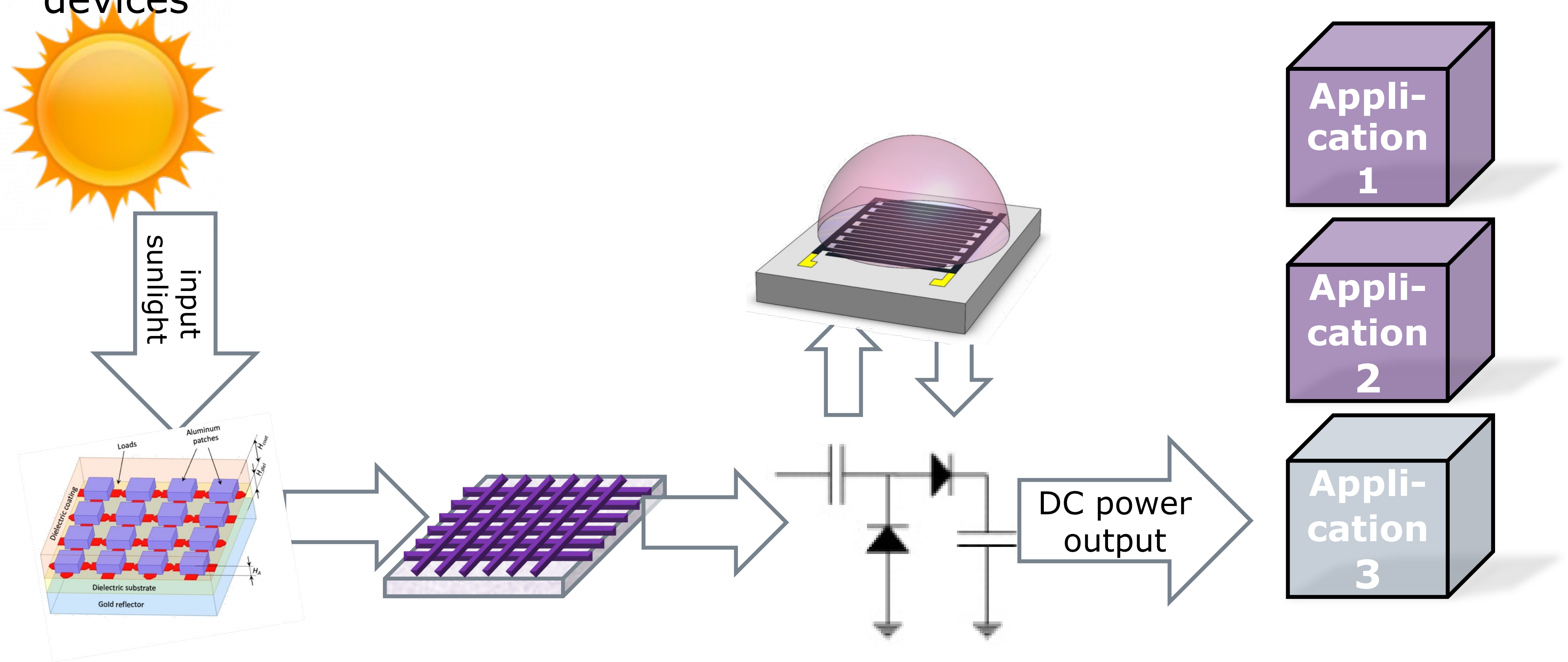
Challenges for integration of electrochemical capacitors

9 September 2024

GreEnergy Workshop “Wideband optical antennae for use in energy harvesting applications”

- Challenges for integration of electrochemical capacitors in energy harvesting devices



Challenges for integration of electrochemical capacitors in energy harvesting devices

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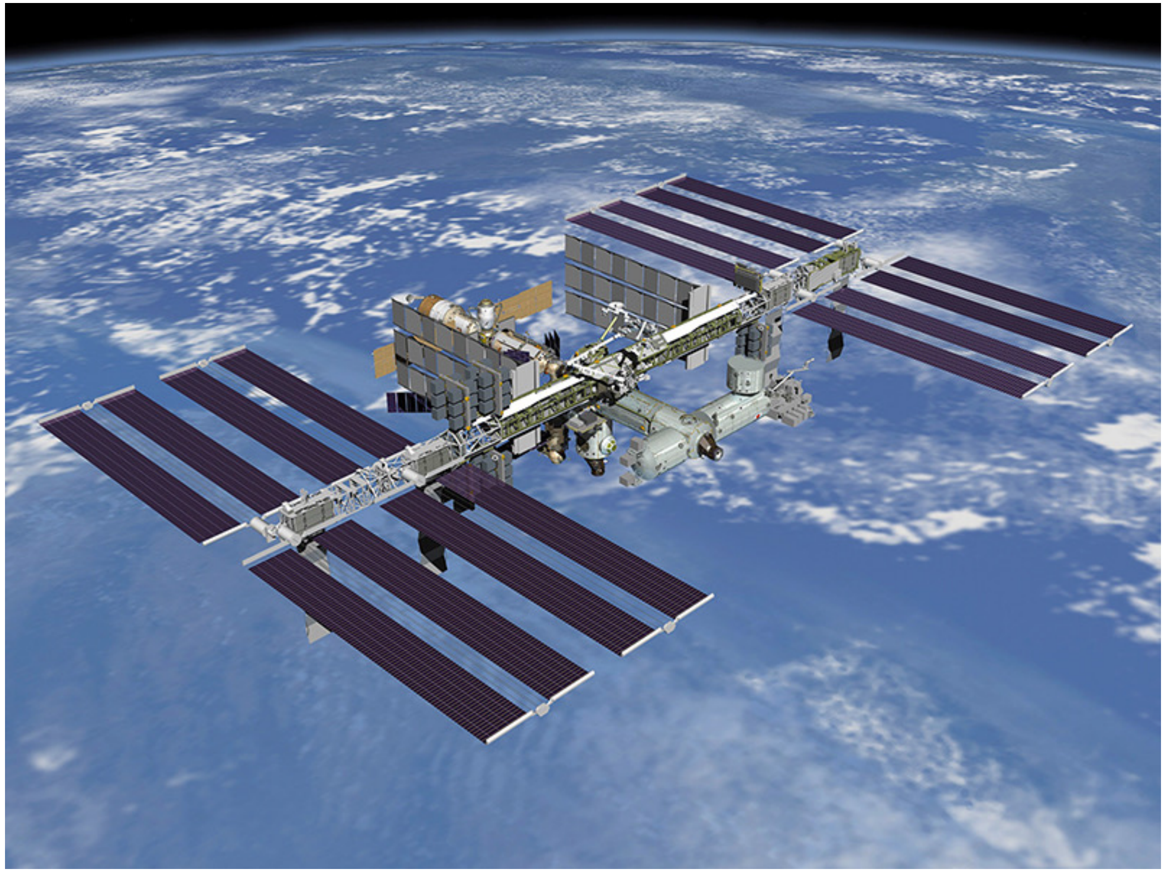
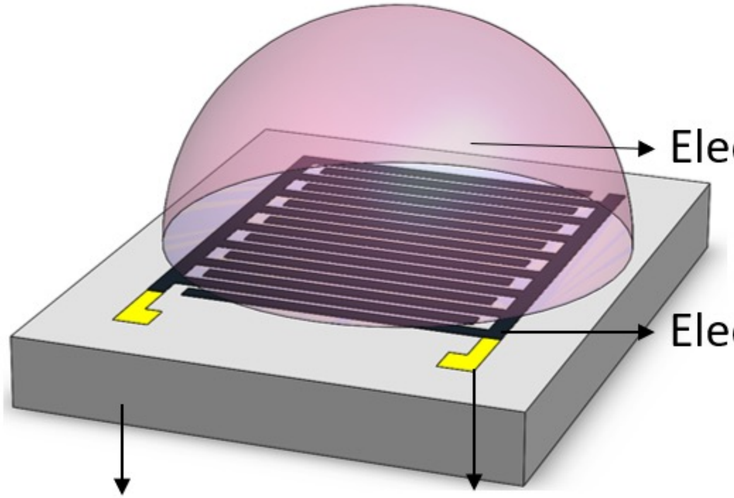


The input intensity from the sun is 1 kW·m^{-2}.

Assuming we can convert this to DC-power at very high efficiency -

what level of intermittencies can we manage using electrochemical energy storage?



State-of-the art maximum specific energy (per unit area) for electrochemical on-chip capacitors is on the order of…

…1 kWs·m^{-2}.

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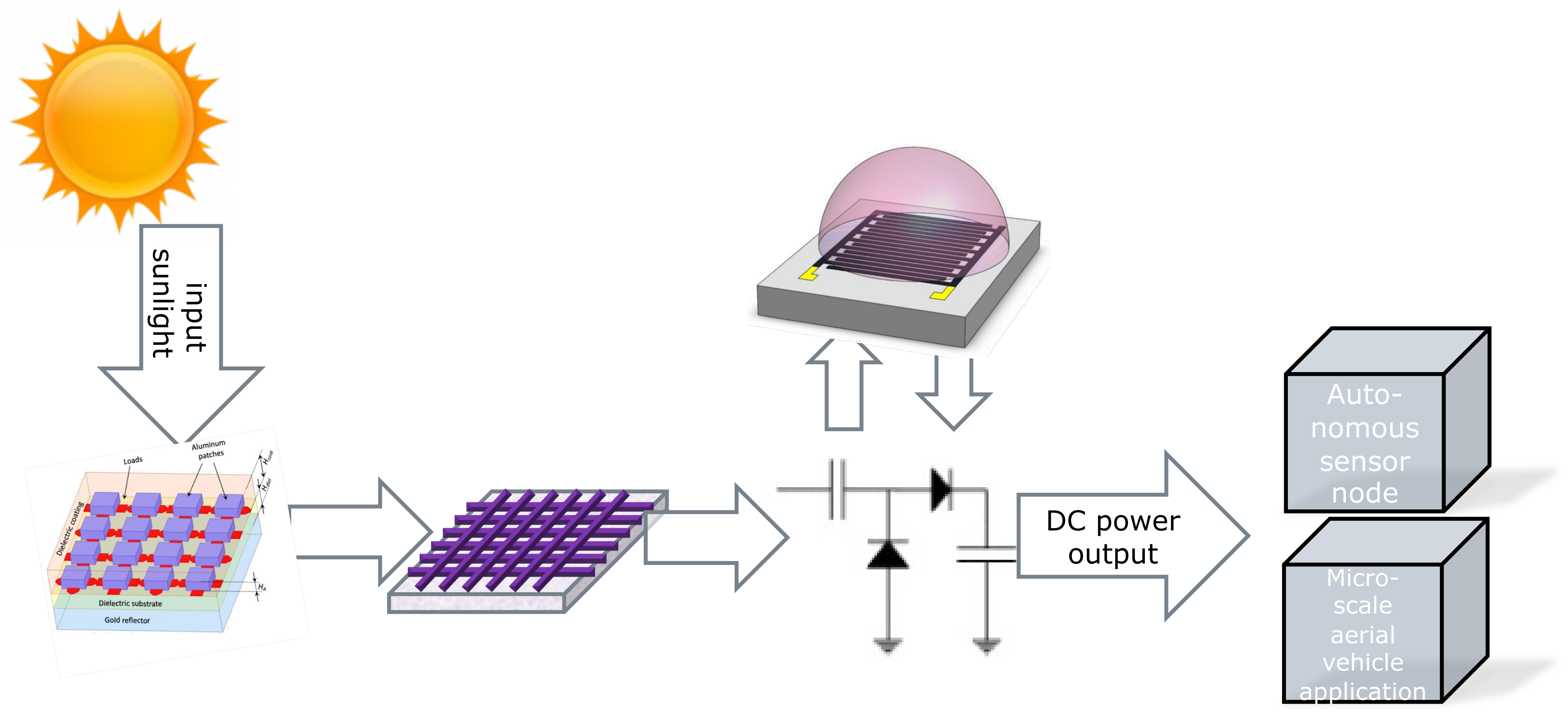
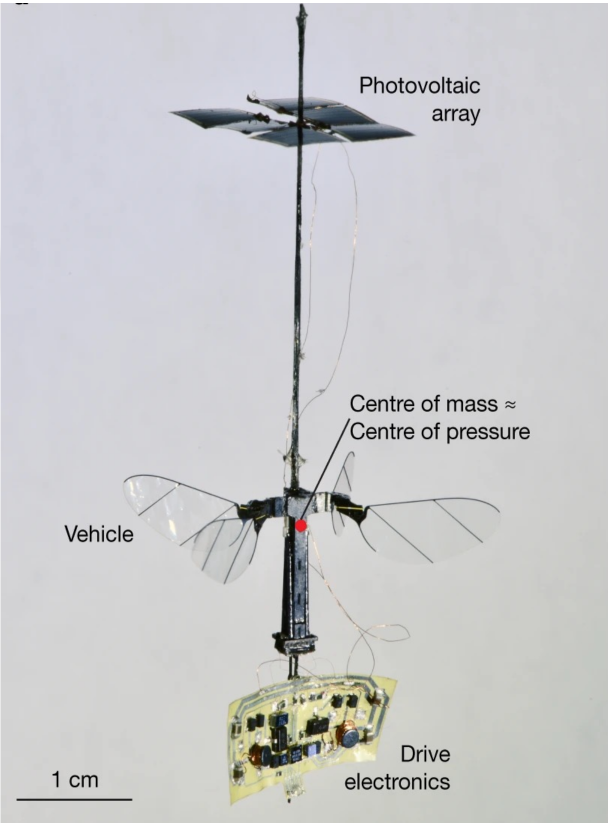
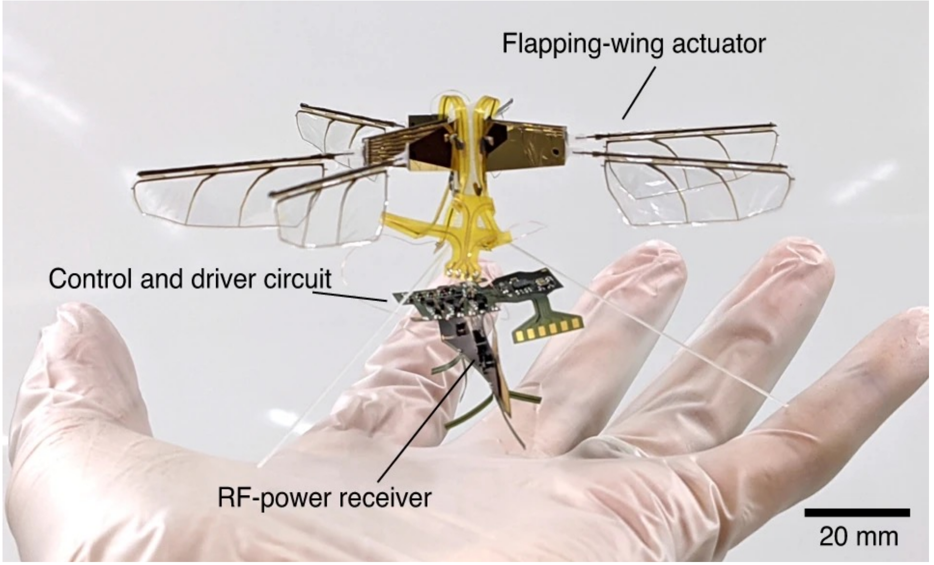


Challenges for integration of electrochemical capacitors in energy harvesting devices

Micro-scale aerial vehicle application

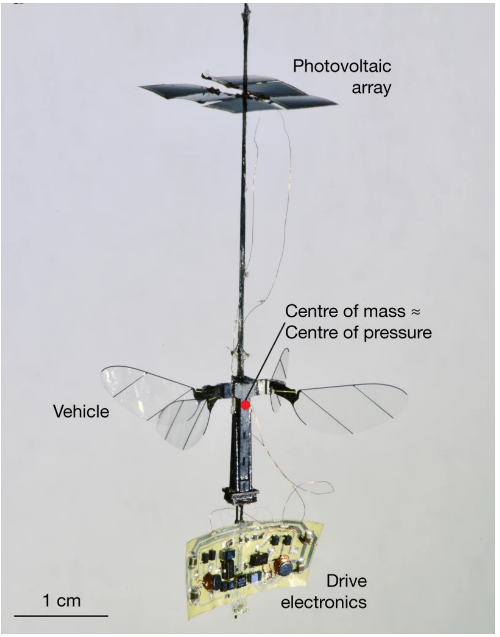


Jafferis, N.T., Helbling, E.F., Karpelson, M. *et al.* Untethered flight of an insect-sized flapping-wing microscale aerial vehicle. *Nature* 570, 491–495 (2019). https://doi.org/10.1038/s41586-019-1322-0



Ozaki, T., Ohta, N., Jimbo, T. *et al.* A wireless radiofrequency-powered insect-scale flapping-wing aerial vehicle. *Nat Electron* 4, 845–852 (2021). https://doi.org/10.1038/s41928-021-00669-8

Micro-scale aerial vehicle application

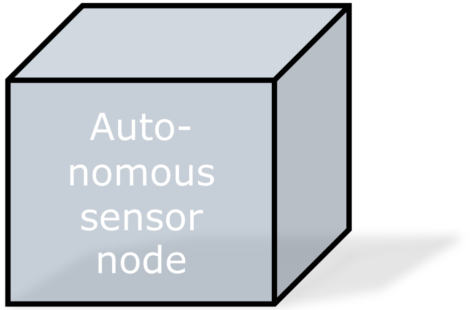


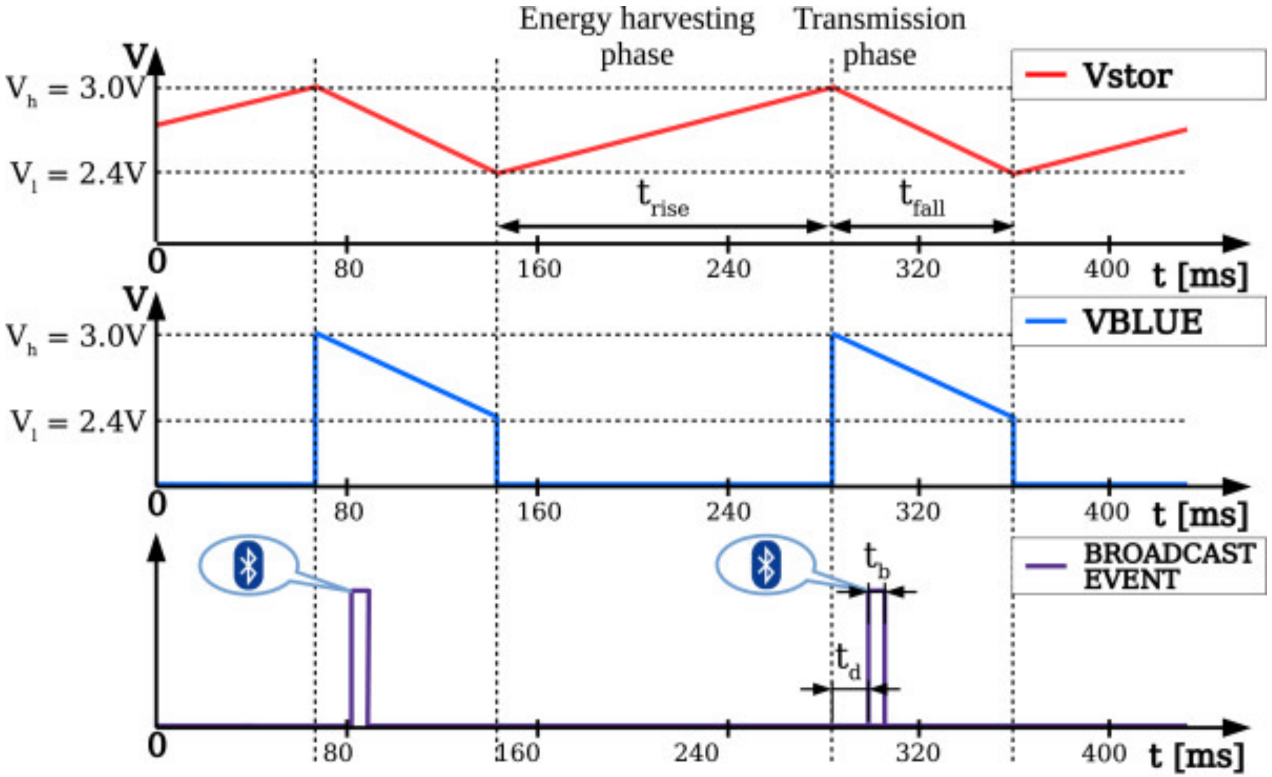
In the microdrone application the supercapacitor would provide power for safe(r) handling of a situation where the main power is cut off.

Critical performance parameters are specific power and energy (per unit mass and area).

Ideally one could conceive of wings used for power conversion and storage.

Challenges for integration of electrochemical capacitors in energy harvesting devices





La Rosa, R *et al.*, An energy autonomous and battery-free measurement system for ambient light power with time domain readout, Measurement 186, 110158 (2021). https://doi.org/10.1016/j.measurement.2021.110158

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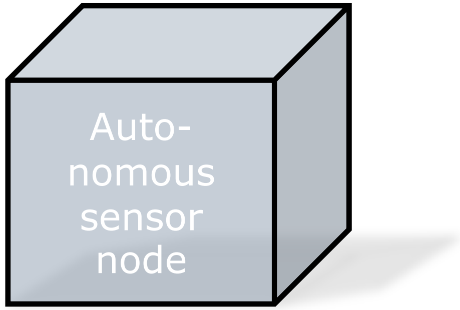

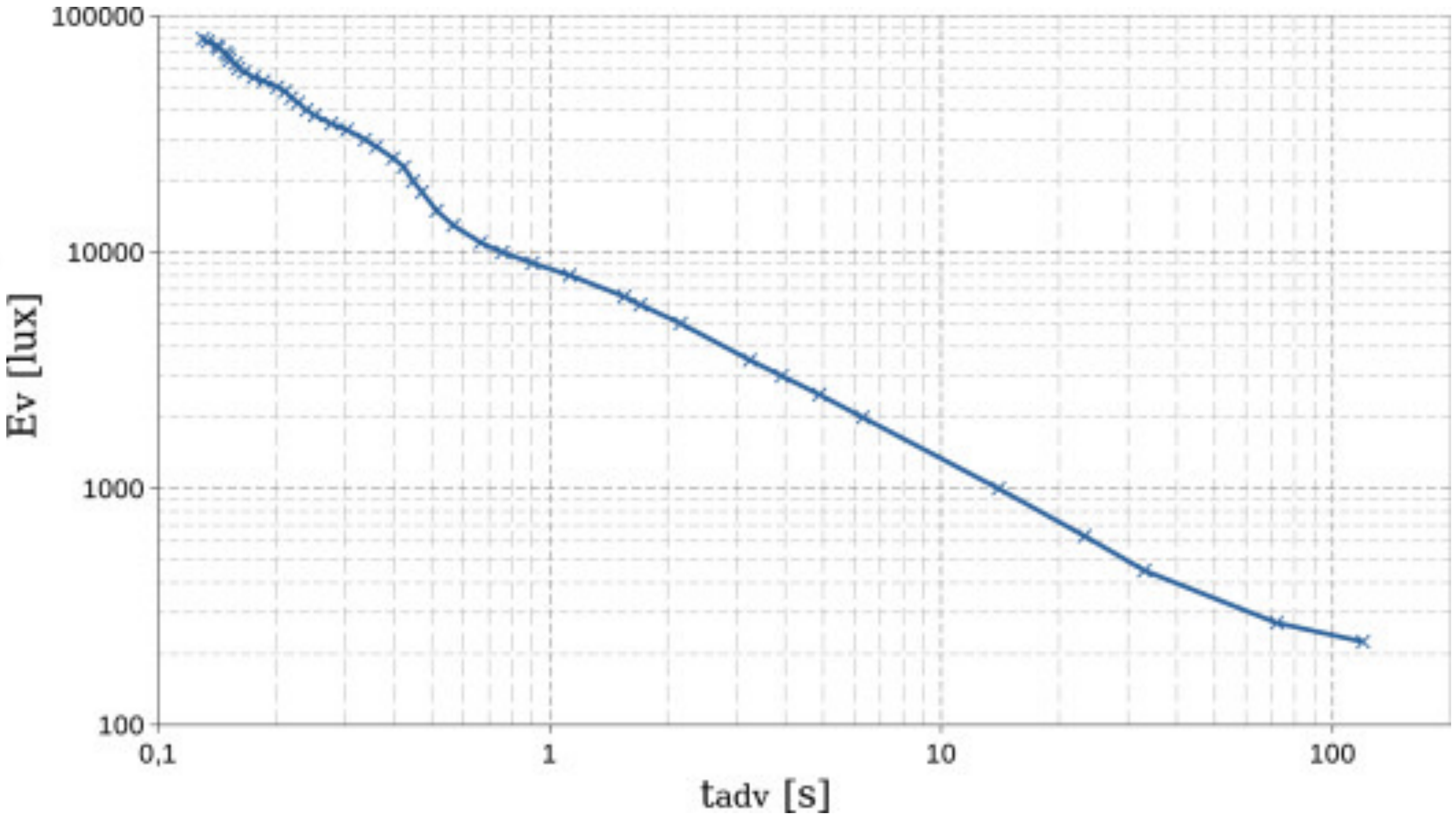

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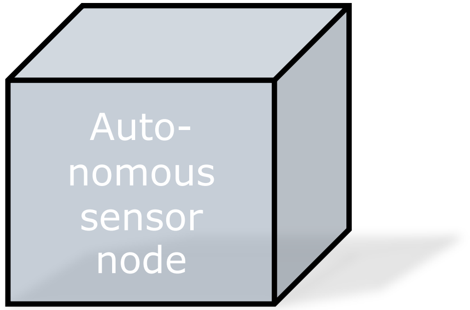


In the low power harvesting sensor application the supercapacitor would provide power for enabling wireless communication.

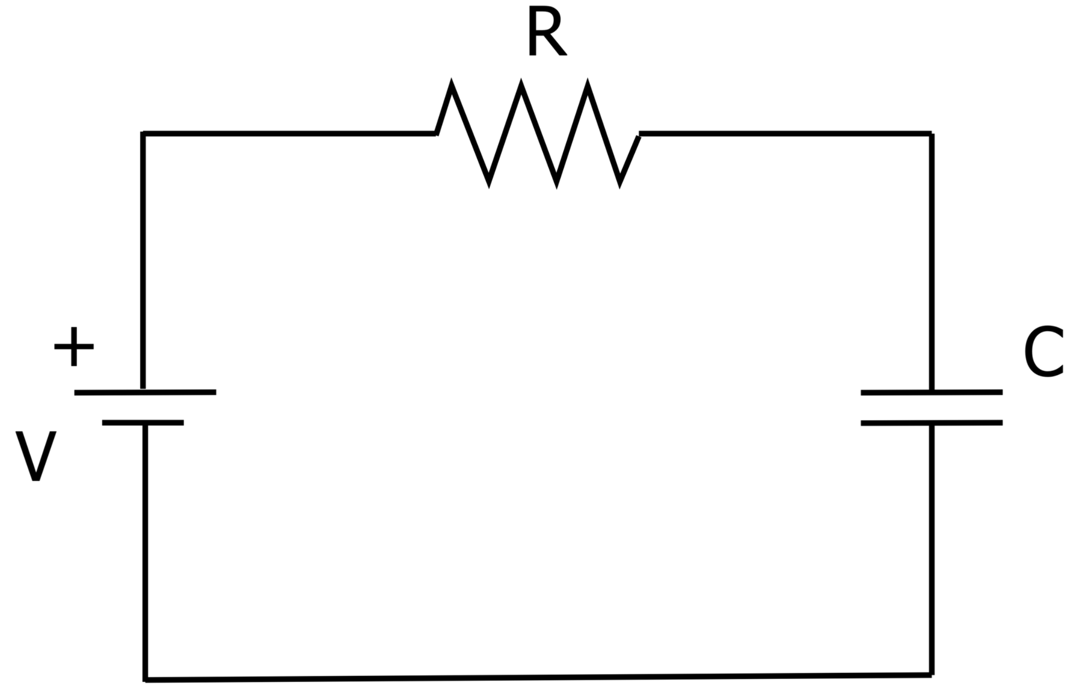
One critical performance parameters is sufficiently low leakage current and sufficiently high specific power.

The intermittency of transmission would be set by the harvested input power.

- The curse of storing energy in a capacitor.

Should you charge as quickly as possible, or as slowly as you can for high efficiency?

$$E = \int_0^\infty V \cdot I \; dt$$



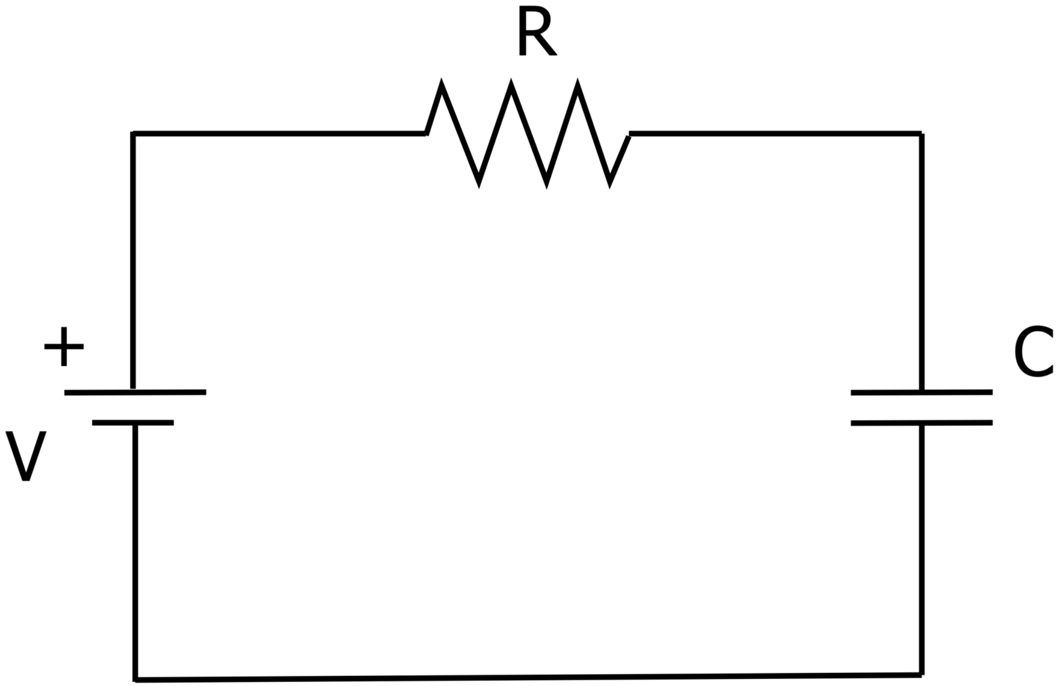
- The curse of storing energy in a capacitor.

Energy delivered from the ideal voltage source with a step function.

$$E_V = V \int_0^{\infty} \frac{V}{R} \cdot e^{-\frac{t}{RC}}\, dt$$

$$= \frac{V^2}{R}\left[-RC \cdot e^{-\frac{t}{RC}}\right]_0^{\infty} = V^2 C$$

$$Q = C \cdot V$$

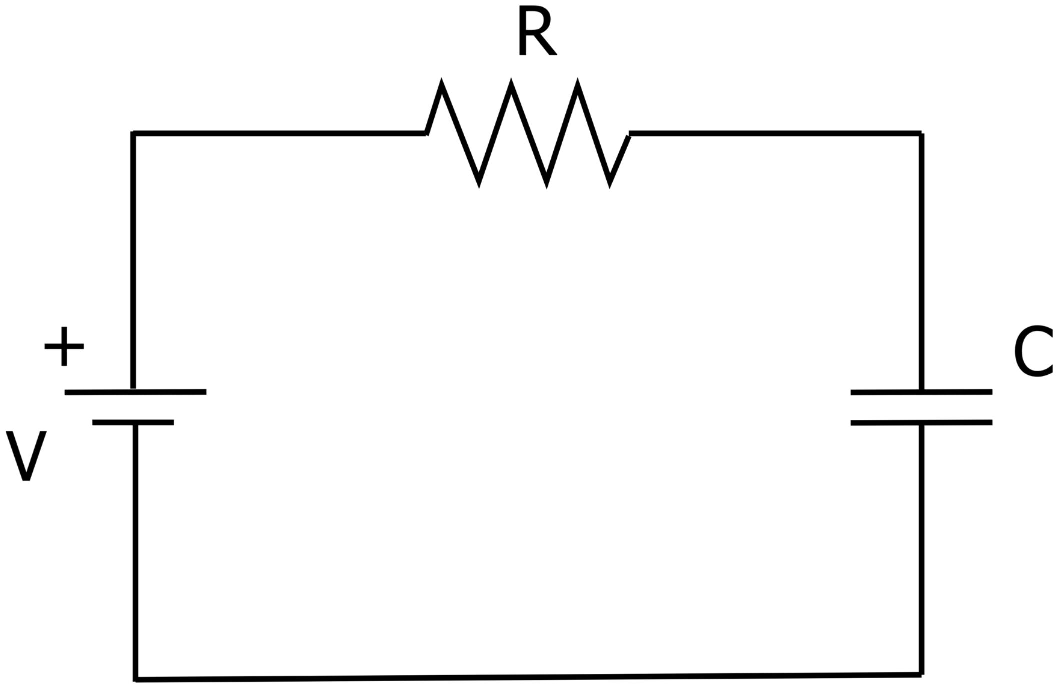


- The curse of storing energy in a capacitor.

Energy dissipated in the resistor during charging.

$$E_R = \int_0^\infty R \cdot I^2 \, dt = \frac{V^2}{R} \int_0^\infty e^{-\frac{2t}{RC}} dt$$

$$= \frac{V^2}{R} \left[-\frac{RC}{2} \cdot e^{-\frac{2t}{RC}} \right]_0^\infty = \frac{V^2 C}{2}$$



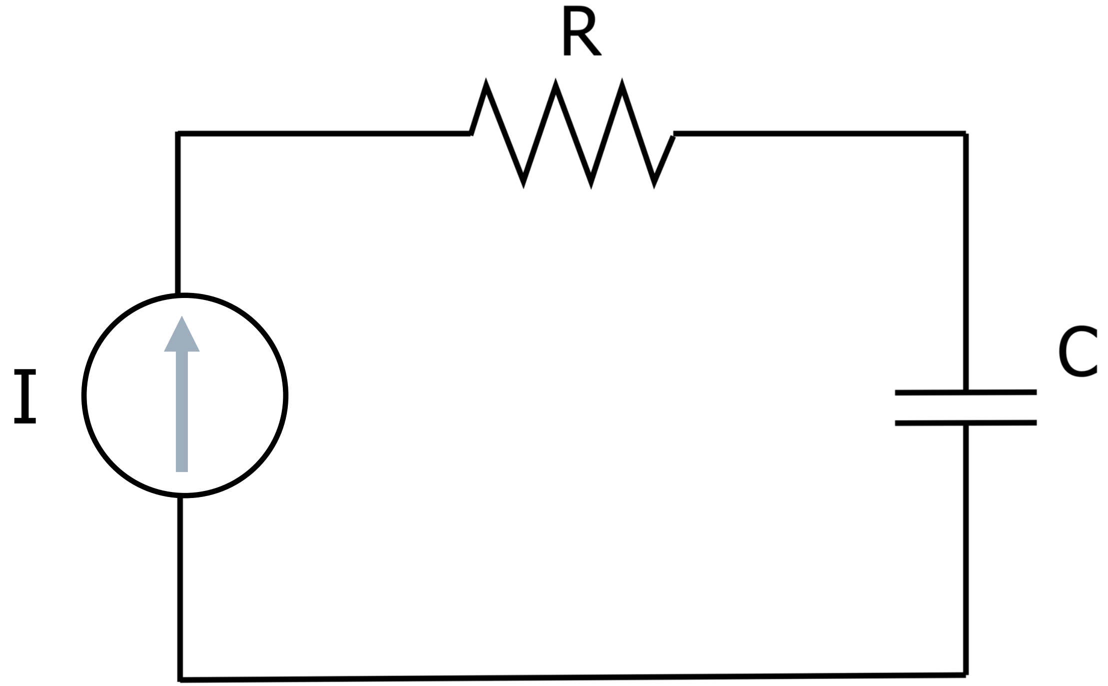
- The curse of storing energy in a capacitor.

Energy delivered from the ideal constant current source. For how long should we charge?

t_{stop} given by:

$$I \cdot t_{stop} = C \cdot V$$

$$Q = C \cdot V$$

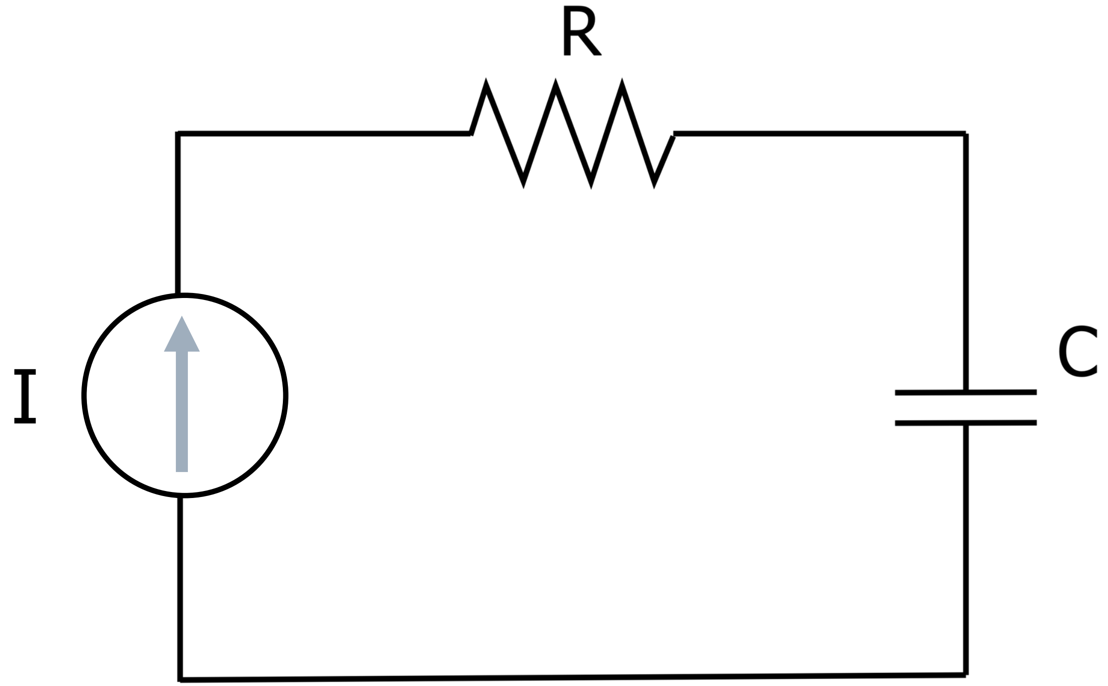


- The curse of storing energy in a capacitor.

  Energy delivered from the ideal constant current source.

$$E_I = \int_0^{t_s} (V_R + V_C) \cdot I \, dt$$

$$= I \cdot \left(\int_0^{t_s} V_R \, dt + \int_0^{t_s} V_C \, dt \right)$$

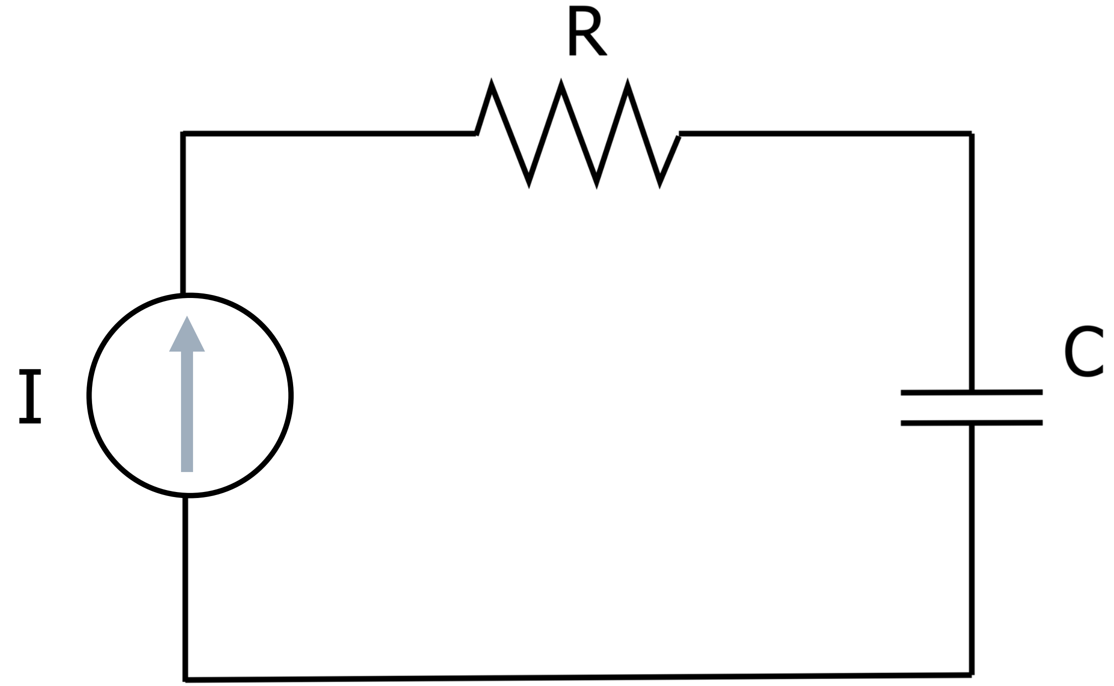


- The curse of storing energy in a capacitor.

Energy delivered from the ideal constant current source.

$$E_I = R \cdot I^2 \cdot t_s + I \cdot \int_0^{t_s} \frac{I \cdot t}{C} dt$$

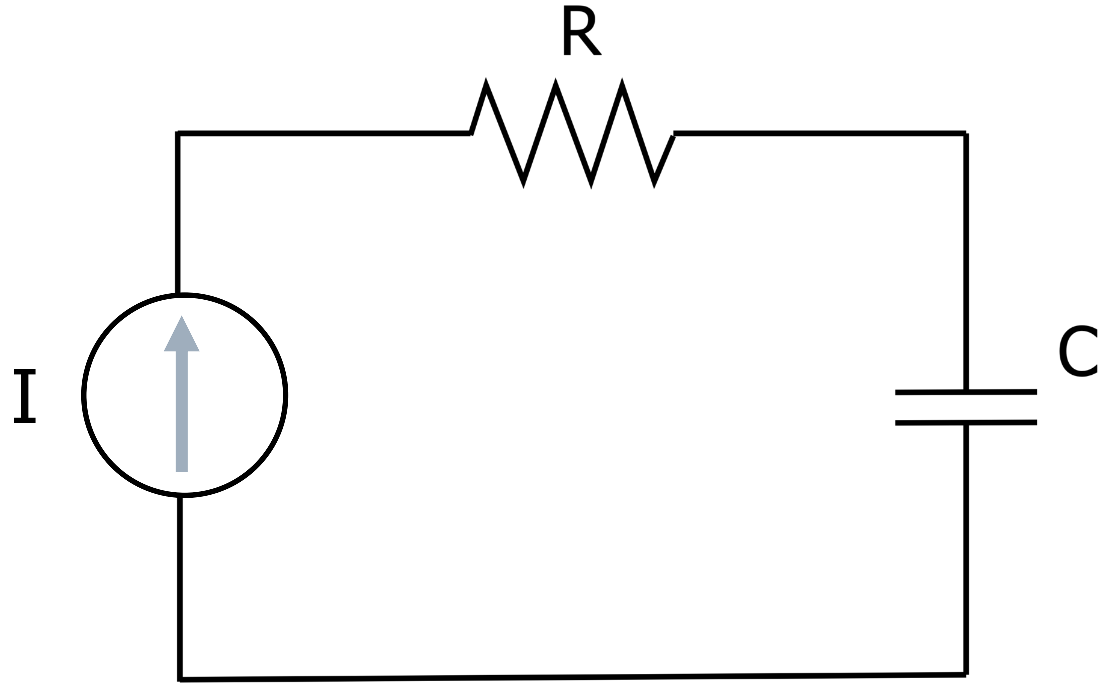
$$= R \cdot I \cdot C \cdot V + \frac{I^2}{C} \cdot \frac{C^2 V^2}{2 \cdot I^2}$$



- The curse of storing energy in a capacitor.

Energy delivered from the ideal constant current source.

$$E_I = R \cdot I \cdot C \cdot V + \frac{C \cdot V^2}{2}$$

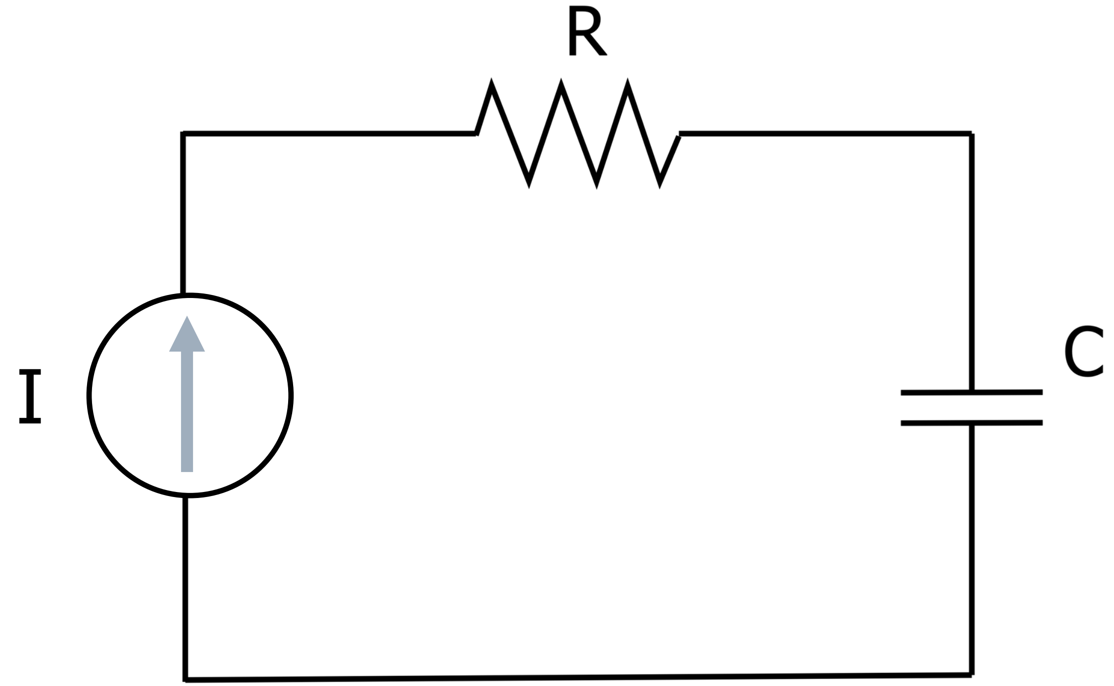


- The curse of storing energy in a capacitor.

Constant current charging gives a loss that depends on the current.

$$\frac{E_R}{E_I} = \frac{R \cdot I \cdot C \cdot V}{R \cdot I \cdot C \cdot V + \frac{C \cdot V^2}{2}}$$

$$= \frac{RI}{RI + \frac{V}{2}} \rightarrow I \ll \frac{V}{2R}$$



Thank you!

GreEnergy

Power from optical antennas

www.greenergy-project.eu

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