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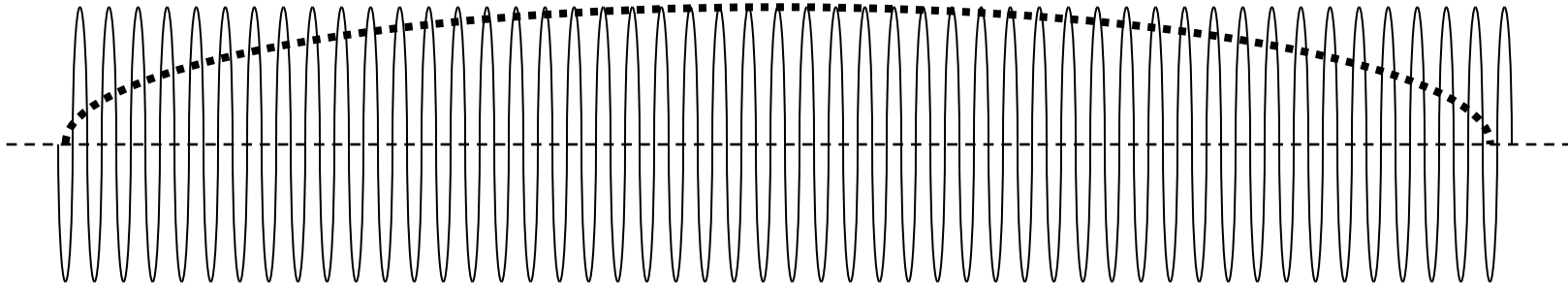
# PMU Algorithms and Testing

Dr. Andrew Roscoe

## A “unique” problem for power systems

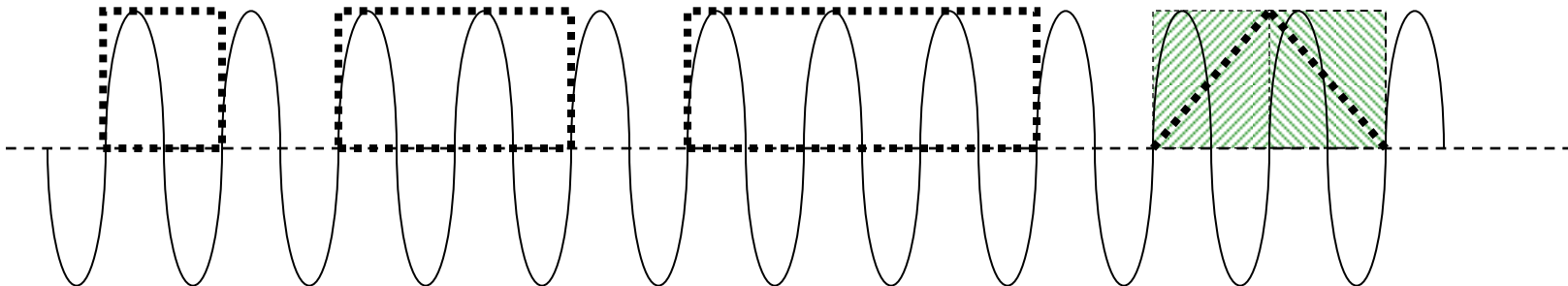
### 1) Measurement timeframe $\gg$ Fundamental period

- e.g. Radio-frequency measurements



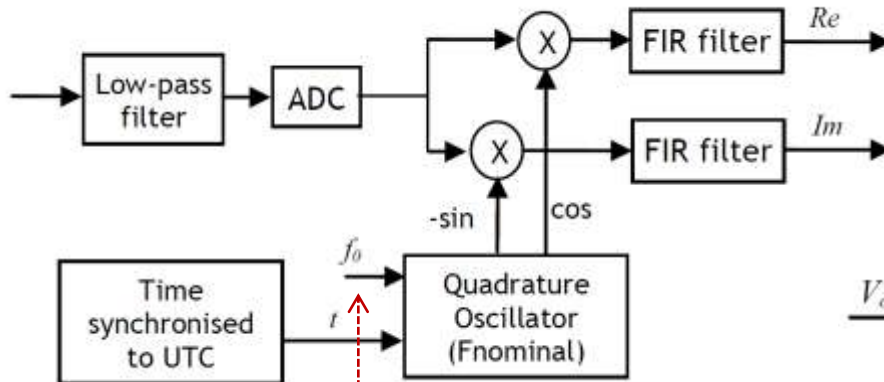
### 2) Measurement timeframe not $\gg$ Fundamental period

- e.g. Power system measurements over  $<20$  cycles

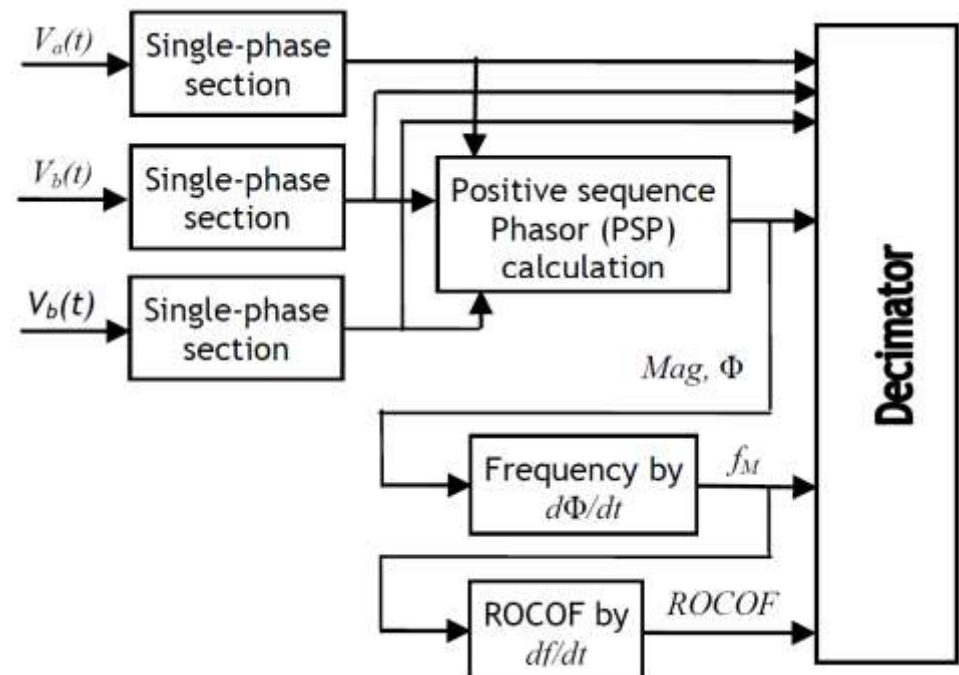


# The “Reference” algorithm from C37.118.1

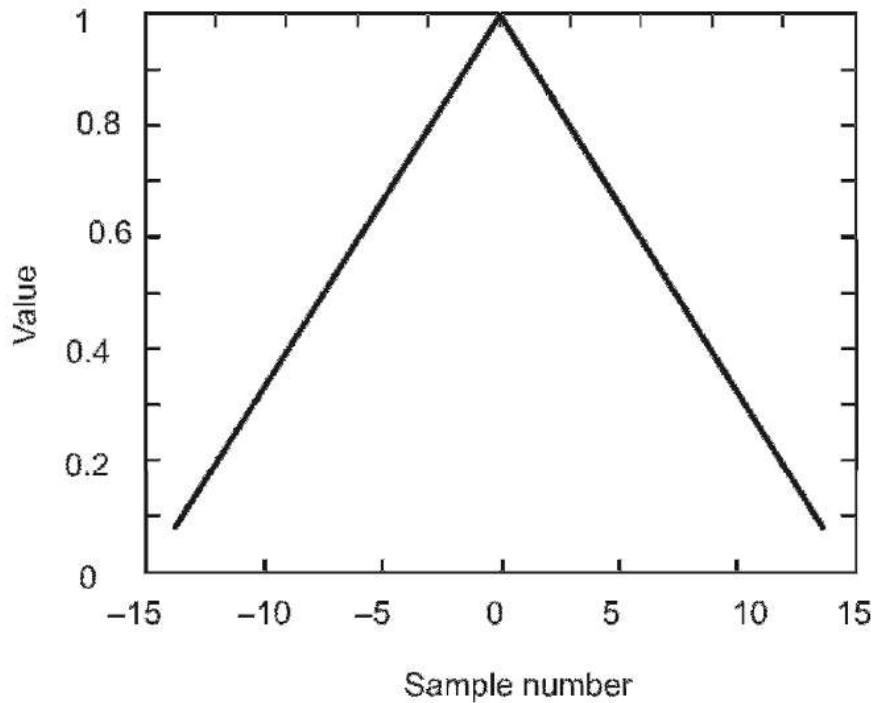
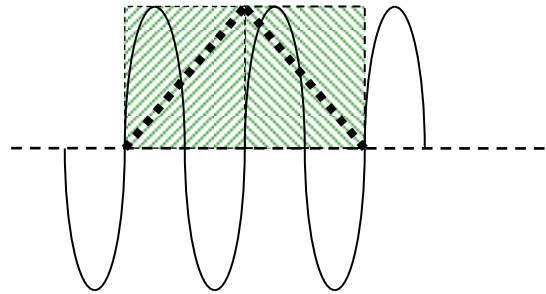
Single-phase section



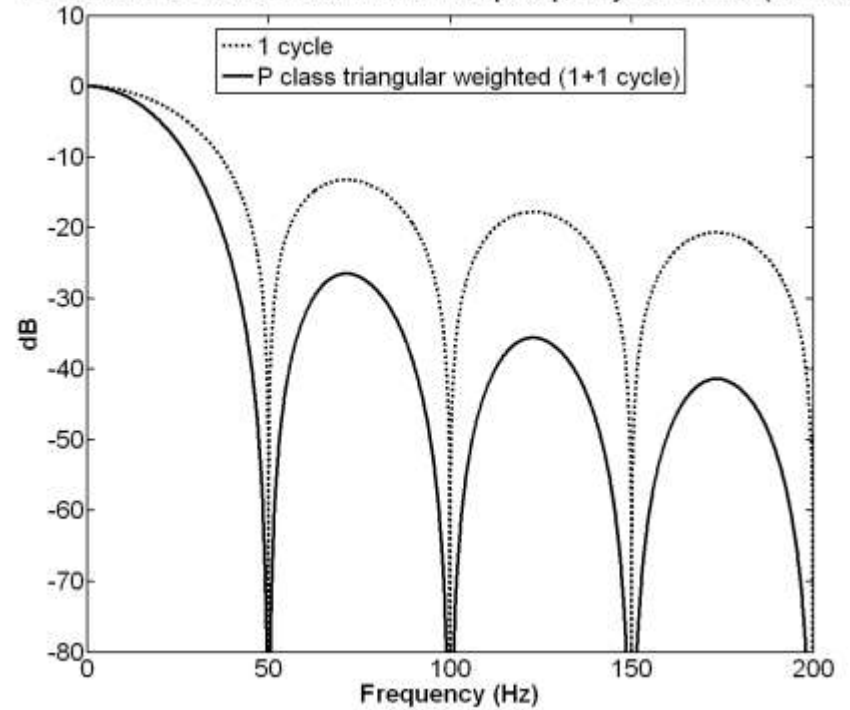
$f_0$  fixed at nominal frequency



# P class filter

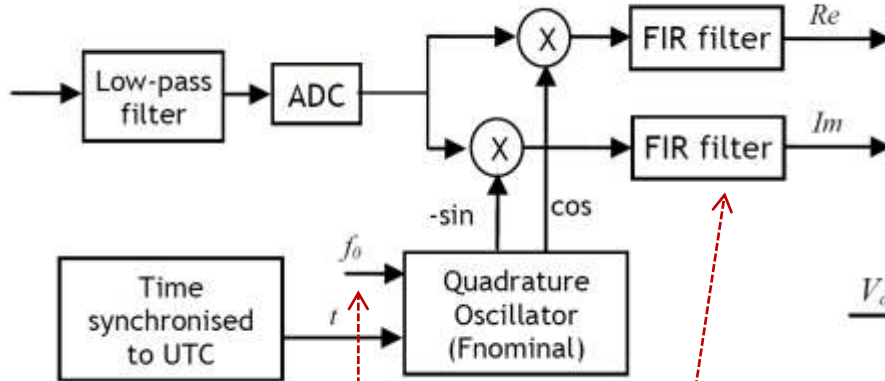


IEEE C37-118 P Class filter with 40 samples per cycle at 50Hz (nominal)



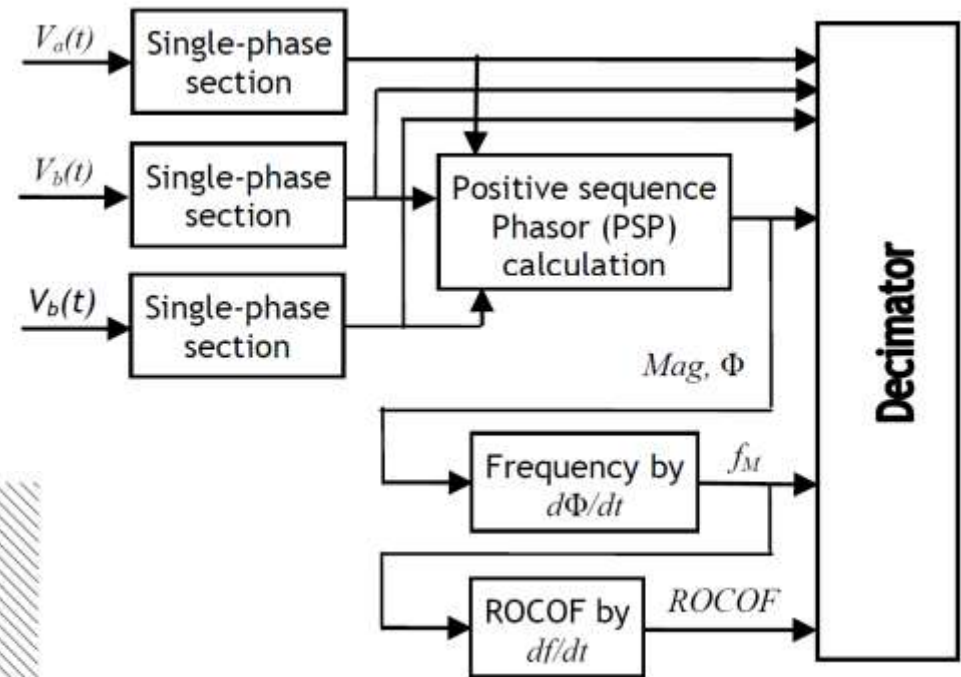
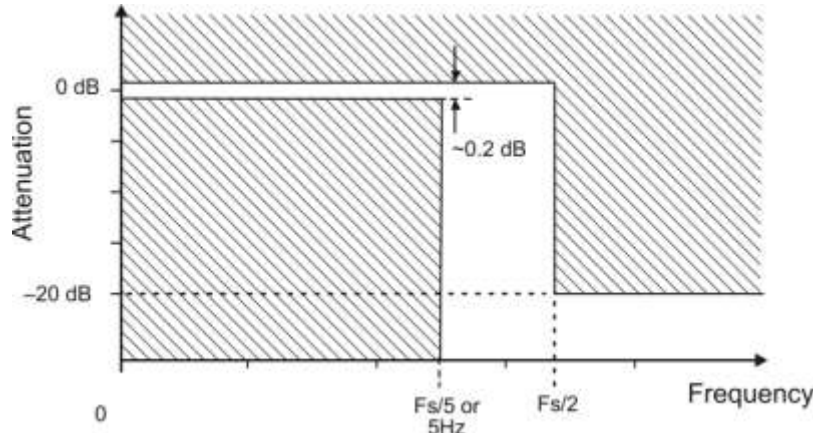
# M class filters

## Single-phase section



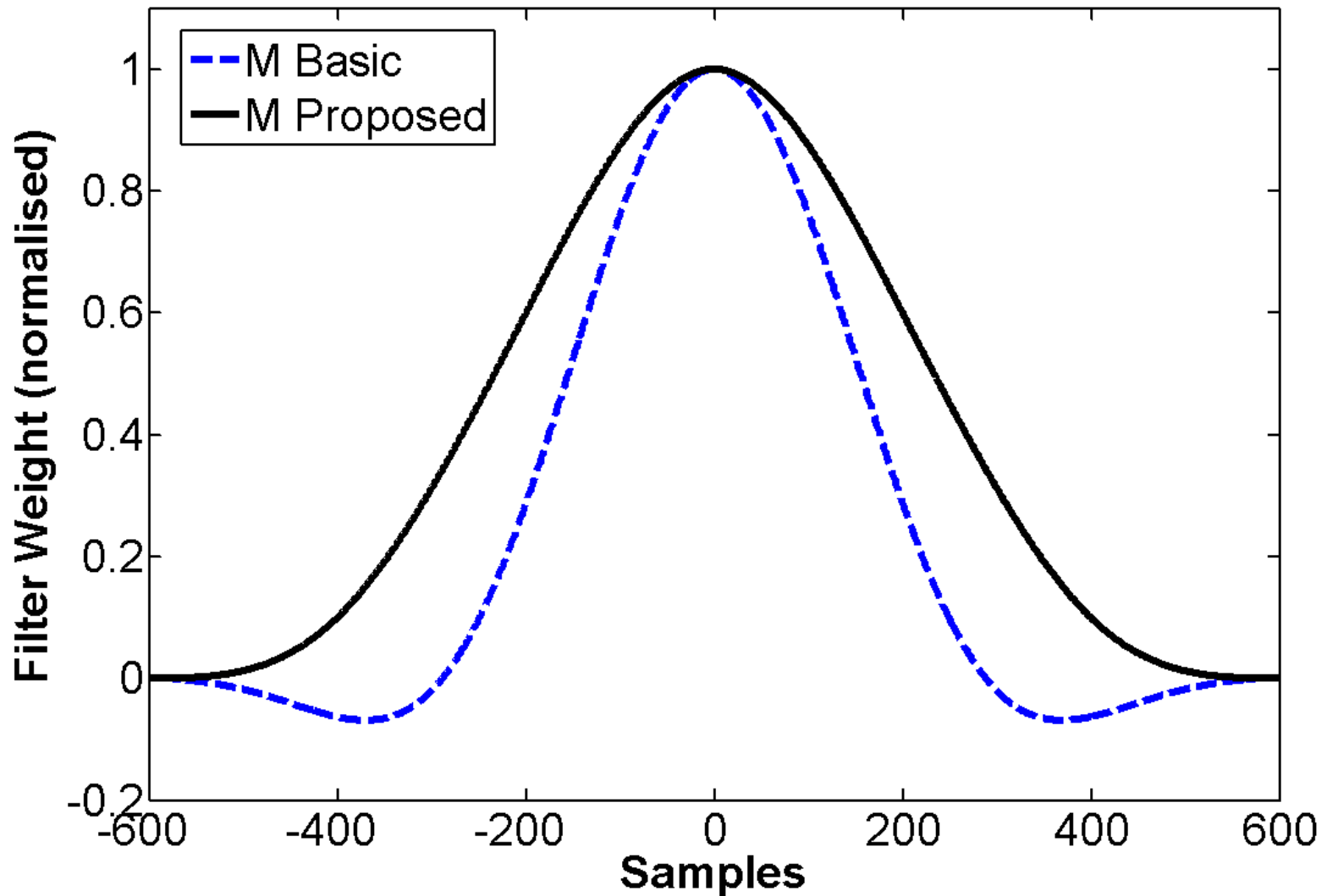
$f_0$  fixed at nominal frequency

Symmetric filter with fixed weights  
To create a “brick wall” filter

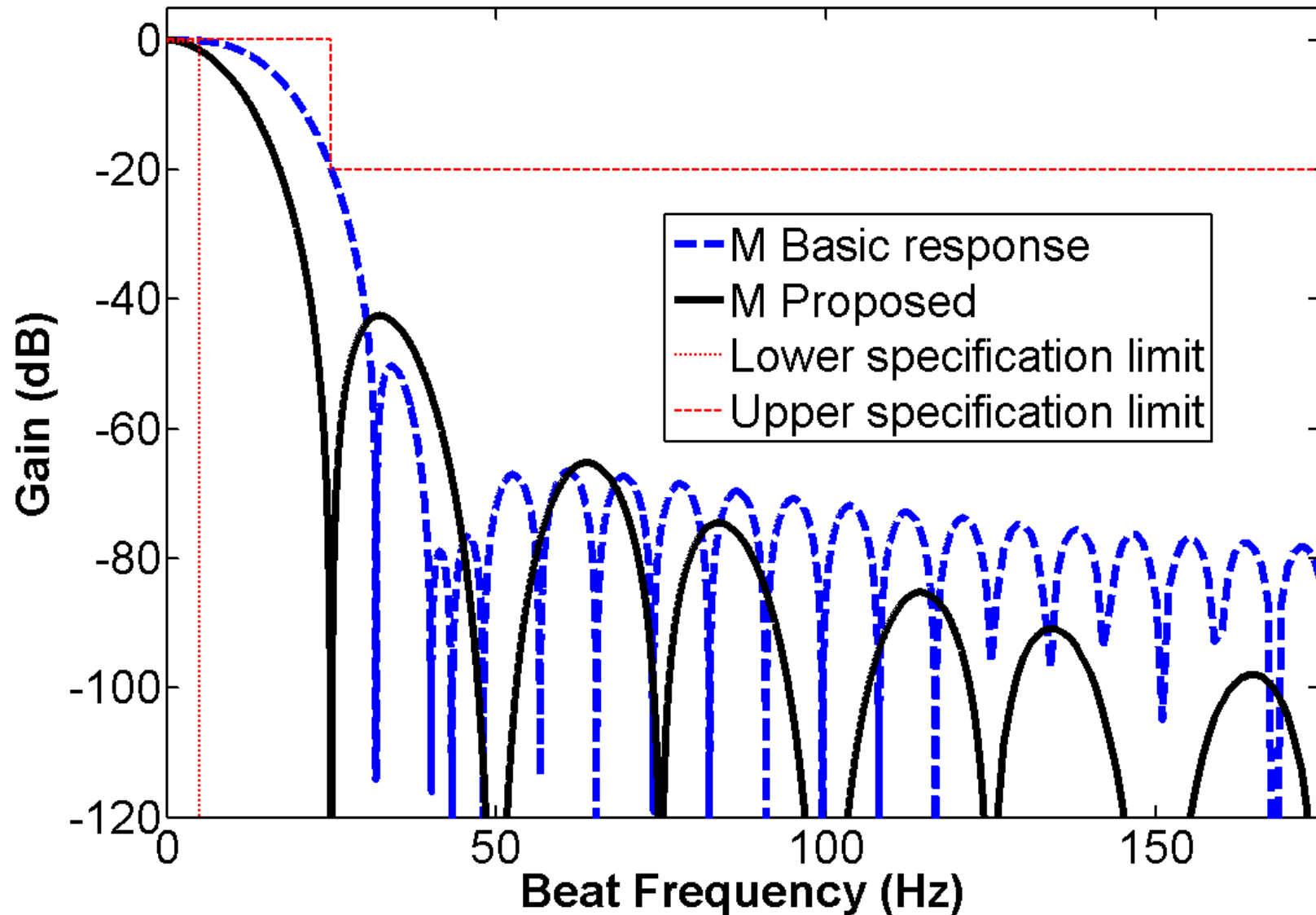




# M class filters



# M class filters





# Testing

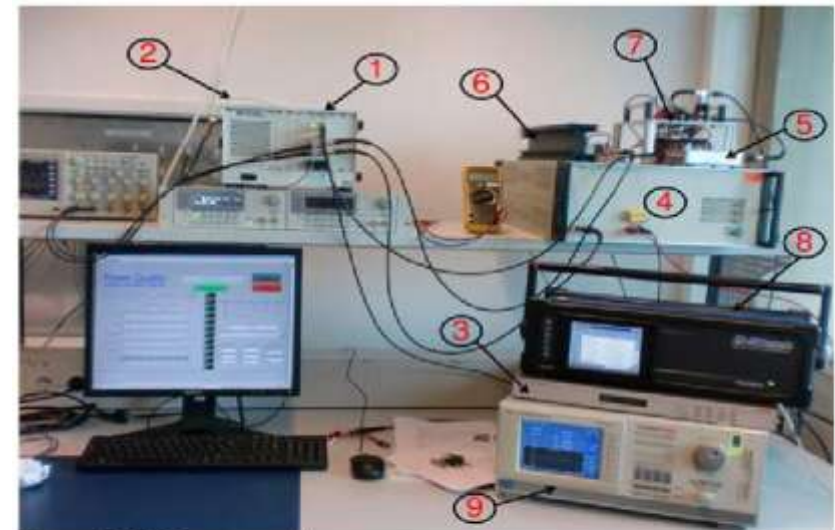
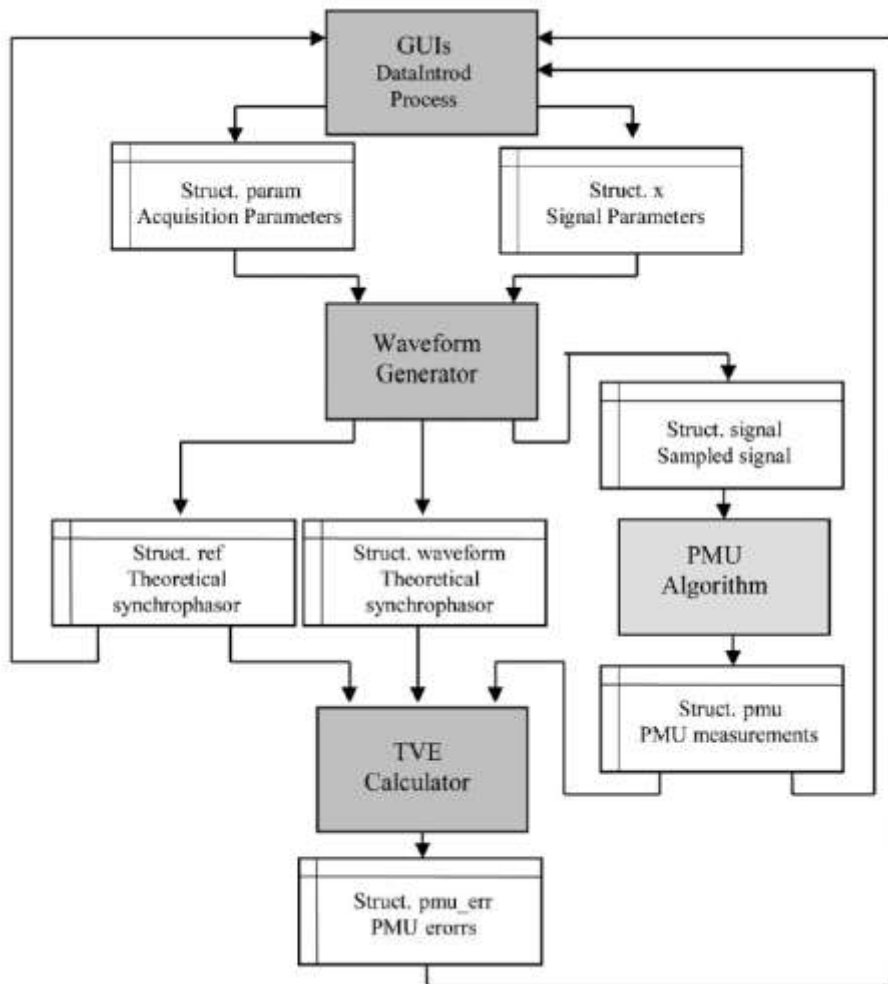
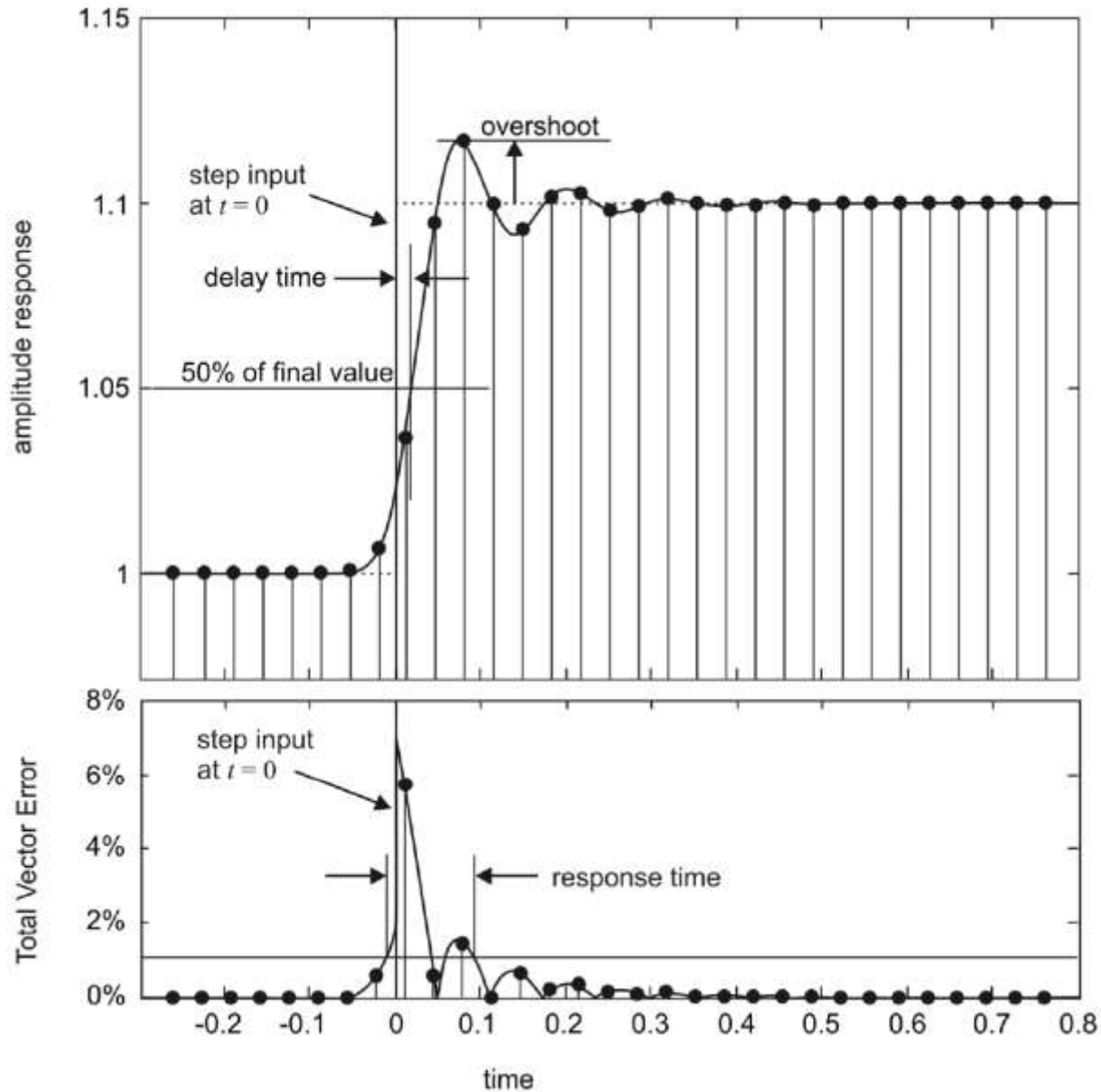


Figure 3. PMU test setup picture.

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.

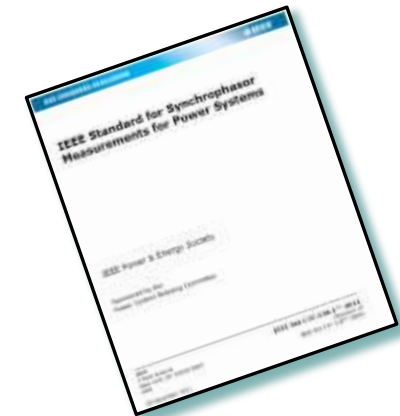
M.Sc. thesis Nhi, TU Delft  
 Nguyen, Popov, Rietveld.: VSL/TU Delft

# Dynamic tests and “equivalent time sampling”



# C37.118.1 Harmonics test, $F_s=50\text{Hz}$

	Conditions	Max TVE	Max Freq. Error	Max ROCOF Error	Max Latency
		(%)	(Hz)	(Hz/s)	(ms)
P Basic+	1.0 pu 50 Hz $H_a=1\%$	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 $H_a=10\%$	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 $\pm 2$ Hz $H_a=1\%$	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 $\pm 5$ Hz $H_a=10\%$	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, $F_s=50\text{Hz}$

	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?