Energy Harvesting from Ambient Vibrations

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L2EP – University Lille1

November 27, 2012

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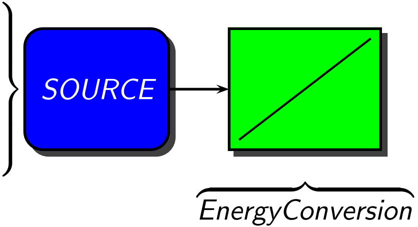

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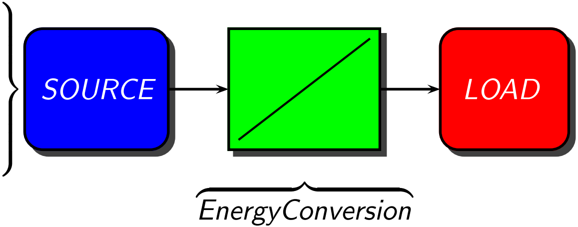

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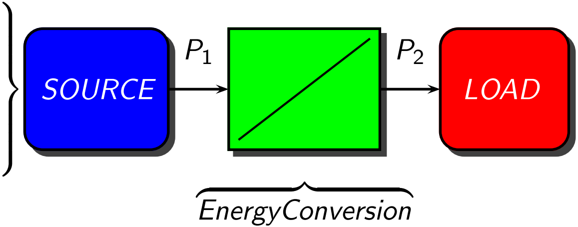

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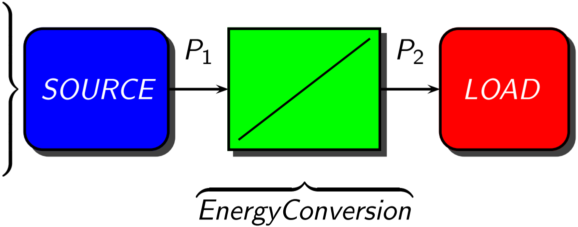

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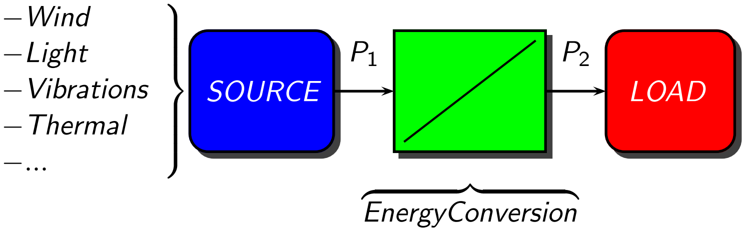

We talk about **Energy Harvesting** *or also* **energy scavenging** *when the converted power is small, typically less than* $1W$.

$\eta = \frac{P_2}{P_1} = 1 - \frac{P_1 - P_2}{P_1} \longrightarrow$ *Losses in the energy converter should be as small as possible.*

Objectives: Sensors Network

www.perpetuum.com

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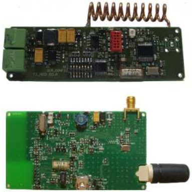

Gutiérriez,A Heterogeneous Wireless Identification Network for the Localization of Animals Based on Stochastic Movements

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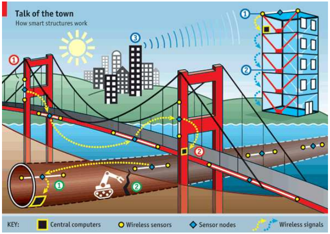
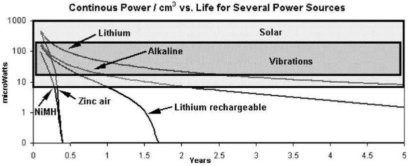


http://www.rfwirelesssensors.com, 2012



Roundy et Al.:A study of low level vibrations as a power source for wireless sensor nodes.

Objectives: Power, just where you need it

http://enocean.com

- Wireless
- Reduce Cost, and is reconfigurable
- Better Waste Cycle (Information from Enocean)

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Innowattech's systems produces power with vehicles

http://www.innowattech.com

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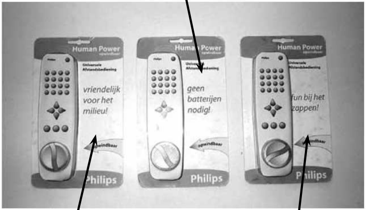
The economist – April 28th 2007

Objectives: Marketing Purpose

Experience: Same Remote controller energized by human power, but with different packaging.

"No need for Batteries"



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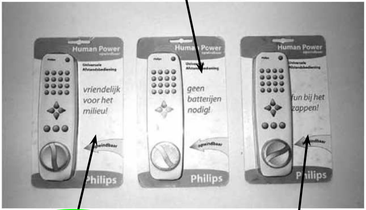

"Green" "Fun"

54% of people Will choose the first one because it is eco-friendly.
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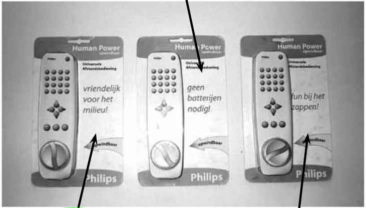

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Several projects are born from this fact: **Metis** Produces energy from dancers' movements.

In Toulouse, the system **VIHA** proposes Smart Tiles to energies street lights.

The energy converter

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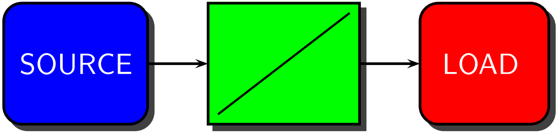

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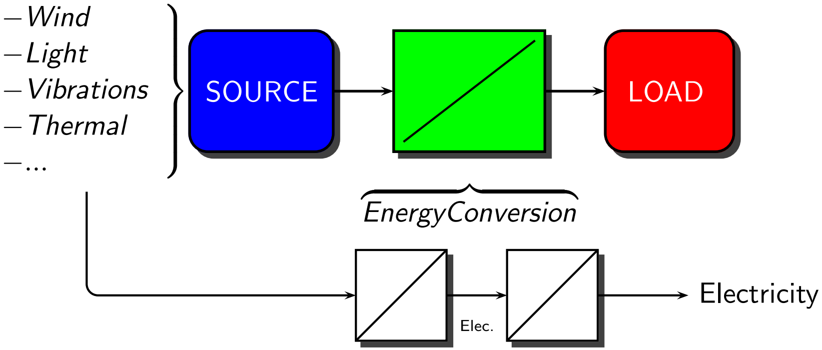

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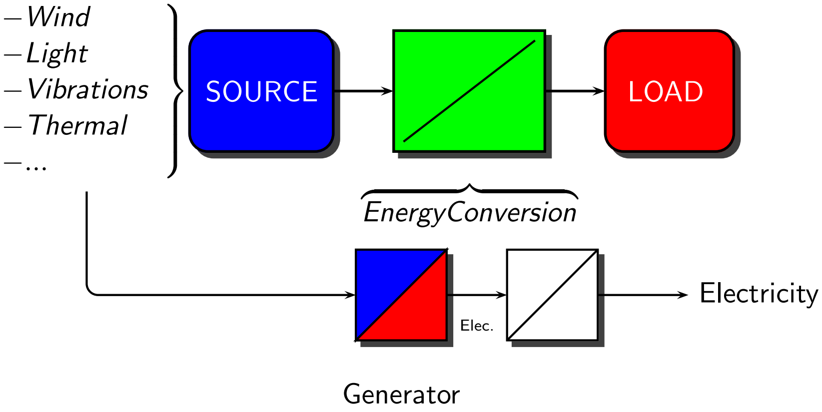

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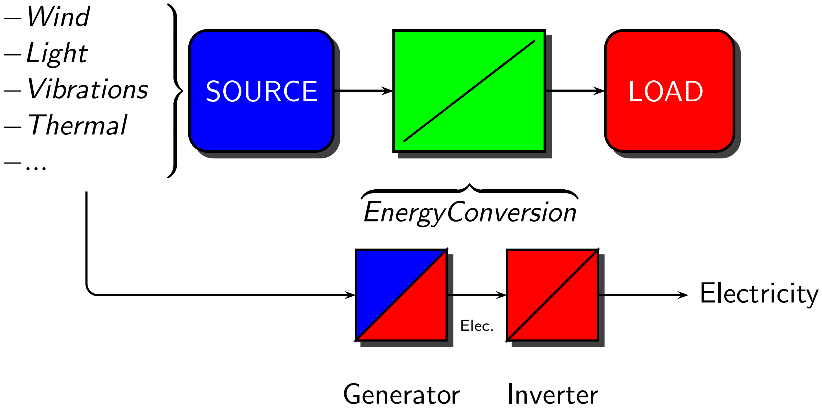

Solar Harvesters:

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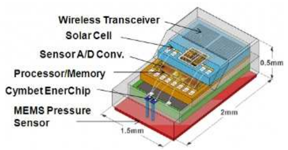

This sensor measures IntraOccular Pressure http://cymbet.com

Handbag to recharge electronic devices http://www.neubers.de

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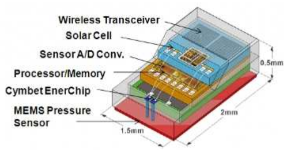

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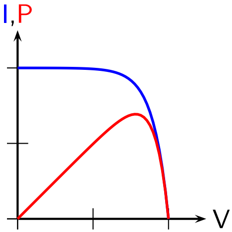

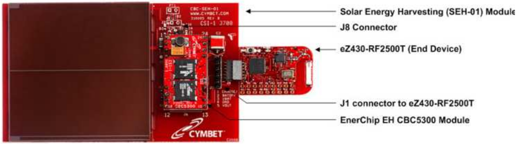

Solar Energy Harvester Evaluation Kit http://ti.com

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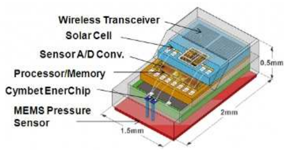

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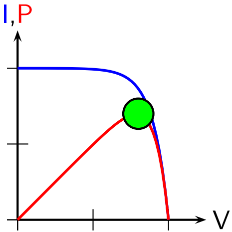
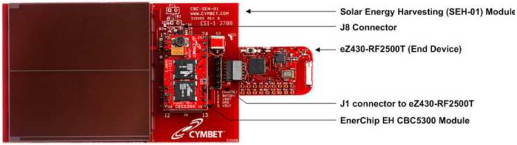


MPPT strategies, require Energy management of the system



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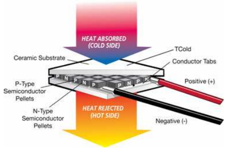
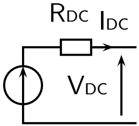
Thermoelectric



A Peltier module from http://www.tellurex.com



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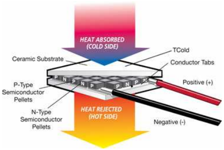

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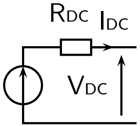

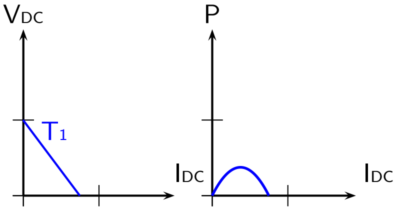

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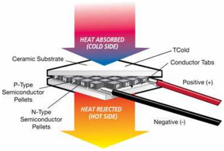

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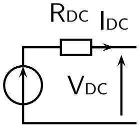

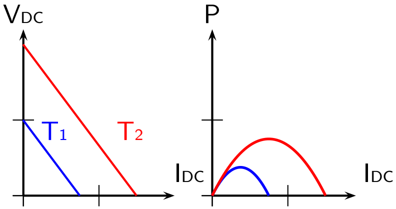

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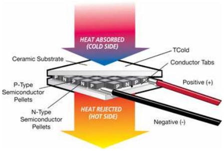

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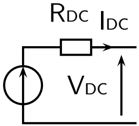

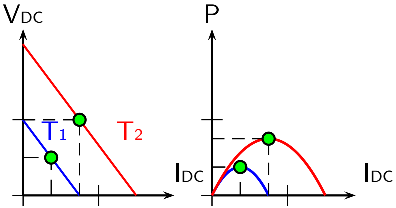

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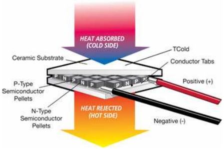

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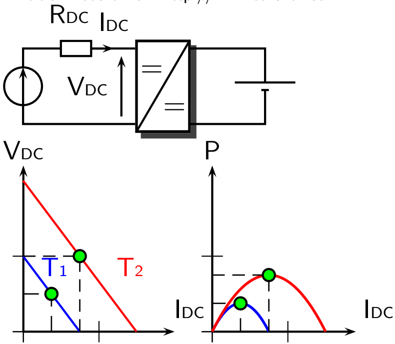

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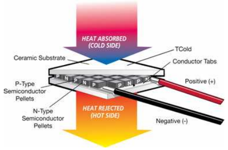

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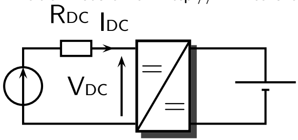
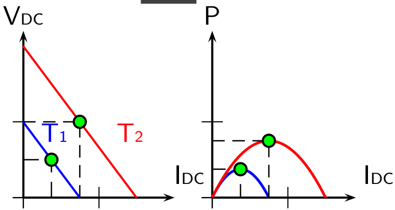
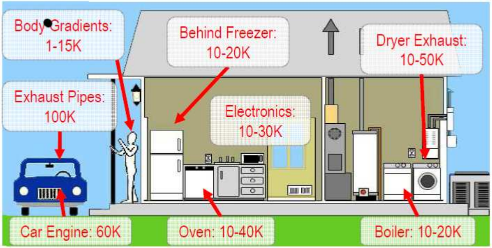
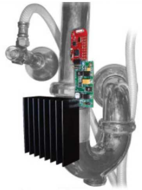


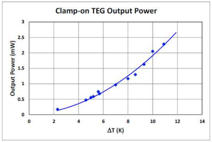




Temperature Gradient (residential). Lindsay Miller, http://uc-ciee.org

Clamp-on Drain Harvester

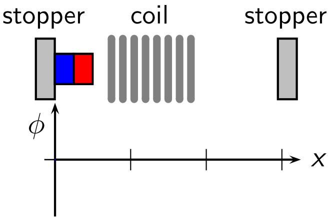




DT	V_{load} (mV)	Pmax (mW)
5.0	38	0.56
8.0	55	1.16
10.0	73	2.05

plumbing application from http://www.nextreme.com

Magnetic



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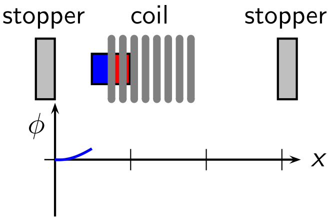

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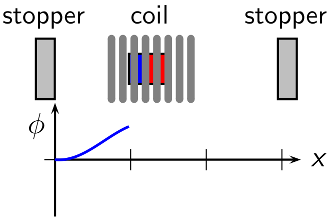

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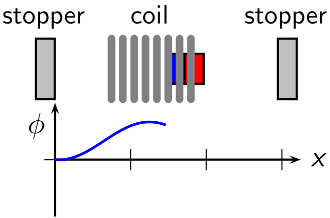

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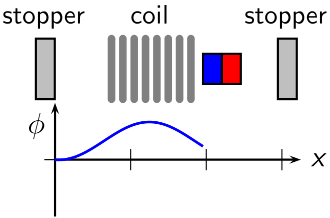

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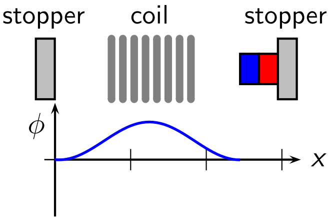

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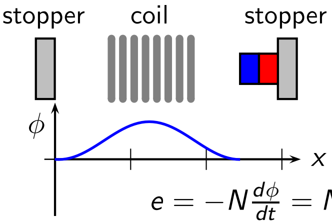

$$e = -N\frac{d\phi}{dt} = N\frac{d\phi}{dx}\frac{dx}{dt}$$

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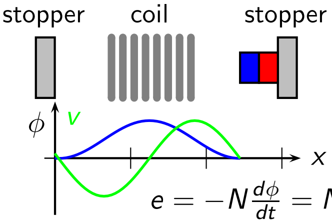

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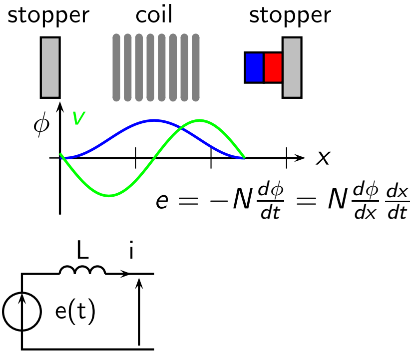
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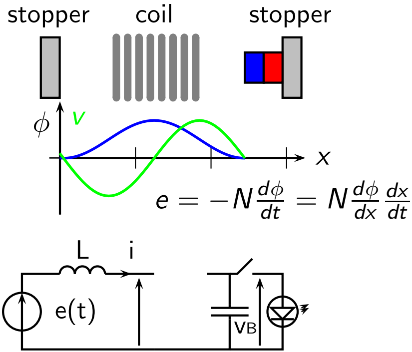
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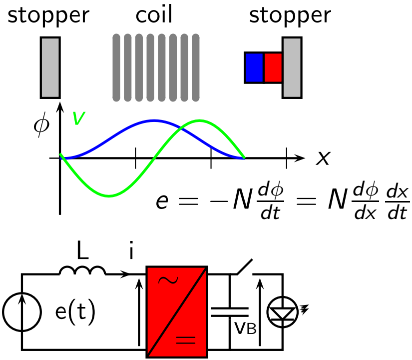
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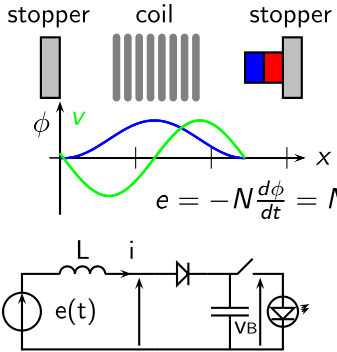

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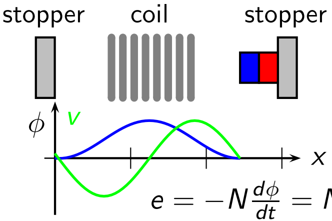

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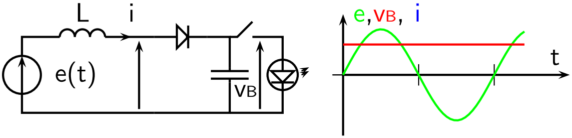

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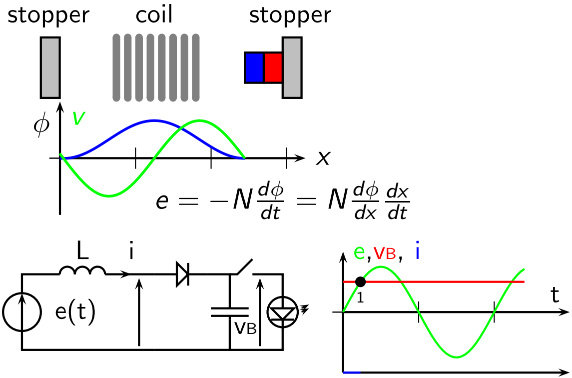
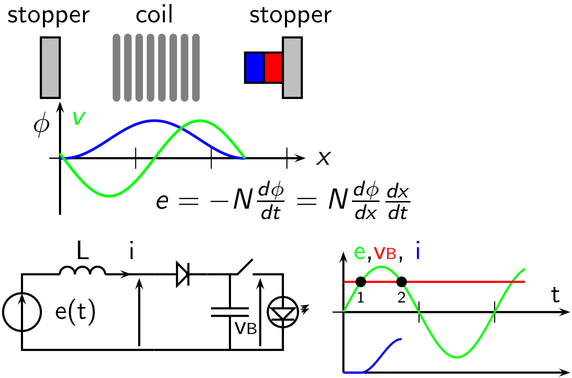


1) Diode turns ON

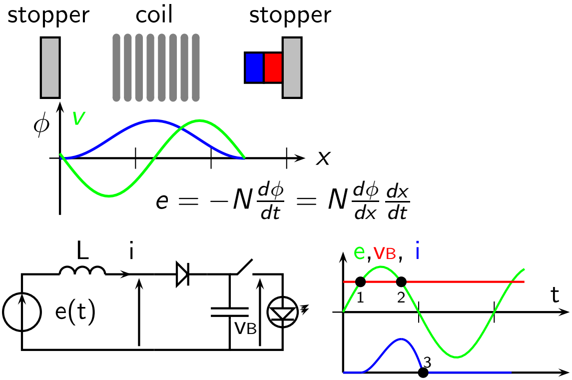
Magnetic



1) Diode turns ON

2) $\frac{di}{dt} = 0$ because $e - v_B = 0$

Magnetic



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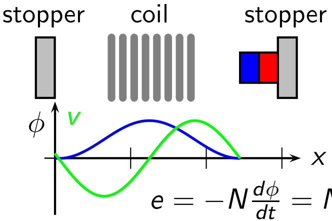
2) $\frac{di}{dt} = 0$ because $e - v_B = 0$
3) $i = 0$, diode turns OFF

Magnetic



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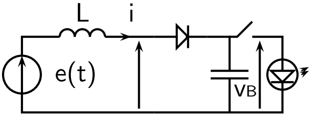

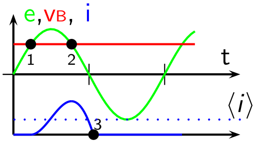

1) Diode turns ON
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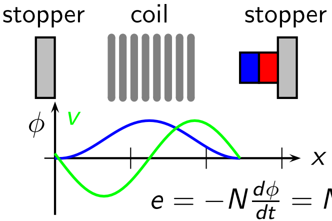
3) $i = 0$, diode turns OFF

Magnetic



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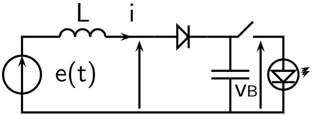

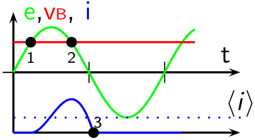

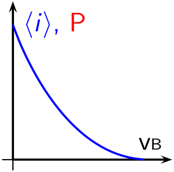

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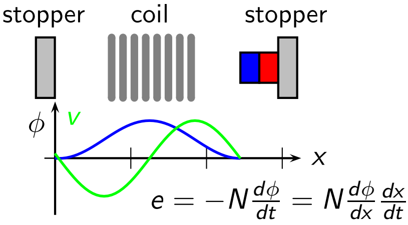

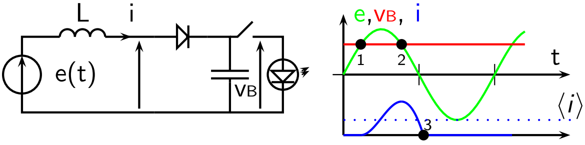

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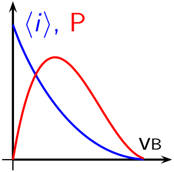
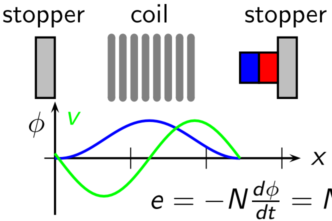


$P = \langle v_B i \rangle = v_B \langle i \rangle$

Magnetic



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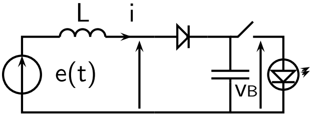

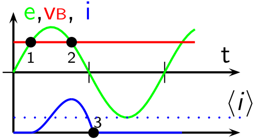

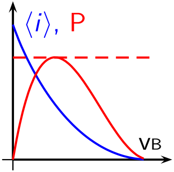

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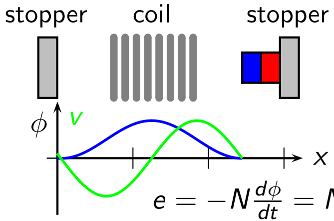

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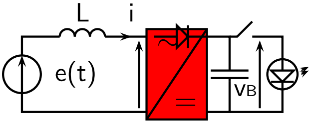

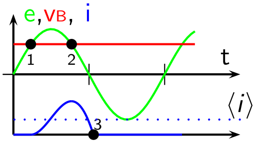

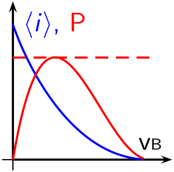

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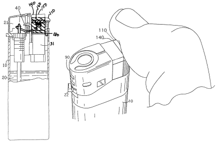
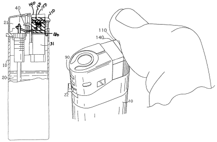
Piezoelectric



An electronic lighter,
http://freepatentsonline.com

Piezoelectric crystals

Piezoelectric



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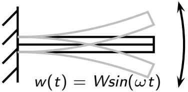
Piezoelectric crystals

Cantilever beam



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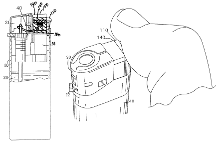

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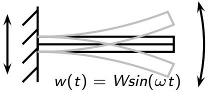

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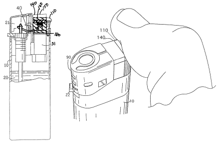

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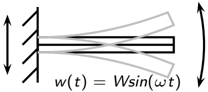
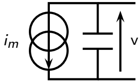
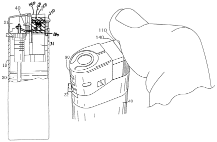


Equivalent electrical circuit



i_m is a current proportional to the deformation speed

Piezoelectric



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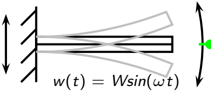

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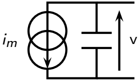

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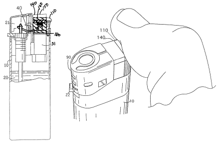

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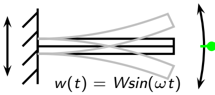

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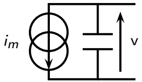
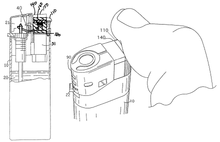


i_m is a current proportional to the deformation speed

Comparison Magn. Piezo

Magnetic	Piezo.
Voltage source	Current source
Inductive	capacitive
Large Stroke	Small Stroke
Remote action	

Piezoelectric



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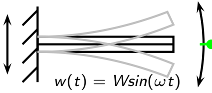

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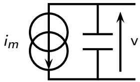

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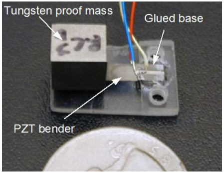
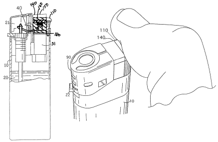


Roundy, A piezoelectric vibration based generator for wireless electronics (2004)

Piezoelectric



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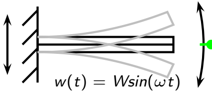

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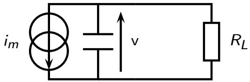

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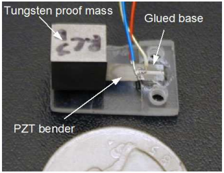

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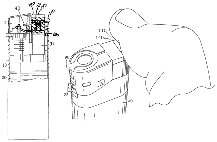

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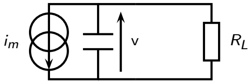

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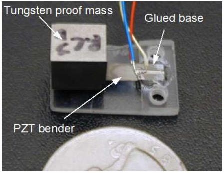

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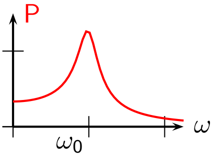
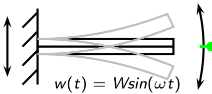
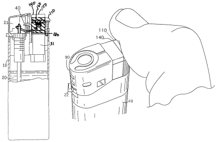


Cantilever beam



Piezoelectric



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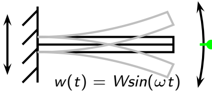

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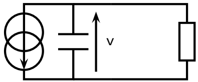

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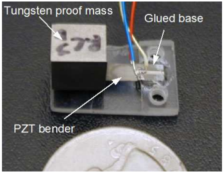

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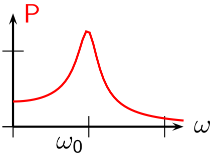

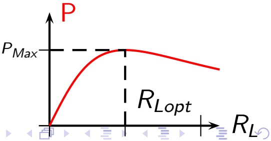

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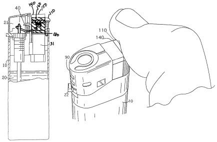


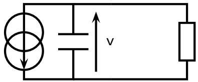
An electronic lighter, http://freepatentsonline.com

Piezoelectric crystals

Cantilever beam

Energy Management

Equivalent electrical circuit



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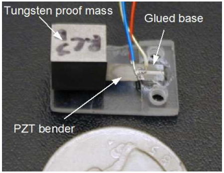

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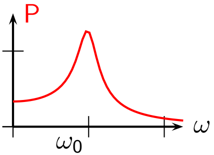

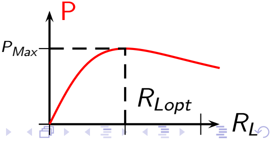

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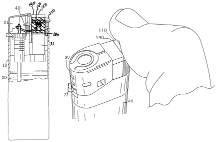

An electronic lighter, http://freepatentsonline.com

Piezoelectric crystals

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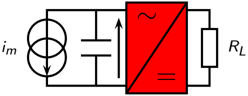

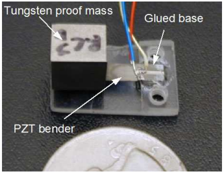

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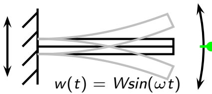
Cantilever beam



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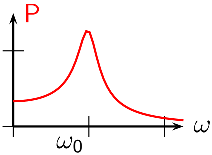
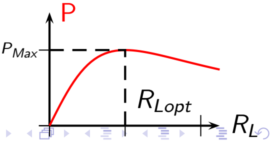
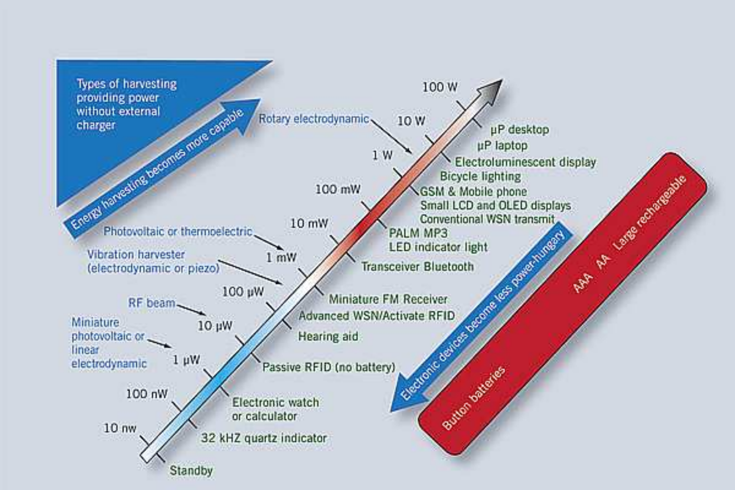




There is no "one fit all" solution



Each solution may be efficient in a certain range of Power.
Meanwhile, shrinking Chips consumption come at a time when energy harvesting becomes efficient and practical
(source: IDtechex.com)

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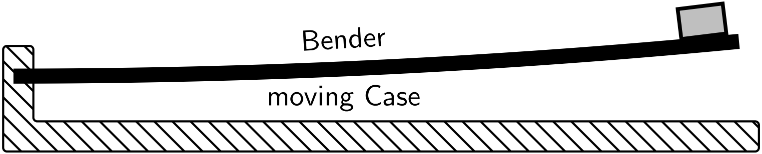
Coordinates and assumptions



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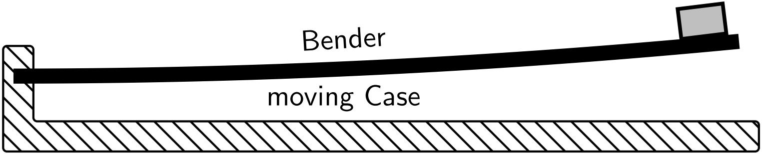

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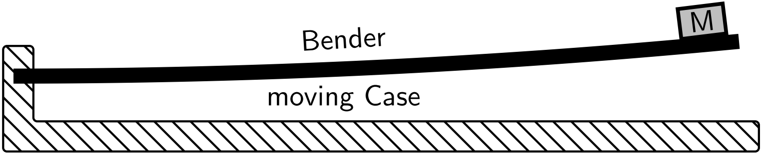

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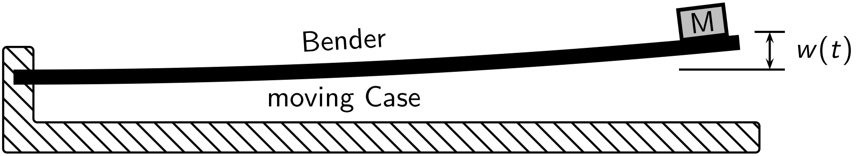

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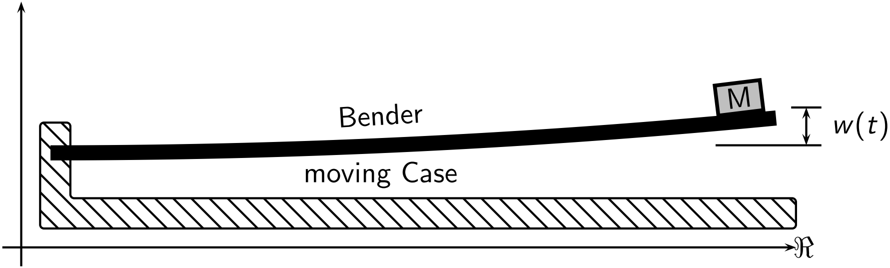

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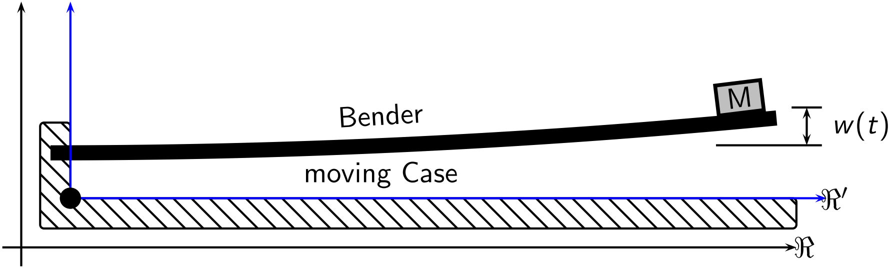

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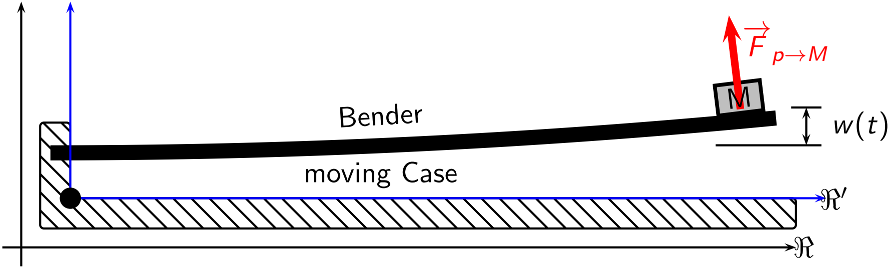

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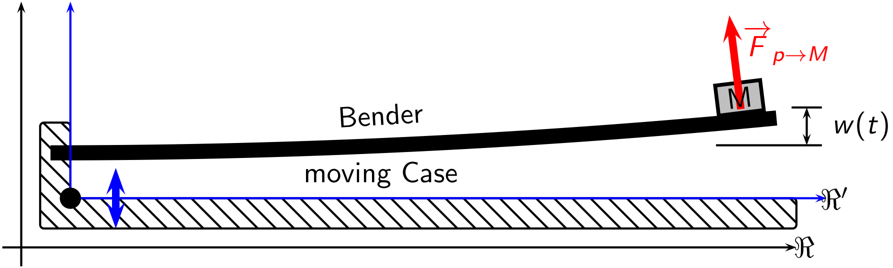

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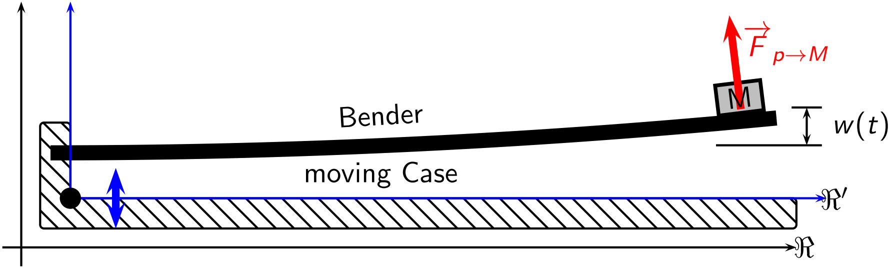

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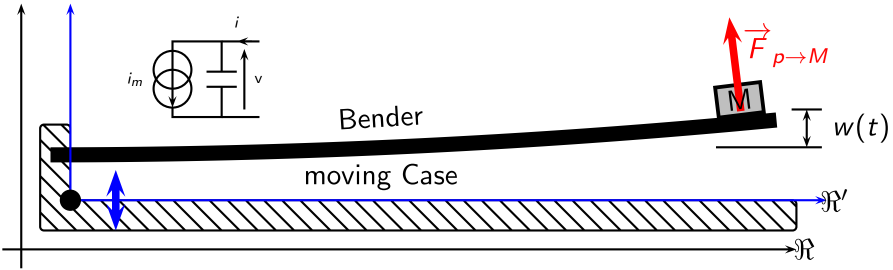

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Equations

- **Dynamic of the mass M:**

Glossary

- M the mass
- f, the force onto M
- A, vibration's amplitude
- ω, vibration's pulsation
- f_{acc} is the inertial force
- i current of the device (actuator convention)
- i_m motional current
- f_p inside piezo force
- N Piezoelectric force factor (depends on geometry)
- f_p Piezo internal force
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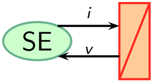

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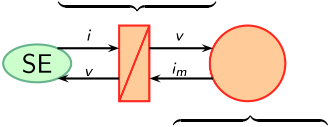

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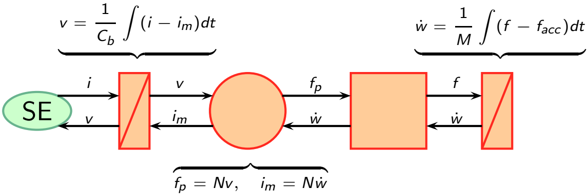

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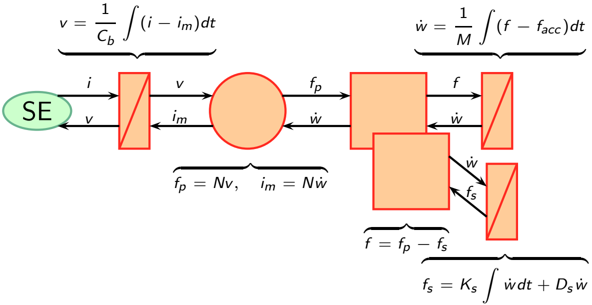

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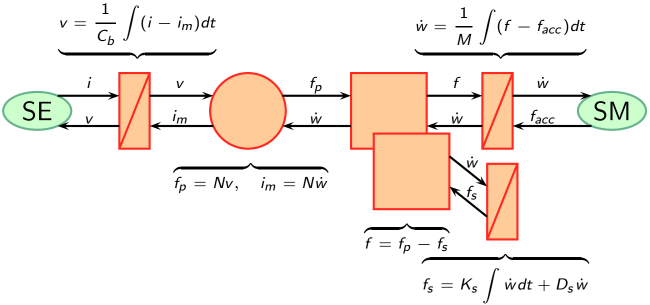

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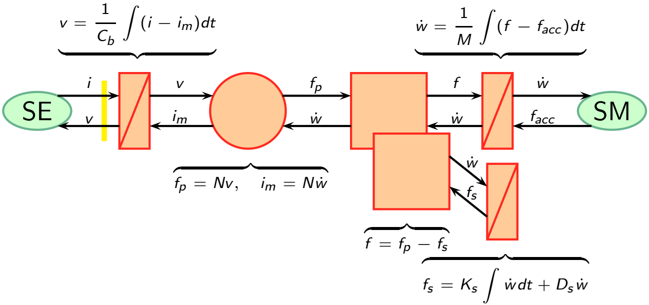

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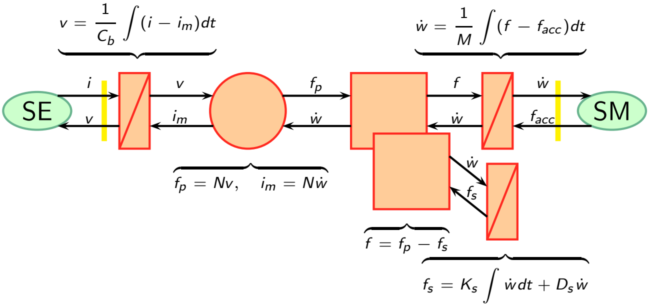

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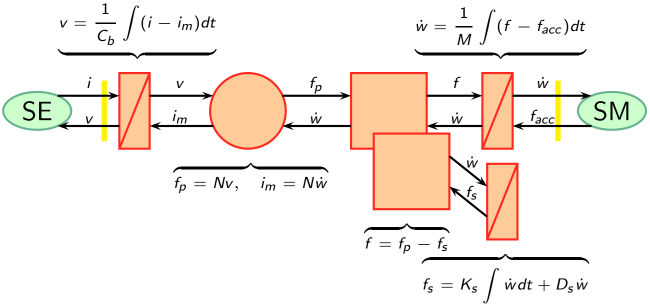

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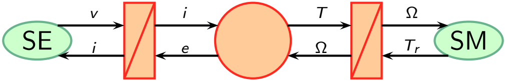

Comparison with a DC motor

Things are not so differerent.

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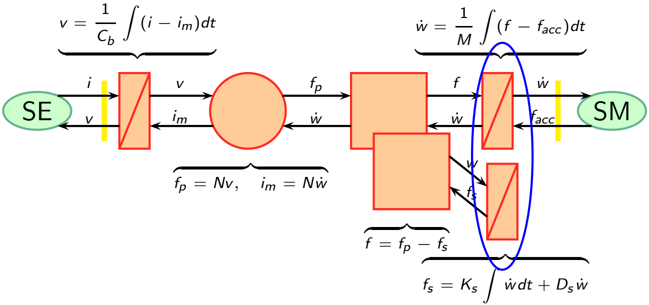

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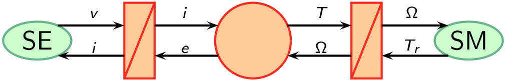

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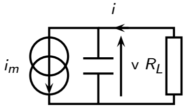
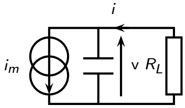


Asumption

- $f_{acc} = MA\omega^2 sin(\omega t)$ for harmonic oscillations
- complex notation: $\underline{x}$ is the complex phasor of $x(t)$, means $x(t) = \Im(\underline{x})$
- since oscillations are harmonic, we will write:$\underline{x} = \underline{X} e^{j\omega t}$
- for steady state operation, $\underline{X}$ is constant, leading to $\frac{d\underline{x}}{dt} = j\omega \underline{X} e^{j\omega t}$
- $|\underline{x}| = |\underline{X}| = X$
- for example, $\underline{f}_{acc} = MA\omega^2 e^{j\omega t}$ and $|\underline{f}_{acc}| = MA\omega^2$.
- $v = -R_L i$



And $R_L \ll \frac{1}{C_b\omega}$, yields
$v \simeq -R_L i_m$

For an ideal generator ($D_s = 0$)

- $M\underline{\ddot{w}} = \underline{f} + \underline{f}_{acc}$

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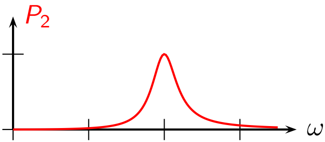

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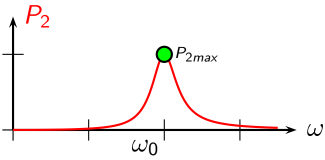

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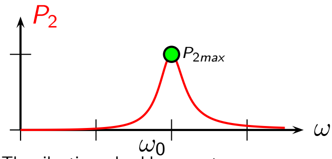

The vibrations should occur at generator's resonance frequency

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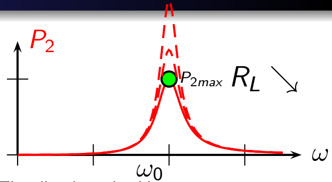

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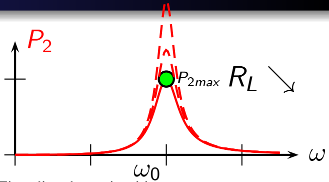

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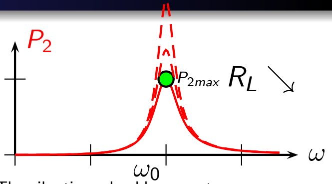

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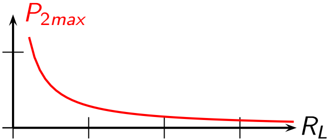

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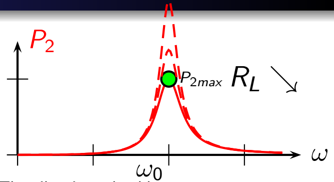

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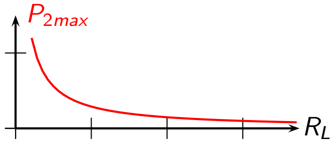

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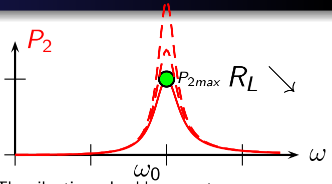

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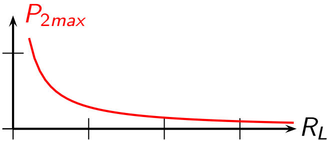

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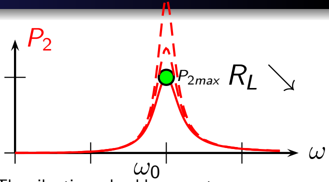

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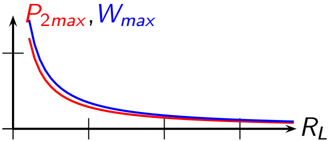

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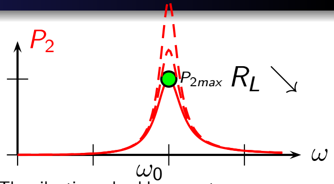

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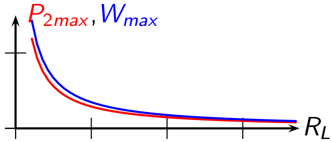

We can harvest as much power as we want, at the expense of large displacement of the bender's tip

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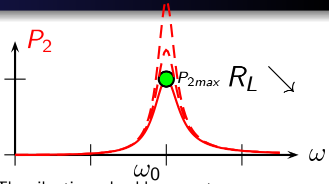

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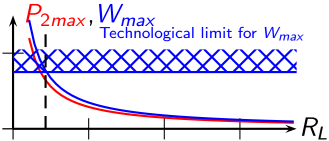

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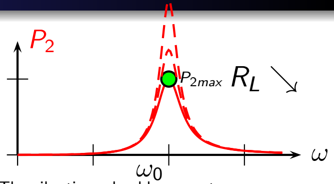

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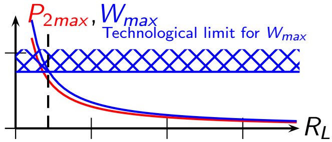

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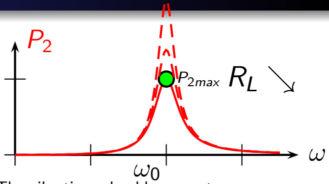

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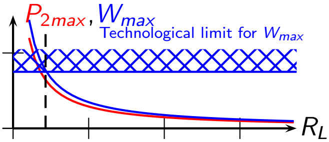
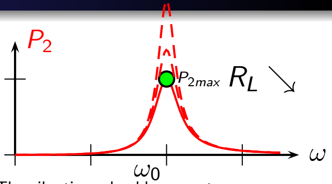


We can harvest as much power as we want, at the expense of large displacement of the bender's tip

For an ideal generator ($D_s = 0$)

- $M\underline{\ddot{w}} = \underline{f} + \underline{f}_{acc}$
- $\underline{f} = N\underline{v} - K_s\underline{w}$
- $\underline{v} = -R_L\underline{i}_m = -R_L N\underline{\dot{w}}$
- $M\underline{\ddot{w}} + N^2R_L\underline{\dot{w}} + K_s\underline{w} = \underline{f}_{acc}$
  $\longrightarrow R_L$ acts as a damping
- $P_2 = -\frac{1}{2}R_L|i_m|^2$
- $|i_m| = N|\dot{w}| = \frac{\omega.N.|f_{acc}|}{\sqrt{(K_s - M\omega^2)^2 + (N^2R_L\omega)^2}}$
- $P_2 = -\frac{1}{2}\frac{N^2R_L\omega^2|f_{acc}|^2}{(K_s - M\omega^2)^2 + (N^2R_L\omega)^2}$
- $P_{2Max} = \frac{(MA\omega^2)^2}{2N^2R_L}$, $W_{max} = \frac{MA\omega}{N^2R_L}$,
  $v_{max} = \frac{MA\omega^2}{N}$
- $P_{1Max} = \frac{1}{2}f_{acc}\omega W_{Max} = \frac{(MA\omega^2)^2}{N^2R_L} = P_{2Max}$



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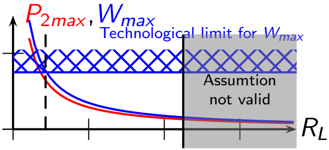

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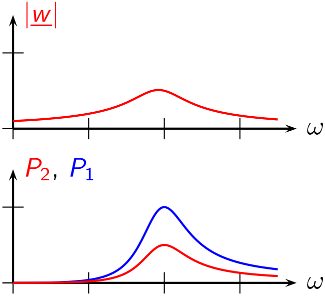

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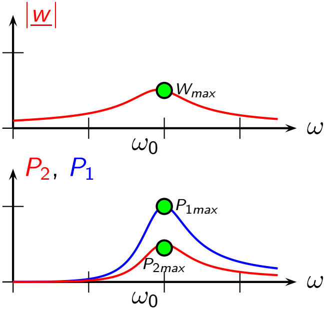

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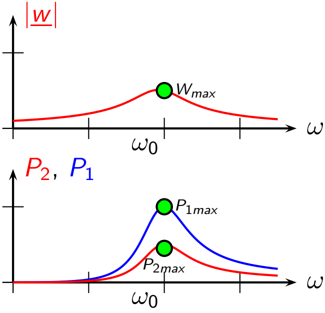

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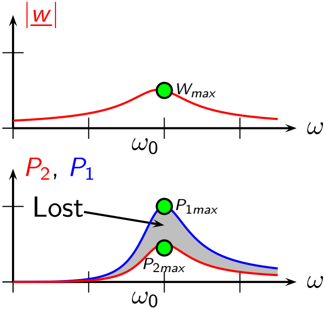

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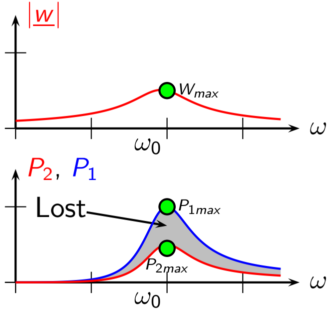

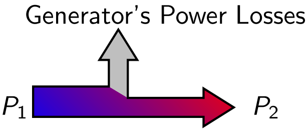

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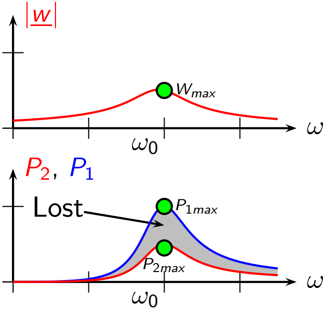
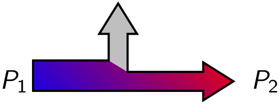


Generator's Power Losses



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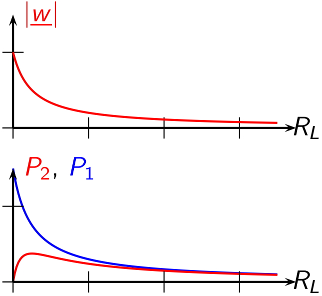

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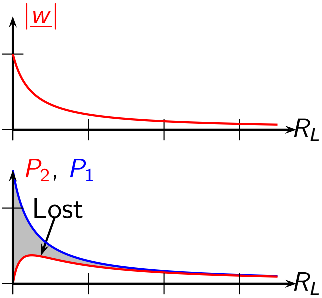

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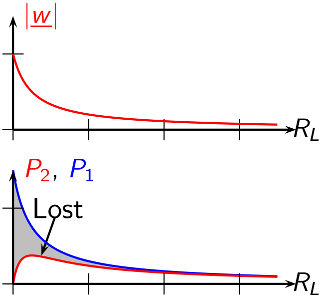

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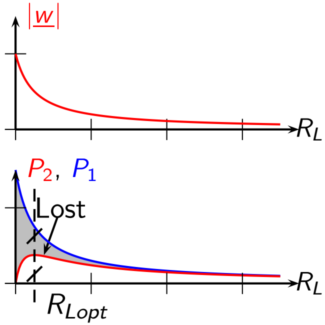

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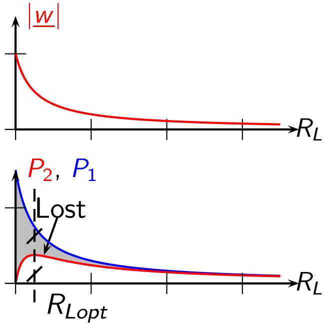

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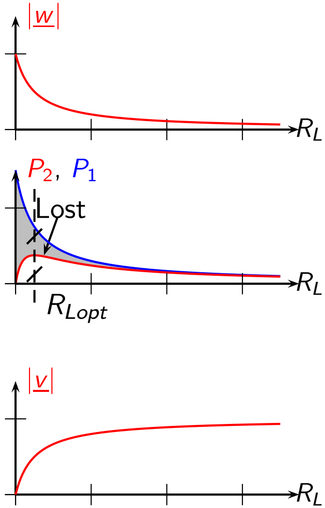

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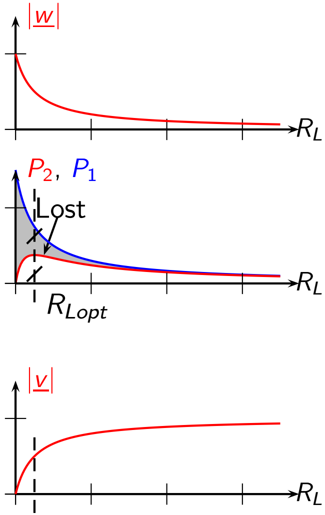

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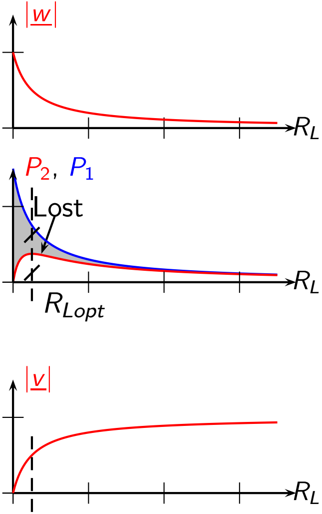

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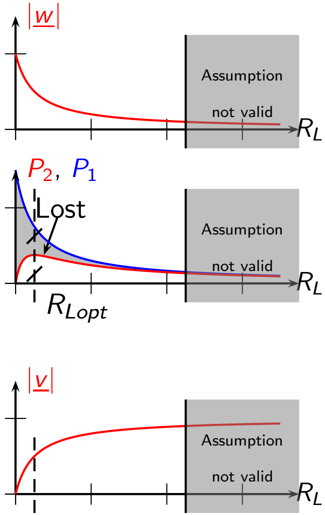

Example

Device's properties

$N = 0.012N/V,\ K_s = 6300N/m,\ C_b = 300nF,\ D_s = 0.17Ns/m,$
$M = 1g$

Calculate for $A = 0.1mm$

- the best working frequency,
- the harvested P_2 power in the best case,
- the power of the source P_1 in such best case,
- the optimal resistor R_L,
- the deflection amplitude of the bender,
- the voltage for this working point.

Validation

Is $v = -R_L i_m$ a valid assumption?

Answers

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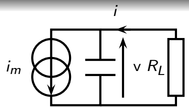
For a real Generator, $D_s \neq 0$ and $v \neq -R_L i_m$



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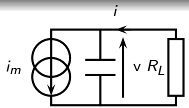

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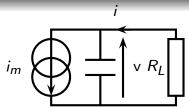

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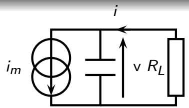

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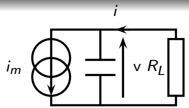

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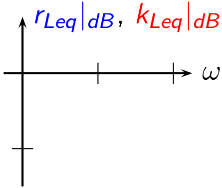

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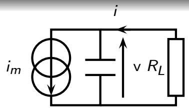

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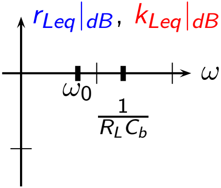

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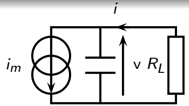

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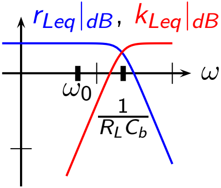

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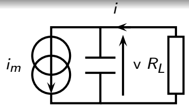

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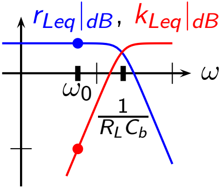

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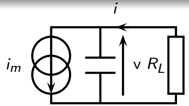

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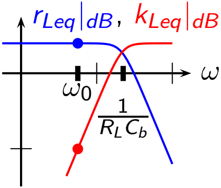

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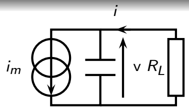

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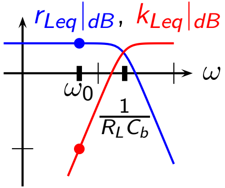

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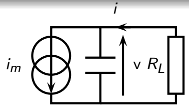

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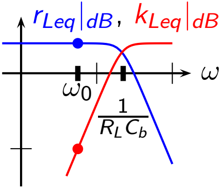

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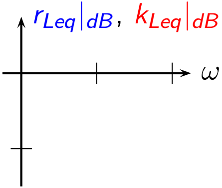

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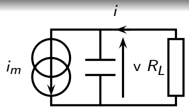

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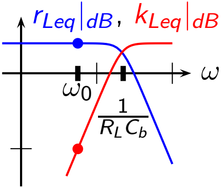

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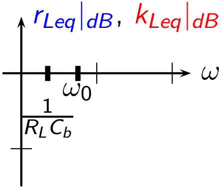

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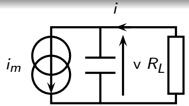

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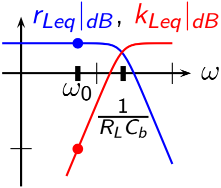

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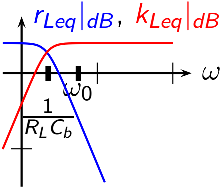

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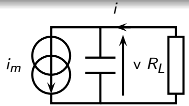

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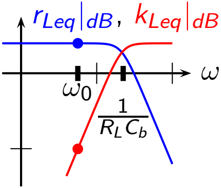

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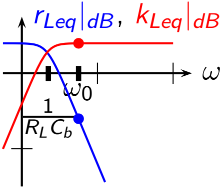

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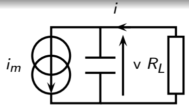

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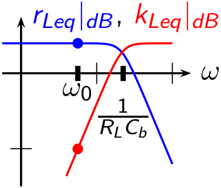

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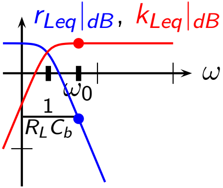

$r_{Leq} \ll R_L$ and k_{Leq} is high, an other study is needed

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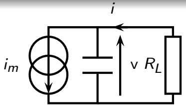

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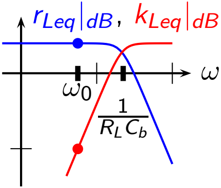
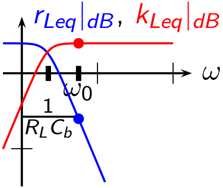
$\omega_0 \ll \frac{1}{R_L C_b}$



$r_{Leq} \simeq R_L$ and $k_{Leq} \simeq 0$, no problem, just use the assumption

$\omega_0 \gg \frac{1}{R_L C_b}$

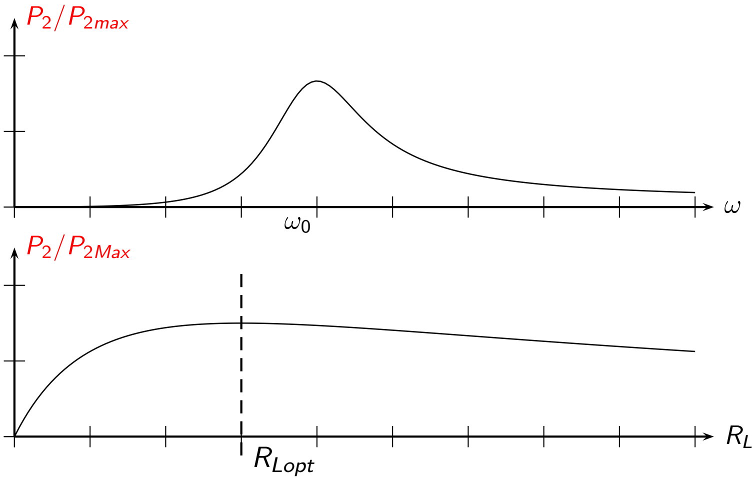


$r_{Leq} \ll R_L$ and k_{Leq} is high, an other study is needed

$$((K_s + N^2 k_e q) - M\omega^2) + j\omega(D_s + N^2 r_{Leq})\underline{w} = \underline{f}_{acc}$$

Rule of the Thumb

Let R_b defined as $R_b C_b \omega_0 = 1$, $\omega_0 < \frac{1}{R_L C_b} \rightarrow R_L < R_b$



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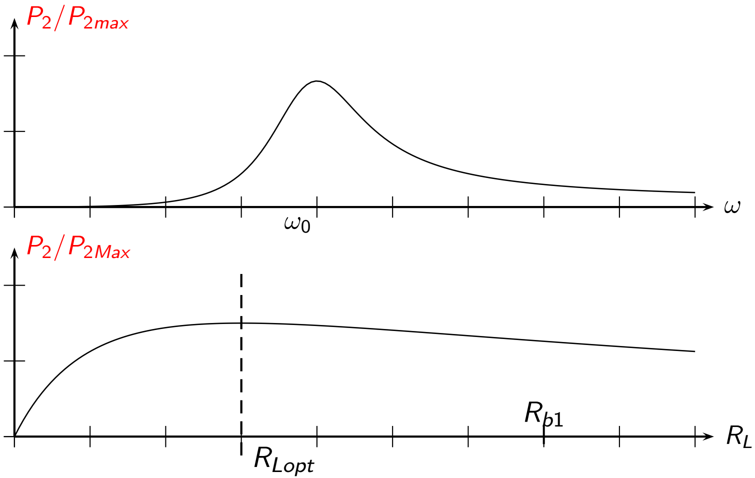

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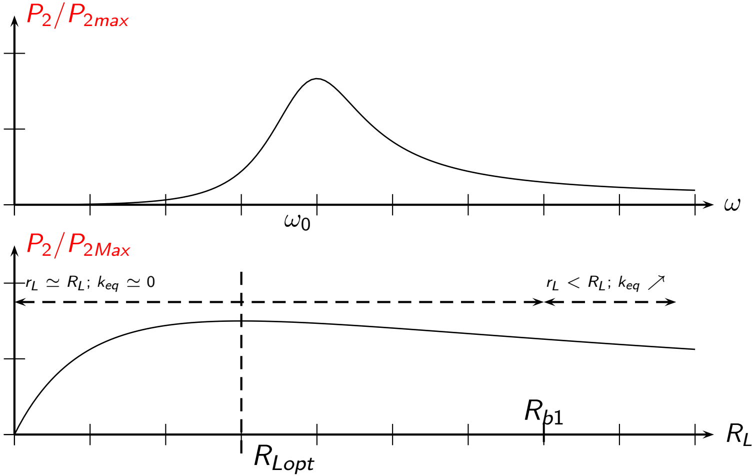

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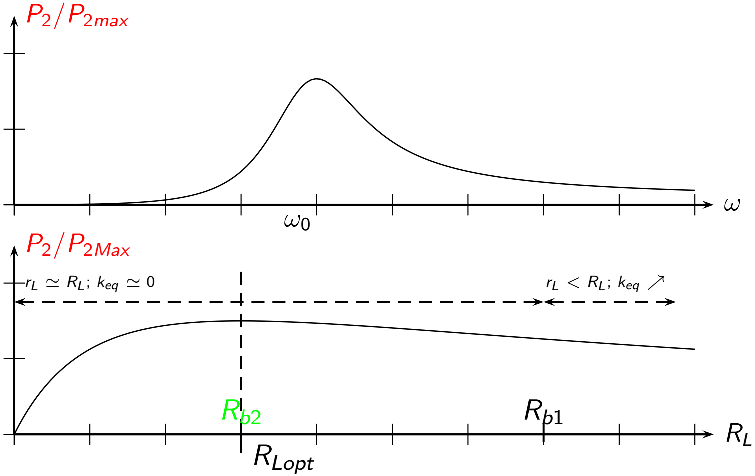

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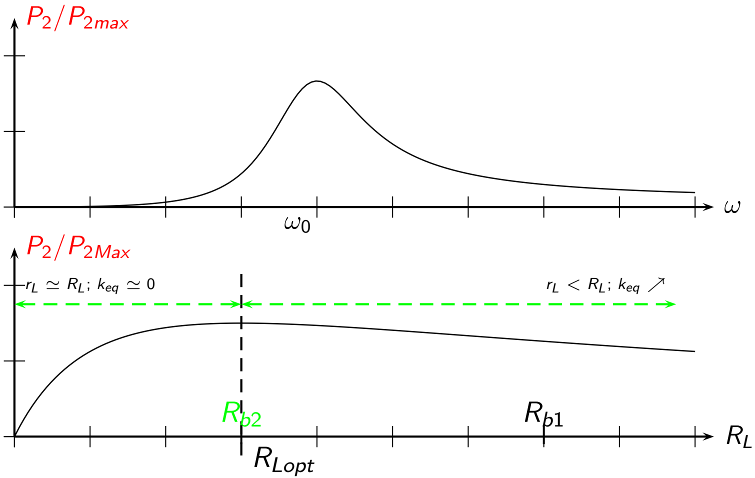

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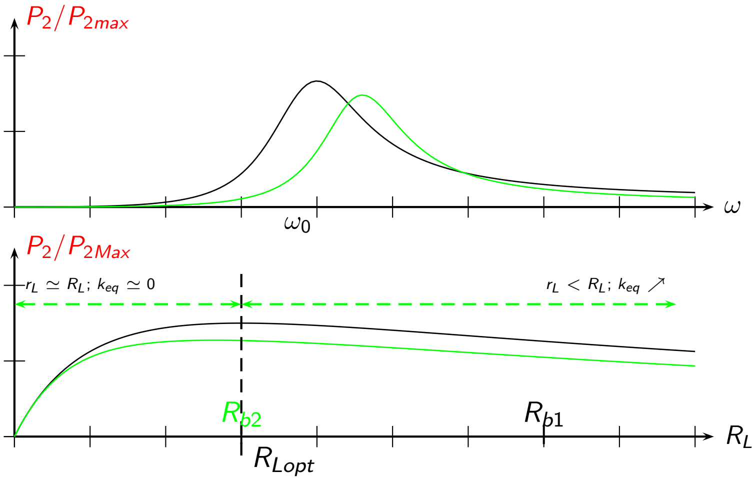

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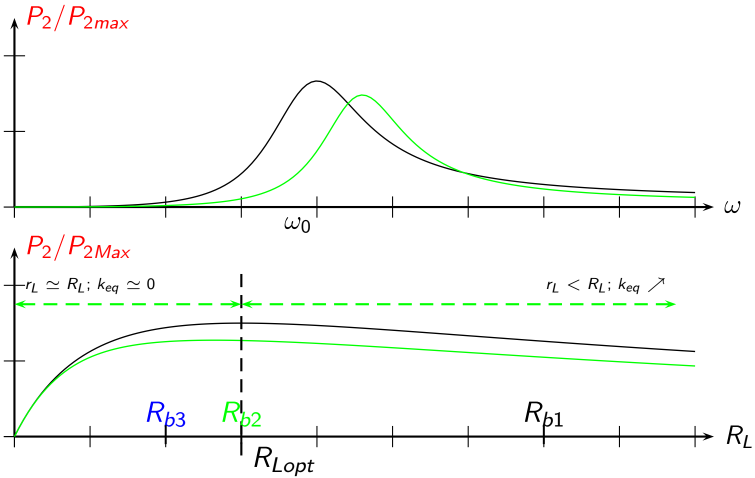

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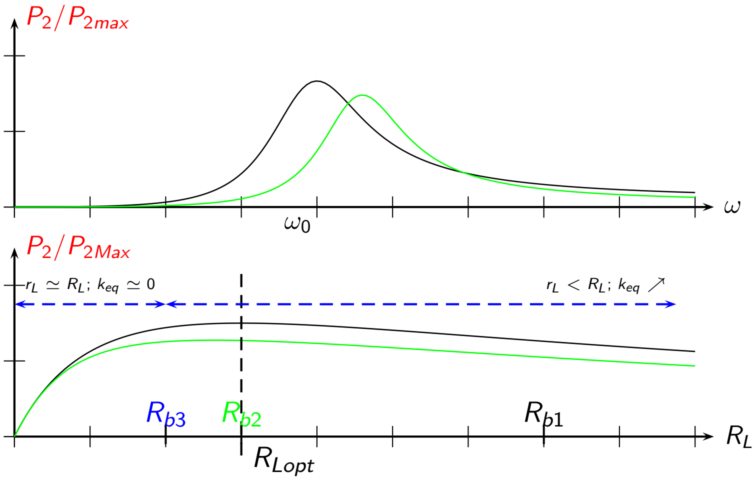

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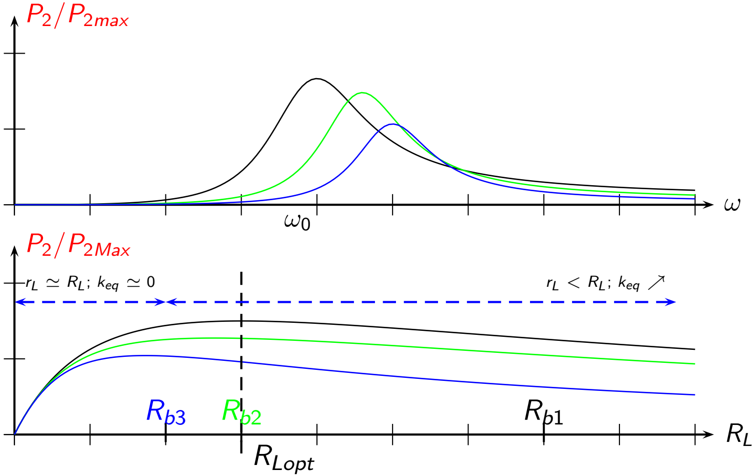

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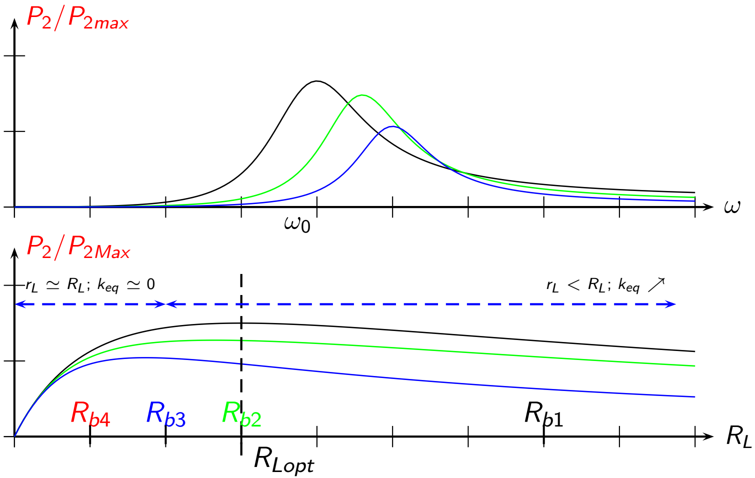

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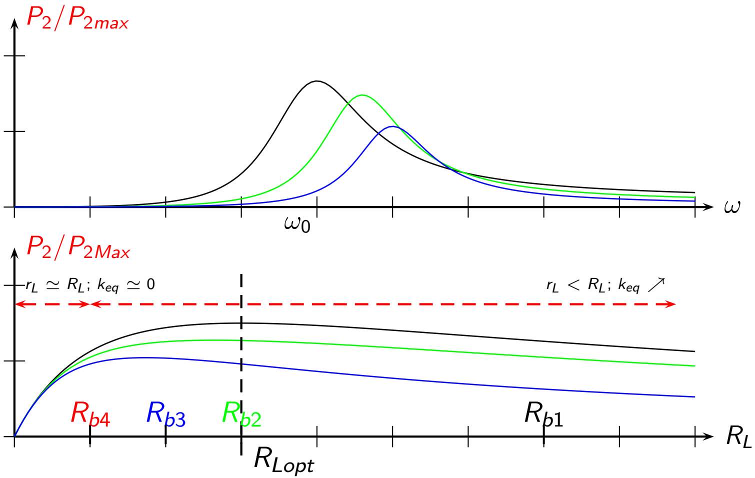

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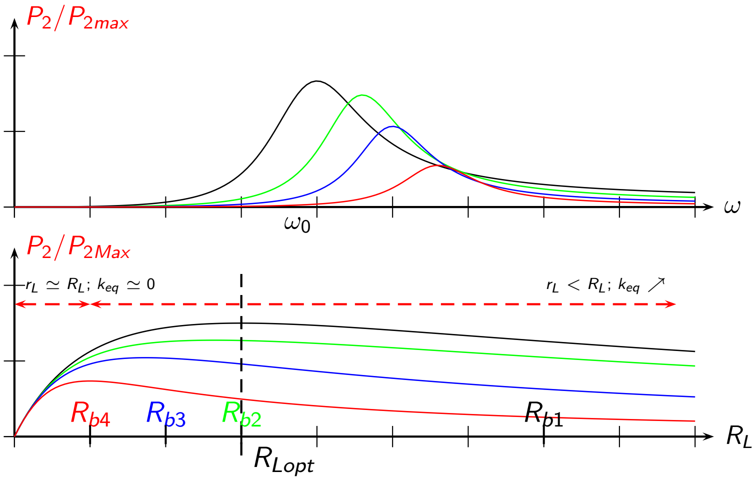

Partial Conclusion

If $R_{opt} < R_b$

A resistor can recover the power optimally. But the study was not valid for high R_L. What happens for $R_L \gg R_b$?

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If $R_{opt} < R_b$

A resistor can recover the power optimally. But the study was not valid for high R_L. What happens for $R_L \gg R_b$?

If $R_{opt} > R_b$

The power is not well extracted because $P_2 < P_{2max}$. This happens for high damped mechanisms.
A simple resistor cannot recover the power optimally (and this is due to C_b).

What happens if $R_{opt} < R_b$ and $R_L \gg R_b$?

resonance is shifted

- $r_{Leq} = \frac{R_L}{1+(R_L C_b \omega)^2} \simeq \frac{R_L}{(R_L C_b \omega)^2}$
- $k_{eq} = R_L \frac{\omega^2 R_L C_b}{1+(R_L C_b \omega)^2} \simeq \frac{1}{C_b}$

$((K_s + N^2 k_e q) - M\omega^2) + j\omega(D_s + N^2 r_{Leq})\underline{w} = \underline{f}_{acc}$ leads to:

$$\omega_0' = \sqrt{\frac{K_s + N^2 k_e q}{M}} = \sqrt{\frac{K_s + \frac{N^2}{C_b}}{M}}$$

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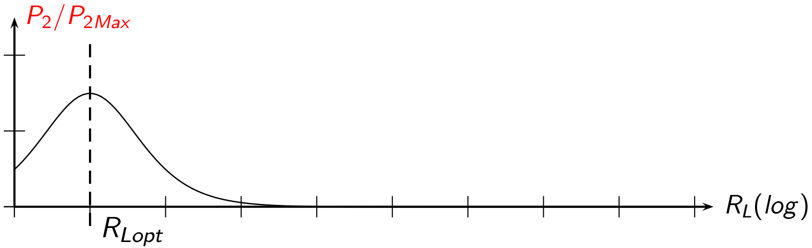
Another optimal resistor

The optimal power is harvested is $N^2 r_{Leq} = D_s$, leading to:

$$\frac{N^2 R_L}{(R_L C_b \omega_0')^2} = \frac{N^2}{R_L C_b^2 \frac{K_s + \frac{N^2}{C_b}}{M}} = D_s$$

$$R_{Lopt2} = \frac{N^2}{D_s} \frac{1}{C_b^2 \frac{K_s}{M}(1+\frac{N^2}{K_s C_b})} = \frac{R_b^2}{R_{Lopt}} \frac{1}{1+\frac{N^2}{K_s C_b}}$$

What happens if $R_{opt} < R_b$ and $R_L \gg R_b$?



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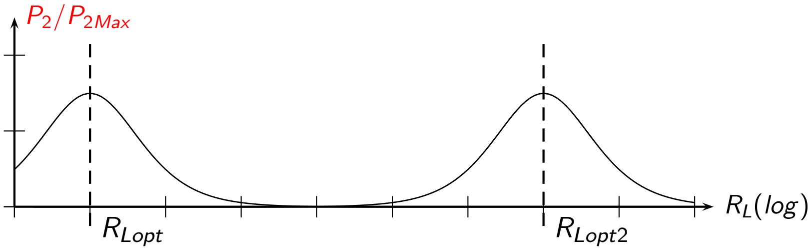
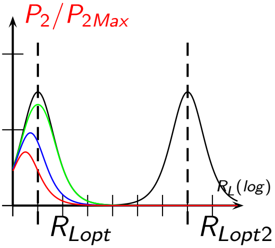


Conclusion

- For the realistic case, there is one or two resistive loads which allow to extract the maximum of power,



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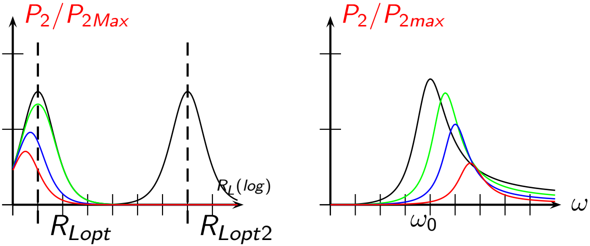

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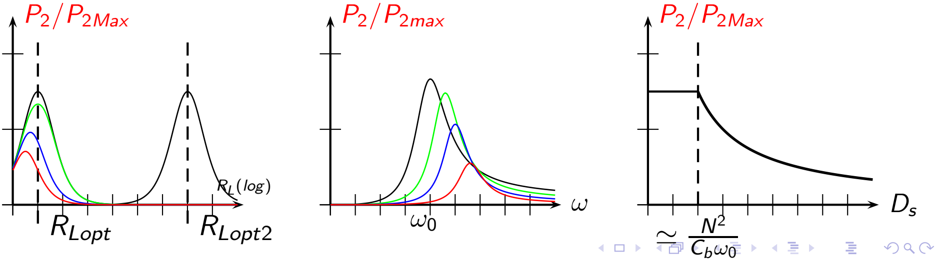

Conclusion

- For the realistic case, there is one or two resistive loads which allow to extract the maximum of power,
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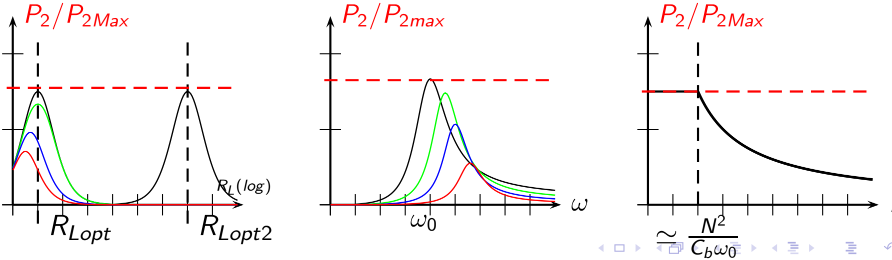
→ we always want to harvest the maximum of power!



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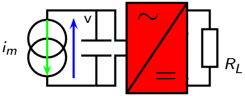

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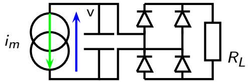

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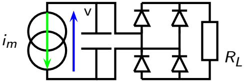

$i_m > 0$

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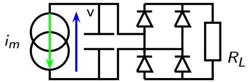

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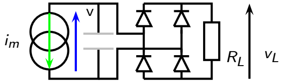

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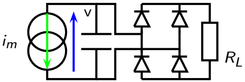

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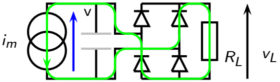

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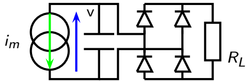

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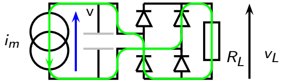

$v_L = R_L i_m$ which is > 0
and $v = -v_L = -R_L i_m$

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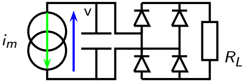

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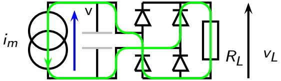

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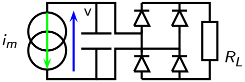

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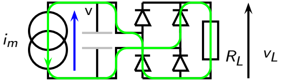

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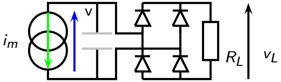

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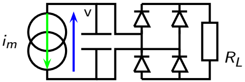

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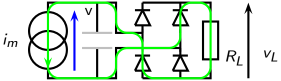

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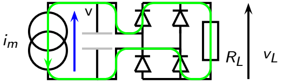

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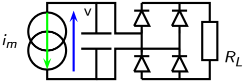

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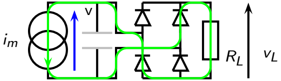

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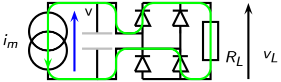

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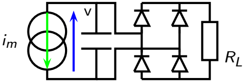

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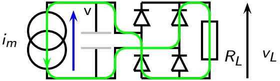

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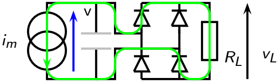

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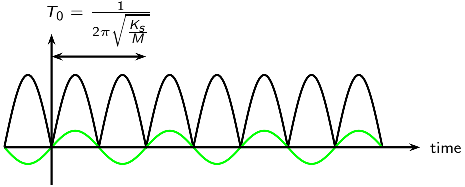

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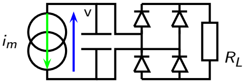

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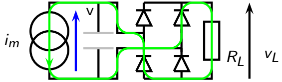

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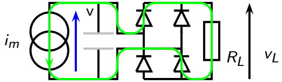

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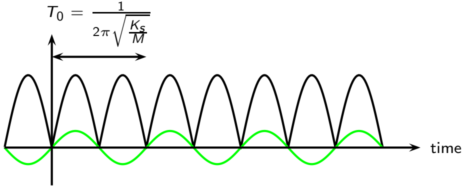

The current is rectified, but we still have $v = -R_L i_m$: Power harvesting depends on R_L

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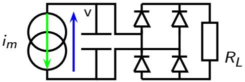

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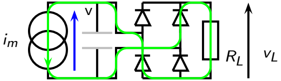

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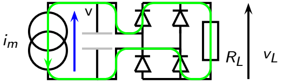

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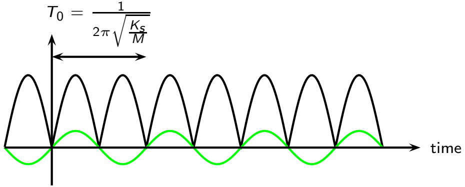
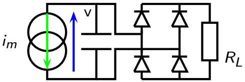


The current is rectified, but we still have $v = -R_L i_m$: Power harvesting depends on R_L
Moreover, it is still not optimal if $R_{opt} > R_b$.

Introduction



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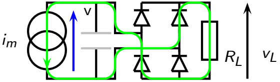

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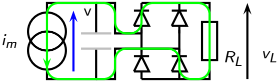

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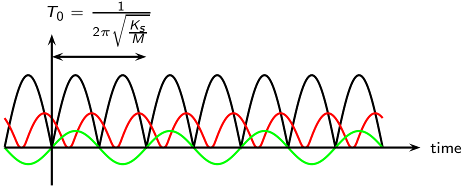

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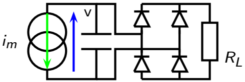

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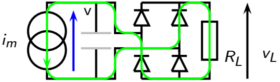

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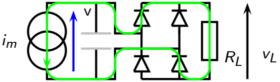

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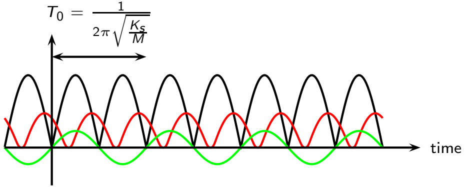

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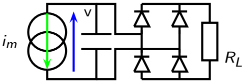

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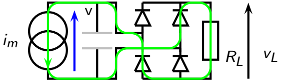

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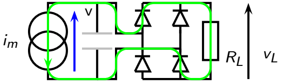

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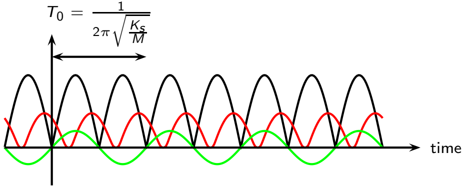

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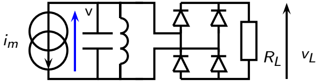

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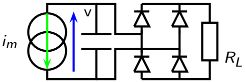

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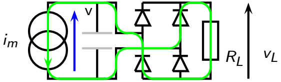

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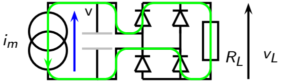

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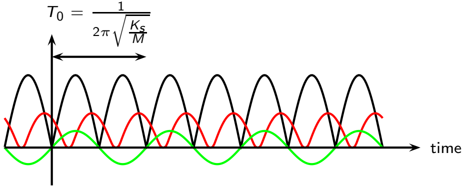

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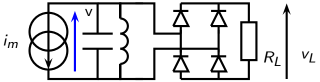

This is a bad solution because it works only for ω_0 (what if the frequency shifts?), and the Inductor is large (because ω_0 usually is small)

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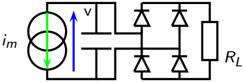

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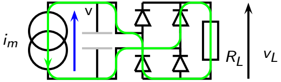

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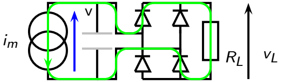

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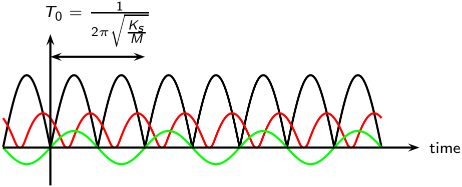

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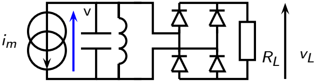

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$\longrightarrow$Non linear Techniques

Why Synchronized

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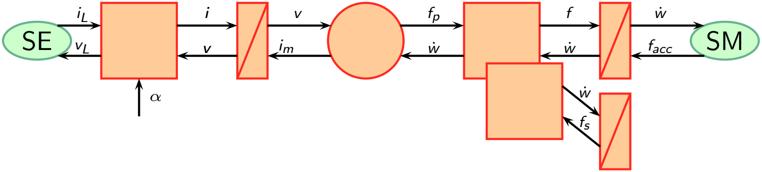

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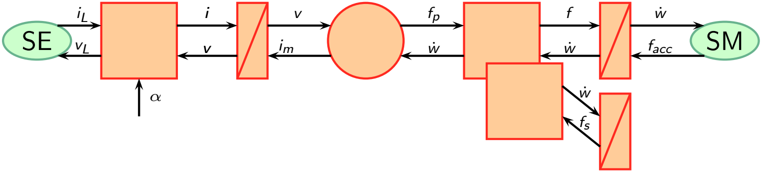

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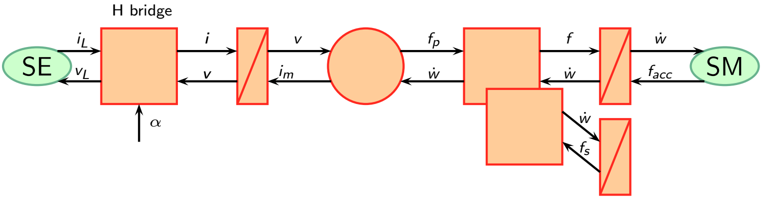

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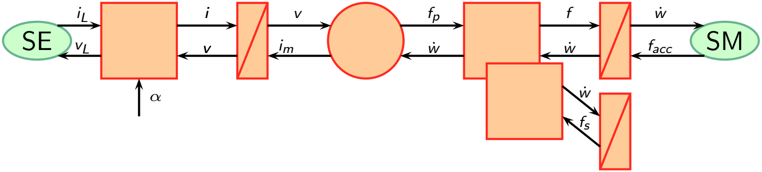

Strategy: $v = -R_{opt} i_m$ leads to $\frac{f_p}{N} = -\frac{D_s}{N^2} N\dot{w}$ or, $f_p = -D_s\dot{w}$.

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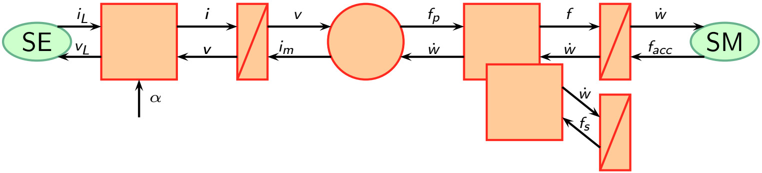

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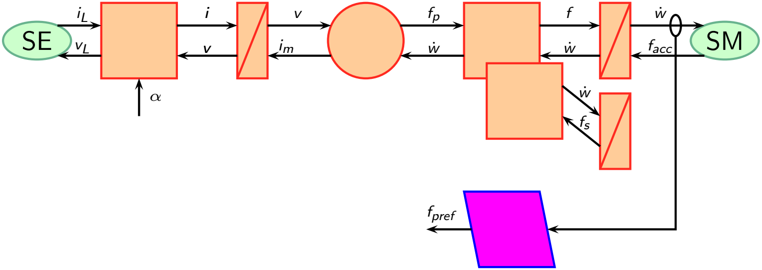

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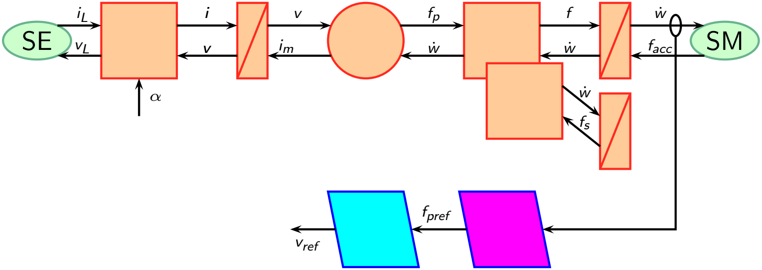

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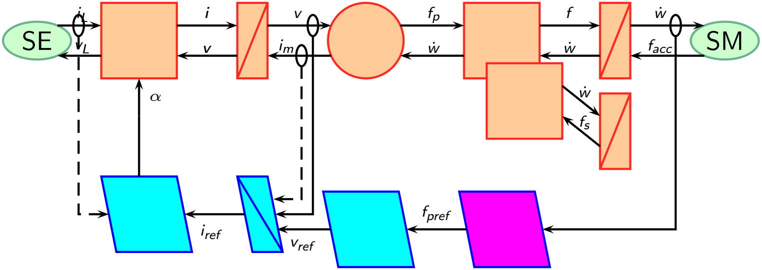

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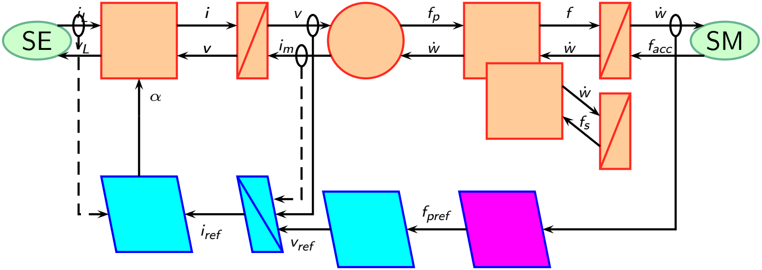

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How it works

LC oscillations

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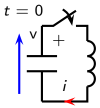

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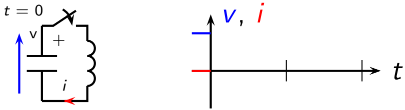

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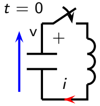
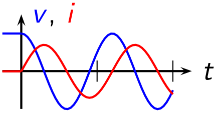
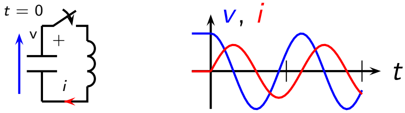




How it works

LC oscillations	Switched inductor
	

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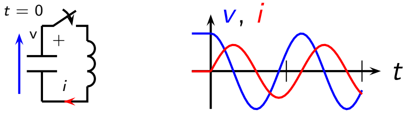	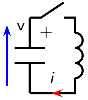

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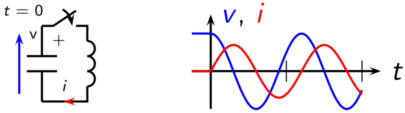	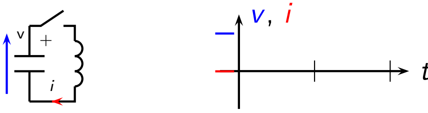

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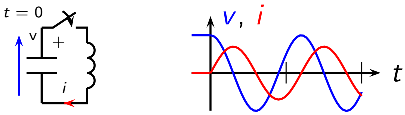

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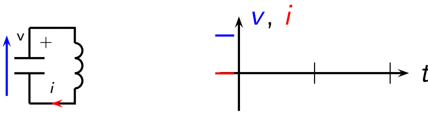

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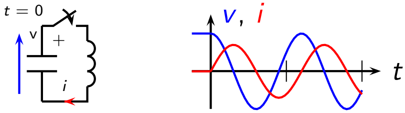

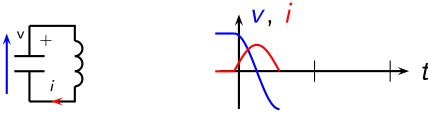

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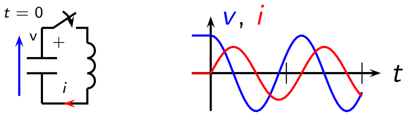

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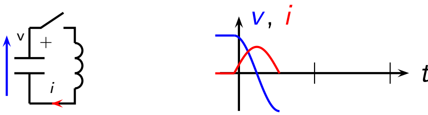

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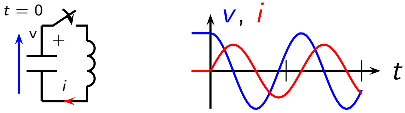

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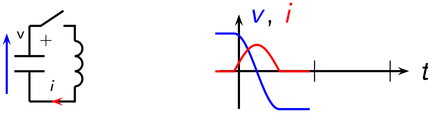

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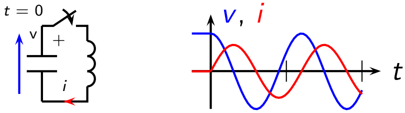	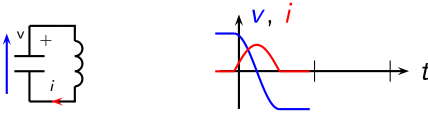

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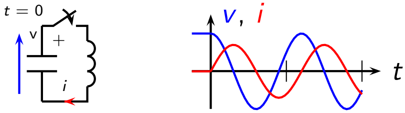

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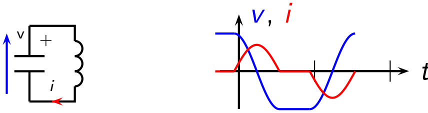

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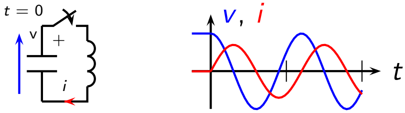	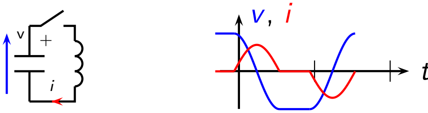

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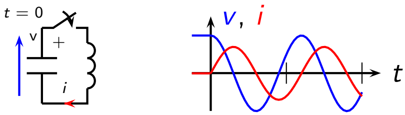	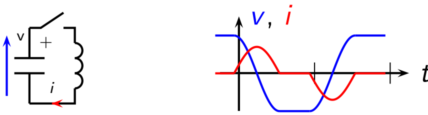

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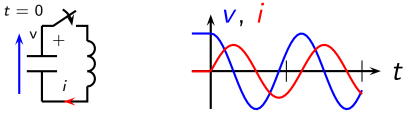

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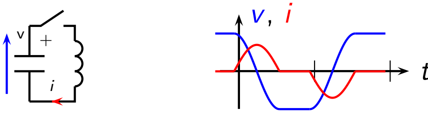

SSHI

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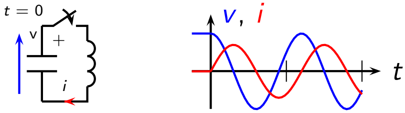

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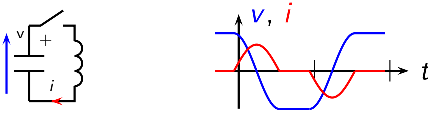

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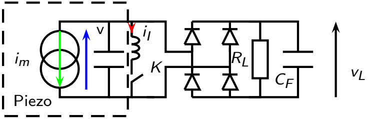

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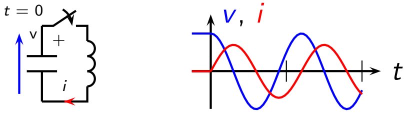
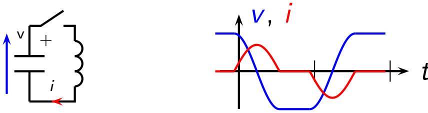
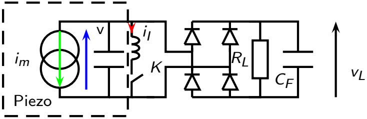
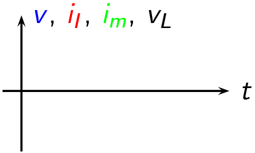


Switched inductor



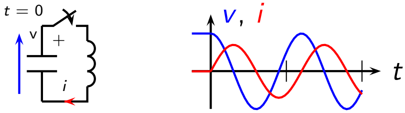
SSHI





How it works

LC oscillations



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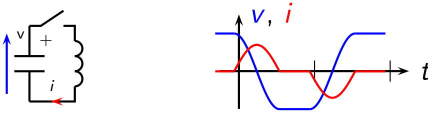

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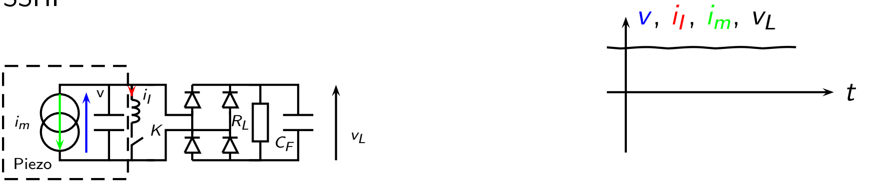

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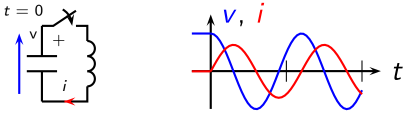

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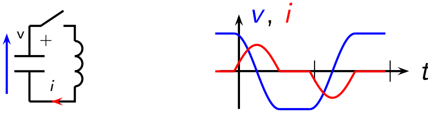

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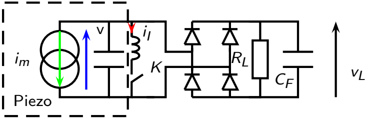

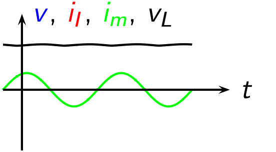

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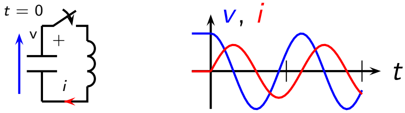
LC oscillations



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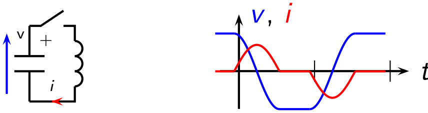

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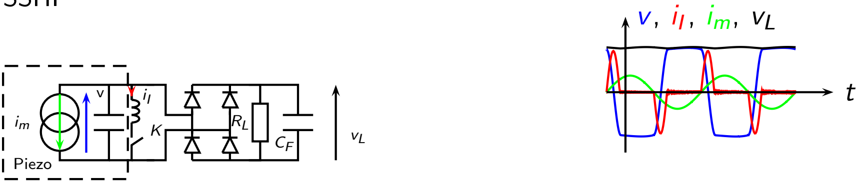

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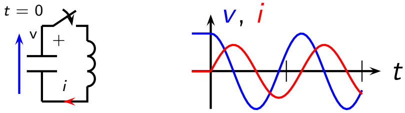
LC oscillations



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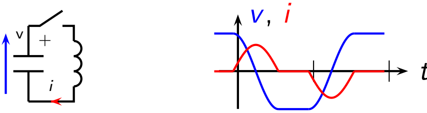

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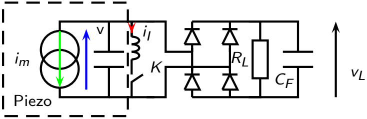
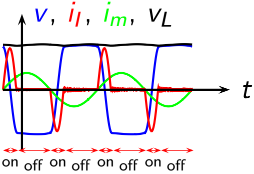


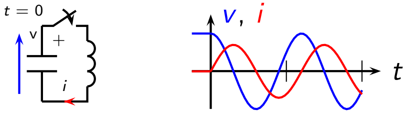


Switching is synchronized on $\dot{w}$, or

$i_m = N\dot{w}$.

How it works

LC oscillations



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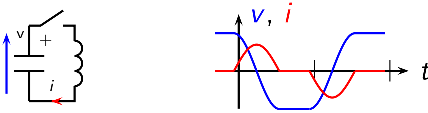

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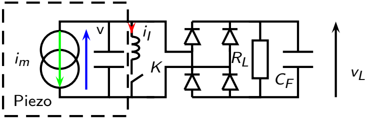
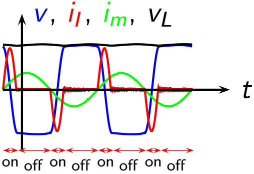


Operating point: calculate v_L from i_m

1[st] Harmonic assumption: $P = \frac{1}{2}\frac{V_L^2}{R_L} \simeq \frac{1}{2}\frac{4V_L I_m}{\pi}$, $V_L = \frac{4}{\pi} R_L I_m$



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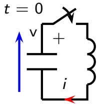

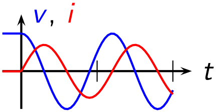

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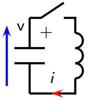
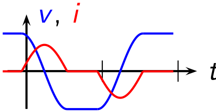
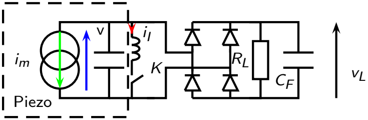




SSHI



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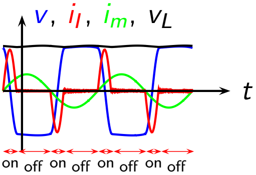
SSHI controls v and synchronises it, but doesn't impose $f_p = -D_s \dot{w}$.



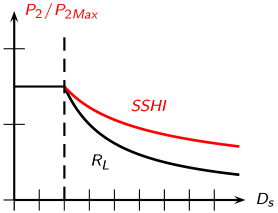
Switching is synchronized on $\dot{w}$, or

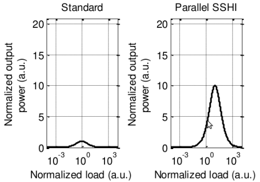
$i_m = N\dot{w}$.

Conclusion

Performances

- SSHI can extract energy more efficiently than a resistor when damping is important,

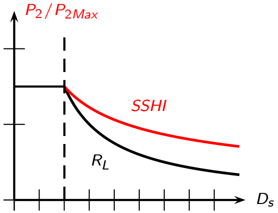


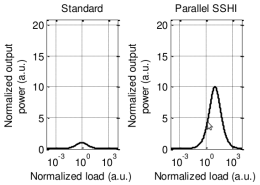


Conclusion

Performances

- SSHI can extract energy more efficiently than a resistor when damping is important,
- But Power extraction still depends on the load,

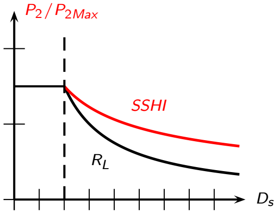


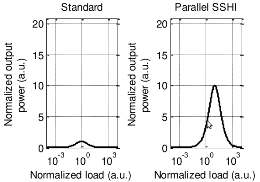


Conclusion

Performances

- SSHI can extract energy more efficiently than a resistor when damping is important,
- But Power extraction still depends on the load,
- Needs to measure bender's deflection $w(t)$.





General conclusion

In this presentation, applications of Energy Harvesting were shown. The modelling of a piezoelectric generator has shown that the power source needs an adaptation:

- in frequency,
- in load.

to maximize the harvested poer.
The key energy management rules were presented through the analysis of the EMR of the system. A typical power electronic circuit was also presented, but the bibliography shows a lot of example.

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End of the presentation

Questions?