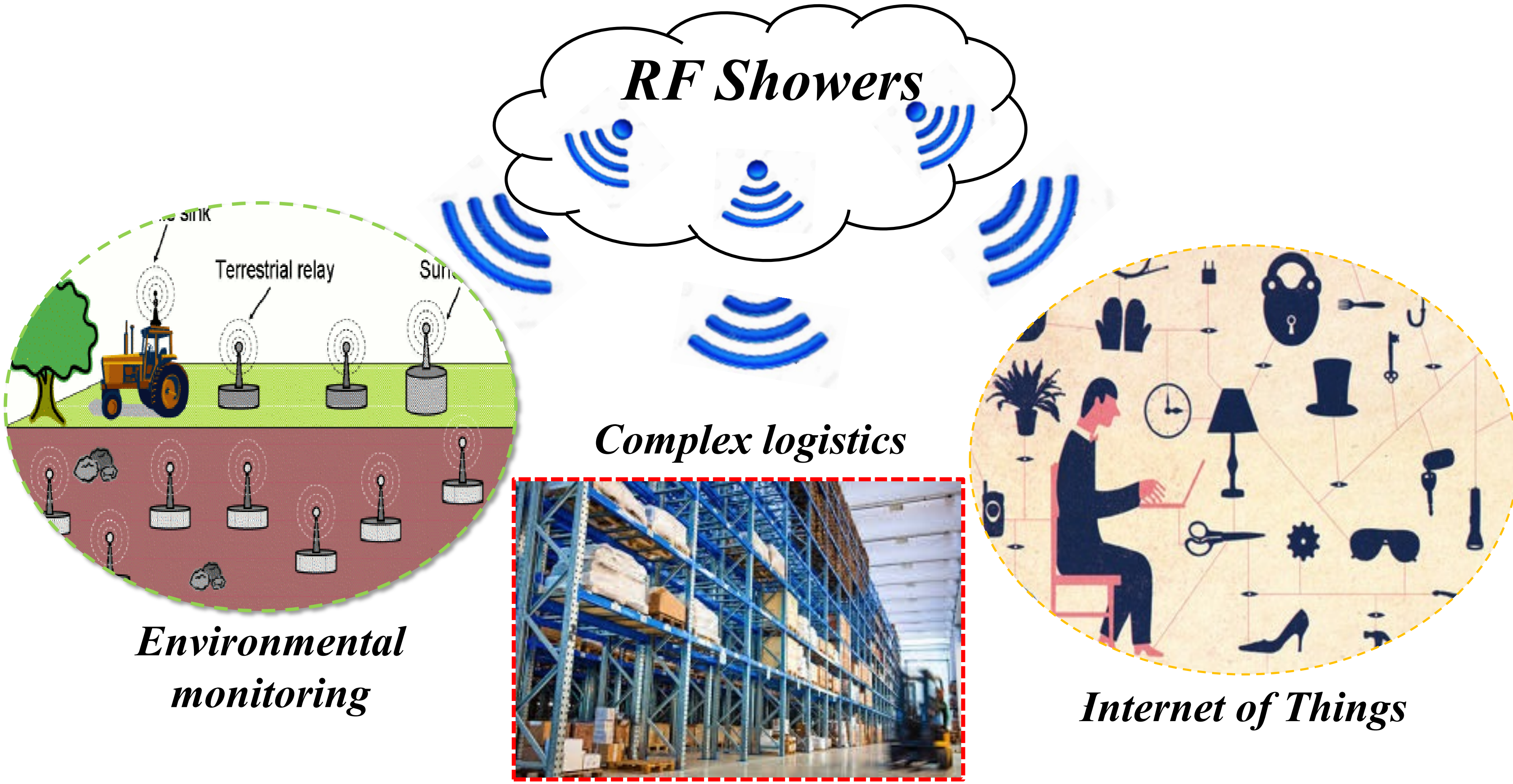
UWB-UHF CIRCUIT AND SYSTEM SOLUTIONS FOR SIMULTANEOUS WIRELESS POWERING TRACKING AND SENSING AT ULTRA-LOW POWER

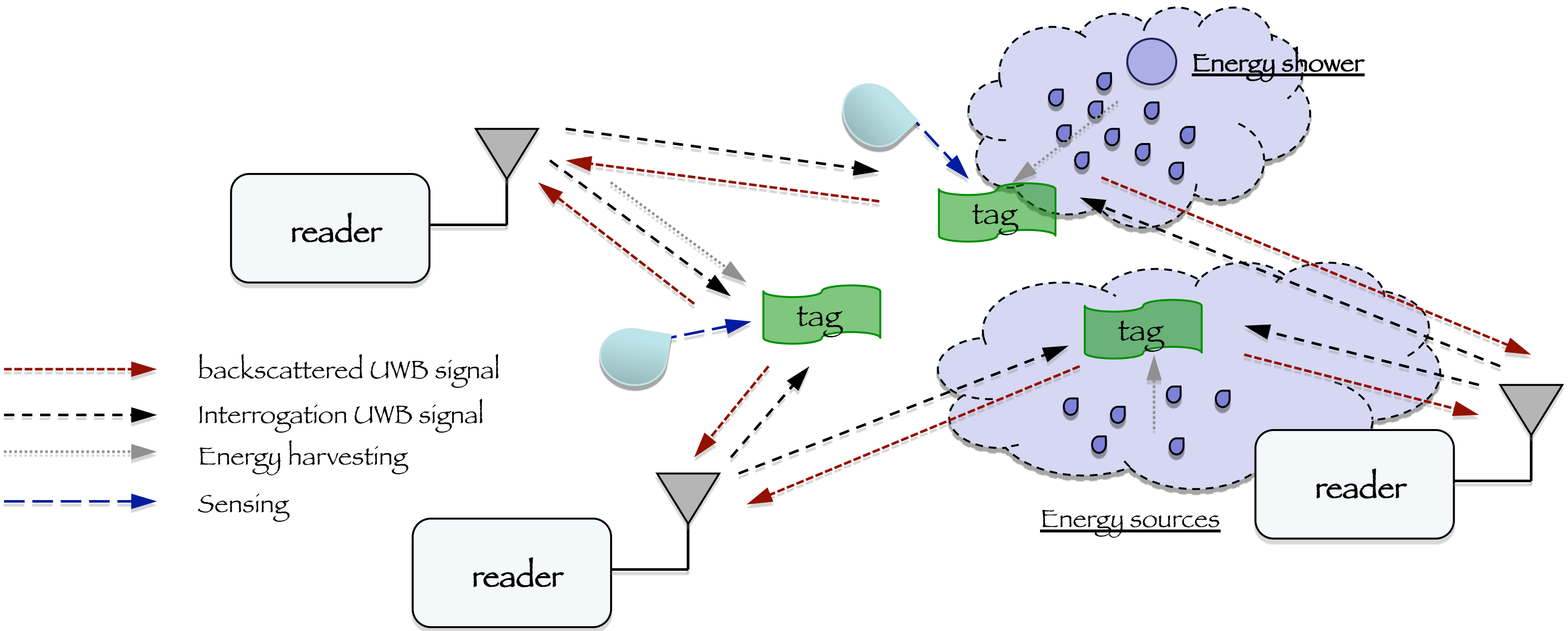
Alessandra Costanzo

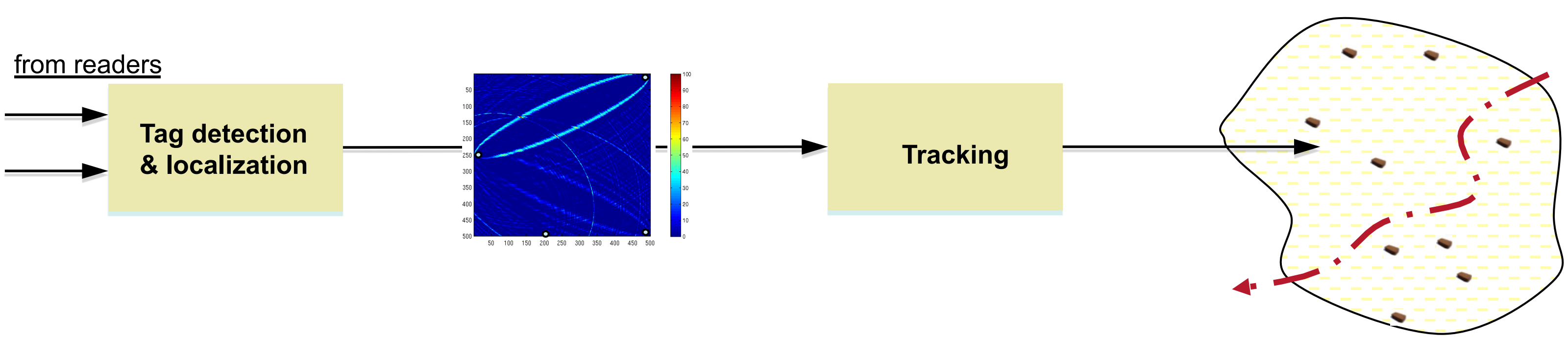
CTTC, Castelldefelles 10 November 2015

Energy Autonomous nodes



NG-RFID system architecture





http://www.greentags.eu

GReen TAgs with ultrawideband identification and localization capabilities

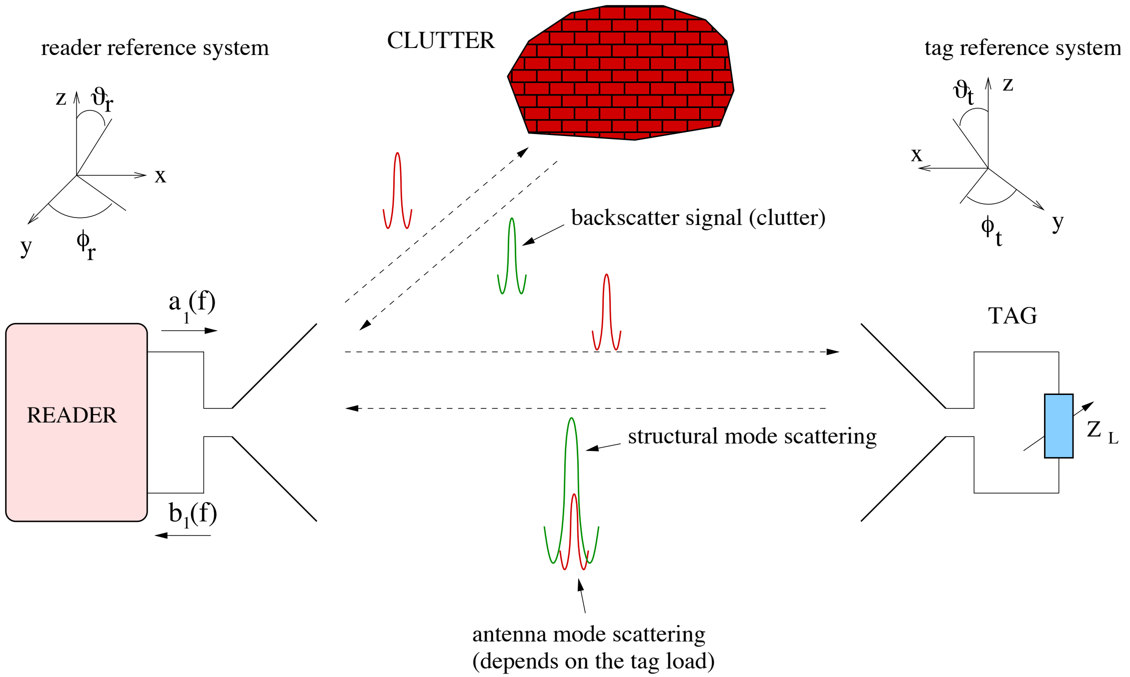
Tag characteristics:

- Localization, even in indoor scenarios: **UWB techniques**
- No batteries: **Energy Harvesting** and passive backscattering
- "**Green electronics**" with recyclable materials

Applications:

- Internet of Things, eHealth, factories of the future, ICT for food,…

UWB Backscatter communication principle

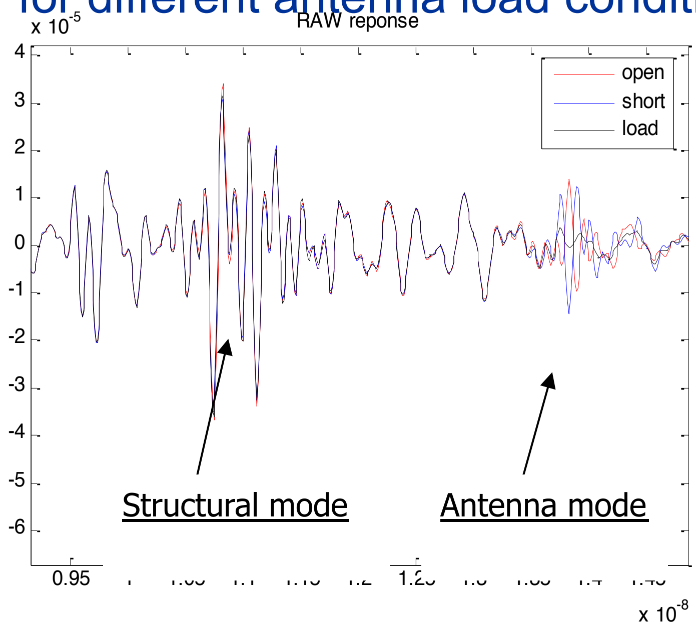


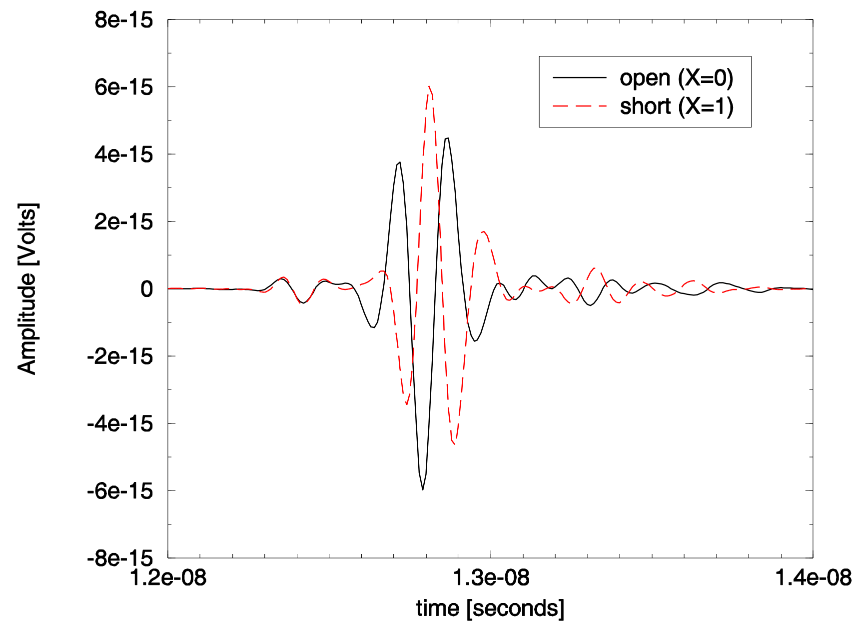
Reflected signals coming from surrounding objects (*clutter*) and antenna structural mode are in general dominant (green pulses)

Need for efficient signal structure and processing to mitigate the effect of clutter

Experimental Round-trip Channel Characterization

Example of measured backscattered signal at reference distance $d_{ref} = 1.44$ m for different antenna load conditions (open-short).





BAV antenna in the direction of maximum radiation (only antenna mode shown, delay line present)

The cross-correlation between the 2 measured waveforms is $\rho = -0.98$ which confirms a good pulse symmetry between the two load conditions.

→ 2-PAM signaling scheme possible

Remarks from link budget analysis

- Very limited link-budget available in backscatter mode (passive tags)
- The adoption of UWB showers (multi-static scenario) can increase the coverage for moderate roof heights
- The use of non-regenerative relays improves the coverage in the presence of obstacles

Possible solutions for coverage extension:

- Relays
- Higher processing gain (more pulses per symbol) → Longer symbol time, lower data rate
- Antenna array (DoA, higher gain) → 1 reader sufficient for localization (hybrid DoA/ToA)

Communication & Synchronization Schemes

Purpose: accurate ranging through UWB signaling, data transmission (for ID and sensors), and energy harvesting (via UHF showers)

Main issues: pulse (fine) synchronization, spreading code (coarse) synchronization, UWB poor link-budget, transmission time, backward compatibility

Ingredients:

- UHF signal for energy harvesting
- Exploit the UHF signal for synchronization at chip level (around 1us accuracy, coarse synch.) → no oscillator (less energy consuming)
- UWB used for accurate ranging through round-trip time measurement of the backscattered signal → no need for fine synchronization
- Identification and data transmission: via UHF or UWB?

GREen TAgs

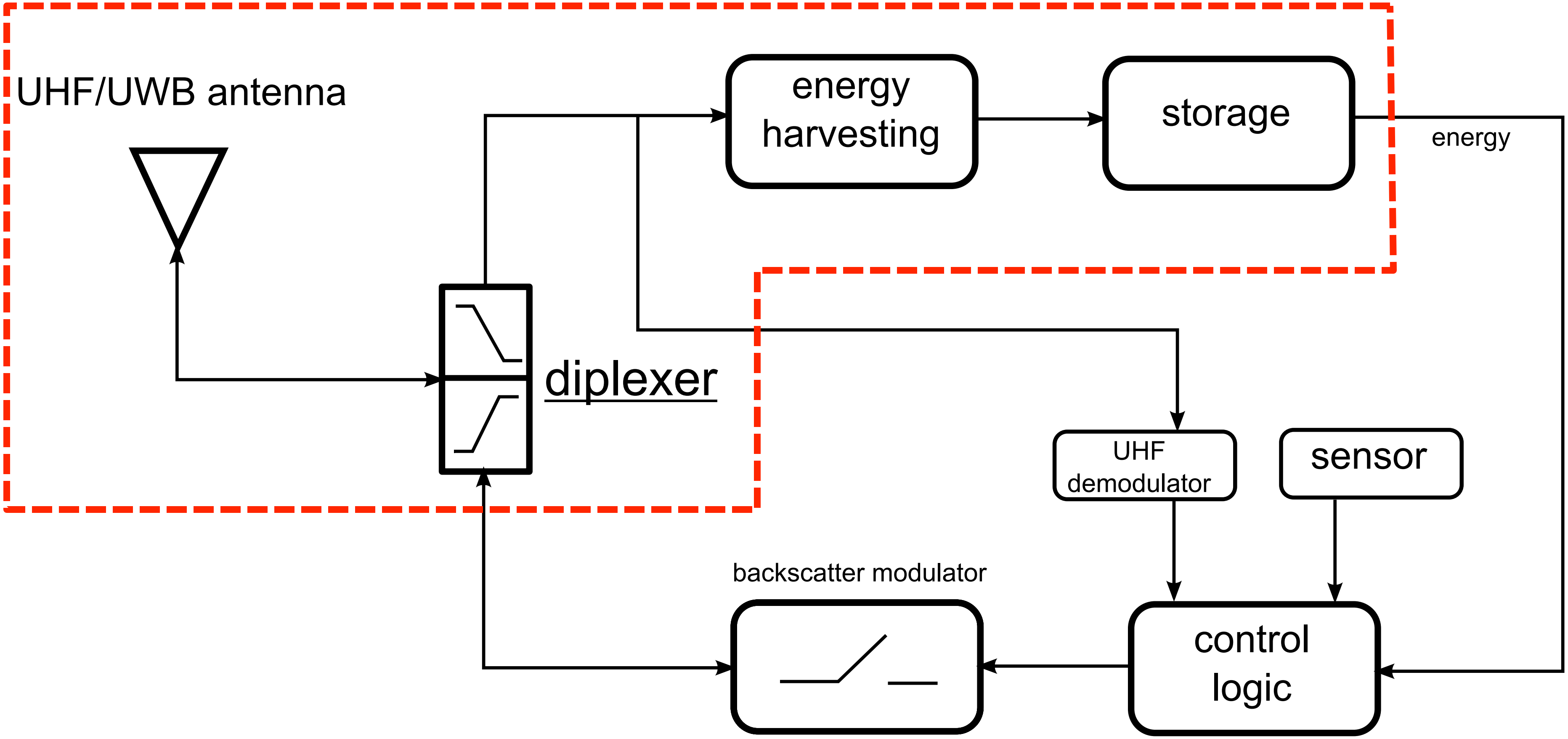
www.greentags.eu

GREen **TA**gs and sensors with ultra-wide-band identification and localization *with sub-meter precision.*

CAPABILITIES: identification, localization, tracking and monitoring, indoor and outdoor. scenarios.

TECHNOLOGY: environmentally friendly materials, small-sized and lightweight, eco-compatible energy-autonomous;
easy integrable in goods
capable of sensing physical quantities of the environment.

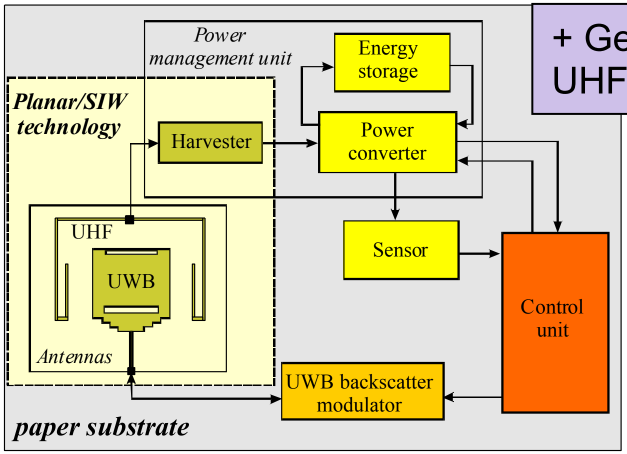
GRETA tag architecture



Tag Architecture choice

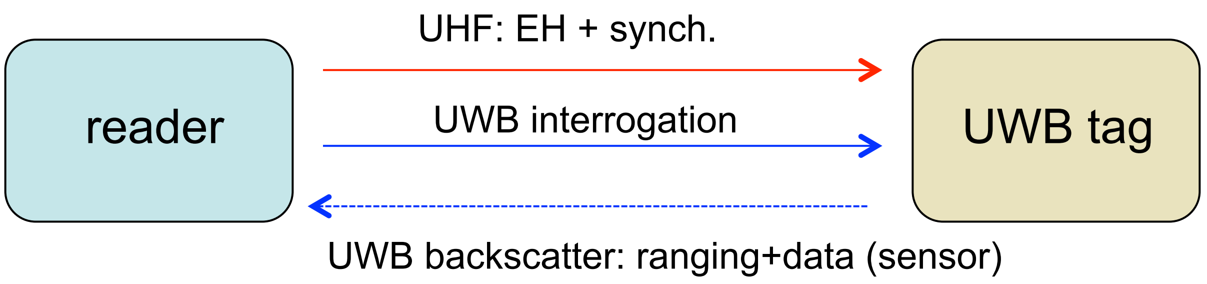
- Only stand-alone UWB tag (no backward compatibility) → cheaper, easier to optimize, limited applications

- UWB as add-on of standard Gen2 UHF tag → backward compatibility, UWB only used to provide accurate localization capabilities, possibility to exploit UHF tag outputs for synchronization and code assignment



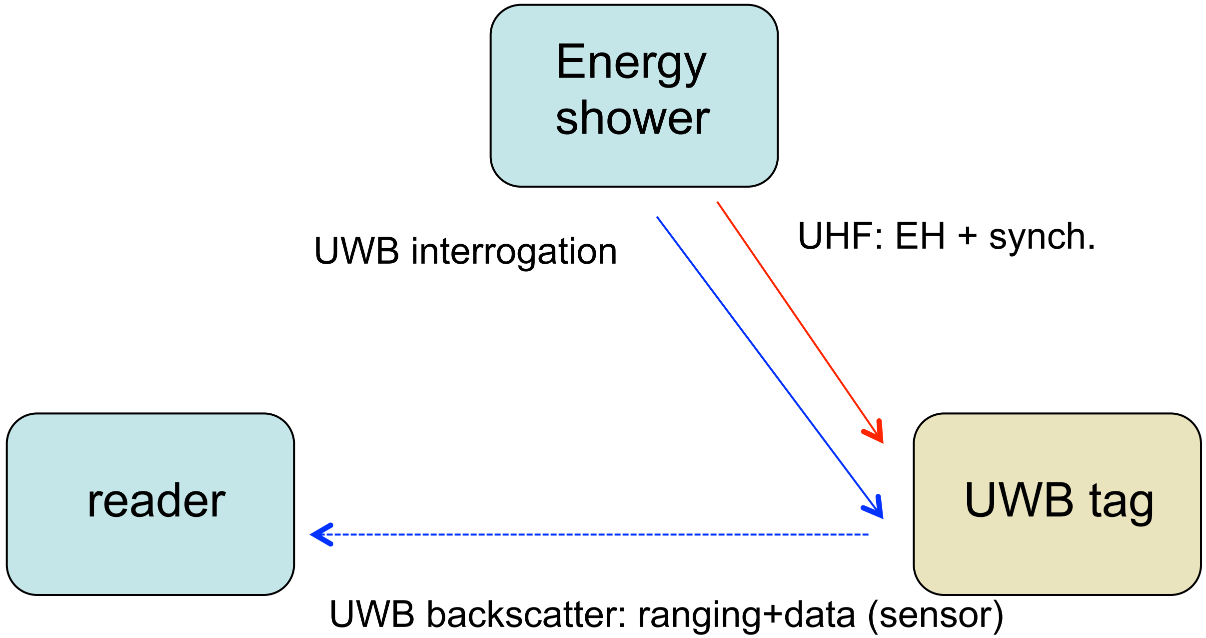
+ Gen2 UHF tag ??

Chosen architecture: Stand-alone UWB tag



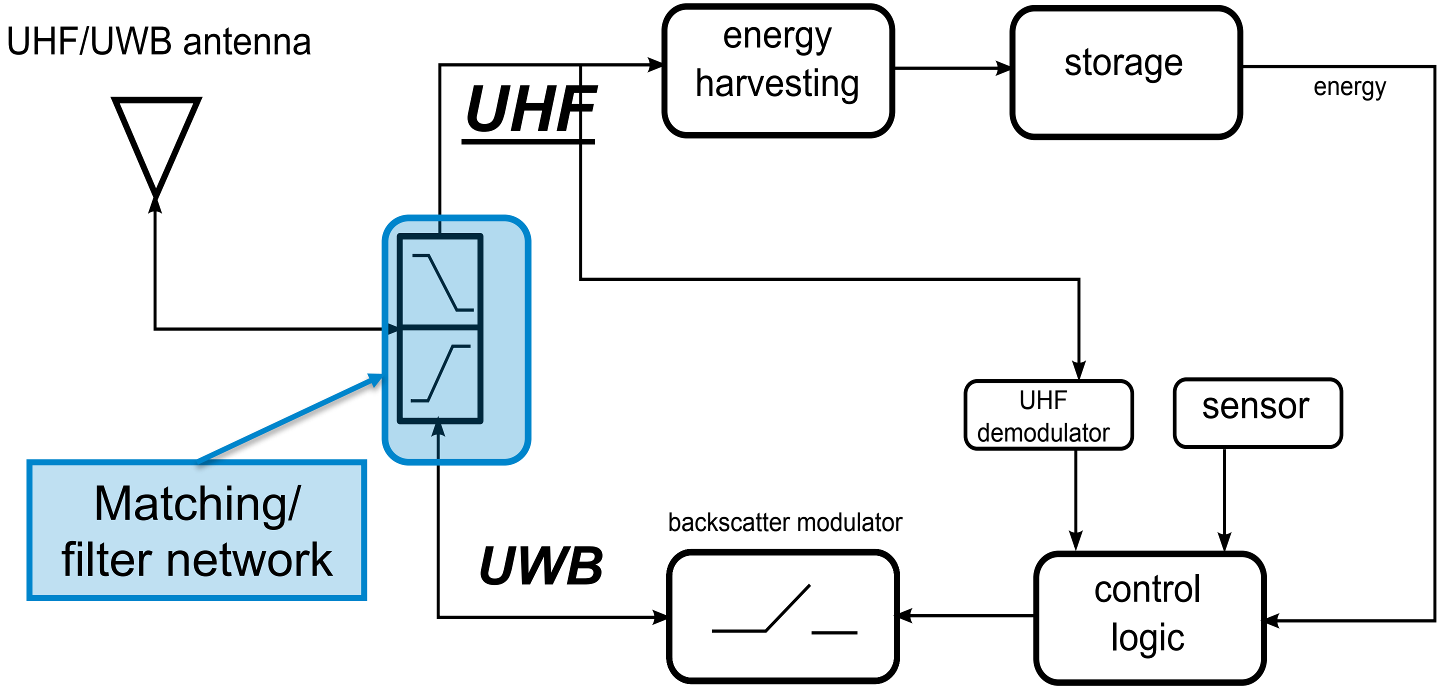
- Several tags can be interrogated simultaneously provided they have different spreading codes and the reader has multiple de-spreading units
- UHF is used only for EH and to provide the clock (thus avoiding the local oscillator in the tag and clock drift problems)
- In principle, more than 1 reader could interrogate the same tag simultaneously (using different coded signals), however the inter-reader interference could be detrimental. Better a TDMA access between readers
- The tag is simple and potentially “green”

Chosen architecture: Stand-alo UWB tag

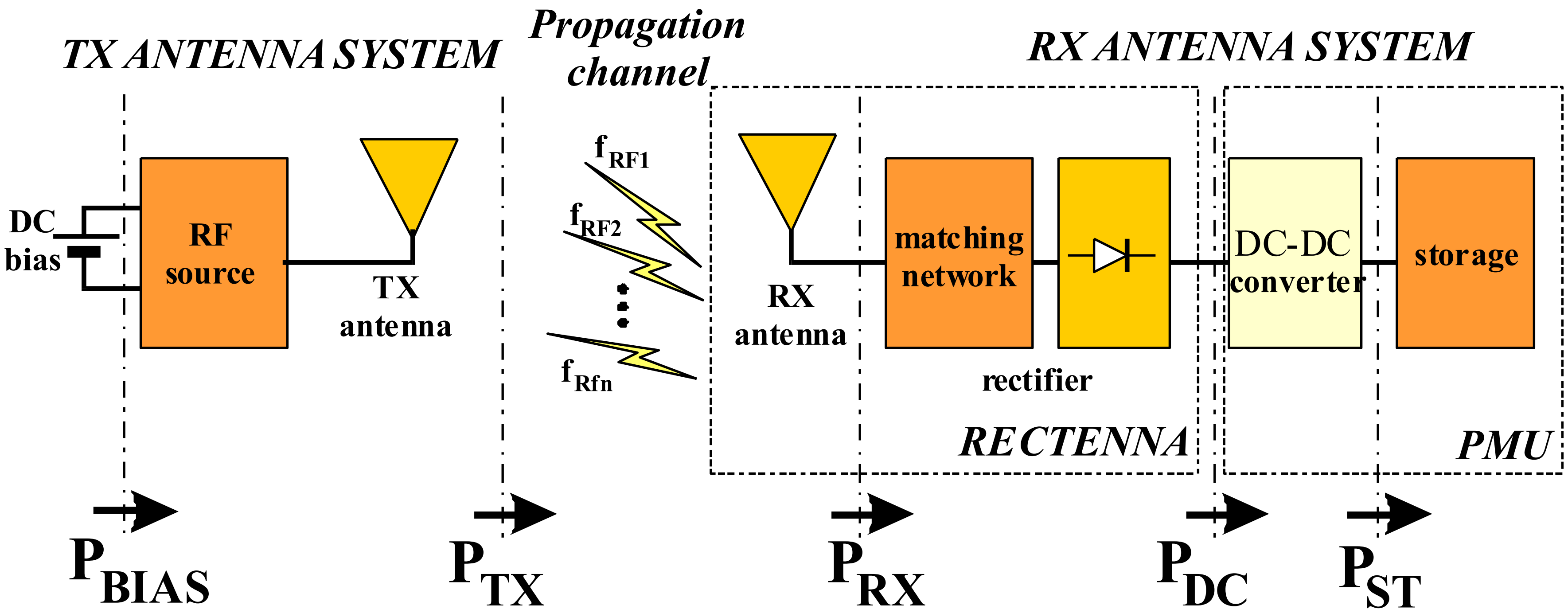


- Part of the reader functionalities could be delegated to distributed “energy showers”
- The UHF and UWB interrogation signals could be generated by energy showers deployed in the environment to facilitate the coverage and energy harvesting
- Problem: how to synchronize multiple showers?

A possible tag architecture



Far-field WPT system



end-to-end efficiency

$$\eta_{TOT} = \eta_{BIAS-RF} \cdot \eta_{RF-RF} \cdot \eta_{RF-DC} \cdot \eta_{DC-DC} = \frac{P_{TX}}{P_{BIAS}} \cdot \frac{P_{RX}}{P_{TX}} \cdot \frac{P_{DC}}{P_{RX}} \cdot \frac{P_{ST}}{P_{DC}}$$

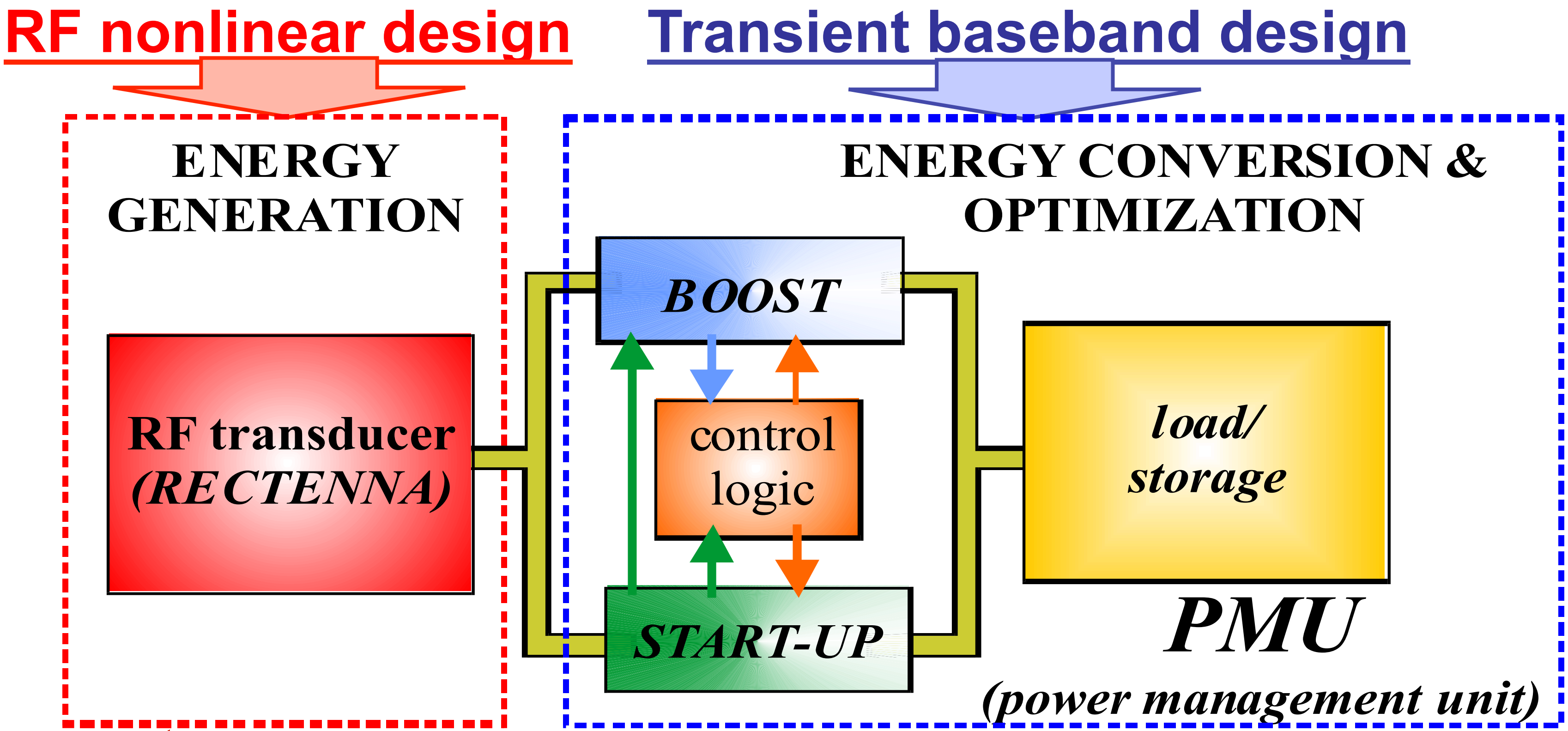
Wireless powering from the ambient

WIRELESS POWERING FROM THE AMBIENT		
TRANSMITTER SIDE (TX)	**POWER GENERATOR**	Not controllable multi-tone
	dc-to-RF EFFICIENCY	annot be optimized
	TX ANTENNA SPECS	Directivity unknown Polarization and position unknown Multi-band sources
RADIO CHANNEL	**RF-to-RF EFFICIENCY**	Unknown Worst case (statistical) estimate
RECEIVER SIDE (RX)	**RECTIFIER**	Design as a compromise for a broad range of power densities and frequencies
	RF-to-dc EFFICIENCY	Can be optimized
	RX ANTENNA SPECS	1. Non directive 2. Circularly or dually polarized 3. Multi-band resonant

Intentional Wireless powering

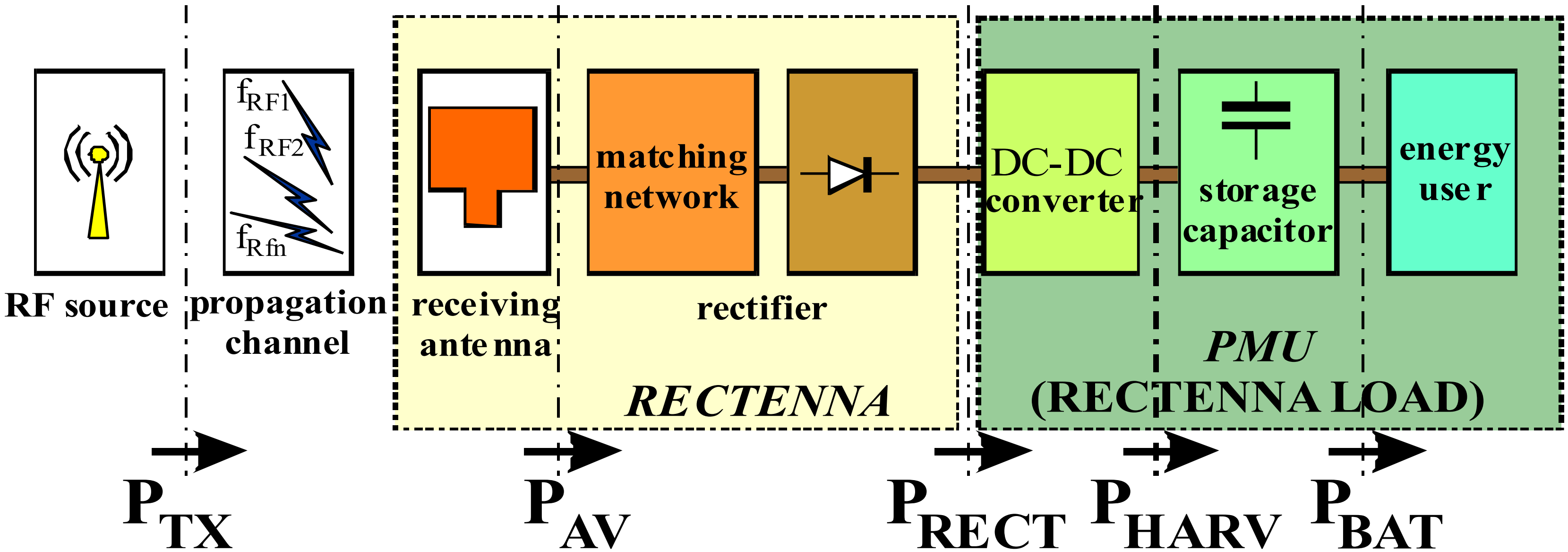
WIRELESS POWERING ON DEMAND		
TRANSMITTER SIDE (TX)	POWER GENERATOR	• high efficiency PA • optimized signal waveforms (multisine, UWB, chaotic signals)
	dc-to-RF EFFICIENCY	Can be optimized
	TX ANTENNA SPECS	• Directive • Defined polarization and position • Smart beaming is possible
RADIO CHANNEL	RF-to-RF EFFICIENCY	• Known • Optimized
RECEIVER SIDE (RX)	RECTIFIER	Design for specific power densities and RF frequencies, multistage topology
	RF-to-dc EFFICIENCY	Can be optimized
	RX ANTENNA SPECS	• Directive • Defined polarization and position • Single-band

Concurrent CAD tool



- **1st step**: full-wave description of the receiving antenna operating at RF in realistic environmental conditions
- **2nd step**: time-domain analysis of the storage subsystem

Global system efficiency



depends on the radio channel

depends on rectenna load

1st step

2nd step

$$\eta_{EH} = \eta_{TX-RX} \bullet \eta_{RF-DC} \bullet \eta_{DC-DC} = \frac{P_{AV}}{P_{TX}} \bullet \frac{P_{RECT}}{P_{AV}} \bullet \frac{P_{HARV}}{P_{RECT}}$$

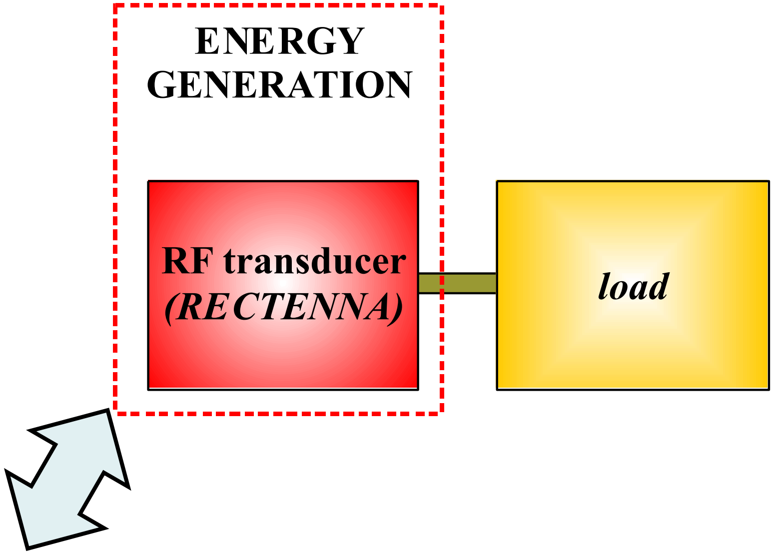
Strictly correlated

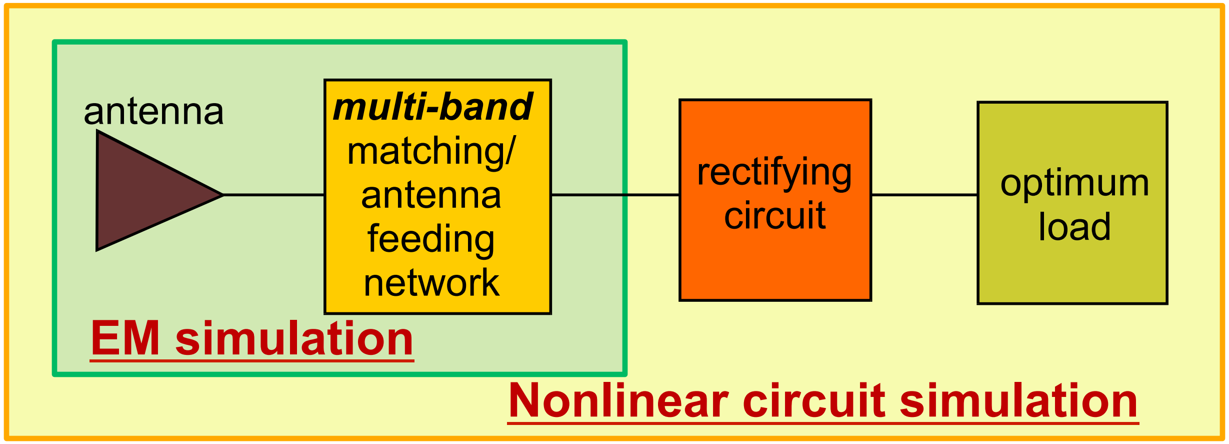
depends on rectenna output impedance

RECTENNA DESIGN IN STATIONARY CONDITIONS

Rectenna design in stationary conditions

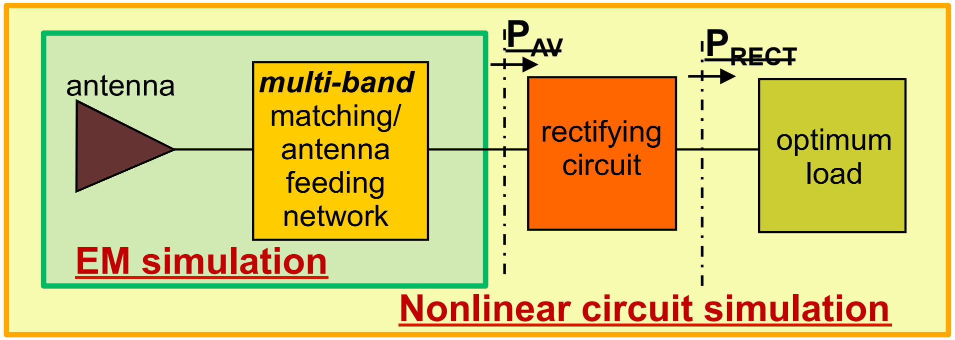
- Broadband **Harmonic Balance nonlinear** design and analysis of rectenna (using broadband antenna EM simulation)
- Constraint: RF source with extremely variable ***low-power*** range

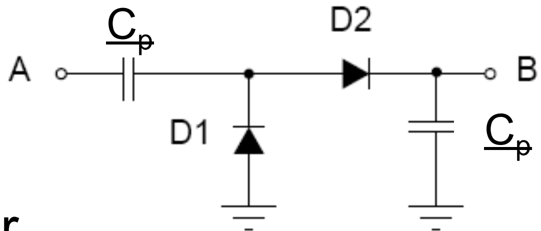




Rectenna design in stationary conditions

- HB NL design parameters [1, 2]:
  - Load: device (e.g., a PMU for sensor biasing) input impedance
  - Antenna/rectifier matching network
  - Rectifier topology:





Single stage full-wave peak-to-peak low-threshold Schottky-diode RF-DC power converter

- **GOAL**: optimum RF-to-DC ***power conversion efficiency***

$$\eta_{RF-DC} = \frac{P_{RECT}}{P_{AV}}$$

[1] D. Masotti, A. Costanzo, M. Del Prete, V. Rizzoli, “A Genetic-Based Design of a Tetra-Band High-Efficiency RF Energy Harvesting System”, *IET Microwaves Antennas & Propagation*, Vol. 7, no. 15, 2013, pp. 1254 – 1263.

[2] V. Rizzoli, A. Costanzo, D. Masotti, F. Donzelli, "Integration of numerical and field-theoretical techniques in the design of single- and multi-band rectennas for micro-power generation", *EuMA Int. Journal of Microwave and Wireless Technologies* , vol. 2, No. 3-4, pp. 293-303, July 2010.

Circuital representation of incident field

- A rigorous application of **EM theory** allows to accurately evaluate the Norton equivalent of the actual incoming field [2, 3], when
  - Antennas are in Fraunhofer region
  - Incident field (E_{inc}) ≈ uniform plane wave

$$J_{eq}(\omega) = j \frac{\frac{1}{U}}{1 + R_0 Y_A} \frac{2\lambda r}{\eta} e^{j\beta r} \left(E_{inc}(\omega, \theta, \varphi) \right) \bullet E_{rectenna}(\omega, \theta, \varphi)$$

Far-field radiated by the Tx antenna/ RF source

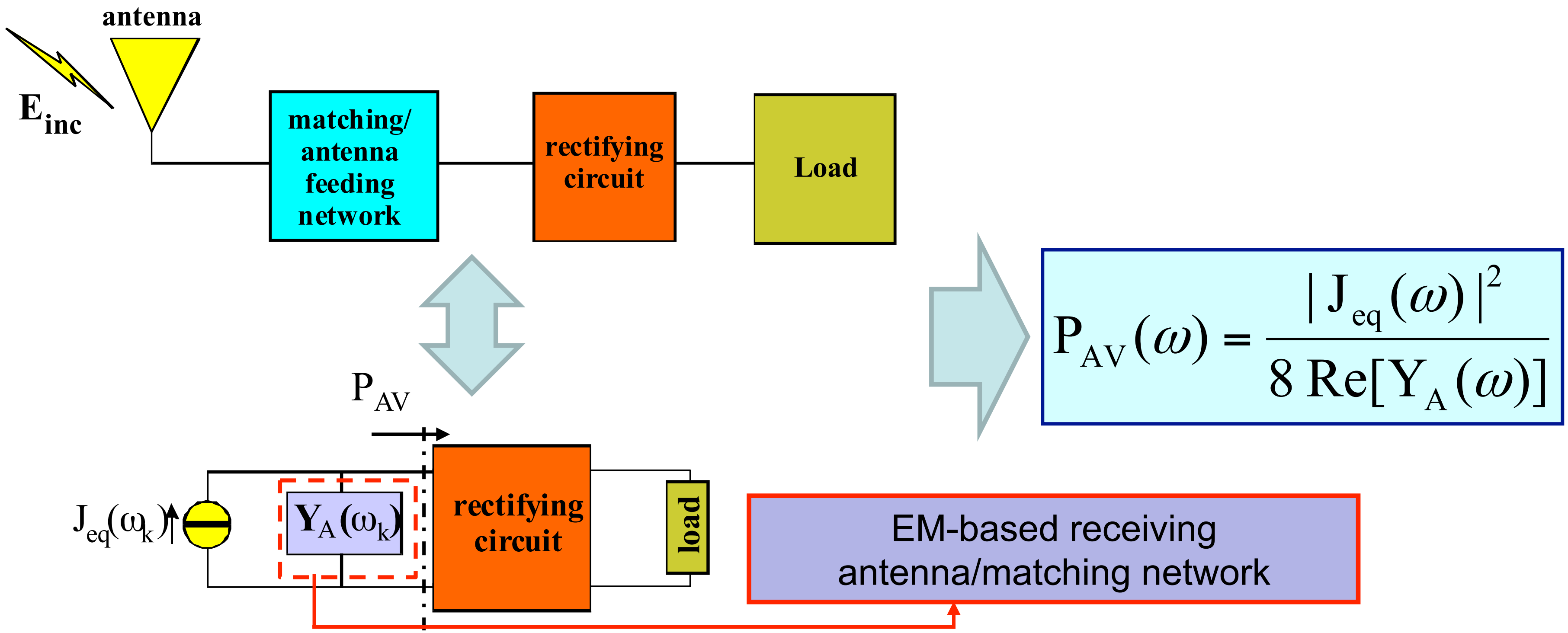
Far-field radiated by the rectenna (when in Tx mode)

[2] V. Rizzoli, A. Costanzo, D. Masotti, F. Donzelli, "Integration of numerical and field-theoretical techniques in the design of single- and multi-band rectennas for micro-power generation", *EuMA Int. Journal of Microwave and Wireless Technologies*, vol. 2, No. 3-4, pp. 293-303, July 2010.

[3] V. Rizzoli, D. Masotti, N. Arbizzani, and A. Costanzo, "CAD Procedure for Predicting the Energy Received by Wireless Scavenging Systems in the Near- and Far-field Region ", *2010 IEEE MTT-S International Microwave Symposium Digest* (Anaheim), May 2010, pp 1768-17710

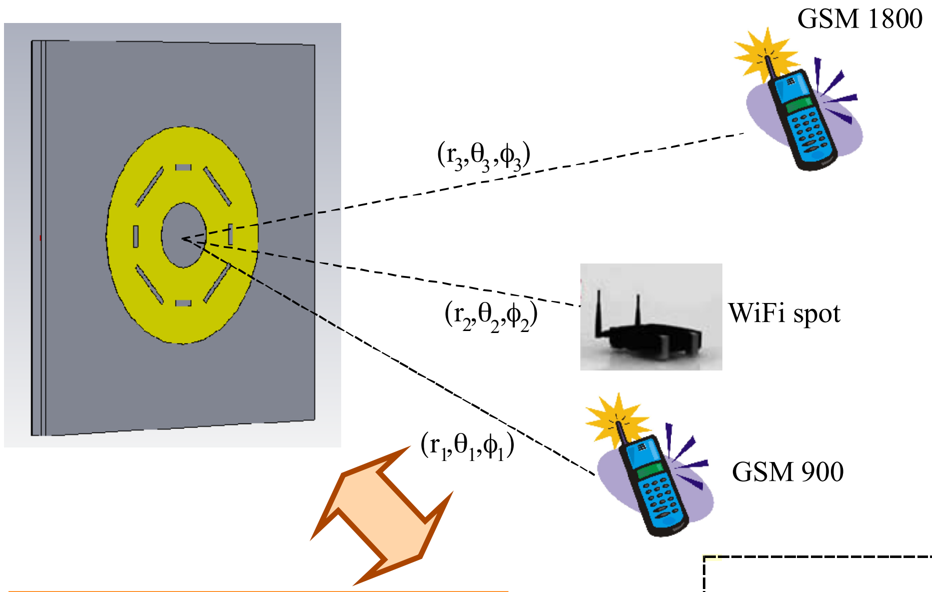
Circuital representation of incident field

- Easy evaluation of actual circuit excitation



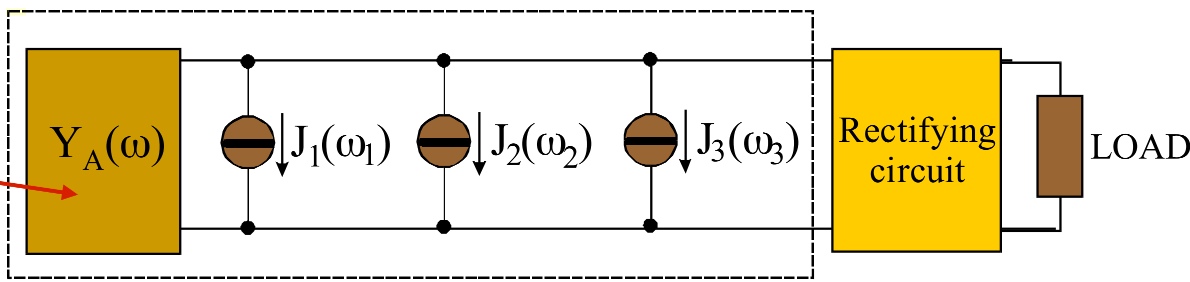
$$P_{AV}(\omega) = \frac{|J_{eq}(\omega)|^2}{8\,\mathrm{Re}[Y_A(\omega)]}$$

Single or Multi-tone analysis



By means of this rigorous approach a single or multi-tone simulation can be performed ***straightforwardly*** [4]

Antenna/feeding network sub-assembly



$$P_{AV} = \sum_{k=1}^{3} \left| J_{eq}(\omega_k) \right|^2 / \left\{ 8\,\mathrm{Re}\left[Y_A(\omega_k) \right] \right\}$$

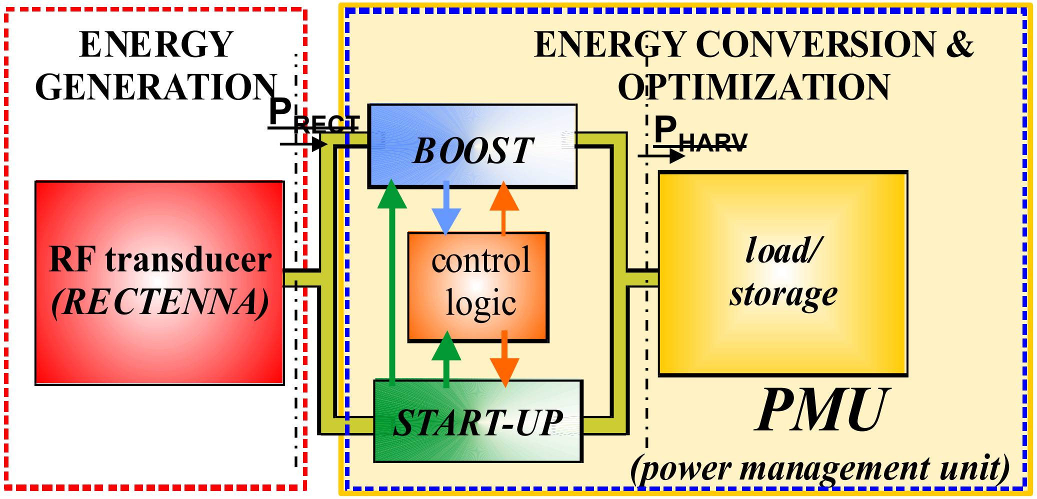
[4] A. Costanzo, D. Masotti, M. Aldrigo, "Compact, Wearable Antennas for Battery-Less Systems Exploiting Fabrics and Magneto-Dielectric Materials", *Electronics*, vol. 3, No. 3, pp. 474-490, 2014

TIME-DOMAIN DESIGN OF THE PMU

Time-domain design of the PMU

- **Transient design** of a switching circuit to optimize RF-baseband subsystems interactions [5, 6]
  - Design parameters:
    - switching elements
    - timings
    - storage capacitor

WHILE ACCOUNTING FOR THE ACTUAL RF OPERATING REGIME



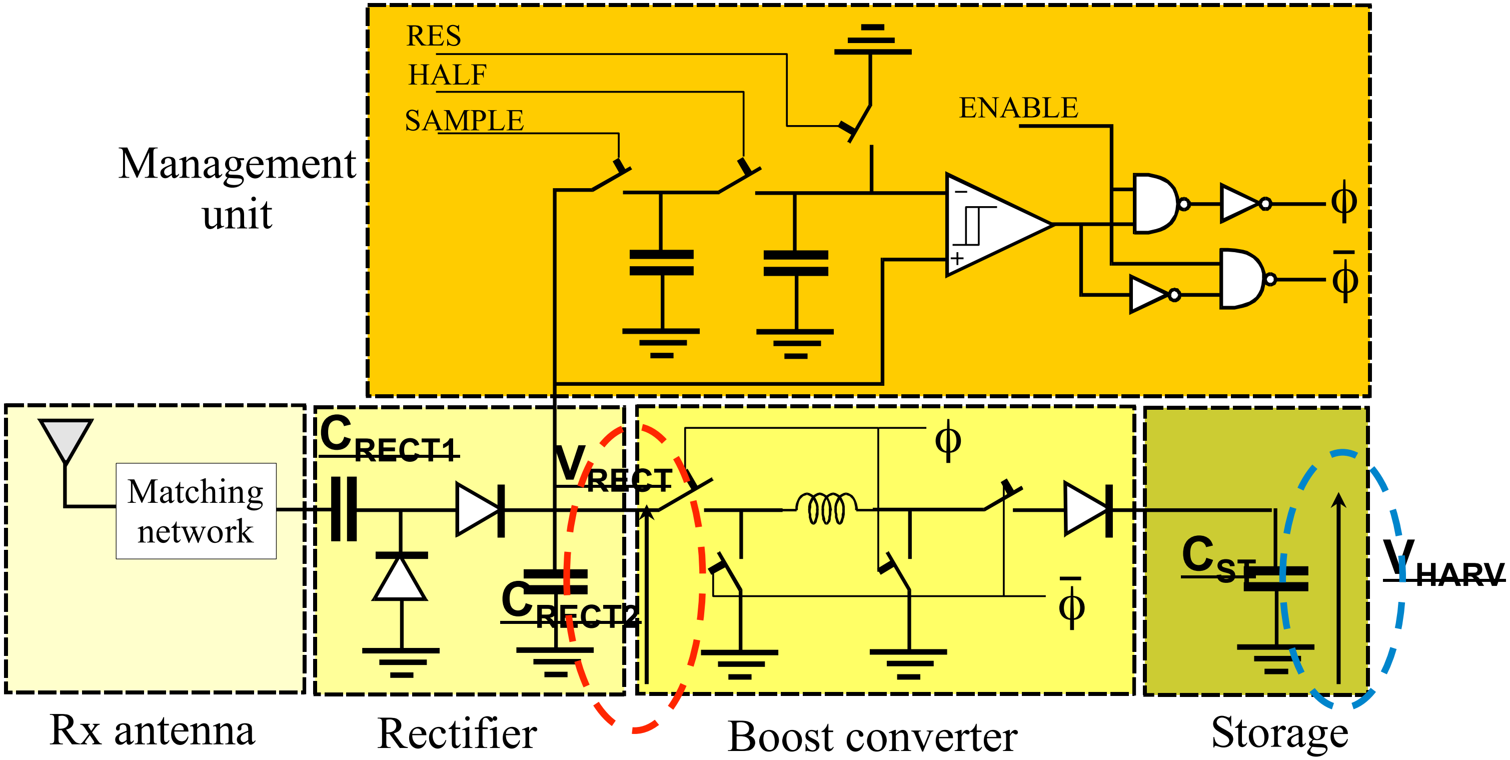
- **GOAL**: fraction (F < 1, ~90%) of the maximum energy stored in the capacitor (E_{HARV}) during the charging time T_C (DC-to-DC ***conversion efficiency)***

$$\eta_{DC\text{-}DC} = \frac{F\,E_{HARV}}{P_{RECT}\,T_C} = \frac{P_{HARV}}{P_{RECT}}$$

[5] A. Costanzo, M. Fabiani, A. Romani, D. Masotti, and V. Rizzoli, "Co-design of Ultra Low Power RF/Microwave Receivers and Converters for RFID and Energy Harvesting Applications ", 2010 IEEE MTT-S International Microwave Symposium Digest (Anaheim), May 2010, pp. 856-859.

[6] A. Costanzo, A. Romani, D. Masotti , N. Arbizzani, and V. Rizzoli “RF/Baseband Co-design of Switching Receivers for Multiband Microwave Energy Harvesting”, Elsevier Sensors & Actuators: A. Physical, Mar. 2012, Vol. 179, No. 1, pp. 158-168.

RF harvester with a boost converter

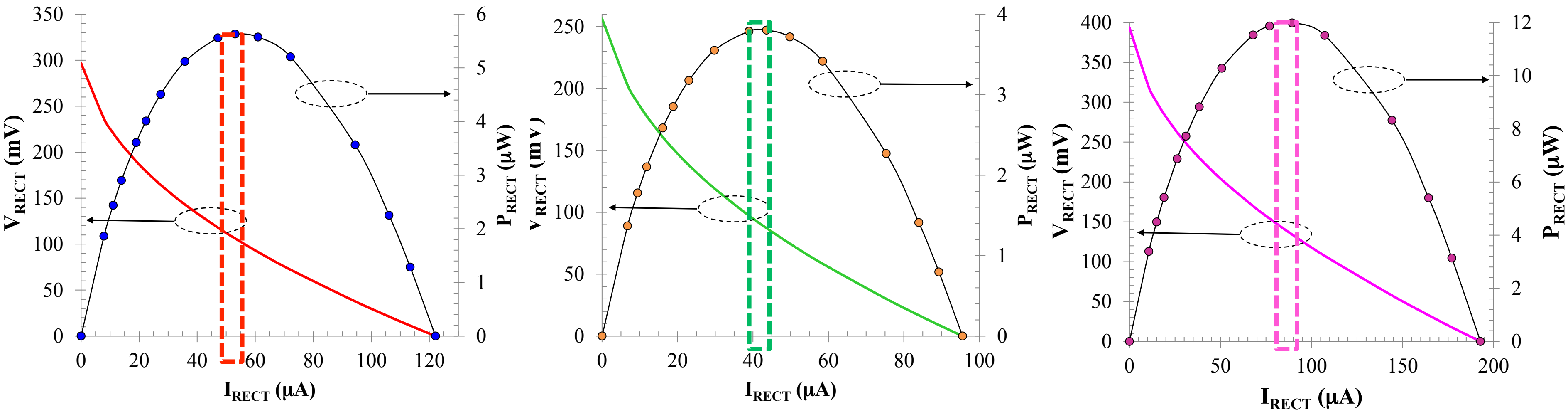


The load must be replaced by a switching converter able to dynamically track the maximum power point (MPP) condition for any frequency and power level

MPP boost converter design

- **Design rule**: the converter is dimensioned to keep the rectified voltage at about one half of the open-circuit voltage, which has been demonstrated to be close to the MPP [6]

$$V_{RECT} \approx V_{OPEN}/2$$



900 MHz: P_{AV} = -14 dBm | **1750 MHz: P_{AV} = -15 dBm** | **2450 MHz: P_{AV} = -12 dBm**

[6] A. Costanzo, A. Romani, D. Masotti , N. Arbizzani, and V. Rizzoli "RF/Baseband Co-design of Switching Receivers for Multiband Microwave Energy Harvesting", Elsevier Sensors & Actuators: A. Physical, Mar. 2012, Vol. 179, No. 1, pp. 158-168.

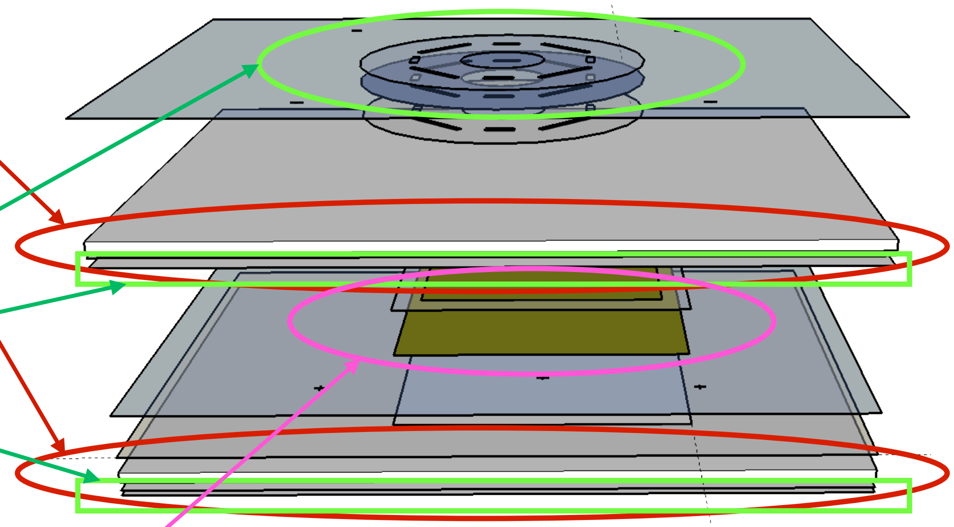
WEARABLE RF ENERGY HARVESTING SYSTEM

Wearable rectenna design

- A 4mm-thick ***pile*** substrate under the patch antenna and as a further separator

  (ε_r=1.23, tanδ=0.0019)

- A 70μm-thick Global EMC-shielding ***conductive fabric*** is chosen for
  - Antenna
  - Ground plane
  - Shield
- A 100μm-thick feeding circuit substrate under the fabric ground plane is *flexible* ***Kapton***
  (ε_r=3.4, tanδ=0.002)



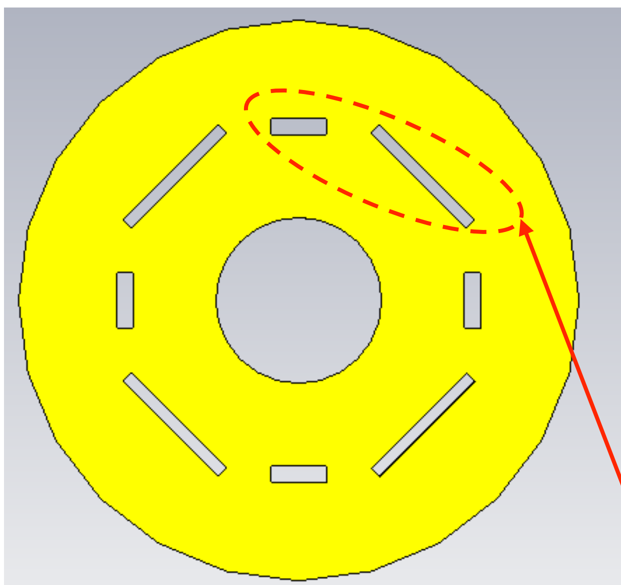
The ***Kapton*** substrate is limited to the area required by the antenna feeding network and the rectifier [7]

[7] D. Masotti, A. Costanzo, S. Adami,"Design And Realization Of A Wearable Multi-Frequency Rf Energy Harvesting System", *Proceedings of the 5th European Conference on Antennas and Propagation* 2011 (Rome), Apr. 2011, pp. 517-520

Antenna selection

- The ***multi-band*** behaviour of the scavenging system is provided by a ***unique*** radiating element [8]:

Slotted annular-ring



able to harvest from two GSM standards and from WiFi with a suitable choice of resonant modes

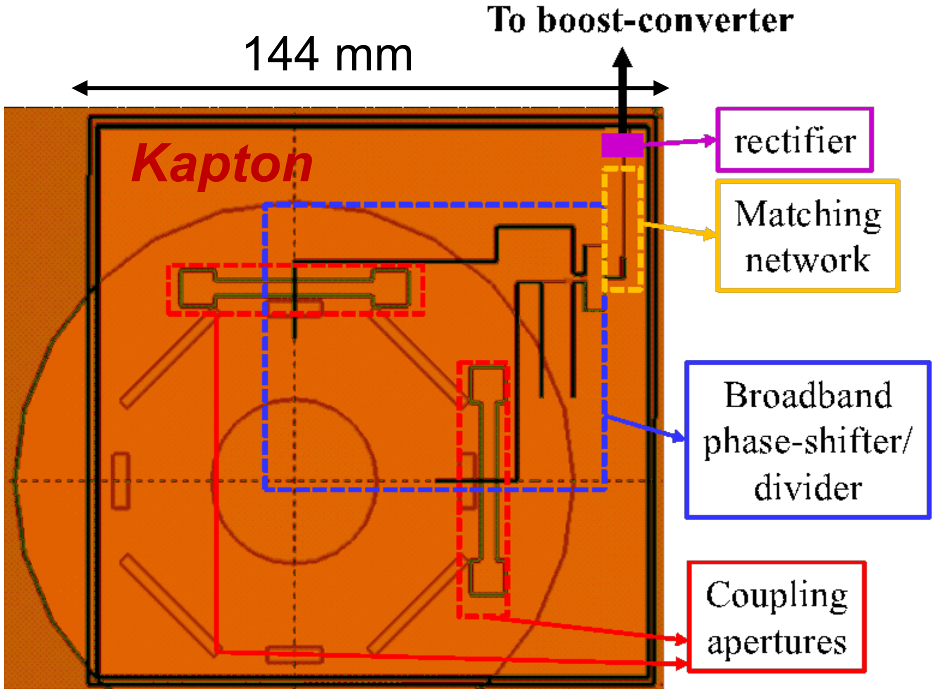
TM11 @ 900 MHz
TM21 @ 1750 MHz
TM12 @ 2450 MHz

slots used for frequency tuning

[8] A. Costanzo, D. Masotti, F. Donzelli, S. Adami, "Device to convert radio frequency electromagnetic energy". WO/2012/042348, PCT/IB2011/002253. Apr. 2012

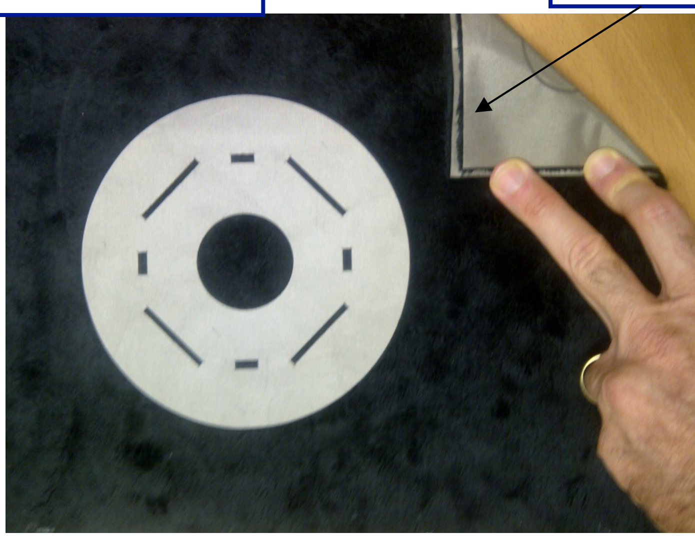
Antenna feeding network

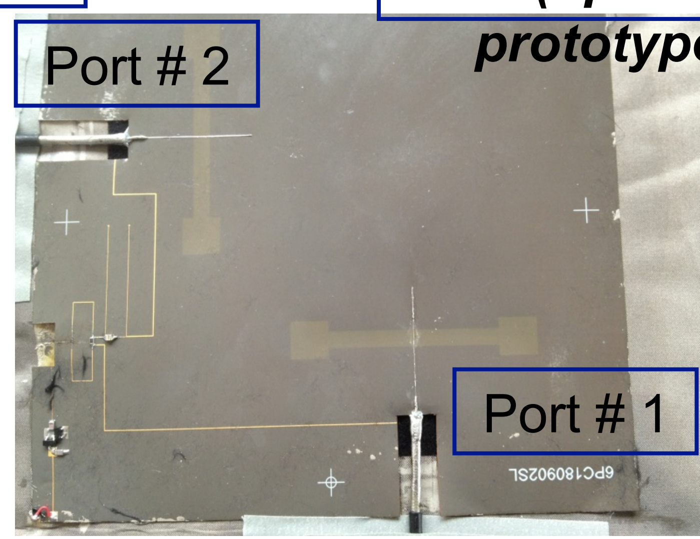
- Two apertures in the ground plane for CP purposes: “dog bone” shapes guarantee best tradeoff between antenna ports matching and decoupling
- A compact, broadband ***power divider & 90° phase-shifter*** on a flexible Kapton substrate has been EM-designed by considering the antenna



Antenna measurement

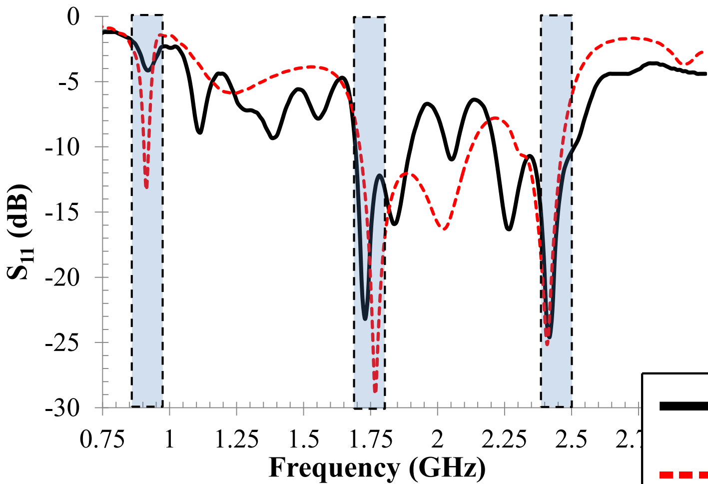
- The measurement of the 2-port antenna scattering parameters is carried out with a modified prototype, where the rectifier and phase shifter subcircuits in the Kapton layer have been barred by cutting the substrate in correspondence of the antenna feeding lines

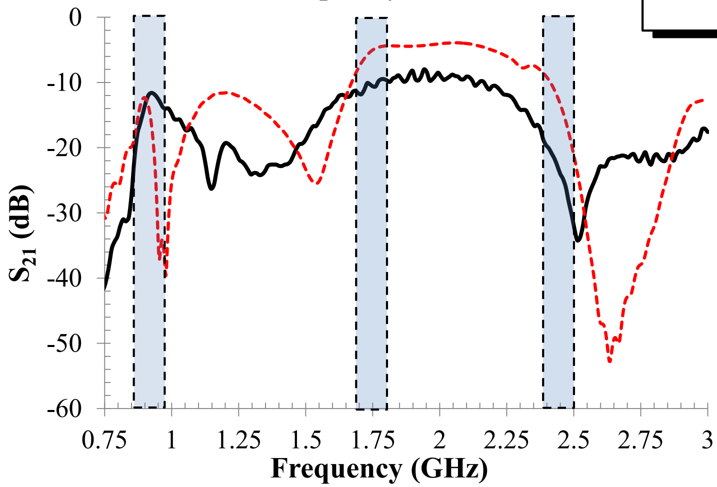


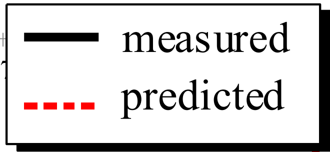


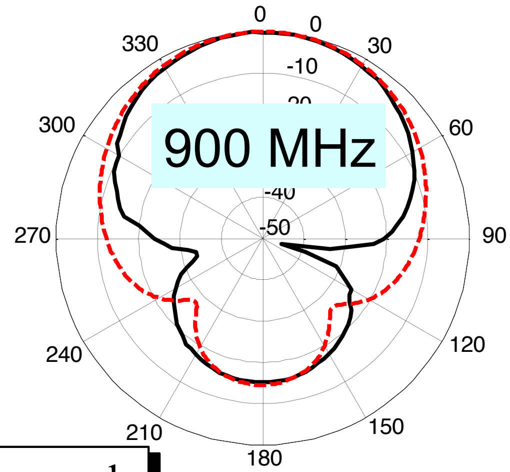
Antenna measurement

NEAR-FIELD PERFORMANCE

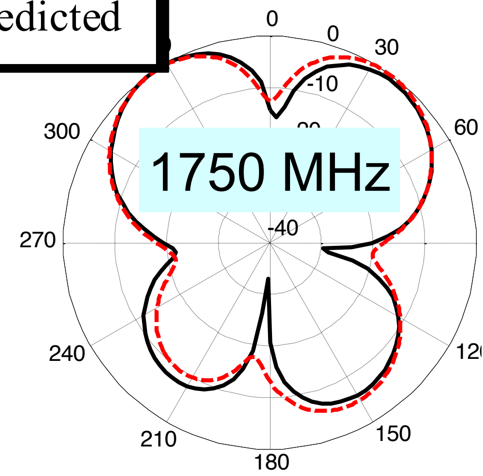


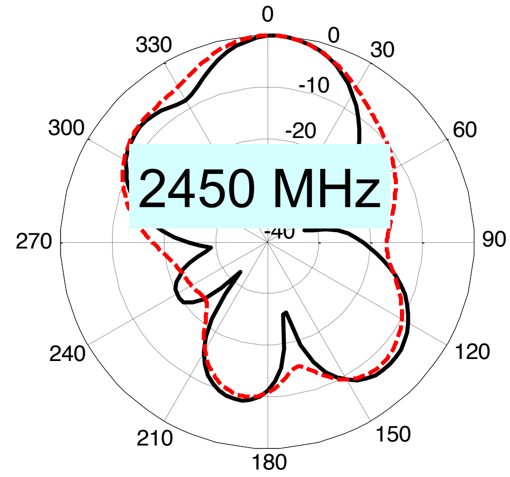






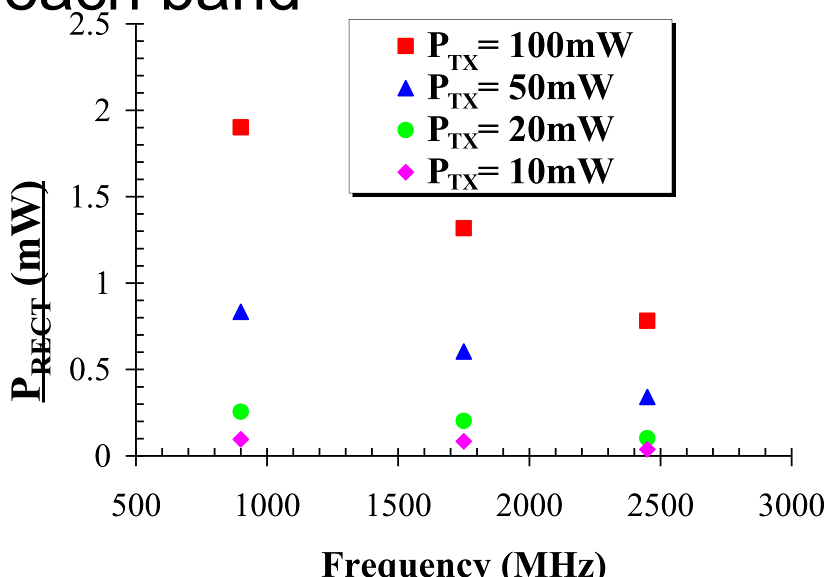
FAR-FIELD PERFORMANCE

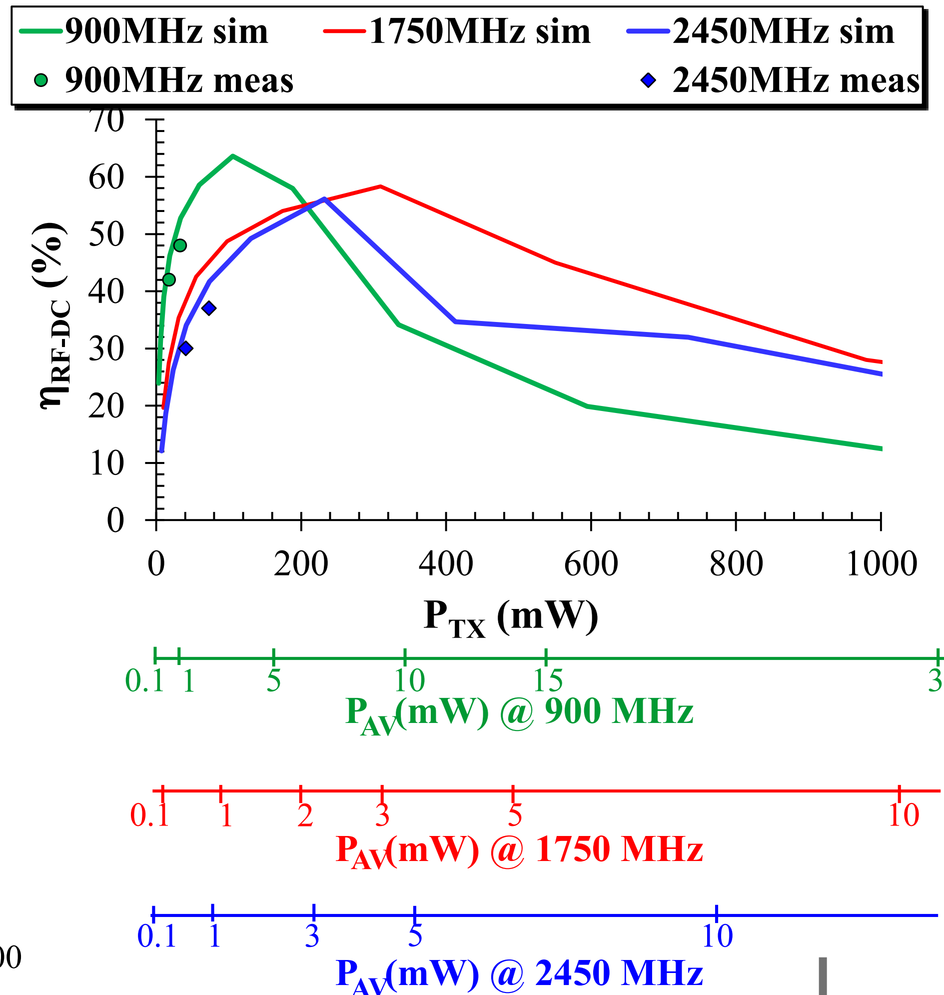




Rectified power and RF-DC conversion efficiency

- P_{TX} represents the transmitted power of an ideal dipole placed at a distance of 30cm, considering the maximum link direction (θ_M, ϕ_M) for each band

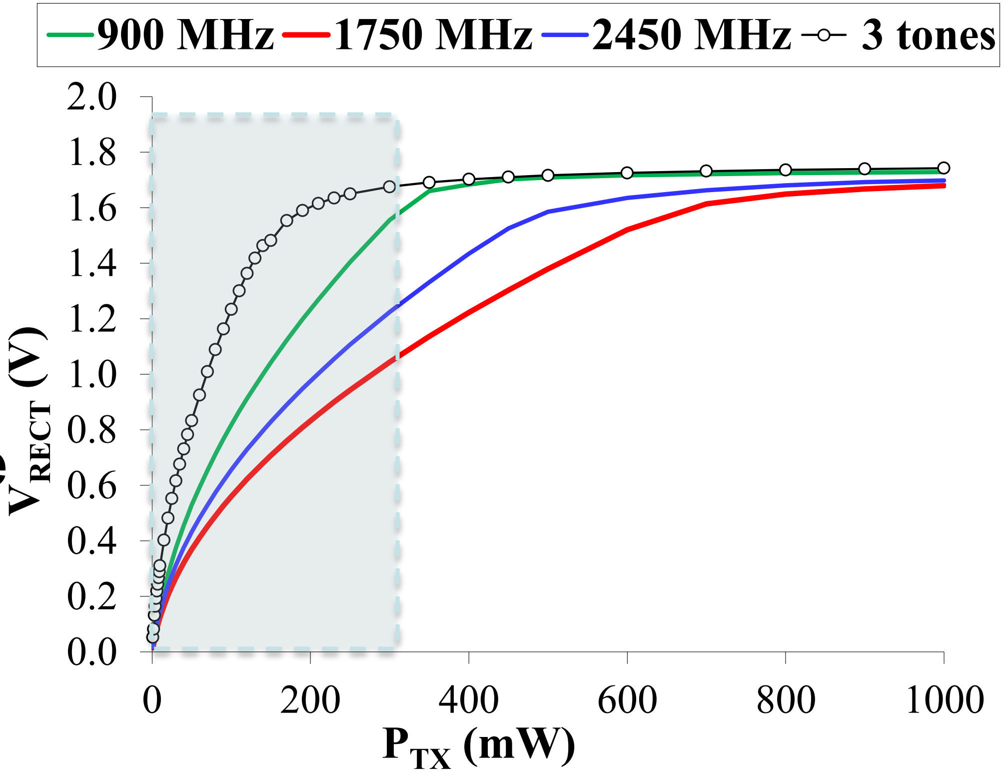




36

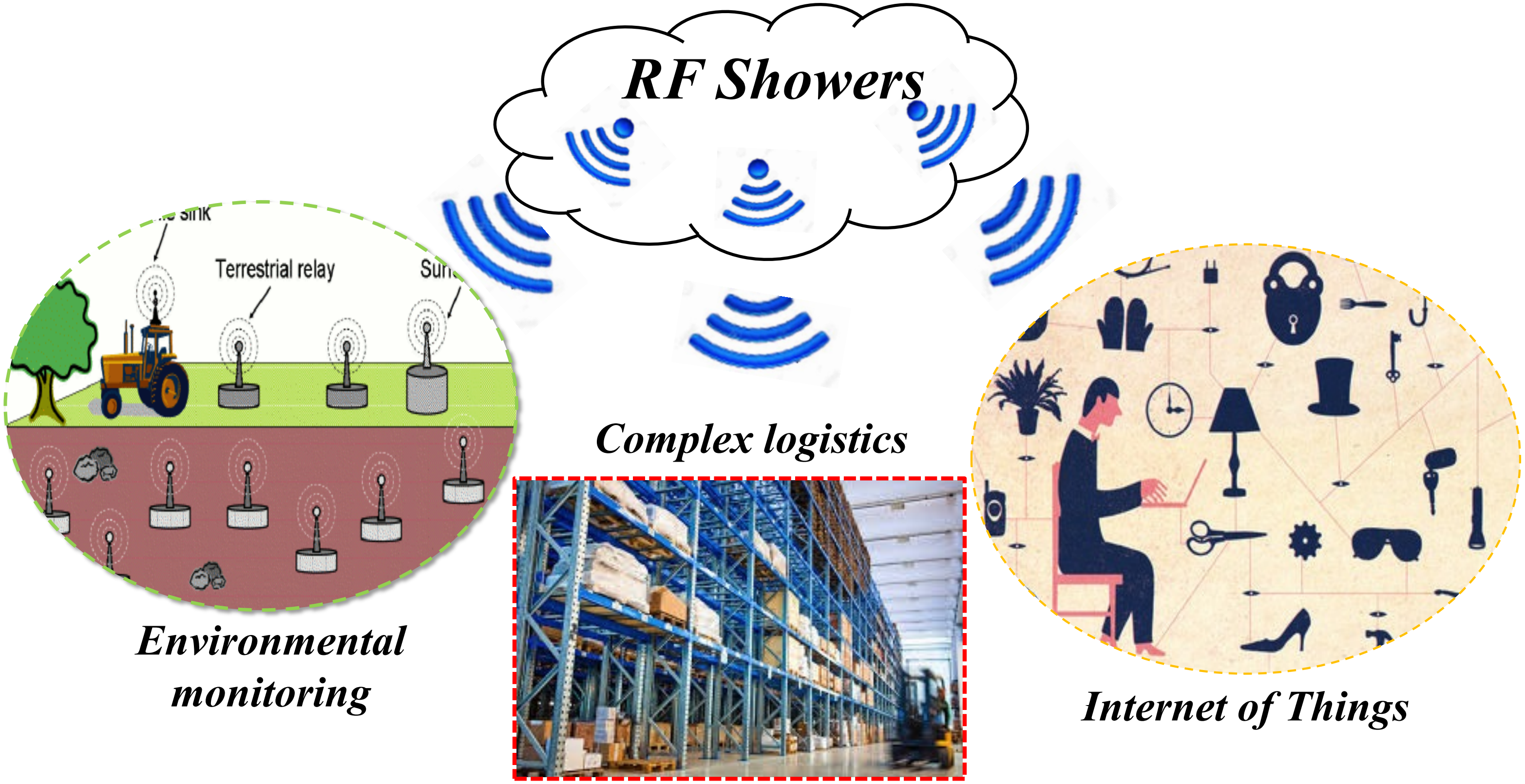
Nonlinear effects: 3-tone *vs* sinusoidal analyses

- For a given P_{TX} :
  - one excitation in the single-tone analysis
  - are equally distributed to the different tones in the multi-tone case
- IM products up to the 3rd order are considered in the HB simulation
- At low power levels, the presence of the IM products improves the rectenna conversion capabilities [9]



[9] D. Masotti, A. Costanzo, "Design of Wearable Rectennas Harvesting from Multi-Tone Ambient RF sources", 4th International Symposium on Applied Sciences in Biomedical and Communication Technologies (ISABEL 2011) (Barcelona), 26-29 Oct. 2011, pp. 1-5

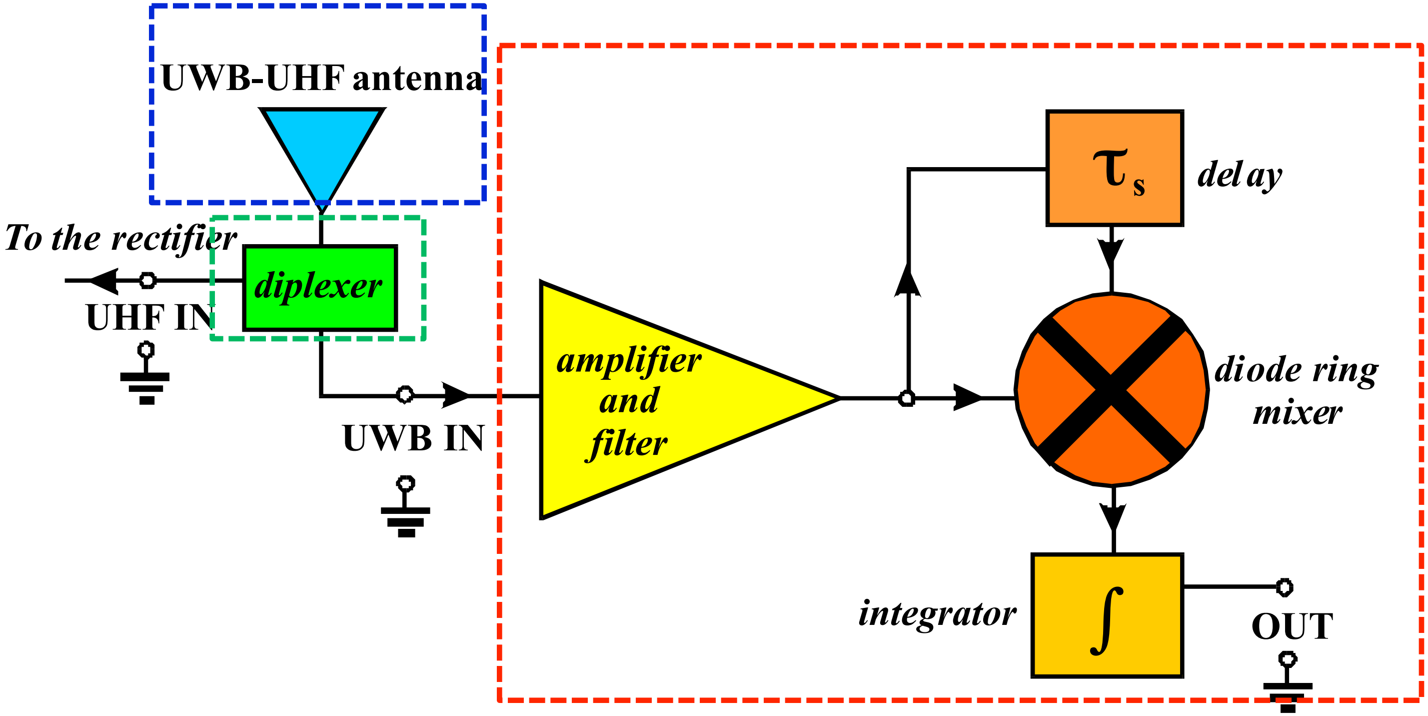
Energy Autonomous nodes



IR-UWB receiver

- The system under test includes:
  - A transmitted-reference UWB receiver
  - A dual-mode UWB-UHF antenna
  - A diplexer

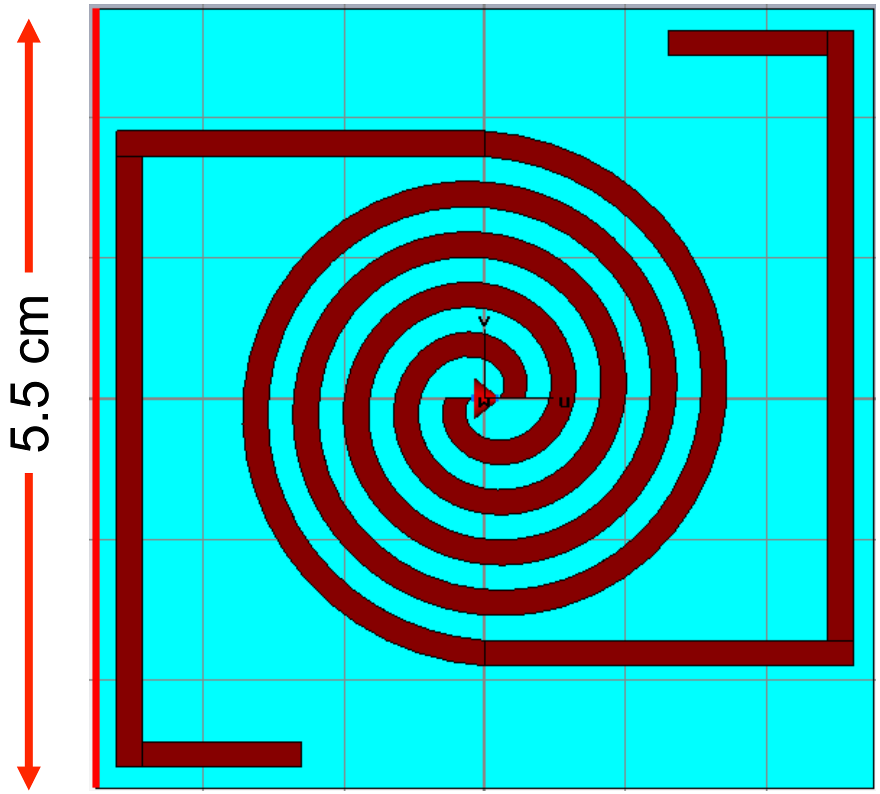
Developed within the Italian national project GRETA



Antenna layout

www.greentags.eu

- Single-port antenna for dual operation [13]:



- Spiral
  - covers the UWB [3.1 – 4.8] GHz band
- Folded dipole
  - all the spiral path contribute to the dipole antenna: 868 MHz resonance

[13] M. Fantuzzi, D. Masotti, A. Costanzo, “A novel integrated UWB-UHF one-port antenna for localization and energy harvesting”, IEEE Trans. Antennas & Propagation, 2015.

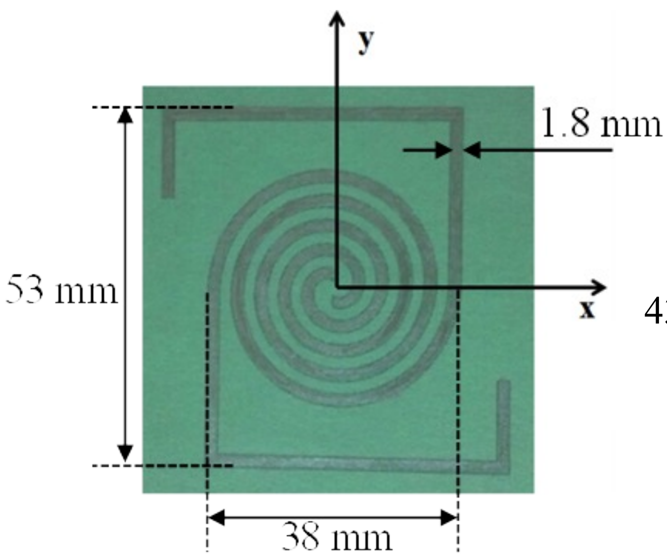
Antenna prototypes

Paper

$\varepsilon_r = 2.85$

$\tan\delta = 0.053$

hand-painted conductive paste

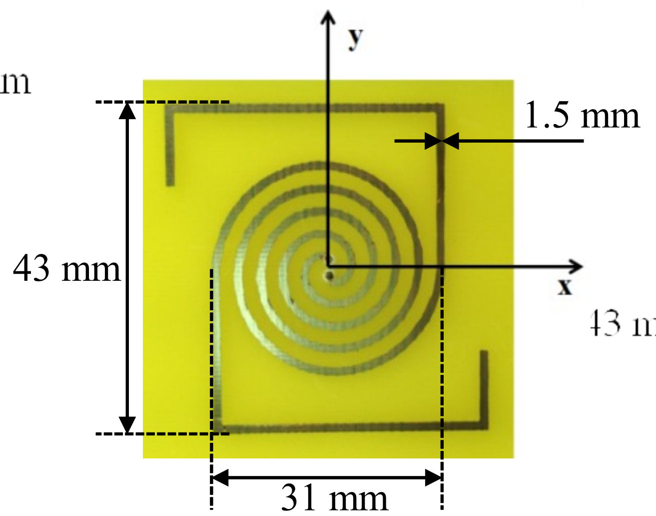


FR-4

$\varepsilon_r = 4.3$

$\tan\delta = 0.025$

chemical etching

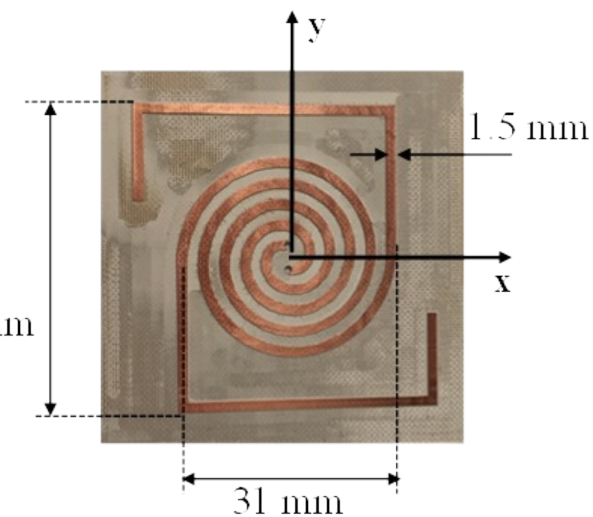


Taconic

$\varepsilon_r = 6.15$

$\tan\delta = 0.0028$

in-house milling machine

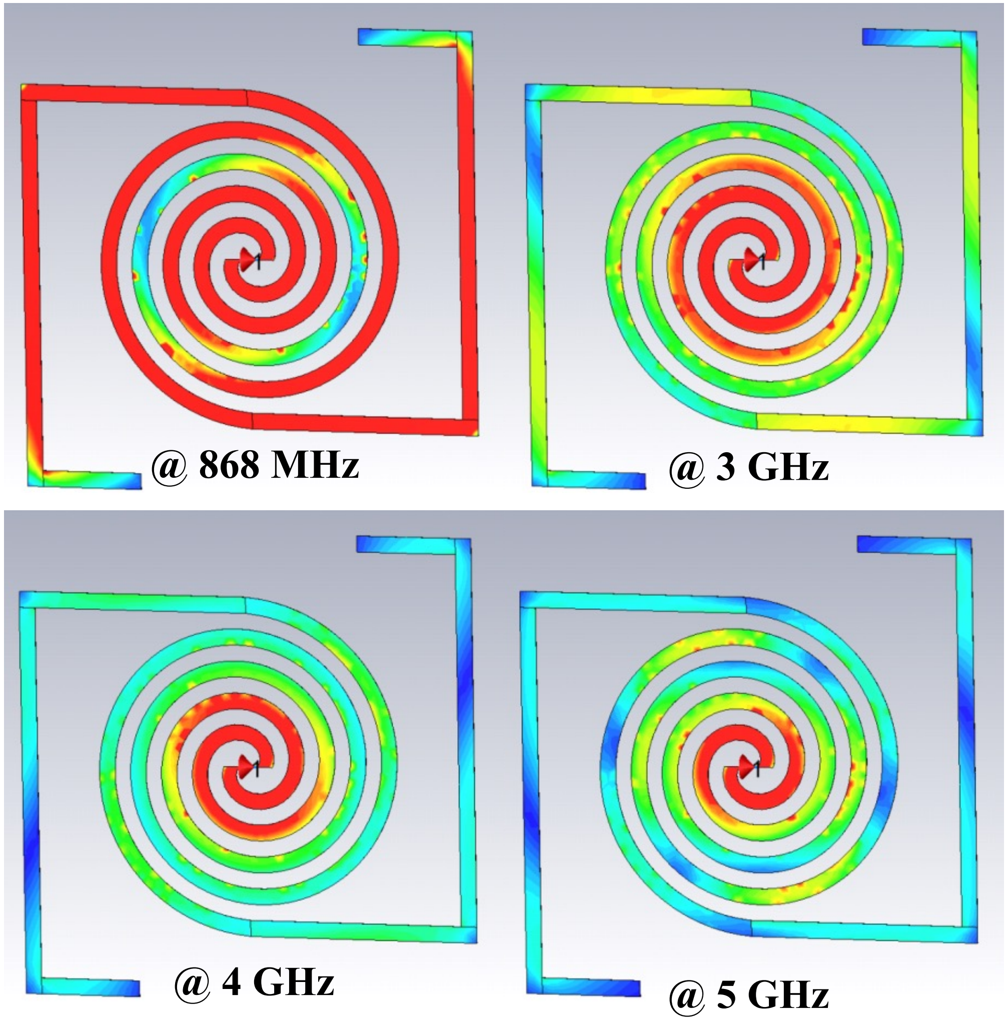


Antenna radiation

Radiation efficiencies and realized gain
Simulation results

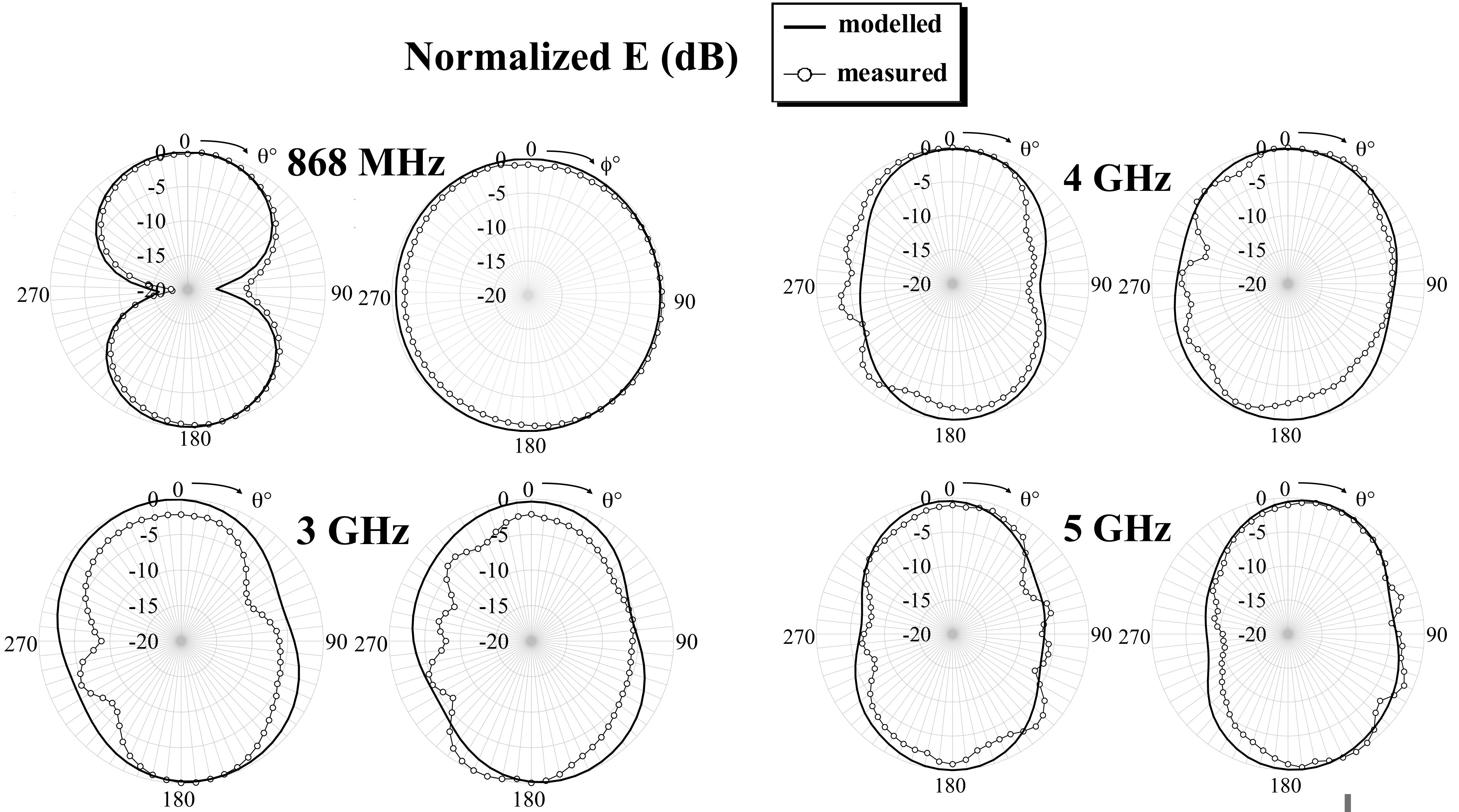
Frequency	Rad. Efficiency			Realized Gain		
	Paper	FR-4	Taconic	Paper	FR-4	Taconic
868 MHz	63.3 %	68.7 %	78.4 %	~ 0 dBi	~ 0 dBi	~ 0 dBi
3.1 GHz	89.2 %	94.2 %	98.4 %	3.4 dBi	3.1 dBi	3.4 dBi
4 GHz	90.4 %	92.6 %	98.2 %	3.2 dBi	2.7 dBi	2.9 dBi
4.8 GHz	91.1 %	91.6 %	98.6 %	4.2 dBi	3.9 dBi	4.3 dBi

Surface current

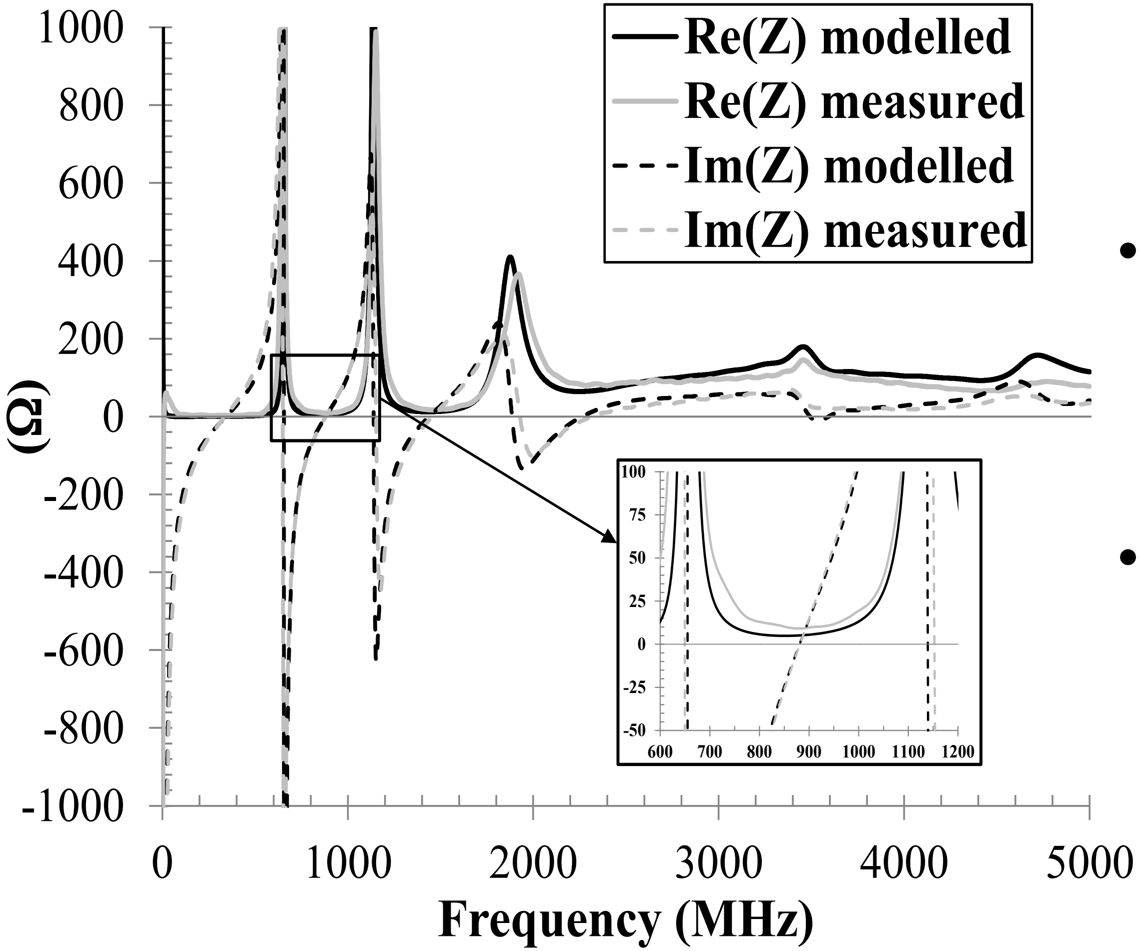


- active zone moving in the UWB band
- 1.5 λ behavior of the dipole

Radiation patterns



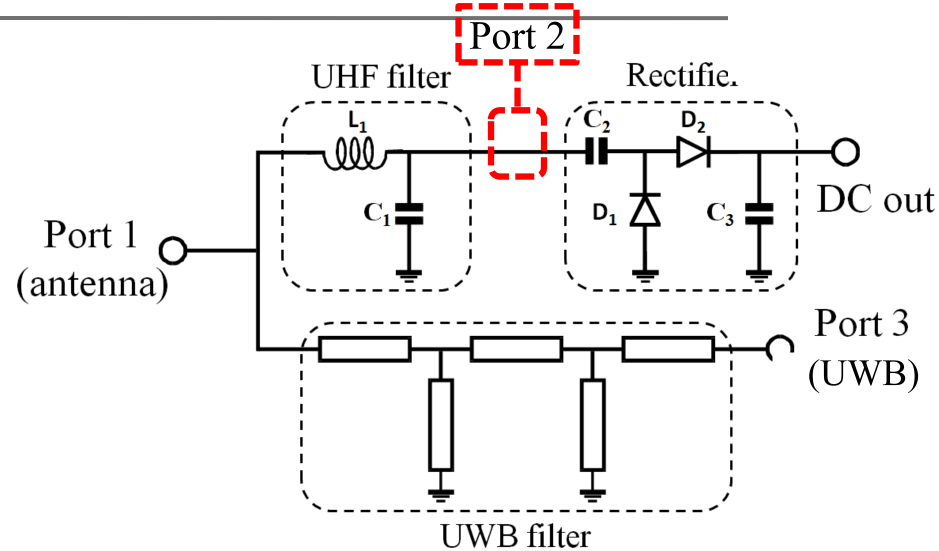
Antenna impedance

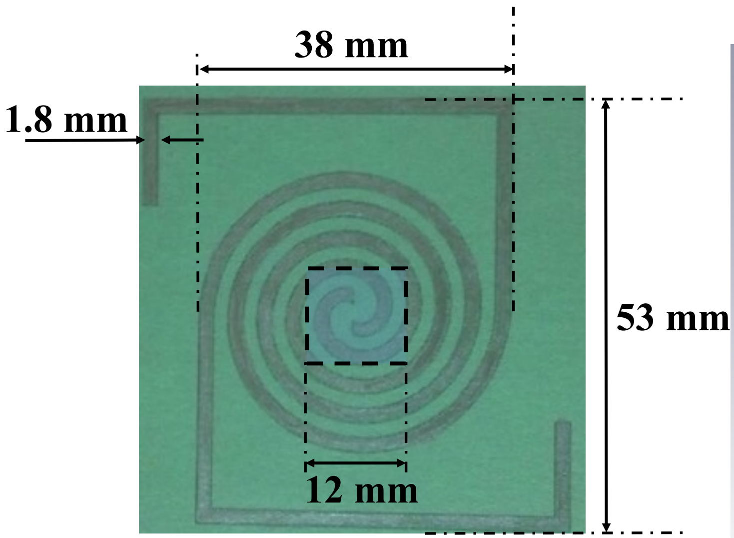


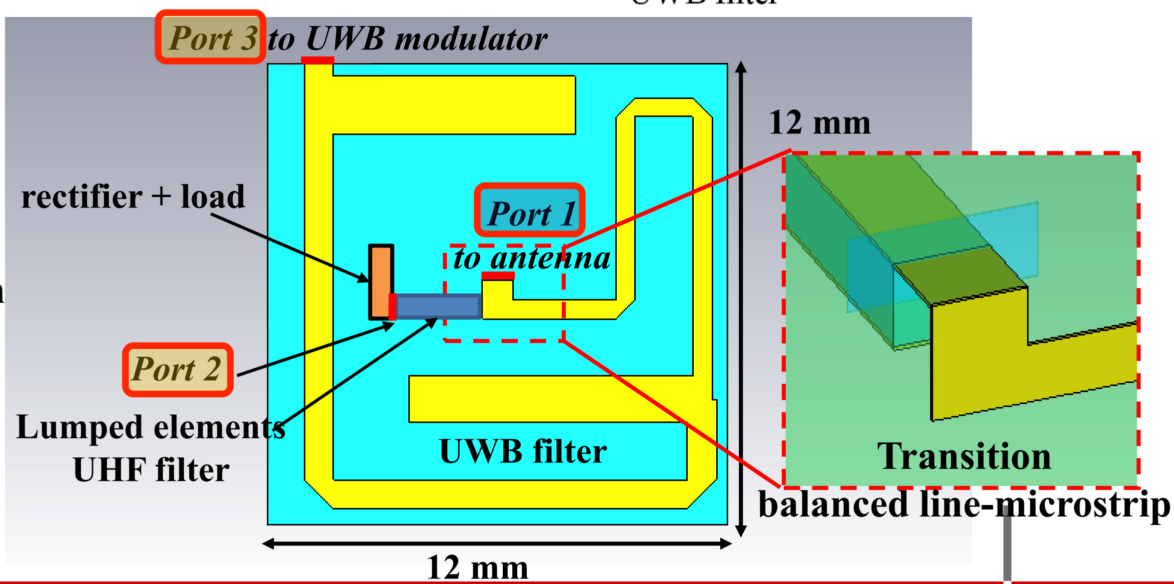
- resonance at 868 MHz (imaginary part ~ 0 Ω)
- real part almost constant in the UWB band

Diplexer network

- Feeding/matching network
  - Lumped elements UHF filter
  - Microstrip filter for UWB band
- Rectifying operations

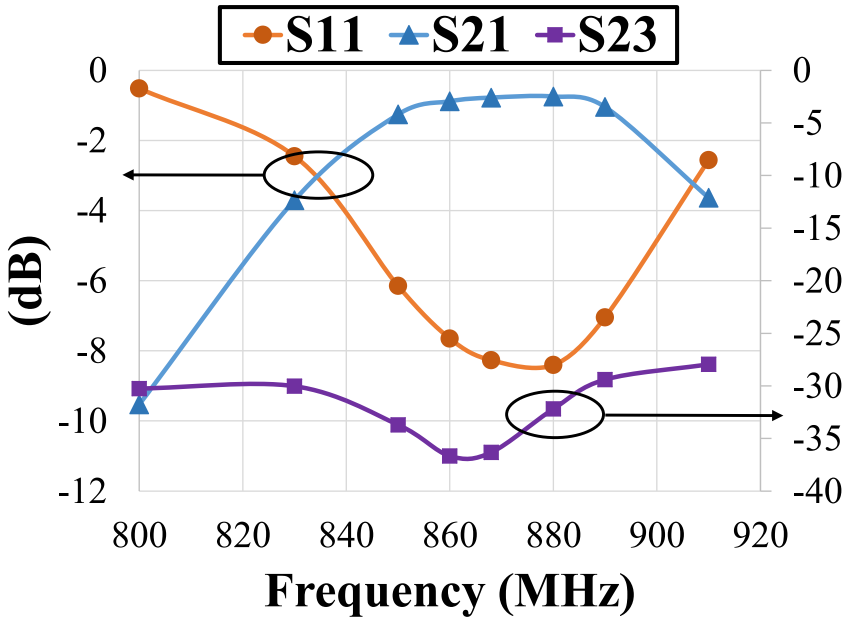


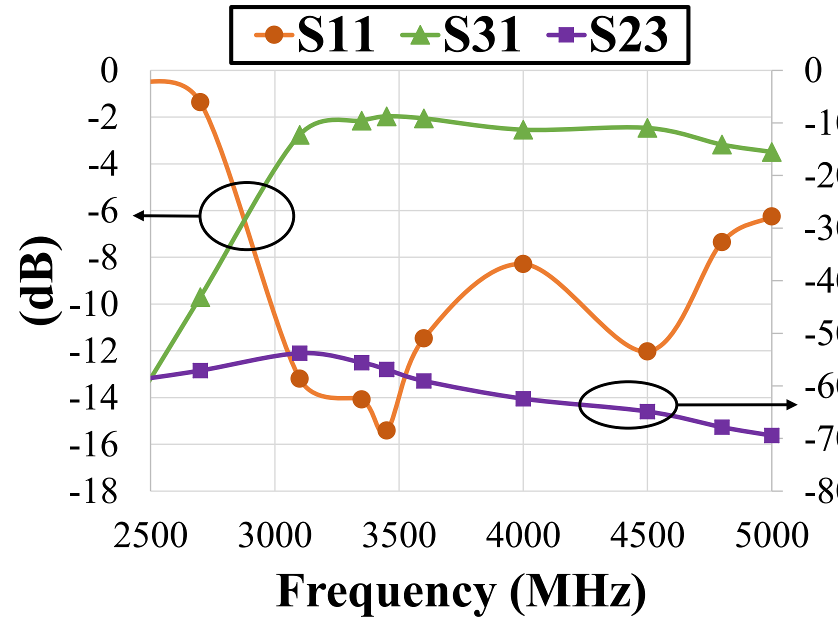




Diplexer network

- Simulated scattering parameters
  - Port 1: antenna
  - Port 2: rectifying section mean-value ($20 - j250\ \Omega$)
  - Port 3: 50 Ω



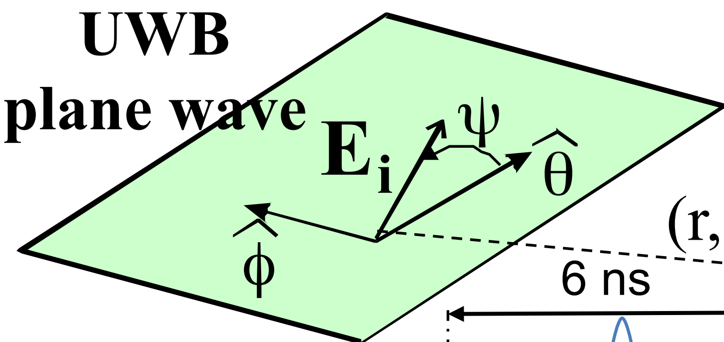


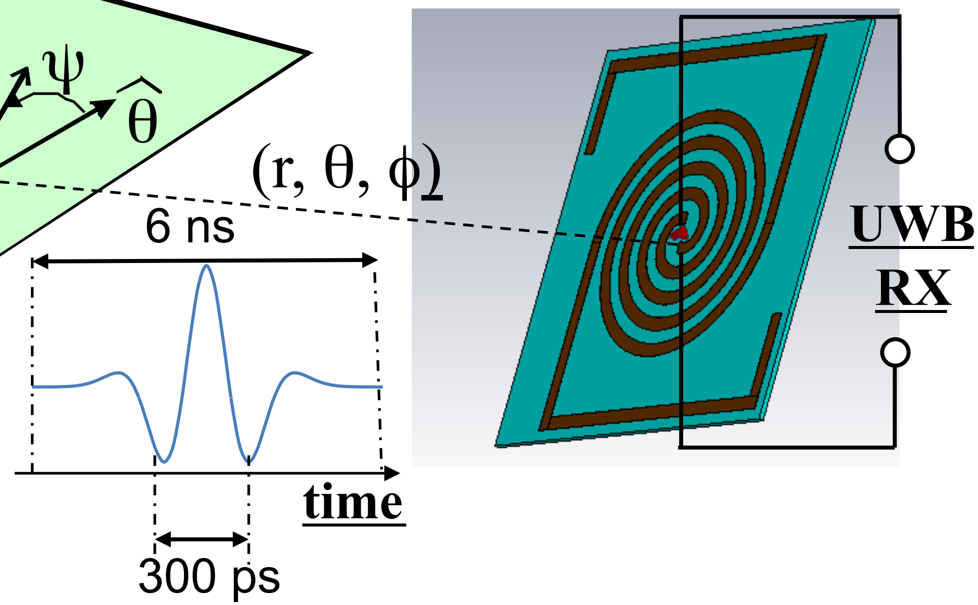
- Insertion loss of ~ 1 dB in the UHF band and 2-3 dB in the UWB band

UWB communication

- Rigorous circuit/electromagnetic co-simulation of the UWB pulse antenna reception [14, 15]

in time domain





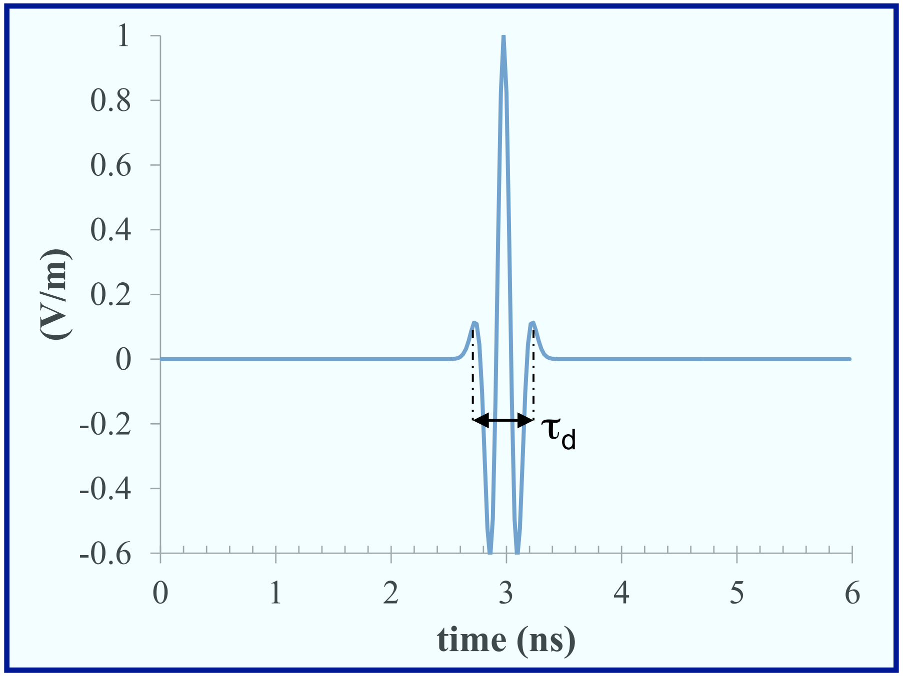
Gaussian pulse with duration of 300 ps and period T_p = 6

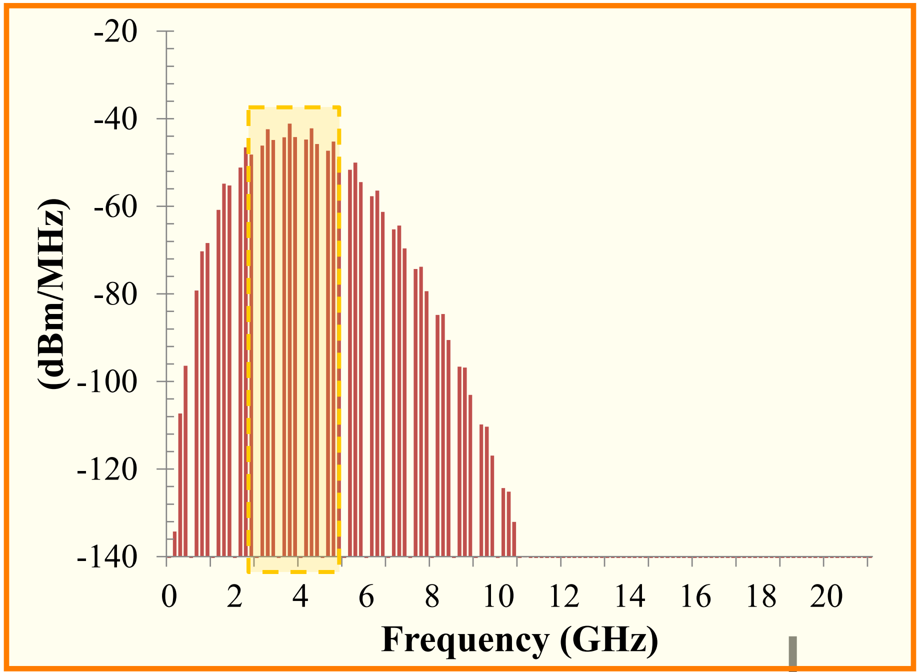
[14] M. Fantuzzi, D. Masotti, A. Costanzo, "Simultaneous UHF Energy Harvesting and UWB-RFID Communication", *2015 IEEE MTT-S International Microwave Symposium Digest*

[15] V. Rizzoli, F. Mastri, A. Costanzo, D. Masotti, "Harmonic Balance Algorithms for the Circuit-Level Nonlinear Analysis of UWB Receivers in the Presence of Interfering Signals", *IEEE Transactions on Computer-Aided Design of Integrated Circuits and Systems*, Vol. 28, No. 4, April 2009, pp. 516 - 527

UWB pulses description

- ***Time*** **domain**
  - Periodic sequence of pulses (fourth derivative of Gaussian pulse)
  - Period T_p = 6 ns
  - Pulse duration τ_d = 300 ps
- ***Frequency*** **domain**
  - Periodic regime with fundamental frequency $f_{UWB} = 1/T_p$ = 166.67 MHz
  - N_H = 64 harmonics

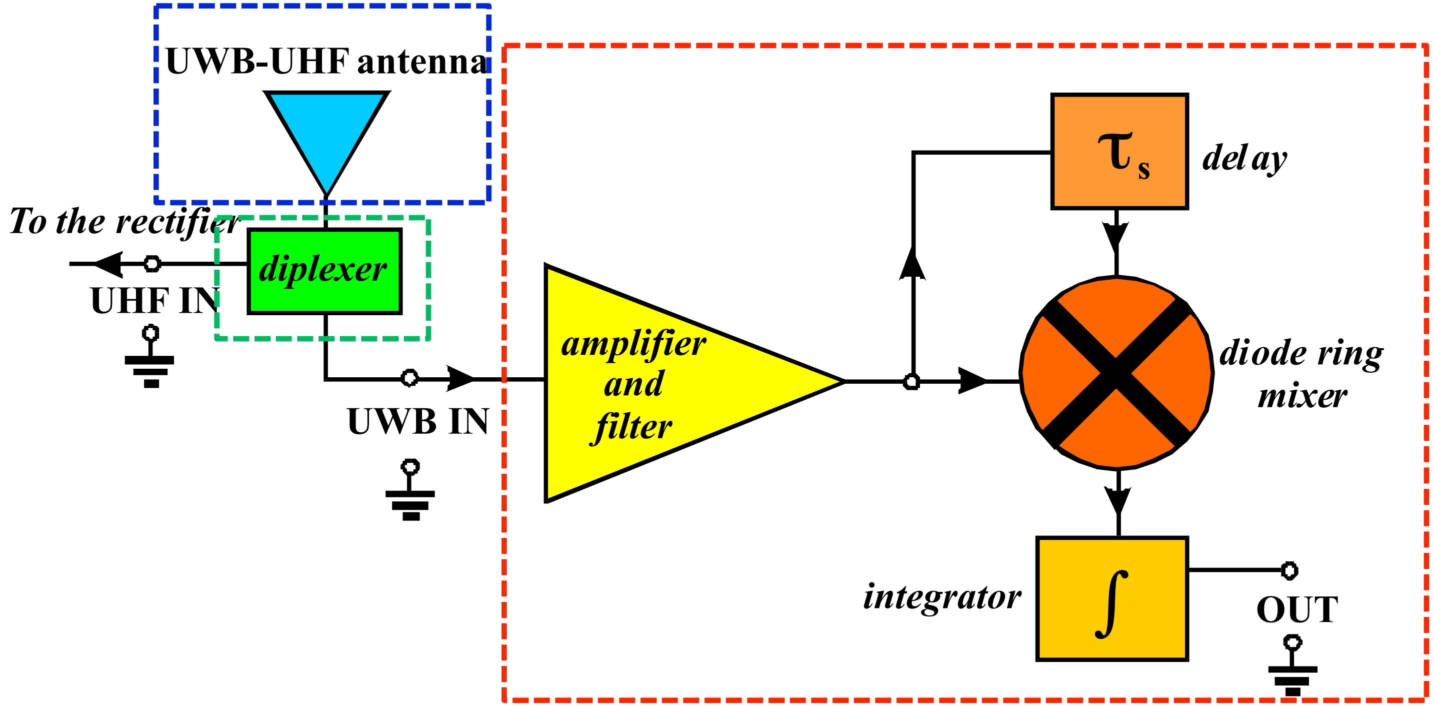




IR-UWB receiver

- The system under test includes:
  - A transmitted-reference UWB receiver
  - A dual-mode UWB-UHF antenna
  - A diplexer

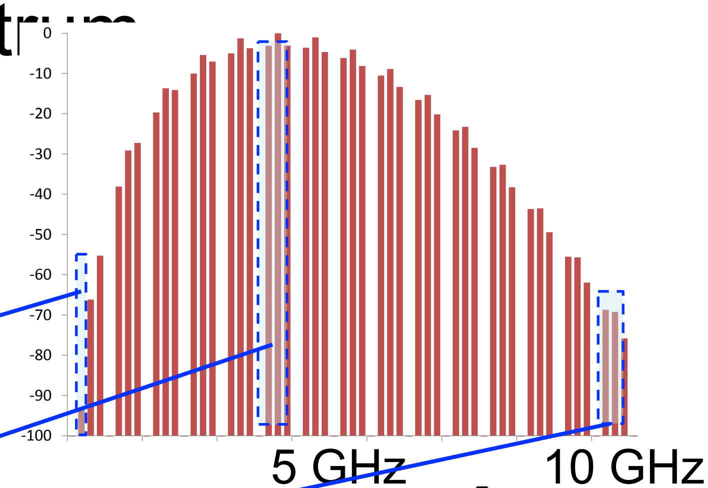
Developed within the Italian national project GRETA



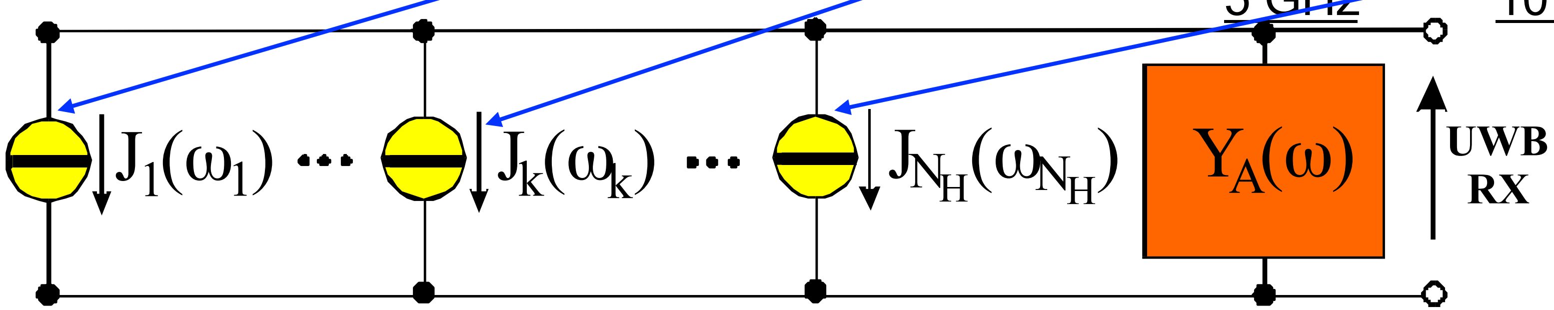
UWB sources equivalent circuit

In frequency domain

- UWB spectrum: described by a fundamental frequency $f_{UWB} = 1/T_p = 166.67$ MHz, with $N_H = 64$ harmonics for the coverage of the UWB spectrum



- 64 Norton equivalent current generators [16]

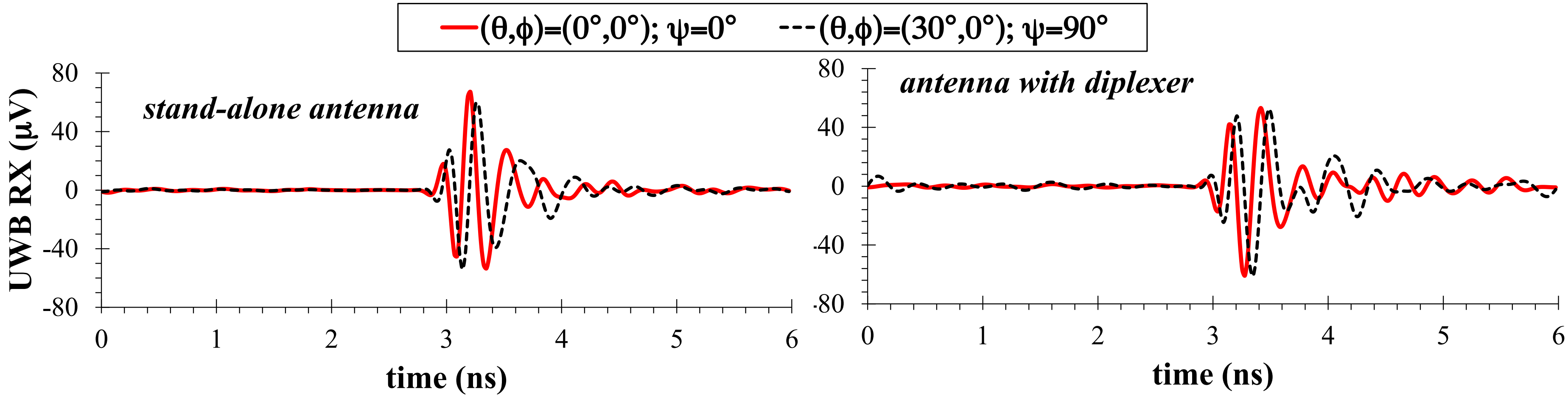


[16] A. Costanzo, F. Mastri, D. Masotti, V. Rizzoli, "Circuit-level nonlinear/EM co-simulation and co-design of UWB receivers", *IEEE International Conference on Ultra-Wideband (ICUWB)*, 2011 (Bologna), Sept. 2011, pp. 425 - 429

UWB comunication

www.greentags.eu

- The distortion effects of the antenna (with and without the diplexer) during the reception of a couple of pulses (of opposite polarity) are compared for different incoming directions ((θ, ϕ)=(0°,0°); (30°,0°)), different field polarizations (ψ = 0°, 90°), and at a fixed distance r = 1 m



- Similar energy levels are obtained in the two cases

Equivalent circuit representation

The reciprocity theorem allows to compute the 64 equivalent Norton current generators necessary to evaluate the actual received UWB voltage at the UWB IN port

Reciprocity theorem

$$J_k(\omega_k) = j\frac{\left[1+R_0 Y_A(\omega_k)\right]}{U}\frac{2\lambda_k r e^{j\beta r}}{\eta}\mathbf{E}_i(\omega_k)\cdot\mathbf{E}_R(\mathbf{r};\omega_k)$$

is the Norton current source, equivalent to the field received by the antenna

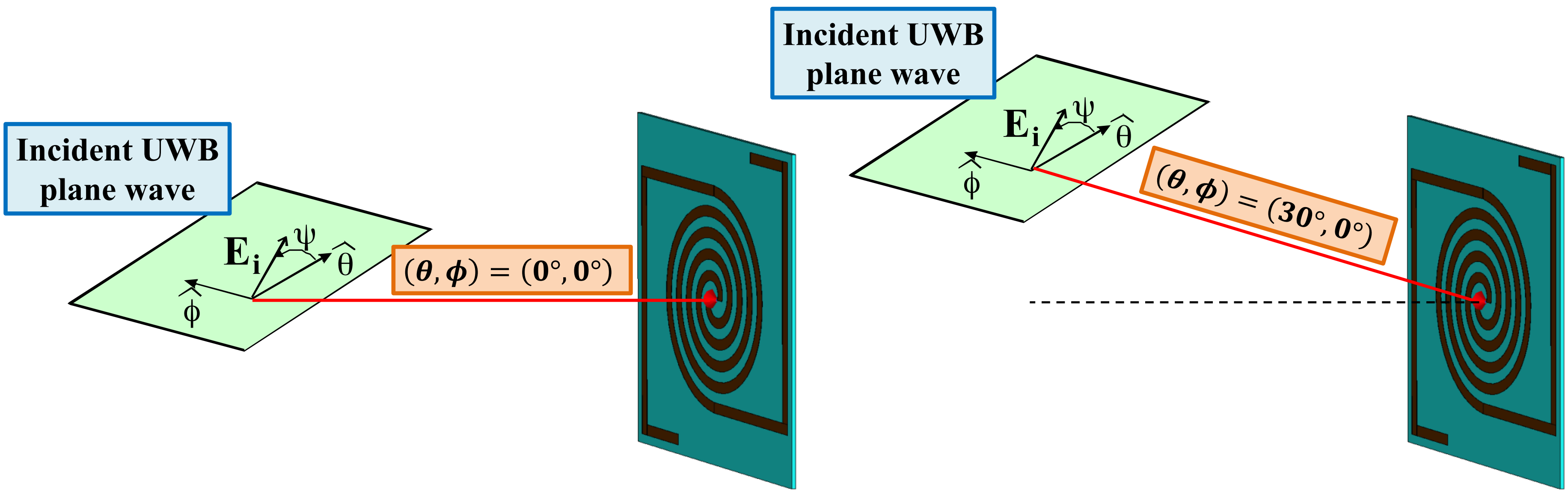
- $\mathbf{E}_R$ is the far-field radiated by antenna in transmitting mode, computed in $\mathbf{r} = (r, \theta, \phi)$, when driven by a sinusoidal voltage source of frequency ω_k, electro-motive force U, and internal impedance R_0
- Y_A is the full-wave description of the antenna admittance matrix

UWB IN port corresponds to:

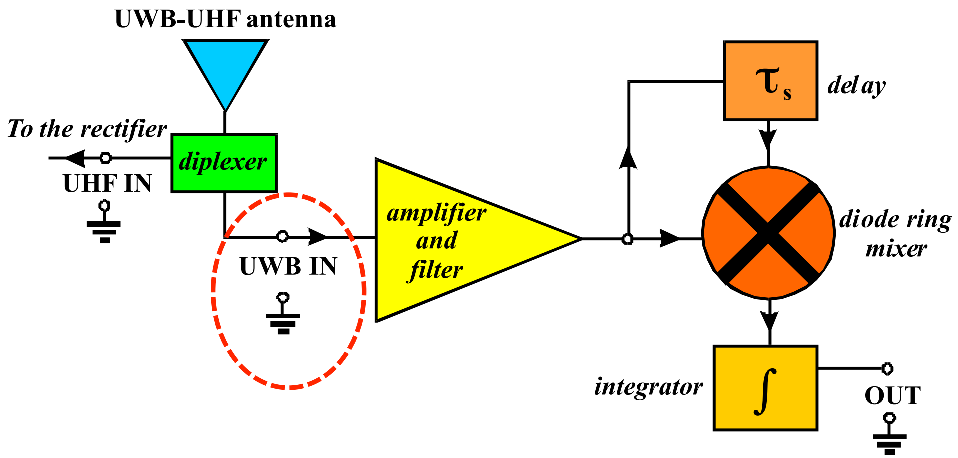
- the balanced antenna terminals in the case of stand-alone antenna
- Port 3 of the circuit in the case with Diplexer

UWB communication performance

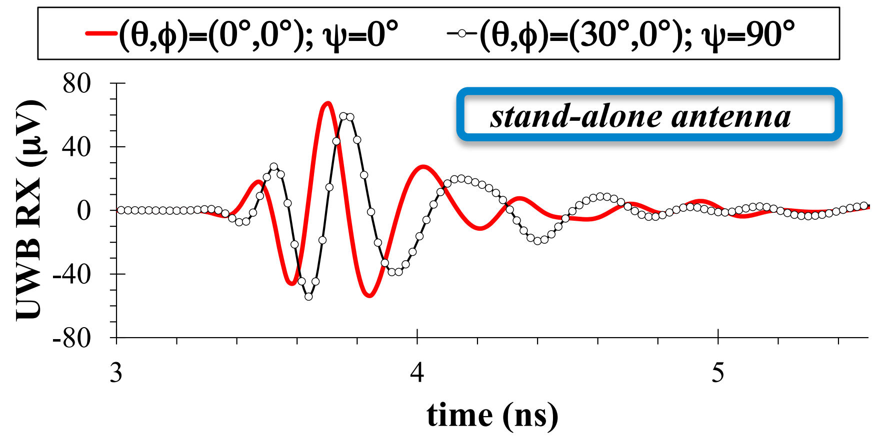
Distortion effects of the antenna are compared for different incoming directions $(\boldsymbol{\theta}, \boldsymbol{\phi})$ and different polarization of the incident plane wave $(\boldsymbol{\psi})$ at a fixed distance $r = 1$ m

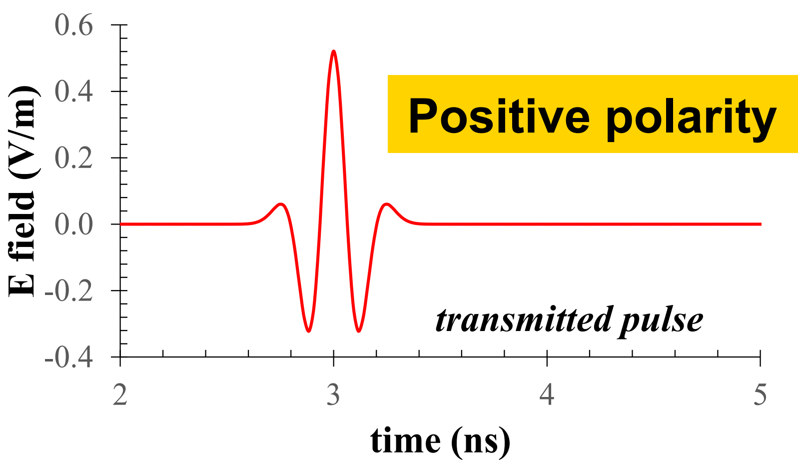


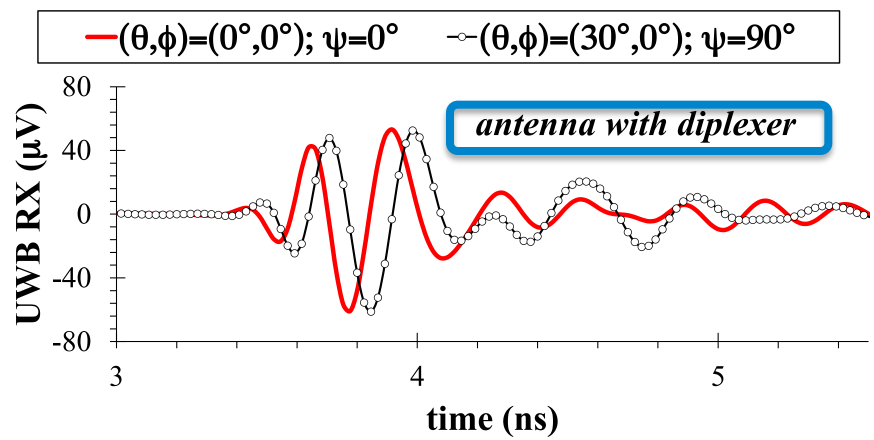
UWB communication performance



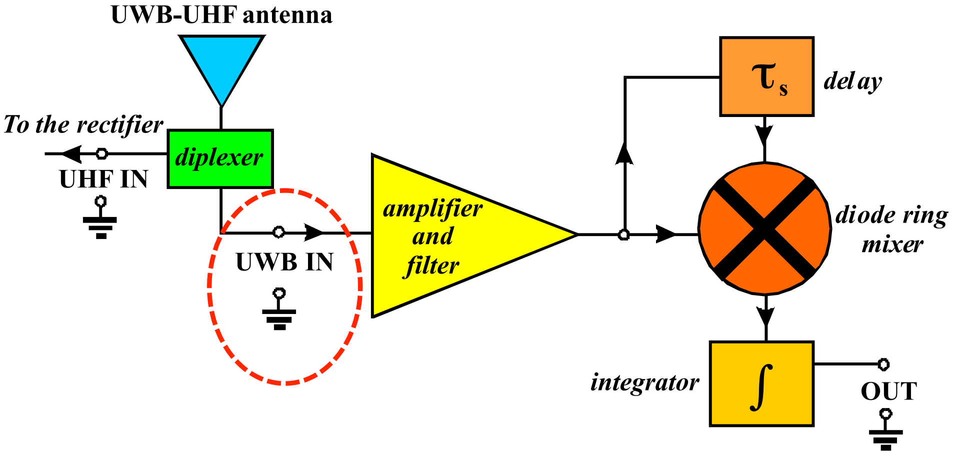
Linear distortion of antenna/diplexer subassembly



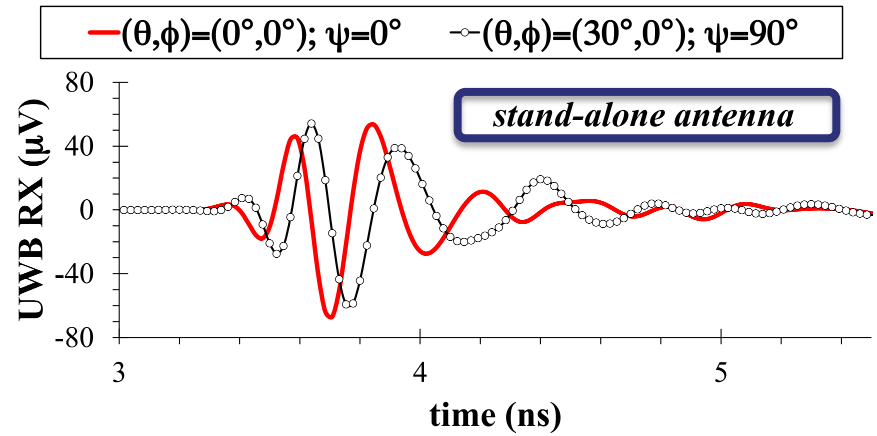


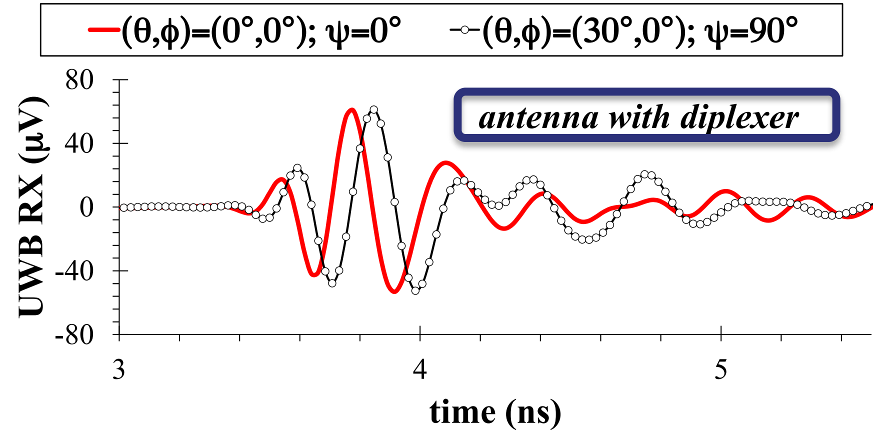


UWB communication performance

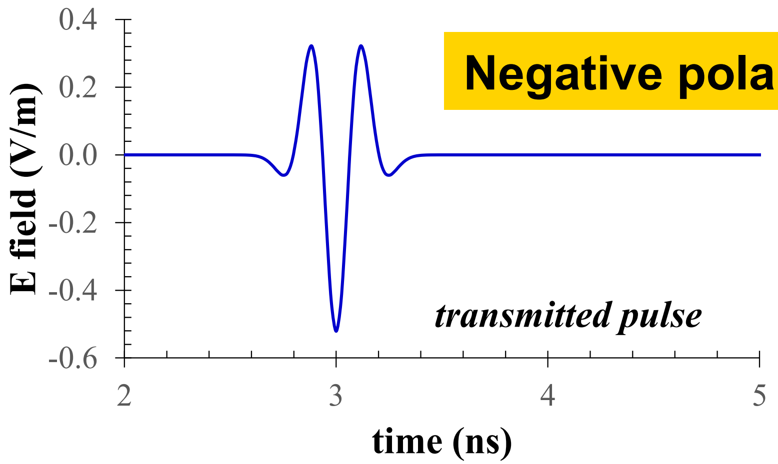


Linear distortion of antenna/diplexer subassembly

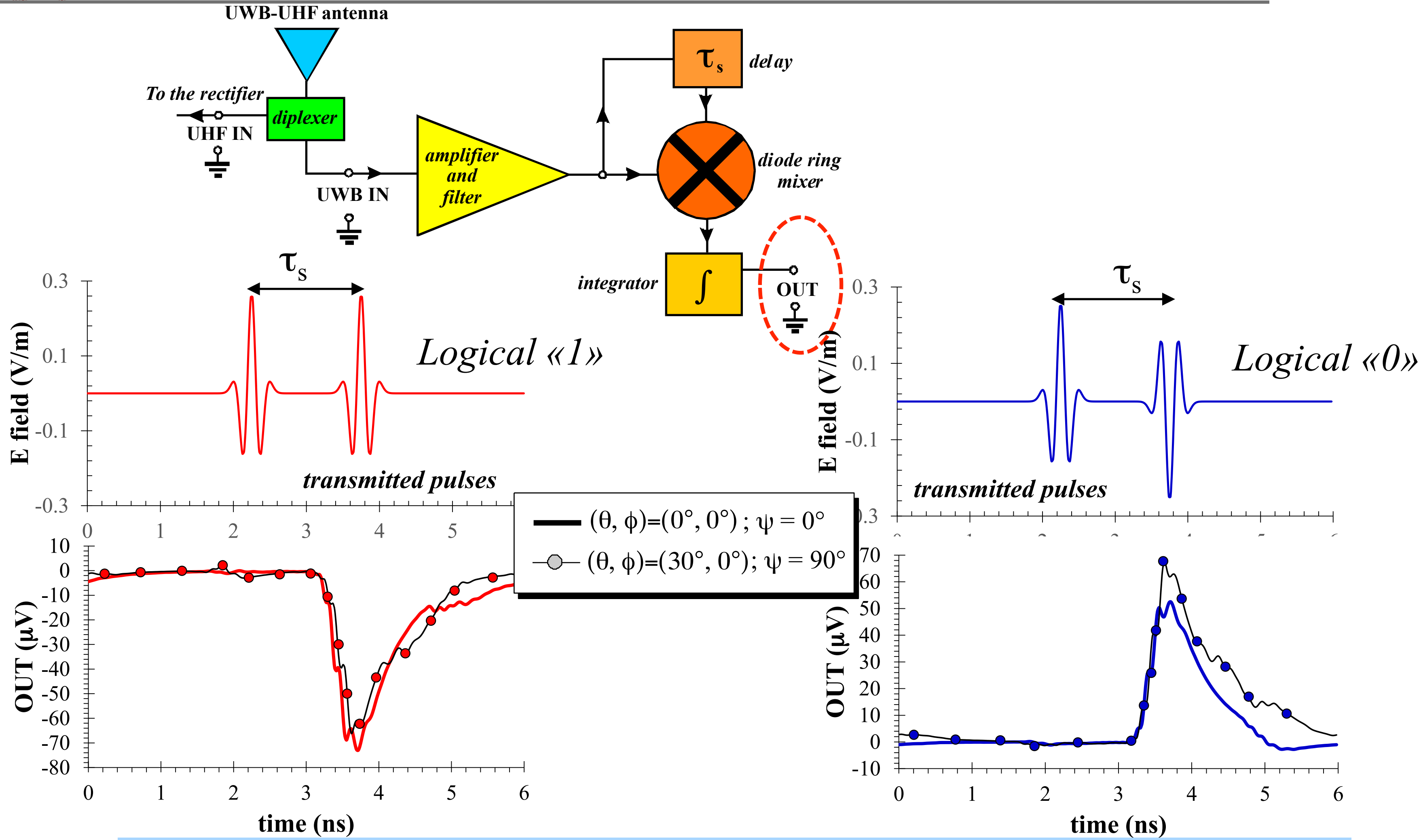




Negative polarity



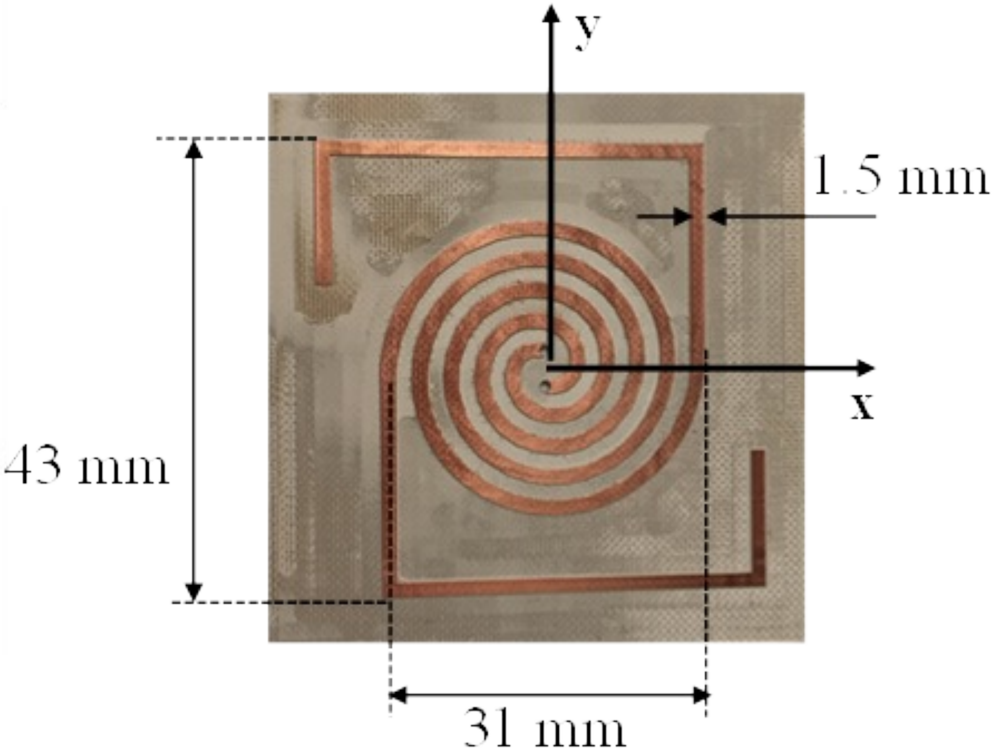
UWB communication performance

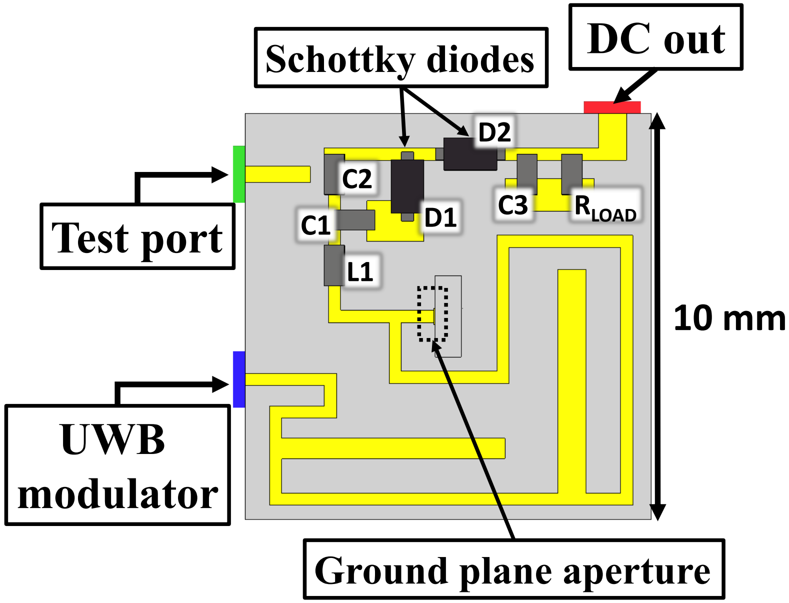


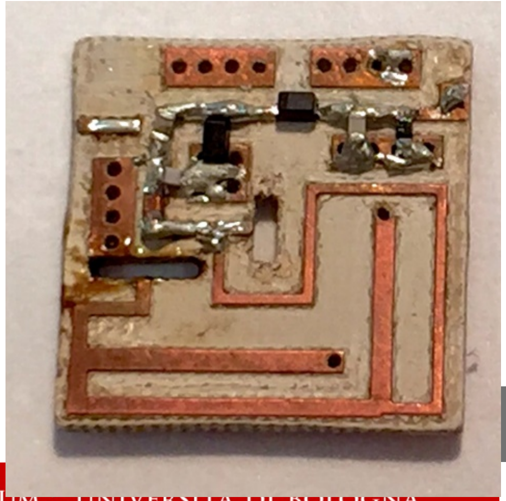
<u>Nonlinear</u> distortion of the entire receiving system (with diplexer)

First prototype on Taconic substrate

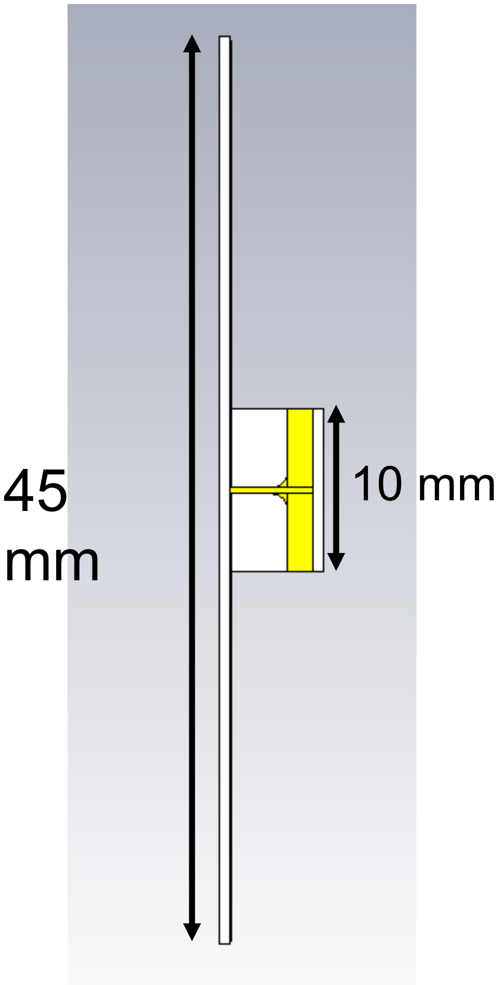
Antenna and circuit (diplexer) realized on Taconic RF60-A

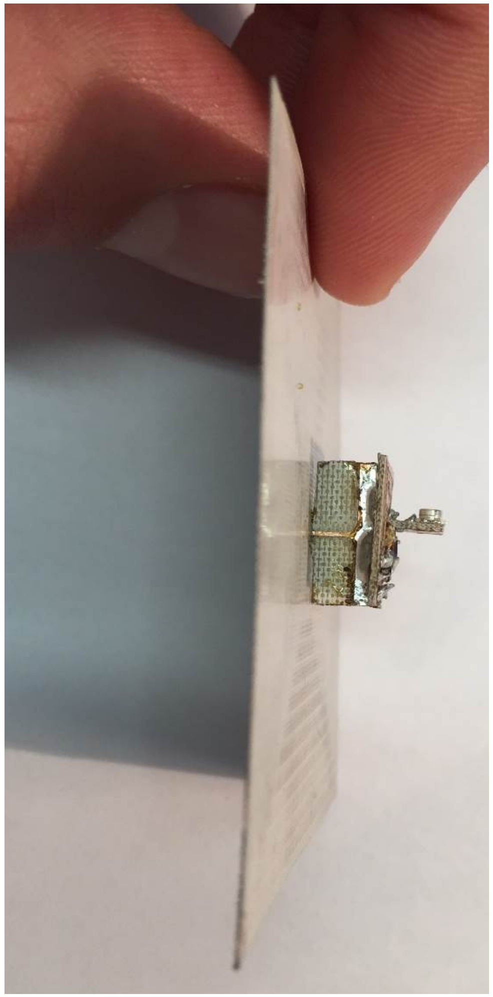


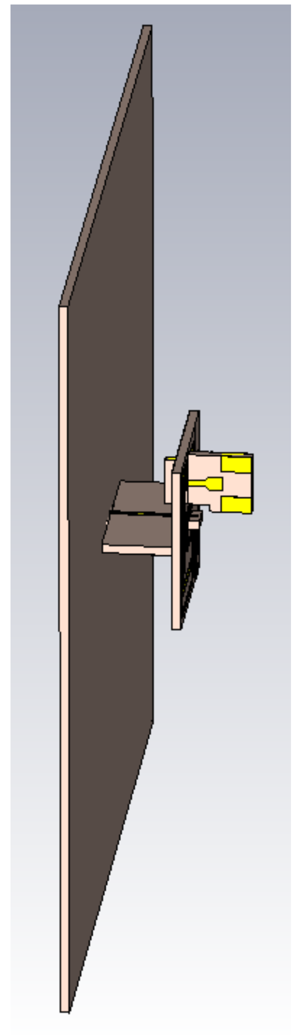


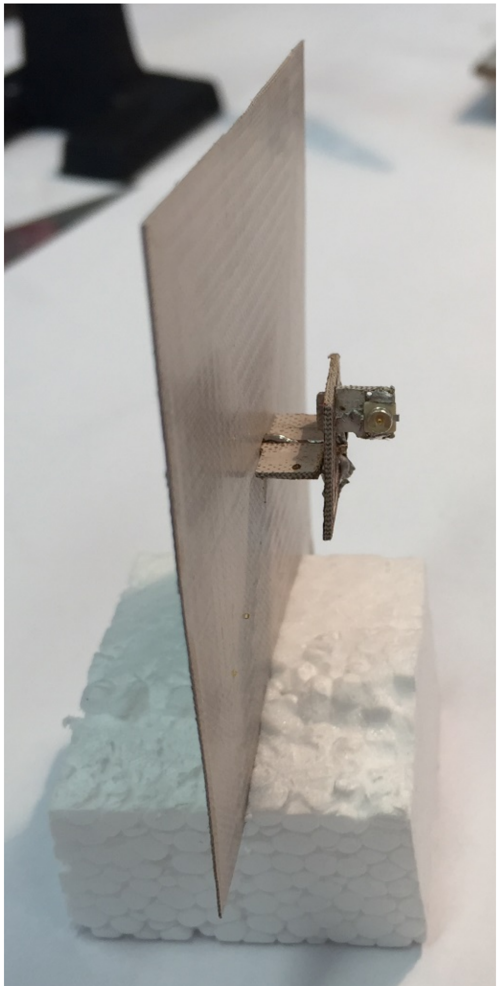


First prototype on Taconic substrate



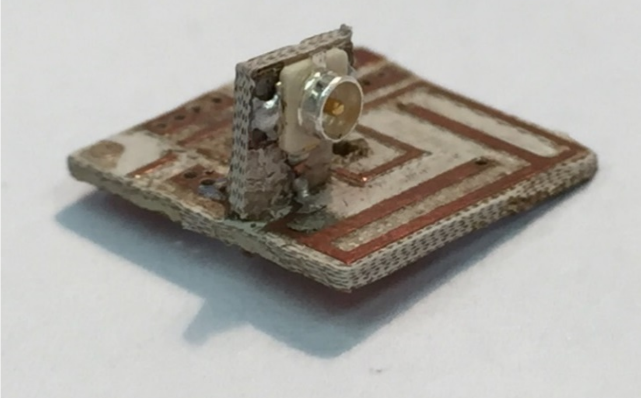


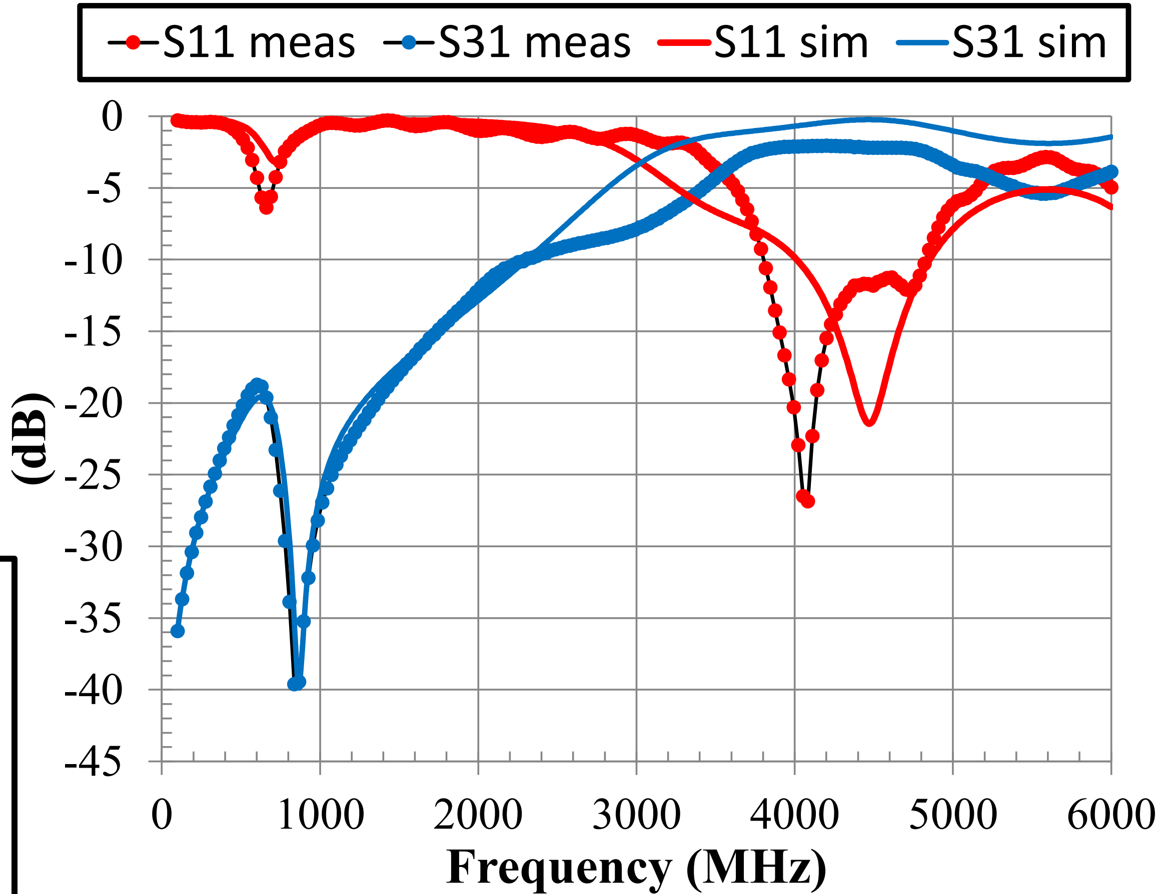




First prototype on Taconic substrate

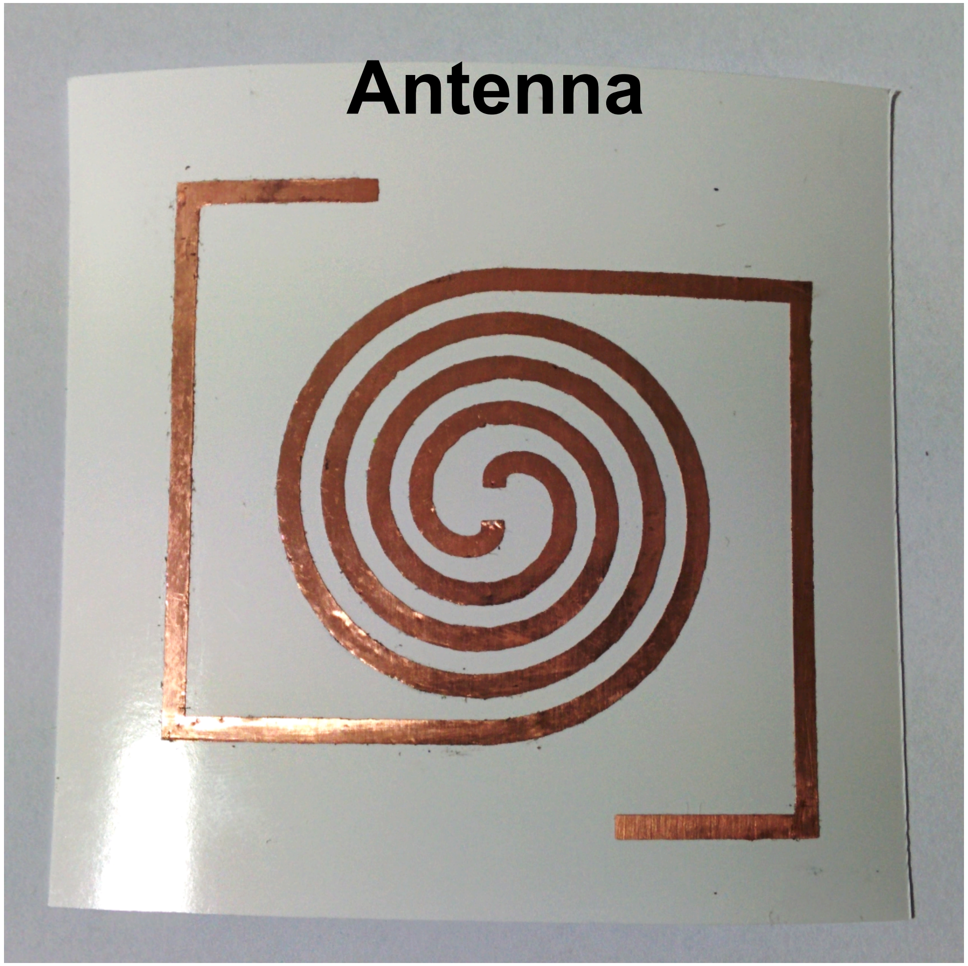
UWB port



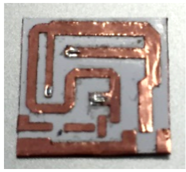


UWB measurement
UWB port and Port 1 (to antenna) loaded on 50 Ω

Implementation on paper



Diplexer



Conclusions

- Concurrent CAD for energy autonomous nodes
- Rectifiers with wake-up facilities
- Simultaneous wireless information and power transfer (SWIPT)
- Novel compact solution for simultaneous UHF Energy Harvesting and UWB backscattering communication
- Simultaneous operations with high decoupling between the two different frequency bands without damaging the UWB communication
- Ubiquitous RFID-Enabled sensors: low-profile structure and eco-compatible material, for *next generation UWB-RFID systems*

References

- M. Fantuzzi, D. Masotti, A. Costanzo “Electromagnetic prediction of antenna layout impact on UWB localization and sensing”, EURASIP RFID Workshop 2015, Oct. 2015
- M. Fantuzzi, D. Masotti, A. Costanzo, “A multilayer compact-size UWB-UHF antenna system for novel RFID applications” accepted for publication at European Microwave Conference (EuMC) 2015, Paris, October 2015
- A. Costanzo, M. Fantuzzi, D. Masotti, F. Mastri, V. Rizzoli, "A rigorous circuit-level description of IR-UWB links," *2015 International Conference on Electromagnetics in Advanced Applications (ICEAA)*, pp.553-556, 7-11 Sept. 2015
- M. Fantuzzi, D. Masotti, A. Costanzo, “A novel integrated UWB-UHF one-port antenna for localization and energy harvesting”, IEEE Transactions on Antennas and Propagation, vol. 63, no. 9, pp. 3839-3848, Sept. 2015
- A. Costanzo, D. Masotti, “Start-up Solutions for Ultra-low Power RF Harvesting Scenarios”, accepted for publication at IEEE MTT-S International Conference on Numerical Electromagnetic and Multiphysics Modelling and Optimization (NEMO 2015), Ottawa, Aug. 2015
- M. del Prete, A. Costanzo, A. Georgiadis, A. Collado, D. Masotti, and Z. Popovic, “Energy-autonomous Bi-directional Wireless Power Transmission (WPT) and Energy Harvesting Circuit”, *2015 IEEE MTT-S International Microwave Symposium (IMS),* pp.1-4, 17-22 May 2015
- M. Fantuzzi, D. Masotti, A. Costanzo, “Simultaneous UHF Energy Harvesting and UWB-RFID Communication”, *2015 IEEE MTT-S International Microwave Symposium (IMS),* pp. 1-4, May 2015, (invited paper)

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

THANK YOU!

Alessandra Costanzo

University of Bologna

alessandra.costanzo@unibo.it

This work has been developed by the PhD students Marco Fantuzzi and Massimo Del Prete under the supeervision of Prof. Costanzo and Masotti

http://www.dei.unibo.it/en/research/research-facilities/Labs/rfcal-rf-circuit-and-antenna-design-lab