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# Wind Turbine Noise Measurements in Practice

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# Background



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- Denmark as "home" of wind turbines
- Standardization Process
- Field Experience



# Standardization



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- IEC 61400-11, Edition 2 and 3
- The Danish paradox
- Multiple national standards





# Tools



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- Wireless acoustic front end
- Meteorology
- Turbine DSC interfaces
- Data Recording
- Basic Signal Processing
- Front end software
  - Now in second generation software, noiseLAB Wind
- Post-processing and reporting
- Certification

# Logistics



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# Front end



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- Digitizers
  - 24 bit anti-aliased 4 ch. ADCs
  - IEPE powering of instrumentation microphones
  - Battery powered





# 1000 m wireless real time audio streaming

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# Wi-Fi Receiver with Ethernet to Data logger PC

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# Data Collection Software (noiseLAB Wind)

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DELTA WMS V 0.03 Urup Fieldtest.wmsproj

Disk Space Free (GByte): 218.172G Recording Duration: 00:00:41

Setup Monitor Trim & Filter Recordings Report Status Utilities Measure Record Wind Turbine Noise Record Background Noise FFT Avg. Time: 02 s FFT Blocks: 001 View Input Launch TDM5 Viewer

Open

Test Operator: MSO Base Standard: IEC 3.ed Leq/SL: 10 s FFT: 10 s Oct: 10 s

Make: Vestas Rated power: 3075.0 kW Turbine type: V112  
 Turbine ID: Rotor diameter: 112.0 m Hub height: 94.0 m  
 Mic Angle Ref Tower: 0.0 deg Mic Tower Distances: 150.0 m Suggested Mic Dist.: 150.0 m  
 Anem. ht. over ground: 9.6 m Anem-Tower Distance: 180.0 m Roughness Length: 0.050 m

Note

Path for the original Power Curve  
 C:\Users\test.Docu...\WMS\Projects\PowerCurves\V112 mode0 marts 2012.bt

V112 mode0 marts 2012

Hub to 10m factor: 1.42 Mast to 10m factor: 0.99 Range Start: 5.0 % Range End: 95.0 % Power Curve Tolerance: 2.0 %

Acoustic Channel Name	Physical Channel	Range	AC	IEPE	Sample Rate	Sensitivity	Unit	CalibRefdB	Mic Shield Correction
Reference Mic A	MicA/a0	± 5.00	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	51.20k Hz	448.4 mV/EU	Pa	93.8 dB	Calib. Vindmaas
Nabo mic	MicB/a0	± 5.00	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	51.20k Hz	452.1 mV/EU	Pa	93.8 dB	Calib. Vindmaas
<Type in name>	<Select IO Ch>		<input type="checkbox"/>	<input type="checkbox"/>	0.00 Hz	40.0 mV/EU	Pa	94.0 dB	Calib. Mic Shield 1
<Type in name>	<Select IO Ch>		<input type="checkbox"/>	<input type="checkbox"/>	0.00 Hz	40.0 mV/EU	Pa	94.0 dB	Calib. Mic Shield 1

Schiltknecht

Analog Channel Name	Physical Channel	Range	AC	Sample Rate	Sensitivity	Offset	Wind Speed Source	1.	2.	Backgnd.
<Type in name>	<Select IO Ch>		<input type="checkbox"/>	0.00 Hz	40.00	2.00	DELTA Anemometer	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
<Type in name>	<Select IO Ch>		<input type="checkbox"/>	0.00 Hz	40.00	2.00	Nacelle (Analog)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<Type in name>	<Select IO Ch>		<input type="checkbox"/>	0.00 Hz	40.00	2.00	Nacelle (RS-232)	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
<Type in name>	<Select IO Ch>		<input type="checkbox"/>	0.00 Hz	40.00	2.00	From Power (Analog)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<Type in name>	<Select IO Ch>		<input type="checkbox"/>	0.00 Hz	40.00	2.00	From Power (RS-232)	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

IFM DELTA-Phoenix COM7 Update Rate: 100 ms

Label	Index	Offset	Gain	Result
Nacelle Wind Speed	0	0.0 V	1 Unit/V	3.22
Turbine Power	1	0.0 V	1 Unit/V	5.03
	0	0.0 V	1 Unit/V	0.00
	0	0.0 V	1 Unit/V	0.00

SPL Leq: A-weighting

Octave Settings: A-weighting, 1/3 octave, Lower Frequency: 4.0 Hz, Upper Frequency: 10000.0 Hz

FFT & Tone Analysis: Linear, Hanning, 2.0 Hz Resolution, 50 % Overlap

VP. n: 2.2 m/s VP. Z: 1.5 m/s Vnac. n: 2.1 m/s Vnac. Z: 1.5 m/s VZ: NaN m/s Power: 5.0 kW Generator: NaN RPM Pitch: 147483647 ° Yaw: 147483647 ° LAeq: 40.1 dB Averaging Time: 1.0 s

# Inputs



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- Up to 16 acoustic channels (USB, Ethernet or Wi-Fi) with autocal.
- Up to 16 analog channels (Anemometers, process control outputs, other instrumentation (gain/offset adjustable))
- N channels via COM ports (turbine specific)



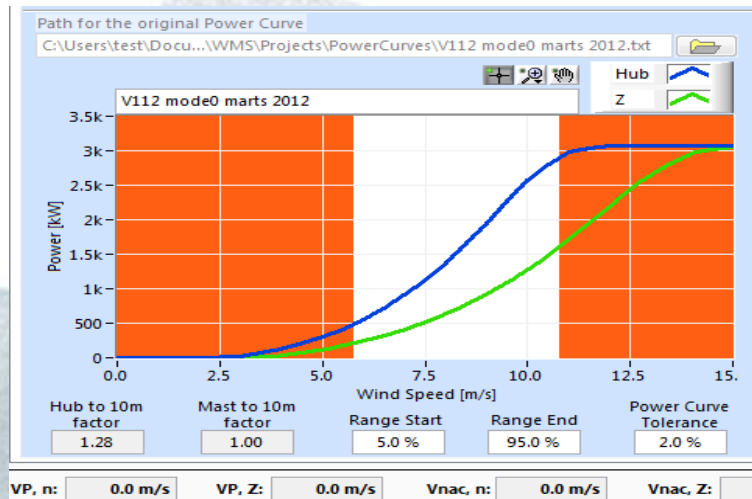


# Other inputs



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- Wind Turbine Power Curve
- Anemometer cal factors
- Wind Screen calibration curve
- Turbine metadata
- Operator time-stamped log of comments.



# Data pre-processing



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- Acoustical Time Slice (10 or 60 s as per standard)
  - FFT
  - 1/3 octave (A weighted and Linear in parallel)
  - Sound Level/Leq
- All turbine parameters (1 s averaging)
  - Yaw, pitch, power, RPM etc.
- All Meteo parameters (1 s averaging)
- All derived parameters as per IEC 61400
  - $V(P,n)$ ,  $V(Z,n)$  etc.



# Stream to disk



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- All time waveforms with 128-bit time-stamp, 32 bit floating point,  $2^{64}$  max samples.
- TDMS (National Instruments) readable from
  - LabVIEW
  - MatLab
  - Diadem
  - Excel etc.
- Robust, crash survivable format.

# Spectra to Disk



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- FFT (10 or 60 s blocks) (crash robust format)
- Octave A and Lin





# Monitoring

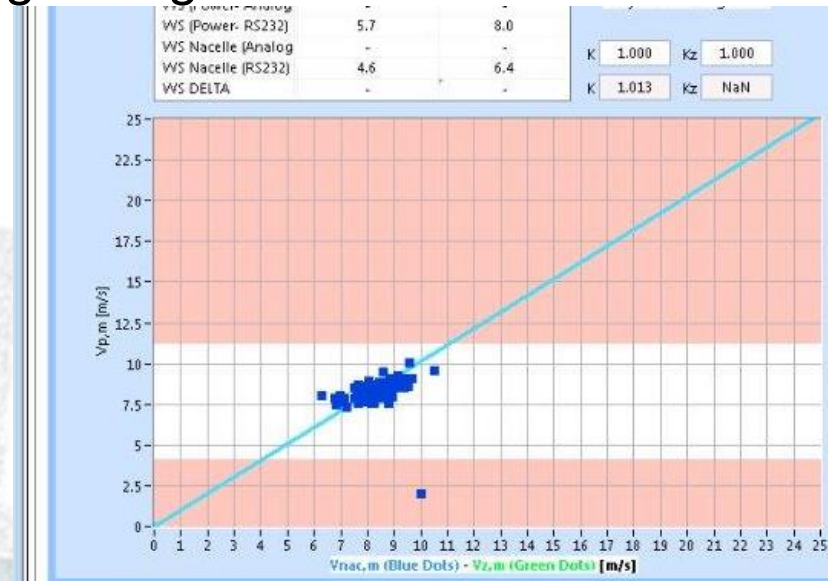


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- Real time scalar parameters: Always visible

it:	5.3 m/s	VP, Z:	3.7 m/s	Vnac, n:	5.7 m/s	Vnac, Z:	4.0 m/s	VZ:	5.2 m/s	Power:	367.2 kW
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- Real time listening of any acoustic channel (with enough gain so you can hear it)
- Real time “scope” on any input signal regardless of source.
- Real time kappa mu curve fitting
- Wind direction function of time

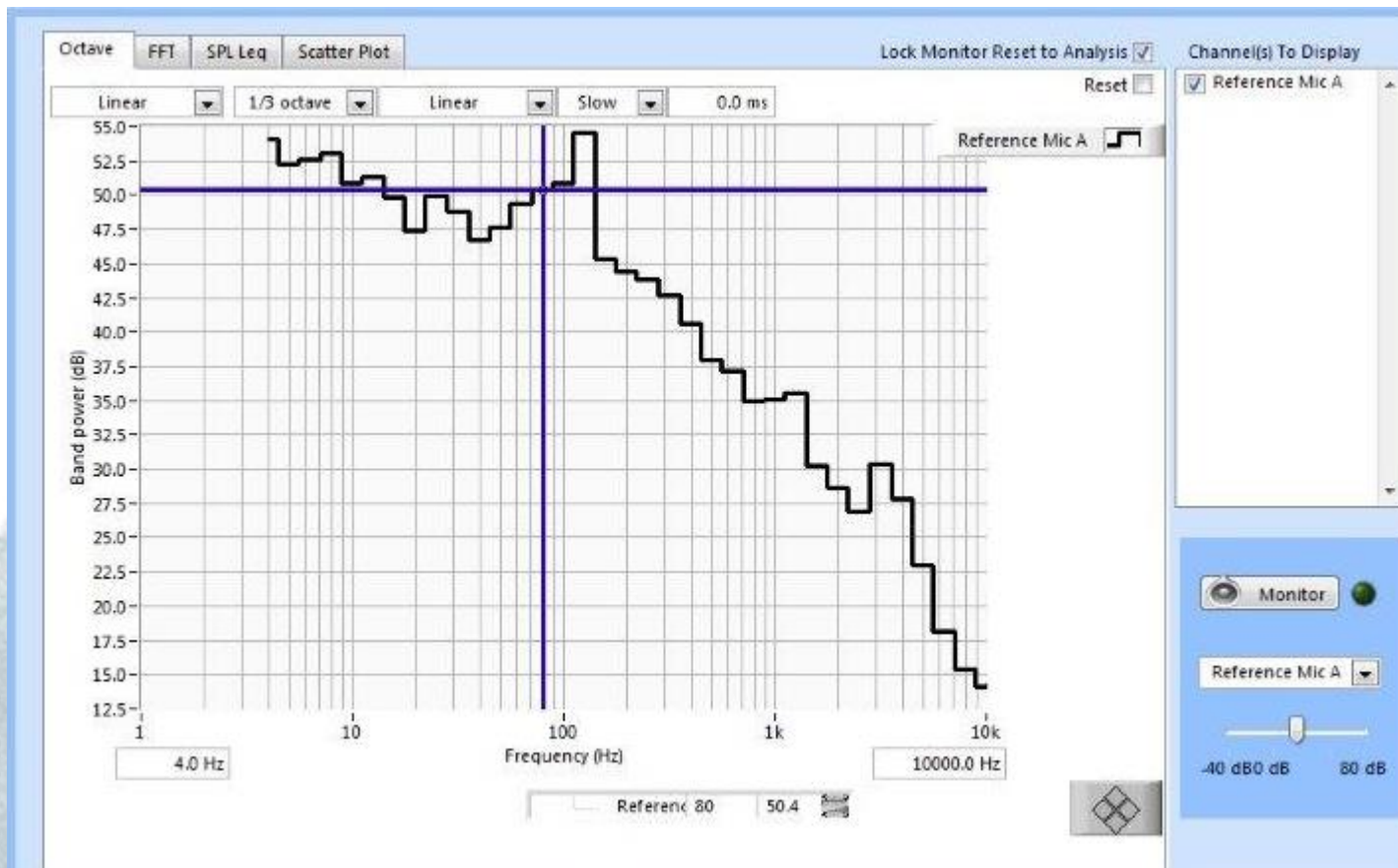


# Ad hoc monitoring



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- User-defined parameters for ad hoc FFT, Sound Level and 1/N octave analysis (independent of spectra stored to disk)
- Ugly fat plots readable in daylight



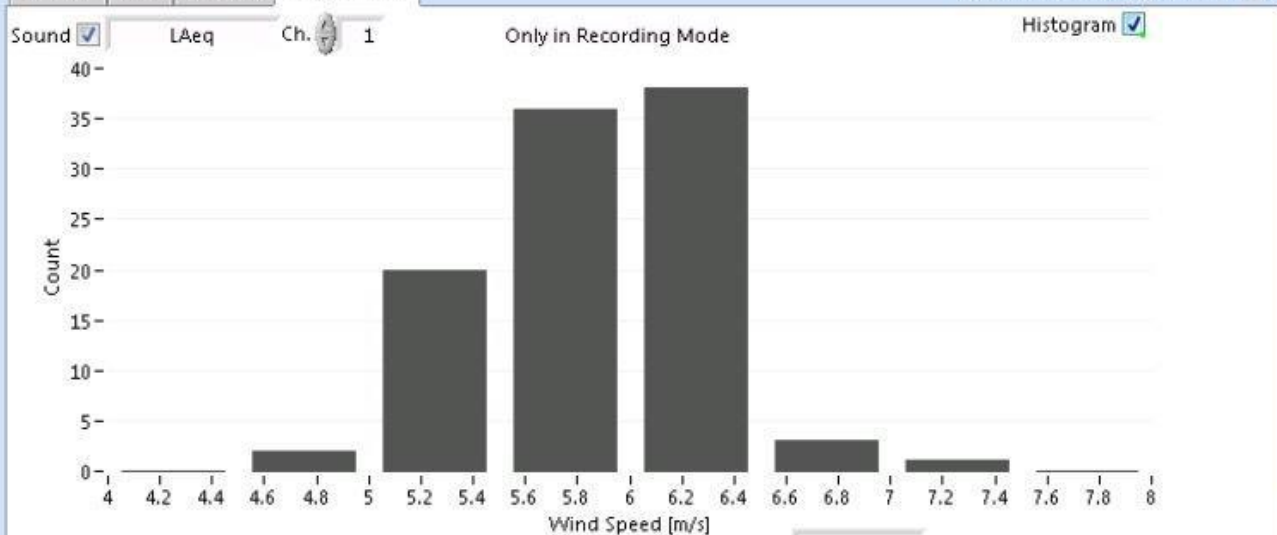
# Monitoring of wind-binning



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Recording ... Record Background Noise FFT Avg. Time: 51 s FFT Blocks: 197 View Input Launch TDMS Viewer

Octave FFT SPL Leq Scatter Plot Lock Monitor Reset to Analysis Channel(s) To Display



V(ana) Red Dots

IEC	0.00	0.50	1.00	1.50	2.00	2.50	3.00	3.50	4.00	4.50	5.00	5.50	6.00	6.50	7.00	7.50	8.00	8.50	9
Turbine	1	0	0	0	0	0	0	0	0	1	10	34	43	11	1	0	0	0	
Background	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Sound Power	-Inf	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	101.9	102.3	99.9	99.9	95.4	101.0	NaN	NaN	NaN	N

MST	0.25	0.75	1.25	1.75	2.25	2.75	3.25	3.75	4.25	4.75	5.25	5.75	6.25	6.75	7.25	7.75	8.25	8.75	9
Turbine	1	0	0	0	0	0	0	0	0	2	20	36	38	3	1	0	0	0	
Background	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Sound Power	-Inf	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	105.7	101.7	100.2	97.3	101.2	-Inf	NaN	NaN	NaN	N

Channel(s) To Display

- Reference Mic A

Monitor

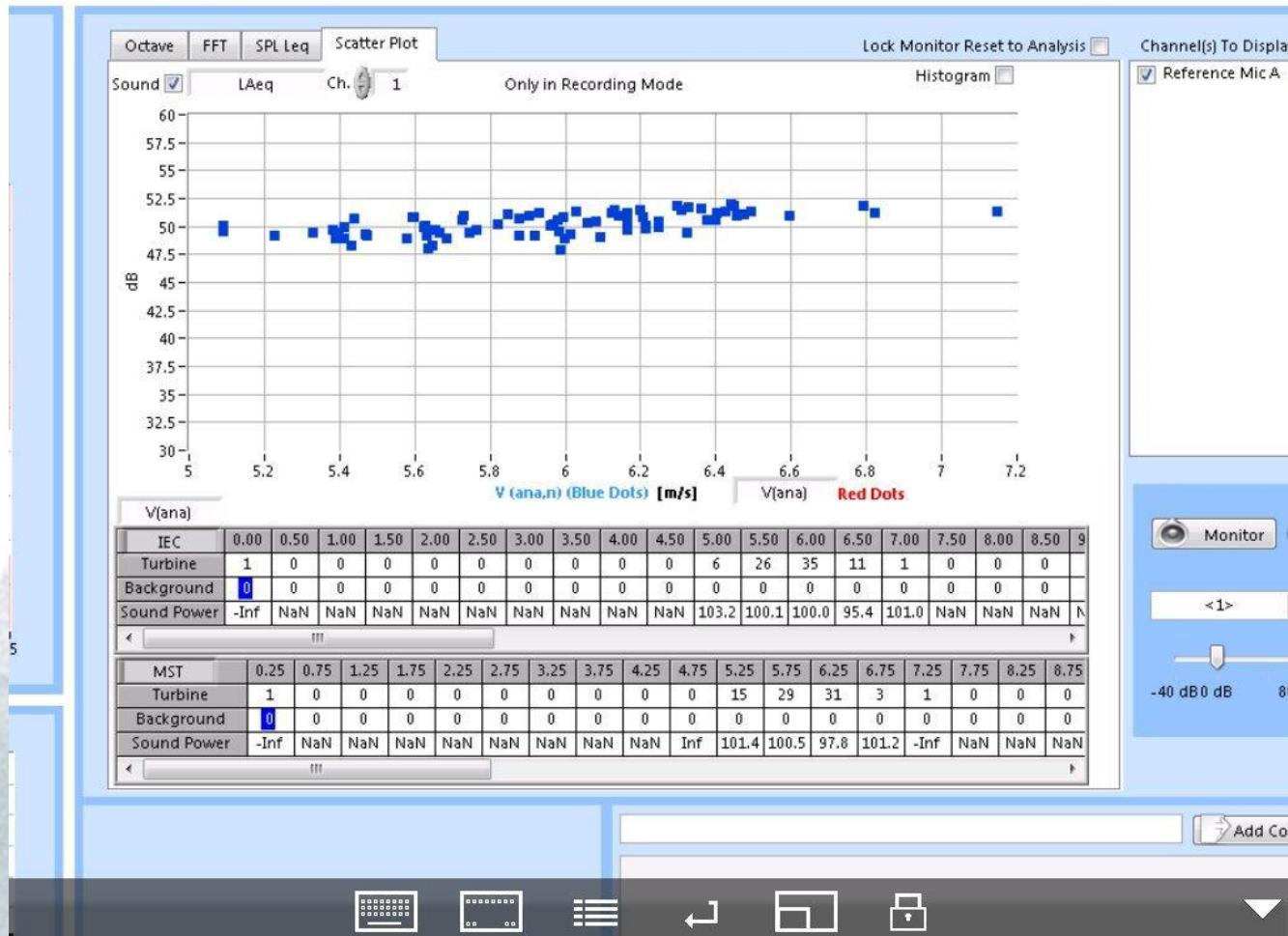
<1>

-40 dB 0 dB 80 dB



# Scatter plots of anything vs. anything.

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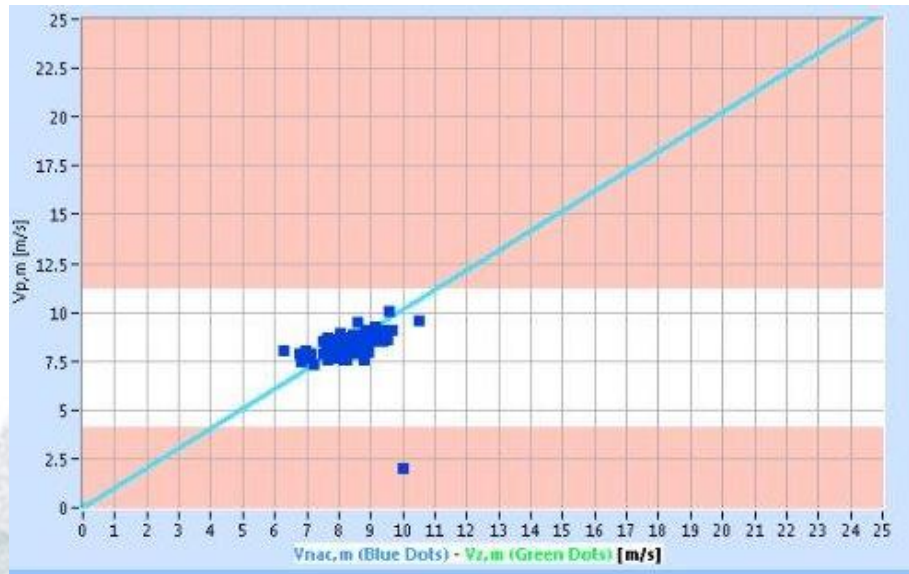


# Post-processing (MatLab or Excel)

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- Sound Level
- Sound Power
- Tone Analysis



- Data selection (outliers etc.)
- Measurement uncertainty calculations.

# Challenges solved



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- Wireless data acquisition
- Full IEC 61400-11, Danish MST support
- Robustness
- Highly interactive user interface
- High performance
- “Go-back-to ability” (raw waveforms for everything saved)
- ISO 9001 audited



# Remaining challenges



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- Diversity of standards
- Lower power battery operation
- Inexpensive synchronization (small GPS ADCs on the way)
- Complexity/Training



# Questions



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