

Hardware-In-Loop Testing of Phasor Measurement Unit using Miniature Full Spectrum Simulator

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Guided By:

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MTP Stage - 1

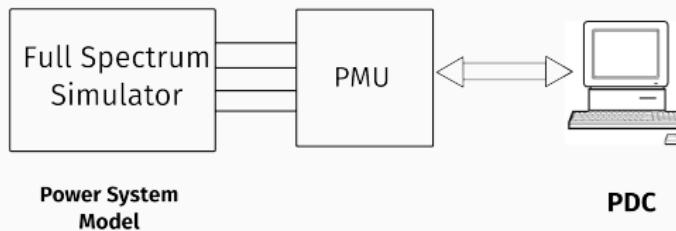
Introduction

Overview

1. Theoretical background
2. Literature Survey
3. Proposed Scheme
4. Implementation
5. Plan of work

Aim of Project

- Test the feasibility of using Full Spectrum Simulator (FSS) as a test bench for PMU testing
- Test PMU device compliance as per IEEE C37.118.1 standard

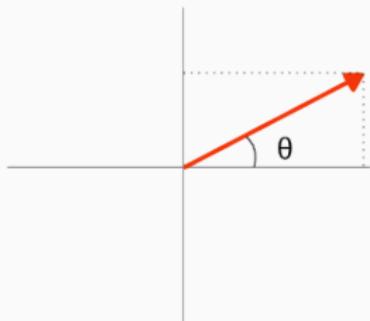


- Implement a power system model having different test case scenarios in FSS
- To use indigenously developed or self-designed PMU hardware
- Evaluate the performance of FSS and PMU both

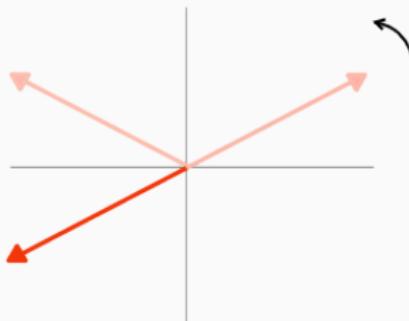
Background - Terms

C37.118 It is a synchrophasor standard stating the measurement provisions, performance criterion and data communication protocol.

- **Phasors:** A complex number which represents both magnitude and phase of an AC quantity.
- **Synchrophasors:** Synchronized sampling/measurement of phasor at a precise reference (time)



Phasor



Time Varying Phasor
(Synchrophasor)

Background - PMU Basics

PMU: It is a device which gives you an estimate of the phasor



Figure 1: Sine to Circle representation [2]

Sinusoid: $x(t) = X_m(t)\cos(\omega_0 t + \phi)$

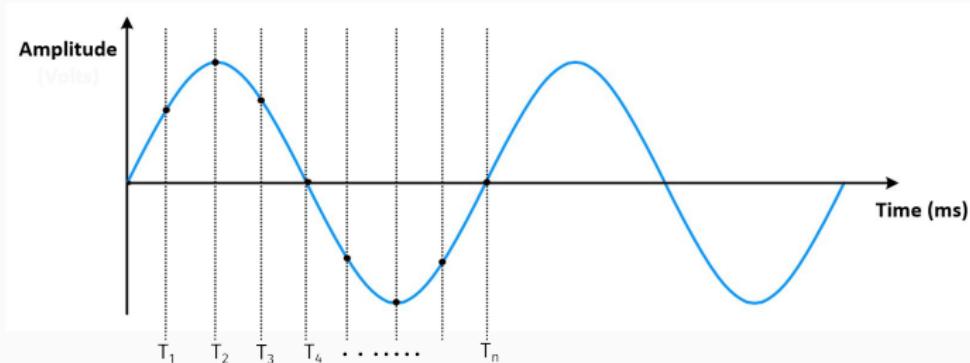
Synchro Phasor Representation: $\mathbf{X} = \frac{X_m}{\sqrt{2}}e^{j\phi(t)}$ or $\mathbf{X} = X_r + jX_i$

Frequency $f(t) = \frac{1}{2\pi} \frac{d\psi(t)}{dt}$ (where, $\psi = \omega_0 t + \phi$)

ROCOF = $df(t)/dt$

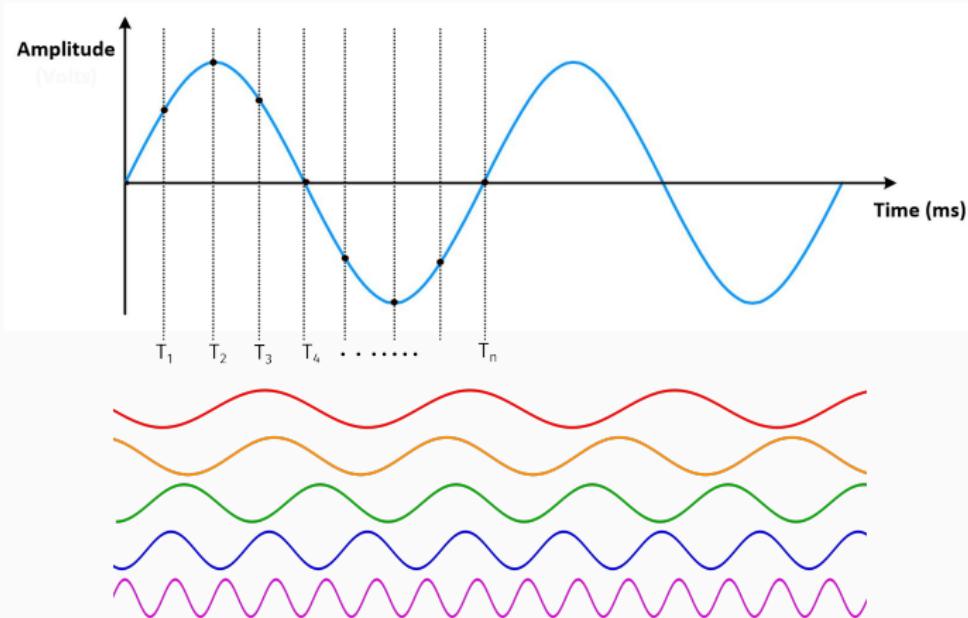
Why Standards are required?

All previous equations are frequency dependent - f_0 - Fundamental frequency



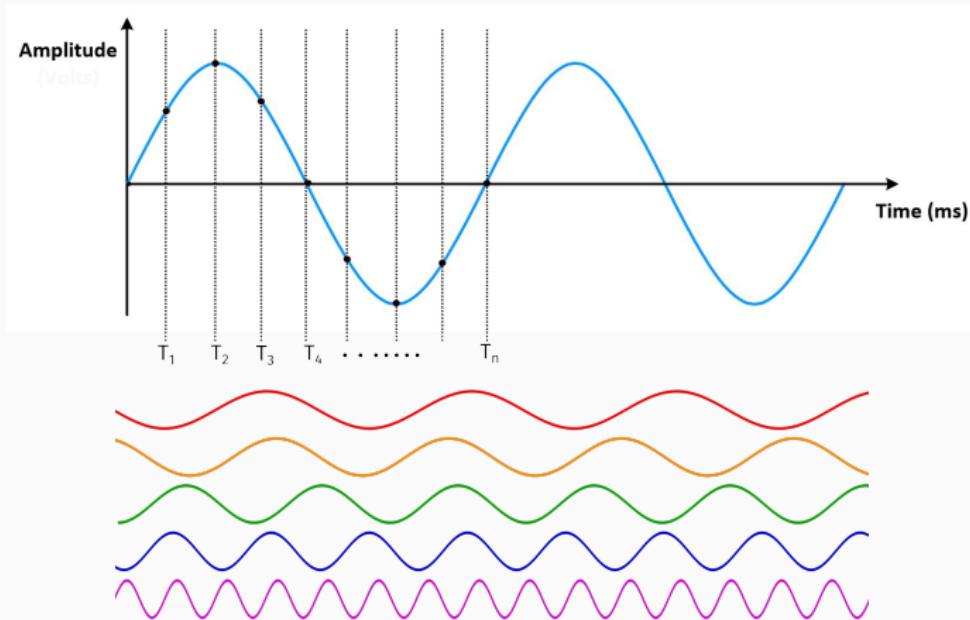
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Different make - Incompatibility

Total Vector Error

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- Frequency dependency of the result
- It require a reference which is independent and time invariant.

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Type of PMU:

-Protection Class: Time critical application, More stringent requirement

-Measurement Class: Greater precision not (very) time critical

Types of Tests

To find the TVE, compliance test(s) are performed, recommended by C37.118

1. Steady-state compliance
 - 1.1 Steady-state synchrophasor measurement requirements
 - 1.2 Steady-state frequency and ROCOF measurement requirements
2. Dynamic compliance
 - 2.1 Synchrophasor measurement bandwidth requirements using modulated test signals
 - 2.2 Frequency ramp test
 - 2.3 Step changes in phase and magnitude

Literature Survey

Literature Survey

Basically there are 3 components in any test arrangement

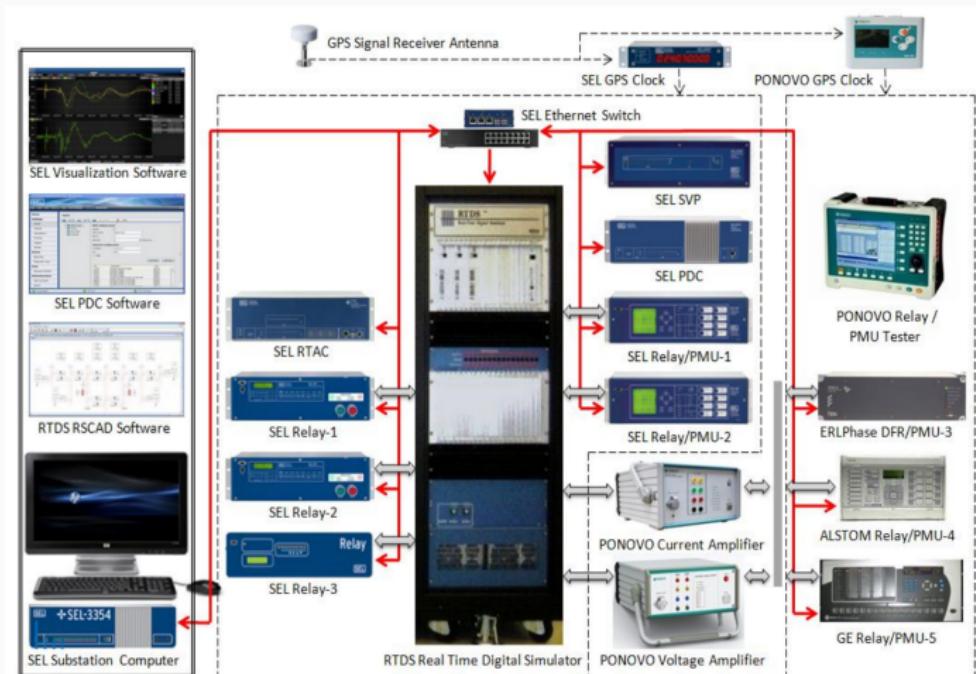
- Device Generating Test Signal
- PMU under test
- Recording device (PDC etc.)

Dynamic PMU Compliance Test under C37.118.1a-2014¹

- Doble F6150 Power System Simulator
- Three Different PMUs
- Direct PMU - Power Sys Simulator interfacing
- Test Performed [6] :
 - Amplitude Modulation: 0.9 - 1.1 PU (0.1 to 5 Hz)
 - Phase Modulation: 0.1 rad
 - Ampli. Step Test: ± 0.1 PU step
 - Phase Step Test:
 - Freq. Ramp: ± 1 Hz/s between (44 to 55 Hz)
- IMP: Test signals are **not** time synchronised.

¹R. Ghiga, Q. Wu, K. Martin, W. Z. El-Khatib, "Dynamic PMU Compliance Test under C37.118.1a-2014"

Development of a Smart Grid Test Bed and Applications in PMU and PDC Testing²



² Saugata S. Biswas, Jeong Hun Kim, Anurag K Srivastava "Development of a Smart Grid Test Bed and Applications in PMU and PDC Testing"

Development of a Smart Grid Test Bed and Applications in PMU and PDC Testing³

- Test signals are GPS synchronised
- Multiple devices acting as PMU - Multi-vendor relays
- Results validated by PMU Tester

³Saugata S. Biswas, Jeong Hun Kim, Anurag K Srivastava Development of a Smart Grid Test Bed and Applications in PMU and PDC Testing

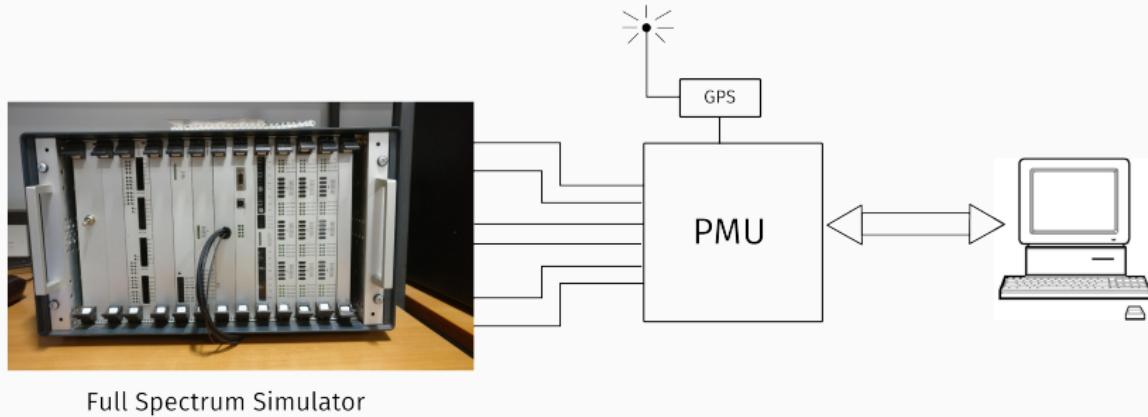
Dynamic Performance Evaluation and Testing of PMU under C.31.118-2011⁴

- Doble F6150 Power System Simulator
- TESLA 4000 PMU
- Direct PMU-RTDS interfacing
- Testing Steps:
 - PSCAD/EMTDC generates precise current and voltage signals
 - Power System Sim. plays it in realtime
 - Test signals are time synchronised
 - The M class operating range is considered, as P class is subset of M.

⁴ Krish Narendra, Dinesh Rangana Gurusinghe, "Dynamic Performance Evaluation and Testing of Phasor Measurement Unit (PMU) as per IEEE C37.118.1 Standard"

Implementation

Test Setup



- Use Full Spectrum Simulator
- Develop PMU using OMAP-L137 EVM
- Use **iPDC** in a PC

Full Spectrum Simulator

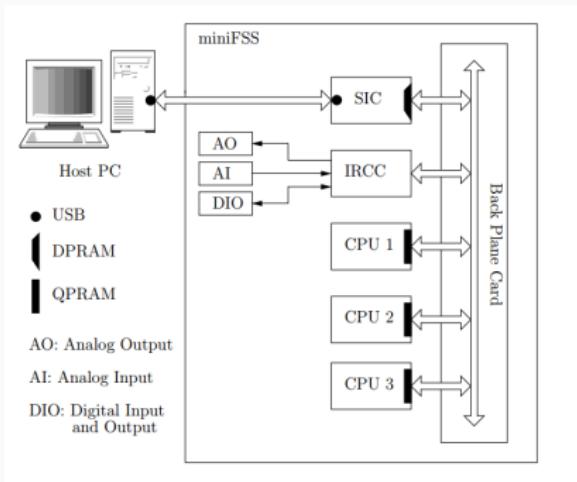


Figure 2: FSS Architecture

- Card Based Structure
- System Interface Card (SIC)
- Intra Rack Control Card (IRC Card)
- Three CPU Cards, each having 3 DSPs. So total 9 processors
- One Analog Input Card (± 10 V)
- One Analog Output Card (± 10 V)
- Digital I/O Card (0 – 5 V)

PMU Architecture - Platform

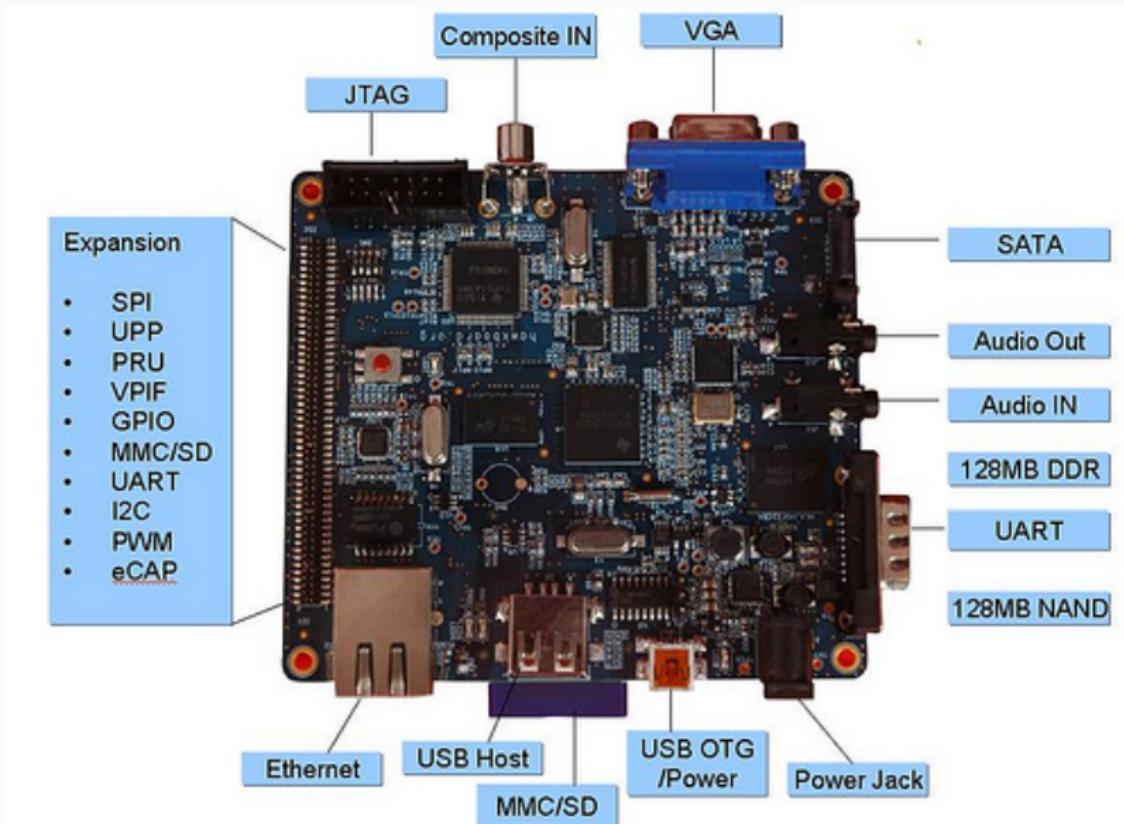
We require a platform which can do two things

- High speed -Digital signal processing
- Upper level tasks - packet forming, Time stamping, ethernet communication

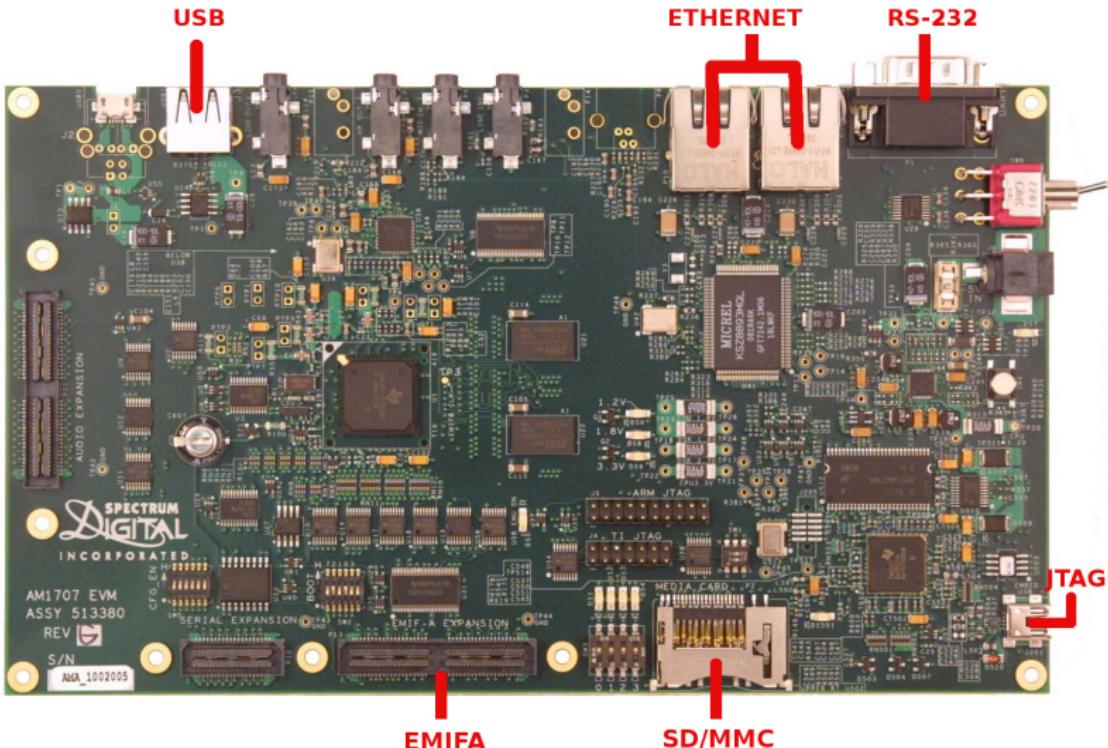
Hence an asymmetric dual core processor - DSP + ARM

- OMAP L-137 or L-138 (C6747 DSP + ARM 926EJ)
- Hawk-Board V/s Omap-L137 Evaluation Module

PMU Architecture - Platform



PMU Architecture - OMAP L137 EVM



PMU Architecture - ADC Board

For sensing supply inputs we require ADCs which should have:

- Good sampling rate: ~ 200 Samples/Sec
- No of channels: $3 + 3 = 6$ ($3 - \phi$ voltage and current)
- Interfacing type: It should be memory addressable and voltage level compatible to the EVM.
- Input type: FSS analog output is differential which can be configured as single ended, its voltage level is $\pm 10V$

PMU Architecture - ADC Board

- Out of several options we have narrowed down to **AD7606** or **AD7864**
- AD7864 was chosen has following specification
 - High speed 12-bit ADC
 - **4 simultaneously sampled** dedicated ADC
 - $0.35 \mu\text{s}$ track-and-hold acquisition time
 - $1.65 \mu\text{s}$ conversion time per channel
 - HW/SW select of channel sequence for conversion
 - $\pm 10\text{V}$ & $\pm 5\text{V}$ input voltage range
 - Special interfacing mode for 3.3 V processor

PMU Architecture - EMIFA

EMIF-A controller is a 16-bit databus based versatile controller [10], designed to interact with variety of devices like

- Single Data Rate (SDR) RAM
- Asynchronous devices like NAND & NOR flash memory and SRAM

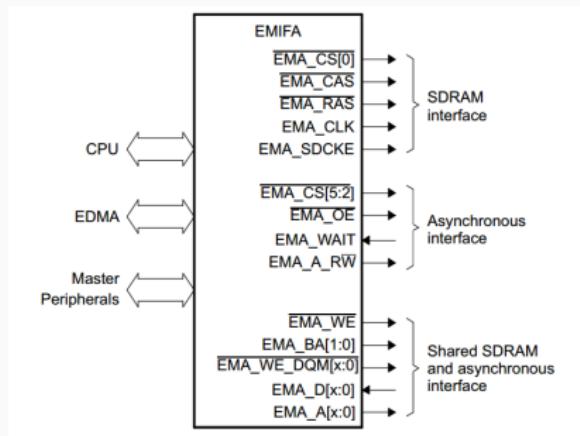
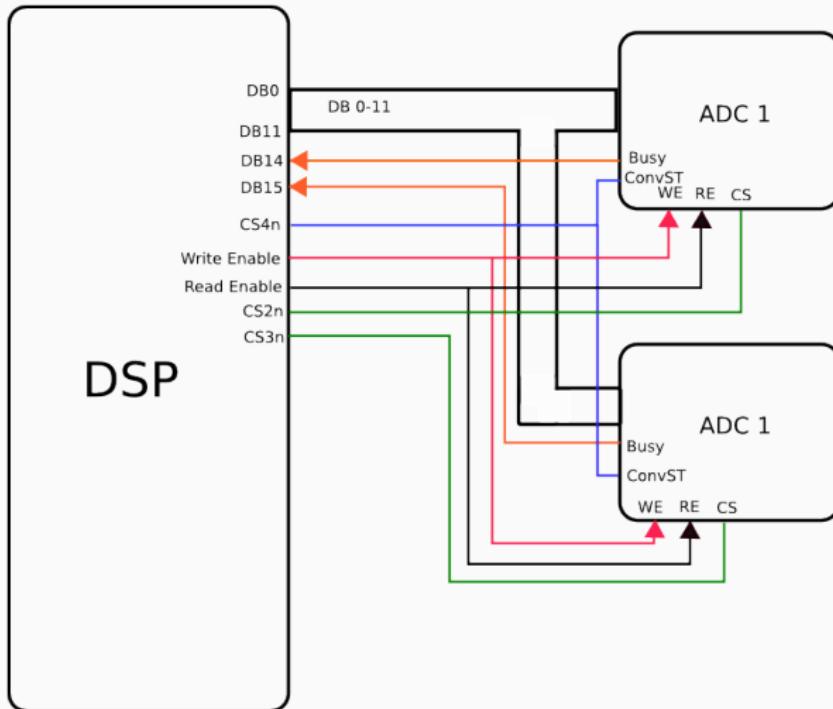


Figure 3: EMIFA Block Diagram

Lot of features to ease and facilitate the usage of asynchronous devices

PMU Architecture - ADC board Arrangement



Future Scope

Future Scope

- Test ADC board, check its performance after connecting it with OMAP-L137 EVM.
- Interfacing of GPS module and DSP programming for time based signal sampling.
- Implement and test DFT algorithm for the phasor estimation and reconstruction.
- Testing of whole setup along with simple test input from FSS.
- Test PMU setup using FSS as real time player and analyse the result.
- Implement a test system in FSS using multi-cores and do the testing and analysis.

References

-  C37.118 - IEEE Standard for Synchrophasor Measurements for Power Systems
-  <http://westernau.com/images/Circle-To-Sine-Wave.png>
-  Phadke, A.G., Thorp, J.S., *Synchronized Phasor Measurements and Their Applications*, Springer US, 2008.
-  iPDC & PMU simulator, ipdc.codeplex.com/
-  Phadake A.G., *HISTORY AND APPLICATIONS OF PHASOR MEASUREMENTS*, IEEE, 2006.
-  R. Ghiga, Q. Wu, K. Martin, W. Z. El-Khatib, L. Cheng and A. H. Nielsen "Dynamic PMU Compliance Test under C37.118.1aTM-2014", *IEEE PES GM*, PAge 1-5, 2015
-  Saugata S. Biswas, Jeong Hun Kim, Anurag K Srivastava "Development of a Smart Grid Test Bed and Applications in PMU and PDC Testing", *IEEE Conference Publications*, 2012.
-  Krish Narendra, Dinesh Rangana Gurusinghe, *Dynamic Performance Evaluation and Testing of Phasor Measurement Unit (PMU) as per IEEE C37.118.1 Standard*, Doble Client Committee, 2012
-  <http://www.ti.com/tool/tmdxevm1707>
-  TMS320C674x/OMAP-L1x Processor External Memory Interface A (EMIFA) User Guide, Texas Instrument
-  Technical Report of Full Spectrum Simulator under National Mission on Power Electronics Technology (NaMPET Phase-II), Submitted by Power Electronics Group CDAC, Thiruvananthapuram

Thank You