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RF Energy Harvesting System for Battery-Less Internet of Things Devices

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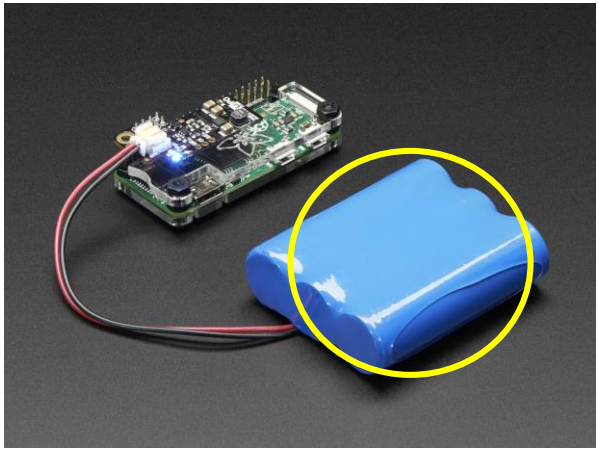
I. Introduction



Most low – powered devices use batteries.

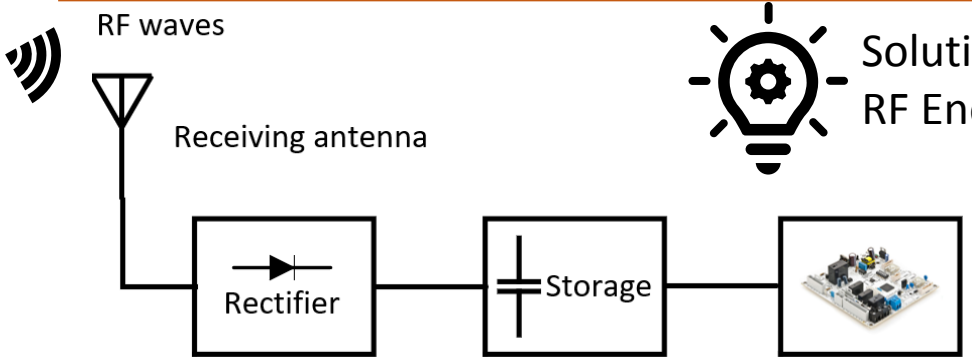
Limited lifespan

Environmentally hazardous

High maintenance cost

Not sustainable!

I. Introduction



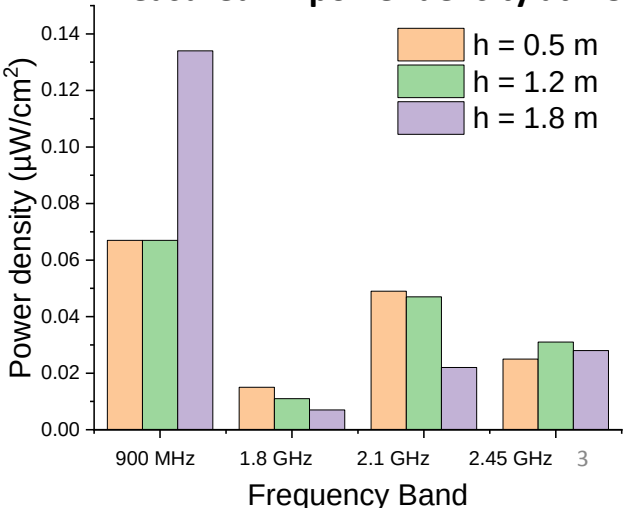
RF Energy Harvesting structure

Solution:
RF Energy Harvesting

Main challenge:

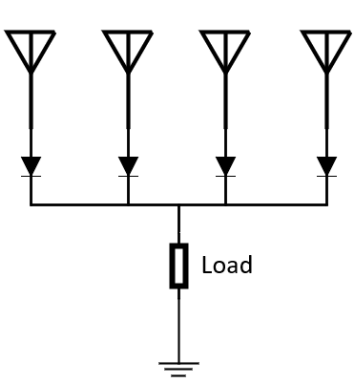
Low power density

Measured RF power density at HUST

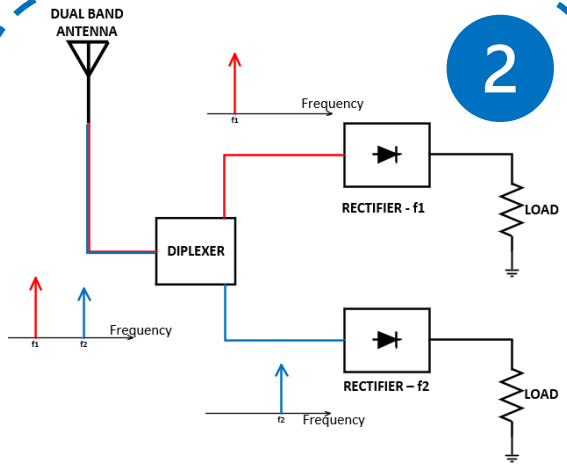


I. Introduction

Solutions for rectenna with low incident power density:



Using multiple rectennas (array) to harvest more power from single frequency band



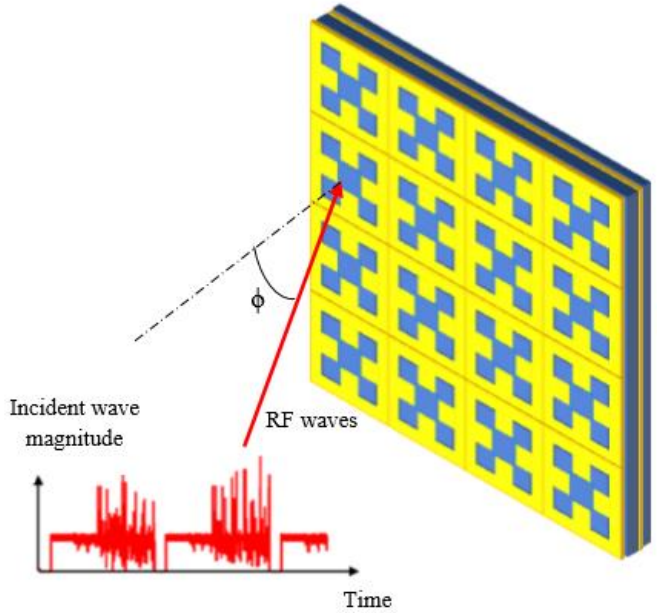
Harvest from multiple frequency bands

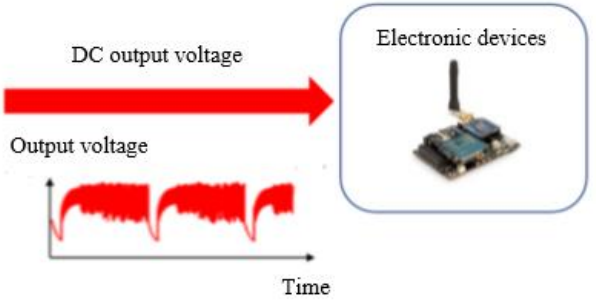
II. Array Harvester: Idea

Metamaterial absorber (MMA) as antenna array

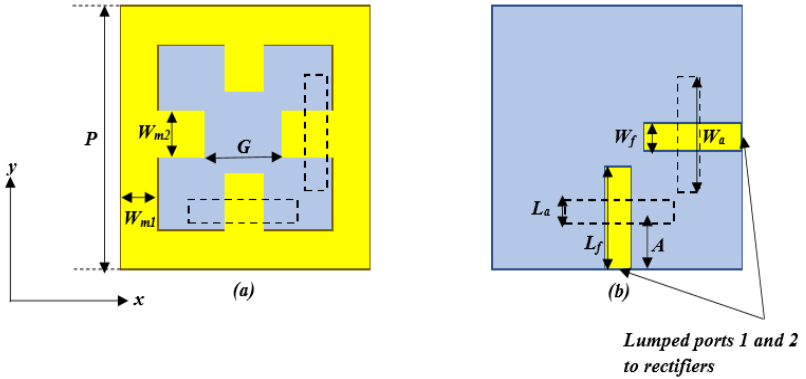
Single frequency band

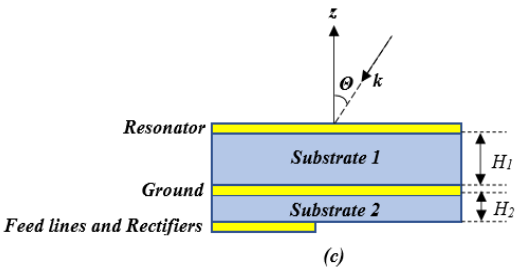
- Wide surface area → More power harvested
- Symmetry → Polarization insensitivity
- DC – combine → Wide – angle property





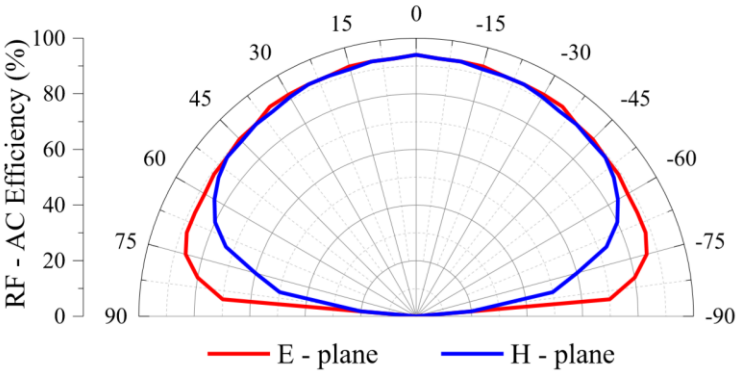
II. Proposed Array Harvester: unit cell



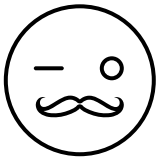


- Substrate: RT Duroid 5880
- Feeding technique: Aperture couple
- Port 1 and 2 represent the rectifiers in CST simulation!

II. Proposed Array Harvester: unit cell

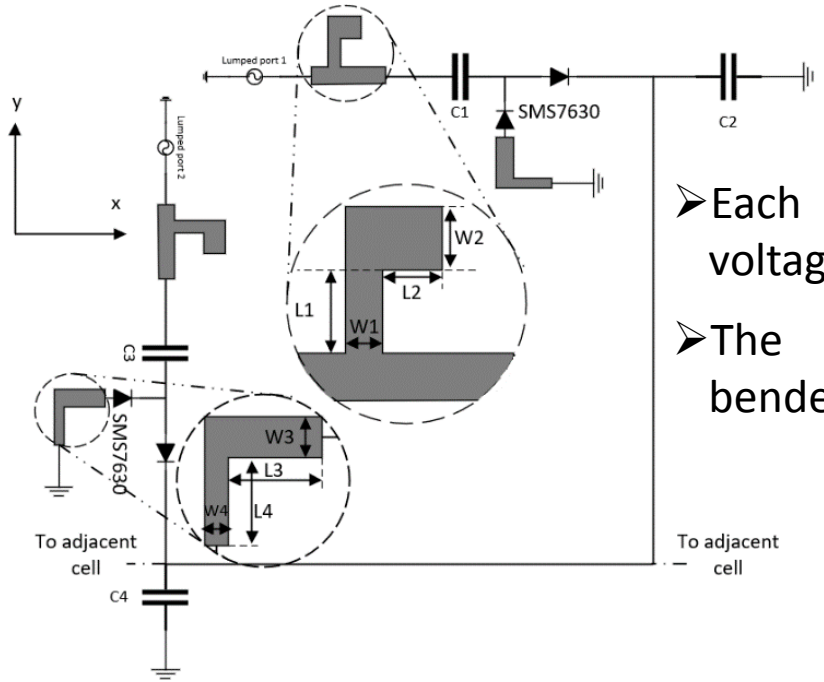


- Maximum RF – AC efficiency: 94% (normal incidence).
- Wide – angle absorption confirmed!



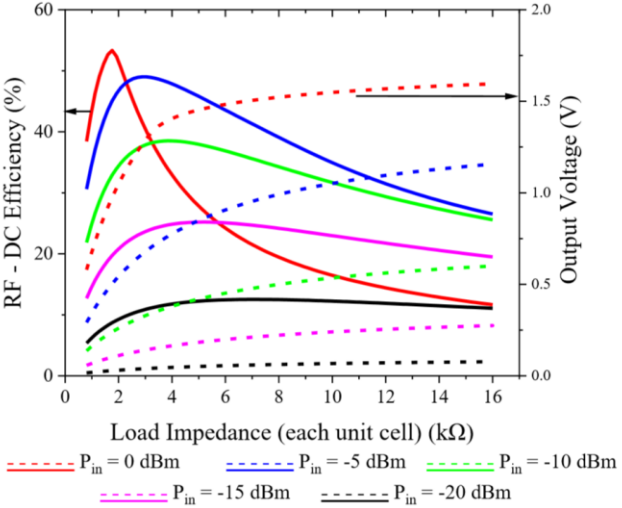
In some previous works on MMAs, the terms "TE" and "TM" are used instead of E – plane and H – plane. They are equivalent nevertheless.

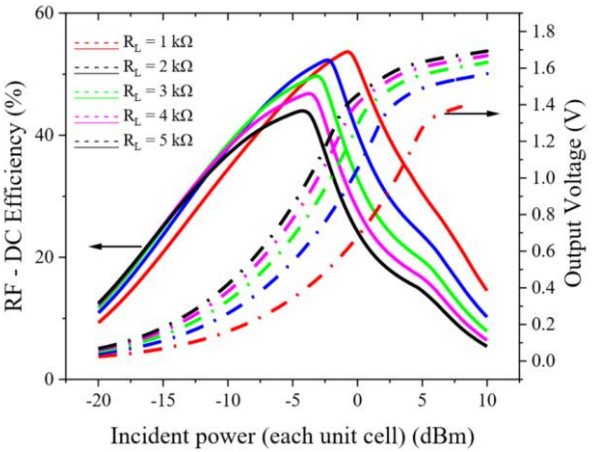
II. Proposed Array Harvester: unit cell



- Each unit cell has two voltage doubler rectifiers.
- The matching stubs are bended to reduce size.

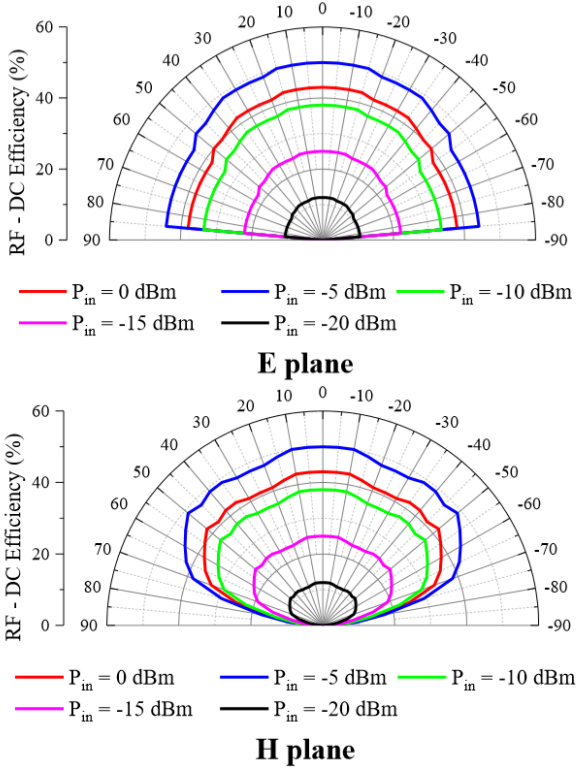
II. Proposed Array Harvester: unit cell





- Maximum efficiency: 53% at 0 dBm.
- At low input power: 43% at -5 dBm, 38% at -10 dBm.

II. Proposed Array Harvester: Full Structure



- The angle – dependency is tested on simulation (4 x 4 array).
- The unit cells have their phased modelled as

$$\Delta\phi = \frac{2\pi . p . sin\theta}{\lambda}$$

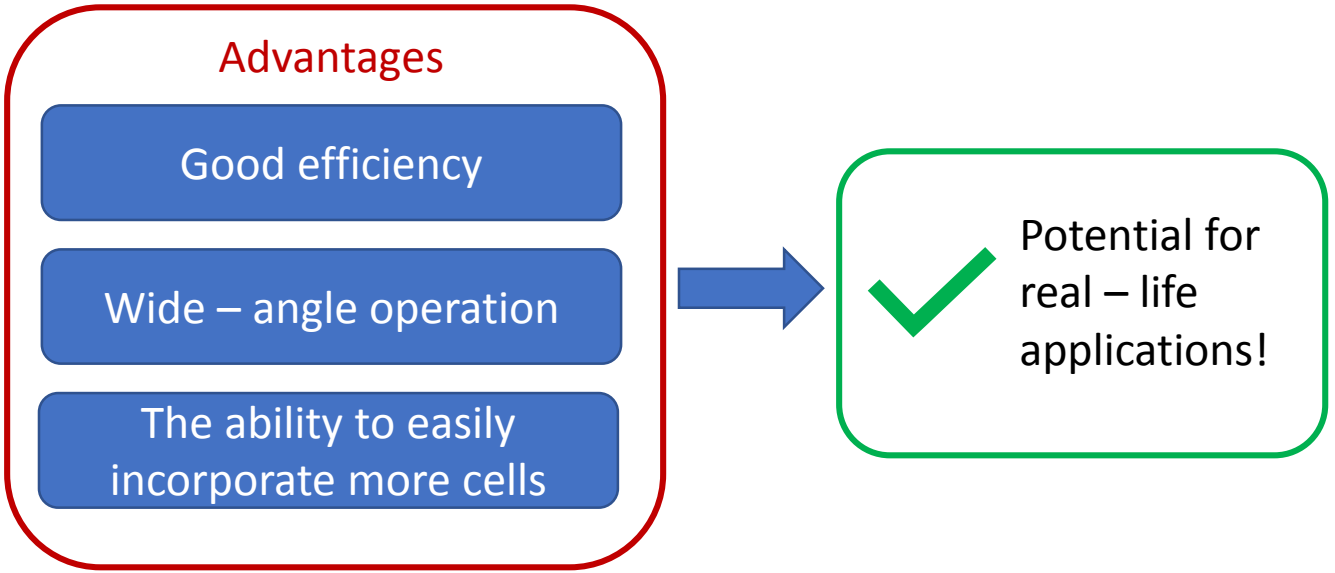
p: inter – cell distance

θ: incident angle

λ: wavelength at 3.75 GHz

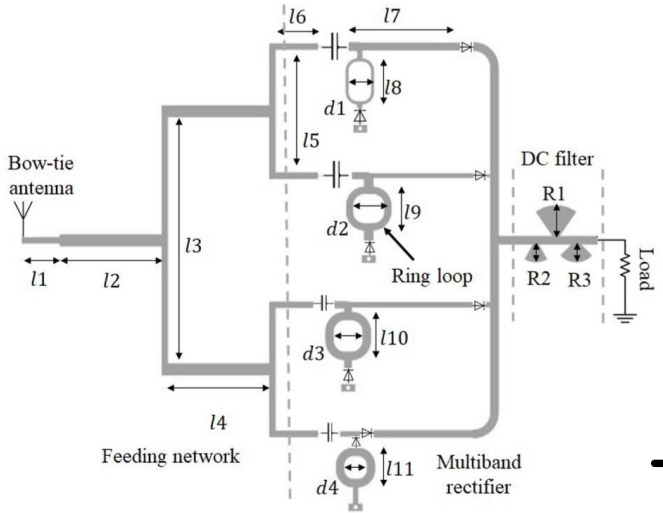
- Wide – angle RF – DC conversion is confirmed!

II. Proposed Array Harvester: Discussion



IV. Multiband Rectenna: Idea

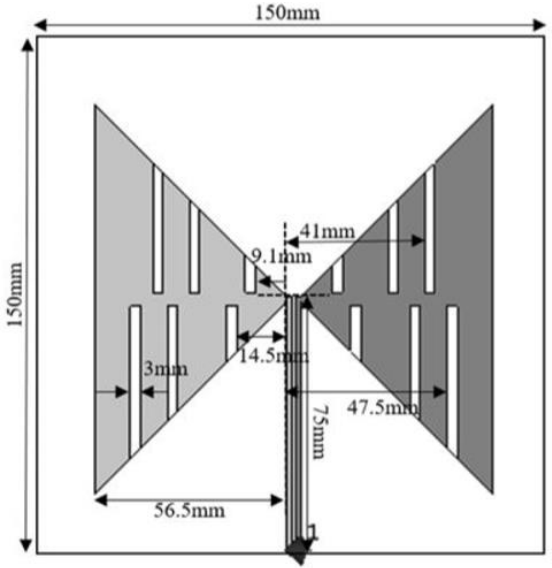
Multiband rectennas
Multiple frequency bands



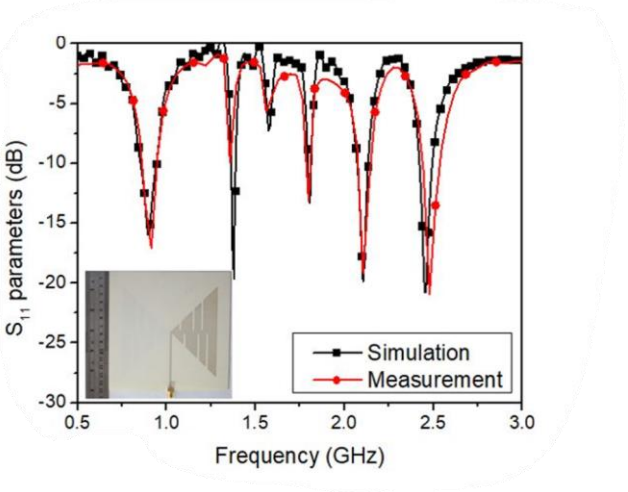
- Using multiband rectennas to harvest from multiple available RF frequency bands.
- Harvest energy from 4 most available RF sources:
  - GSM 840 MHz.
  - GSM 1.8 GHz.
  - 4G 2.1 GHz.
  - WiFi 2.45 GHz.

→ Maximize the amount of power harvested

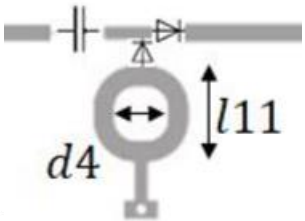
IV. Proposed Multiband Rectenna: Antenna

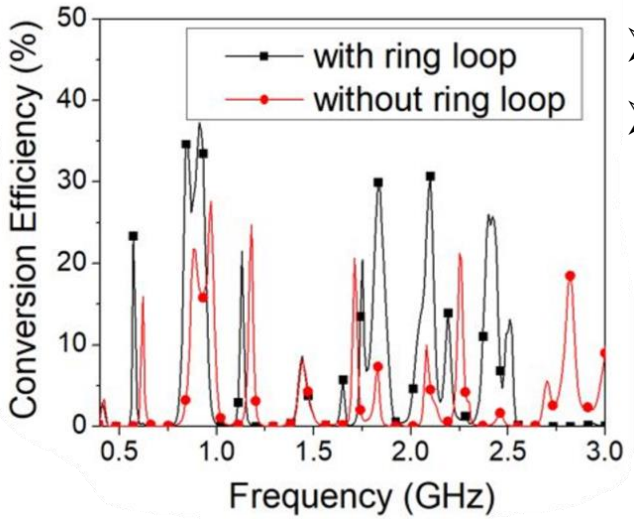


- Multiband bow-tie antenna.
- Multiple resonances are excited and controlled by creating and arranging the slits.



IV. Proposed Multiband Rectenna: Rectifiers

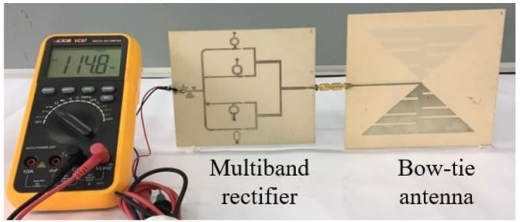




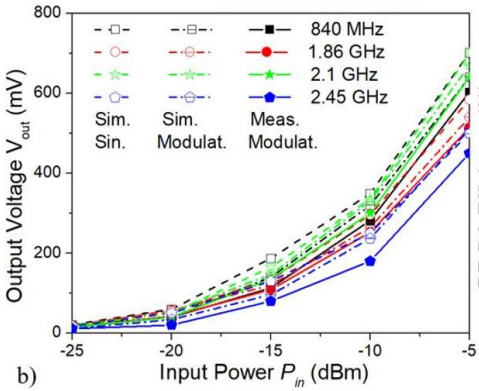
- Multiband rectifier:
  - Consists of 4 monoband rectifier.
  - Each monoband rectifier is a half-wave voltage doubler.
- Diode: SMS7630.
- Good rectification efficiency at -10 dBm input power:
  - 840 MHz: 38%.
  - 1.8 GHz: 30%.
  - 2.1 GHz: 32%.
  - 2.45 GHz: 27%.

IV. Proposed Multiband Rectenna: Full Structure

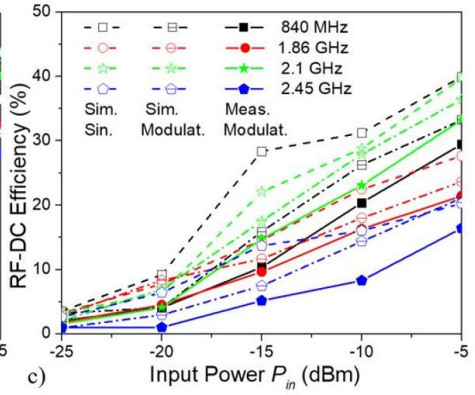
- The full structure was tested under both pure sine wave and modulated wave.



a)



b)



c)

- Good RF-DC efficiency (at -10 dBm):
  - 840 MHz: 21%.
  - 1.8 GHz: 15%.
  - 2.1 GHz: 22%.
  - 2.45 GHz: 10%.

IV. Multiband Rectenna: Discussion

- Advantages:
  - Compact size.
  - Good efficiency at low input power.

- Notable drawback:
  - Difficult to design and optimized.
  - Difficult to incorporate more frequency bands

V. Discussions and Conclusion

- **What we have achieved so far:**
  - Single-band rectenna array with good efficiency and wide harvesting angle.
  - Dual-band rectenna with good efficiency and the ability to incorporate more frequencies.
  - Multiband rectenna with good efficiency and compactness.
  - Enough power supply for an IoT device at sleep mode

- **Ongoing challenge:**
  - The amount of power harvested is still insufficient for an IoT device at active mode.
  - Wireless power transfer instead of ambient RF energy harvesting
  - Power management solution must be integrated

Thanks for your attention!

All comments and questions are appreciated!