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WPT at 2.45 GHz for space applications

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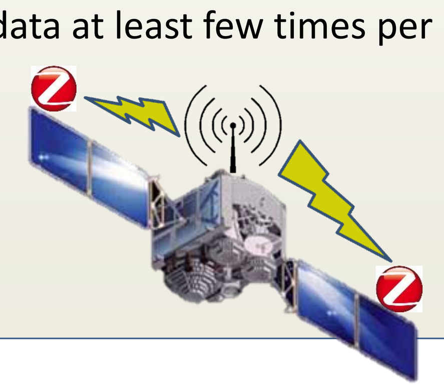
Introduction

This work presents a concept for Wireless Power Transfer, which could be potentially used on boards of satellites in the outer space. The concept includes a fully operational Wireless Power Transfer system working at 2.45 GHz, which powers up ZigBee modules capable of measuring various quantities and sending the measured data back to the processing unit using a supercapacitor

Objective

Satellites, after being launched into the orbit, must unwrap themselves. During this process (and after its end), a number of quantities must be regularly measured, e.g., temperature. To avoid using cables, which can break and are rather inconvinient for designers, a WPT system can be used. This system should allow the ZigBee nodes to succesfully send measurement data at least few times per hour.



ZigBee protocol

ZigBee is:

- Low power (1 uA in sleep, less than 30 mA during transmission at 3V)
- Low throughput (up to 250 kbps)
- Low range (not a concern in space)
- Self-Configuring (adding a new node will cause an automatic reconfiguration of the network – possibility to turn off modules for a longer time)
- Self-Healing (in case of network node failure, the ZigBee network will reorganize itself to provide a full operation readiness

Modules used in this work:

Anaren A2530R24CZ1

for WPT signal generation

Texas Instruments CC2530EMK

for ZigBee communication

Microwave power transmission

The Friis formula:

$$P_r = \frac{G_t G_r \lambda^2}{(4\pi R)^2} P_t \text{ [W]}$$

- P_r - Received power
- P_t - Transmitted power
- G_r - Receiver antenna gain
- G_t - Transmitter antenna gain
- R - Distance between antennas
- λ - wavelength

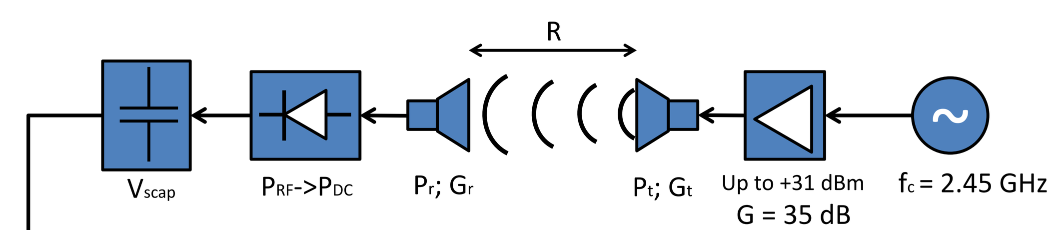
Ways to increase the received power at a constant frequency and distance:

- Increase of transmitter antenna gain
- Increase of receiver antenna gain
- Increase of transmitted power

Increase of transmitted power is not always possible, therefore the best way to improve transmission efficiency is to use high gain antennas.

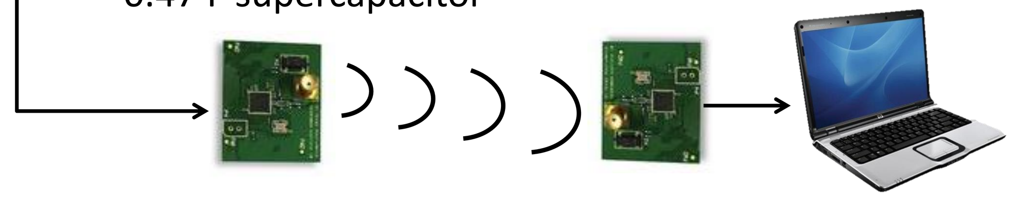
High gain? Use antenna arrays!
Approximately +3 dB to gain with 2x more array elements

System block diagram



WPT system components:

- Single frequency (2.45 GHz) signal generator (Anaren)
- 35 dB amplifier (P1dB = + 31 dBm)
- 2x2 and 4x1 patch array antennas
- Rectifier with 5-stage voltage multiplier
- 0.47 F supercapacitor



Network components:

- ZigBee module operating as end node (TI)
- ZigBee module operating as coordinator/data sink (TI)
- PC for evaluation

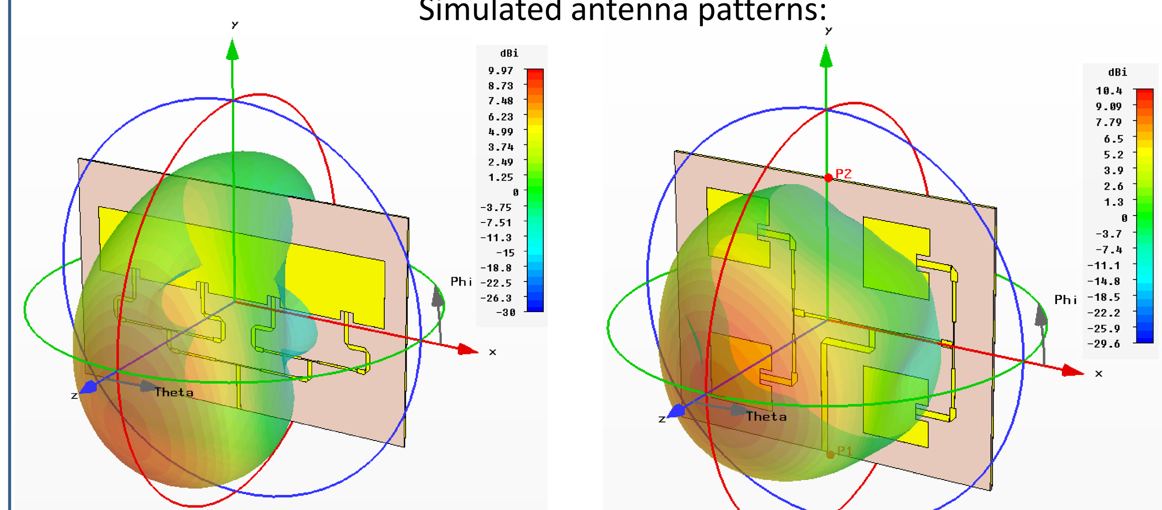
System component designs

Antennas:

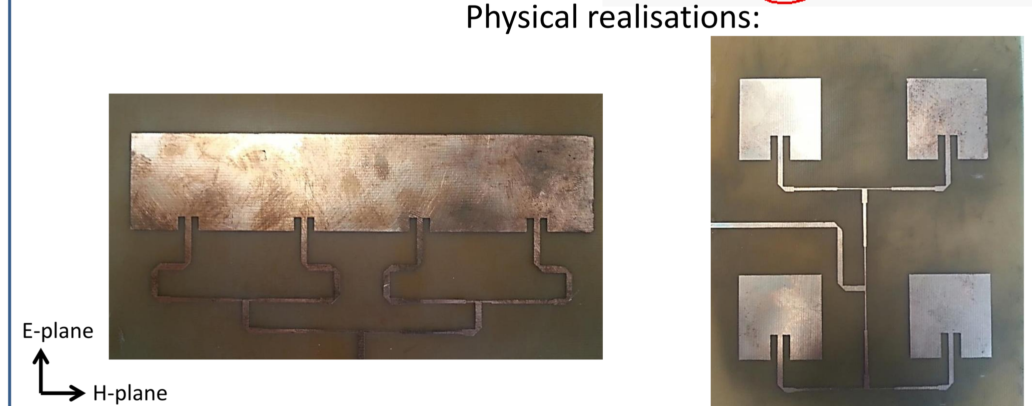
4x1 microstrip patch array
with connected radiators

2x2 microstrip patch array

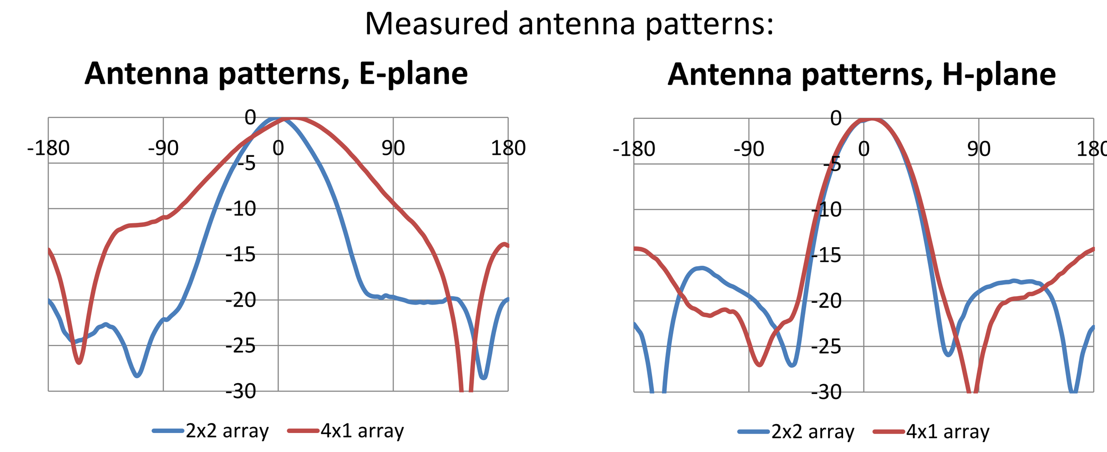
Simulated antenna patterns:



Physical realisations:



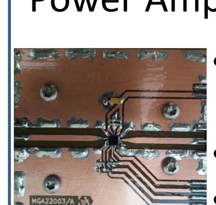
Measured antenna patterns:



2x2 array: approx. max. Directivity = 11.6 dBi (meas); 10.4 dBi (sim)
S11 @ 2.45 GHz = -18 dB

4x1 array: approx. max. Directivity = 9.3 dBi (meas) ; 10 dBi (sim)
S11 @ 2.45 GHz = -30 dB

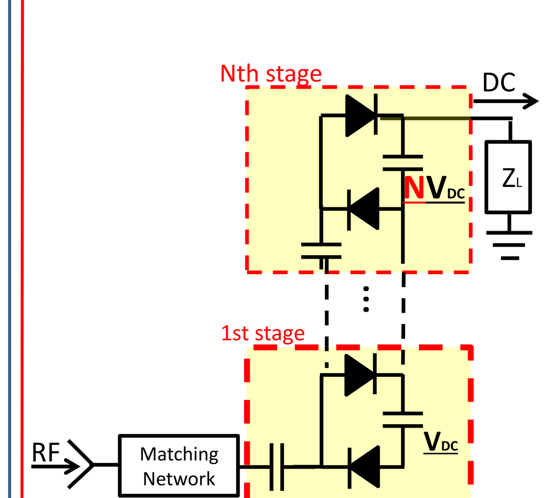
Power Amplifier:



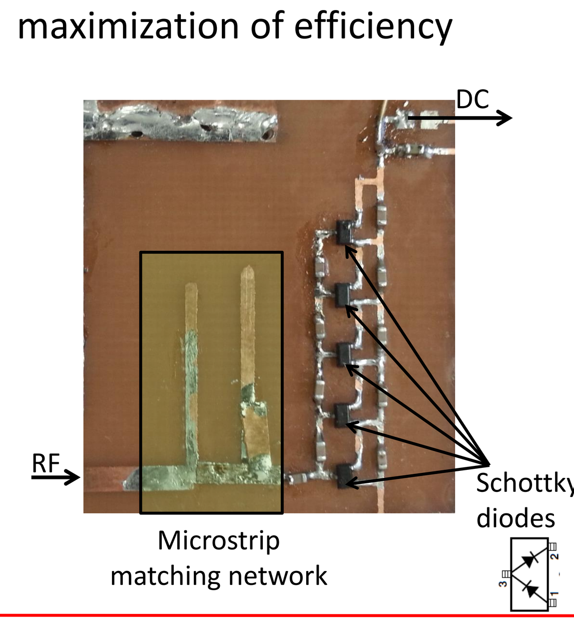
- Amplifies the 2.45 GHz signal
- G = 35 dB
- P1dB = 31 dBm
- Based on Avago MGA22003

Rectifier:

- Converts RF power into DC voltage charging the supercapacitor
- Rectification using Avago 285C Schottky diodes
- 5-stage voltage multiplier (Villard cascade) for higher DC voltages
- Impedance matching network for maximization of efficiency



Voltage multiplier

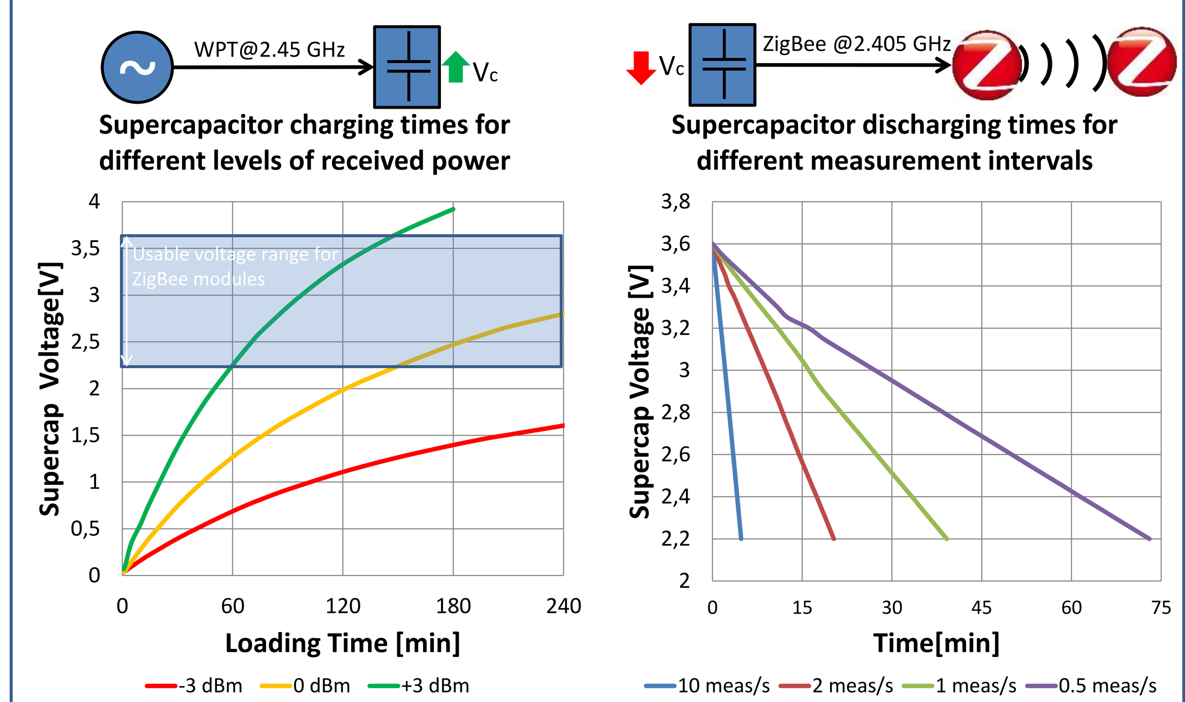


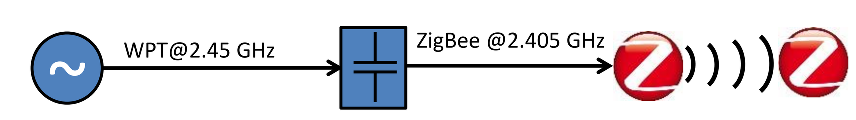
Microstrip
matching network

In all experiments WPT @ 2.45 GHz, ZigBee communication @ 2.405 GHz

Charging Experiment

Charging of the supercapacitor using WPT (left) and discharging of the supercapacitor using ZigBee module operating with different measurement frequencies (no WPT).

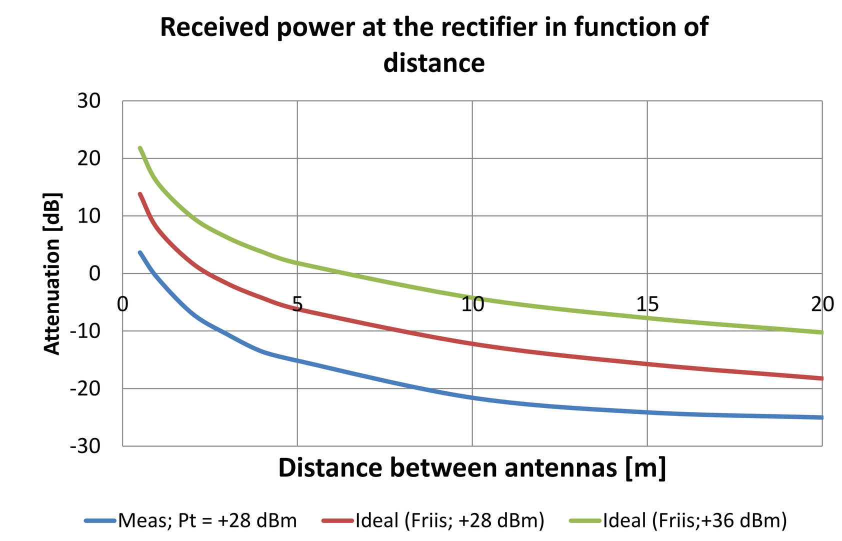




WPT + ZigBee meas
Meas time: 5 minutes
Start V_{cap}[V]: 2,800
End V_{cap}[V]: →

	Received Power		
Measurement frequency [meas/min]	-3 dBm	0 dBm	3 dBm
24	↓2,734	↓2,761	↑2,809
12	↓2,767	↓2,798	↑2,843
6	↓2,786	↑2,811	↑2,860
3	↓2,795	↑2,821	↑2,868

Voltage change after 5 minutes of simultaneous WPT charging (-3 ÷ +3 dBm at the receiver antenna) and transmission of measured data with different ZigBee measurement frequencies. Green fields and arrows show positive energetic balance (charging of the supercapacitor), whereas red fields and arrows show negative energetic balance (discharging of the supercapacitor).



A large difference between the measured and the ideal (calculated for the same system parameters) received power curves can be seen. The difference can be caused by antenna losses (very lossy laminate FR4) and losses of other system components (cables, connectors etc.). However, it can be seen that with some improvements and slightly higher transmitter power (+36 dBm), effective operation of the system for measurement intervals higher than 10 s can be assured for distances up to approx. 5 m.

In the final version of the system, a large antenna array with beamforming capabilities to direct the RF power to more than one ZigBee node should be used

Conclusions

WPT can be potentially used to power ZigBee modules monitoring the status of satellite's components, however to obtain the optimum working conditions, a high-gain antenna for both transmitter and receiver must be used. Also the distance of WPT must be limited to few meters. Transmission of measurement data can be completed while wireless charging of the supercapacitor using separate frequency channels.

WIPE
COST IC1301 Wireless Power Transmission for Sustainable Electronics