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A review and comparison of published 2-150kHz measurement methods

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Introduction

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- Need for a normative method by utility community
- IEC 61000-4-30 Annex C lists 3 methods under consideration
- Other methods for 2-150 kHz emissions have been developed
- Review and compare these methods as baseline for a normative specification

Aspects to consider:

- Accuracy of measurement values
- Reproducibility
- Comparability with IEC 61000-2-2 compatibility levels
  - → *200 Hz bandwidth*
  - → *9-150 kHz defined in terms of CISPR 16-1-1 quasi-peak values*
- Computational resource requirements
- Characterization of time-varying emission

Framework

Overview of measurement methods

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1. **IEC 61000-4-7 Annex B**
2. **IEC 61000-4-30 Annex C**
3. **Digital CISPR 16 Compatible Method** (M. Schwenke et al., 2019)
   - Lanczos window → STFT → envelope reconstruction → RMS and quasi-peak detection
4. **Wavelet Approach** (Lodetti et al., 2020)
   - Wavelet packet decomposition by recursive filtering and downsampling
5. **Subsampling Technique** (Mendes et al., 2019)
   - Bandpass filtering by analogue filter bank → sampling at lower frequency → DFT
6. **Multiple Measurement Vectors Compressive Sensing** (S. Zhuang et al., 2019)
   - DFT → multiple measurement vectors model → sparse approximation algorithm:
     1. Orthogonal Matching Pursuit (OMP)
     2. Sparse Bayesian Learning

Acknowledgment: *Thanks to S. Zhuang, W. Zhao, S. Lodetti, J. Bruna, J. J. Melero, D.Klingbeil, M. Schwenke, and T. Mendes for making their measurement methods available for this comparison and providing helpful support.*

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Features of methods under comparison

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	IEC 61000-4-7	IEC 61000-4-30	Digital CISPR 16	Subsampling	Wavelet Approach	Compressive Sensing
Principle	DFT	DFT	DFT	DFT	recursive filtering	DFT
Sampling frequency, kHz	> 300	1024	409.6	32	409.6	500
Time resolution, ms	200	6.25	0.5	5	10 cycles	0.5
Measurement interval, ms	200	0.5	20	5	10 cycles	0.5
Window function	Rect.	Rect.	Lanczos	Rect.	Rect.	Rect.
Bandwidth, Hz	200	***2000***	200	200	200	200

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Test signals

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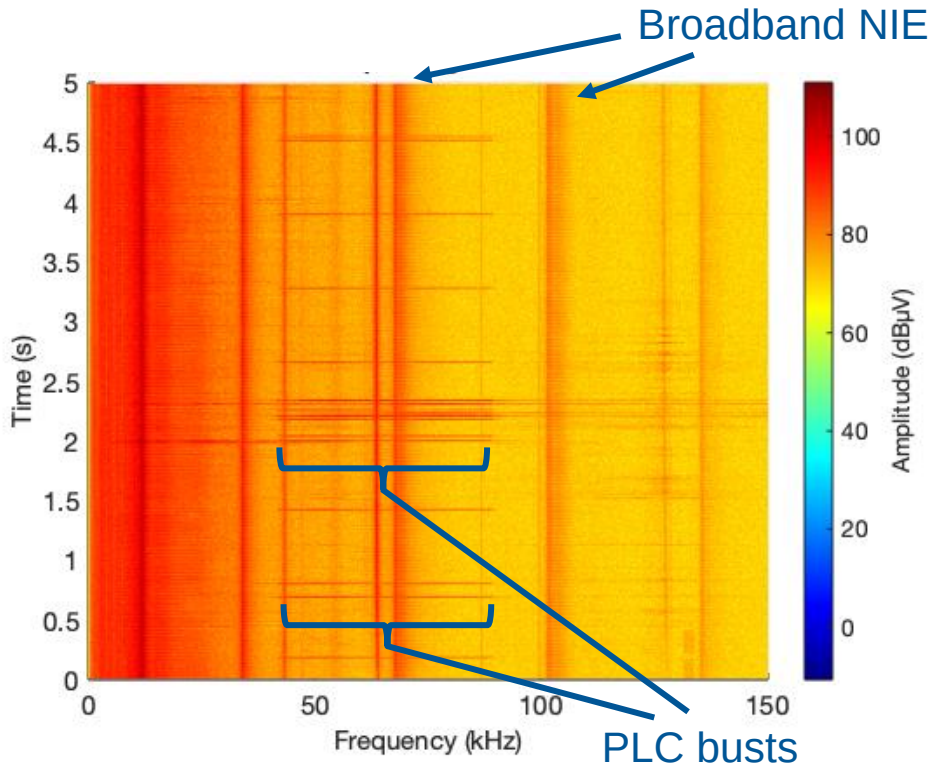
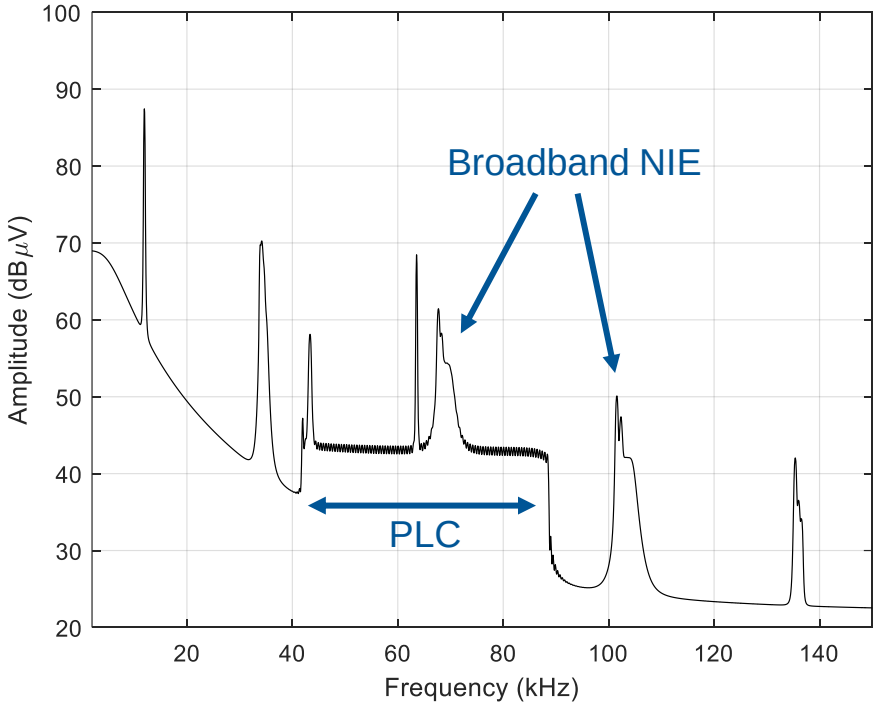
- **LV grid recording**
  - Narrowband and broadband NIE
  - PLC
  - Coloured noise



- **Synthetic signals**
  - Single-frequency sine waves
  - Narrowband and broadband emissions
  - Emulated grid signal



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Metrics

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Measurement values:

- Amplitude values per frequency bin per time interval (U_B)

Characterisation of emission:

- RMS value ($U_{\mathrm{RMS},B}$)

  *RMS of amplitude values over time for each frequency bin. Linked to the **additional (thermal) stress** of electronic components*

- Total Supraharmonic Voltage (TSHV)

  Aggregate value of emission in a certain frequency range

  $$\mathrm{TSHV} = \sqrt{\sum_{B=f_1}^{f_2} U_{RMS,B}^2}$$

- Quasi-peak value

  Peak value of the weighted amplitude envelope of a frequency bin (weighting by duration and repetition rate)

Performance of methods:

- Error with respect to reference values

Comparison results

Synthetic grid signal

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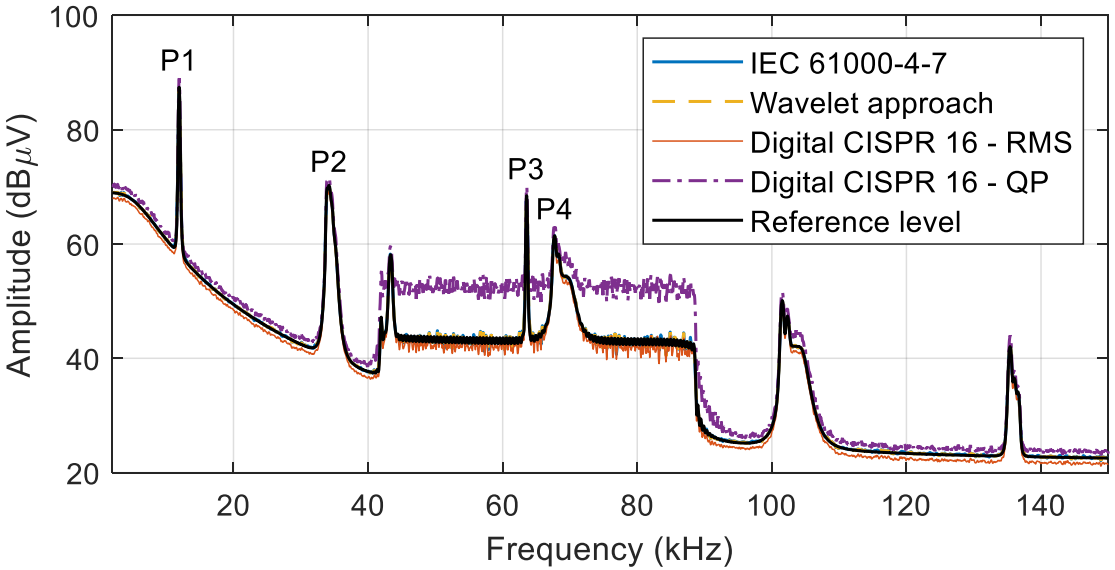

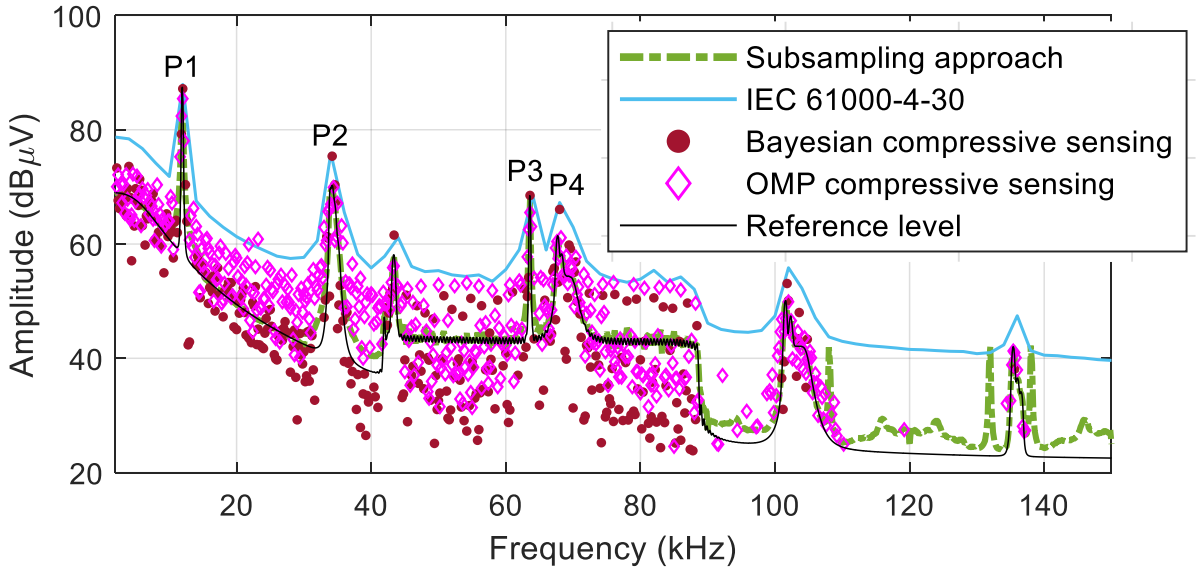

		IEC 61000-4-7	Wavelet approach	Digital CISPR 16 – RMS*	Subsampling approach	Bayesian compressive sensing	OMP compressive sensing
Error in	frequency (Hz)	0	0	0	0	0, 284	0, 484
	amplitude	-10.5%...1.3%	-11.1%…1.0%	-12.2%…-5.9%	-19%…-1.9%	-2.9%…80%	-28.8%…-2.5%
	TSHV	0.5%, 0.8%	0.6%, 0.9%	n/a	2.4%, 2.9%	-4.2%, 1.3%	4.9%, 8.8%

**Errors related to different bandwidth definition*

Conclusion
Summary

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- **IEC 61000-4-30** — 2 kHz resolution not comparable with IEC 61000-2-2 compatibility levels
  Lack of accuracy and reproducibility due to unspecified gaps
- **IEC 61000-4-7** — High accuracy with respect to signal energy and thermal impact
- **Digital CISPR 16** — Quasi-peak values directly comparable to compatibility levels
  Integral values not (yet) defined
- **Wavelet approach** — Results comparable to IEC 61000-4-7 Annex B
- **Subsampling approach** — NIE emissions can be identified with lower sampling of subbands
- **Compressive sensing** — Capable of increasing frequency resolution while maintaining 0.5 ms time resolution, further development for non-sparse wideband emissions

Conclusion

Towards a normative specification

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✓ Comparison shows that different methods fulfill different requirements

approach

Focus on representation of thermal impact & comparison against IEC 61000-2-2 compatibility levels

IEC 61000-4-7 Annex B

Digital CISPR 16