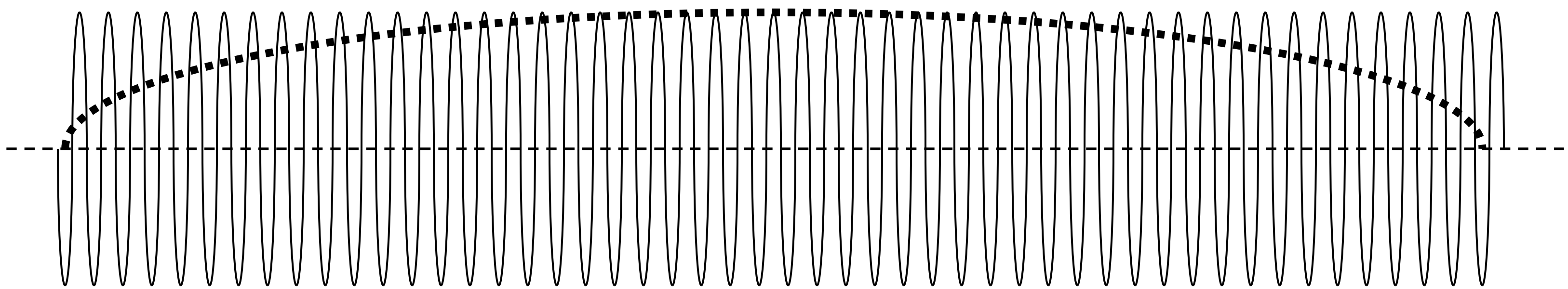
PMU Algorithms and Testing

Dr. Andrew Roscoe

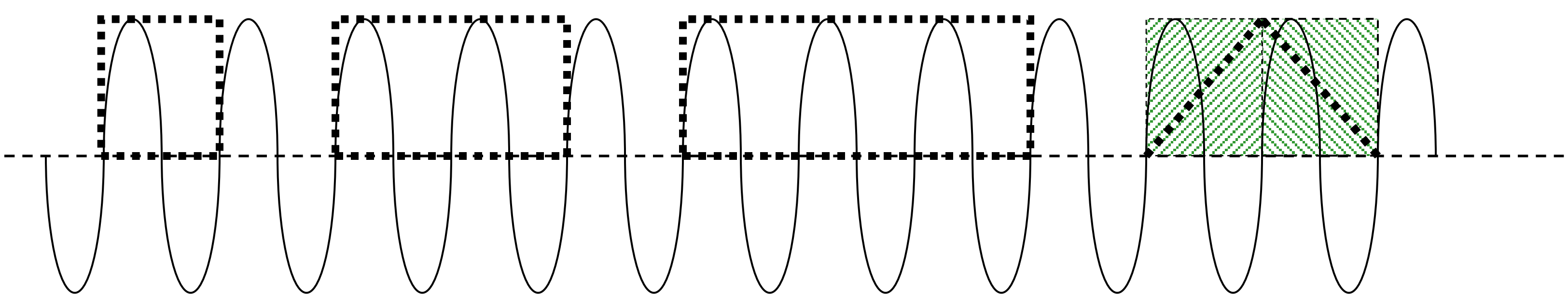
University of Strathclyde

A “unique” problem for power systems

1) Measurement timeframe >> Fundamental period
   - e.g. Radio-frequency measurements

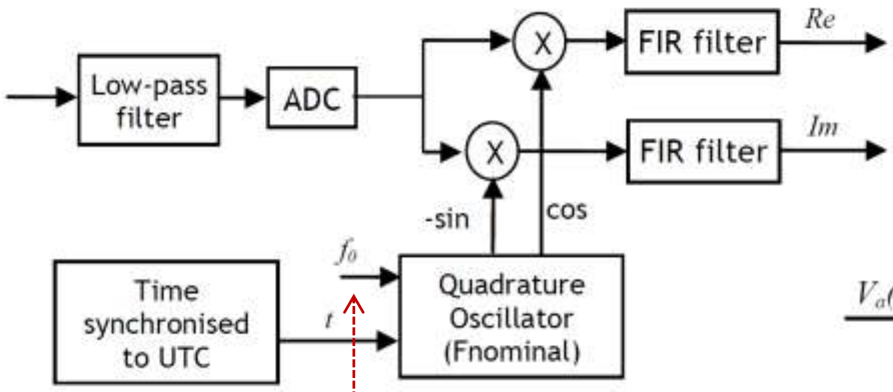


2) Measurement timeframe not >> Fundamental period
   - e.g. Power system measurements over <20 cycles

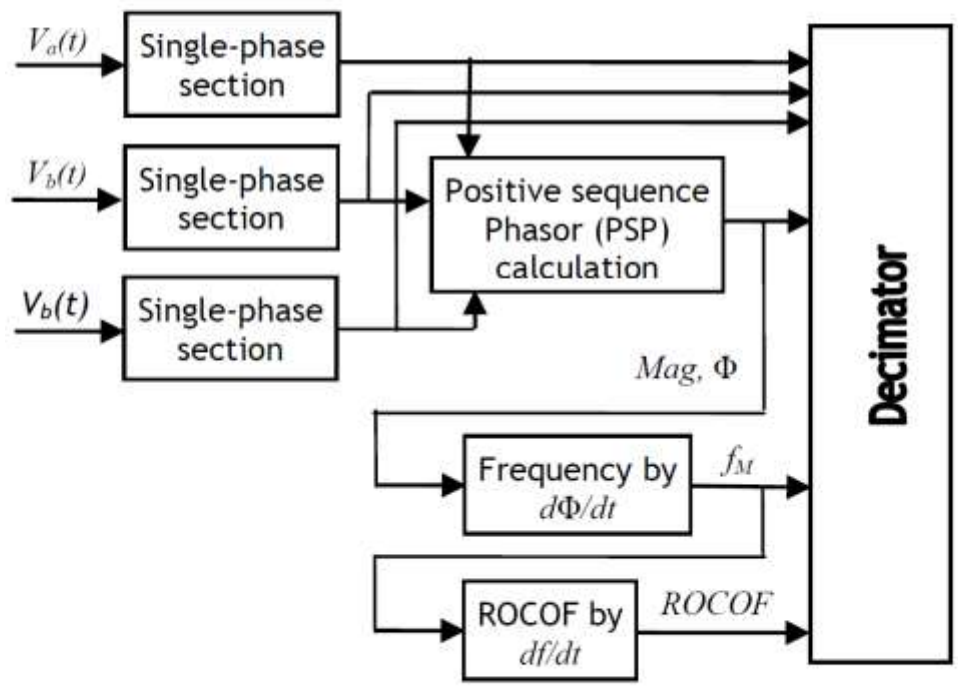


The "Reference" algorithm from C37.118.1

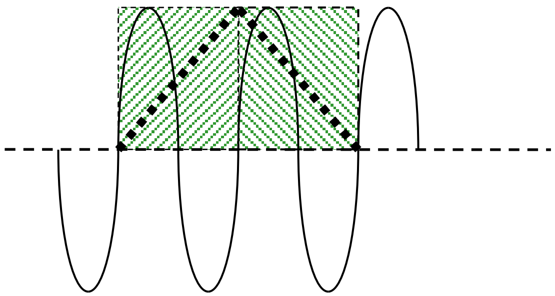
Single-phase section

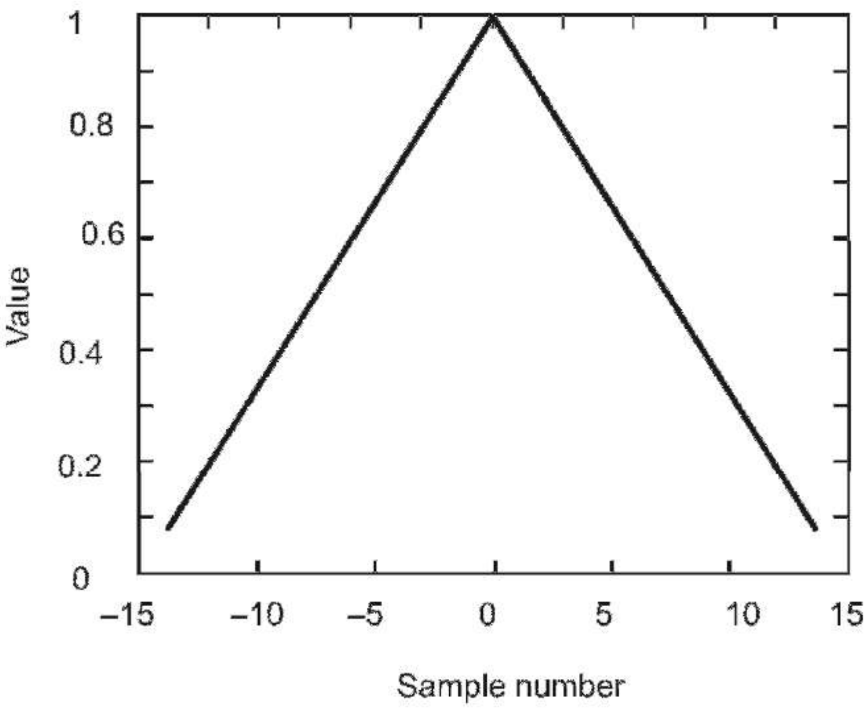


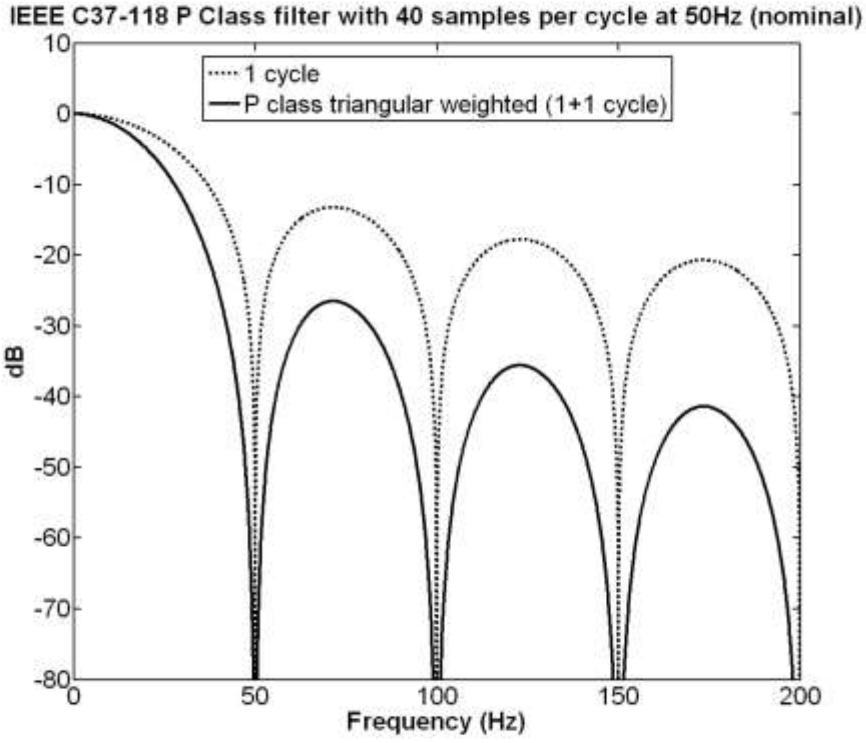
f_0 fixed at nominal frequency



P class filter

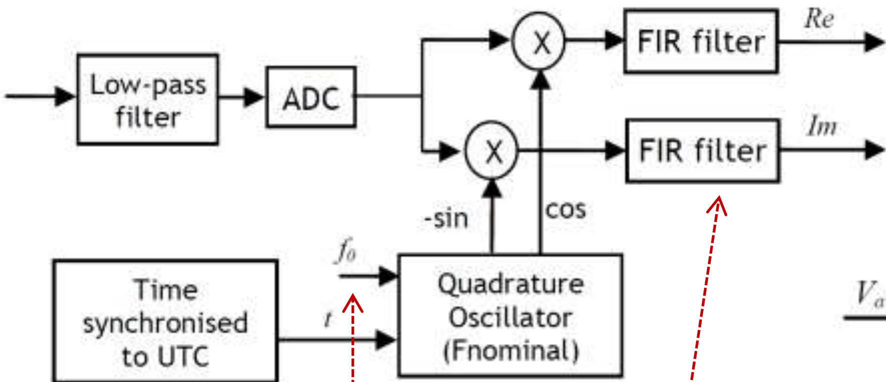






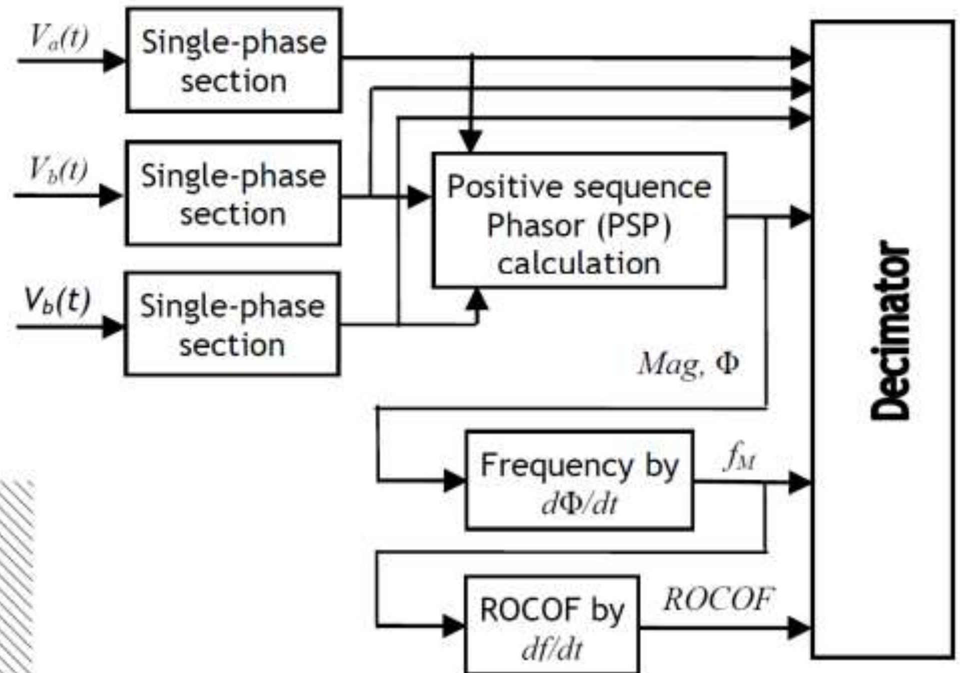
M class filters

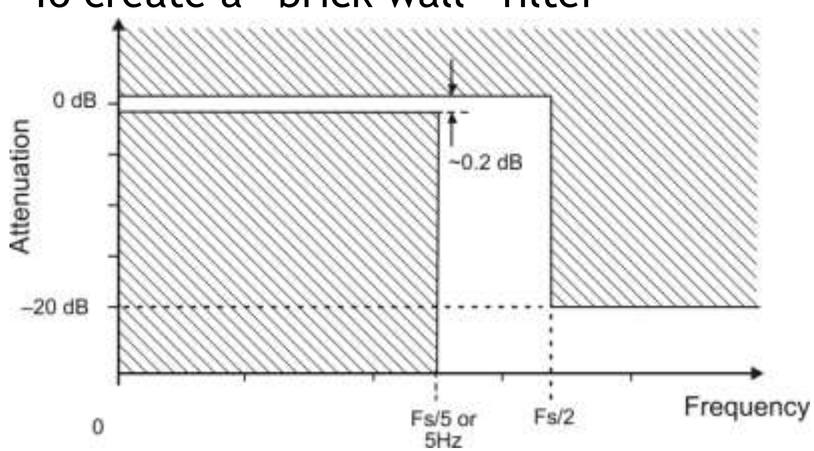
Single-phase section



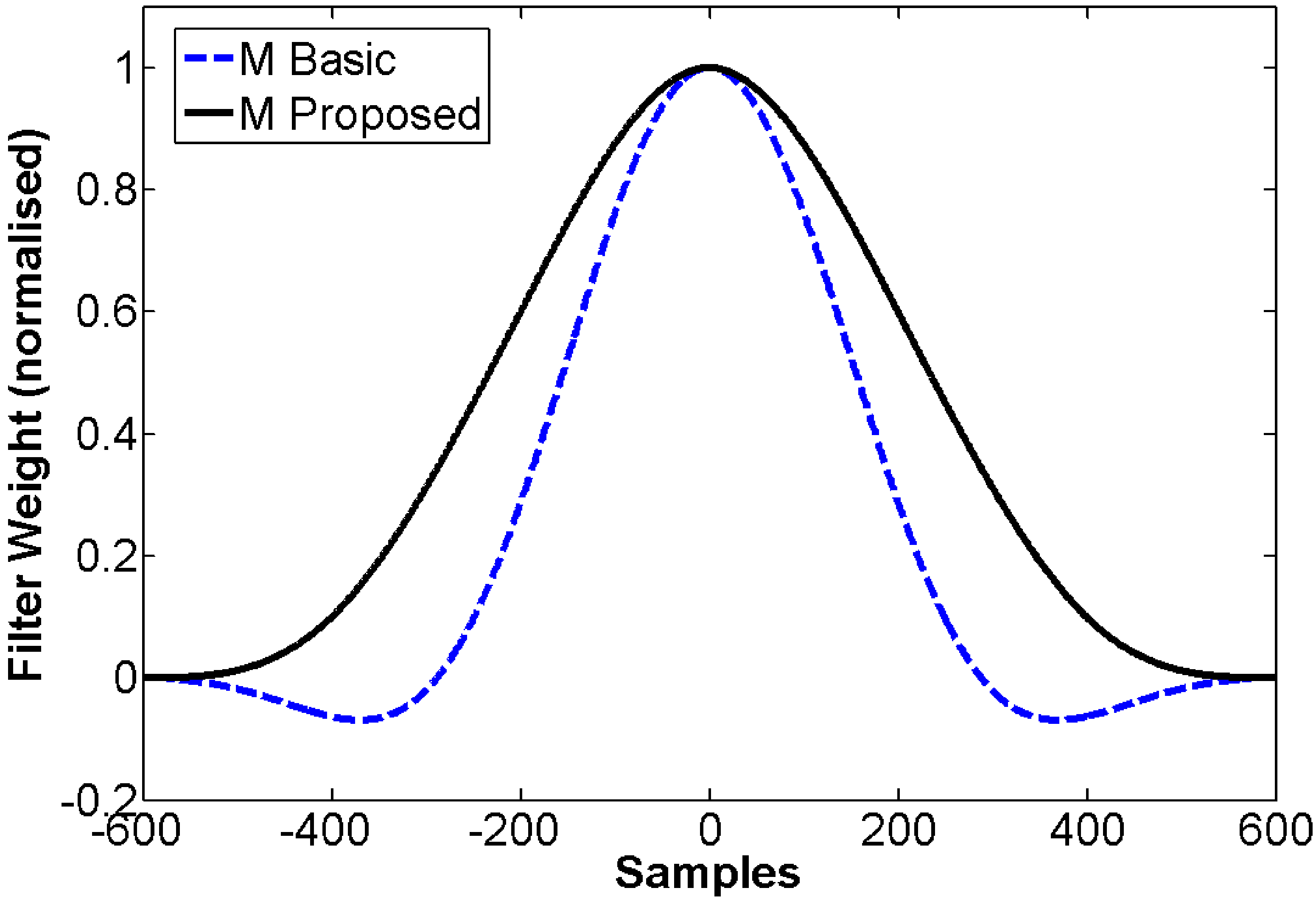
f_0 fixed at nominal frequency

Symmetric filter with fixed weights
To create a "brick wall" filter

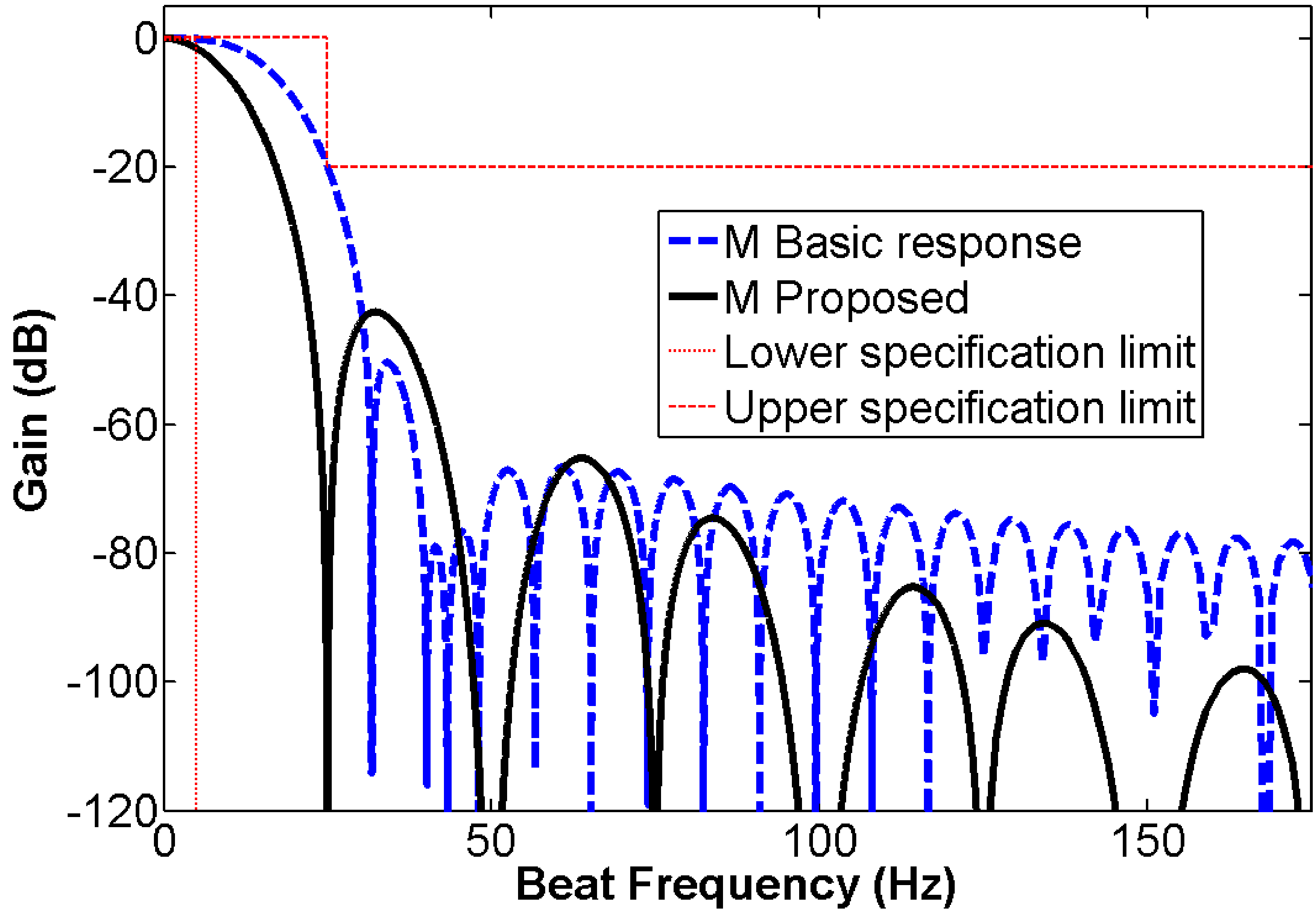




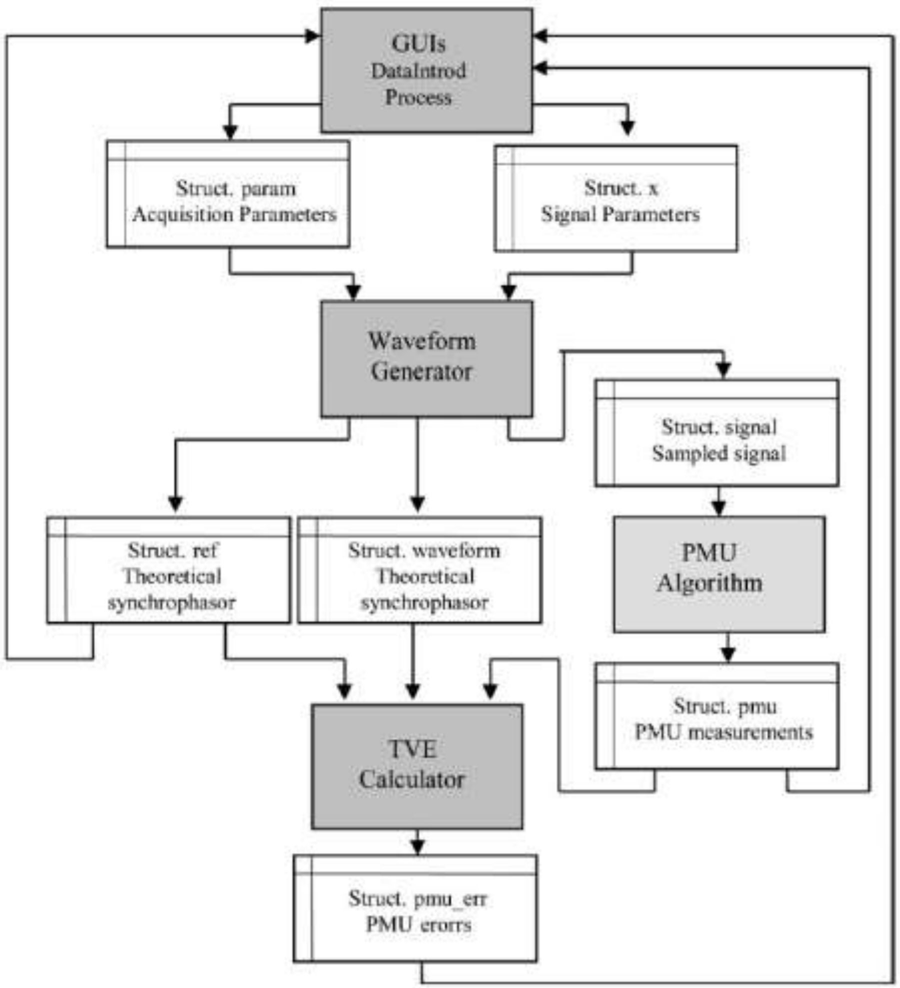
M class filters



M class filters



Testing



Pogliano, U., Braun, J.-P., Voljˇ, B., and Lapuh, R.:
'Software Platform for PMU Algorithm Testing',
IEEE Transactions on Instrumentation and Measurement, 2013, 62, (6)

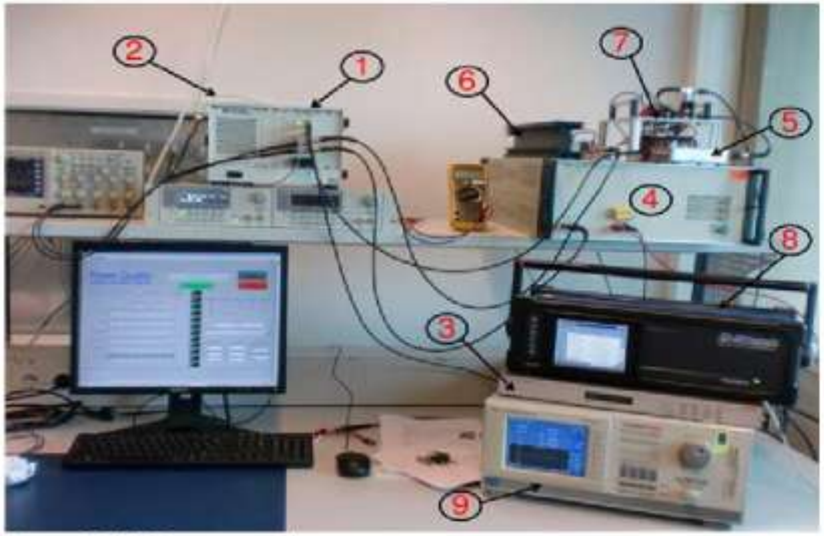
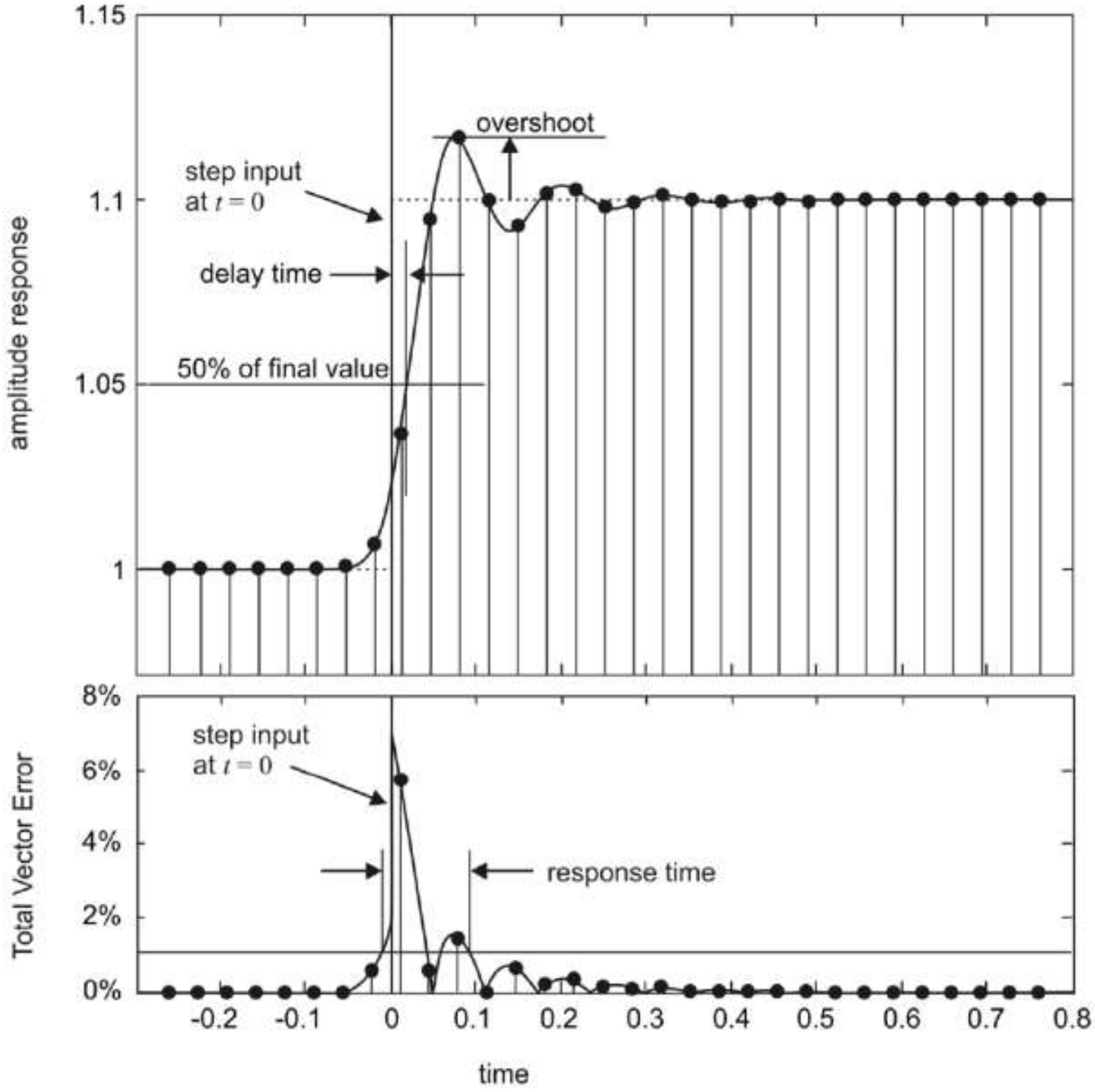


Figure 3. PMU test setup picture.
1: Digitizer NI PXI-4461; 2: Atomic Clock 1 PPS signal; 3: Model 1133A Power Sentinel PMU; 4: Current amplifier 1A/1V; 5: Shunt; 6: Voltage amplifier 25V/1V; 7: Transformer; 8: RD-33 Dytronic Three-Phase Reference Standard; 9: PZ-4000 Power Analyzer.

M.Sc. thesis Nhi, TU Delft
Nguyen, Popov, Rietveld.: VSL/TU Delft

Dynamic tests and “equivalent time sampling”



C37.118.1 Harmonics test, Fs=50Hz

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	Conditions	Max TVE	Max Freq. Error	Max ROCOF Error	Max Latency
		(%)	(Hz)	(Hz/s)	(ms)
P Basic+	1.0 pu 50 Hz Ha=1%	0.03	0.0001	0.007	20.0
P TickTock		0.03	0.0001	0.007	20.1
P Spec.		1.00	0.0050	0.010	40.0
M Basic+	1.0 pu 50 Hz Ha=10%	0.03	0.0044	0.878	58.9
M TickTock		0.03	0.0001	0.001	66.7
M Spec.		1.00	0.0250	6.000	100.0

Harmonics test, ONLY at 50 Hz

Harmonics test, over the standard frequency range, OUTWITH the standard!

	Conditions	Max TVE	Max Freq. Error	Max ROCOF Error	Max Latency
		(%)	(Hz)	(Hz/s)	(ms)
P Basic+	0.8 pu ±2 Hz Ha=1%	0.03	0.0048	0.476	20.0
P TickTock		0.03	0.0001	0.011	20.9
P Spec.		1.00	0.0050	0.010	40.0
M Basic+	0.1 pu ±5 Hz Ha=10%	0.07	0.0008	1.584	58.9
M TickTock		0.03	0.0003	0.019	66.7
M Spec.		1.00	0.0250	6.000	100.0

Worst-case real signals, Fs=50Hz

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	Max TVE	Max Freq. Error	Max ROCOF Error
	(%)	(Hz)	(Hz/s)
P Basic+	0.11	0.0942	9.334
P TickTock	0.05	0.0118	1.146
M Basic+	0.07	0.0042	0.817
M TickTock	0.03	0.0001	0.005

NON-LINEAR FREQUENCY RAMP
WITH UNBALANCE, EN50160 HARMONICS
AND HIGH-FREQUENCY INTERHARMONICS

	Max TVE	Max Freq. Error	Max ROCOF Error
	(%)	(Hz)	(Hz/s)
P Basic+	0.35	0.2432	24.596
P TickTock	0.34	0.1706	16.875
M Basic+	0.11	0.0210	2.823
M TickTock	0.05	0.0013	0.167

NON-LINEAR FREQUENCY RAMP
WITH UNBALANCE, EN50160 HARMONICS
LOW AND HIGH-FREQUENCY INTERHARMONICS

NIST testing, Standard changes, and Forward look

- Work by NIST (and others within or associated with WG H11) shows
  - "Reference" algorithm is not compliant with C37.118.1 (2011).
  - There are errors in the M class filter design tables
  - There are typos in some other tables
  - There are (in particular) RFE specifications which cannot be met by the Reference PMU, (and some cannot be met by ANY PMU).
- There is a tendency now to widen or remove RFE specs, to allow such large inaccuracies that they would be unacceptable for most power system uses, because the "Reference" algorithm is no good when off-nominal.
- Conflict in signals used for testing:
  - Standard likes to use synthetic, repeatable and understandable signals. Has no meaning for the user.

  vs

  - Real-world examples. Have meaning but what is the actual signal?