Nonlinear Energy Harvesting

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Noise in Physical Systems

www.nipslab.org

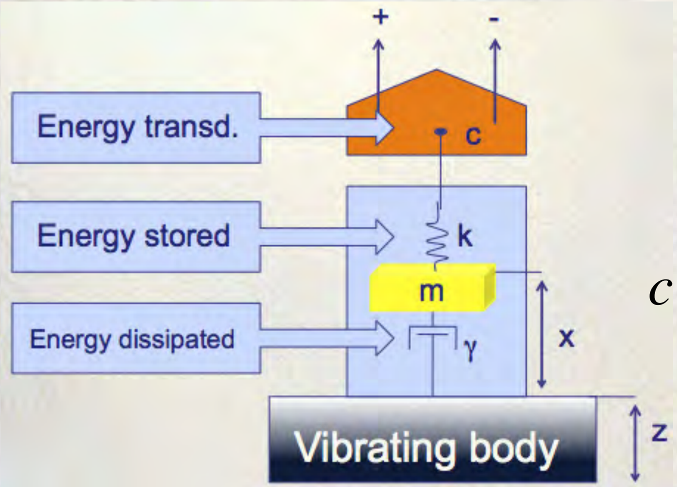
Noise energy harvesting

Dynamical model for a vibrational energy harvester

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

Details depend on the physics…

Equations that link the vibration-induced displacement with the Voltage



$U(x)$ 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

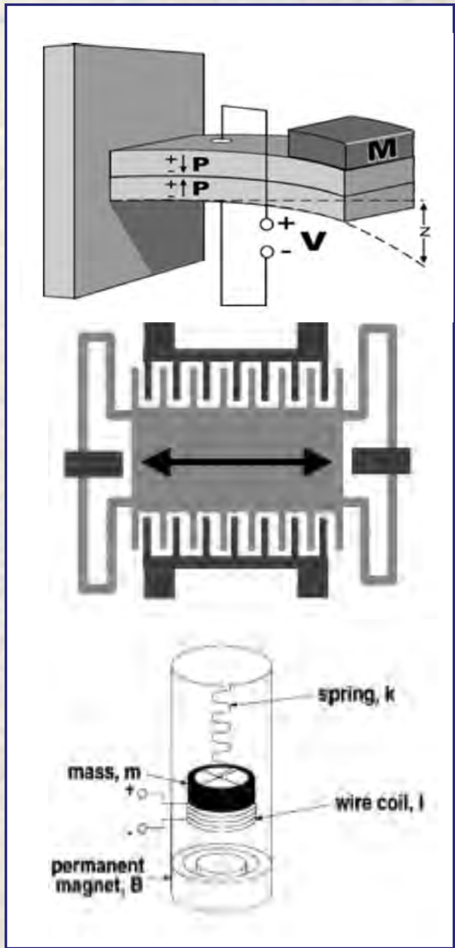
Noise energy harvesting

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



Noise energy harvesting

Transduction mechanisms

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 Physics of piezo materials

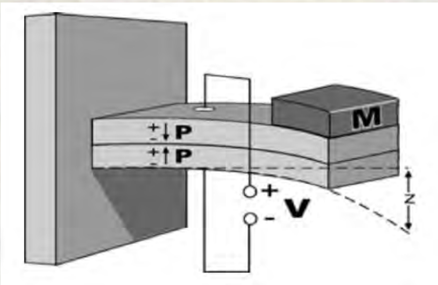
Noise energy harvesting

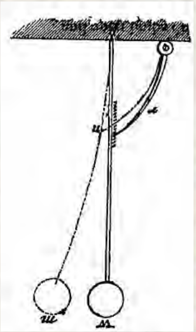
Linear systems

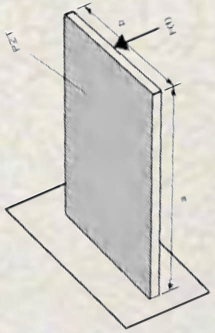
When $U(x) = \frac{1}{2}kx^2$ it is called a linear system

Linear systems have some interesting features… (and people like them most)

1) There exist a simple math theory to solve the eq.s
2) They have a resonant behaviour (resonance freq.)
3) They can be "easily" realized with catilevers and pendula







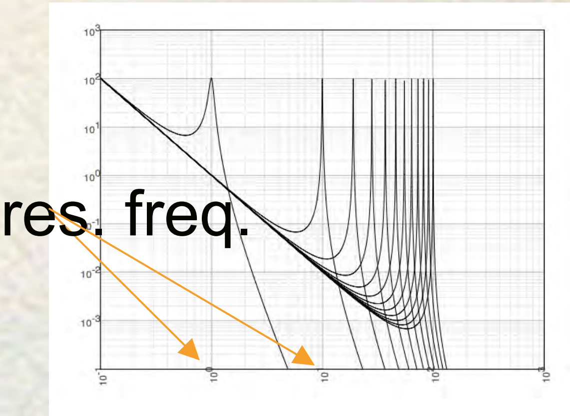
Noise energy harvesting

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…

Why ?!!



For two main reasons…

- The frequency spectrum of available vibrations instead of being sharply peaked at some frequency is usually very broad.
- 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…

Noise energy harvesting

Wish 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

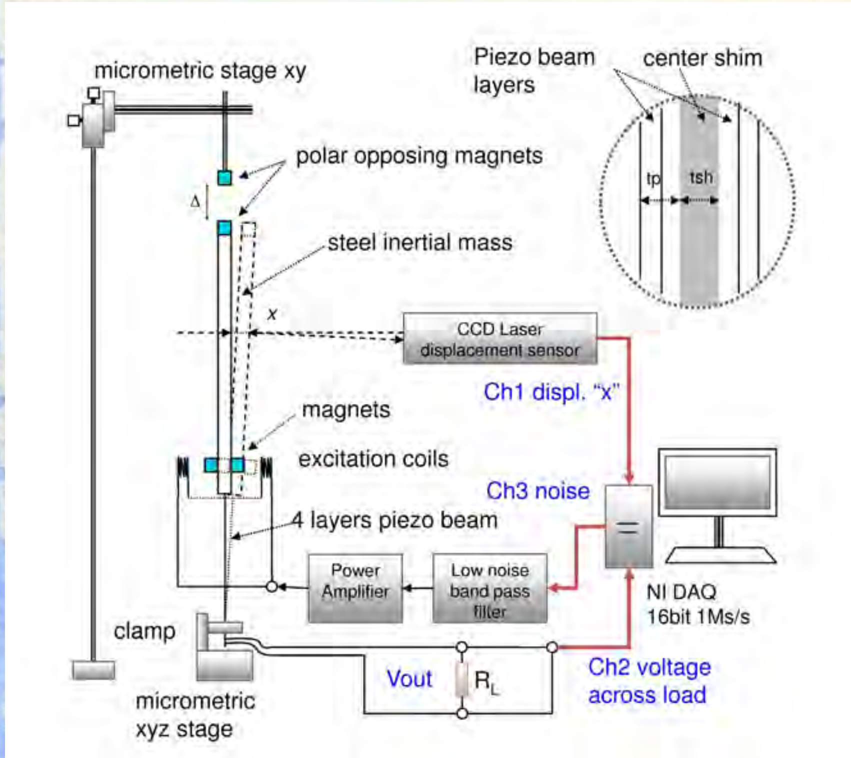
Our approach:

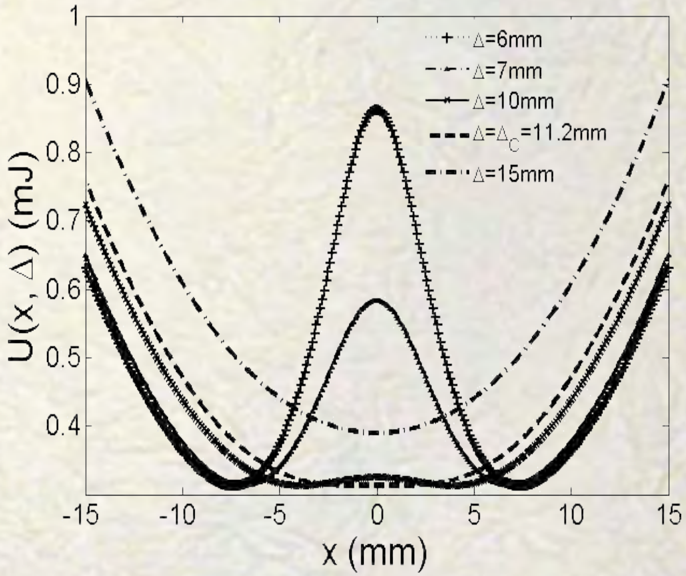
NON-Linear mechanical oscillators

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

Noise energy harvesting

NON-Linear mechanical oscillators

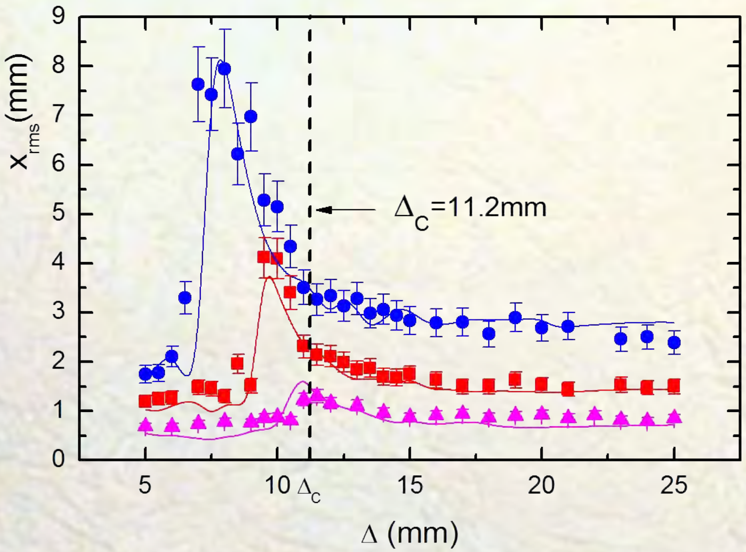


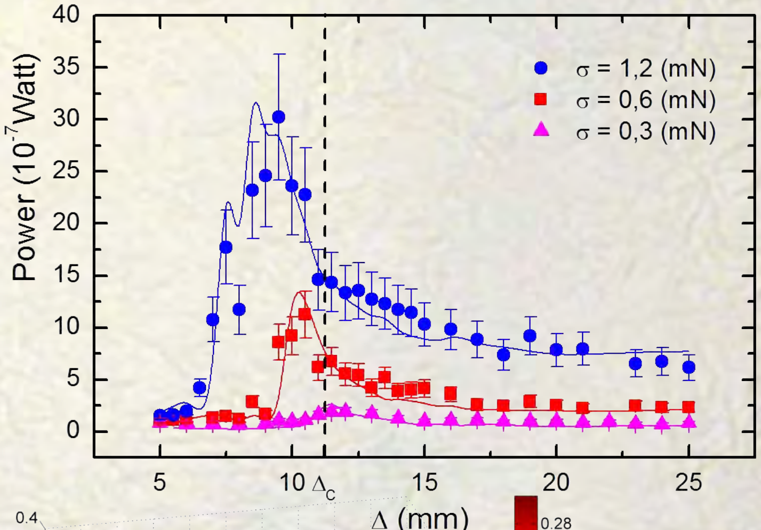


Nonlinear Energy Harvesting, F. Cottone; H. Vocca; L. Gammaitoni
Physical Review Letters, 102, 080601 (2009)

Noise energy harvesting

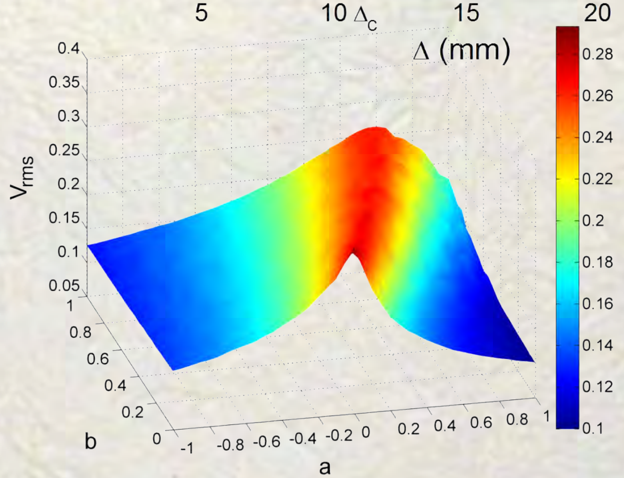
NON-Linear mechanical oscillators





Duffing potential

$$U(x) = -\frac{1}{2}ax^2 + \frac{1}{4}bx^4$$



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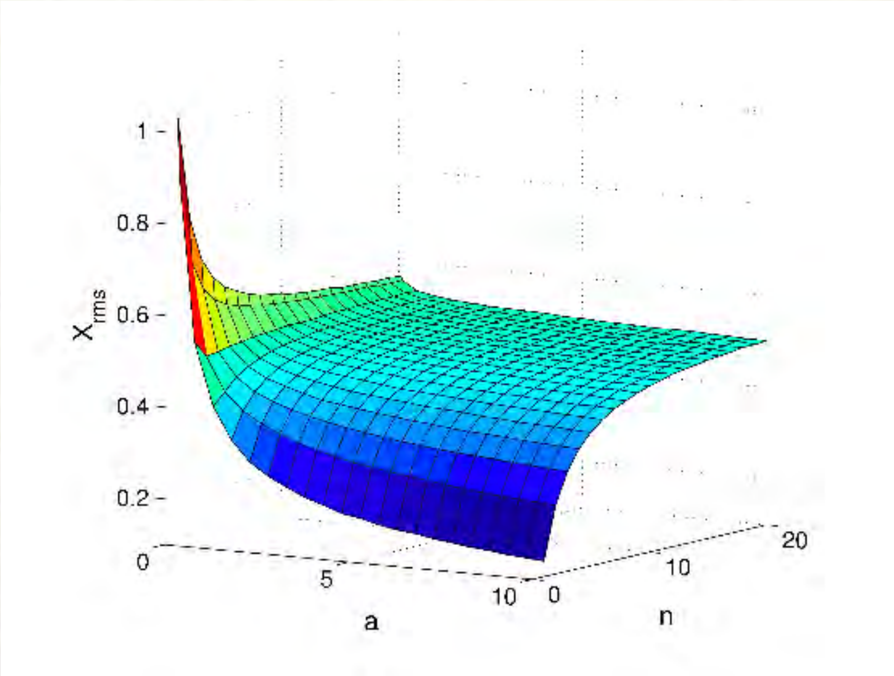
Only bistability???

A more general monostable potential…

$$U(x) = ax^{2n}$$

$$with : a > 0$$

$$n = 1,2,...$$



$$a_{th} \approx \frac{D}{4} = \sigma^2 \tau$$

L. Gammaitoni, I. Neri, H. Vocca, Appl. Phys. Lett. 94, 164102 (2009)

To think about…

1) Non resonant (i.e. non-linear) mechanical oscillators can outperform resonant (i.e. linear) ones*
2) Non-linear systems are more difficult to treat
3) Bistability is not the only nonlinearity available…

   and

An Iphone application is pending…

* **wisepower technology** patent. For more info see: www.nipslab.org, www.wisepower.it