RF Energy Harvesting for Wearable IoT, *from Cellular to mmWave Rectennas*

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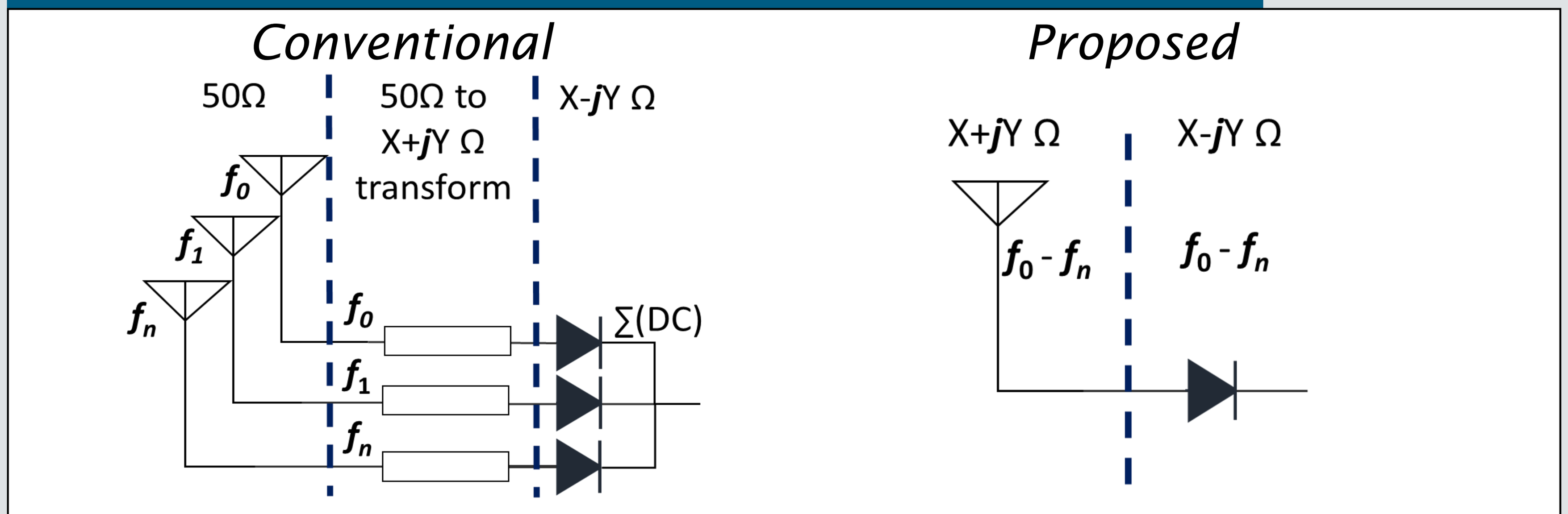
1. Abstract

Ambient Radio Frequency (RF) Energy presents a potential source for powering autonomous IoT devices in urban environments. Nevertheless, the **low sensitivit**y of existing RF energy harvesting (RFEH) systems and the **inefficient RF to DC** power conversion at low power densities have hindered the materialisation of an integrated solution.

This work presents methods to maximise the power harvesting and conversion efficiency, enabling **efficient recycling** of **ambient RF power** for wearable applications. A **broadband rectenna**, for harvesting power from **ambient** networks, is presented using low-cost high-efficiency multi-polarisation **textile antennas,** optimised for on-body operation. Millimetre-Wave WPT is investigated towards implementing high efficiency **RFEH rectennas** for future **5G mmWave networks**, enabling short-range **high-density wirelessly-powered networks**.

2. Novel Broadband Rectenna Architecture

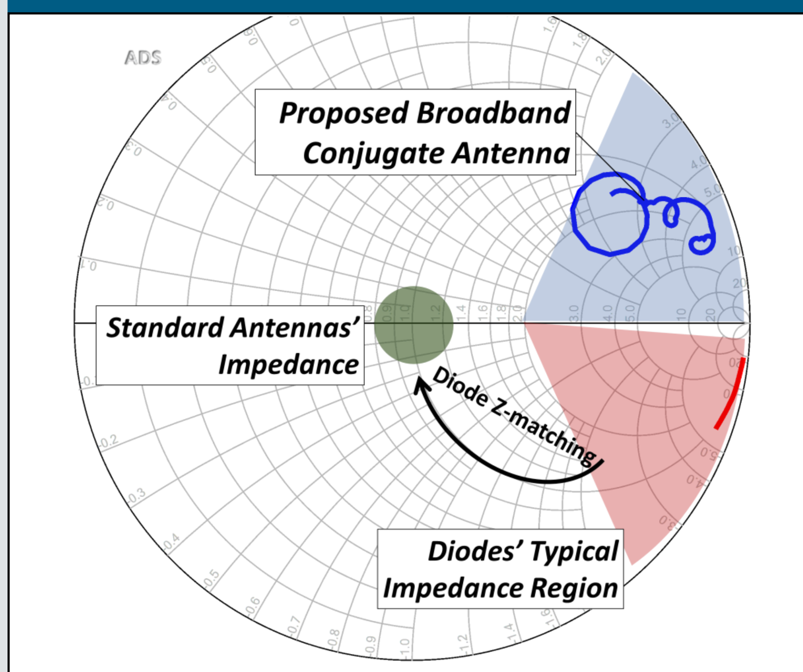


Matching network elimination using broadband high-impedance inductive antennas results in reduced losses, size and cost.

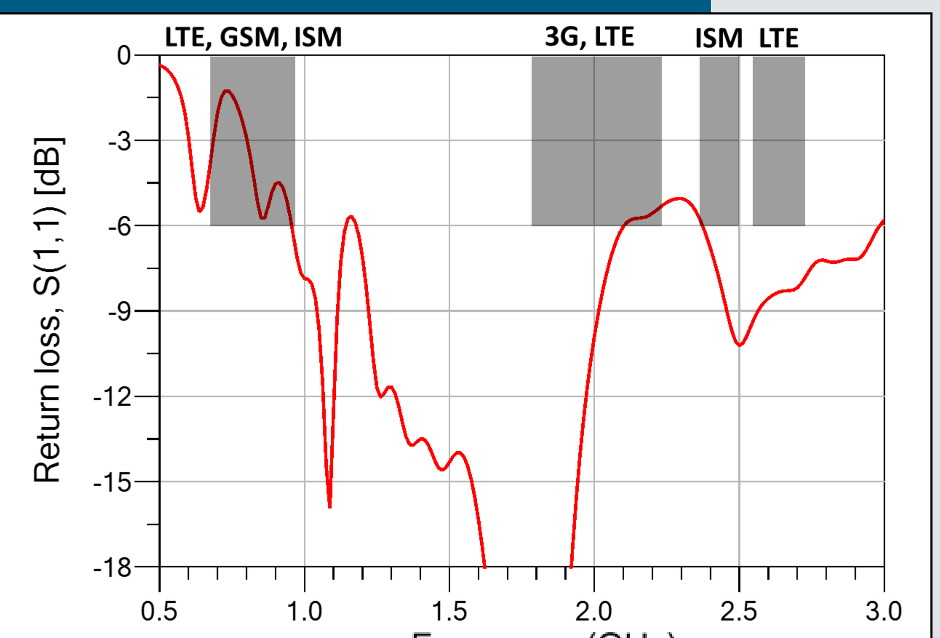
Wearable RFEH Challenges:

- Low antenna efficiency due to dielectric losses in textiles and in human tissue, at Up-microwave and mmWave bands.
- Low rectifier efficiency at low RF power levels
- Low Output voltage levels from RF rectifiers.

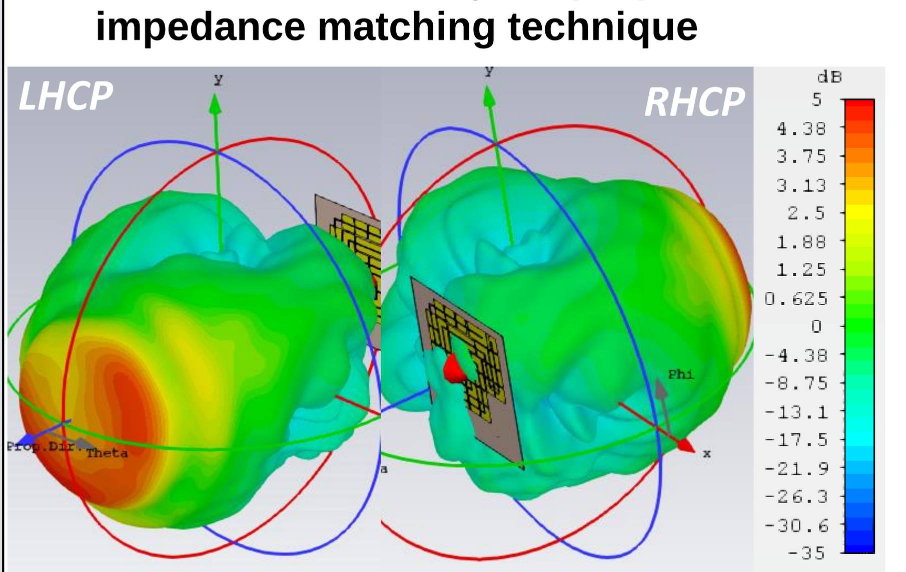
3. Broadband UHF Rectenna for Cellular RFEH



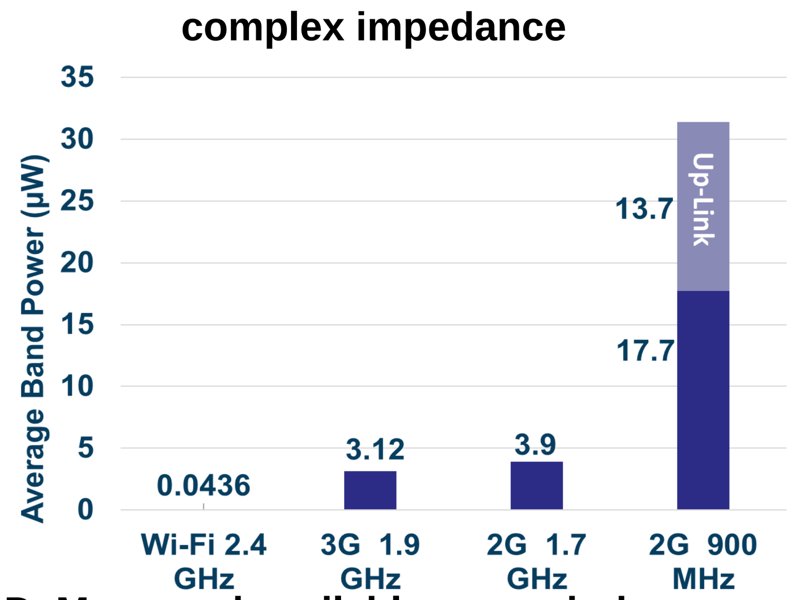
A. Smith chart showing the proposed impedance matching technique



B. Antenna bandwidth relative to the rectifier's complex impedance



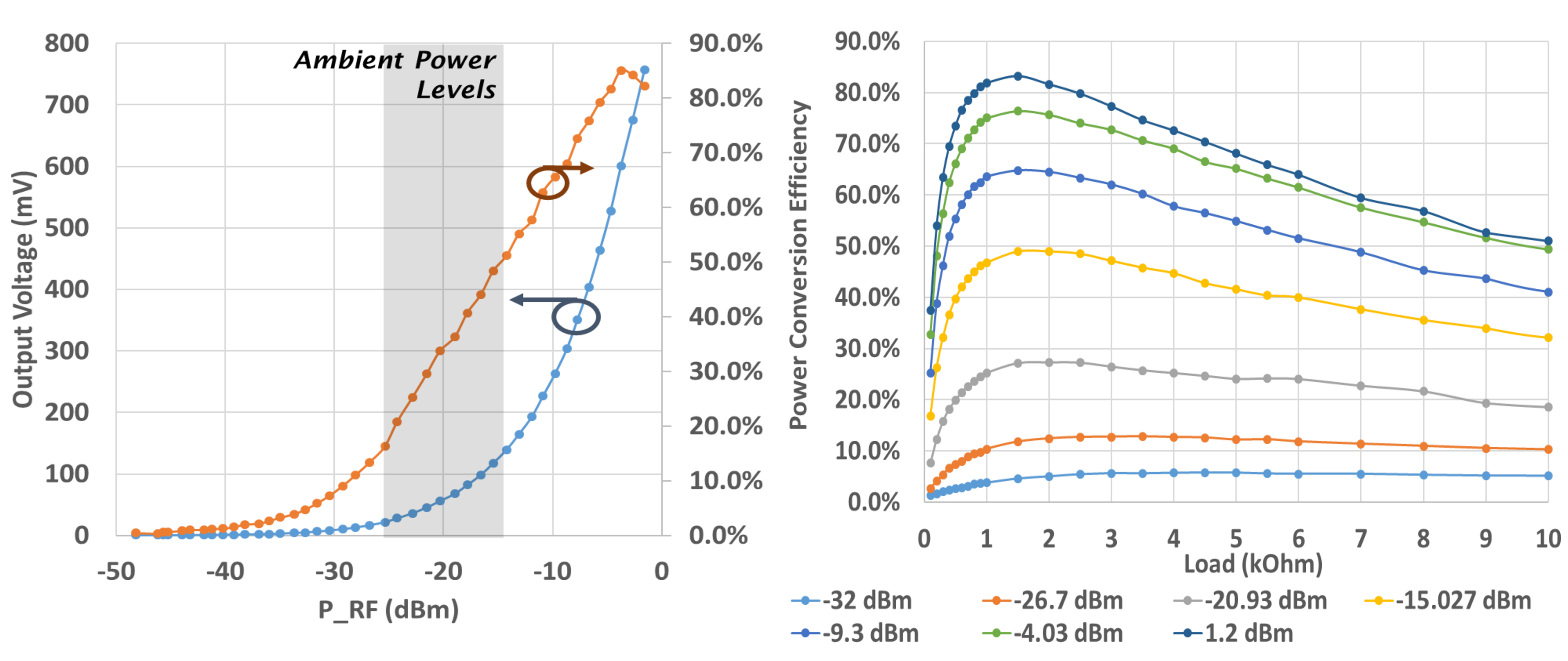
C. Simulated circularly-polarized gain at 1.8 GHz (left and right hand CP)



D. Measured available power indoor on-body

- The antenna's **high inductive-impedance** (Fig. 3A) enables directly matching (Fig. 3B) the rectifier's capacitive impedance.
- The **high gain** (>4 dB from 1 GHz in Fig. 3C) enables higher power harvesting from **low ambient RF densities** (Fig. 3D).
- The **dual-circular polarization** enables harvesting arbitrarily polarized incident waves.

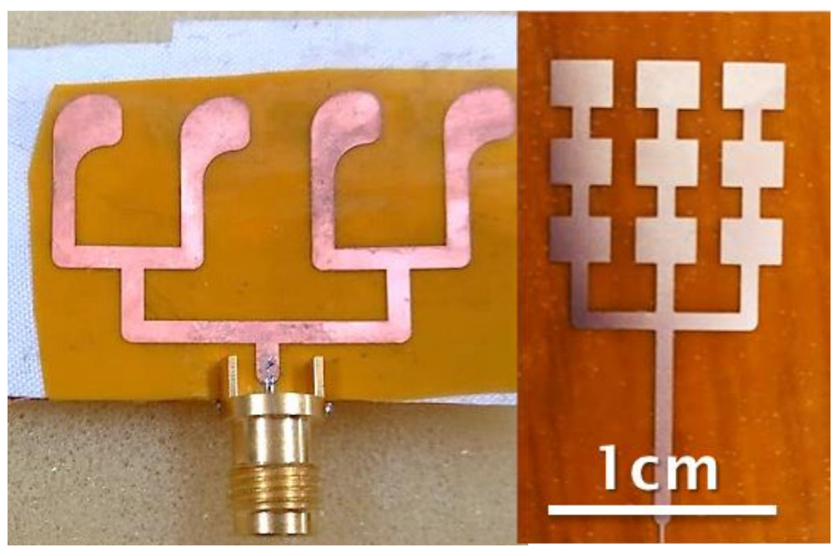
4. UHF Broadband Schottky Rectifier



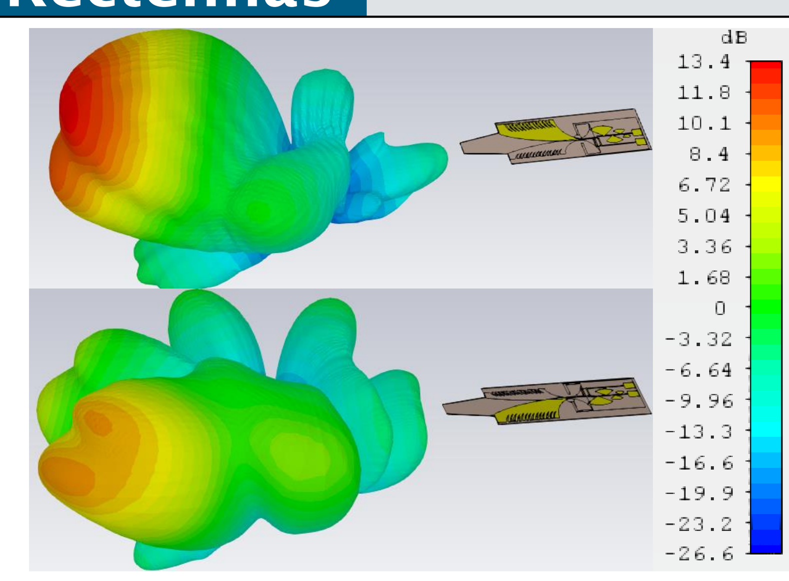
Measured PCE at different P_{RF} levels (left) and load impedances (right) at 1.8 GHz

Zero-bias Schottky RF diodes were experimentally characterized to design a **rectifier** with the **highest power sensitivity.** The rectifier demonstrates **High power conversion efficiency (PCE) (>25% from -20 dBm)** across the full UHF spectrum (0.7-2.7 GHz) using a single-series diode topology.

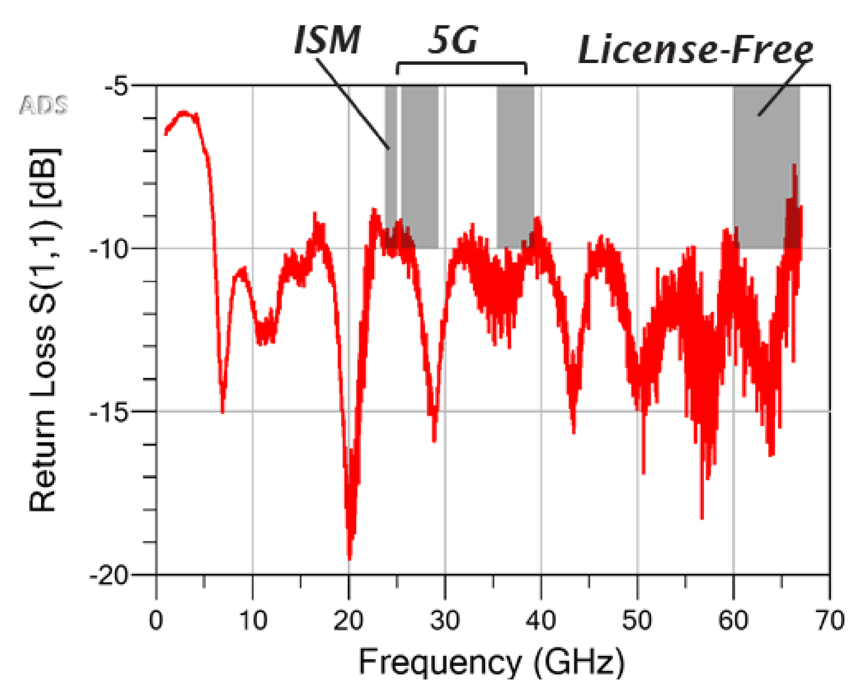
5. Towards Textile mmWave Rectennas



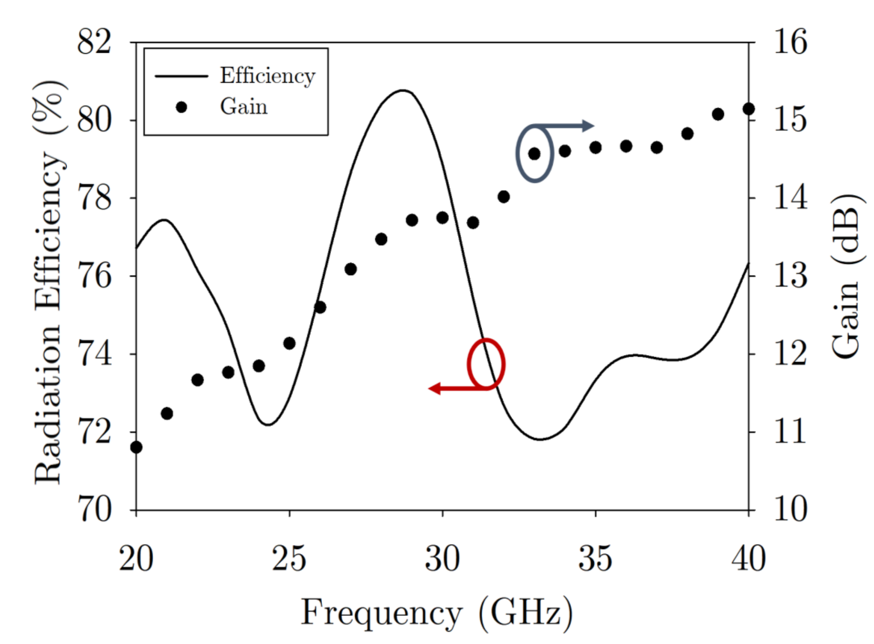
A. Textile UWB 4x1 array (left), 3x3 Polyimide patch array (right)



B. 3D 28 GHz radiation pattern, cross-pol (top) and co-pol (bottom) showing dual-linear polarization



C. Ultra-wide band (UWB) mmWave antenna S_{11} bandwidth



D. UWB antenna On-Body simulate gain and efficiency

High gain and efficiency UWB textile antennas (Fig. 5A) are presented with multi-polarization (Fig. 5B) for efficient mmWave WPT, achieving an impedance-bandwidth over the full mmWave spectrum (Fig. 5C).

The small antennas' size enable **high-gain arrays** within constrained-area. A novel area-reduction technique reduces the dielectric losses and result in **improved gain and efficiency** [1]. Up to **15 dBi single-antenna gain** is achieved **on-body** (Fig. 5D) using an UWB modified Vivaldi antenna.

6. Conclusion

Dual-polarisation, high gain, **broadband UHF** and **mmWave** antennas, for RFEH have been presented with matching-network-elimination for improved bandwidth and efficiency. A high-efficiency **rectifier** using **RF Schottky diodes** has been presented for broadband UHF ambient RFEH. Future work includes **reconfigurable multi-stage rectifier** design in a standard **CMOS** process, with **integrated power management** and cold-start circuit.

References:

1. Wagih et. al. "Millimeter-Wave Textile Antenna for On-Body RF Energy Harvesting in Future 5G Networks" *IEEE Wireless Power Transfer Conference*, 2019 [Accepted]

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