High Efficiency RF Energy Harvester for IoT Embedded Sensor Nodes

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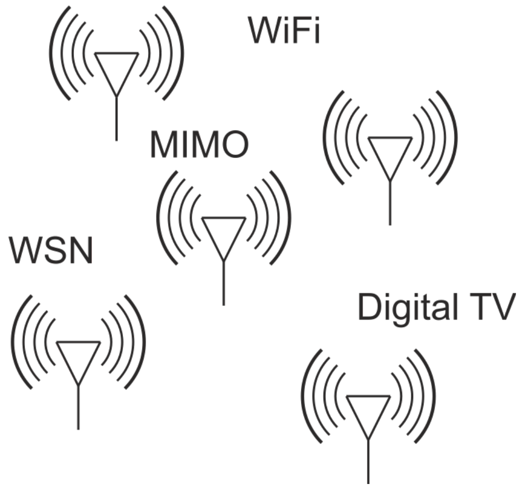
Outline

- Introduction
- Rectifier’s design
- Application – Continuous supply of a battery-less wireless sensor node

Ocean of Electromagnetics Waves

- We live into an electromagnetics waves ocean.
- The number of radio frequency emitters has been rapidly increasing over the last decades due to the development of new technologies
- Countless wireless applications need antennas, which emit power in order to serve numerous customers
- However, most of **this energy remains unused**, since usually a receiver captures only a very small fraction of the transmitted power
- Ambient RF power is created, remaining unspent.
- Hence, it is an **engineering challenge** how to **efficiently collect** this **unused ambient RF energy**

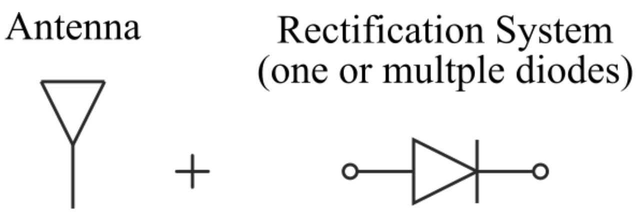


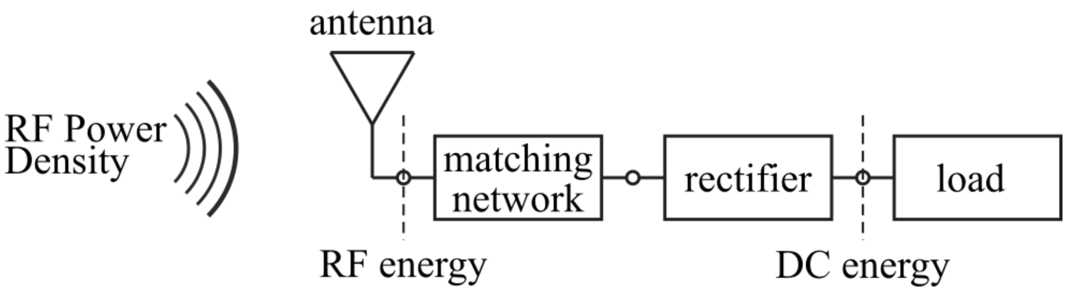
RF energy to DC energy

- RF-to-dc efficiency

$$\eta = \frac{\text{DC power input}}{\text{RF power output}}$$

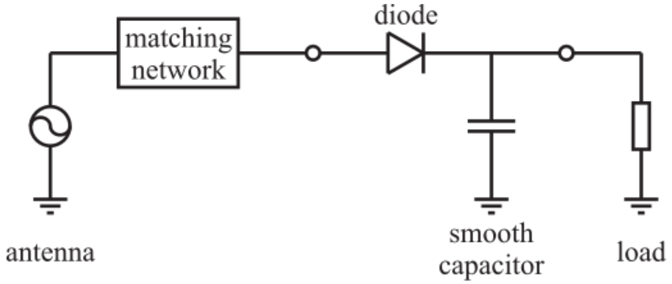
- Prior-art designs
  - Usually operate optimally ($\eta > 60\%$) for high power input, e.g., > 0 dBm
- For low power input
  - Maximum efficiency 30% for -20 dBm power input
  - Sensitivity higher than -30 dBm power input

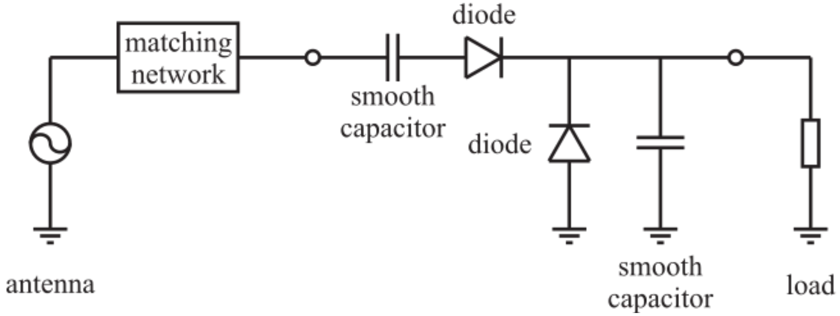


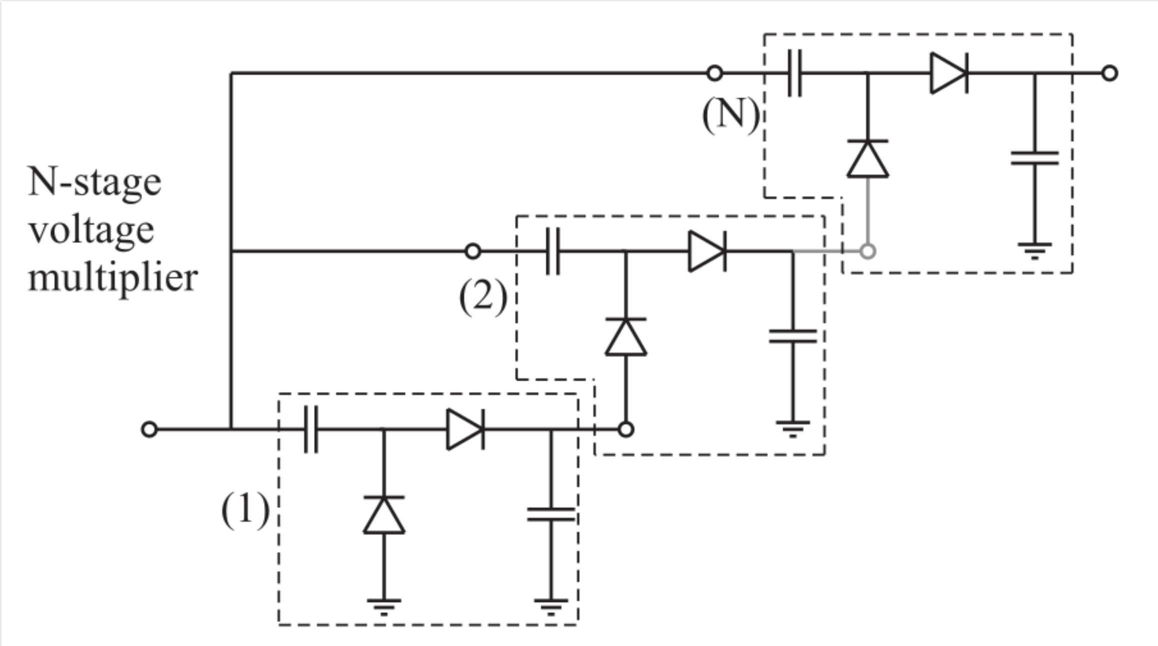


[1] W. C. Brown, ``The history of power transmission by radio waves,'' IEEE Trans. Microw. Theory Techn., vol. 32, no. 9, pp. 12301242, 1984.

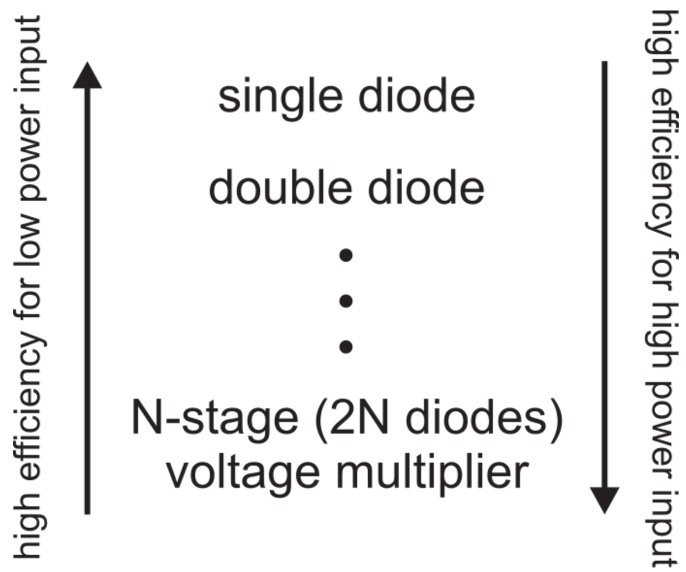
Number of diodes







Number of diodes

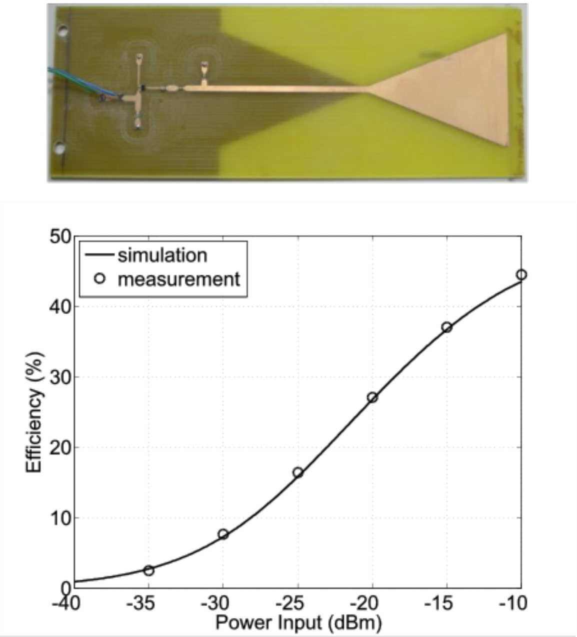


[2] P. Nintanavongsa, U. Muncuk, D. R. Lewis, and K. R. Chowdhury, ``Design optimization and implementation for rf energy harvesting circuits,'' IEEE Trans. Emerg. Sel. Topics Circuits Syst., vol. 2, no. 1, pp. 2433, 2012

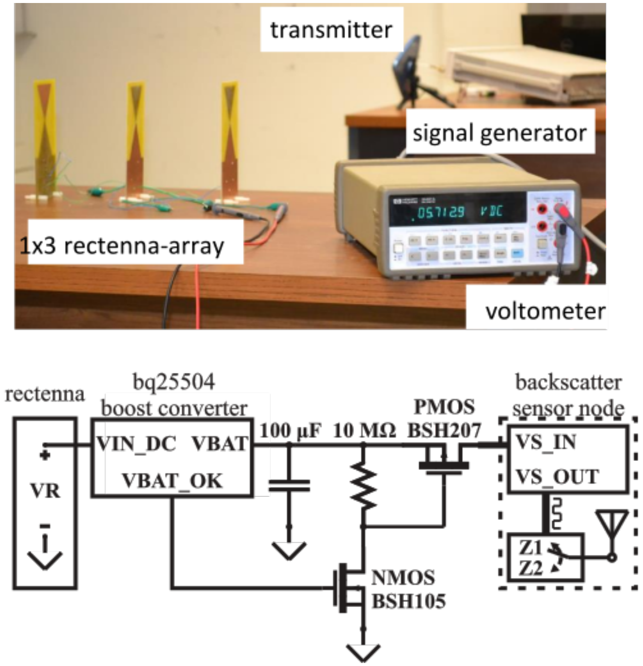
Goal/Contribution of this work

- The design of a high efficiency for low-power input rectification system, appropriate for IoT Embedded Applications
- The rectification systems is
  - co-planar,
  - low-complexity series circuit with one single diode
  - directly impedance matched to the antenna
- The absence of matching network results to
  - losses reduction and thus,
  - leads to **RF-to-dc enhancement**

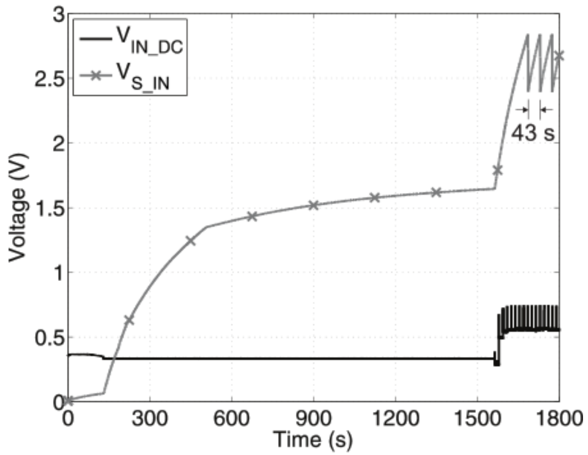
Conventional Rectenna with Matching Network



Rectenna and efficiency η
size: $\lambda/2 \times \lambda/4$
$\eta = 28.4\%$ @868MHz,-20dBm



Load: sensor node with consumption of 100 uW@1.6V

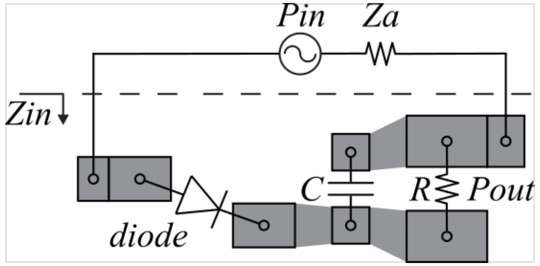


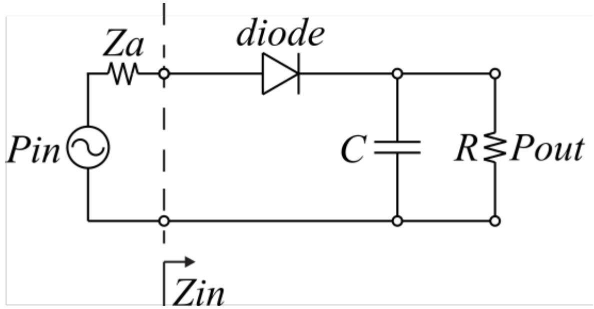
For **0.0139 uW/cm2:**
cold start: 1687 s, operates every 43 s

[3] S. D. Assimonis, S. N. Daskalakis and A. Bletsas, "Sensitive and Efficient RF Harvesting Supply for Batteryless Backscatter Sensor Networks," in *IEEE Transactions on Microwave Theory and Techniques*, vol. 64, no. 4, pp. 1327-1338, April 2016.

Proposed Rectifier's Design

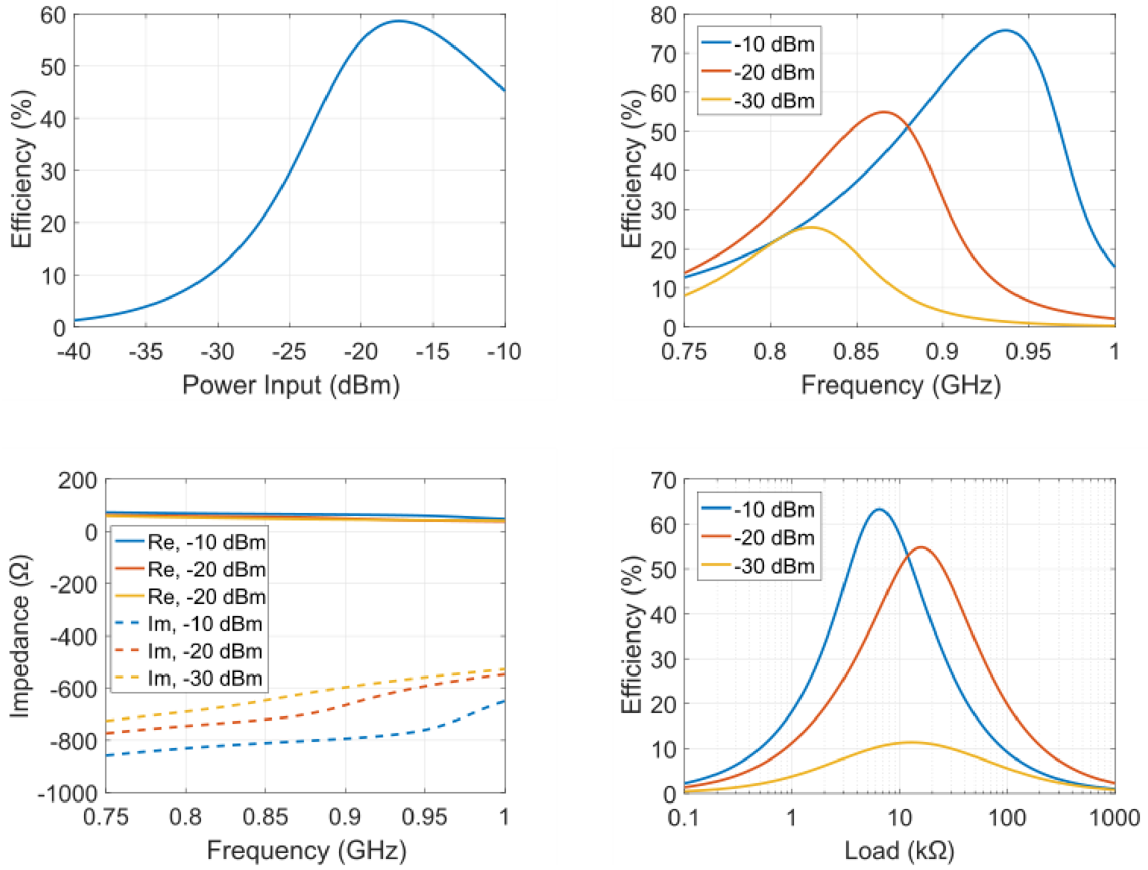
- The rectifier's topology (top) and circuit schematic (bottom):
  - co-planar
  - single diode (HSMS285B) in series configuration with the load
  - Substrate (Taconic TLY-5) with $\varepsilon_r = 2.17, \text{tand} = 0.0009$
  - Total size: 7mm x 2mm x 0.508 mm
- Design optimized to operate
  - for -20 dBm power input
  - at 868 MHz (UHF RFID frequencies in Europe)
- Fitness function
  - RF-to-dc efficiency
  - degrees of freedom Z_a and R
- Results: efficiency was maximized for
  - $Z_a = 54.6 + j707.6\ \Omega$ and $R = 15.4\ k\Omega$





Reflection coefficient and RF-to-dc efficiency

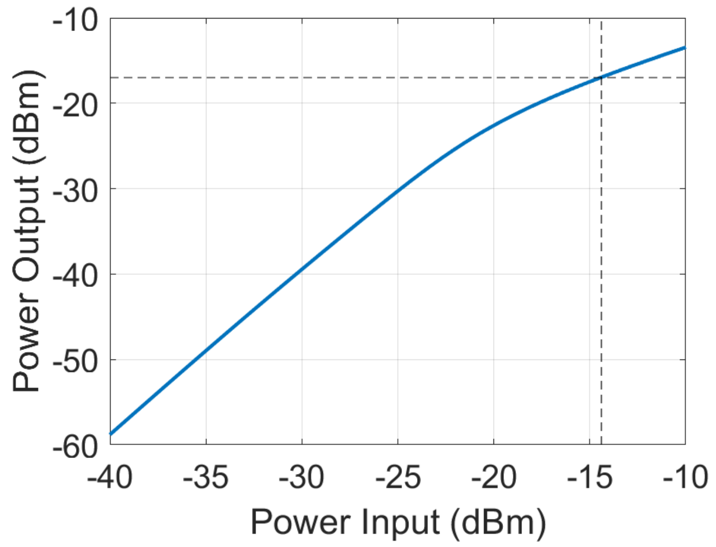
- $\eta = 54.9\%$ @868MHz, -20dBm
- rectifier is capacitive and non-linear
- high power input leads to higher efficiency which now occurs to higher frequency (load fixed at 15 kΩ)
- higher power input leads to resistance degradation of the optimal output load



Rectifier's design

Continuous supply of a battery-less sensor node

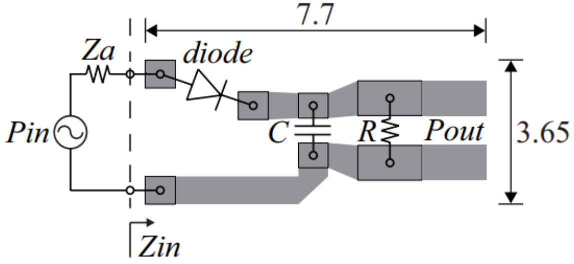
- In [4] authors presented a backscatter sensor node with power consumption of the order of $20\ \mu W$, or equivalently, of -17 dBm
- This Fig. shows that for -14.4 dBm power input, the system delivers to the optimal load more than -17 dBm.
- Thus, the proposed rectifier is able to **supply continuously**, i.e., without the use of any boost converter, battery-less backscatter sensor nodes.

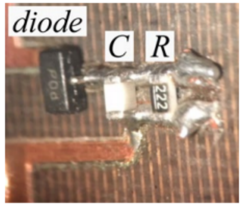


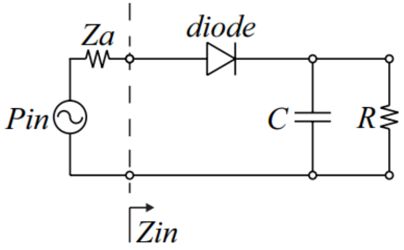
[4] S. N. Daskalakis, G. Goussetis, S. D. Assimonis, M. M. Tentzeris, and A. Georgiadis, “A uw backscatter-morse-leaf sensor for low-power agricultural wireless sensor networks,” IEEE Sensors Journal, vol. 18, no. 19, pp. 7889–7898, Oct 2018.

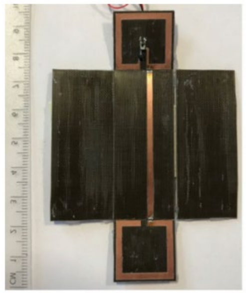
Example

- Non-optimized rectifier directly connected to an electrically small antenna



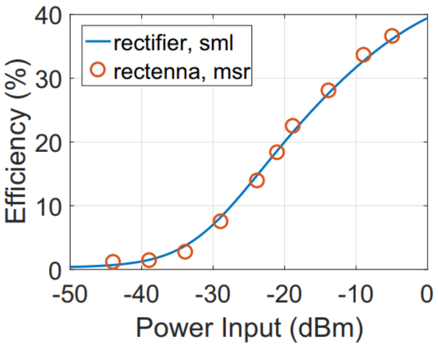


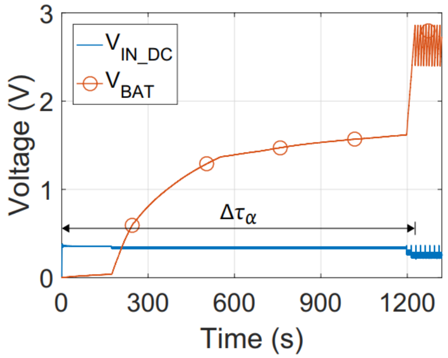




non-optimized co-planar rectifier directly connected to the electrically small antenna

$\eta = 22.5\%$
@868MHz, -19 dBm





For **0.39 uW/cm2:**
cold start: 1227s,
operates every 43 s

[5] S. D. Assimonis, V. Fusco, A. Georgiadis, and T. Samaras, “Efficient and Sensitive Electrically Small Rectenna for Ultra-Low Power RF Energy Harvesting,” Scientific reports, vol. 8, no. 1, p. 15038, 2018.

Conclusions

- A high efficiency for low power input and low-complexity rectifier, directly connected to the antenna, was proposed
- Under given circumstances, the rectifier can supply a typical battery-less, wireless sensor node
- **Next goal**: Design of a complete, optimized, high efficiency RF energy harvesting system

Conclusions

Thank you!

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