Laminate-Embedded Multimodal Energy Harvester for Multilevel Power Supply

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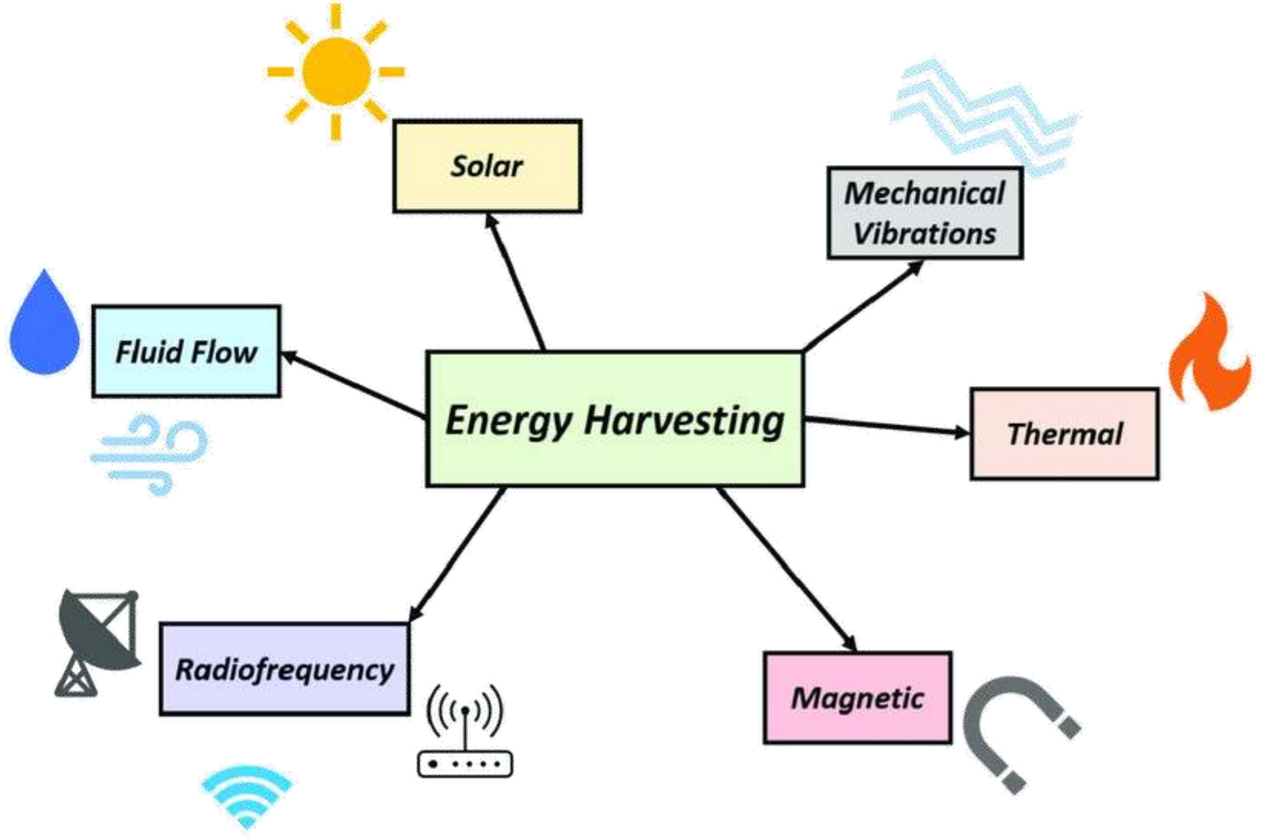
Introduction

Power harvesting offers unique opportunities to eliminate tethered power supply and, in certain cases, the requirement for large power storage with batteries. The requirements vary from microwatts to much higher values based on system needs and functions.



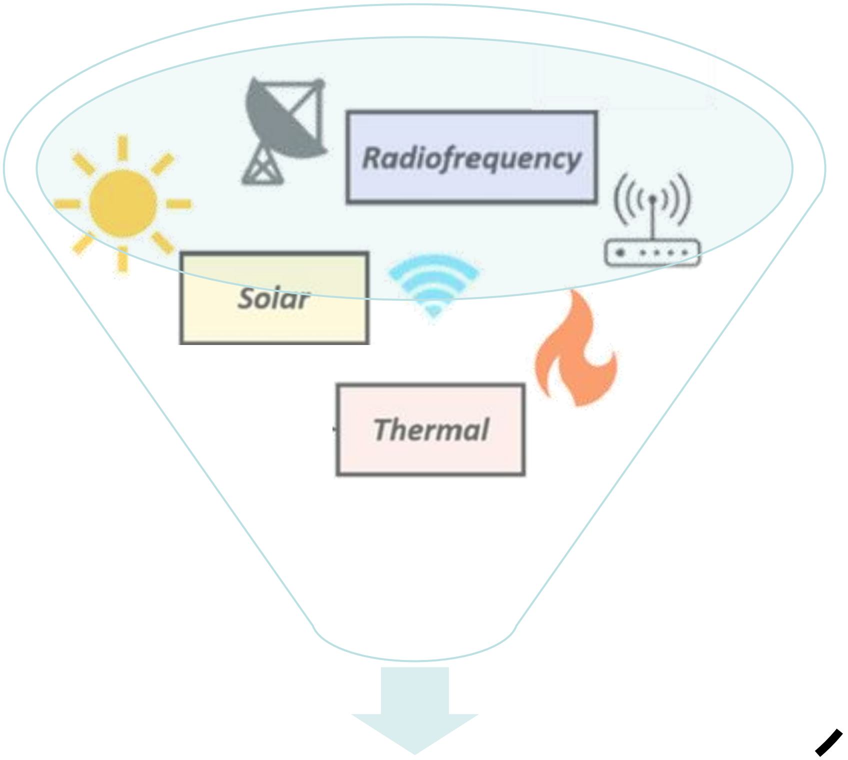
IoT Sensors

Health Monitoring Devices

Portable Communication Systems

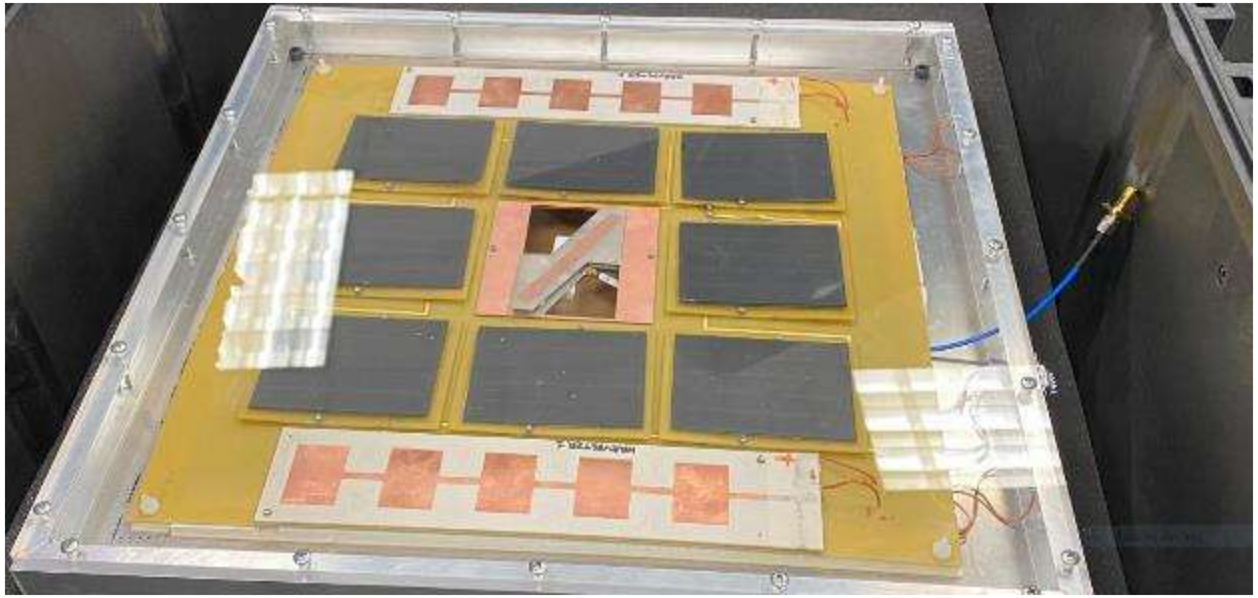
Proposed Concept

More complex emerging systems, require power supply at multiple voltage levels to address different system functions and for efficient power management. It is beneficial to simultaneously power multiple modes to produce output at multiple voltage and power levels. The goal of this research is to utilize multiple modes of power harvesting for ubiquitous and continuous power generation and supply.



Three modes of simultaneous harvesting are packaged in this work: RF, solar, and thermoelectric power harvesting

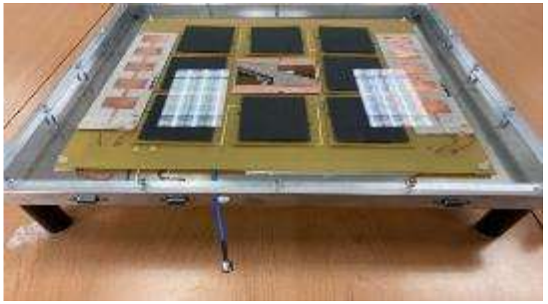
3D Power Packaging Concept



Overall Design

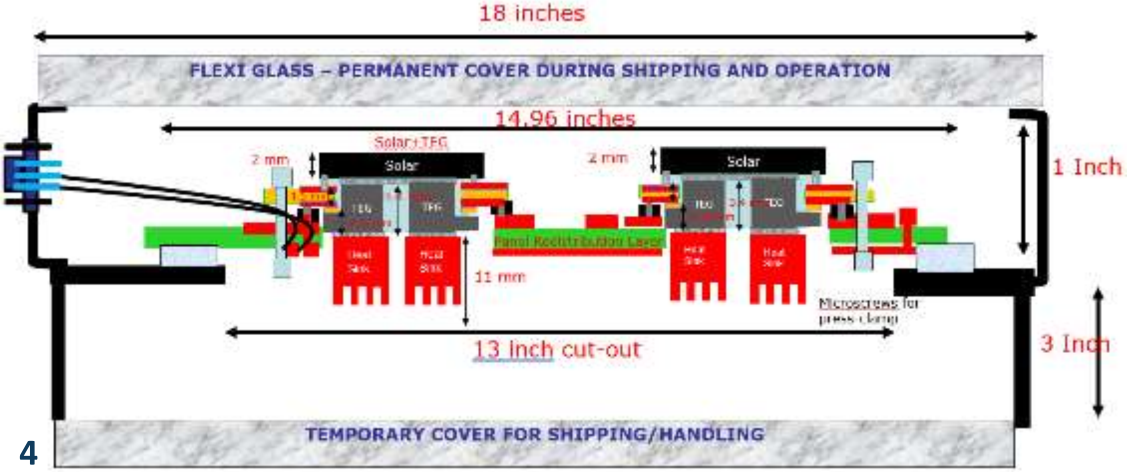
A unique multimodal 3D power packaging concept with broadband communication. The panel supports solar, thermoelectric, and RF harvesting, along with a 2-18 GHz broadband communication with a slot-array antenna. The package consists of: 1) 8 solar cells, 16 TEGs with 16 heat sinks, an ultra-wideband (UWB) antenna array, and 2 antenna harvesters. Harvesting units are mounted on the top and bottom sides while the antenna array is mounted on the center.

Top View



Bottom View

Assembly of STEG on Panel

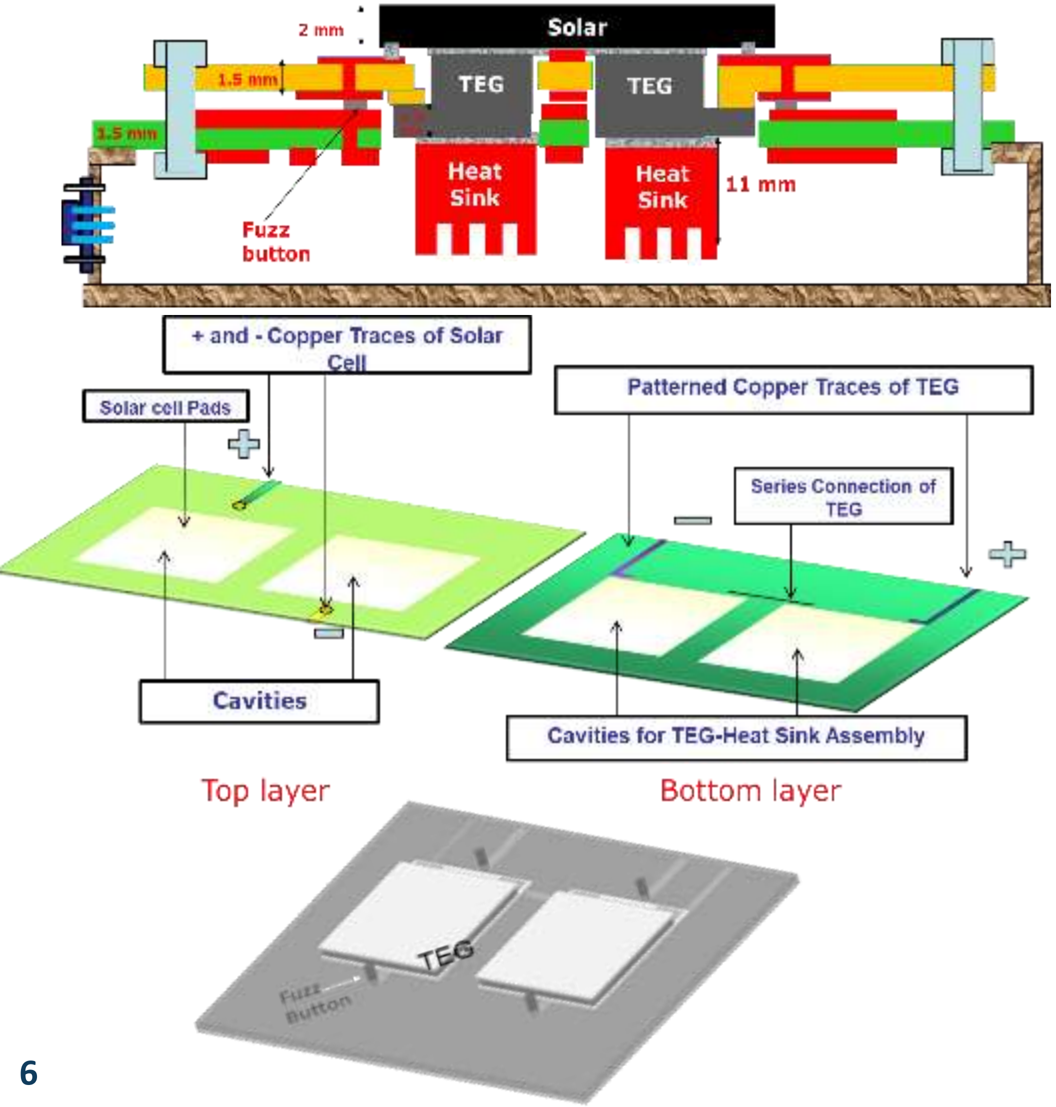


1. 3D vertical stacking with substrate-embedding of RF and solarTEG module assembly with integrated broadband communication antenna
2. High-gain linear antenna arrays for RF power harvesting
3. Remateable clamped fuzz-button assembly from the module to the panel for easy removal
4. Simultaneous harvesting of multi-voltage domains (i.e.: 4.1 mV, 1.5 V, and 51V)
5. Glass encasing for increased thermal gradient and output power

I. Solar and Thermoelectric Harvesting

Solar-TEG Module Operation and Assembly

In this concept, solar cells, thermoelectric generators (TEGs) and heatsinks are stacked with silver adhesives in the vertical direction for low thermal impedances.



01 TEGs are designed with a top functional layer and an extended ceramic layer on the bottom with interconnection pads.

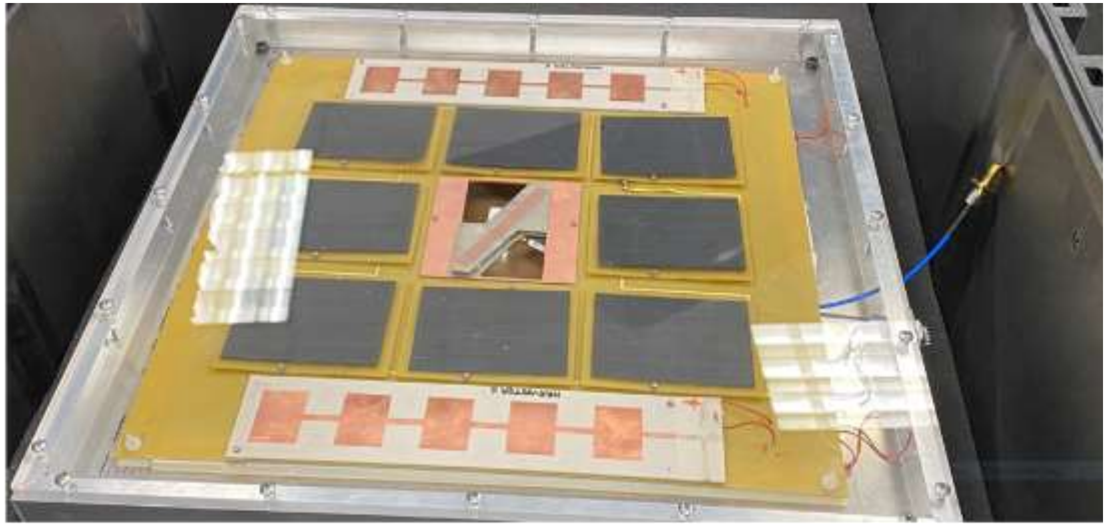
02 TEGs are embedded inside the module substrate cavities and are assembled facing up.

03 Solar cells are interconnected onto the top trace layers by flipchip assembly with silver adhesives.

04 The solar-TEG (S-TEG) modules are interconnected in series and are assembled on a panel with redistribution layers (with fuzz button connections).

Solar-TEG Module Operation and Assembly (Cont.)

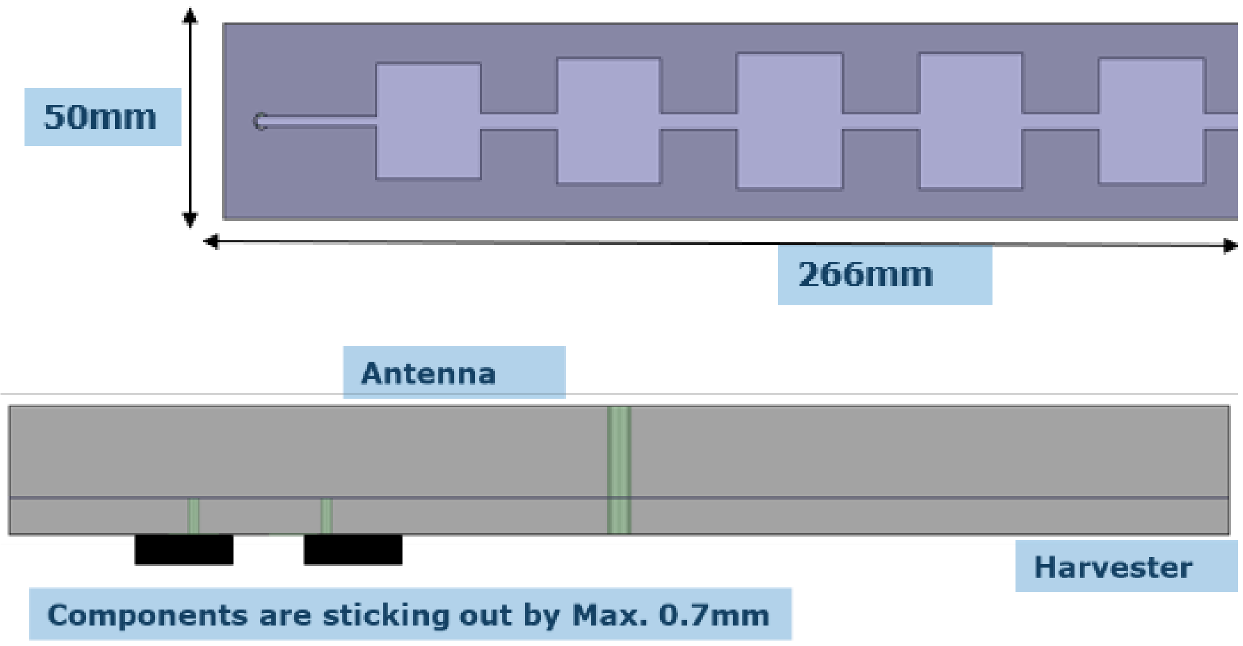
- Fuzz Buttons are used to provide electrical connections from module to the panel.
- Low resistance is achieved with sufficient compressive clamping forces between the module and panel through nuts and bolts.
- Whole panel assembly is mounted onto a c-bracket aluminum frame with total dimensions 15’’x15’’x 1”, sitting on 4 legs of 3” each and covered by a plexiglass.
- By mounting a glass substrate on the top, the solar cell temperatures are further raised to generate more power through the TEGs.
- The panel outputs are connected to DB9 connectors with soldered wires.
- The final output voltage is tested. The eight solar cells provided ~54 V while the 16 TEGs in series provided as high as 1.4 V.



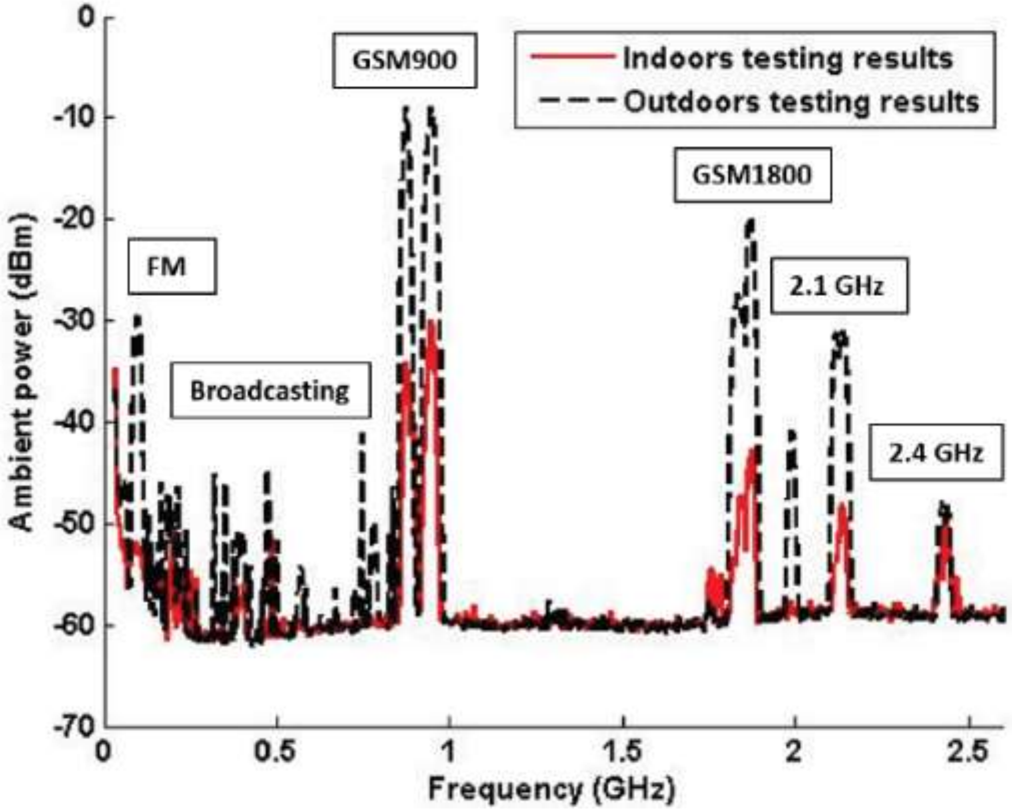
II. RF Harvesting

RF Harvesting Antenna Design

The harvester antenna design consists of 1x5 series fed linear patch array. This design is based on GSM frequency (1800 MHz) because of the large available ambient power.



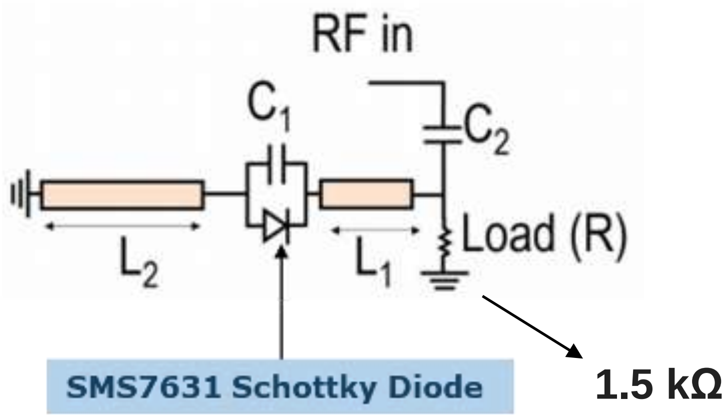
Ambient Power at Different Frequency Bands



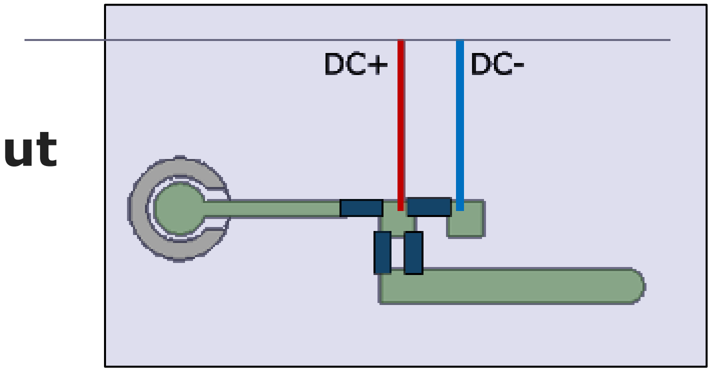
RF Harvesting Circuit Design and Testing

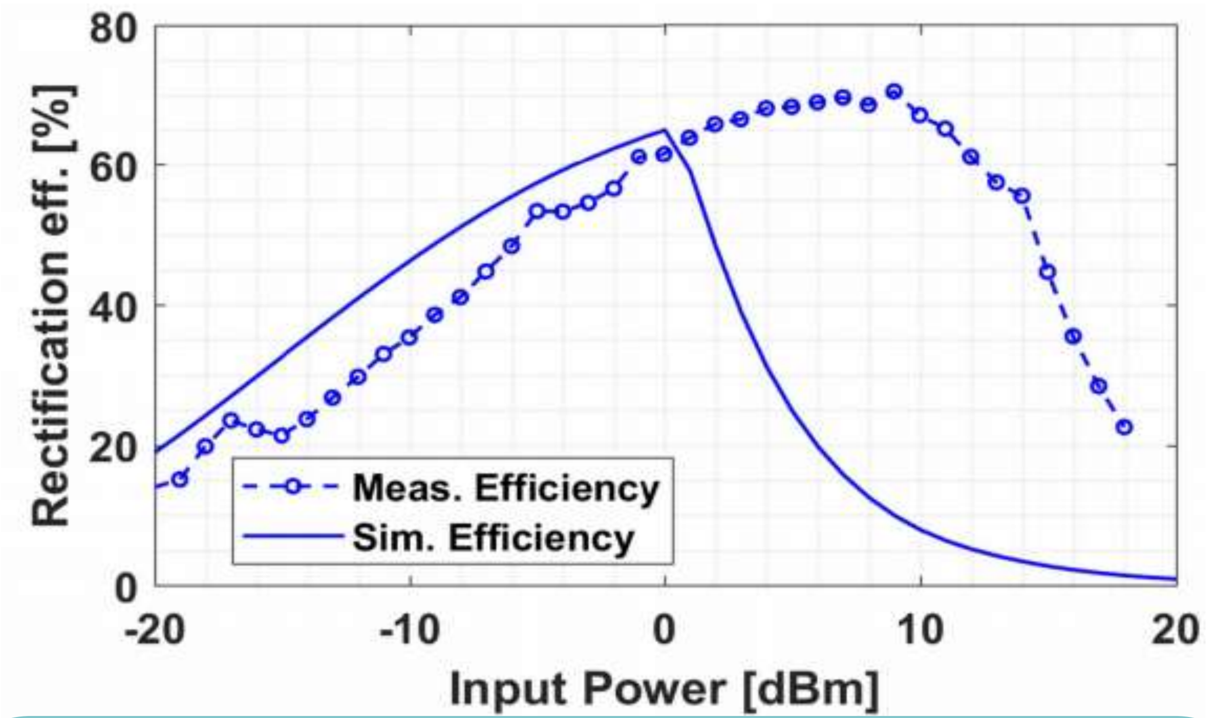
The design is optimized assuming a -10 dBm ambient power and a 10 dBi antenna gain. The realized efficiency in this case is 40%.

Harvester Circuit



Board Layout





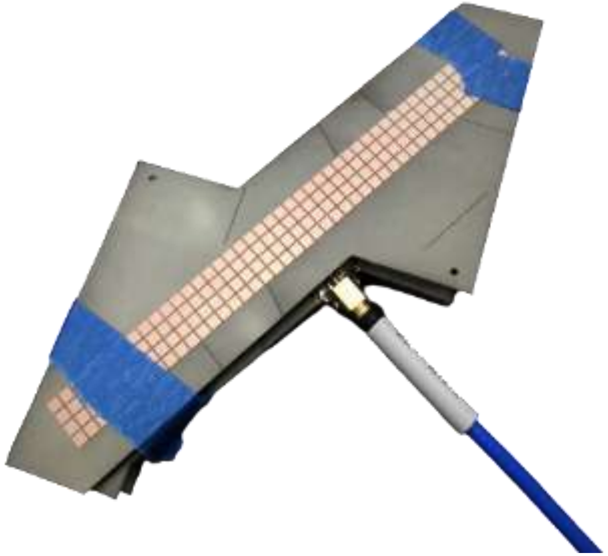
1) Horn antenna is plugged to a 1.8GHz source with a variable power.
2) To achieve the adequate power level, the cable is calibrated, and the output power of the Horn antenna is measured using a power spectrum analyzer.
3) The antenna gain as well as the free space loss between the Horn and the Harvester are accounted for to calculate the shined power in the direction to the Harvester.
4) The DC output versus the power shined at the antenna is measured to calculate the efficiency.

Efficiency: $\frac{P_{RFin}}{P_{DC}} \times 100$

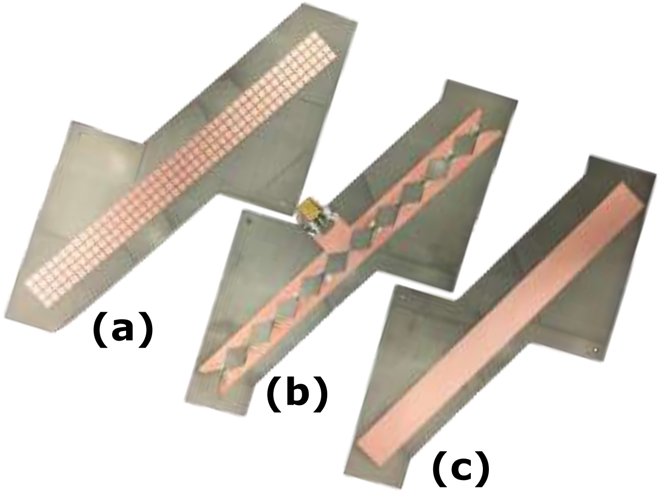
III. Communication System: UWB Antenna

1.8 – 18 GHz (10:1) Ultra-Wideband Antenna Array

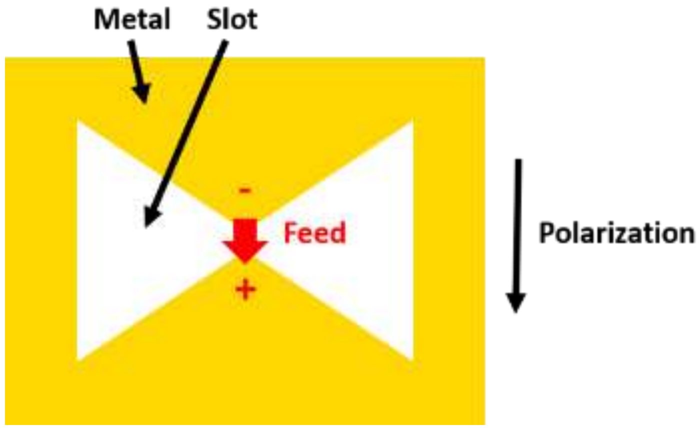
We have designed an 11×1 bowtie slot antenna array with a 10:1 bandwidth in a low-profile package.



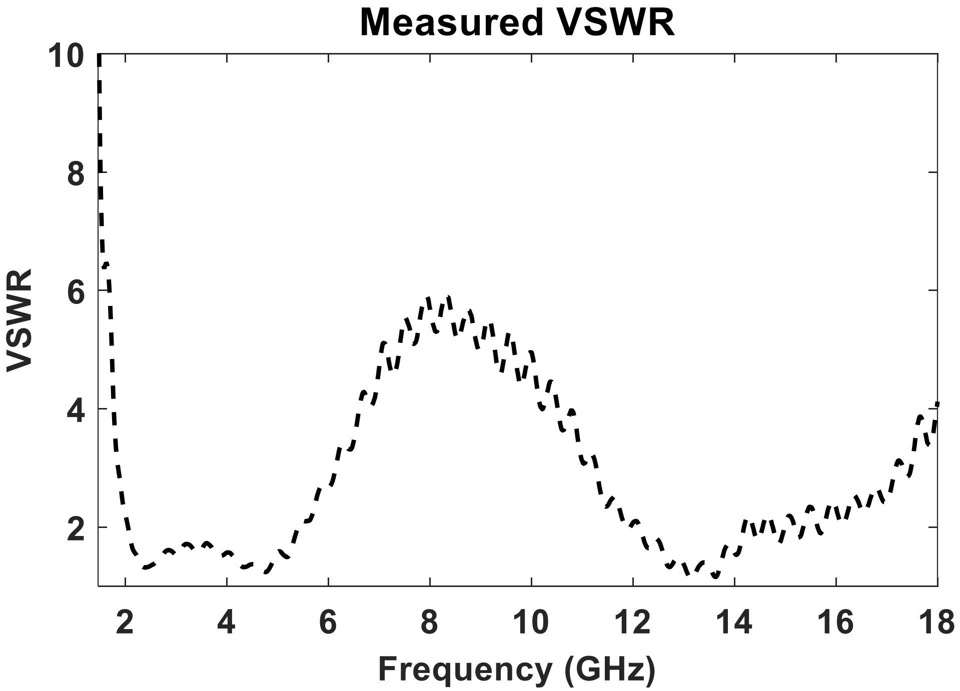
Assembled array.



(a) FSS; (b) slot; & (c) ground.



Unit cell and its polarization.



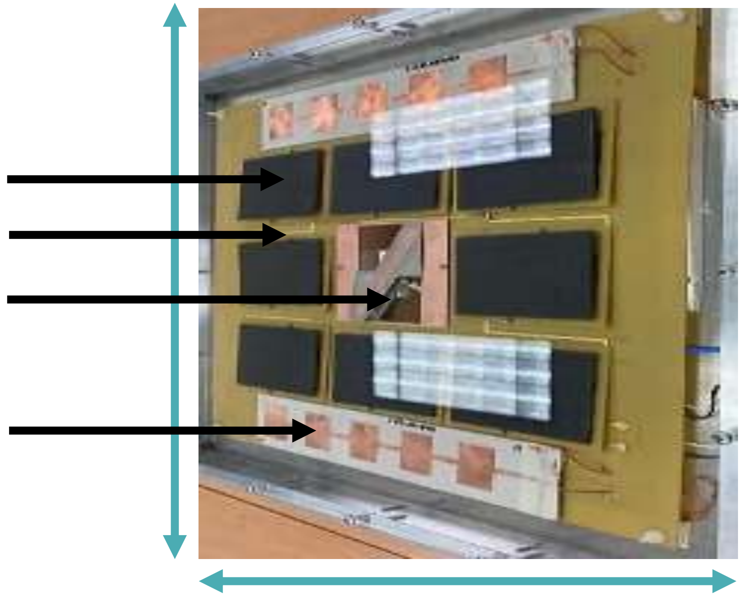
Frequency	1.8 to 18 GHz
Impedance	50 Ω
VSWR	2.82 average <2 from 2 to 5.4 GHz
Polarization	Linear (perpendicular to the antenna length)

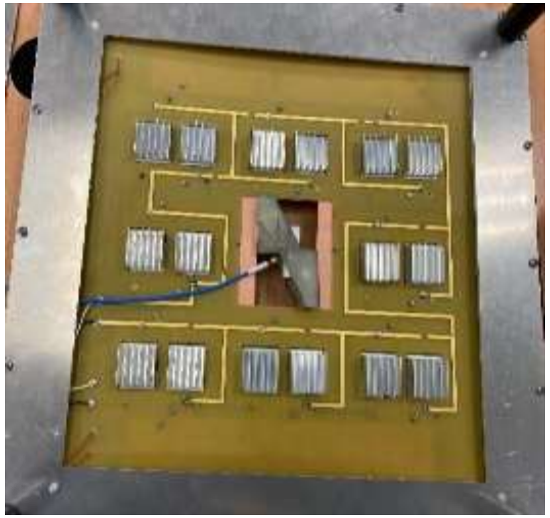
IV. Final System Testing

Final System’s Testing Specifications

Solar Panels	**Voltage**	50.81 V
	Current	550 mA
	Power Output	28 W
TEGs	**Voltage Output**	1.26 V
Power Harvester	**Gain**	10 dBi at 1.8 GHz
	Voltage Output	4.1 mV
UWB Antenna	**Frequency**	1.8 to 18 GHz
	Impedance	50 Ω
	VSWR	2.82 average <2 from 2 to 5.4 GHz
	Polarization	Linear (perpendicular to the antenna length)

Top View





Bottom View

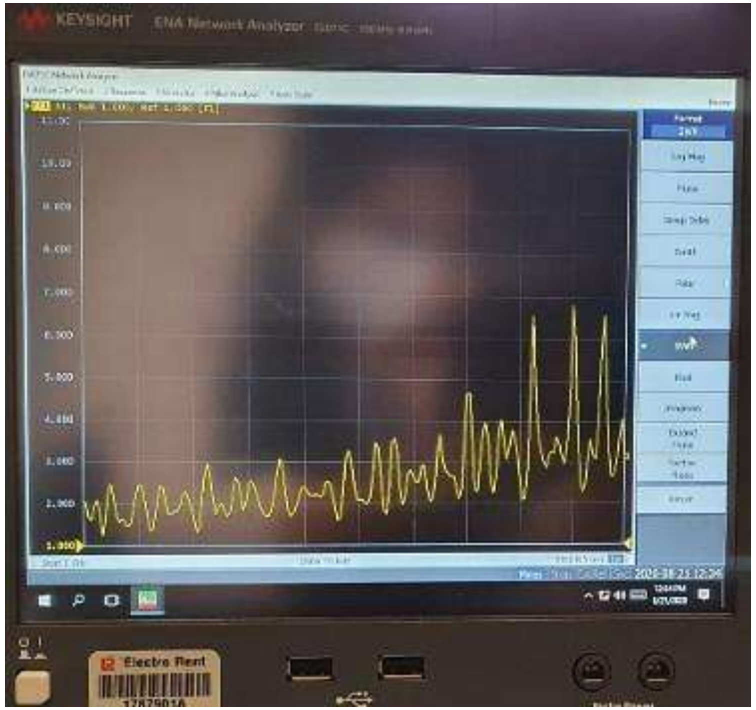
Final System's Measurements

Solar Output Voltage

Harvester Output Voltage

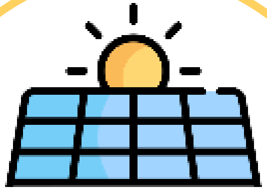
TEG Output Voltage

Antenna Output



Conclusion

The 3D power packaging concept with broadband communication supports **solar, thermoelectric, and RF harvesting**, along with a 2-18 GHz broadband communication with a slot-array antenna.



Solar Cells

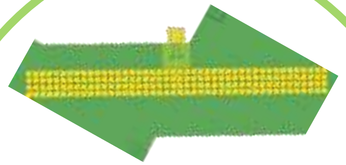
are interconnected onto the top trace layers

08

16

TEGs

and 16 heatsinks embedded inside the substrate cavities



Antenna Array

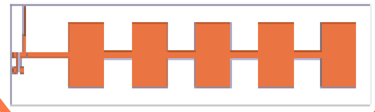
with a 10:1 bandwidth and low-profile

01

02

RF Harvesters

working at the GSM band (1.8 GHz)



*the modular design enables quick replacement and repair.


Thank you