Energy harvesting II – dynamics

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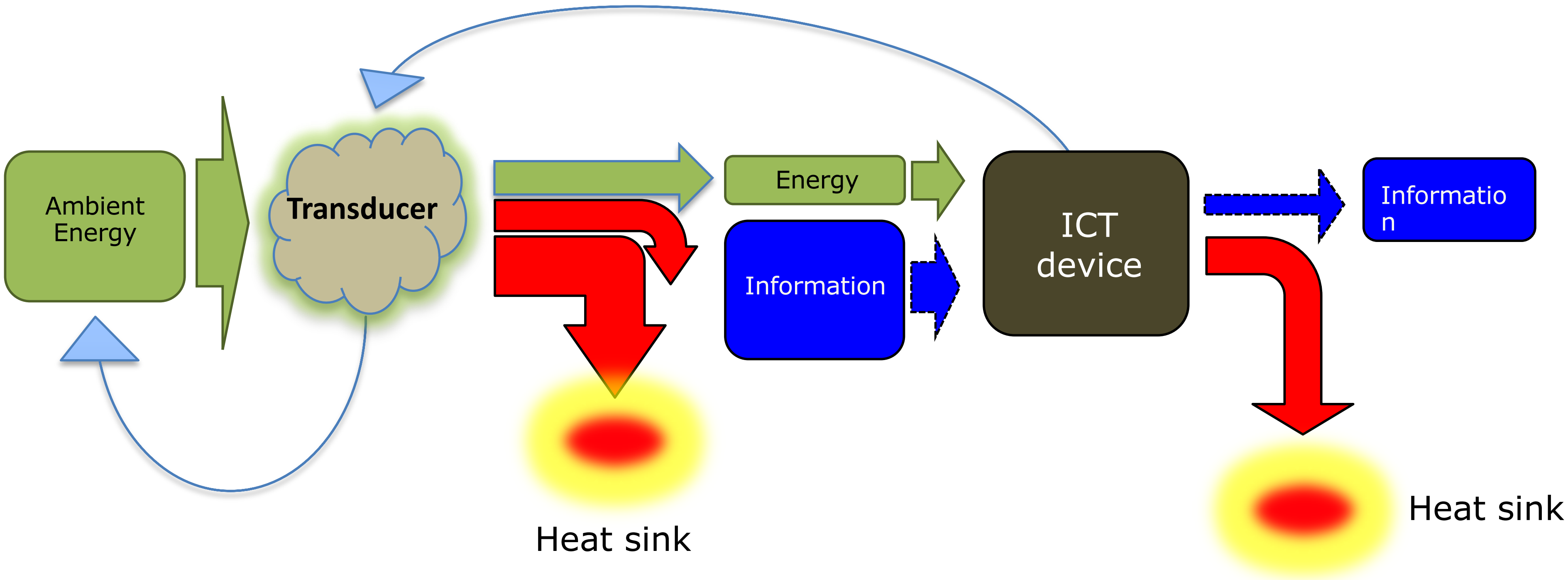
The device powering issue:

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:

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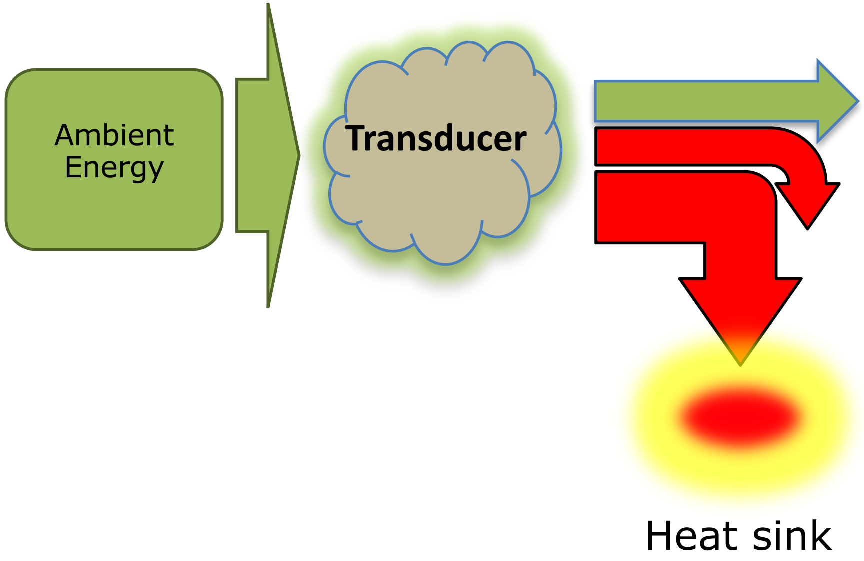

Clearly this energy is obtained from the ambient…

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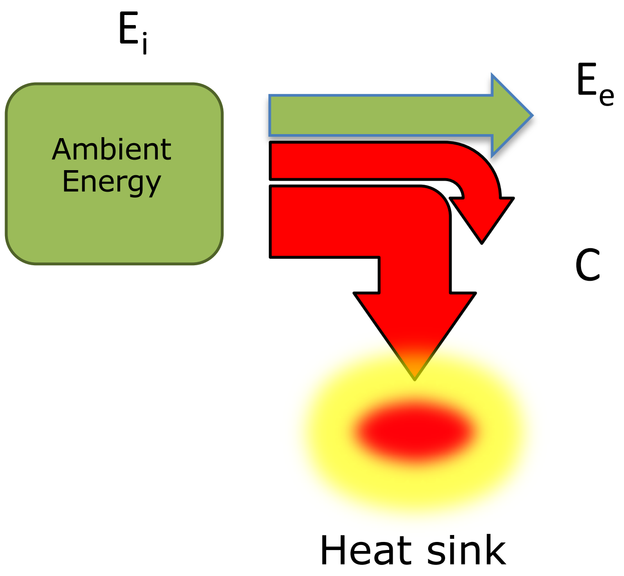

Energy is conserved….

$E_e = E_i - C$

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(γ) 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(γ) can be a function of time and change with the dissipation process.
Viscous damping, thermo-eleastic 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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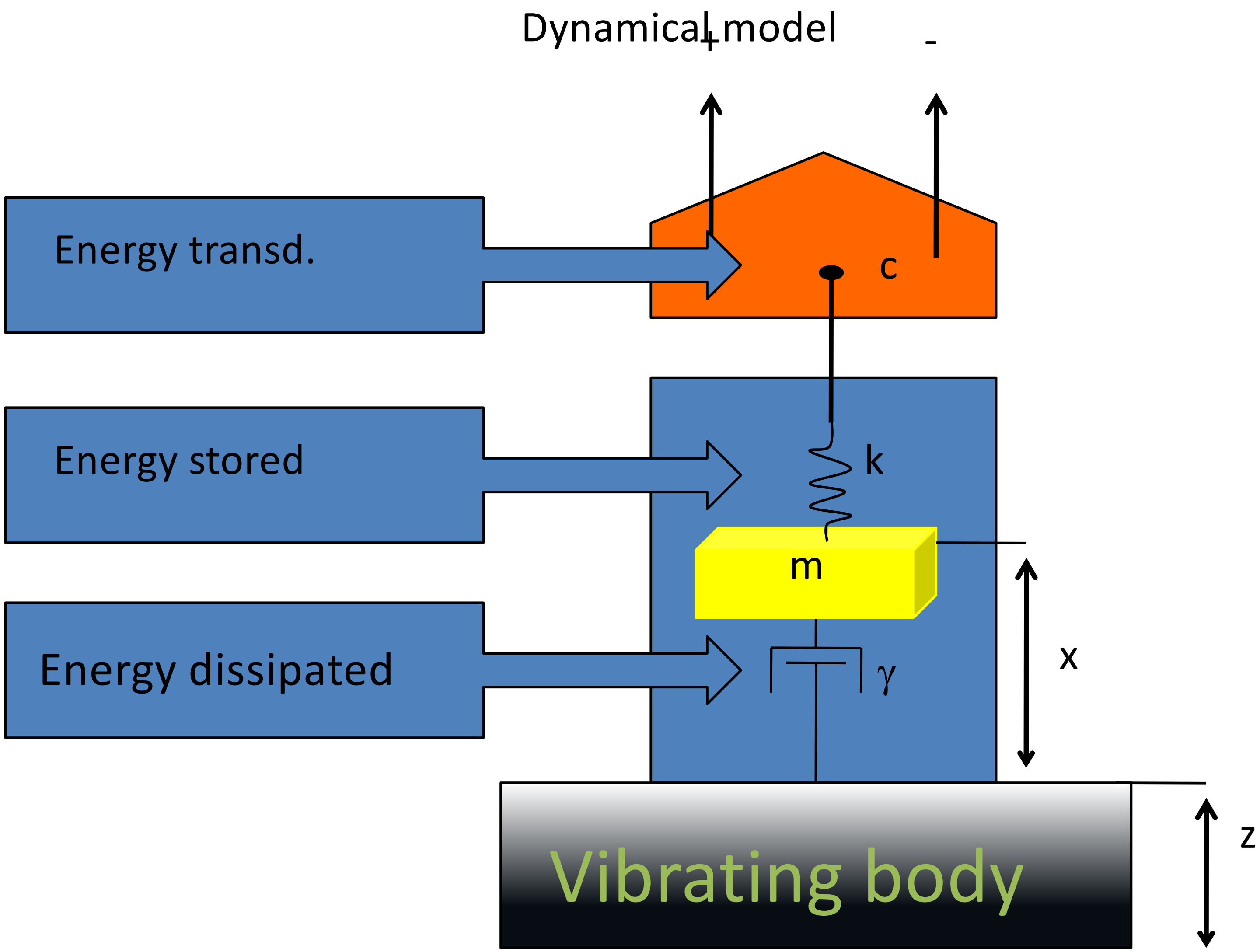
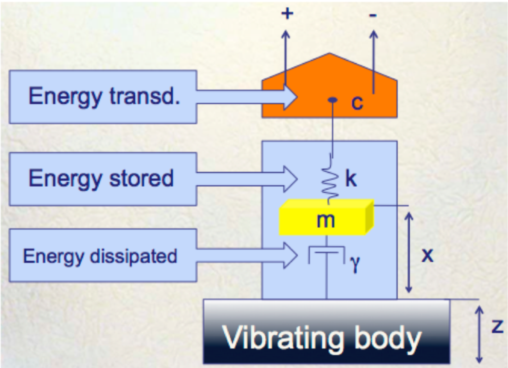
Finally, the role of the potential energy *U(x,t)*

Vibrations energy harvesting



Vibrations energy harvesting



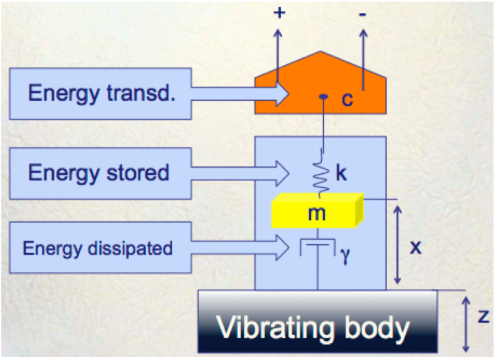
Dynamical model

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

Where:

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

Vibrations energy harvesting

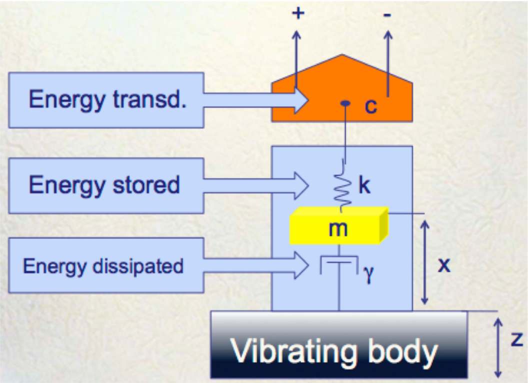


Dynamical model

$$\begin{cases} m\ddot{x} = -\dfrac{dU(x)}{dx} - \gamma\dot{x} - c(x,V) + \zeta_z \\ \dot{V} = F(\dot{x},V) \end{cases}$$

Equations that link the vibration-induced displacement with the Voltage

Vibrations energy harvesting



Dynamical model

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Details depend on the physics of the conversion principles…

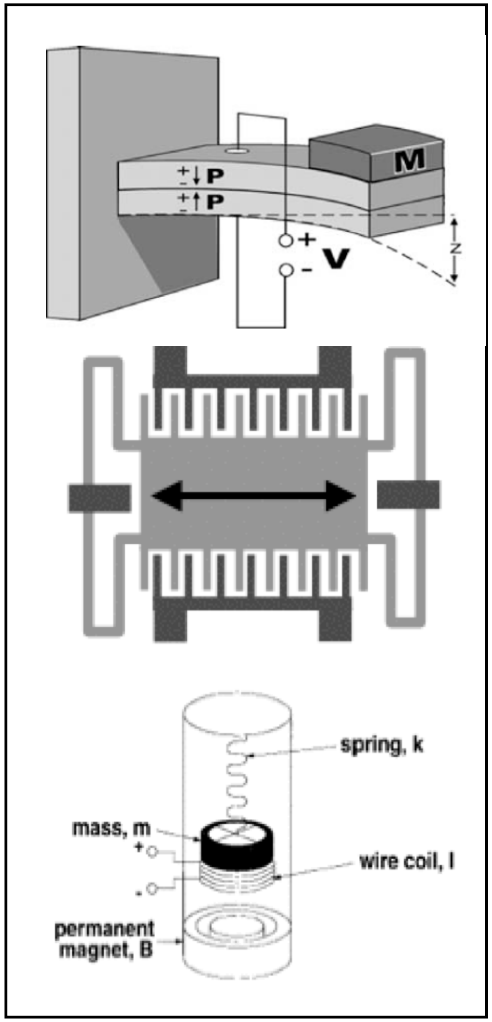
Vibrations energy harvesting

Transduction mechanisms

1 Piezoelectric: dynamical strain is converted into voltage difference.

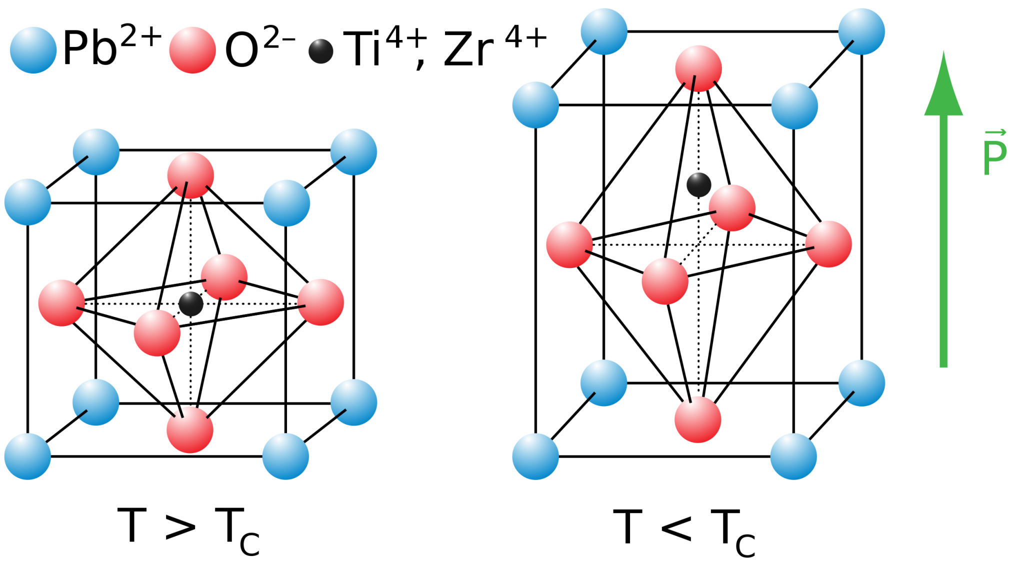
2 Capacitive: geometrical variations induce voltage difference

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.

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

The available power is proportional to V^2

Vibrations energy harvesting

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$$
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\end{cases}
$$

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

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$$
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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.

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Noise in Physical Systems

www.nipslab.org

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

realvibrations.nipslab.org