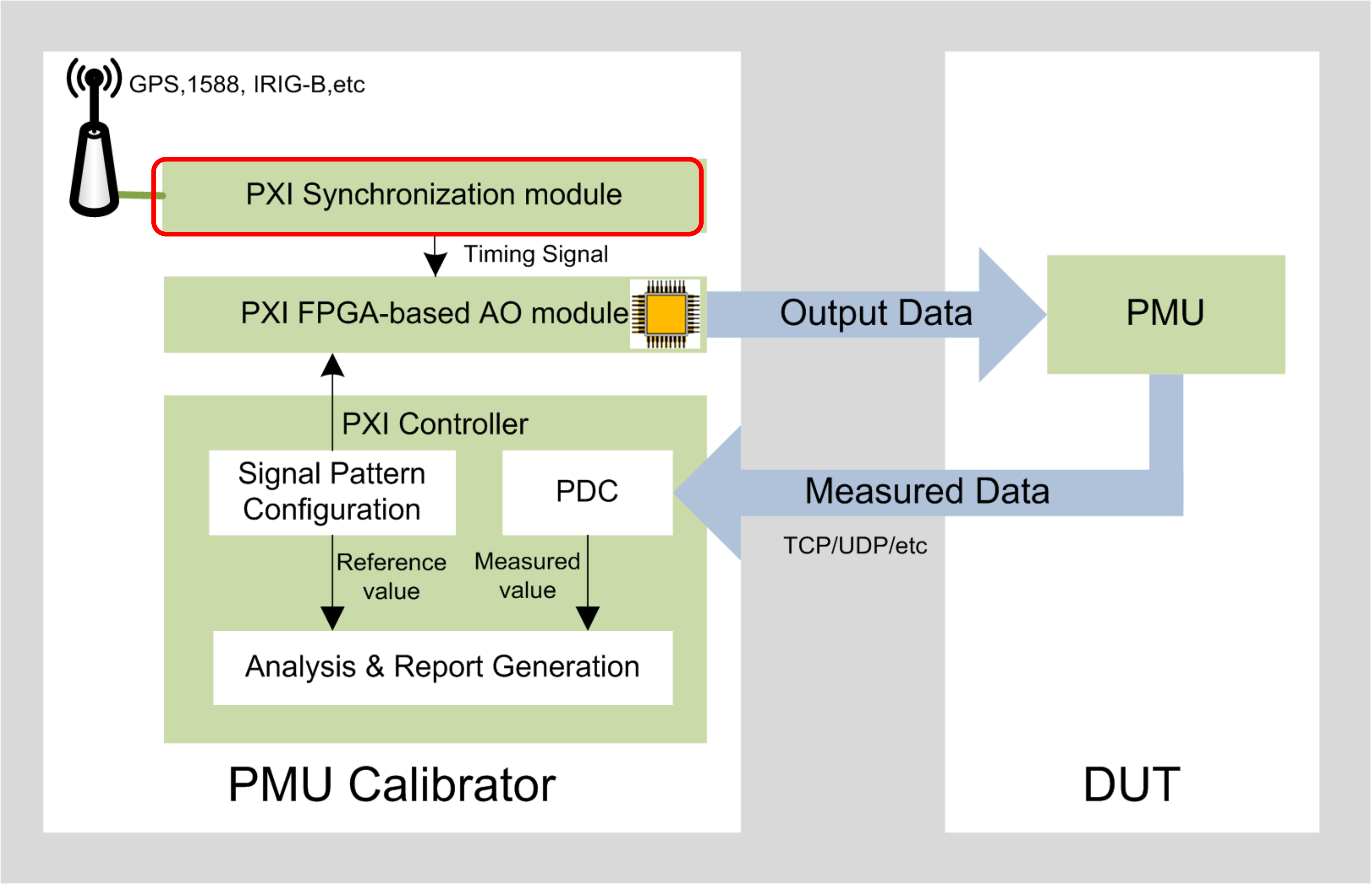
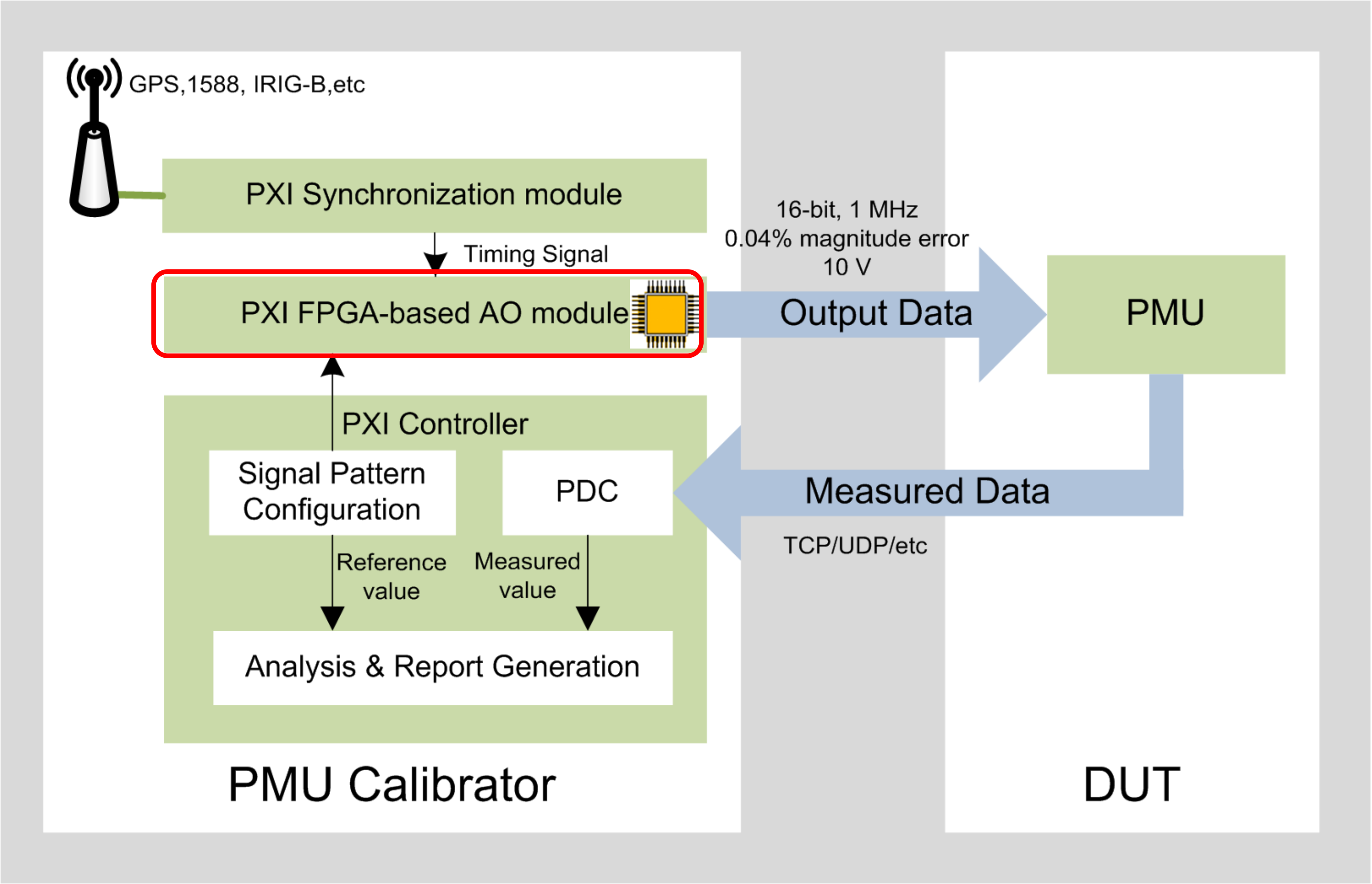
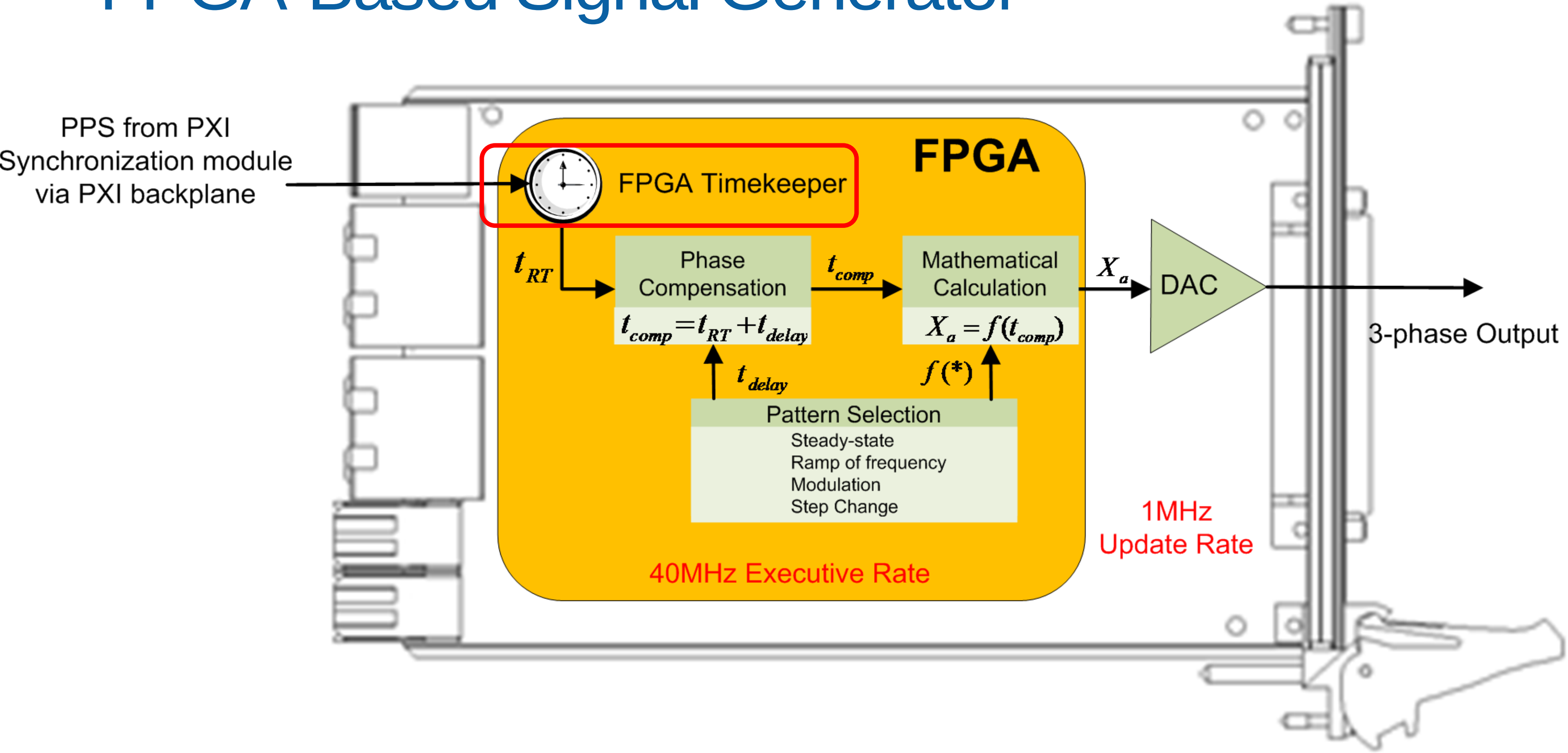
PXI-Based PMU Calibrator



PXI-Based PMU Calibrator

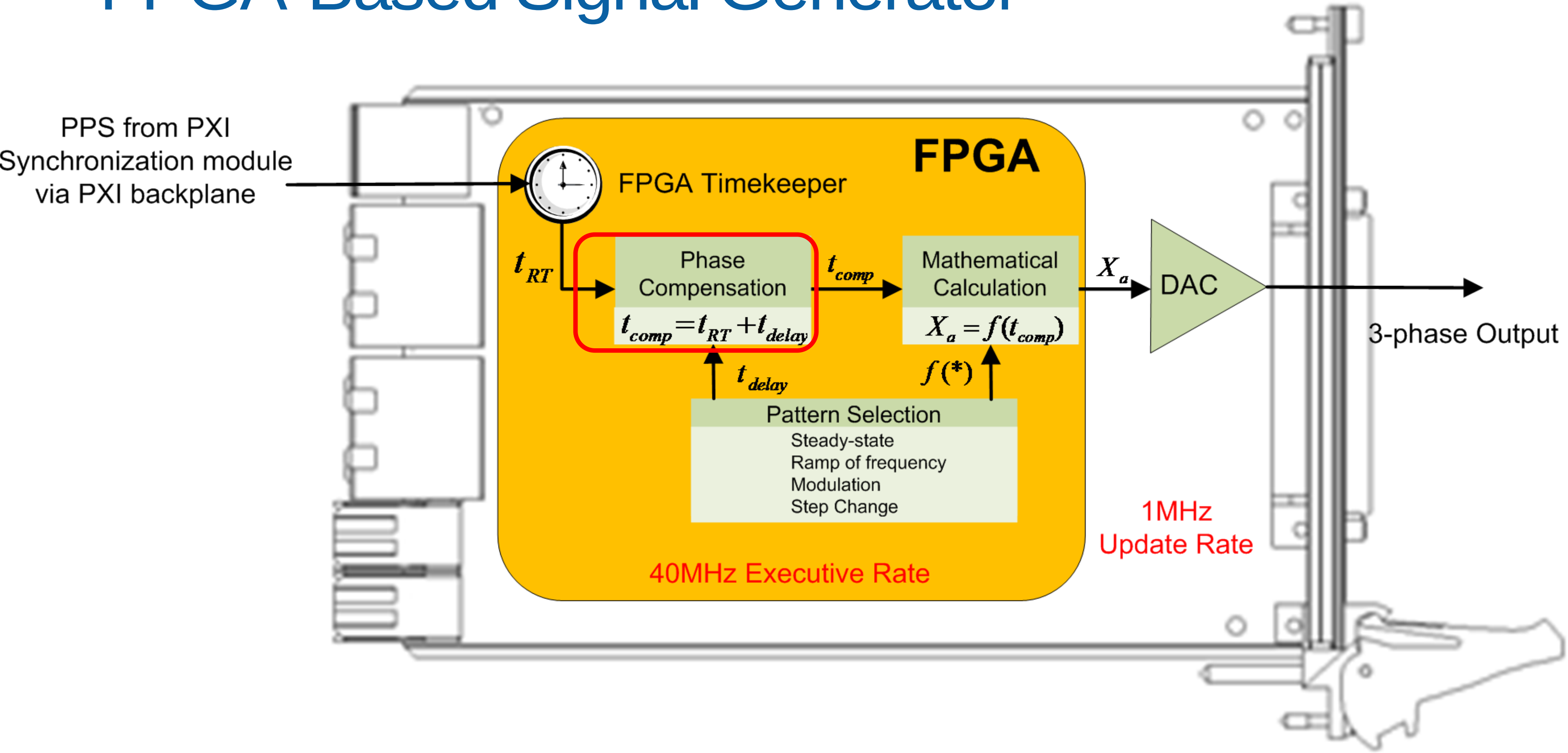


FPGA-Based Signal Generator



- FPGA timekeeper – Synchronizes FPGA 40 Mhz clock with GPS timestamp in 100 ns deviation

FPGA-Based Signal Generator



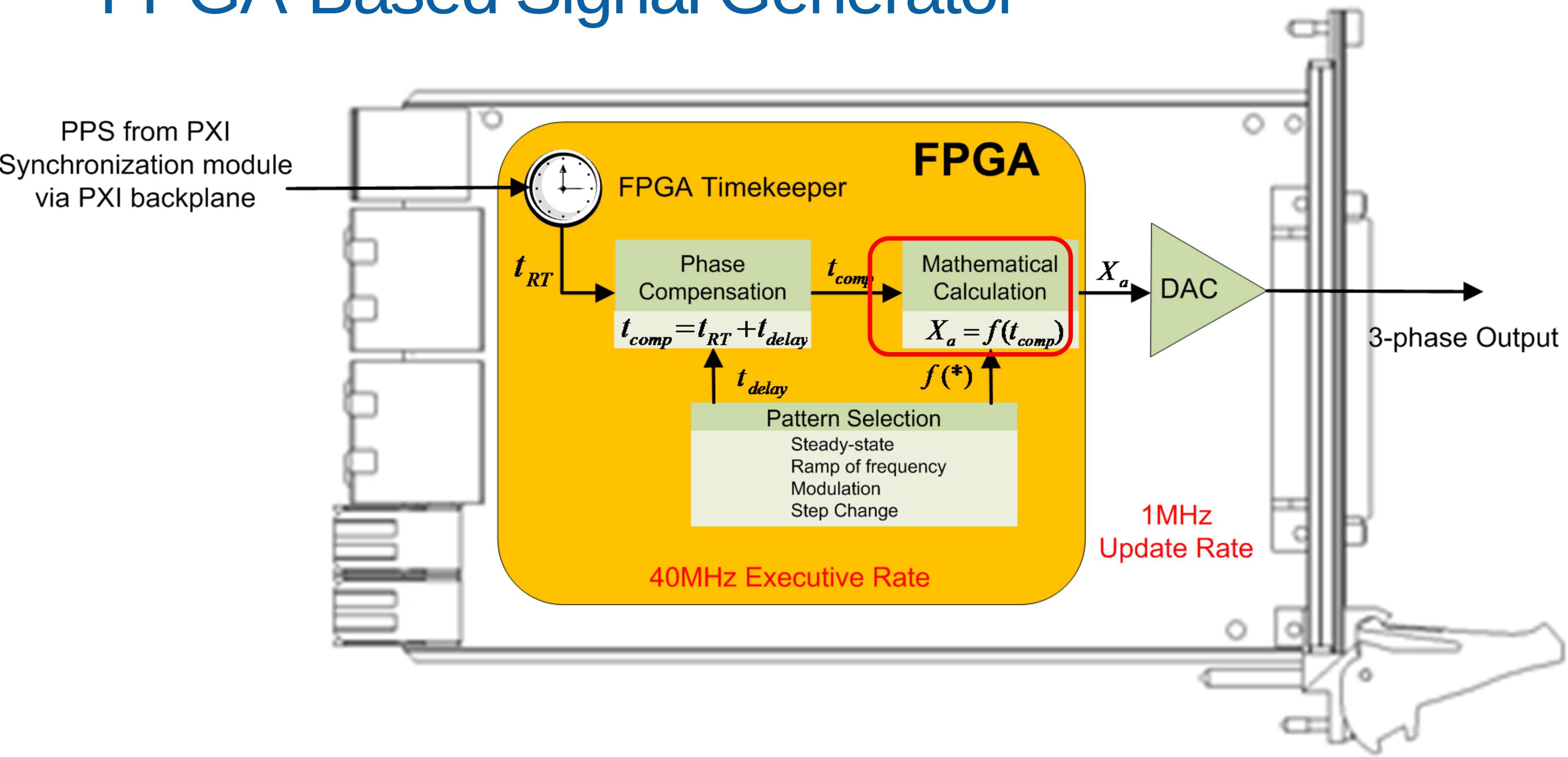
- Phase compensation - Takes account of all the factors before the analog output signal

Phase Compensation

- Introduced by various factors
  - Synchronization, FPGA processing, DAC output filter, loading effect, …
- Measured first by oscilloscope

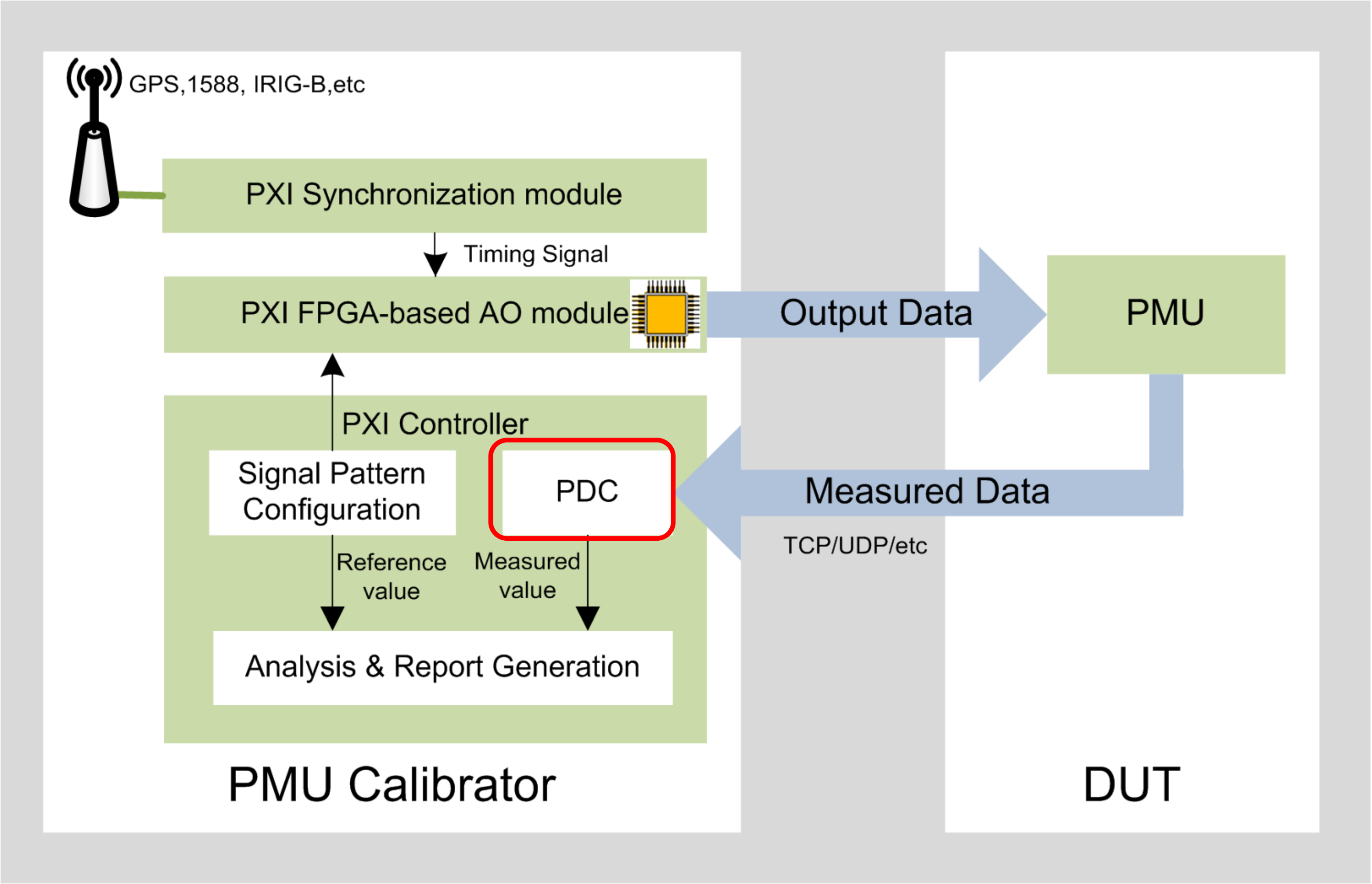
Signal Pattern	Phase Delay
Steady-state	3 us
Modulation	4 us
Frequency ramp	6 us
Step change	4 us

FPGA-Based Signal Generator

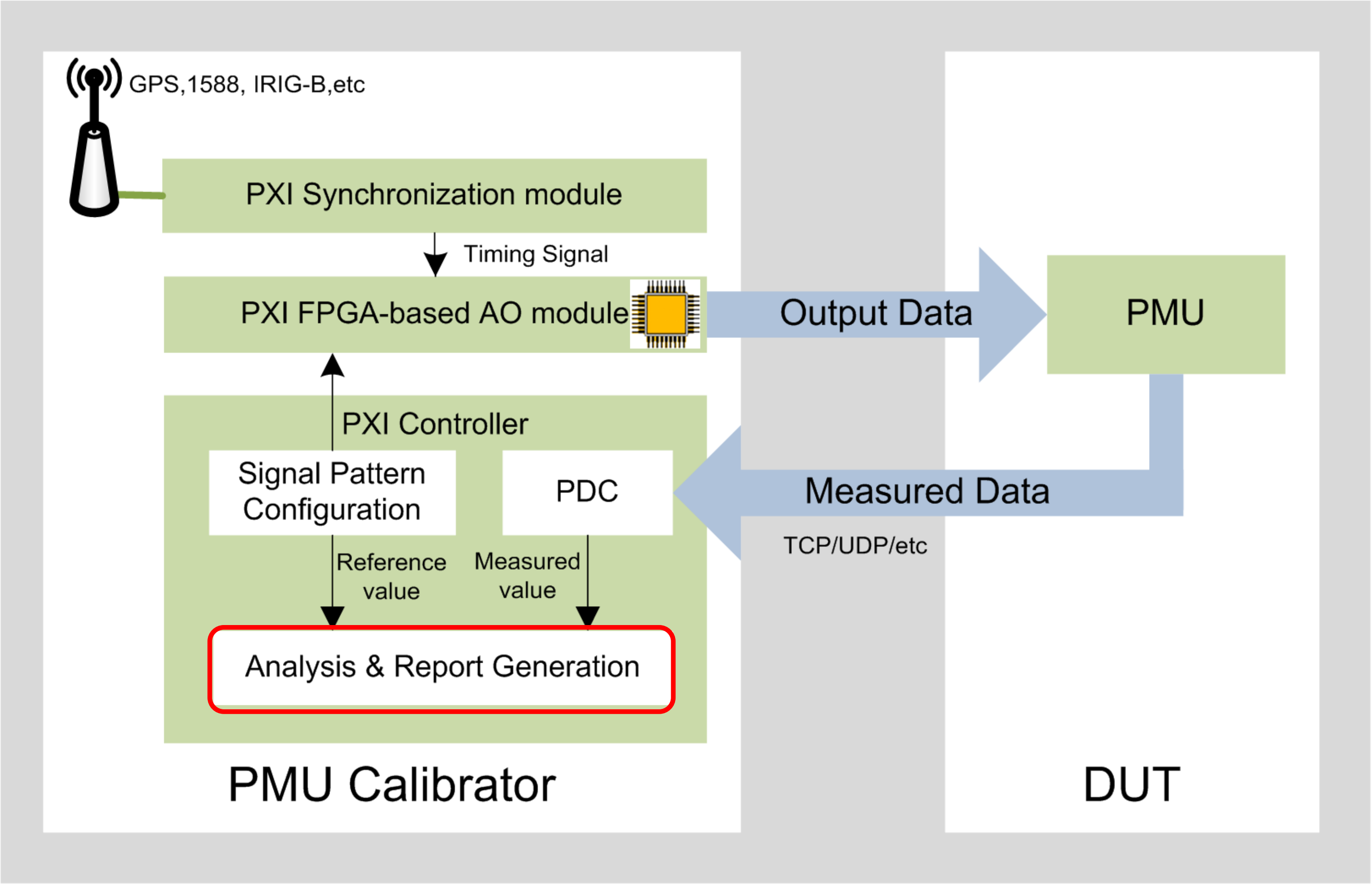


- Mathematical calculation - Generates various steady-state and dynamic-state signals according to mathematical equations

PXI-Based PMU Calibrator



PXI-Based PMU Calibrator



Error Analysis

- Not feasible to leverage a calibrated reference PMU
- Mathematical-model-based method removes the potential negative effects of uncertainty and unrepeatability
  - Calculate the true values

$$X_a = X_m[1 + 0.1\cos(2\pi \cdot 5 \cdot t)]\cos[2\pi \cdot 50 \cdot t + 0.1\cos(2\pi \cdot 5 \cdot t - \pi)]$$

$$\Downarrow$$

$$phasor = X_m / \sqrt{2}[1 + 0.1\cos(2\pi \cdot 5 \cdot t)]\angle[0.1\cos(2\pi \cdot 5 \cdot t - \pi)]$$

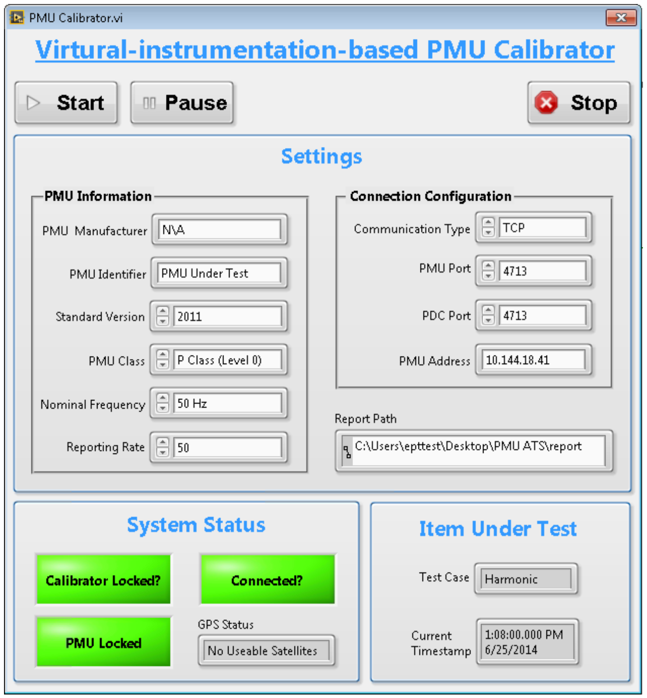
$$frequency = 50 - 0.1 \cdot 5\sin(2\pi \cdot 5 \cdot t - \pi)$$

$$ROCOF = -0.1(2\pi \cdot 5)^2 \cos(2\pi \cdot 5 \cdot t - \pi)$$

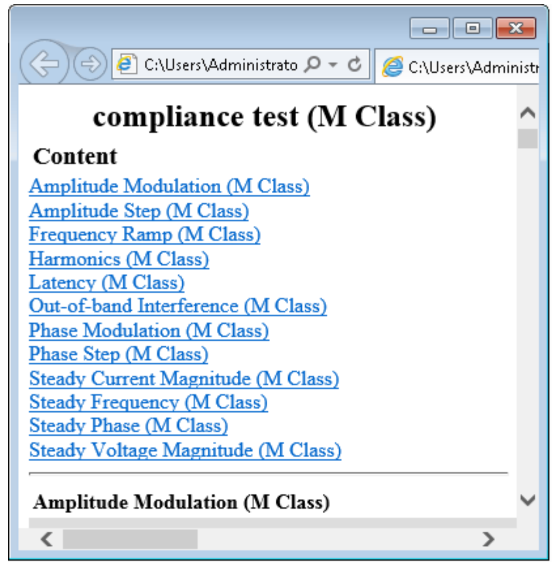
- Error = Measured value – true value

Report Generation

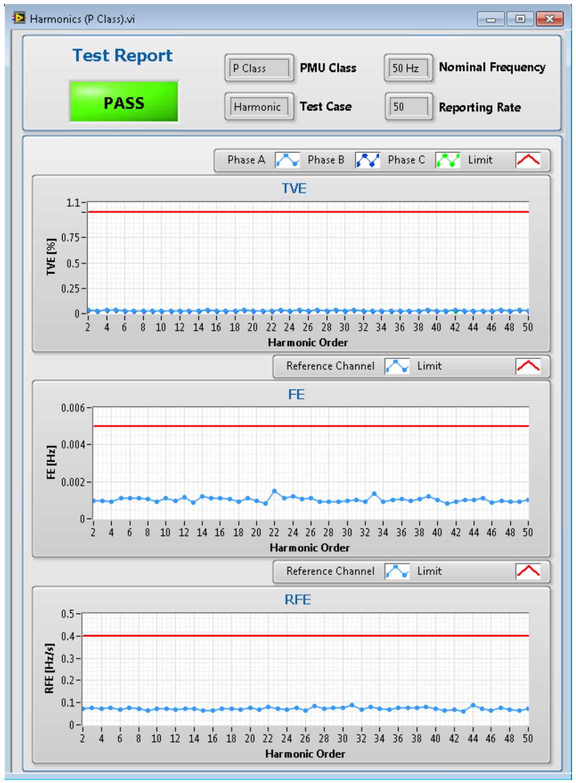
- Automated, customizable for user-defined report format



Configuration



HTML test report



Detailed report

NATIONAL INSTRUMENTS

Functional Extendibility

- Flexible and customizable enough to cover
  - GPS RF signal simulator
  - Higher reporting rates support
  - EIA-232, EIA-485 communications
  - IEC 61850-90-5
  - Compensate the magnitude error and phase delay introduced by 3rd party power amplifier

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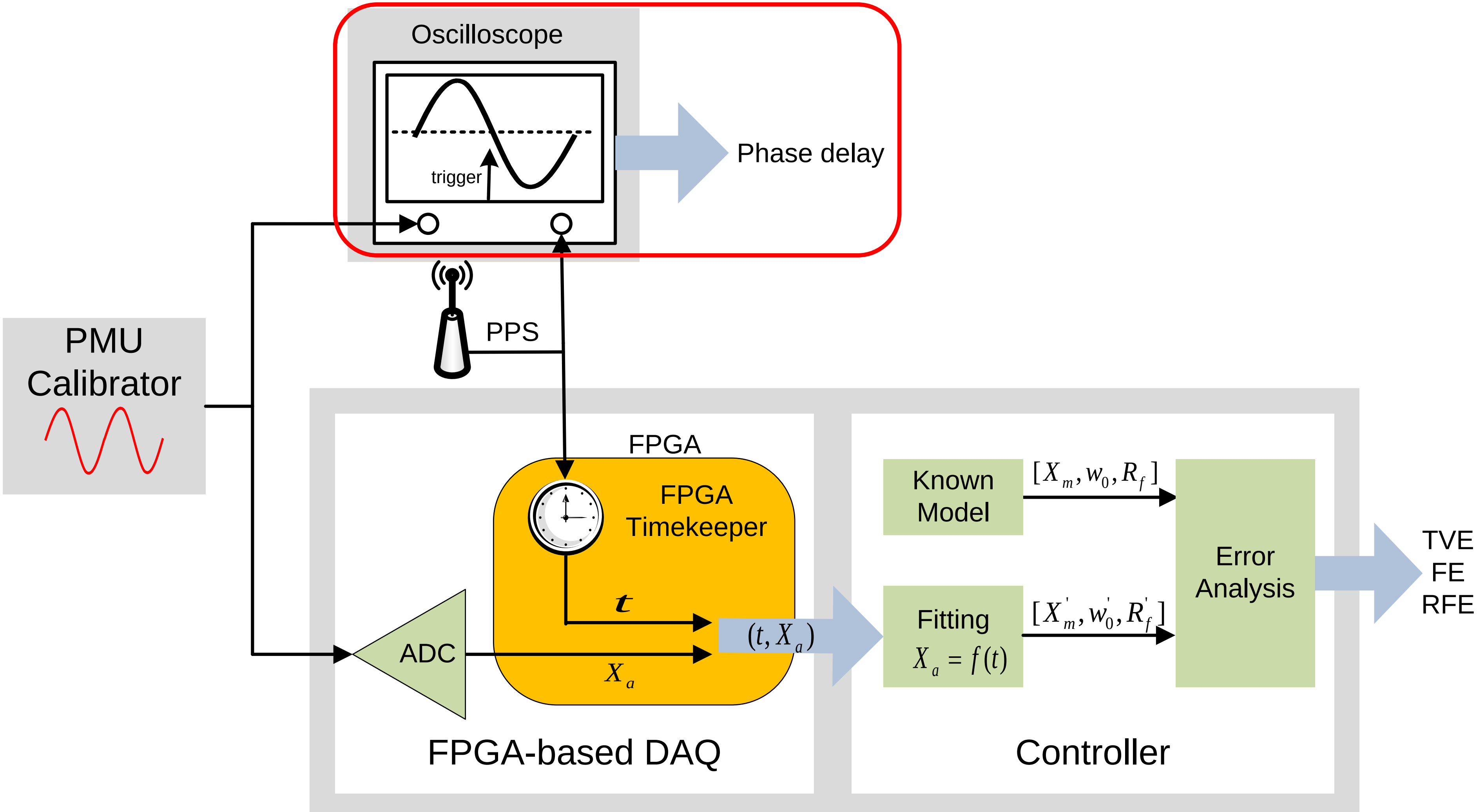
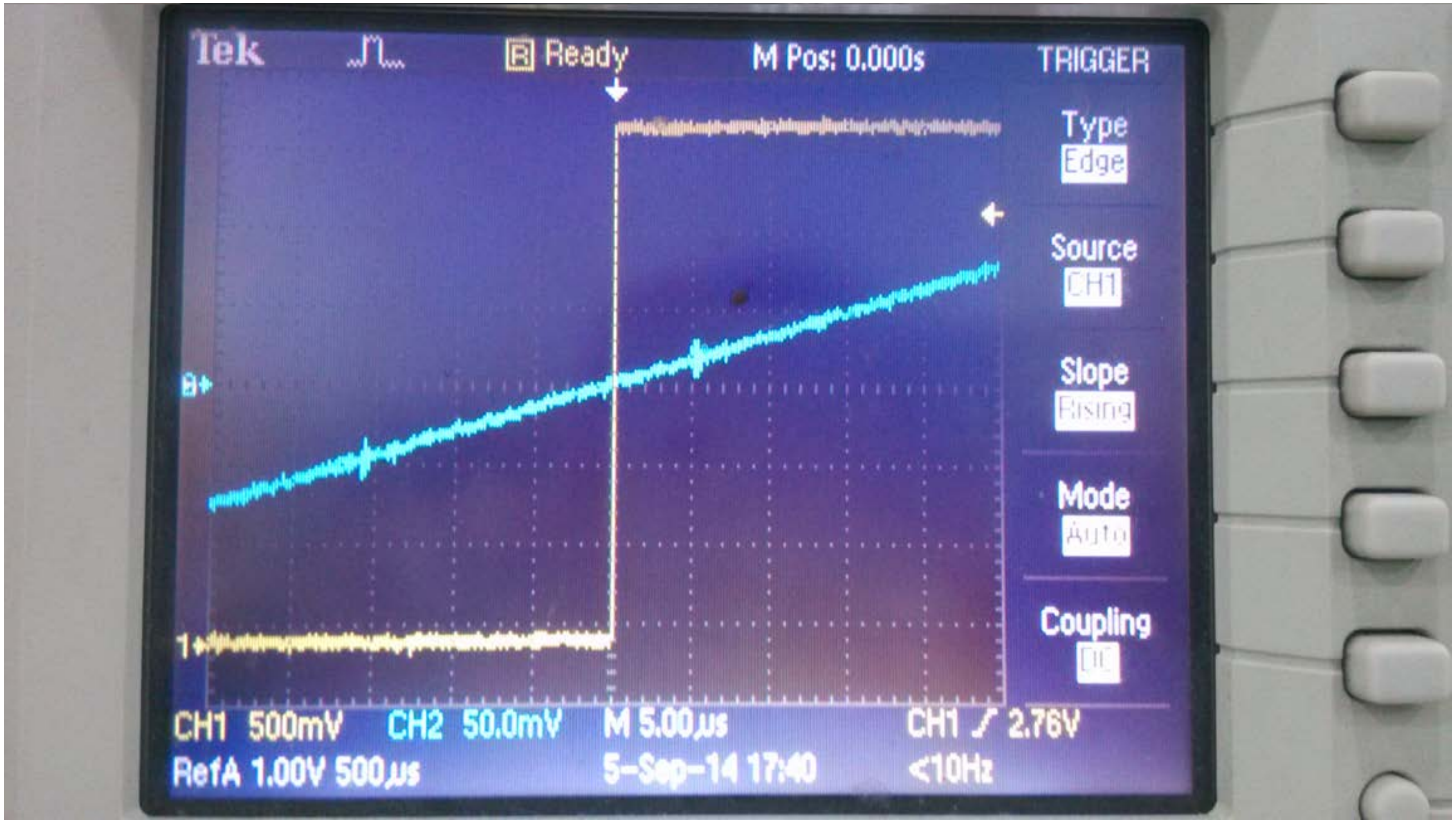


Verification Using Oscilloscope

- Within 1 us = 0.3 mrad = 0.05% TVE (given 0.04% magnitude error)



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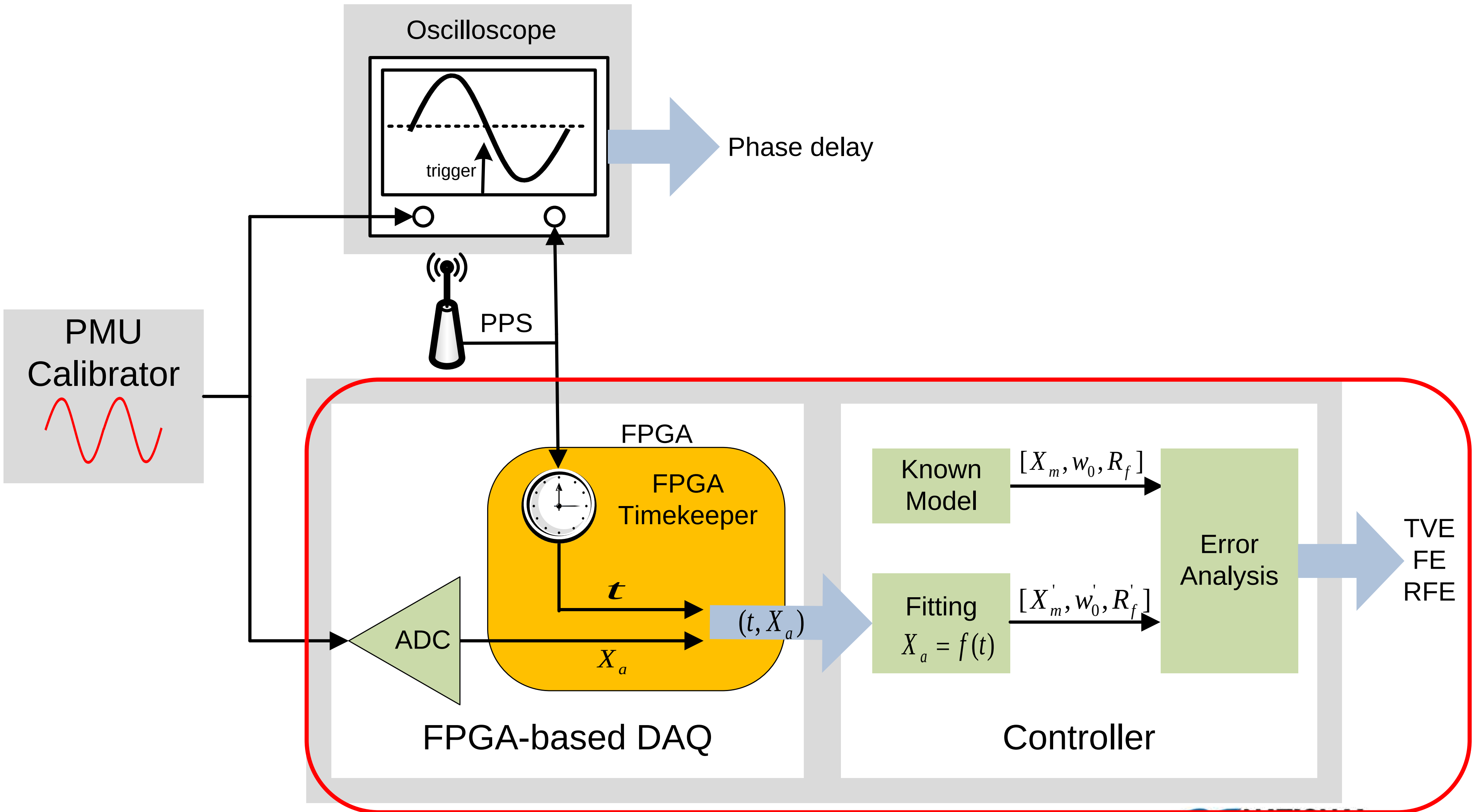

Verification through Samples Fitting

Sampled values with timestamps

Known user-configured values

$$[X_m, w_0, R_f]$$

Known signal type ↓ **Levenberg-Marquardt non-linear fitting**

$$[X_m^{'}, w_0^{'}, R_f^{'}]$$

↓

TVE

FE

RFE

Summary

- Various synchronized signals can be generated to cover all the C37.118.1-2011 based steady-state, dynamic-state, and reporting latency tests for both M class and P class at all reporting rates.
- FPGA technology allows the accurate signal generation algorithms on hardware, achieving TVE/FE/RFE within the limit as defined in IEEE C37.242 – 2013.
- Versatile software platform with open-source is customizable enough to quickly respond to standard evolvement or the error compensation of 3rd party power amplifier.
- Uncertainty is well proved by two verification methods.