SIMULTANEOUS WIRELESS INFORMATION AND POWER TRANSMISSION

Prof. Nuno Borges Carvalho
Universidade de Aveiro
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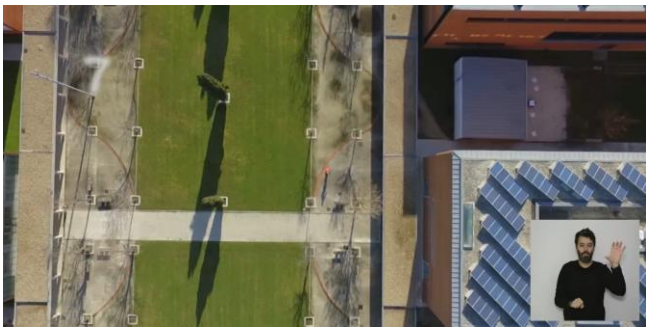
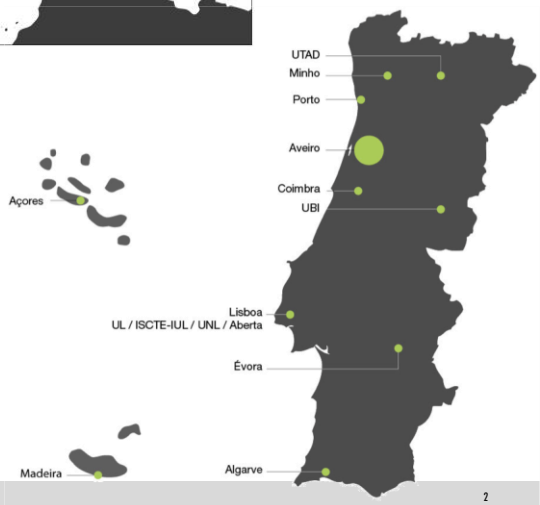
universidade de aveiro
um campus que pensa
1973.2013





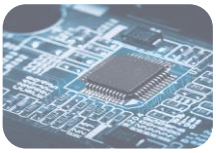
INSTITUTO DE TELECOMUNICAÇÕES

wireless technologies

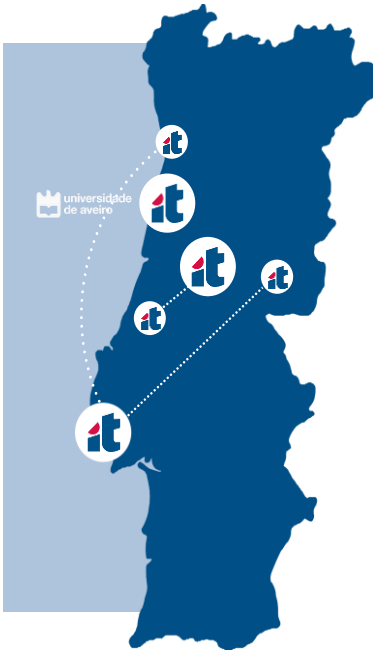
optics & photonics

information & data sciences

networks & services



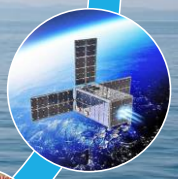
basic sciences & enabling technologies



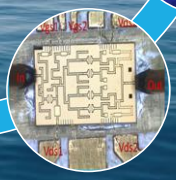
radio systems

SDR – 5G/6G Technologies

Wireless Power Transmission – RFID - IoT



Satellite New Space Communications

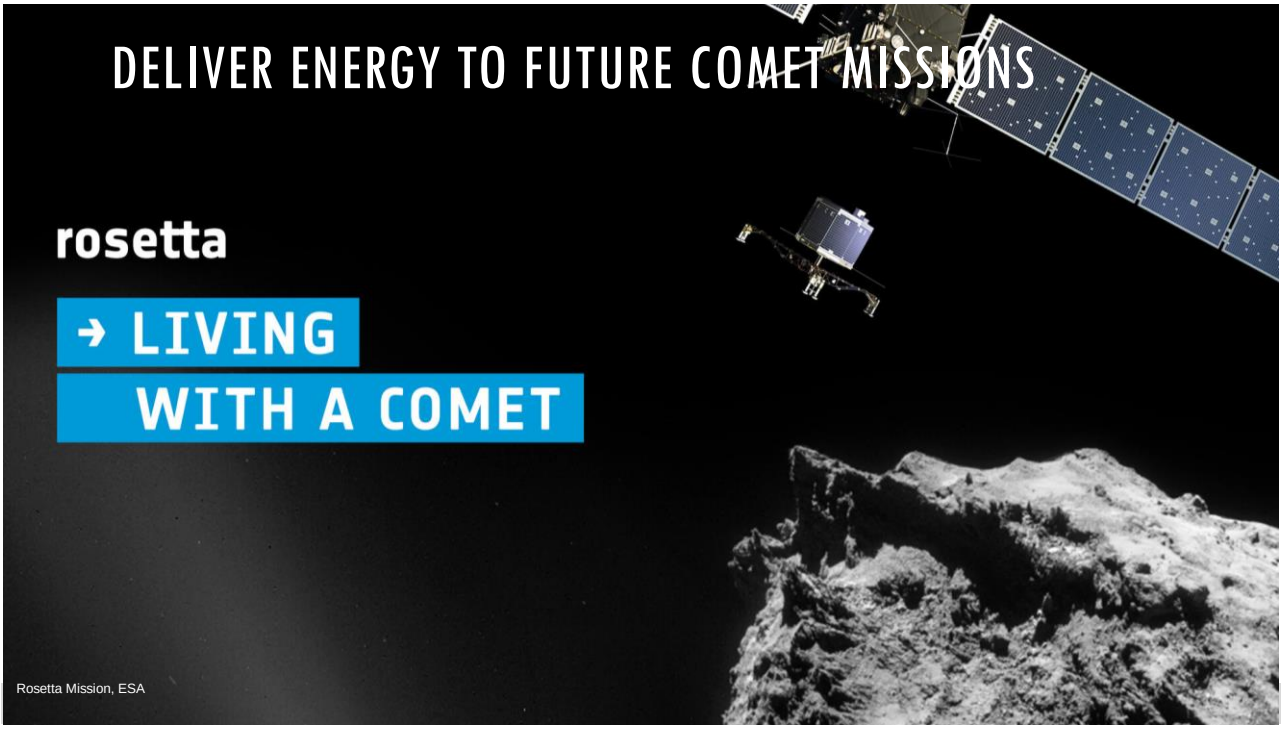


Space and Automotive Radar Technologies

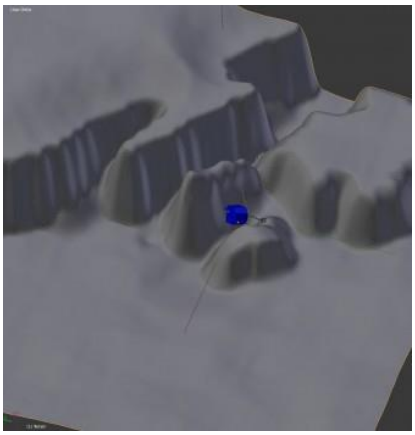
WIPE
COST IC1301

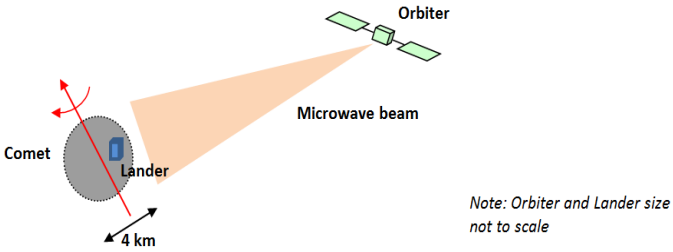
cost
EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY


DELIVER ENERGY TO FUTURE MOON MISSIONS
Intermittent energy 2 weeks
Artist impression of a Moon Base concept, P. Carril ESA


DELIVER ENERGY TO FUTURE COMET MISSIONS
rosetta
→ LIVING
WITH A COMET
Rosetta Mission, ESA

MOTIVATION – ROSETTA MISSION





•The likely orientation of Philae probe, shown in a visualization of a topographic model of the comet's surface. Credits: ESA/Rosetta/Philae/CNES/FD, from [1]

WHAT CAN WE DO?

Harvest Clean Energy

- Energy Harvesting

Reduce Battery Needs

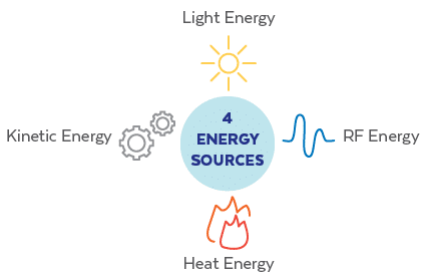
- Wireless Power Transmission/Micro Generation

Improve Energy efficient Electrical devices

- Backscatter

universidade de aveiro · instituto de telecomunicações · radio systems

ENERGY HARVESTING



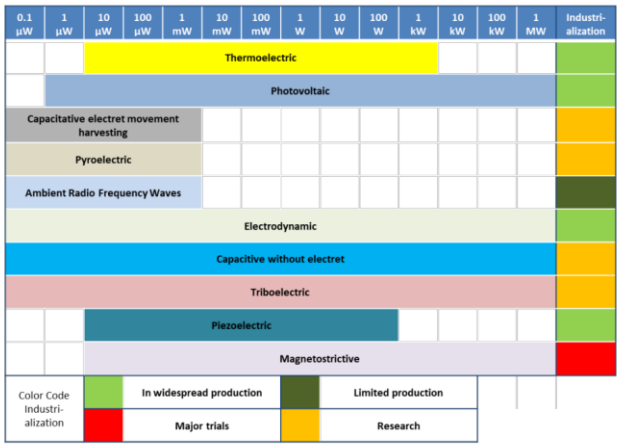
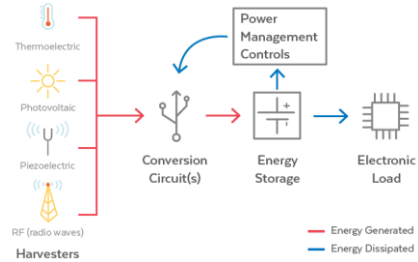
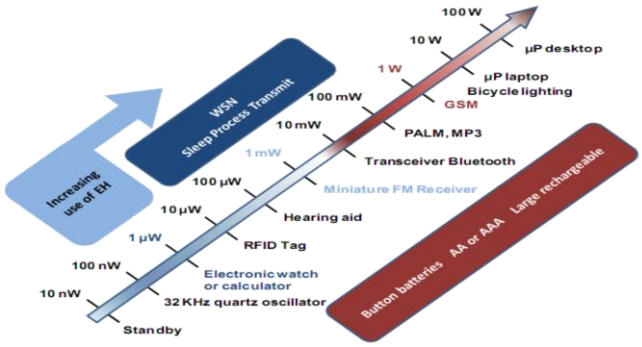


Figure 3: State of EH technologies and their generated intermittent power [18].

https://www.versatek.com/what-is-energy-harvesting/

HOW MUCH POWER

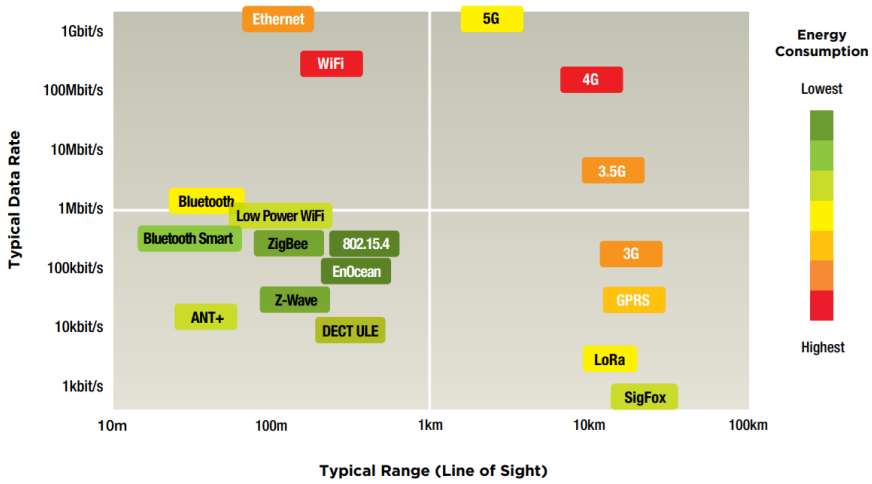




https://www.versatek.com/what-is-energy-harvesting/

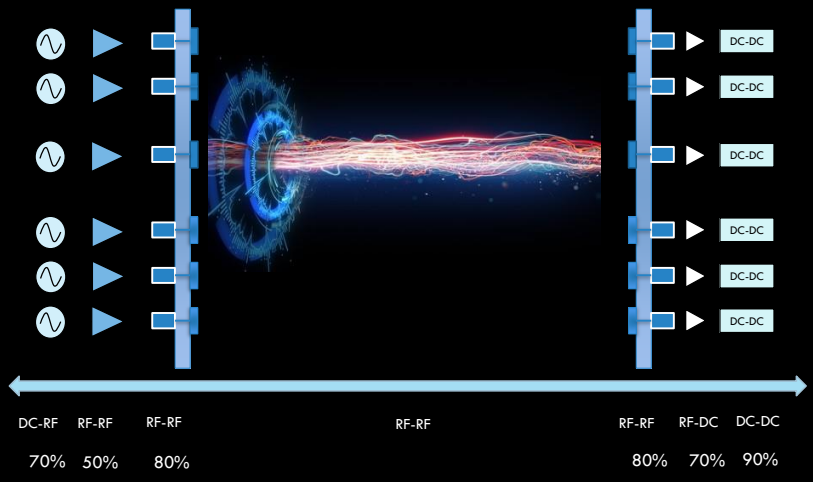
Source: ID Tech Ex report 'Energy Harvesting and Storage for Electronics Devices' 2009-2019

ENERGY NEED



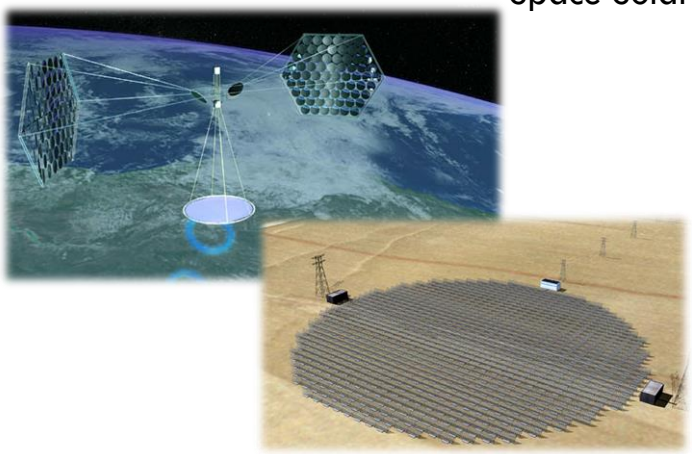
http://edna.iea-4e.org

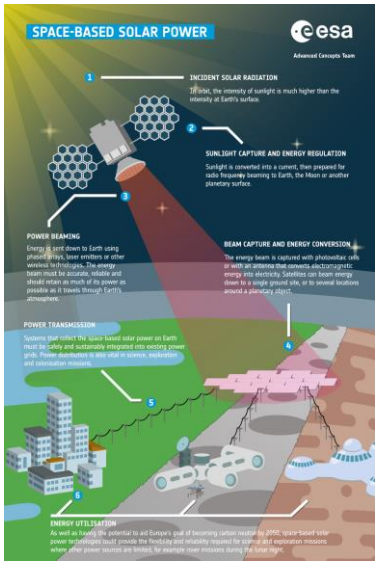
WPT BEAM ENERGY



WIRELESS POWER TRANSMISSION

Space Solar Power





TECHNOLOGY

Xiaomi's long-range wireless charger shows a glimpse of a cord-free future

A base station could beam out power, which means no more plugging in your device or even plunking it on a charging pad.

Stan Horaczek | *February 1, 2021*

Outage Response

https://emrod.energy/

Mobile truck-mounted units, and compact permanent systems, for addressing planned and unplanned outages by bridging the "gap" in the network caused by downed lines.

Outages are significant cost-drivers for both electricity distribution companies and power-critical companies such as Telcos and hospitals. Generators are expensive to run, polluting, noisy and in case of an outage require some time to deploy or activate.

Using Emrod's fixed or Mobile Outage Response systems, outage downtime time and cost are reduced to near zero.

Powering Cellular Base Stations

Providing an easy and cost-effective solution for transmitting power across difficult terrain by removing the need for traditional poles and lines.

Cellular base stations require power, which is normally sourced from utility supplies. Making the connection from the utility point of supply to the cellular base station can be expensive. It can also take excessive amounts of time when compared to the time taken to install a cellular base station itself.

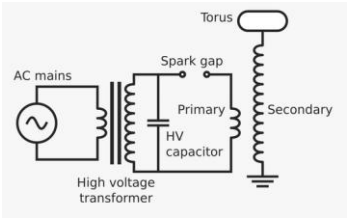
Emrod's system provides a wireless point to point connection between the utility point of supply and the base station using a pair of antenna.

HISTORICAL INTRODUCTION AND CURRENT TRENDS

- **1890 – First intentional WPT experiment**

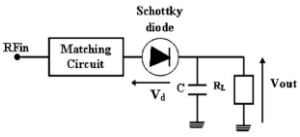
Nikola Tesla - inductive and capacitive coupling using spark-excited radio frequency resonant transformers, now called Tesla coils.

How to build a Tesla coil:

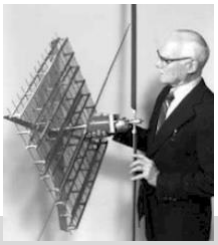


- **1960 – First Long-Range WPT experiment**

William C. Brown pioneered microwave power transmission.
Also, he invented the rectenna which could efficiently convert microwaves to DC power.



William C. Brown

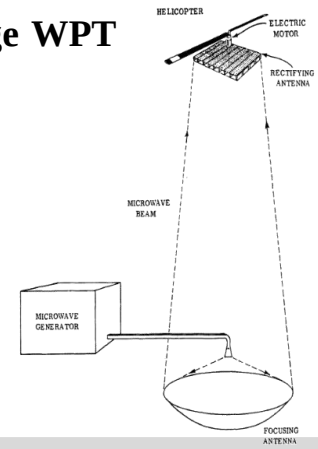


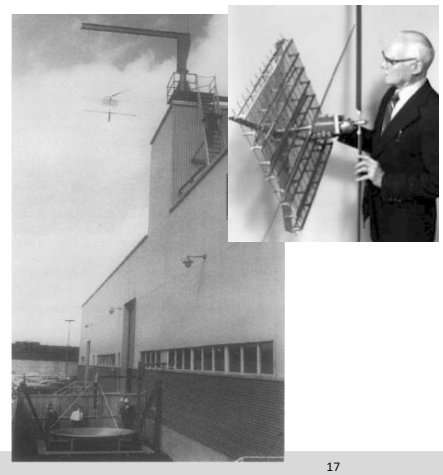
HISTORICAL INTRODUCTION AND CURRENT TRENDS

William C. Brown

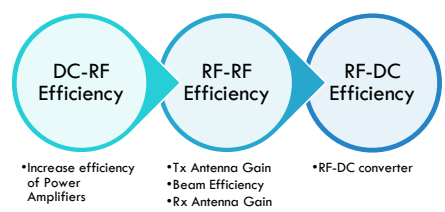
- **1960 – First Long-Range WPT experiment**

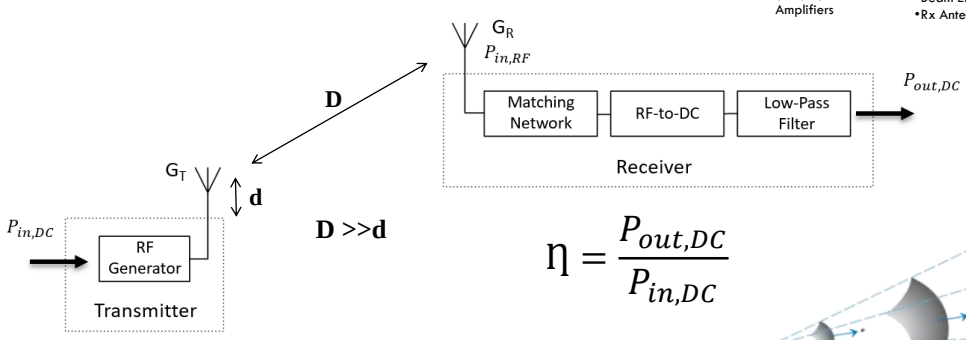
- Development of the Rectenna 1963
- Flying helicopter 1964
- Solar Power Satellite (SPS) 1968
- JPL Experiments 1975
- Rectenna improvement
- Venus Site Goldstone Facility 1.54 km
- SPS first serious assessment 1980





WPT GENERAL CONCEPTS

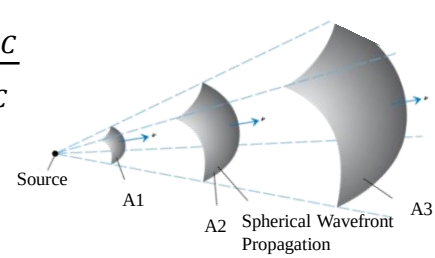




D >>d

$$\eta = \frac{P_{out,DC}}{P_{in,DC}}$$

$$\eta_{WPT} = \frac{P_{DCOSC}\eta_{OSC}G_{PA}G_{BEAM}G_{RF-DC}}{P_{DCOSC} + P_{DCPA}}$$



WPT STUDIES IN AVEIRO

Nuno Borges Carvalho

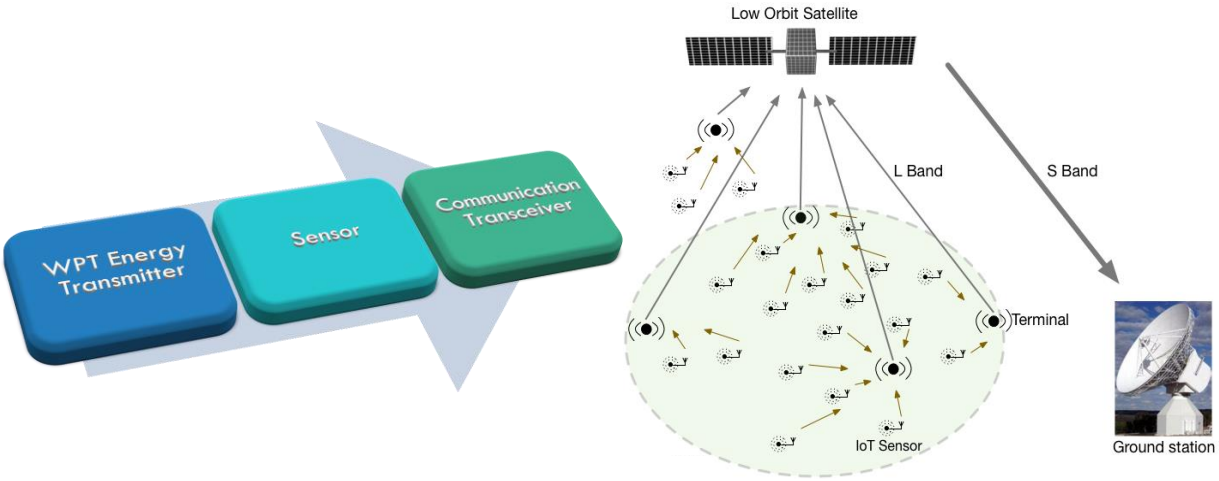
ACTIVITIES IN AVEIRO

Technologies

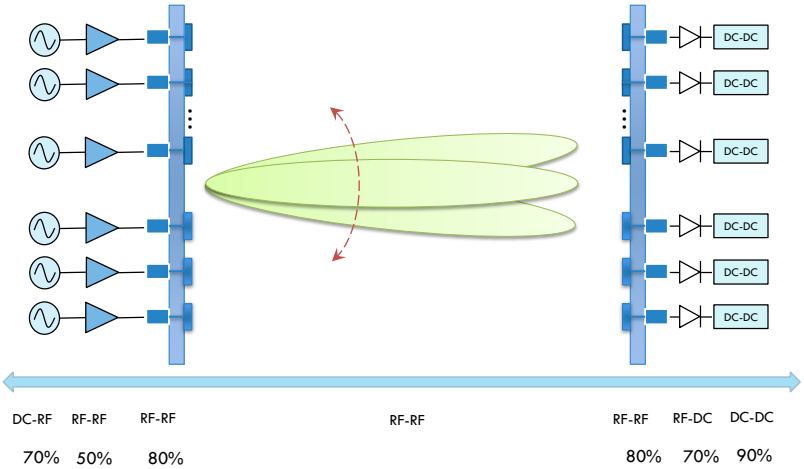
Wireless Power Transmission + **Backscatter** + **Energy Harvester** + **MMIC**

SWIPT – Simultaneous Wireless Information and Power Transmission

DEVELOPING A DEEP SPACE SENSOR IOT



GENERAL CONCEPTS



GENERAL CONCEPTS

DC-RF

RF-RF

$$\left(\frac{\lambda}{4\pi r}\right)^2$$ RF-RF

RF-DC

DC-DC

Signal Information				
Frequency [GHz]	2	5	10	18
Wavelength [m]	0,15	0,06	0,03	0,017
RF-DC Conversion				
DC Power in Transmmmiter [W]	3700	3700	3700	3700
DC-RF Efficiency [%]	80	75	65	60
RF Transmitted Power [W]	2960	2775	2405	2220
Beam Efficiency				
Antenna size [m]	18	13	10	7
Apperture Efficiency	80	80	80	80
Antenna gain [dB]	51,6	56,7	60,5	62,5
Distance [m]	6000	6000	6000	6000
Far field [m]	4320	5633	6667	5880
Free Space Atennuation	3,96E-12	6,33E-13	1,58E-13	4,89E-14
Receive Antenna [dB]	47,3	51,4	52,5	55,1
Rx Antenna Size [m]	11	7	4	3
Beam Efficiency [%]	3,10	4,09	3,16	2,82
DC-RF Conversion				
Received RF power [W]	91,69	113,48	76,01	62,66
RF-DC Efficiency [%]	80	78	76	74
DC power [W]	73,35	88,51	57,77	46,37
DC-DC Efficiency				
DC-DC Efficiency [%]	1,98	2,39	1,56	1,25

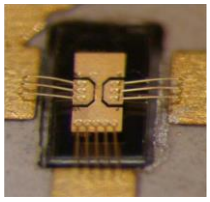
WPT GENERAL CONCEPTS

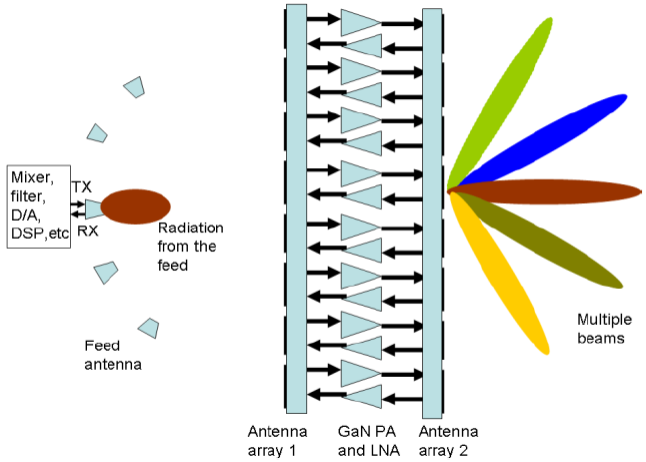
$$\cancel{\left(\frac{\lambda}{4\pi r}\right)^2}$$

- Increase efficiency of Power Amplifiers
- Tx Antenna Gain
- Beam Efficiency
- Rx Antenna Gain
- RF-DC converter

$$\eta_{WPT} = \frac{P_{DCOSC}\eta_{OSC}G_{PA}G_{BEAM}G_{RF-DC}}{P_{DCOSC} + P_{DCPA}}$$

TRANSMITTER BASED ON SSPA

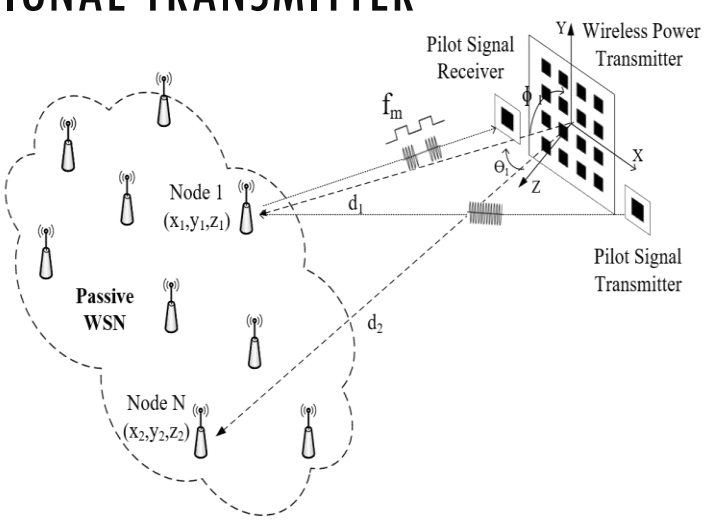


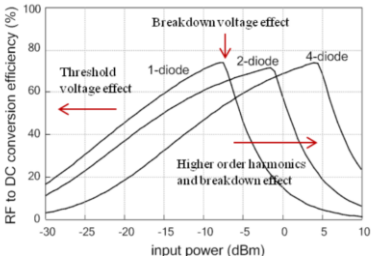


GaN

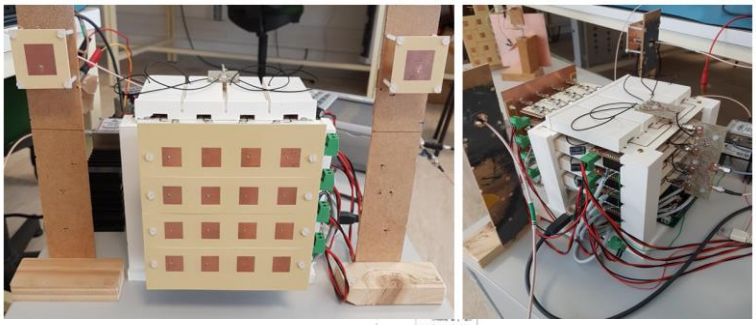
Power Availability at Ka band is limited

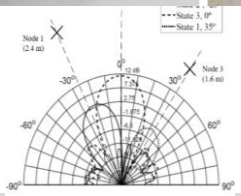
SIGNAL TRANSMITTER





EXPERIMENTAL RESULTS



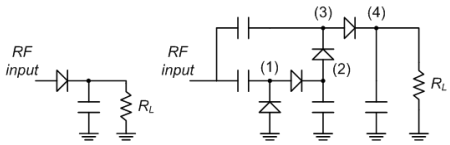


ANTENNA FOR SPACE SENSORS

Overall Efficiency approaching 65% @ 6m

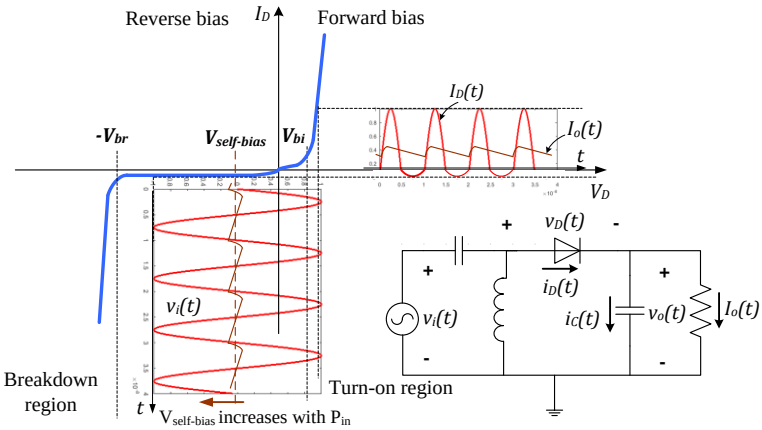
RF-DC CONVERTERS

- Rectifier circuits: envelope detector, charge pump circuits
- Schottky diodes, low / zero barrier diodes



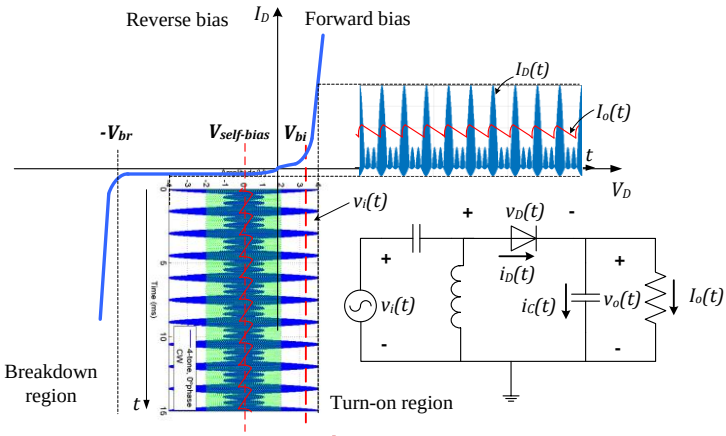
Reported efficiencies for available input power levels in the order of 10 uW are between 10% - 20%, and increase to 30%-60% for available power levels of 100uW.

RF-DC CONVERSION



Rectifying devices exhibit a NON-ZERO turn-on voltage → a certain amount of energy is needed to overcome the turn-on voltage → low power level efficiency is degraded

WAVEFORM DESIGN FOR IMPROVED RF-DC CONVERSION EFFICIENCY

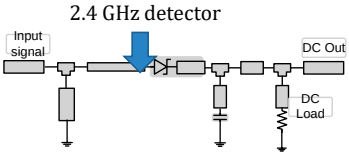


Rectifying devices exhibit a NON-ZERO turn-on voltage → a certain amount of energy is needed to overcome the turn-on voltage → low power level efficiency is degraded

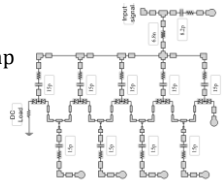
WAVEFORM DESIGN FOR IMPROVED RF-DC CONVERSION EFFICIENCY

Circuits tested under CW and several MS signals with the same average power

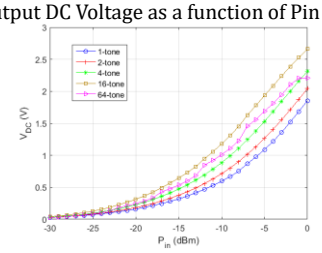
2.4 GHz detector



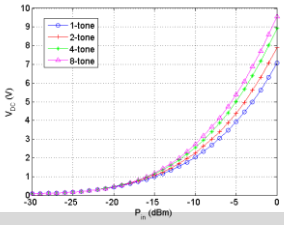
866 MHz Charge pump



Output DC Voltage as a function of Pin



Output DC Voltage as a function of Pin



SIMULTANEOUS WIRELESS INFORMATION AND POWER TRANSMISSION

Nuno Borges Carvalho

BACKSCATTER BATTERY-LESS PARADIGM

Leon Theremin

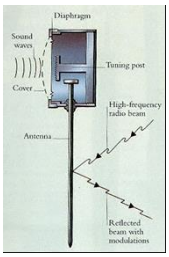
@youtube: Carolina Eyck

HISTORY OF BACKSCATTER RADIO

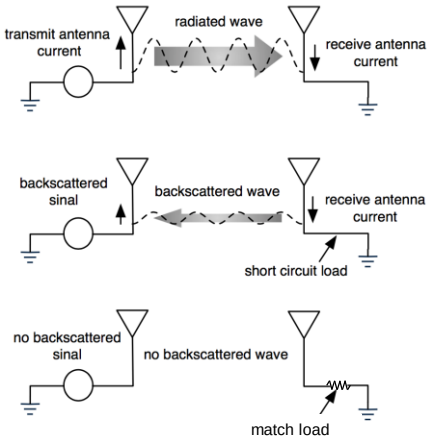
The Great Embassy Seal Bug

- Given as "gift" to US by USSR in 1946;
- Passive transduction of sound, interrogated from across the street in the Soviet Embassy;
- Undiscovered until 1952;

- Invented by Leon Theremin;
- Vibrating diaphragm changes capacitive load seen by antenna;
- Analog speech modulates the backscattered information;
- Reflected signal looks like small-carrier AM;



BACKSCATTER BATTERY-LESS PARADIGM

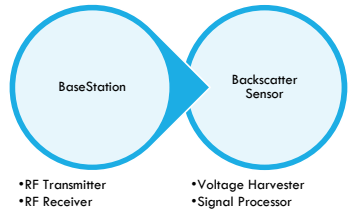


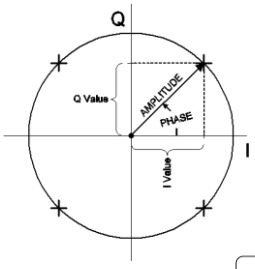
Backscatter communications has its roots in radars type approach

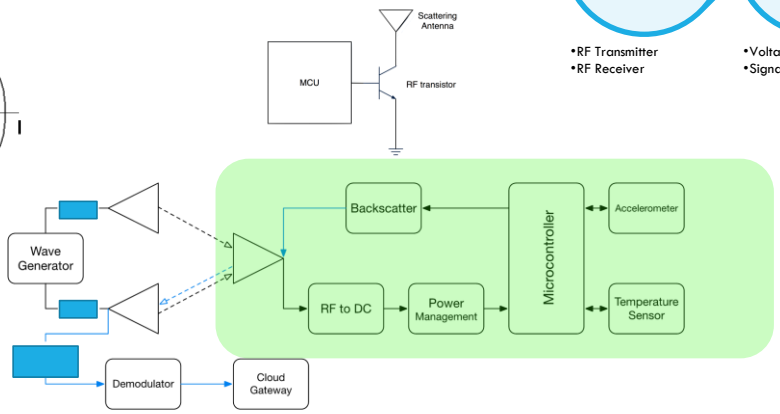
The RF-front end reflects part of an incoming electromagnetic wave back to the reader based on the information pattern

The backscatter reflection efficiency is maximized for antennas that are resonating with the incoming signal frequency.

BACKSCATTER BATTERY-LESS PARADIGM

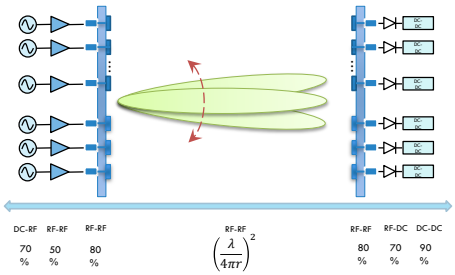




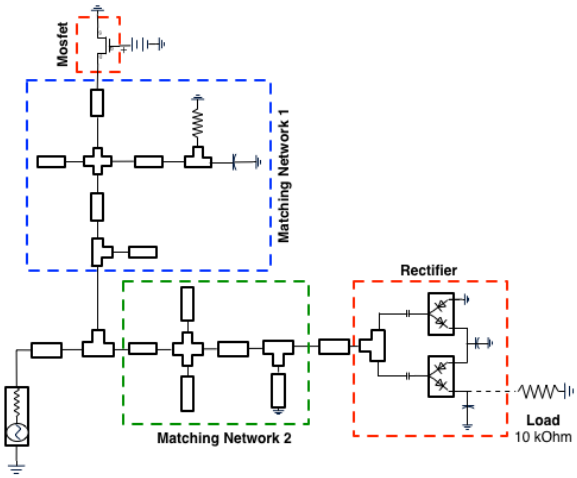


BACKSCATTER SENSOR FRONT END

Combining WPT and Backscatter using dual band sensors



ONE frequency for WPT and OTHER for backscatter

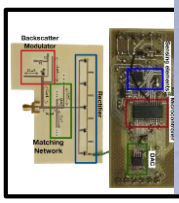


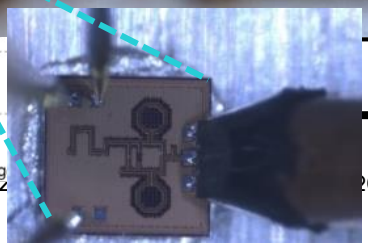
R. Correia, N. Borges Carvalho and S. Kawasaki, "Continuously Power Delivering for Passive Backscatter Wireless Sensor Networks," in *IEEE Transactions on Microwave Theory and Techniques*, vol. 64, no. 11, pp. 3723-3731, Nov. 2016.

AVEIRO DEVELOPMENTS

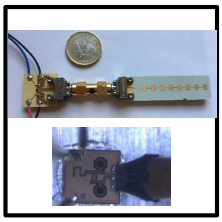
kbit/s

Passive Sensors





Increase frequency and decrease size



10 kbps

1 kbps

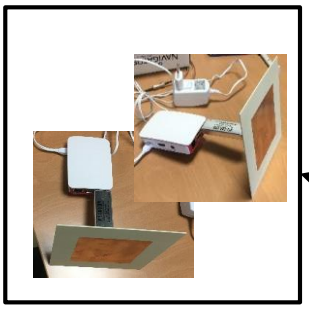
0.1 mW

Averag

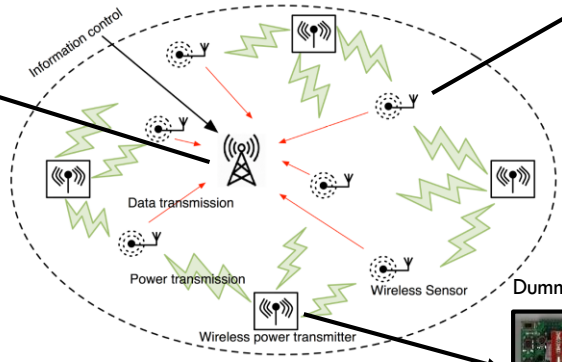
2015 2016 2018 2019

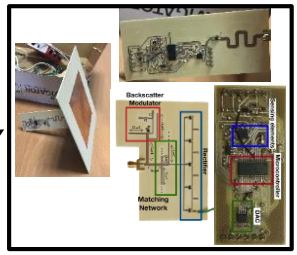
Total size = 0.92 mm^2

OUR SOLUTION – SWIPT BACKSCATTER



Low Cost SDR Readers





Passive Sensors

Dummy Wireless Power Transmitters

QUESTIONS?

wpt.ieee.org

https://www.hindawi.com/journals/wpt/

Acknowledgments

Aveiro Group
Arnaldo Oliveira
Pedro Pinho
José Neto Vieira

Alumni
Alírio Boaventura
Pedro Cruz
Nelson Silva
Fernandes
Bolas
rrego
on Jang
antos
Belo
Ribeiro
Prata
Dinis
Gonçalves
Daniel Malafaia