SMART BEAMING OF RFID READER FOR DATA AND POWER TRANSFER

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UNIVERSITY OF BOLOGNA
UNIVERSITY OF BOLOGNA: THE CAMPUSES

Campuses

- BOLOGNA
- CESENA
- FORLÌ
- RAVENNA
- RIMINI
- BUENOS AIRES
UNIVERSITY OF BOLOGNA: THE STUDIUM FROM OVER 900 YEARS

1088
STUDIUM IN BOLOGNA

1988
MAGNA CHARTA UNIVERSITATUM

IT IS THE OLDEST UNIVERSITY IN THE WESTERN WORLD

CONFIRMS THE ESSENTIAL ROLE OF THE UNIVERSITY IN CONTEMPORARY SOCIETY

ARCHIGINNASIO

ANATOMICAL THEATRE 1653
BOLOGNA AND GUGLIELMO MARCONI

VILLA GRIFFONE
SUMMARY

• Introduction & background of the IoT paradigm

• **The need**: zero-power localization, identification, sensing

• **RX side**: sensor nodes *need* for energy collection from *environmental* and/or *intentional* RF sources: RECTifying antENNAs (RECTENNAS)

• **TX side/RFID reader**: *need* for agile radiating systems
  - *Readers* augmented with *localization* and *selection capabilities*
  - Reader with monopulse RADAR capabilities
  - *Time-modulated arrays (TMAs)*: a highly reconfigurable family of radiating systems. *Design* by nonlinear CAD and EM simulation
  - Real-time exploitation of TMA for multi-frequency beam-forming for *Smart Wireless Power Transmission*

• Conclusions
THE VISION: “INTERNET OF THINGS”

- “Map” the physical world into the internet space

Physical World Web

Expected >50 billion devices!

- Ambient intelligence: almost unlimited applications
Indoor and outdoor crowded areas with movable sensor-less and sensor-enabled objects.

Mobile and fixed wireless nodes are spread out through the scenario to provide energy for multi-parameter monitoring.
INTERNET OF THINGS: TECHNOLOGY REQUIREMENTS

- Devices embedded inside objects
  - Extremely *low cost*
  - Energy autonomous (*energy harvesting, low consumption*)
  - Eco-compatible (disposable)
  - Sub-meter *localizable* sensing capability

Convergence of Radio Frequency IDentification (RFID) and Real-time Locating Systems (RTLS)

(>6 billions new market opportunities in 2022*)

- Zero-power communication and localization

RF ENERGY HARVESTING
NEED FOR LOW ENERGY

• Many applications can be supported by small amounts of power (from a few μW to a few hundreds of μW),

ultra-low power microcontrollers and sensors requiring power consumption few times per day
RECTENNA

- RECtifying anTENNA (RECTENNA) is the subsystem devoted to receive the RF power and rectify it to DC

- 1\textsuperscript{st} level design

- 2\textsuperscript{nd} level design

RECTENNA FOR ENERGY HARVESTING

- RECTENNA for Energy Harvesting: exploits *environmental* RF sources

  *collected power in the low* \( \mu W \) *range*  
  not deterministically predictable, considering: 

  i. Channel fading  
  ii. antennas misalignments  
  iii. Antenna mis-polarization

- These systems could be more suitable for “RF upon request” applications

RECTENNA FOR WPT

- RECTENNA for Wireless Power Transfer: exploits *intentional and dedicated* RF sources ("Energy showers")

**SMART HOSPITAL**

- inventory tracking
- mobile assets tracking
- people tracking
- Energy showers
- Tag + harvester

**collected power in the high $\mu W$ range**
(considering realistic scenarios)

**Italian PROJECT**
**PRIN 2011**


http://www.greentags.eu
GRETA OBJECTIVES

Integration of the concepts of
• Radiofrequency identification (RFID)
• Wireless sensor networks (WSN)
• Real time locating systems (RTLS)

GREen TAGs and sensors with ultra-wide-band Identification and localization capabilities
The GRETA tag exploits the UWB backscattering mechanism

- **The poor link budget**
  Due to the two-hop communication scheme and the standard carrier frequency, the received signal backscattered by the tag is very weak.

- **The multi-tag management**
  When adopting UWB backscatter communication, no anti-collision protocol can be implemented due to the extremely simple tag front-end and the absence of any receiver and processing unit at tag side.

- **The energy-related aspects**
  The circuitry at tag side (UWB switch, control logic and sensors) must be properly powered so energy-harvesting techniques have to be considered.

Joint adoption of UWB and UHF signaling
UWB (3.1÷5.6 GHZ) for communication (Tag ID, sensor data) and localization
Energy-harvesting and synchronization through the UHF (868 MHZ) link
UWB STAND-ALONE TAG

RECTENNA FOR EH

- Rectenna for EH requirements:

**RF EH UNKNOWN info:**
- Frequency source
- Source Intensity
- Polarization
- Direction of arrival
- Antennas requirements:
  - Wideband/multiband
  - Low directivity
  - Circularly polarized

Task level: *demanding*

**Multi-element antenna**

**& multiple rectifiers**
• Rectenna for WPT requirements:

**RF WPT KNOWN info:**
- Frequency source
- Source Intensity
- Polarization
- Direction of arrival

**Antennas requirements:**
- Single frequency
- High directivity
- Linearly polarized
- Task level: medium difficulty

Possible layout:

Antenna array &
single rectifier
RF ENERGY TRANSMISSION
HOW TO SEND POWER?

• What about the requirements of the RF SHOWERS?

SOLUTIONS:

♦ Energy-unaware
• almost omnidirectional behavior (highly crowded-tag scenario)
• a lot of energy is waisted

☺ Energy-aware
• precise and selective powering (multi-tag scenario)
AGILE POWER TRANSMITTERS

- REQUIREMENTS:
  - Able to point in selected directions
  - Real-time Highly reconfigurable
  - Easy to be designed

- complex structures
  - PHASED ARRAYS
  - SERIES-FED/ FREQUENCY SCANNING

- simpler solutions for IoT
  - MONOPULSE RADAR
  - TIME-MODULATED ARRAYS
• **PHASED ARRAY**

- **D**: n-way symmetric power divider
- **Φᵢ**: i-th phase shifter, electronically controlled by a voltage signal (Vi)
  \[
  \Phi_{i+1}(V_{i+1}) - \Phi_i(V_i) = \delta \\
  (2 \leq m \leq n)
  \]
- **Aᵢ**: i-th power amplifier, to guarantee the desired power level (or to have non-uniform arrays)
5.8 GHz phased array for MPT with GaN FET and class-F amplifier, total power >1.9kW.

RETRODIRECTIVE ARRAY

- **RETRODIRECTIVE ARRAY**: reflects an incident RF signal back in the direction of arrival. For applications with *relaxed* pointing accuracy and automatic beam forming
  - Van Atta RDA
  - Pon RDA

- Proper lines length provides proper phase condition
- Complex architecture (for phase-conjugation condition)
REFLECTARRAY WITH FOCAL POINTS

\[ \varphi_n : \text{phase delay to be introduced by the } n\text{-th array element} \]
\[ \varphi_n = \frac{2\pi}{\lambda} \left[ (r_{nS} + r_{nF}) - (r_S + r_F) \right] \]

f=2.4GHz
Focal width W=7.8cm at a plane at 90cm from the reflectarray center

MECHANICAL TUNING OF THE FOCAL POINT

\[
\left(\sqrt{r_m^2 + r_S^2} - r_S\right) + \left(\sqrt{r_m^2 + r_F^2} - r_F\right) = m\lambda / 2
\]

Ka band (32GHz)
Circular plate diameter = 16cm
Feed horn at 9.5cm form the lens surface
Focus width: 1.24cm (focal length=15cm) and 3.4cm (focal length=45cm)

S. Karimkashi and A. A. Kishk, “Focusing Properties of Fresnel Zone Plate Lens Antennas in the Near-Field Region,”
SERIES-FED ARRAY FOR FREQUENCY SCANNING

- Resonant periodic strips / slots fed by a travelling wave instead of a discrete distributed network:
  - Fixed beam for a fixed frequency
  - (Limited) steering capability in a frequency band

\[ f_6 > f_5 > f_4 > f_3 > f_2 > f_1 \]

RFID band
Channel BW = 17MHz

\[ \theta_{RAD} = 65.4^\circ \]
\[ \theta_{RAD} = 8.4^\circ \]

W = 9.19 mm
h = 0.254 mm
\( \varepsilon_r = 11.2 \)
READER ANTENNA SYSTEM: MONOPULSE RADAR

\[ F_\Sigma(\vartheta, \varphi) = e^{j \left( \frac{\pi L}{\lambda} \cos \vartheta - \alpha \right)} + e^{-j \left( \frac{\pi L}{\lambda} \cos \vartheta + \beta \right)} \]

\[ F_\Delta(\vartheta, \varphi) = e^{-j \left( \frac{\pi L}{\lambda} \cos \vartheta - \alpha \right)} - e^{-j \left( \frac{\pi L}{\lambda} \cos \vartheta + \beta \right)} \]

two-element array: *monopole antenna* (almost omnidirectional)

⇒ the array radiation pattern is shaped by in-phase (\(\Sigma\)) and out-of-phase (\(\Delta\)) array factors only:

⇒ same shape in any pointing direction

\(\Sigma\) and \(\Delta\) directions are varied by simultaneously controlling two phase-shifters.
**Challenges:**

- Layout-wise design of phase-shifters
- Nonlinear relationship between varactors bias and phase-shift

OBJECTS DETECTION

starts searching for the object with the ID acquired during "selection"

COARSE POSITIONING
activate closely-spaced Tags
measure of RSSI at the \( \Sigma \) RID ports

FINE POSITIONING
monopulse RADAR measure of RSSI at the \( \Sigma \) and \( \Delta \) READER ports of tags placed around pointed position (same as in selection mode)

performs action and update object properties/state

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ALMA MATER STUDIORUM - UNIVERSITÀ DI BOLOGNA
COMPUTED AND MEASURED \( \Sigma \) AND \( \Delta \) PERFORMANCE

\[ \phi_{PS1} - \phi_{PS2} = 0^\circ \]
\[ V_{PS1} = V_{PS2} = 1V \]

\[ \phi_{PS1} - \phi_{PS2} = -13^\circ \]
\[ V_{PS1} = 3.48 V \]
\[ V_{PS2} = 1V \]

\[ \phi_{PS1} - \phi_{PS2} = 13^\circ \]
\[ V_{PS1} = 1V \]
\[ V_{PS2} = 3.48 V \]

\[ \phi_{PS1} - \phi_{PS2} = 60^\circ \]
\[ V_{PS1} = 6.85 V \]
\[ V_{PS2} = 1V \]

\[ \phi_{PS1} - \phi_{PS2} = -60^\circ \]
\[ V_{PS1} = 1V \]
\[ V_{PS2} = 6.85 V \]
OBJECT SELECTION IN 2 STEPS

1st

IDs ACQUISITION
(only the $\Sigma$ radio is involved):
- RID points to the desired object
- Inquire for IDs

2nd

SCANNING OPERATION
$\Sigma$ and $\Delta$ radios cooperate exploiting the scanning capabilities of the RID
RID stores a list with IDs with the highest figure of merit:

$$MPR = \Sigma_{RSSI}[dB] - \Delta_{RSSI}[dB]$$

The BEST CENTERED MPR is the POINTED OBJECT (scanning zone ($\theta = \pm 45^\circ$) swept in 40 steps, 1.5 ms each)
ACTIVITY DIAGRAM

ID Acquisition
- SendID request
- Reply
- 200 ms

TAG Scanning
- Sendyour ID
- Beam rotation
- 1.5 ms

RID Latency
- 1.5 ms

TAG Latency
- 1.5 ms

Acquisition Time Delay
- 200 ms

Beam rotation #1
- Sendyour ID
- Reply

Beam rotation #2
- Sendyour ID
- Reply

Beam rotation #N
- Sendyour ID
- Reply

time for selection ~ 500ms
OBJECT SELECTION IN HARSH EM ENVIRONMENTS

GOAL
select Tag-01, Tag-03
READING zone
beam steering:±45
⇒±180°phase-shifts outputs

tag-01 shows the best mpr at a 0-rotation angle

PREDICTED AND MEASURED MPR:
RID POINTING TO CENTRAL TAG
excellent agreement with prediction
(carried out in free-space conditions)

NOTE: environment under test with severe multipath scenario
MEASURED PERFORMANCE OF RID FOR SELECTION OF TAG-03

RID POINTS TO TAG-03:
- the S and D radiation patterns rotate symmetrically around the RID pointing position.

**SELECTION SUCCEEDED!** the best centered absolute maximum of MPR, corresponds to Tag-03.

Tag-03 SHOWS THE BEST MPR AT A 0° ROTATION ANGLE

OBJECTS LOCALIZATION
By *beam steering* RID also acquires others tags relative locations

*INFACT* allowed rotation angles are well within the allowed performance of the phase shifter outputs.
RID is positioned perpendicular to the objects plane
Recognizes the sequence correctly.
This operation requires less than 500 ms
Time-modulated arrays (TMAs)
TIME MODULATED ARRAY ARCHITECTURE

Switches controlled by pulse sequences

Each antenna excitation amplitude can vary during $T_M$

Array Factor of a Standard Linear Array

$$AF(\theta, \phi) = \sum_{k=0}^{n_A-1} \Lambda_k e^{j\delta_k} e^{jk\beta L \sin \theta}$$

Array Factor of a Linear TMA

$$AF(\theta, \phi(t)) = \sum_{k=0}^{n_A-1} \Lambda_k U_k(t) e^{j\delta_k} e^{jk\beta L \sin \theta}$$
TIME MODULATED ARRAY
EXCITATION SPECTRA

• $T_M, f_M$: period and frequency of switch modulation

• $T_0, f_0$: period and frequency of sinusoidal RF carrier

$T_M = \frac{1}{f_M} >> T_0 = \frac{1}{f_0}$

Control pulses

- k-th switch **always ON**
- k-th switch **ON-OFF**
- k-th switch **ON-OFF-ON**
**TIME-DEPENDENT ARRAY FACTOR**

\[
AF(\theta, \phi, t) = \sum_{h=-\infty}^{\infty} AF_h(\theta, \phi, t) = \sum_{h=-\infty}^{\infty} e^{j2\pi(f_0+hf_M)t} \sum_{k=0}^{n-1} \Lambda_k u_{hk} e^{jk\beta L \cos \psi} \]

Fourier coefficients of \( U_k(t) \):

\[
u_{hk} = \frac{1}{T_M} \left( e^{-j\omega_M t_K^r} - e^{-j\omega_M t_K^r - \tau_k T_M} \right) ; \quad u_{0k} = \tau_k \text{ (real)}
\]

- Due to switch modulation the array is able to radiate:
  - at the **fundamental carrier** (*h* = 0)
  - at the **sideband harmonics** (*h* ≠ 0)
TMA RADIATION @ FUNDAMENTAL AND SIDE BANDS

- Fundamental radiation pattern (@ $f_0$)
- Sideband radiation pattern (@ $f_0 \pm hf_M$)

Diagram showing normalized far-field in dB across frequency (GHz) and angular direction ($\theta$) with fundamental and sideband radiation patterns indicated.
TMA POTENTIALS

- *Time* as an array further design parameter:
  - almost unlimited *control sequence combinations* in TMAs
  - ease implementation fast switching control

**ANTENNA RECONFIGURATION IN REAL TIME!**

**NO NEED FOR:**

1. phase shifters and complex feeding networks (*as phased arrays*)
2. Large array structure (*as leaky wave antennas*)
3. Large array structure with broadband matching constraints (*as frequency scanning antenna*)
4. Mechanical tuning of the focal point

- Make TMA a versatile and adequate radiation system for modern wireless applications (e.g. SDR)
TMAs CONTROL SEQUENCE EXAMPLES: 1- SIDE LOBES REDUCTION

- **16-element array**

  Switch ON time
  
  Switch OFF time

  **Theoretical radiation pattern**

  fundamental sidebands

  20 dB

L. Poli, P. Rocca, L. Manica, A. Massa, “Pattern synthesis in time-modulated linear arrays through pulse shifting,” *IET Microwaves, Ant. & Prop.*, vol. 4, no. 9, pp. 1157-1164, Sept. 2010
TMAs CONTROL SEQUENCE EXAMPLES:
2- HARMONIC NULLING

20-element array

Switch ON time
Switch OFF time

Theoretical radiation pattern

**TMAs CONTROL SEQUENCE EXAMPLES:**

2- HARMONIC BEAMFORMING

- Exploitation of multi-channel features

*harmonic beamforming.*

TMA analysis/design
Available TMA design methods focus on control sequence optimization, but rely on *ideal* radiating elements and *ideal* control switches.

**VARIABLE APERTURE SIZE:**

design parameter: pulse length

**BINARY OPTIMIZED TIME SEQUENCE**

design parameter: pulse sub-intervals

**PULSE SHIFTING**

design parameter: pulse switch on time interval

---

**NL/EM TMAs CO-SIMULATION**

*Piecewise Harmonic-Balance method*

- a nonlinear subnetwork, consisting of the diodes
- a linear subnetwork, including
  - the EM-based part (array and feeding network)
  - the lumped components

---

**Under sinusoidal regime**

The scalar components of the normalized field generated by EM simulation are given by:

\[
i_A^{(i)}(t) = \text{Re} \left[ \sum_{k=1}^{n_H} I_{A,k}^{(i)} \exp(jk\omega_0 t) \right]
\]

**Field at the fundamental harmonic**

\[
E(r, \theta, \phi; \omega_0) = \frac{\exp(-j\beta r)}{r} \cdot \sum_{i=1}^{n_A} [\hat{A}_{A,1}^{(i)}(\theta, \phi; \omega_0) + \hat{\phi} A_{\phi}^{(i)}(\theta, \phi; \omega_0)] I_{A,1}^{(i)}
\]

**Antenna linearity**

The spectrum harmonics are as follows:

- Current at i-th diode port

Field evaluation

given the i-th antenna array port, the corresponding radiated field is:

\[
E^{(i)}_n(r, \theta, \phi, \omega_0) = \hat{\theta} E^{(i)}_{n\theta}(r, \theta, \phi, \omega_0) + \hat{\phi} E^{(i)}_{n\phi}(r, \theta, \phi, \omega_0) = e^{-j\beta r} \left[ \hat{\theta} A^{(i)}_{\theta}(\theta, \phi, \omega_0) + \hat{\phi} A^{(i)}_{\phi}(\theta, \phi, \omega_0) \right]
\]
Far-field evaluation: modulated regime

\[ T_M = \frac{2\pi}{\omega_M} \gg T_0 = \frac{2\pi}{\omega_0} \]

circuit-envelope HB

Fast carrier time  Slow modulation time

\[ i_A^{(i)} (t, t_M) = \text{Re} \left[ \sum_{k=1}^{n_H} I_{A,k}^{(i)} (t_M) \exp(j k \omega_0 t) \right] \]

\[ I_{A,k}^{(i)} (t_M) = \sum_{h=-N_B}^{N_B} I_{A,kh}^{(i)} \exp(j h \omega_M t_M) \]

Generic excitation current (at \( i \)-th port)

time-dependent complex \( k \)-th envelope (or modulation law)
NL/EM TMAs FAR-FIELD PREDICTION

Under modulated regime ON/OFF switching

\[ E_1 (r, \theta, \phi; t_M) = \frac{\exp(-j\beta r)}{r} \]

\[ \cdot \sum_{i=1}^{n_A} \left[ \hat{\theta} A_{\theta}^{(i)} (\theta, \phi; \omega_0) + \hat{\phi} A_{\phi}^{(i)} (\theta, \phi; \omega_0) \right] I_{A,1}^{(i)} (t_M) - \]

\[ - j \frac{1}{r} \left[ \sum_{i=1}^{n_A} \frac{\partial}{\partial \omega} \left\{ \exp(-j\beta r) \left[ \hat{\theta} A_{\theta}^{(i)} (\theta, \phi; \omega) + \hat{\phi} A_{\phi}^{(i)} (\theta, \phi; \omega) \right] \right\} \right] \]

\[ \cdot \left. \frac{dI_{A,1}^{(i)} (t_M)}{dt_M} \right|_{\omega=\omega_0} \]

- \( A_{\theta}^{(i)} \), \( A_{\phi}^{(i)} \) \rightarrow EM data-base
  - are the scalar components of the normalized field
  - easily evaluated by EM simulation

- For a given array: EM analyses are carried out once for all

16-MONOPOLE ARRAY DRIVEN BY MODULATED DIODES

- 16-monopole planar linear array operating at \( f_0 = 2.45 \) GHz
- The substrate is a 0.635 mm-thick Taconic RF60A (\( e_r = 6.15 \), \( \tan \delta = 0.0028 @ 10\)GHz)
Smart WPT BY TMA
SMART WPT WITH TMA

- The versatility of TMAs allows a **smart transfer of power** by means of a **two-step procedure**
- Scenario: room with randomly placed tagged objects

1st step: **localization**

2nd step: **power transfer**
LOCALIZATION OF TAGS

• The RFID reader augmented by the **Monopulse-RADAR capabilities:**

• By adopting a 2-element arrays: $\Sigma$ and $\Delta$ radiation patterns are obtained from the *in-phase* ($\Sigma$) and *out-of-phase* ($\Delta$) antennas excitation

![Diagram](image)

• Further feature **beam-steering:**
  - by simultaneously driving the proper phase shifts at the two antenna ports

TAG LOCALIZATION BY MONOPULSE RADAR VIA TMA

• **1st step: Localization of tags with TMA**
  - By properly driving a two-element array it is possible to have the sum \((\Sigma)\) pattern @ \(f_0\) and the difference \((\Delta)\) pattern @ \(f_0 \pm f_M\)


- Only the *two-inner-element sub-array* is operating (by keeping the remaining 14 switches open)

TAG LOCALIZATION: ANTENNA ELEMENT SPACING AND DIRECIVITY

- Normalized directivity of an array of \( n \) \textit{in-phase} (S) dipoles vs. element spacing \( L \)

![Graph showing normalized directivity vs. element spacing for different \( n \) values.]

- Shorter spacing (L), allows lower directivity (D)
TAG LOCALIZATION CAPABILITY

- Array of two *isotropic* antennas with $\lambda/8$ spacing.
- **TUNABLE SEQUENCES**: $\Delta$ *pattern* is steered by varying $d$
  
  $d = 0\%, 2\%, 3\%, 4\%, 5\%, 5.5\%$

- $U_1(t)$
  
  $1$

  $\tau$

  $0.5T_M$

  $T_M$

  1st SWITCH

- $U_2(t)$
  
  $1$

  $\tau$

  $0.5T_M$

  $T_M$

  2nd SWITCH

- **Sum ($\Sigma$) pattern @ $f_0$**

- **Difference ($\Delta$) pattern @ $f_0+f_M$**

- **Difference ($\Delta$) pattern @ $f_0-f_M$**
TAGS LOCALIZATION BY TMAs
(array of dipole $\lambda/8$ spaced)

- Array of two real, closer dipoles with tunable sequences
  (for flat and low-directive $\Sigma$ pattern):

$$f_0=2.45 \text{ GHz}, f_M = 25 \text{ kHz}$$

The substrate is a 0.635 mm-thick Taconic RF60A ($\varepsilon_r = 6.15$, tan$\delta=0.0028$)

- Good scanning performance in $\theta \in [-60^\circ:60^\circ]$, but with larger $d$
  variations with respect to the theoretical prediction
TAGS LOCALIZATION BY TMAs
(array of patch $\lambda/3$-spaced)

- Array of two **real patches** with tunable sequences:

- Reduced scanning capabilities due to strong EM couplings
TAGS LOCALIZATION BY TMAs
(array of dipole $\lambda/2$ spaced)

- Array of two *isotropic* antennas with $\lambda/2$ spacing, driven by tunable sequences:

  *the $\Delta$ pattern can be steered by varying $d$*

- Array of two isotropic antennas with $\lambda/2$ spacing, driven by tunable sequences:

  - **Sum ($\Sigma$) pattern @ $f_0$**
  - **Difference ($\Delta$) pattern @ $f_0 + f_M$**
  - **Difference ($\Delta$) pattern @ $f_0 - f_M$**

- $d = 0\%, 8\%, 12\%, 16\%, 20\%$
TAGS LOCALIZATION BY TMAs
(array of dipole $\lambda/2$ spaced)

- Array of two *real dipoles with $\lambda/2$ spacing* with tunable seq.

- Good scanning performance in $\theta \in [-60^\circ:60^\circ]$
TAGS LOCALIZATION BY TMAs
(array of patches $\lambda/2$ spaced)

- Array of two real patches with $\lambda/2$ spacing with tunable seq.

- Good scanning capabilities in $\theta \in [-40^\circ:40^\circ]$
The sharp nulls of the steered D patterns allow high resolution in the tags detection.

The backscattered Received Signal Strength Indicators (RSSI), due to the $\Sigma$ and $\Delta$ patterns, can be suitably combined to build the **Maximum Power Ratio (MPR)**

\[
MPR(\theta) = \Sigma_{RSSI}(\theta) - \Delta_{RSSI}(\theta)
\]

\[\theta^i_{\text{peak}}; \quad i=1,\ldots, N_{\text{tag}}\]

*List of recorded tags position*
ARRAYS FOR LOCALIZATION: A COMPARISON

RFID READER WITH MONOPULSE RADAR CAPABILITIES

TMA-BASED IMPLEMENTATION OF THE RFID READER
2° step: *Transfer of power to tags*

- *The whole 16-element array* is driven by proper *pre-loaded control sequences* involving all the switches.

- Possible decision rule:
  - split the scanning region \( \theta \in [-60° \div 60°] \) into sectors of amplitude equal to the half power beam width (HPBW)
  - for each \( \theta_{\text{peak}} \) falling in the sector centered around \( \theta_{\text{HPBW}} \), the pre-loaded control sequence pointing the *proper harmonic* to the \( \theta_{\text{HPBW}} \) direction is used.
SIMULTANEOUS POWERING OF THREE TAGS

- In case of $\theta_{peak}$ falling into the sectors centered around $\theta_{HPBW} = -30^\circ, 0^\circ, 30^\circ$

Simultaneous powering of 3 tags

POWER HANDLING ISSUES

- Schottky diode (Skyworks SMS7630-079) used as the switching element

For the medium-power diode in use, the input power limit is about 0 dBm. High-power PIN diodes (e.g. Infineon BAR64-02V)
PROTOTYPE AND SET-UP

Medium-power Schottky diodes
Skyworks SMS7630-079
REAL WAVEFORM SEQUENCES FOR LOCALIZATION

- Bias 1
- Bias 2

\[ d = 0\% \]

\[ d = 32\% \]
• Slight asymmetry probably due to an asymmetry of the circuit
• Lower $\Delta$ patterns strength w.r.t. simulation
Simulated radiation patterns

- Diode package parasitics responsible for an alternative path for RF signal to antenna ports not perfect control

\[ \Sigma @ f_0, \Delta @ f_0 \pm f_M, \Delta \text{ (diode package)} @ f_0 \pm f_M \]
Perspectives : GRETA

On paper UWB/UHF Antenna design and rectifiers
Loaded with the UWB and UHF backscatter modulator and the energy-harvesting block

The “GRETA” chip
Layout of the custom chip under test developed at Univ. Bologna containing:
- UWB backscatter modulator,
- energy harvesting unit at UHF,
- power management unit,
- control logic.
RFID/RTLS integration in smartphones:

- Millimeter wave massive antenna arrays
- Efficient energy transfer mechanisms to energize passive/active tags
- Single node localization

CONCLUDING REMARKS

• Need for solutions to integrate RFID, RTLS and energy harvesting capabilities for IoT applications.

• Simple, low-cost, light-weighted solutions for on-demand RF energy transfer
  - Reader augmented the a monopulse RADAR antenna enabling object detection and selection for efficient power “on demand” a
  - Time-modulated arrays demonstrate an unreachable, almost real-time reconfiguration.

• The ease of implementation of the TMAs (no phase shifters) makes them a potential candidate for smart, pervasive WPT solutions
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http://www.dei.unibo.it/en/research/research-facilities/Labs/rfcal-rf-circuit-and-antenna-design-lab