High Efficiency Flexible Compact Rectenna based on Parametric Antenna-Rectifier Co-Design

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Rectenna Requirements

- Antenna Gain: radiation patterns and polarization
- Impedance match ($S_{11}$)

- Rectifier’s performance is dependent on the antenna’s impedance and not only low $S_{11}$

[I. Radiation properties](#)

II. Impedance-bandwidth

[Wagih “Rectennas for RF Energy Harvesting and WPT” *IEEE Antennas Propag. Mag.*]
Rectifier Design and Optimization

- Voltage doubler topology.
  - Reduced input resistance and reactance
- Optimization through source and load impedances in non-linear harmonic balance simulation.

\[ Z_s = R_s + jX_s \]

\[ Z_L \]
Rectifier Design and Optimization

• Unlike source/load-pull, the figure-of-merit is the Power Conversion Efficiency (PCE)
  – PCE is not only controlled by the $S_{11}$, both antenna-rectifier and rectifier-load matching required

\[ Z_s = R_s + jX_s \]
Rectifier Optimization

- SMS7630-079lf (lowest $V_{th}$, low $C_J$)
- EM co-simulation to include the rectifier’s layout influence.
Rectifier Optimization, Simulation

- Rectifier PCE as a function of the source impedance.
- Over 150Ω-reactance half-power impedance range.
Scalable High-Impedance Antenna

- High inductive impedance ($Z_{\text{Ant}}$)
- Simple parametrically tunable geometry
- Electrically-small, $0.012\lambda^2$.
  - Ultra-thin (25 µm) substrate
Input Impedance Tuning by Parameter

- Varying length $L$
  - Resonance shift results in the highest variation in both resistance and reactance
Input Impedance Tuning by Parameter

- Varying the gap width $G$
  - Controls the capacitance between the antenna’s folds
Antenna Fabrication

- Standard photolithography on a flexible polyimide substrate.
  - Encapsulation for reliable integration in textiles/packaging.

[Wagih “Flexible Concealed Rectenna Yarn for Wireless-Powered Electronic Textiles” EuCAP 2020.]
Antenna Fabrication, *Textile Integration*

- Standard photolithography on a flexible polyimide substrate.
- Compatible with integration in textile-weaves for wearable applications.

Flexible rectenna filament

Textile-integrated rectenna concept

[Wagih “Flexible Concealed Rectenna Yarn for Wireless-Powered Electronic Textiles” EuCAP 2020.]
• A power-calibrated transmitter to measure the rectenna’s PCE.
• The highest reported PCE compared to SoA discrete rectennas below 0 dBm ($PCE_{\text{max}} = 83\%$)
• -9 dBm 1 V sensitivity with a 20 kΩ load.
• 7.9% -3 dB fractional bandwidth.
  – Full coverage of the 868 MHz license-free band.
• Highest -20 dBm PCE of 43%.
• 330 mV at -20 dBm.
Testing in Indoor Environment

- Over 65% PCE at 6 m from 3 W 915 MHz Powercast TX.
- 6.3 V maximum DC output despite low diode’s $V_{Br}$
Comparison with State-of-Art Rectennas

<table>
<thead>
<tr>
<th></th>
<th>This Work</th>
<th>Adami 2018 TMTT</th>
<th>Visser 2016 WPT</th>
<th>Song 2015 TAP</th>
<th>Vital 2019 TAP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freq. (GHz)</td>
<td>0.868</td>
<td>2.4</td>
<td>0.868</td>
<td>0.9</td>
<td>2.4</td>
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<tr>
<td>Z-Matching</td>
<td>High-Z Antenna</td>
<td>Distrib. Elements Matching</td>
<td>High-Z Antenna</td>
<td>Resistance Compression Network</td>
<td>Lumped L-match</td>
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<tr>
<td>Diode</td>
<td>SMS7630</td>
<td>SMS7630</td>
<td>HSMS-2852</td>
<td>SMS7630</td>
<td>SMS7630</td>
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<tr>
<td>-20 dBm PCE</td>
<td>43%</td>
<td>33.6%</td>
<td>33%</td>
<td>25%</td>
<td>15%</td>
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<tr>
<td>-10 dBm PCE</td>
<td>70%</td>
<td>56%</td>
<td>55%</td>
<td>51%</td>
<td>35%</td>
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<tr>
<td>Max. PCE</td>
<td>83%</td>
<td>72%</td>
<td>NA</td>
<td>70%</td>
<td>76%</td>
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<tr>
<td>1 V Sensitivity</td>
<td>-9 dBm</td>
<td>-7 dBm</td>
<td>NA</td>
<td>-10 dBm</td>
<td>-6.5</td>
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<tr>
<td>Optimum load</td>
<td>20 kΩ</td>
<td>5 kΩ</td>
<td>NA</td>
<td>25 kΩ</td>
<td>NA</td>
</tr>
</tbody>
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Future Work: *Wide Dynamic-Range Rectenna*

- Future-work: wide-dynamic range rectenna array
- Tightly-coupled FDA array based on two diode models:
  - Low forward voltage $V_F$ diode for $-20$ dBm
  - High breakdown voltage $V_{Br}$ diode for $0$ dBm
Conclusion

• Parametric antenna-rectifier co-design.
  – Source and load impedance tuning for maximum RF-DC PCE.
• Tunable compact folded dipole antenna.
  – Thin and flexible low-cost substrate for textile-integrations
• The highest reported PCE of a discrete rectenna
  – 43%, 73%, and 82% at -20 dBm, -10 and -4 dBm.

• Future work: wide dynamic-range rectenna array
  – 28 dB 50% PCE dynamic range