

Efficiency versus effectiveness in energy harvesting systems

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Trameto overview



Enabling Battery-Free IoT



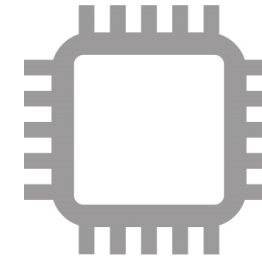
Technology

Energy management IP for autonomous micro energy harvesting



Markets

Micro energy harvesting for IoT
>\$3B semiconductor TAM in 2020



Products

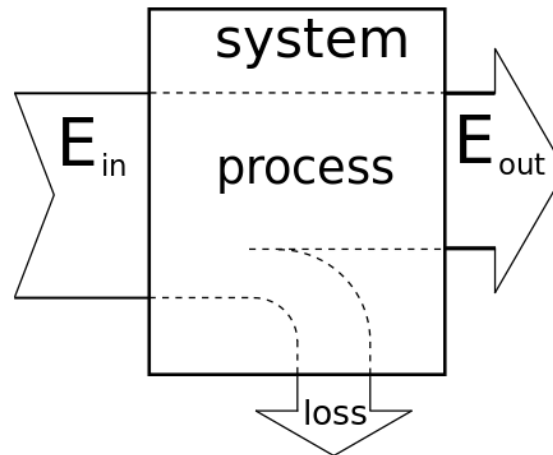
HarvestAll™ multi-source energy management chips (EMIC)



Enabling

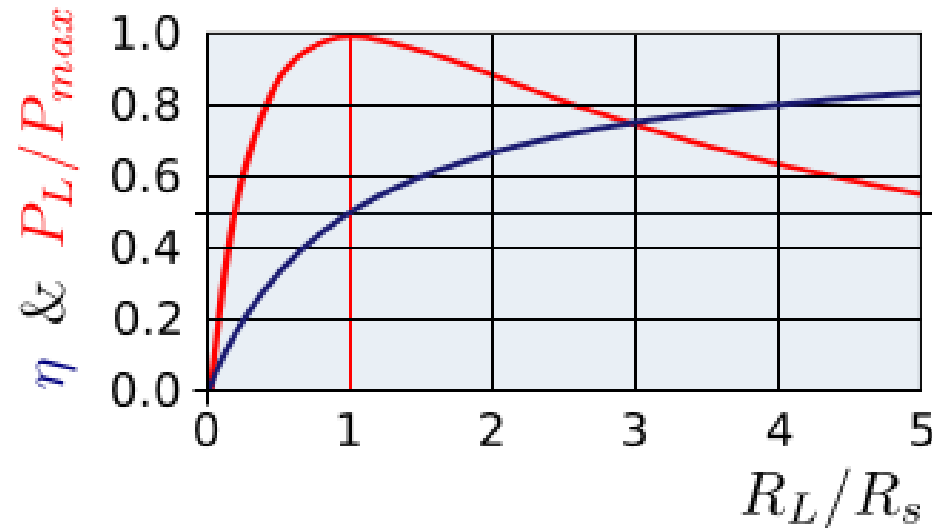
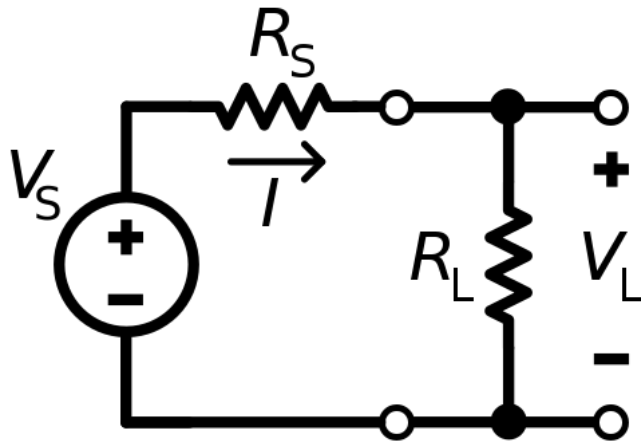
“Self-sustaining” smart sensors
No battery replacement

energy conversion efficiency $\eta = \frac{\text{useful energy output}}{\text{total energy input}}$



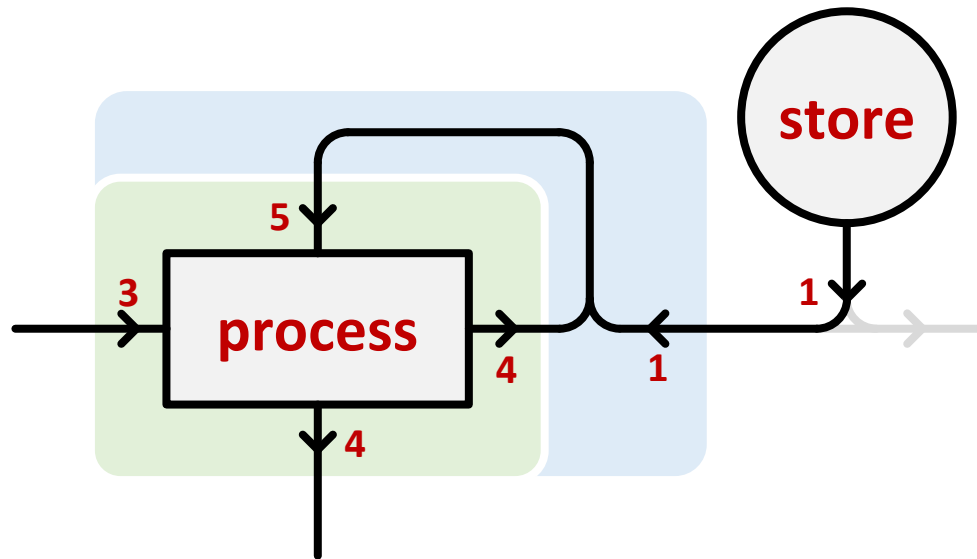
Maximum power theorem

- For maximum power from a source with finite internal resistance, the resistance of the load must equal the resistance of the source



- In an energy harvesting system, which is more important.. Maximizing the input power, or maximizing the conversion efficiency?

Loops



$$\eta_{green} = 4/8 = 50\%$$

$$\eta_{blue} = -1/3 = -33\% ?$$

Effectiveness.. A more useful concept

$$\text{energy conversion effectiveness} = \frac{\text{useful energy output}}{\text{maximum possible}}$$

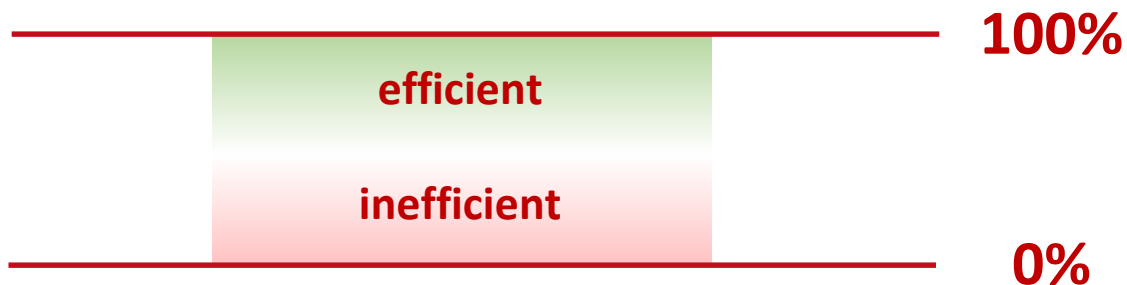
Key publications

- 2004 **‘Architectures for vibration-driven micropower generators’**
Mitcheson, Green, Yeatman and Holmes
- 2005 **‘On the effectiveness of vibration-based energy harvesting’**
Roundy
- 2006 **‘Converter circuit design, semiconductor device selection and analysis of parasitics for micropower electrostatic generators’**
Stark, Mitcheson, Miao, Green, Yeatman and Holmes
- 2008 **‘Energy harvesting from human and machine motion for wireless electronic devices’**
Mitcheson, Yeatman, Rao, Holmes and Green
- 2015 **‘A new figure of merit for wideband vibration energy harvesters’**
Liu, Badel, Formosa and Wu

Efficient

Achieving maximum productivity with minimum waste

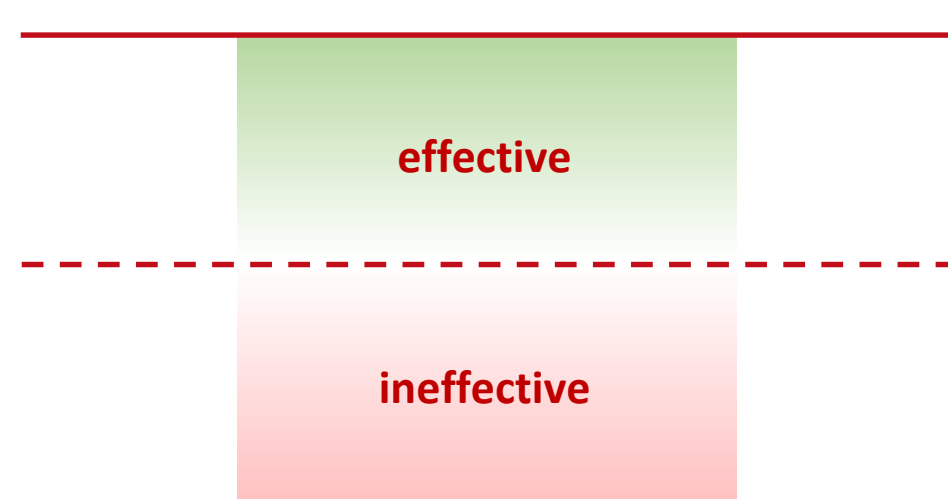
“Doing things right”



Effective

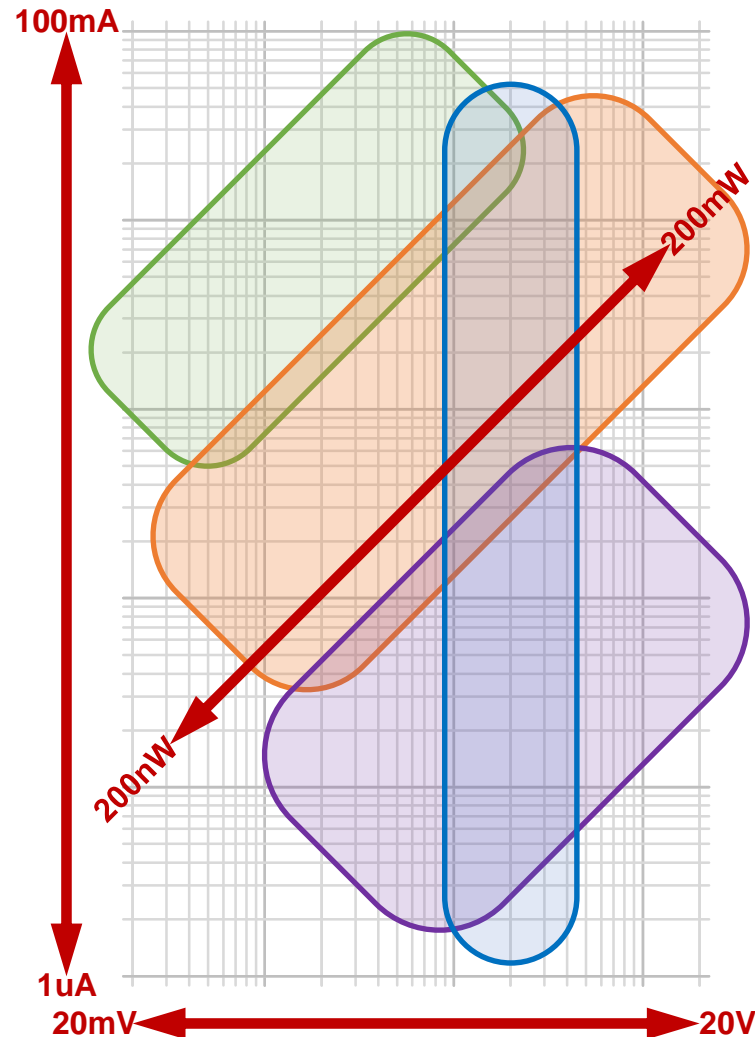
Successful in producing the desired or intended result

“Getting the right things done”



Energy harvesting

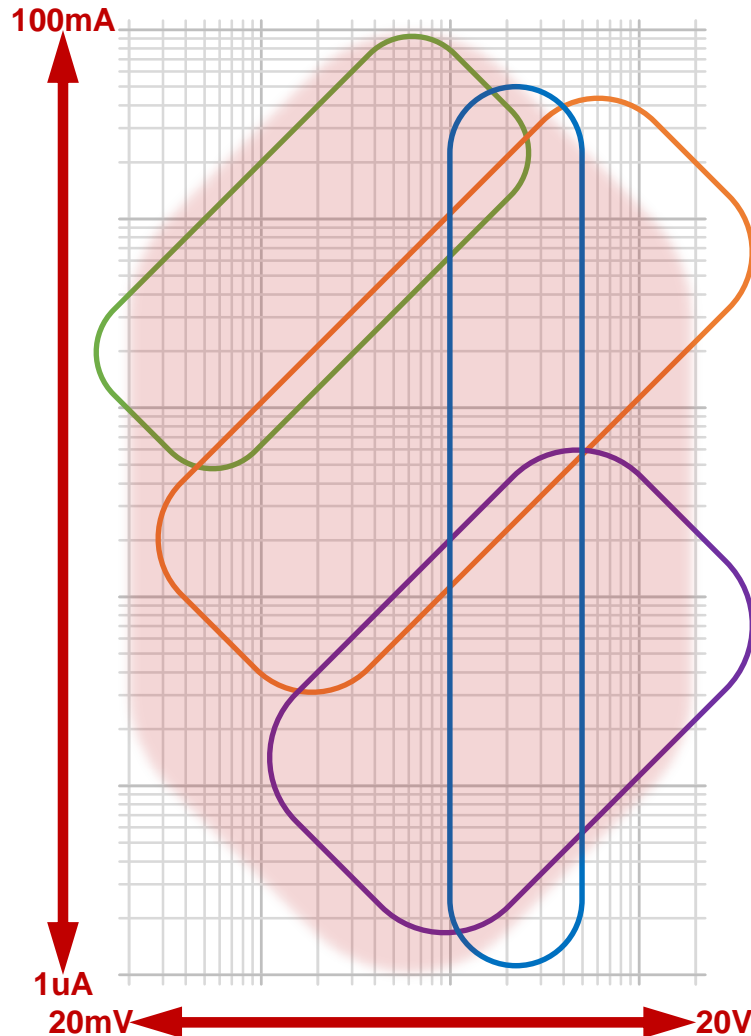
- **Huge dynamic ranges**
 - *EG ambient light levels*
- **Huge static ranges**
 - *EG generator sizes*
- **Log plots please!**
- **Multidimensional**
- **Different ground rules**
 - *Dissipation matters less*
 - *Joules matter differently*



- Thermoelectric
- Electrodynamic
- Photovoltaic
- Piezoelectric

Effective operating area (EOA)

Change the focus from how efficient or effective the converter is at some particular operating point, to the extent of the set of conditions over which the converter remains effective.



This is just one part of Trameto's development of AnyManyMulti™ EMICs (energy management ICs)
Any type of generator
Many identical generators
Multiple different generators

- **Efficiency figures can be misleading**
- **Effectiveness is a more useful concept**
- **The most important thing is the sign!**
- **We need to lose the eff-max mindset**
- **Energy harvesting is multidimensional**
- **Effective operating area (EOA) is key**
- **Some joules matter more than others**

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**“Freeing the IoT from battery power
will be a key enabler in reaching a
trillion devices.”**

Rob Aitken, R&D Fellow at Arm

[HERE'S HOW TO DO IT](#)