SIMULTANEOUS WIRELESS INFORMATION AND POWER TRANSMISSION

Prof. Nuno Borges Carvalho
Universidade de Aveiro
Instituto de Telecomunicações
INSTITUTO DE TELECOMUNICAÇÕES

wireless technologies  optics & photonics  information & data sciences

networks & services  basic sciences & enabling technologies

SDR – 5G/6G Technologies
Wireless Power Transmission – RFID - IoT
Satellite New Space Communications
Space and Automotive Radar Technologies
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
ENERGY HARVESTING

Light Energy

Kinetic Energy

RF Energy

Heat Energy

4 ENERGY SOURCES

Thermoelectric

Photovoltaic

Capacitive electret movement harvesting

Pyroelectric

Ambient Radio Frequency Waves

Electrodynamic

Capacitive without electret

Triboelectric

Piezoelectric

Magnetoelectric

Color Code Industrialization

In widespread production
Limited production
Major trials
Research

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

HOW MUCH POWER

Cars
Mobile Phones
IoT Devices
Space Stations
Critical Communications

ENERGY NEED

WPT BEAM ENERGY
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
15

Outage Response

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.

16

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.

• 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.

How to build a Tesla coil:

William C. Brown
HISTORICAL INTRODUCTION AND CURRENT TRENDS

- 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

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

\[ \eta = \frac{P_{out,DC}}{P_{in,DC}} \]
WPT STUDIES IN AVEIRO

Nuno Borges Carvalho

ACTIVITIES IN AVEIRO

Wireless Power Transmission + Backscatter + Energy Harvester + MMIC

SWIPT – Simultaneous Wireless Information and Power Transmission
DEVELOPING A DEEP SPACE SENSOR IOT

GENERAL CONCEPTS
GENERAL CONCEPTS

**Signal Information**

<table>
<thead>
<tr>
<th>Frequency [GHz]</th>
<th>2</th>
<th>5</th>
<th>10</th>
<th>18</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wavelength [m]</td>
<td>0.15</td>
<td>0.06</td>
<td>0.03</td>
<td>0.017</td>
</tr>
</tbody>
</table>

**RF-DC Conversion**

<table>
<thead>
<tr>
<th></th>
<th>DC Power in Transmitter [W]</th>
<th>DC-RF Efficiency [%]</th>
<th>RF Transmitted Power [W]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3700</td>
<td>80</td>
<td>2960</td>
</tr>
<tr>
<td></td>
<td>3700</td>
<td>75</td>
<td>2775</td>
</tr>
<tr>
<td></td>
<td>3700</td>
<td>65</td>
<td>2405</td>
</tr>
<tr>
<td></td>
<td>3700</td>
<td>65</td>
<td>2220</td>
</tr>
</tbody>
</table>

**Beam Efficiency**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Value</th>
<th>Value</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antenna size [m]</td>
<td>18</td>
<td>13</td>
<td>10</td>
<td>7</td>
</tr>
<tr>
<td>Aperture Efficiency</td>
<td>80</td>
<td>80</td>
<td>80</td>
<td>80</td>
</tr>
<tr>
<td>Antenna gain [dB]</td>
<td>51.6</td>
<td>56.7</td>
<td>60.5</td>
<td>62.5</td>
</tr>
<tr>
<td>Distance [m]</td>
<td>6000</td>
<td>6000</td>
<td>6000</td>
<td>6000</td>
</tr>
<tr>
<td>Far field [m]</td>
<td>4230</td>
<td>5633</td>
<td>6667</td>
<td>5880</td>
</tr>
<tr>
<td>Free Space Attenuation</td>
<td>3.066-12</td>
<td>6.338-12</td>
<td>1.588-12</td>
<td>4.698-14</td>
</tr>
<tr>
<td>Receive Antenna [dB]</td>
<td>47.3</td>
<td>51.4</td>
<td>52.5</td>
<td>55.3</td>
</tr>
<tr>
<td>Rx Antenna Size [m]</td>
<td>11</td>
<td>7</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Beam Efficiency [%]</td>
<td>3.10</td>
<td>4.09</td>
<td>3.16</td>
<td>2.82</td>
</tr>
</tbody>
</table>

**DC-DC Efficiency**

<table>
<thead>
<tr>
<th>Efficiency [%]</th>
<th>DC-DC Efficiency [%]</th>
<th>DC-DC Efficiency [%]</th>
<th>DC-DC Efficiency [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.96</td>
<td>3.39</td>
<td>1.56</td>
</tr>
</tbody>
</table>

WPT GENERAL CONCEPTS

\[
\eta_{WPT} = \frac{P_{DCOSC}\eta_{OSC}G_{PA}G_{beam}G_{RF-DC}}{P_{DCOSC} + P_{D CPA}}
\]

- Increase efficiency of Power Amplifiers
- Tx Antenna Gain
- Beam Efficiency
- Rx Antenna Gain
- RF-DC converter
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 \( \rightarrow \) a certain amount of energy is needed to overcome the turn-on voltage \( \rightarrow \) 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

- Voltage Harvester
- Signal Processor

• RF Transmitter
• RF Receiver

BaseStation

Backscatter Sensor

Wave Generator

Demodulator

Cloud Gateway

Backscatter

RF to DC

Power Management

Microcontroller

Accelerometer

Temperature Sensor

ONE frequency for WPT and OTHER for backscatter

AVEIRO DEVELOPMENTS

Passive Sensors

- Increase data rate and enable WPT capabilities

- Increase frequency and decrease size

Total size = 0.92 mm²

OUR SOLUTION — SWIPT BACKSCATTER

- Low Cost SDR Readers
- Dummy Wireless Power Transmitters
- Passive Sensors
QUESTIONS?

Call for Proposals
IEEE GLOBAL STUDENT WIRELESS POWER COMPETITION

wpt.ieee.org

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

Acknowledgments
Aveiro Group
Arnaldo Oliveira
Pedro Pinho
José Neto Vieira
João Nuno Matos
Ricardo Correia

Alumni
Alírio Boaventura
Pedro Cruz
Nelson Silva
Luis Brás
Ricardo Fernandes
Eduardo Bolas
José Borrego
Wonhoon Jang
Rui Fiel
Jorge Santos
João Santos
Daniel Belo
Diogo Ribeiro
André Prata
Daniel Dinis
Ricardo Gonçalves
Daniel Malafaia