Electrical waveform from vibrational energy harvesters

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Outline

- Energy harvesting introduction
- EMRP: Metrology for Energy Harvesting
- 3 different measurement systems developed
- Results and comparison

About energy harvesting

Input: Mechanical, solar, wind excitation etc.

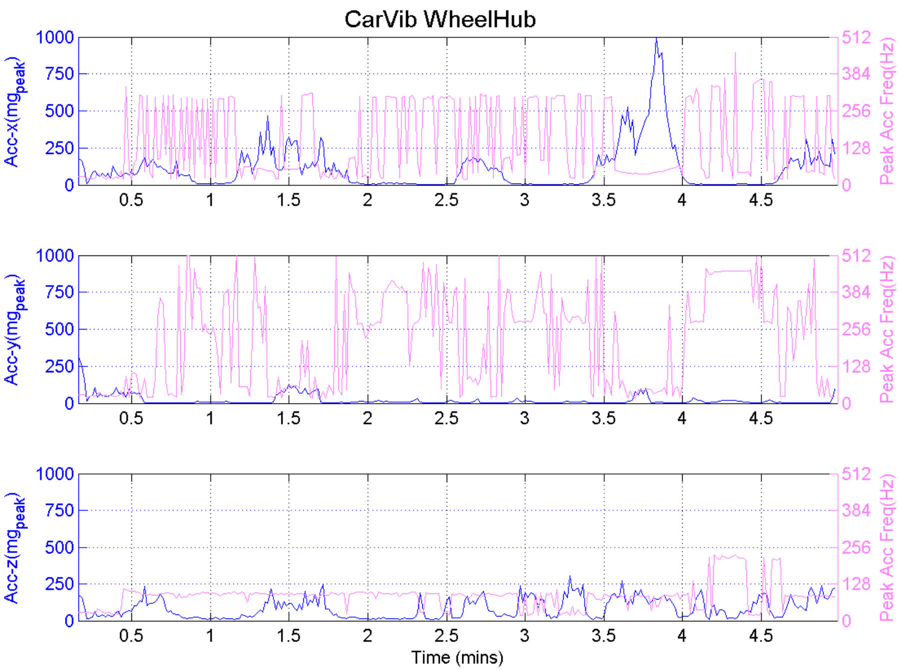
Output: Electrical signal

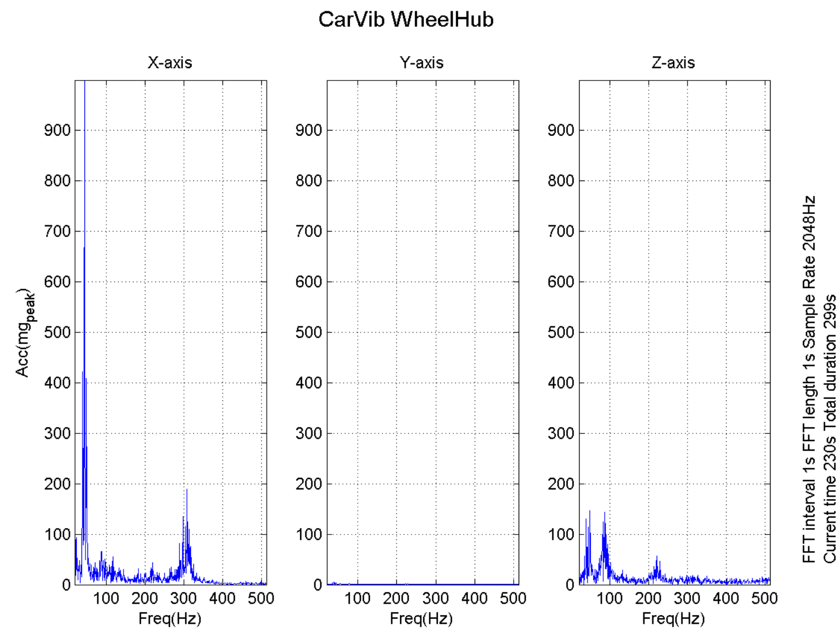
- Properties of output signal:
  - Far from sinusoidal
  - Highly distorted
  - Non periodical
  - Non stationary
- General purposed meters are designed for:
  - Periodical signals
  - near sinusoidal waveforms
  - Poor performance for EH signals

Energy harvester's signal

- Mounted on the VW Transporter

Performed by: University of Southampton



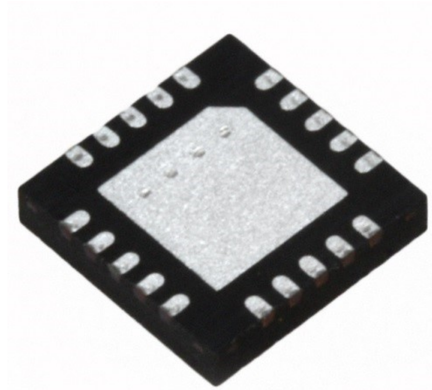


SIQ 50 let/years

Automotive applications 1/2

Piezoelectric EH

- Modern car is fully wired
- More and more electronics is put in economy car with lots of sensors
- Idea: to harvest energy from mechanical, solar and thermo excitation and supply sensors to operate and send data wirelessly to central computer
- Applications:
  - electric window openers
  - door locking
  - mirror and light adjustment systems
  - tire pressure monitoring
  - infotainment systems
- Energy stored in supercapacitors and batteries



Thermoelectric harvester

Supercapacitor

SIQ 50 let/years

Automotive applications 2/2

- Tire Pressure Monitoring System (TPMS)



- Sensor is battery power, replacement is needed 3-5 years
- Alternative is to use MEMS piezoelectric harvester that provide 40 µW which is sufficient for sensor power supply and wireless data transfer

EMRP project: Metrology for energy harvesting

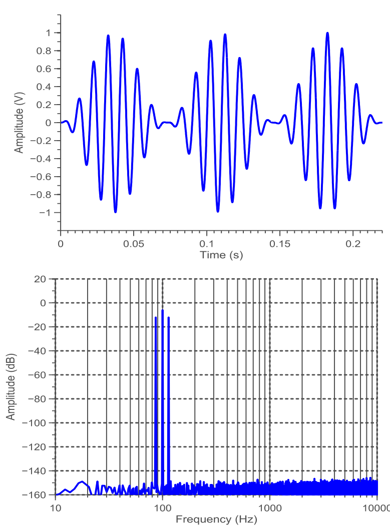
- Motivation:
  - Poor measurement performance with existing meters
  - No traceability
- Traceable measurements are needed for characterization of Energy harvesters
- Three different systems developed (PTB, INRIM and SIQ)
  - 2 different measurement principle
- Comparison of measurements between PTB, INRIM and SIQ

Metrology for energy harvesting
European Metrology Research Programme

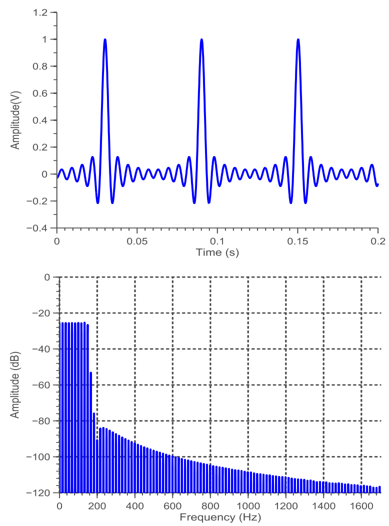
Test signals

1. Signals programmed to mimic output of energy harvesters
2. Generated waveforms are periodical, calculable and rich in spectrum

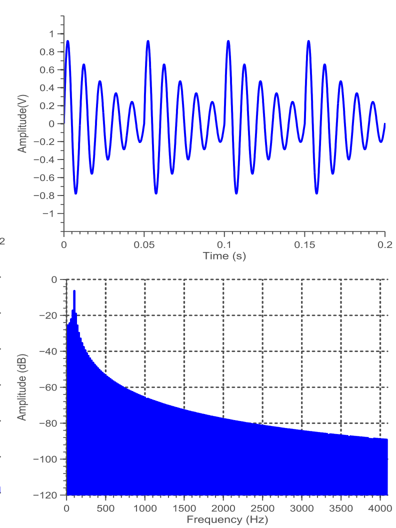
- CS – cosine-shaped burst: f=195 Hz, Vrms=1,361 V
- RC – raised cosine: f=61.5 Hz, Vrms=1,164 V
- DO – damped oscillator: f=97,6 Hz, Vrms=1,392 V



CS



RC



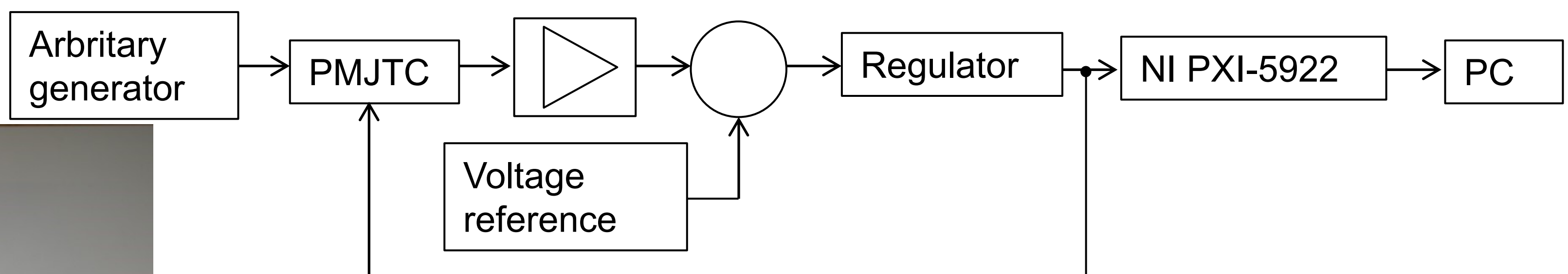
DO

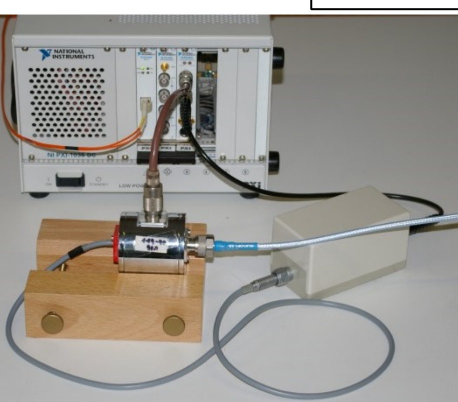
33522A

50 let/years

PTB system

- Based on thermal transfer as used in ac-dc transfer technique
- Planar multijunction thermal converter - PMJTC in an isothermal state
- PMJTC in equipped with a second heating resistor
- Temperature difference between the heater and the ambience is constant
- Power of PMJTC: difference between the energy delivered by the regulator and energy needed for supply





INRIM system

- Sampling system is based on a commercial ADC sampling board
- Agilent Technologies U2542A,
  up to 500 kSs^{-1} sampling rate, 16 bit resolution

Arbitrary generator → Sampling using U2542A → RMS Estimator → Measurement result

RMS Estimator

$$\widehat{V_{\mathrm{RMS}}} = \left(\frac{1}{NW} \sum_{k=0}^{N-1} w[k] \cdot v^2[k] \right)^{\frac{1}{2}}$$

- INRIM uses Hann window function w[k]

SIQ system

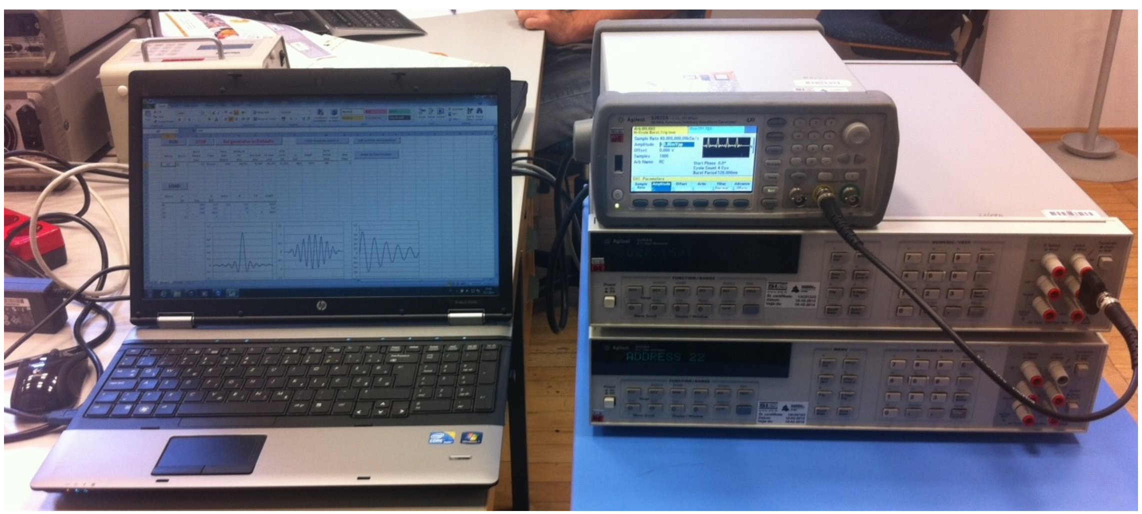
- Sampling system based on a digital multimeter.

Arbitrary generator → Sampling using 3458A → RMS Estimator → Measurement result

RMS Estimator

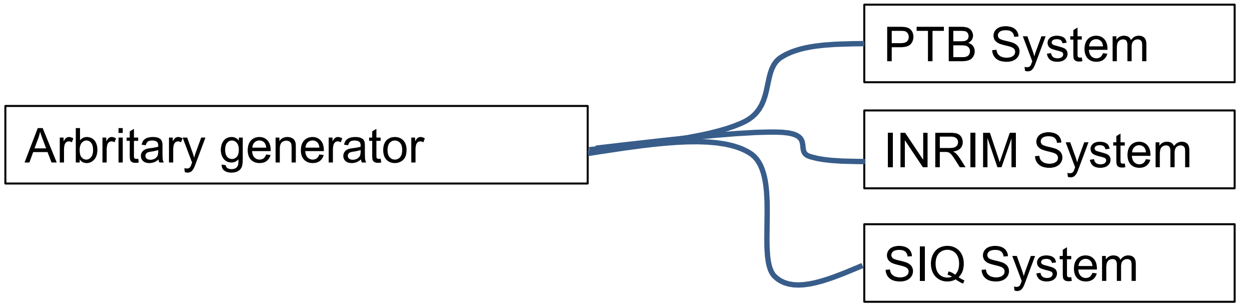
$$\widehat{V_{\mathrm{RMS}}} = \left(\frac{1}{NW} \sum_{k=0}^{N-1} w[k] \cdot v^2[k] \right)^{\frac{1}{2}}$$

- Sampling system based on a digital multimeter.
- SIQ uses Blackman window function
  - v[k] sample set
  - w[k] window function (minimize leakage errors in FFT calculation)
  - W normalization factor



Measurement system comparison

- 3 different EH meters developed traceable to the respective national electrical standards
- All 3 measurement systems were connected in parallel to the output of a waveform generator
- Measurements were performed in controlled conditions in PTB laboratories



Uncertainty sources for SIQ system

- Sampler dc accuracy and stability
- Sampler frequency flatness
- Algorithm accuracy
- Signal stability and noise, including timing jitter

	Uncertainty component				
	DC	Bandwidth	Algorithm	Stability	**Combined**
Sine	1	0.4	1	5	**10**
raised cosine	1	1	1	15	**30**
cosine shaped burst	1	37	1	15	**80**
damped oscillator	1	2	1	15	**30**

Uncertainty budget and total uncertainty for RMS value measurement of sampled voltages for four different signals. All values are given in µV/V.

Uncertainty sources for IRIM system

- SINAD = signal to noise and distortion ratio (the ADC quality)
- CMRR = common-mode rejection ratio
- Algorithm accuracy
- Signal stability and noise, including timing jitter
- …

	Uncertainty component							
	Type A	Vcal	Drift	Flat	Voffset	SINAD	CMRR	**Combined**
Sine	4	12	5	10	3	1	10	**17**
raised cosine	7	12	5	10	3	1	10	**18**
cosine shaped burst	7	12	5	10	3	1	10	**18**
damped oscillator	6	12	5	10	3	1	10	**18**

SIQ 50 let/years

Uncertainty sources for PTB system

- 40 ppm for sinusoidal signals
- **430 ppm** for non-sinusoidal signals
- Dependency from the ambient conditions was found
- Uncertainty could possibly be reduced by using a different heater material and a different geometry for the heaters

Conclusion

- Comparison confirms feasibility of accurate measurements of non-sinusoidal waveforms