Energy harvesting III – micro vibrations

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Vibrations energy harvesting

1 Piezoelectric: dynamical strain is converted into voltage difference.

$$
\begin{cases}
m\ddot{x} = -\dfrac{dU(x)}{dx} - \gamma\dot{x} - K_V V + \zeta_z \\[2ex]
\dot{V} = K_c\dot{x} - \dfrac{1}{\tau_p}V
\end{cases}
$$

The available power is proportional to V^2

Vibrations energy harvesting

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$$

The Physics of piezo materials

K_c and K_v depends on **materials**

Vibrations energy harvesting

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$$

The oscillator dynamics

U(x) is the “elastic” potential mechanical energy of the oscillator

Vibrations energy harvesting

1. Piezoelectric: dynamical strain is converted into voltage difference.

$$\begin{cases} m\ddot{x} = -\dfrac{dU(x)}{dx} - \gamma\dot{x} - K_V V + \zeta_z \\ \dot{V} = K_c \dot{x} - \dfrac{1}{\tau_p} V \end{cases}$$

The environmental energy available

What are fluctuations and how can we harvest them ?

The random character of kinetic energy

ζ_z Represents the vibration (force)

What does it look like?

At the micro-to-nano scales most of the energy available is **kinetic energy** present in the form of **random fluctuations**, i.e. **noise**.

Thus the challenge is to:

use the noise to power nano-scale devices aimed at Sensing/computing/acting and communicating.

The random character of kinetic energy

Random vibrations / noise

Thermal noise
Acoustic noise
Seismic noise
Ambient noise (wind, pressure fluctuations, …)
Man made vibrations (human motion, machine vibrations,…)

All different for intensity, spectrum, statistics

Vibration database: RealVibrations

It is very important that we can characterize the spectral features of the vibration we want to harvest…

Vibration sources digital library

This Task is devoted to the realization of database containing digital time series and spectral representations of experimentally acquired vibration signals.

WISEPOWER

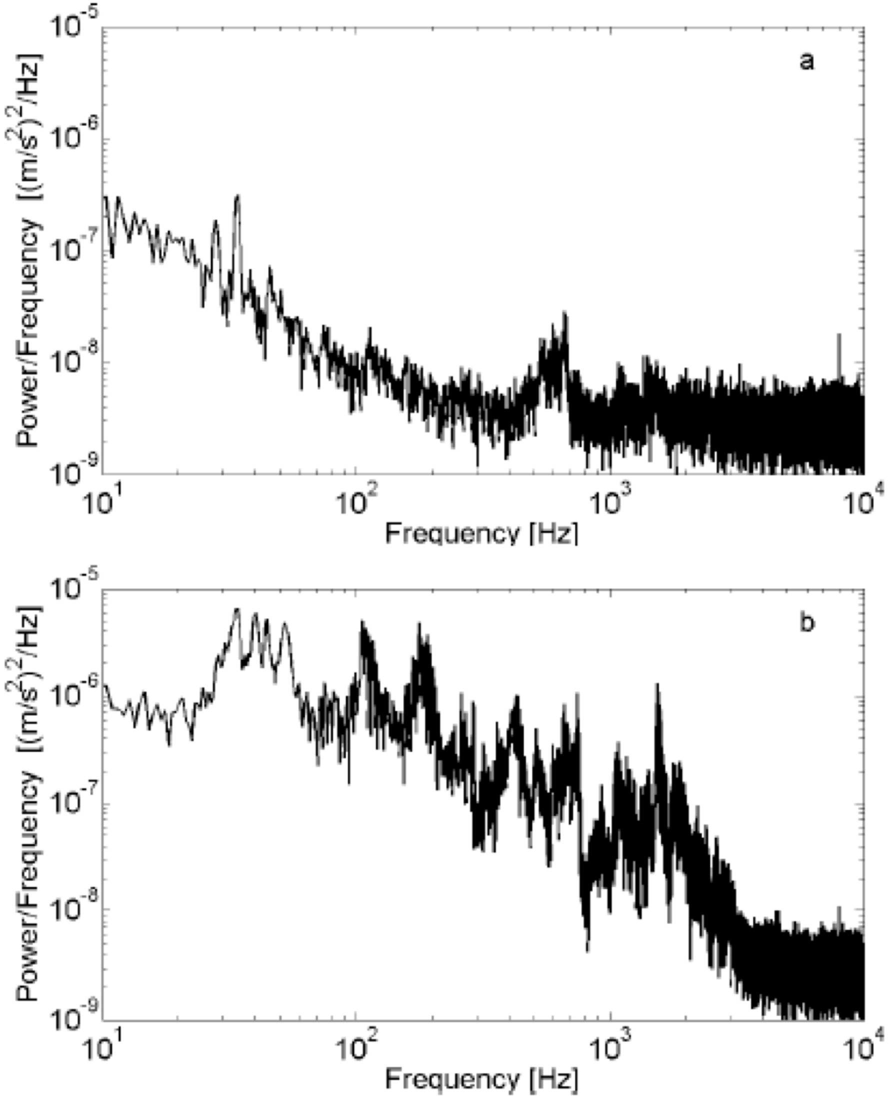
NiPS Laboratory
Noise in Physical Systems
www.nipslab.org

Signal presentation:

- Description
- Power spectrum
- Statistical data
- Time series download (authorized users)

realvibrations.nipslab.org

Bridge vibrations



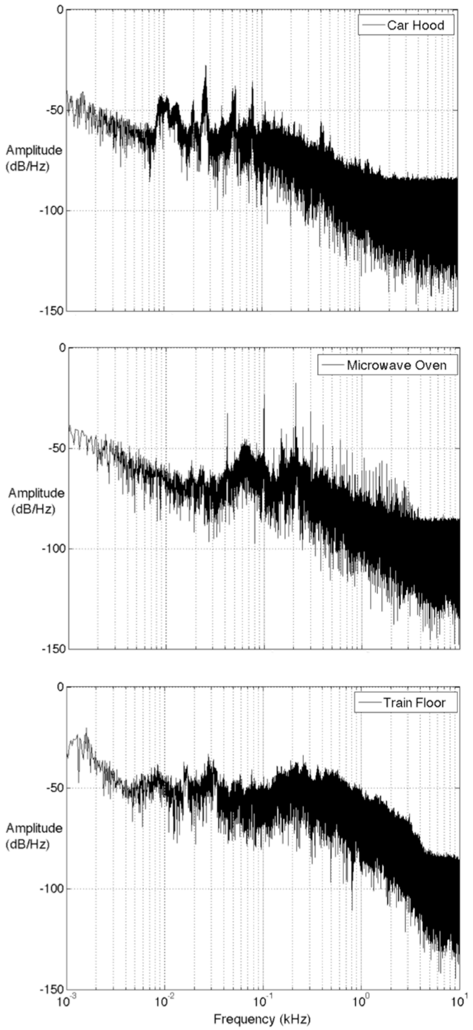
realvibrations.nipslab.org

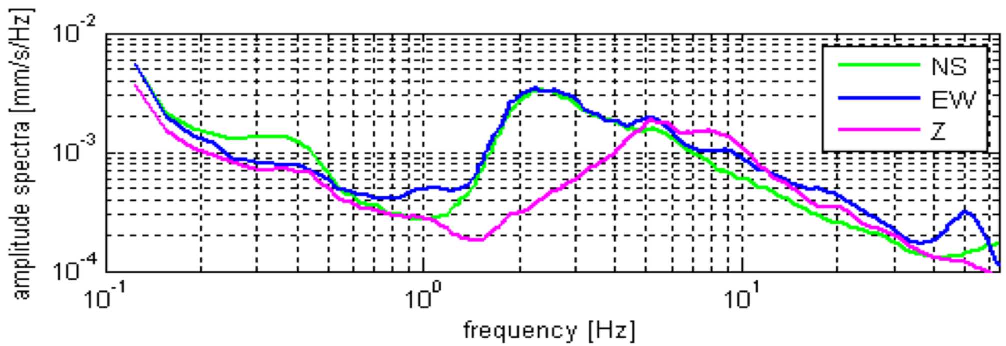
Vibrations energy harvesting

For two main reasons…

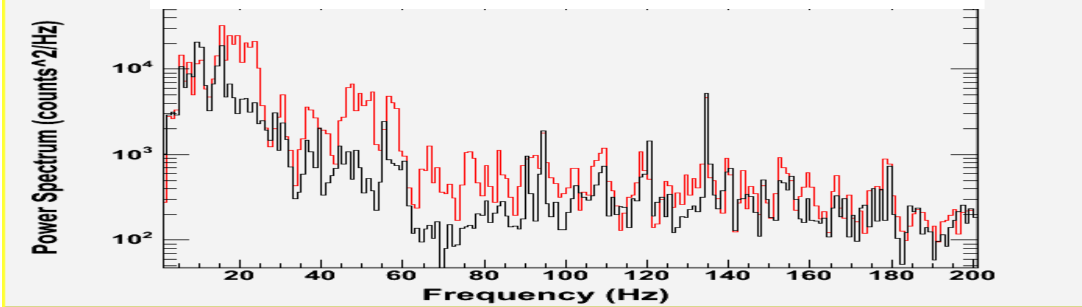
(1) the frequency spectrum of available vibrations instead of being sharply peaked at some frequency is usually very broad.

(2) The frequency spectrum of available vibrations is particularly rich in energy in the low frequency part… and it is very difficult, if not impossible, to build small low-frequency resonant systems…

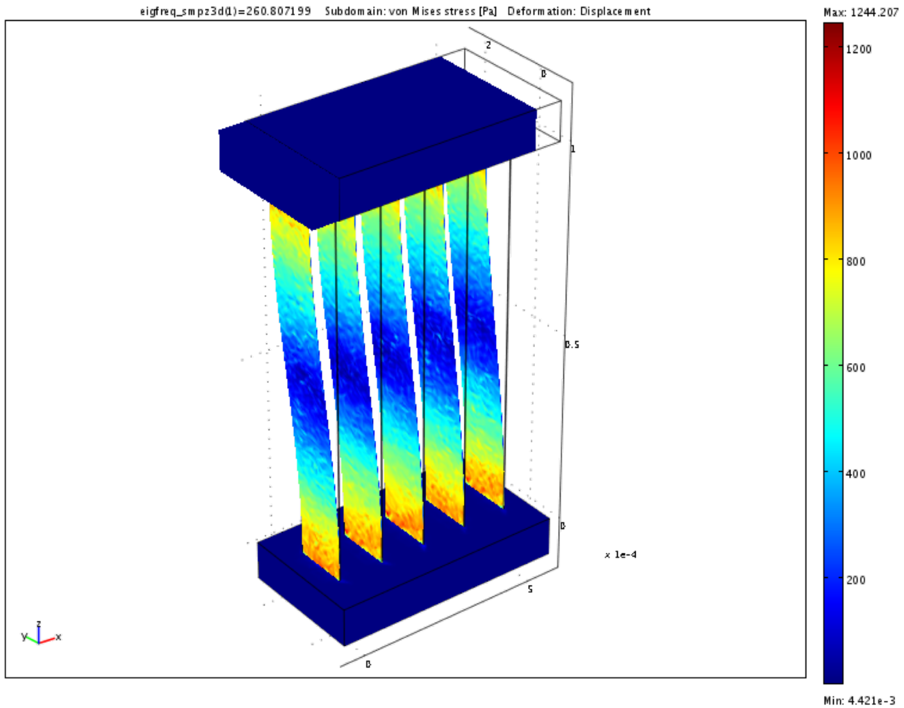




Acoustic noise – quiete working env.

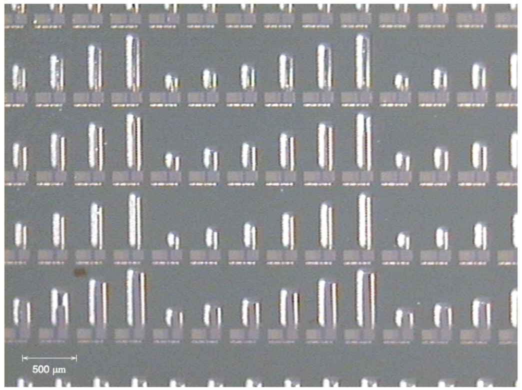


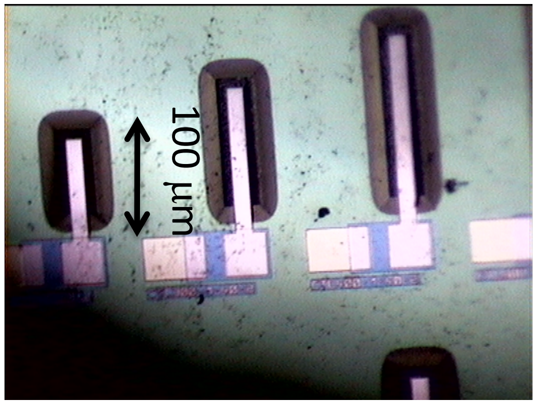
Micro energy harvesting system…

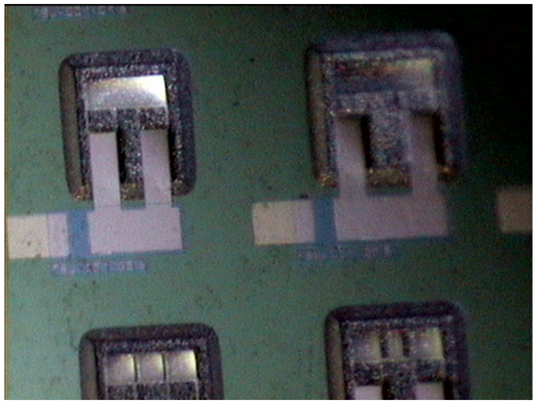


25 μm thick
1 mm high

Freq. 10 KHz







Collaboration with CEA-LETI Grenoble (FR)

Vibrations energy harvesting

Whish list for the perfect vibration harvester

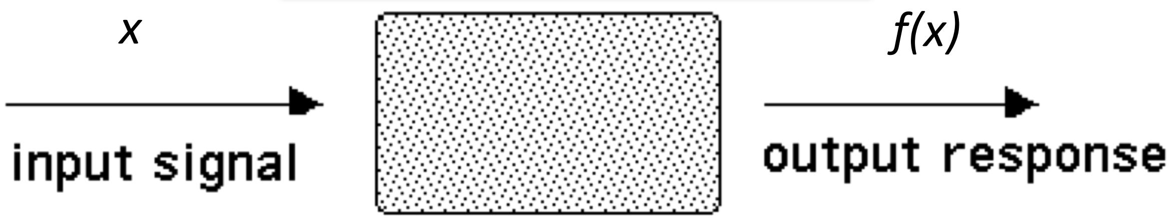
1) Capable of harvesting energy on a broad-band
2) No need for frequency tuning
3) Capable of harvesting energy at low frequency

1) Non-resonant system
2) “Transfer function” with wide frequency resp.
3) Low frequency operated

Linear vs non linear systems

If $f(x)$ represents the output to the input x

Physical system model



Linear system $f(x_1 + x_2) = f(x_1) + f(x_2)$ addittive property

$f(cx) = c\, f(x)$ homogeneous property

Example1 : $f(x) = 3x$

$f(x_1 + x_2) = 3(x_1 + x_2) = 3x_1 + 3x_2 = f(x_1) + f(x_2)$

$f(cx) = 3cx = c\, 3x = c\, f(x)$

Linear

Example2 : $f(x) = x^2$

$f(x_1 + x_2) = (x_1 + x_2)^2 = x_1^2 + x_2^2 + 2\, x_1 x_2 \neq f(x_1) + f(x_2)$

$f(cx) = c^2 x^2 \neq c\, x2 = c\, f(x)$

Nonlinear

Frequency response function

If y(t) is the output when the input is x(t), then for a linear system, it exists a function h(t) (Unit impulse response function) such that

$$y(t) = \int_{-\infty}^{+\infty} h(\tau)x(t-\tau)d\tau \qquad (1)$$

If we define the Frequency response function H(f) as the Fourier transform of h(t):

$$H(f) = \int_{0}^{+\infty} h(\tau)e^{-i2\pi f t}dt$$

We have that taking the Fourier transform of both sides of eq.(1), we have:

$$Y(f) = H(f)\,X(f)$$

See: printed notes from “Random Data”, chapter 2.

Frequency response function 2

the Frequency response function H(f) can be written as

$$H(f) = \int_0^{+\infty} h(\tau) e^{-i2\pi f t} dt = |H(f)| e^{-i\varphi(f)}$$

And the relations hold:

$$|Y(f)| = |H(f)||X(f)|$$

$$\varphi_y(f) = \varphi_H(f) + \varphi_x(f)$$

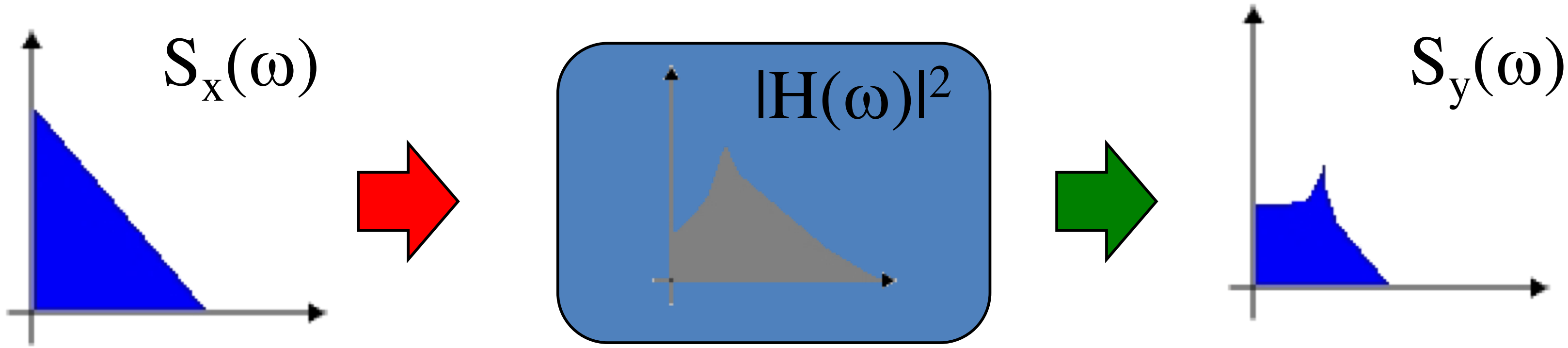
This has important practical applications as the power spectrum can be expressed as

$$S_y(f) = |H(f)|^2 S_x(f)$$

See: printed notes from “Random Data”, chapter 2.

Linear systems

The transfer function is important because it acts as a filter on the incoming energy…



Freq. spectrum of the available energy

Transfer function of the transducer

$$S_y(\omega) = |H(\omega)|^2 \, S_x(\omega)$$

Freq. spectrum of the usable energy

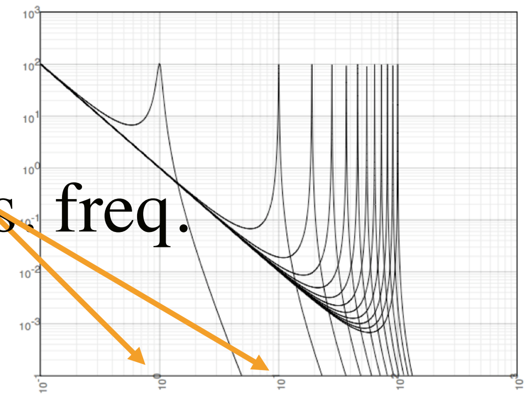
Vibrations energy harvesting

Linear systems

For a linear system the transfer function presents one or more peeks corresponding to the resonace frequencies and thus it is efficient mainly when the incoming energy is abundant in that regions…

This is a serious limitation when you want to build a small energy harvesting system…

res. freq.



Limitations of linear energy harvesters

$$S_y(\omega) = | H(\omega) |^2 \, S_x(\omega)$$

- Transfer function: one or more peaks corresponding to the resonance frequencies
- Difficult, if not impossible, to build small low-frequency resonant systems
- The frequency spectrum of available vibrations not sharply peaked.

Vibrations energy harvesting

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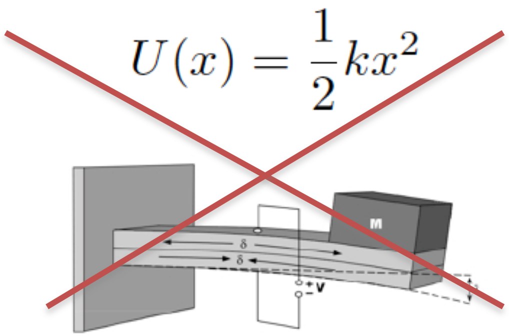
The oscillator dynamics

$U(x)$ Represents the Energy stored



$$U(x) \neq \frac{1}{2}kx^2$$