A Novel Battery-less Remote Control System based on Low-Cost Passive RFID Technology

Alírio Jesus Soares Boaventura
And Nuno Borges Carvalho
Presentation outline

- Introduction to E. Harvesting and WPT
  - Application examples
- Battery-less remote controls: Motivation
- Proposed approaches
  - PWS-alike Configuration
  - Multi-RFID configuration
- The Multi-RFID scheme
- Simulations and Measurements
- A demonstration Prototype
- Safety Issues
Brief Introduction to E. Harvesting and WPT

- Energy Harvesting
  Ambient Electromagnetic Energy

- Wireless Power Transmission
  Dedicated and known Transmitter

- In both cases: Received RF energy is converted into DC power
Use of cables or batteries … sometimes is unpractical, undesirable or even impossible

WPT Application examples:
✓ Medical applications → Implantable Electronic Devices (IED’s) placed within the patient’s body
✓ Smart Houses → Sensors can be placed within walls
✓ Automotive → Tire Pressure Sensors (TPS’s) inside car tires
✓ Electric vehicles → Wireless car charging
✓ Home Automation (we believe 😊)
Battery-less remote controls: Motivation

- Remote controls are used to wirelessly control TV’s, doors, games, …

- Major drawbacks of conventional Infra-Red (IR) technology:
  - IR communication requires line-of-sight
  - Use of chemical disposable batteries:
  - Cost associated to battery maintenance
  - Limited lifetime of batteries
  - Batteries generate toxic waste in the end of lifecycle
  - Beyond monetary cost, there is an environmental price
Batteries take hundreds of years to decompose, posing a serious threat to the public health and to the environment.

- Considering 4 Million habitual residences in Portugal (INE – Censos 2011) and assuming that:
  - 75% of them have a TV equipment
  - 40% have a cable TV Box
  - 30% have a Sound System

- We end up with an average of **5.8 Millions of remotes in Portugal**
- Assuming two batteries per remote and two battery changes per year we have a total of **23.2 Millions batteries being wasted every year!!**
Proposed approaches

A battery-free **Remote Control System** is proposed:

- The Remote **requires no battery**, based on passive RFID technology
- Device to be Controlled wirelessly powers the remote control using radio waves
- The remote control send back information using Backscattering (Power reflection)

**Advantages compared to conventional IR technology:**

- Elimination of costs associated to battery maintenance and treatment of toxic waste
- Long range and no line of sight communication thanks to the use of radio waves
- Cost-effective solution, thanks to the use of a low-cost RFID technology (UHF EPC)
Proposed approaches

**Option I: Passive Wireless Sensor - alike**

- Multi-RFID scheme is implemented
  - Several RFID chips are used, each one associated to a key
  - Only the chip associated to the pressed key should be read by the RFID reader to identify the key

**Option II: Multi-RFID scheme**
The Multi-RFID scheme

Operating principle:
- N passive RFID tags associated to N keys/switches
  - By default, no tag responds to reader (silent mode)
  - Once a key is pressed the respective tag is allowed to respond
  - Inactive tags must not interfere with the active one
- Two challenges: Antenna sharing, Tag activation/deactivation

Tags interconnection (N-port Network)

Port termination
- = 0 Ohms by default
- = 50 Ohms if user presses the key
The Multi-RFID scheme

Novel N-Port Microstrip Network (866.6MHz)

\[ Z_i' = Z_0 \frac{Z_i + jZ_0 \tan(\beta_1 l_1)}{Z_0 + jZ_i \tan(\beta_1 l_1)} ; \quad Z_A' = Z_0 \frac{Z_A + jZ_0 \tan(\beta_2 l_2)}{Z_0 + jZ_A \tan(\beta_2 l_2)} \]

If \( \beta_2 l_2 = k.180^\circ \) then: \( \tan(k\beta_2 l_2) = 0 \)

\[ Z_A' = Z_A \]

Thus, this is simplified to a parallel association

\[ Z_{IN}' = \left[ \sum_{i=1}^{N} \frac{1}{Z_i'} \right]^{-1} = \left[ \sum_{i=1}^{N} \frac{Z_0 + jZ_i \tan(\beta_1 l_1)}{Z_0(Z_i + jZ_0 \tan(\beta_1 l_1))} \right]^{-1} \]

Now, if \( Z_{i=n} = Z_0 \) and \( Z_{i\neq n} = 0 \) and \( \beta_1 l_1 = 90^\circ + k.180^\circ \) then:

\[ Z_{IN}' = \left[ \frac{Z_0 + jZ_1 \tan(90^\circ)}{Z_0(Z_1 + jZ_0 \tan(90^\circ))} + \frac{Z_0 + jZ_2 \tan(90^\circ)}{Z_0(Z_2 + jZ_0 \tan(90^\circ))} + \cdots + \frac{Z_0 + jZ_n \tan(90^\circ)}{Z_0(Z_n + jZ_0 \tan(90^\circ))} \right]^{-1} = Z_n = Z_0 \]
The Multi-RFID scheme

Example: key # 4 is pressed $\rightarrow$ RFID4 is routed to the antenna port without interference of idle tags
Simulations and Measurements

RFID chip measurement

DUT1 (switch) DUT2 (chip)

chip activation point
Simulations and Measurements

Switch characterization

Closed Position
Inductive behavior

Open Position
Capacitive behavior

NC switch

Switch Closed
Zin ≈ 0 Ohms

Switch Open
Zin ≈ 50 Ohms

Port termination
Simulations and Measurements

N-Port Network Simulation and Measurement

Objective: measure Return loss (S11, S22) and Transmission coefficient (S21, S12)

Scenario: Only one tag is active, rest of them are short-circuited (inactive)

![ADS Model Diagram]
Simulations and Measurements

N-Port Network Simulation and Measurement

- Measurements agree well with Simulations
- Good return loss (S11,S22) less than -14dB in the band of interest
- Acceptable insertion loss, around -1dB
Simulations and Measurements

Remote control prototypes: 3, 4 and 5 keys

Return loss (S11) of 4-key prototype when each key is pressed by the user

S11 - Return Loss (dB)

- o – key 1 pressed
- x – key 2 pressed
- □ – key 3 pressed
- < – key 4 pressed
A demonstration Prototype

- The complete system has been successfully tested and validated
- The remote control system has been integrated in a TV device
- CH +, CH -, Vol + and Vol – functions were implemented.

The prototype is composed by:
1) TV
2) RFID reader and Computer
3) RFID-IR adapter

Flowchart of demo application software running in a computer
A demonstration Prototype

Demo Setup

TX and RX antennas

RFID-IR adapter

Alien RFID Reader

Java Interface Application
Safety Issues

- It is important to comply with safety regulation standards, namely maximum radiated power.
- Maximum radiated power levels between 20 - 27dBm (~100mW : ~500mW) were used (Maximum of 33dBm (2W) is allowed by ETSI [1] and ANACOM).
- Recommended Maximum exposure level at UHF band is $580\text{uW/cm}^2$, FCC[3], IEEE [1].
- For $P_t=500\text{mW}$, $G_t=6\text{dBi}$ (4), $D=3\text{m}$ ($P_r=0.17\text{mW}$) $\Rightarrow S_{av} = 0.44 \text{uW/cm}^2$
- State-of-art RFID chip sensitivity is between -10dBm ($0.1\text{mW}$) and -15dBm.


Conclusions

- A battery-less remote control system has been prototyped
- The system complies with regulations in regard to maximum exposure levels …
- However, more work is needed to solve the problem of having the RFID reader always turned on (e.g. using an ON/OFF approach in TX).
- The proposed Multi-RFID scheme find many other applications such as:
  - Battery-less keyboards
  - Multi-function cards
  - User-controlled cards
- A patent application has been requested for the Multi-RFID scheme [1]

Thank you!

Questions?