

Energy harvesting II – dynamics

Luca Gammaitoni

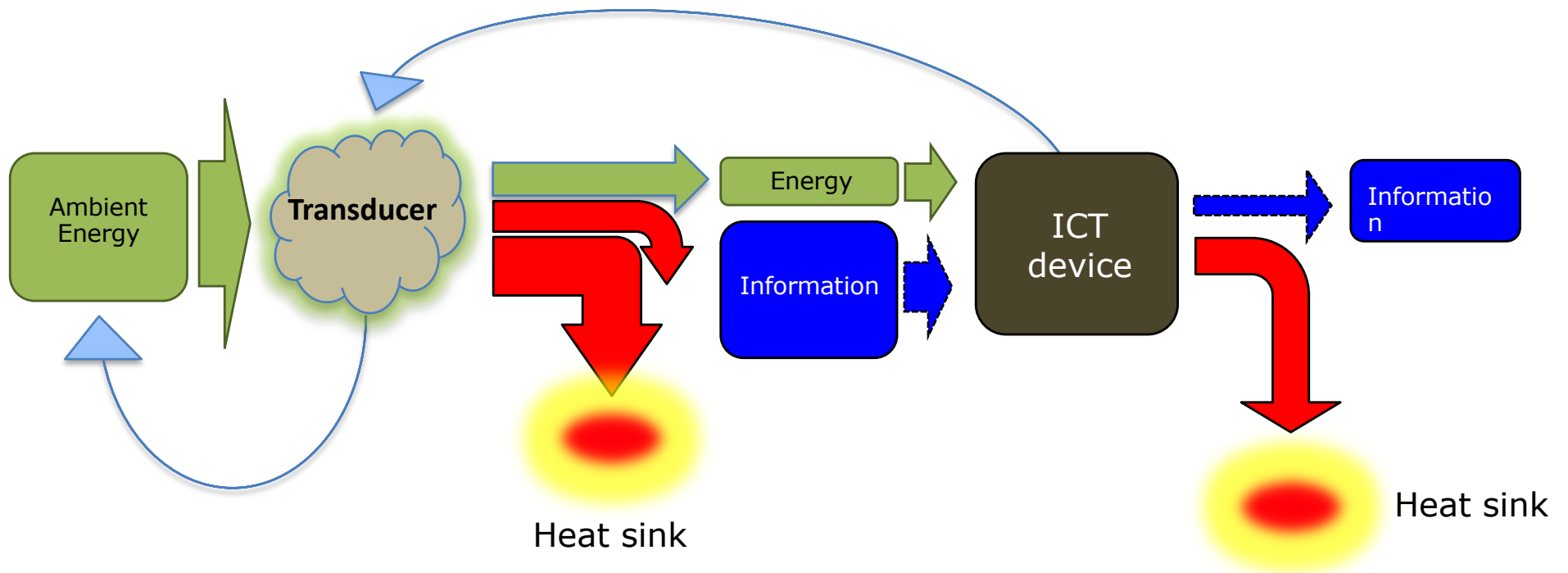
NiPS Laboratory, University of Perugia

The device powering issue:

- 1) How much energy is needed to power a device ?
- 2) Where does the device get the needed energy ?

We consider devices at MEMS scale and below

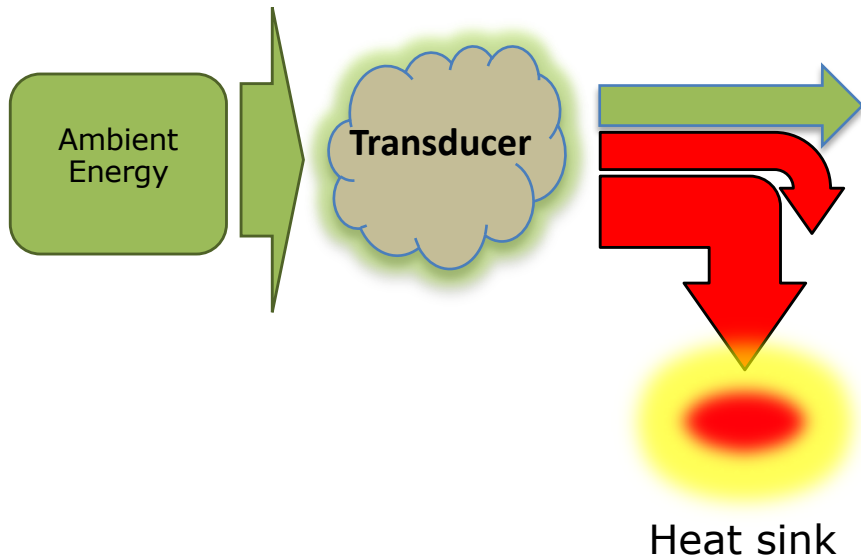
We consider “ICT devices”: i.e. devices mainly devoted to computing task



An **ICT device** is an info-thermal machine that inputs **information** and **energy** (under the form of work), processes both and outputs information and energy (mostly under the form of heat).

The device powering issue:

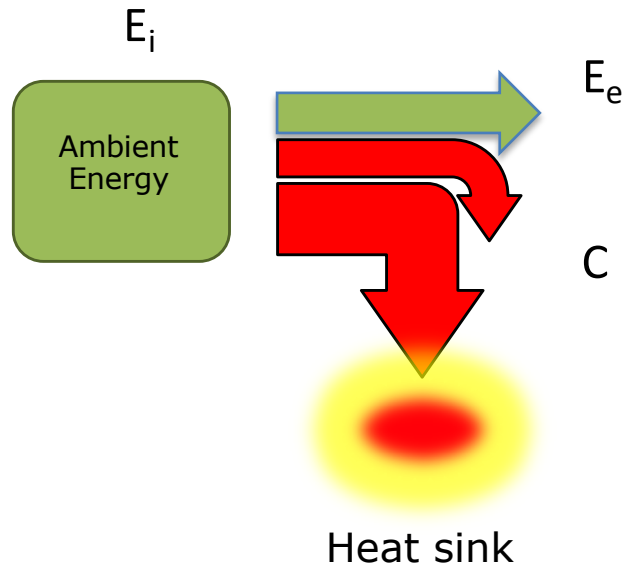
- 1) How much energy is needed to power a device ?
- 2) Where does the device get the needed energy ?



Clearly this energy is obtained from the ambient...

The device powering issue:

- 1) How much energy is needed to power a device ?
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Energy is conserved....

$$E_e = E_i - C$$

Question: can we make $C = 0$?

C is the energy dissipated during the transformation. $m\ddot{x} = -\frac{dU(x,t)}{dx} + \zeta_z - \gamma\dot{x} + \zeta$

$C=C(\gamma)$ and γ is associated with the relaxation to equilibrium and depends on the characteristics of the device/material.

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The usual solution is to go very slow, i.e. to minimize \dot{x}

Good news: In principle there is no physical law that forbids to make $C = 0$

Bad news: This affects the power we can use in the device

$C=C(\gamma)$ can be a function of time and change with the dissipation process.

Viscous damping, thermo-elastic damping, structural damping, ...

Generalized Langevin equation $m\ddot{x} = -\frac{dU(x,t)}{dx} + \zeta_z - \int_{-\infty}^t \gamma(t-\tau) \dot{x} d\tau + \zeta$

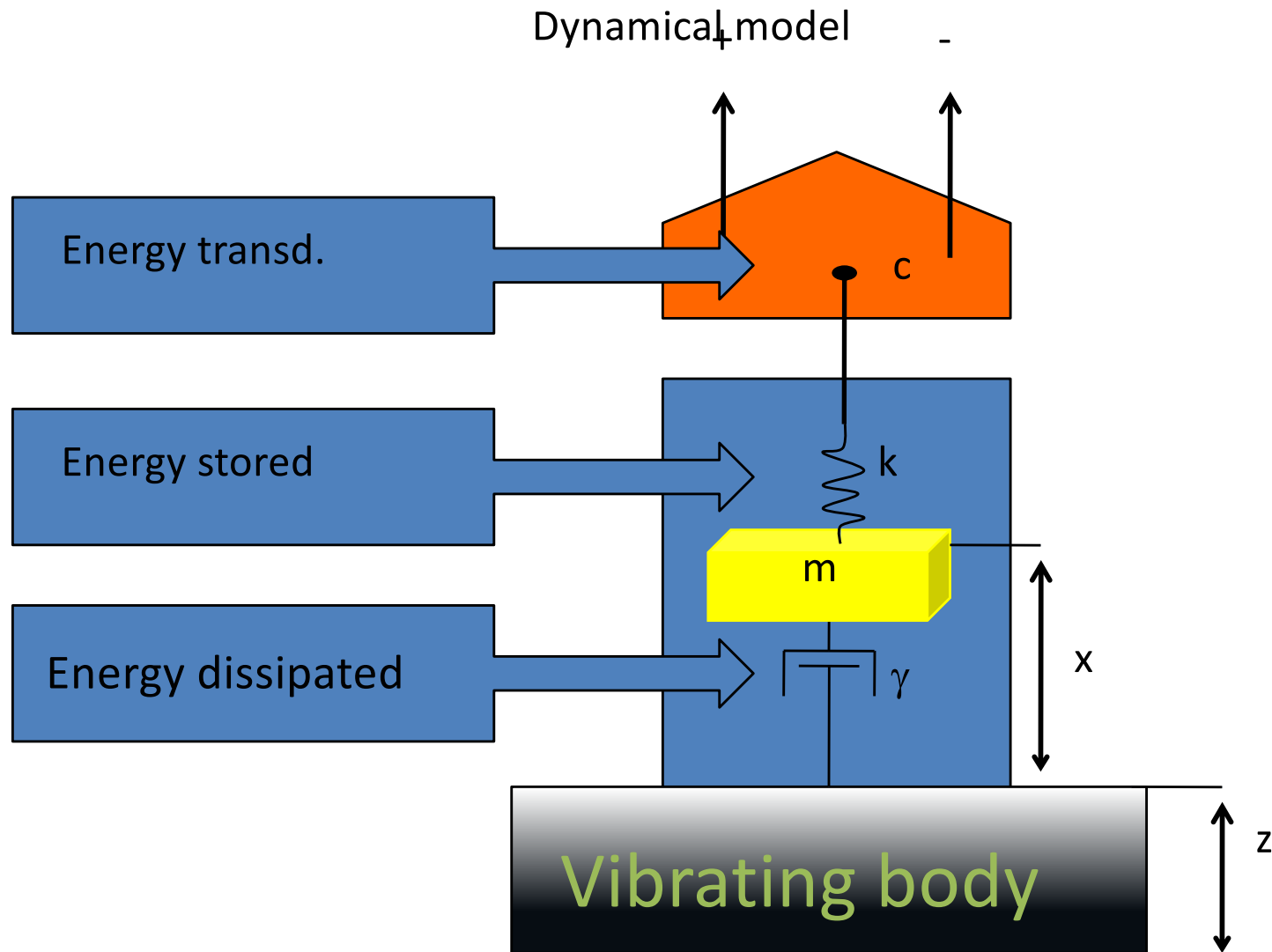
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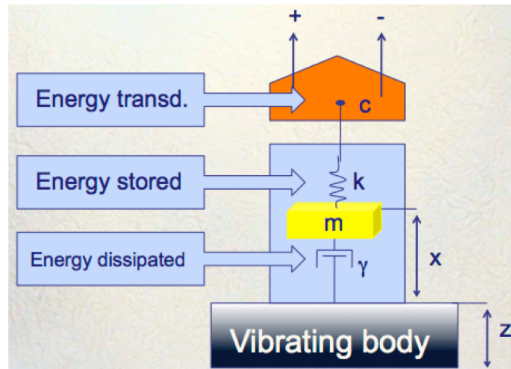
$$m\ddot{x} = -\frac{dU(x,t)}{dx} + \xi_z - \gamma\dot{x} + \xi$$

Finally, the role of the potential energy $U(x,t)$

Vibrations energy harvesting



Vibrations energy harvesting

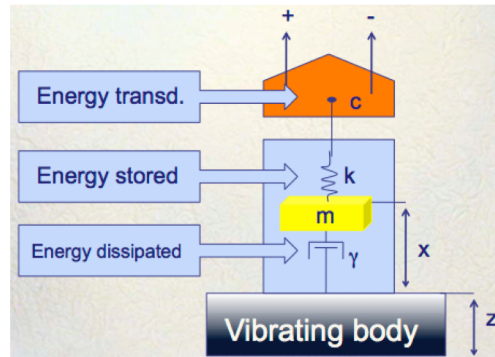


Dynamical model

$$m\ddot{x} = -\frac{dU(x)}{dx} - \gamma\dot{x} - c(x, V) + \xi_z$$

- Where:
- $U(x)$ Represents the Energy stored
 - $\gamma\dot{x}$ Accounts for the Energy dissipated
 - $c(x, V)$ Accounts for the Energy transduced
 - ξ_z Accounts for the input Energy

Vibrations energy harvesting

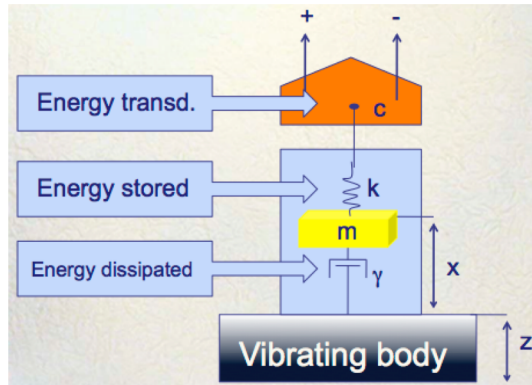


Dynamical model

$$\left\{ \begin{array}{l} m\ddot{x} = -\frac{dU(x)}{dx} - \gamma\dot{x} - c(x,V) + \xi_z \\ \dot{V} = F(\dot{x},V) \end{array} \right.$$

Equations that link the vibration-induced displacement with the Voltage

Vibrations energy harvesting



Dynamical model

Equations that link the vibration-induced displacement with the Voltage

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Details depend on the physics of the conversion principles...

Vibrations energy harvesting

Transduction mechanisms

1

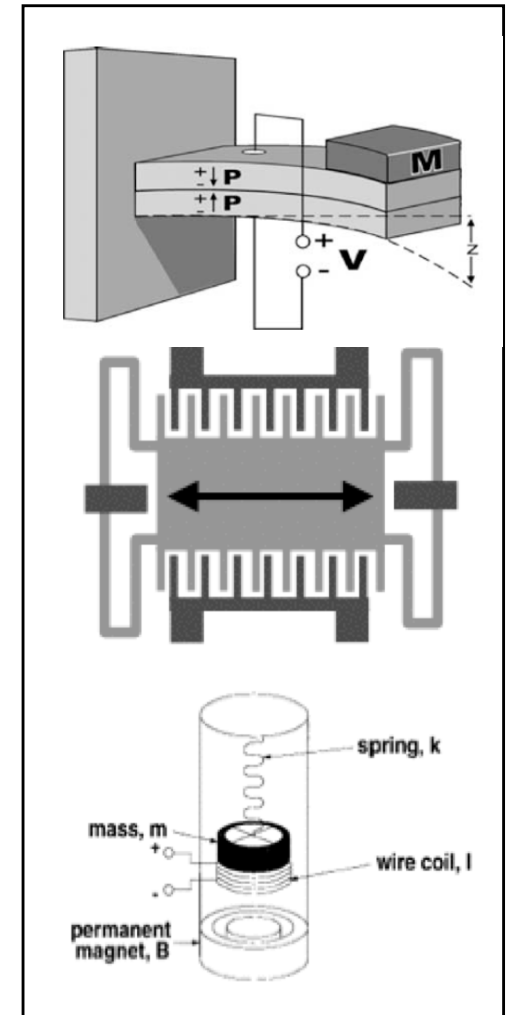
Piezoelectric: dynamical strain is converted into voltage difference.

2

Capacitive: geometrical variations induce voltage difference

3

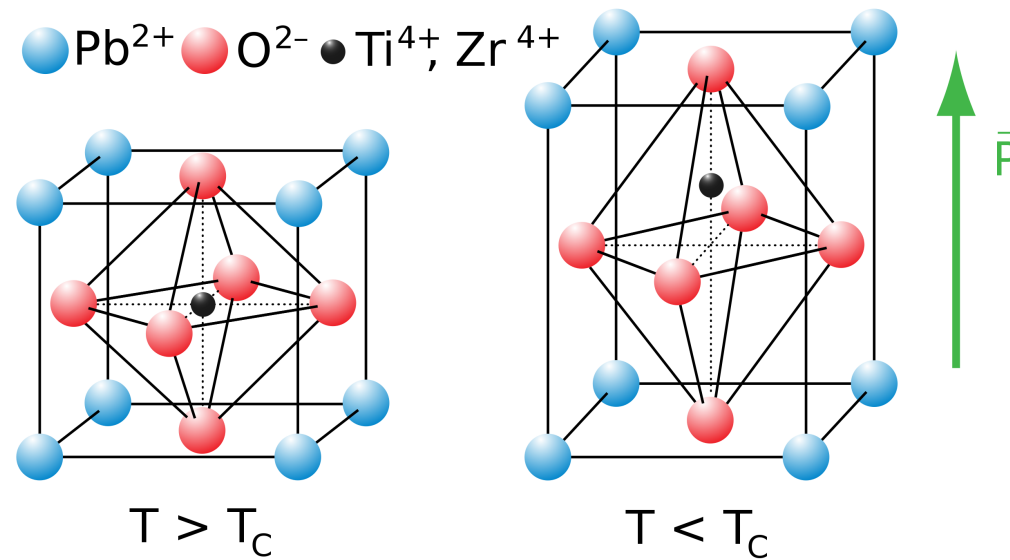
Inductive: dynamical oscillations of magnets induce electric current in coils



1

Piezoelectric: dynamical strain is converted into voltage difference.

La piezoelettricità è la proprietà di alcuni materiali cristallini di polarizzarsi generando una differenza di potenziale quando sono soggetti a una deformazione meccanica e al tempo stesso di deformarsi in maniera elastica quando sono sottoposti ad una tensione elettrica.



Struttura cristallina di un materiale piezoelettrico (piombo-zirconato di titanio).

Vibrations energy harvesting

1

Piezoelectric: dynamical strain is converted into voltage difference.

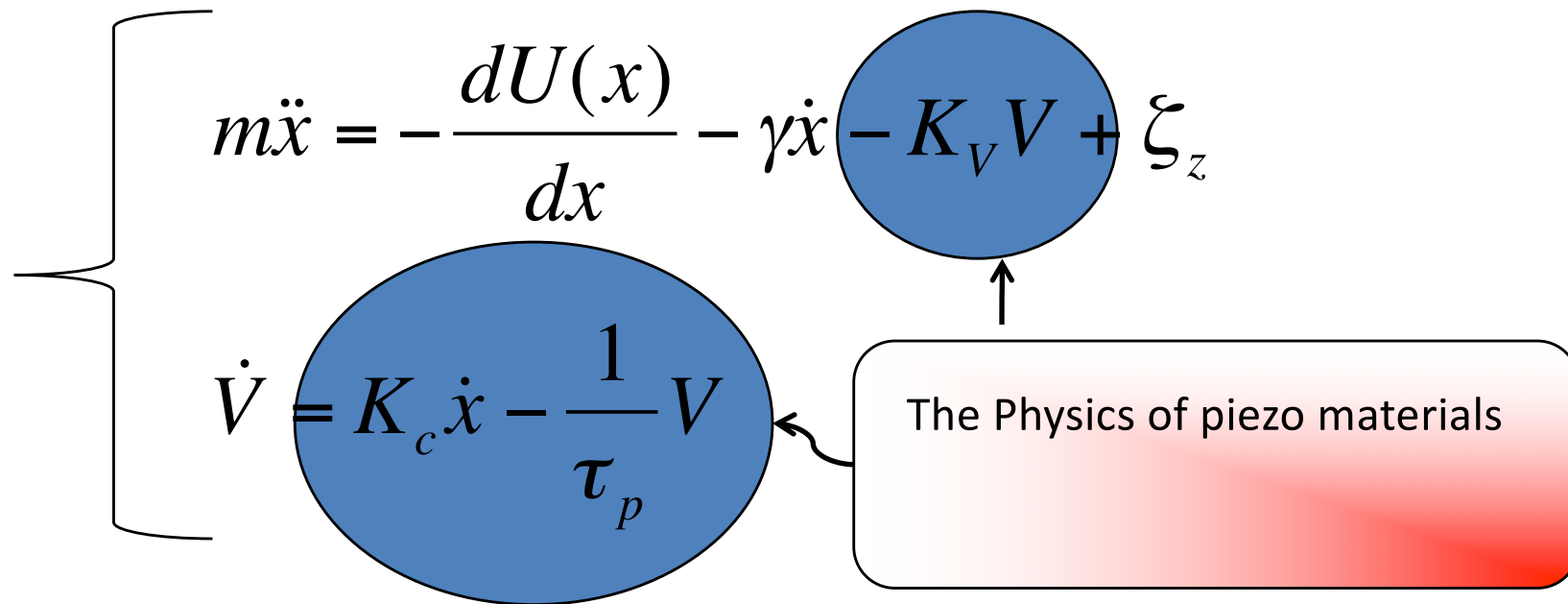
$$\left\{ \begin{array}{l} m\ddot{x} = -\frac{dU(x)}{dx} - \gamma\dot{x} - K(x, V)\xi_z \zeta_z \\ \dot{V} = K(\dot{x}, V) \frac{1}{\tau_p} V \end{array} \right.$$

The available power is proportional to V^2

Vibrations energy harvesting

1

Piezoelectric: dynamical strain is converted into voltage difference.



K_c and K_V depends on **materials**

Vibrations energy harvesting

1

Piezoelectric: dynamical strain is converted into voltage difference.

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

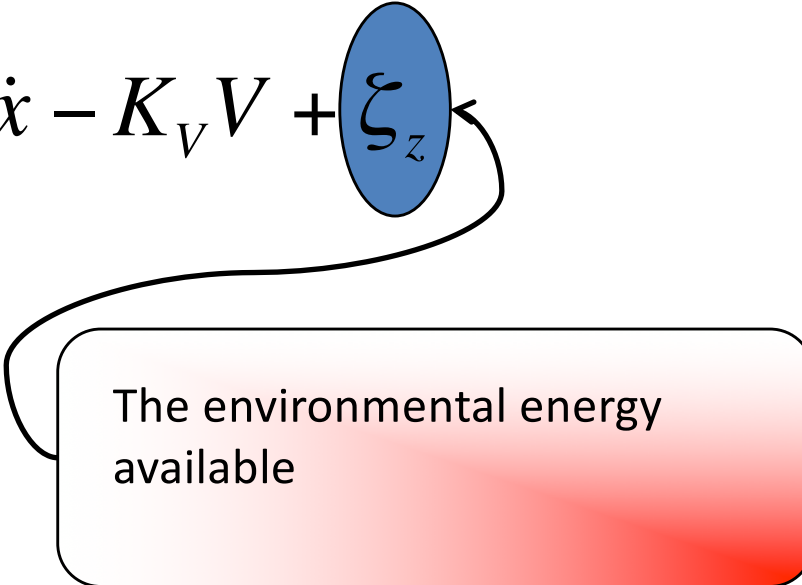
The oscillator dynamics

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

Vibrations energy harvesting

1

Piezoelectric: dynamical strain is converted into voltage difference.

$$\left\{ \begin{array}{l} m\ddot{x} = -\frac{dU(x)}{dx} - \gamma\dot{x} - K_V V + \xi_z \\ \dot{V} = K_c \dot{x} - \frac{1}{\tau_p} V \end{array} \right.$$


The environmental energy available

The diagram shows a blue oval containing the symbol ξ_z in the first equation. A curved arrow points from this oval to a red-to-white gradient rounded rectangle containing the text "The environmental energy available".

What are fluctuations and how can we harvest them ?

The random character of kinetic energy

ξ_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.



The screenshot shows the homepage of the Real Vibrations website. The browser address bar displays 'realvibrations.nipslab.org'. The website header includes the title 'Real Vibrations' and a navigation menu with links for Home, Signals, DAQ Kits, Info, Policy, and Contacts. A search bar is located below the navigation menu. The main content area features a 'Home' section with a welcome message and a 'What is Real Vibrations?' section. The 'What is Real Vibrations?' section includes a paragraph describing the database and a photograph of a hand holding a vibrating object. Below this, there is a 'What are these data for?' section and a 'How to take part in the project?' section. The left sidebar contains a 'User login' section with fields for Username and Password, and a 'Latest Signals' section with several signal plots. The bottom of the page features a 'Popular Tags' section.



NiPS Laboratory
Noise in Physical Systems



www.nipslab.org

Signal presentation:

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

realvibrations.nipslab.org