PASSIVE RADIO COMMUNICATIONS COMBINING BACKSCATTER WITH WPT

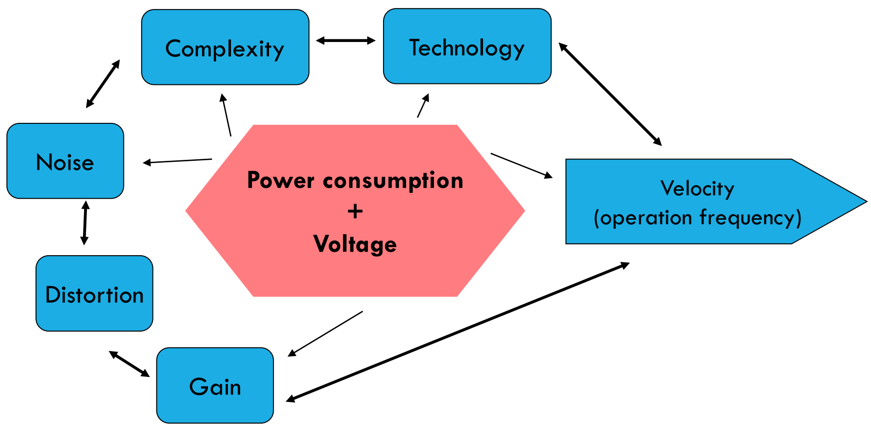
Nuno Borges Carvalho
Alírio Boaventura
Ricardo Correia
Hugo Gomes
nbcarvalho@ua.pt

FUNDAMENTAL CONCEPTS OF RADIO SYSTEMS

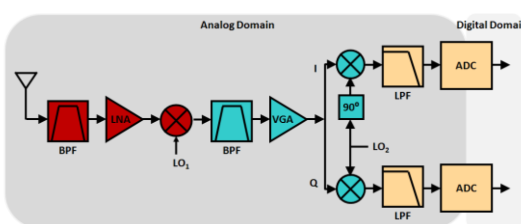
Class
Transceiver Design

RADIO SYSTEM DRAWBACKS

Limitations



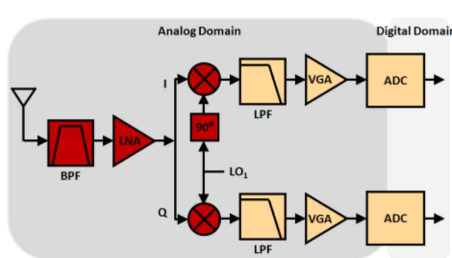
RF RECEIVERS



- Conversion to the digital domain at baseband where it can be processed
- Currently adopted in most radio receivers due to low cost components
- Full on-chip integration is concerned and its design to a specific channel → prevents the expansion of receiving band

Super-heterodyne

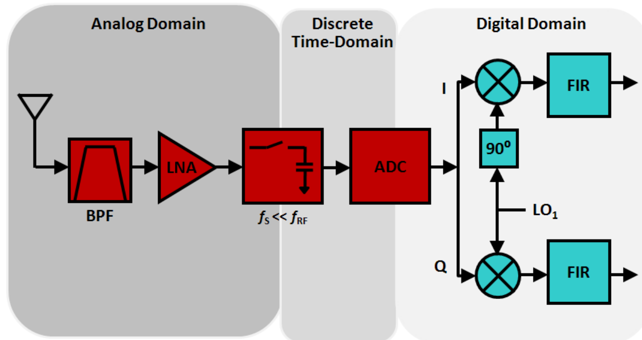
Zero-IF



- Signal is selected at RF by BPF, amplified and directly translated to DC
- Evident reduction in number of components → high level integration
- Components much more difficult to design DC offset, 2nd order IMD products generated around DC

SOFTWARE DEFINED RADIO

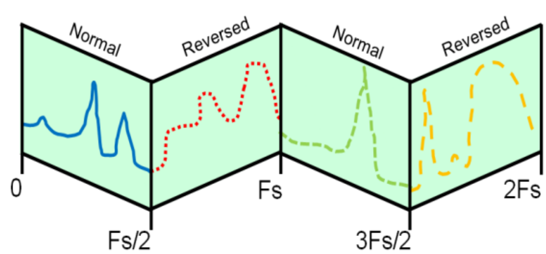
Bandpass Sampling Receiver:



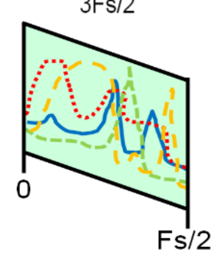
- Takes the fact that S/H circuit translates the signal to 1st Nyquist zone
- Digital processing capabilities exploited ⟶ multi-band reception
- Mandatory BPF to avoid overlap of signals ⟶ tunable or bank of filters
    - Analog BW of ADC must include RF carrier

SOFTWARE DEFINED RADIO

S/H circuit translates any input signal to 1st Nyquist zone



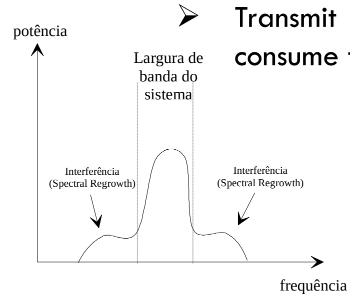
$$\text{if} \quad \text{fix}\left(\frac{f_C}{f_S/2}\right) \quad \text{is} \quad \begin{cases} \text{even}, & f_{fold} = rem(f_C, f_S) \\ \text{odd}, & f_{fold} = f_S - rem(f_C, f_S) \end{cases}$$



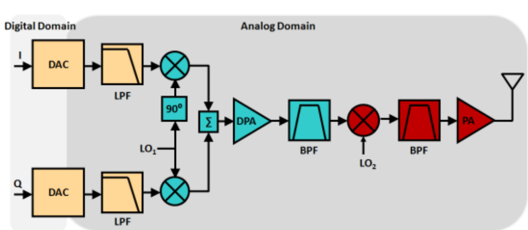
TRANSMITTER

The RF transmitter should also fulfill some requests, for instance:

- Use only the bandwidth that refers to the system standards
- Create low values of harmonic distortion
- Transmit the maximum RF power and simultaneously consume the minimum DC power from the system



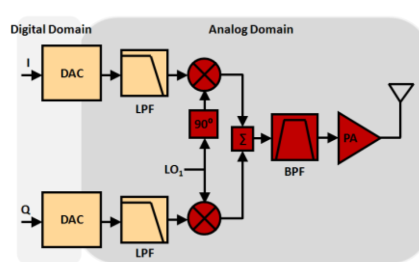
TRANSMITTER – ALL DIGITAL



Super-Heterodyne Transmitter

- Signal created in digital domain, modulated at IF, and up-converted
- I/Q modulator working at IF; Output spectrum is far away from LO
- Suffers from similar problems of the receiver case
- Multi-mode implementation is difficult

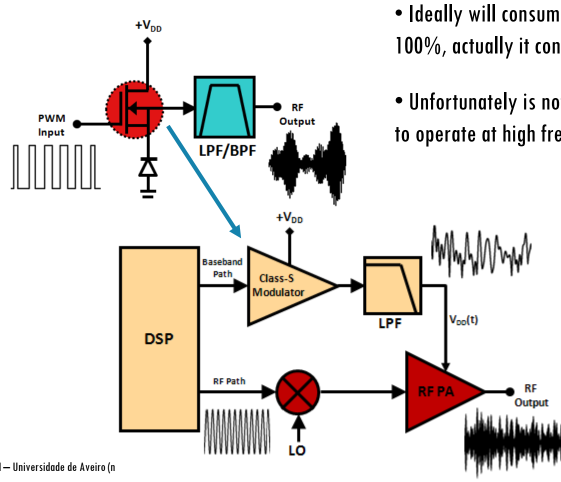
Direct-Conversion Transmitter



- Digital baseband signals are converted and directly modulated to RF
- Reduced amount of circuitry that allows high level integration
- Carrier leakage, phase gain mismatch, and requires highly linear PA
- With careful design can be employed in SDR TX's

TRANSMITTER – ALL DIGITAL

Visionary solution pointed the use of PWM/ΔΣ Modulator to create an all-digital TX

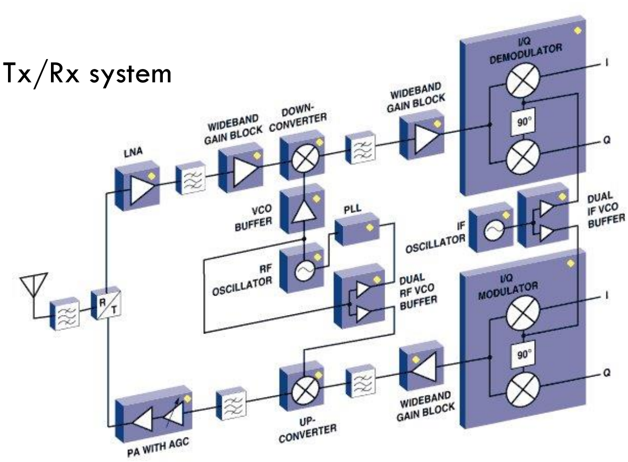


- Ideally will consume no DC power and achieve an efficiency of 100%, actually it consumes
- Unfortunately is not possible to design such PA with high efficiency to operate at high frequencies

- Been used in digital versions of EER, known as Polar TX's
- Time misalignment can be compensated in digital domain

TX/RX EXAMPLE

Typical Tx/Rx system



RADIO COMMUNICATIONS

These radio architectures are responsible for a large amount of energy consumption….

THE BATTERY PROBLEM

Class
Transceiver Design

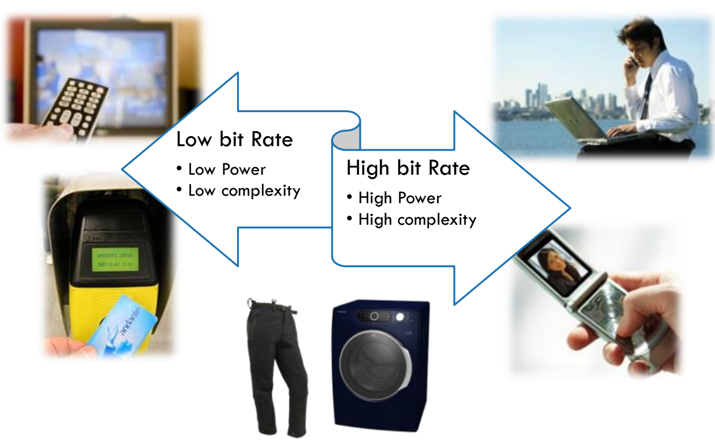
BATTERIES

- Batteries take **hundreds of years to decompose**, posing a serious threat to the public health and to the environment.

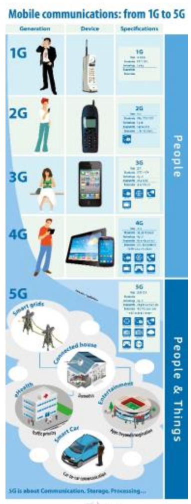
- Considering 4 Million habitual residences in Portugal (INE – Censos 2011) and assuming that:
  - ✓ 75% of them have a TV equipment
  - ✓ 40% have a cable TV Box
  - ✓ 30% have a Sound System

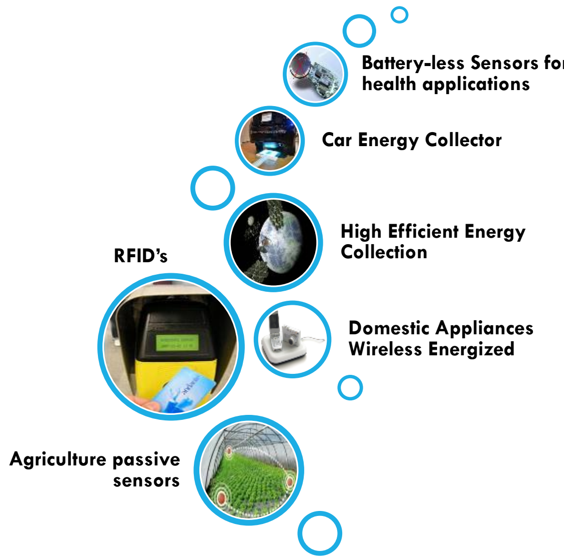
- We end up with an average of **5.8 Millions of remotes in Portugal**
- Assuming two batteries per remote and two battery changes per year we have a **total of 23.2 Millions batteries being wasted every year !!**

NEXT FRONTIER WIRELESS THINGS

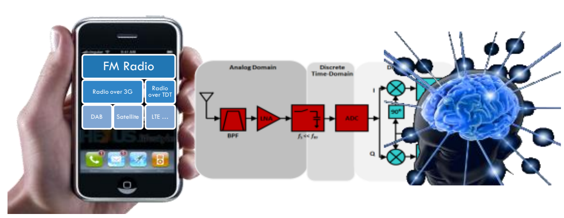


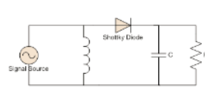
5G

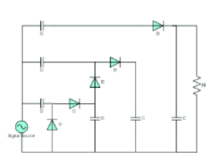


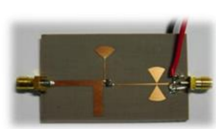


CHALLENGES









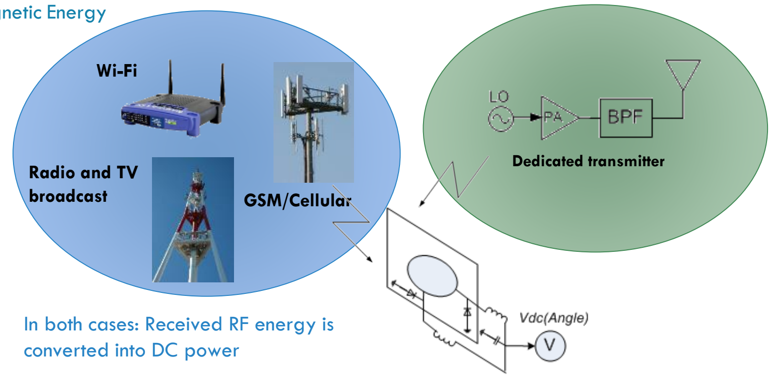
ENERGY HARVESTING AND WPT

Energy Harvesting

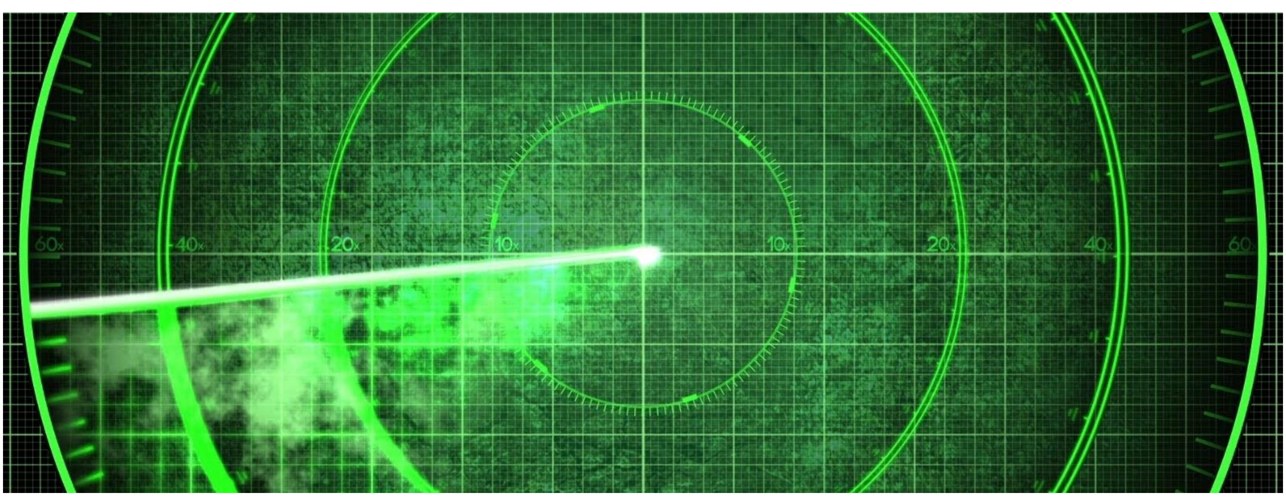
Ambient Electromagnetic Energy

Wireless Power Transmission (WPT)

Dedicated and known Transmitter



In both cases: Received RF energy is converted into DC power

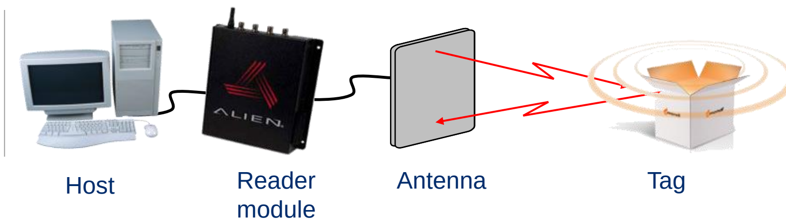


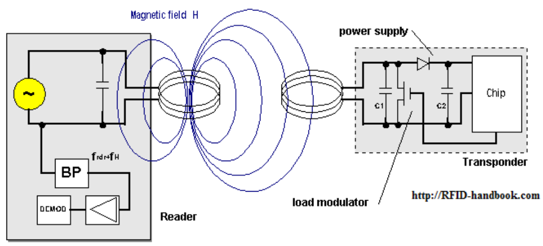
BACKSCATTER RADIO

Class

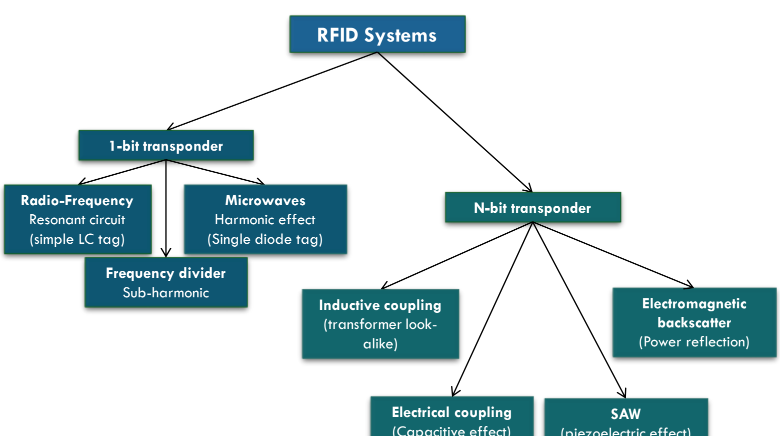
Backscatter Radios

RADIO FREQUENCY IDENTIFICATION - RFID





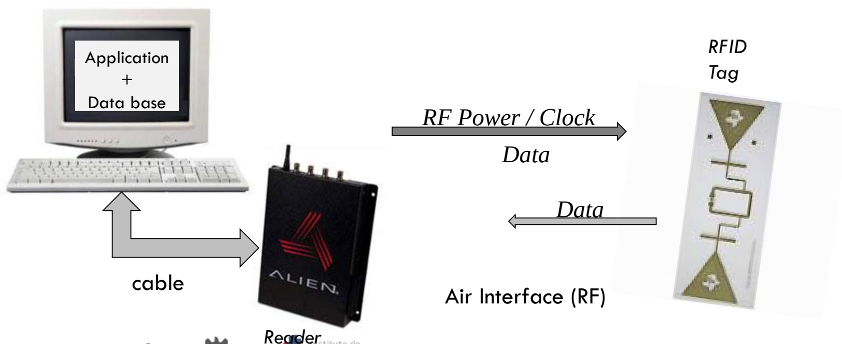
RADIO FREQUENCY IDENTIFICATION - RFID



PRINCIPLE OF OPERATION

Basic components

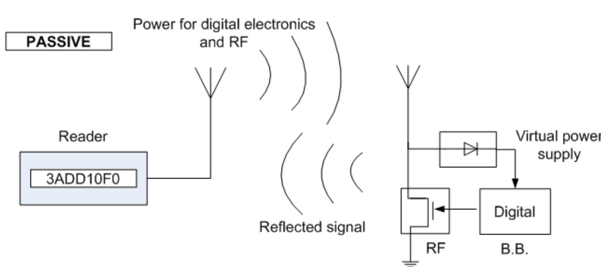
1) **Reader/Interrogator** – Used for read and store information in Tag
2) **Tag/Transponder** – small device which carries data (e.g. Tag ID)
3) **Host** - computer running user application



PRINCIPLE OF OPERATION

Passive Tags:

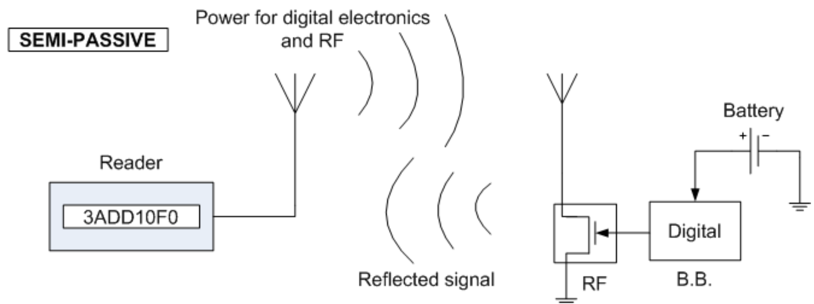
- Tag has no self battery
- Tag electronics is remotely powered by the reader
- Communication made by power reflection (Backscattering)
- Short range



PRINCIPLE OF OPERATION

Semi-Passive or Battery-Assisted Tags

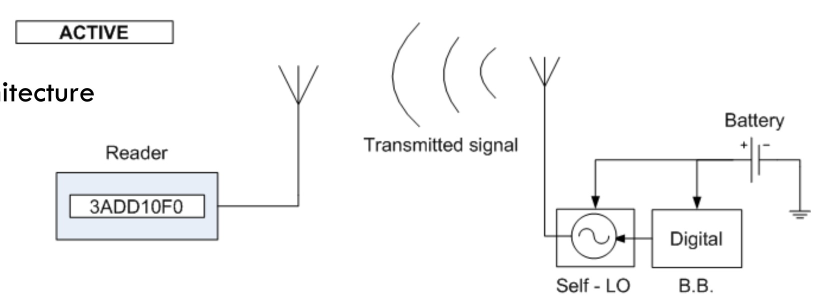
- Electronics powered by a battery
- communication made by power reflection
- medium range



PRINCIPLE OF OPERATION

Active Tags

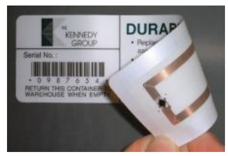
- Tag electronics powered by a battery
- Tag has a self-oscillator
- long range
- conventional radio architecture



PRINCIPLE OF OPERATION

Active Tags:

Passive Tags

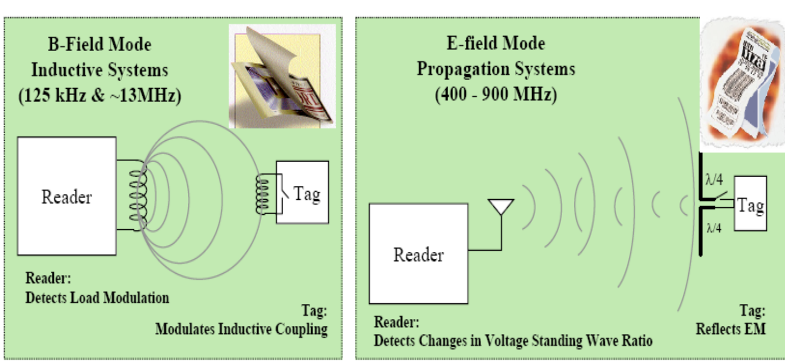


Semi-Passive Tags

PRINCIPLE OF OPERATION

The two main air interface method in today's systems:

- Propagation systems – using Electromagnetic E-fields
- Inductive systems – suing magnetic B-fields

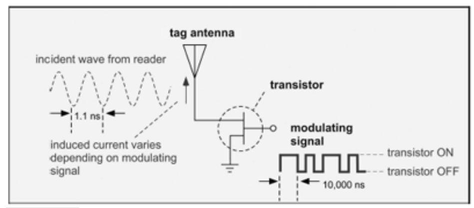


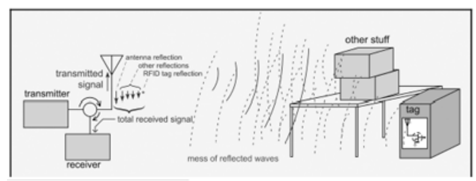
BACKSCATTER

RF RFID Tags are most of the time based on electromagnetic backscatter configurations.

- Backscatter is similar to radars.
- The TAG Antenna reflects part of an incoming electromagnetic wave back to the reader.
- Electromagnetic wave are reflected by most objects that are larger than half the wavelength.
- The backscatter reflection efficiency is maximized for antennas that are resonating with the incoming radar frequency.

    The short wavelengths of UHF facilitate the construction of antennas with smaller dimensions and greater efficiency.



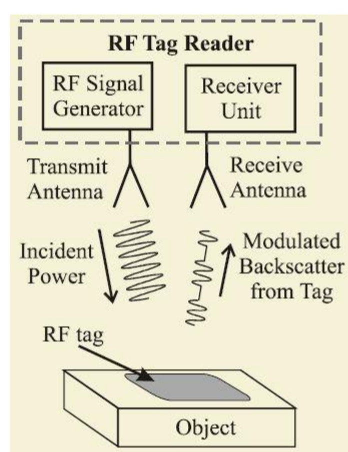


ELECTROMAGNETIC BACKSCATTER

The energy reflected from the tag is radiated into free space.

  A copy of this signal severely attenuated due to the free-space attenuation is received by the reader's antenna.

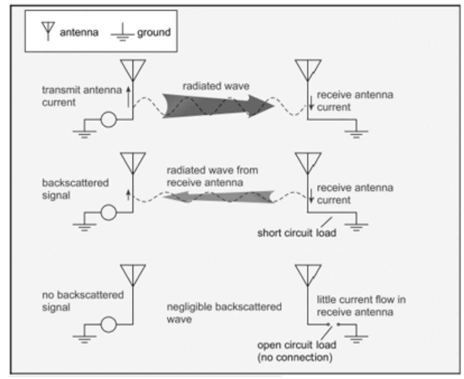
The reflected signal is returned back to the reader antenna and interpreted conveniently.

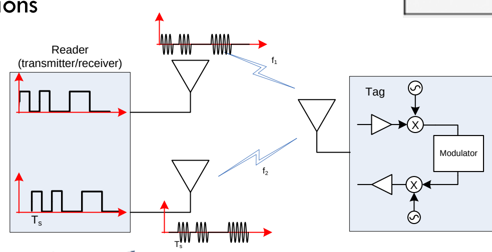


UHF RFID

Radio frequency RFID systems usually include :

- Passive RFID's
  Mainly based on Backscatter
- Active RFID's
  Based on typical wireless communications





UHF RFID

Typical Reader systems include:

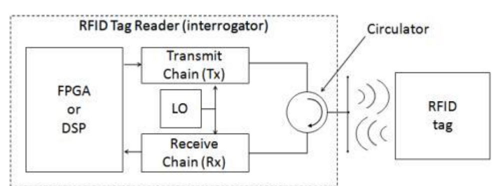
1. RF Transmitter
2. RF Receiver
3. A Digital Signal Processor
4. An Antenna

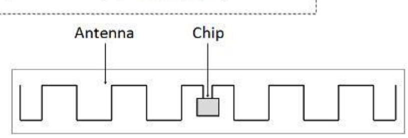
Typical RF TAG systems include:

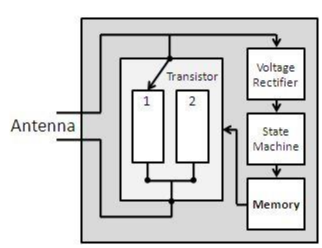
1. An Antenna
2. A chip

Typical TAG chip systems include:

1. A Voltage Harvester
2. A digital processor and a simple transmitter

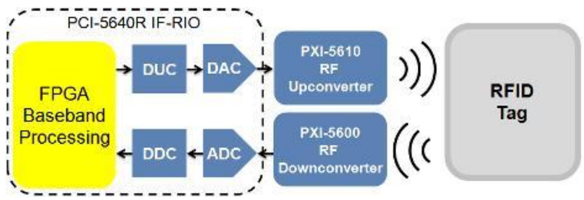


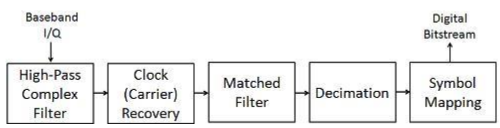




UHF RFID

Typical Readers are moving fast to a Software Defined Radio Solution, including a digital part and a RF up-converter and RF down-converter….





FAR FIELD OPERATION

Contrary to inductive coupling, electromagnetic backscatter operates in the far field.

The range can be calculated based on the energy available at the transponder which is calculated using the Friis formula:

$$P_T = A_{e2}\frac{P_{in}}{4\pi r^2}G_1 = \frac{\lambda^2}{4\pi}G_2\frac{P_{in}}{4\pi r^2}G_1 \Leftrightarrow P_T = P_{in}\left(\frac{\lambda}{4\pi r}\right)^2 G_t G_r$$

Table 3.7 Free space path loss a_F at different frequencies and distances. The gain of the transponder's antenna was assumed to be 1.64 (dipole), the gain of the reader's antenna was assumed to be 1 (isotropic emitter)

Distance r	868 MHz	915 MHz	2.45 GHz
0.3 m	18.6 dB	19.0 dB	27.6 dB
1 m	29.0 dB	29.5 dB	38.0 dB
3 m	38.6 dB	39.0 dB	47.6 dB
10 m	49.0 dB	49.5 dB	58.0 dB

ELECTROMAGNETIC BACKSCATTER

Main frequencies for backscatter are at UHF frequencies: 868 MHz (Europe) and 915 MHz (USA); and microwave frequencies: 2.5 GHz and 5.8 GHz

The signal is modulated mainly in ASK and BPSK configurations.

Main use for long-range systems

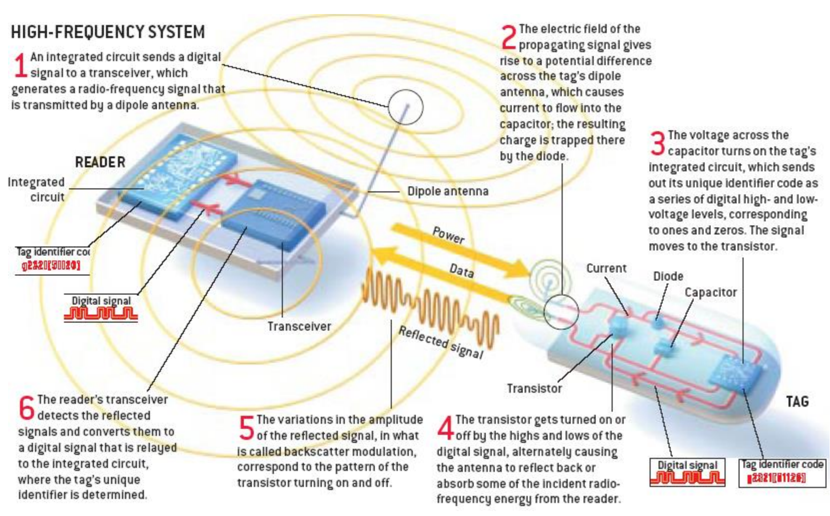
- Distance between reader and tag > 1m

For higher distances >15m – backscatter tag's usually use a battery

The tag in this situation is normally put in a stand-by mode for saving battery time, when out of the reader range

The battery of an active backscatter tag never provides power for the transmission of data between tag and reader. The battery is used exclusively for supply power to microchip.

UHF RFID



READER ARCHITECTURES

- Bistatic Configuration: Separate Transmitter and Receiver Antennas
- Monostatic Configuration: **Same Antenna for Transmitter and Receiver**

(Circulator or Directional coupler isolates TX and RX)

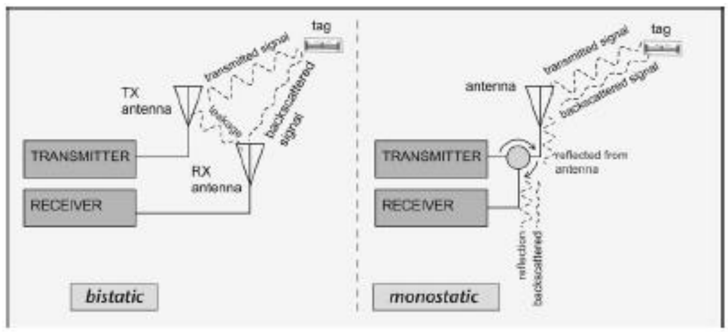


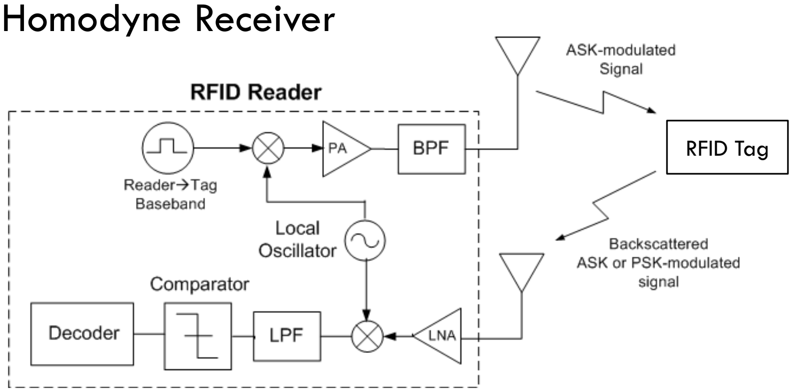
Figure 4.1: Bistatic and Monostatic Antenna Configurations.

Source: The RF in RFID : Passive UHF RFID in Practice, Daniel M. Dobkin

READER ARCHITECTURES

✓Transmitter → ASK Modulator

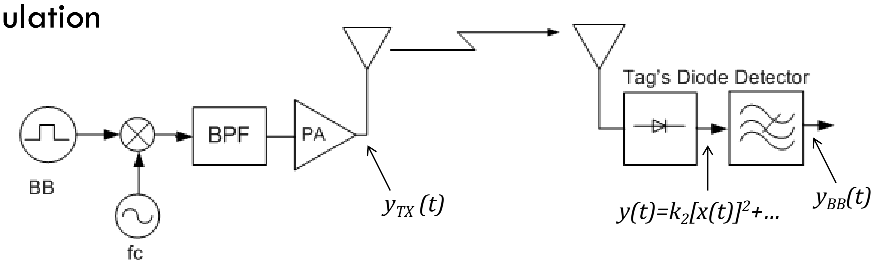
✓Receiver → Homodyne Receiver



DOWNLINK DATA COMMUNICATION

Downlink: Rader → Tag communication

- ASK modulation



Baseband ASK signal: $m(t)=\sum_{k=-\infty}^{+\infty} a_k \delta(t-kT)$

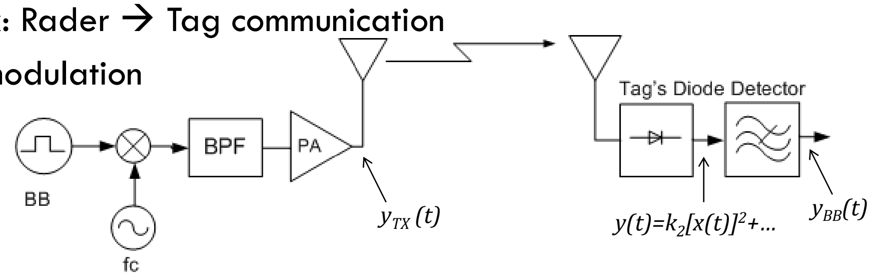
Transmitted Signal: $y_{TX}(t) = m(t)\left\{A_C \frac{e^{j\omega_c t}+e^{-j\omega_c t}}{2}\right\}$

RF Carrier

DOWNLINK DATA COMMUNICATION

Downlink: Rader → Tag communication

- ASK modulation



Envelope Demodulation: $y(t) = k_2\left[m(t)\left\{A_C \frac{e^{j\omega_c t}+e^{-j\omega_c t}}{2}\right\}\right]^2$

After low-pass filtering, the baseband signal sent by the reader is recovered by the Tag:

$$y_{BB}(t) = \frac{A_c^2 k_2}{2}[m(t)]^2$$

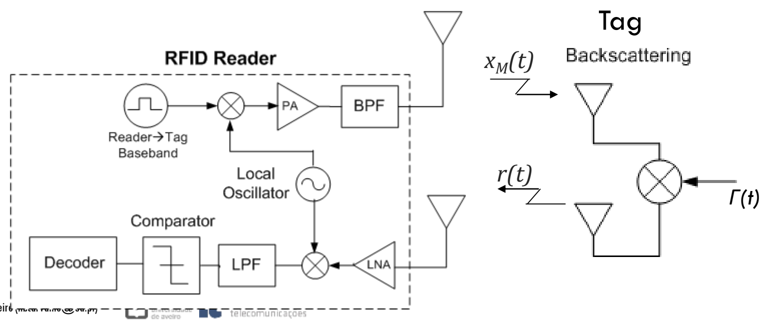
UPLINK DATA COMMUNICATION

Uplink: Tag → Reader communication

- Load-Modulated Backscatter (ASK or PSK)

The uplink is a two-step operation:

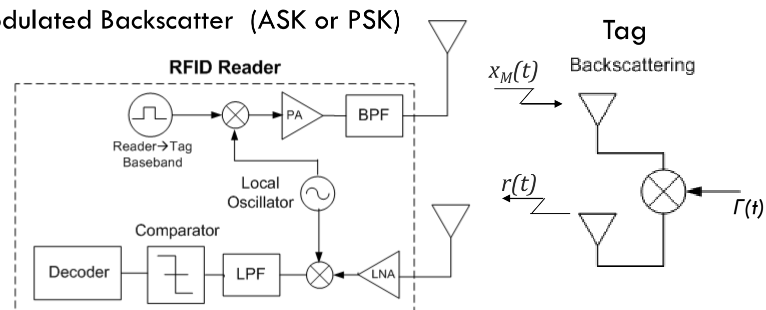
- ❑ First the reader illuminates the tag with an un-modulated carrier, $x_M(t)$
- ❑ Tag send back information by reflecting power with a time-varying coefficient $\Gamma(t)$



UPLINK DATA COMMUNICATION

Uplink: Tag → Reader communication

- Load-Modulated Backscatter (ASK or PSK)



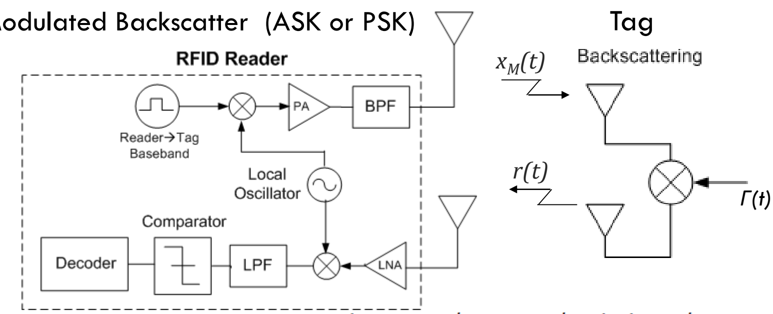
Transmitted Un-modulated Carrier: $x_M(t) = \left\{ A_C \frac{e^{j\omega_c t} + e^{-j\omega_c t}}{2} \right\}$

Signal Reflected back with tag information: $r(t) = \Gamma(t) \left\{ A_C \frac{e^{j\omega_c t} + e^{-j\omega_c t}}{2} \right\}$

UPLINK DATA COMMUNICATION

Uplink: Tag → Reader communication

- Load-Modulated Backscatter (ASK or PSK)



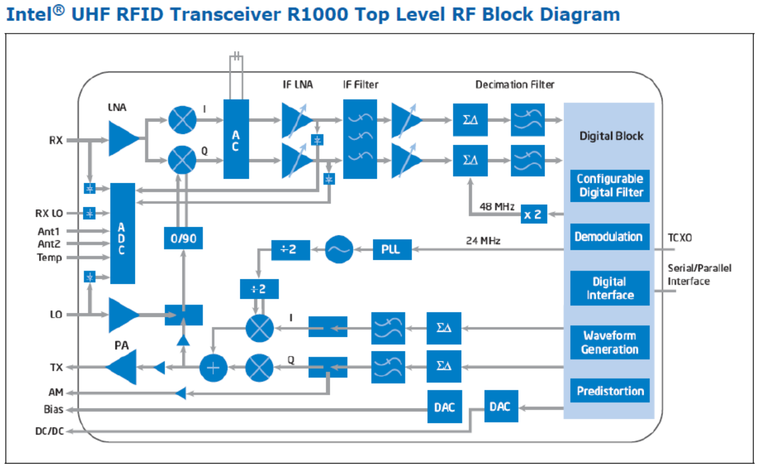
Receiver Mixer Output: $z(t) = \left\{\Gamma(t)A_C \dfrac{e^{j\omega_c t} + e^{-j\omega_c t}}{2}\right\}\left\{A_C \dfrac{e^{j\omega_c t} + e^{-j\omega_c t}}{2}\right\}$

Recovered Tag baseband information at the Low-pass filter output:

$$z_{BB}(t) = \frac{1}{2}\Gamma(t)A_c^2$$

COMMERCIAL UHF READER (900MHZ)

Intel® UHF RFID Transceiver R1000 Top Level RF Block Diagram



Source: *Intel datasheet*

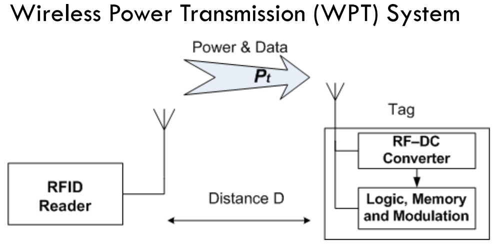
WIRELESS POWER TRANSMISSION

Class
Wireless Power Transmission

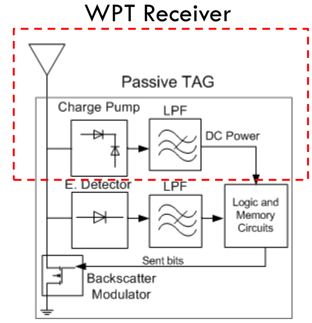
WIRELESS POWER TRANSMISSION FOR PASSIVE RFID

- ✓ **Passive RFID tags have no self-battery**
- ✓ Energy is harvested from reader RF signal
- ✓ RF Energy is converted into DC Power and used as Power Supply
- ✓ RF-DC converters are key components of passive RFID tags

Wireless Power Transmission (WPT) System



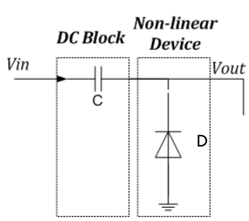
WPT Receiver

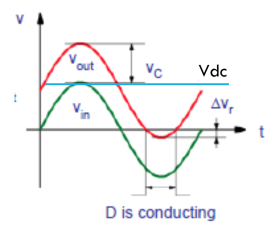


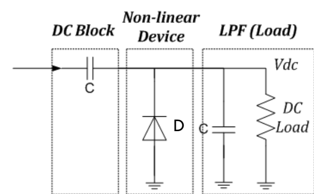
WIRELESS POWER TRANSMISSION

- ✓ Typically High Speed Schottky Diodes are used in RF-DC converters
- ✓ Commonly used configurations: single-diode detectors (high RF-DC efficiency), voltage multipliers (high voltage), full-wave rectifiers (current stability), …

Single-diode Envelope Detector



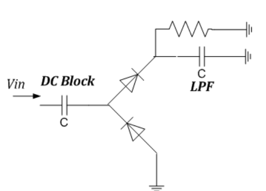




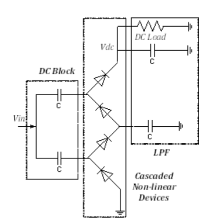
WIRELESS POWER TRANSMISSION

Half-wave Voltage Multipliers (Charge Pumps)

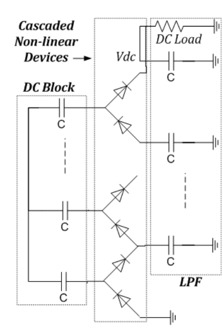
Voltage Doubler (1-stage)



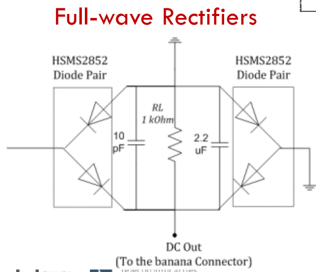
2-stages



N-stages

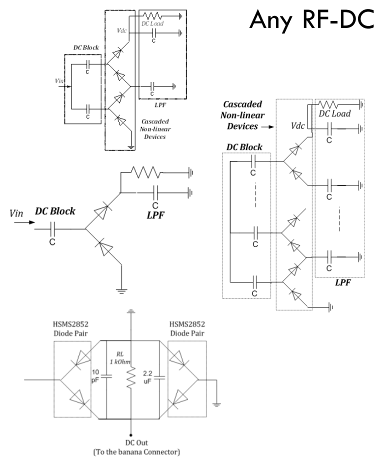


Full-wave Rectifiers



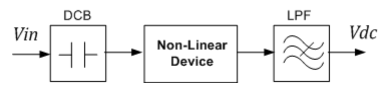
WIRELESS POWER TRANSMISSION

Non-linear Analysis of RF-DC Converters

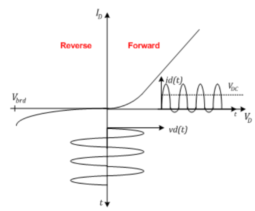


Any RF-DC Converter can be described by a non-linear Model:

General Model

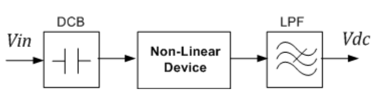


Diode Non-linear Characteristic (I-V Curve)



WIRELESS POWER TRANSMISSION

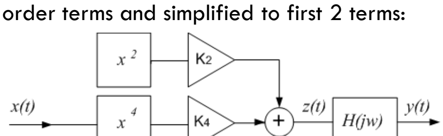
Non-linear Analysis of RF-DC Converters



Non-linear part can be approximated by a polynomial memoryless model :

$$y(t) = \sum_{n=0}^{N} k_n x(t)^n$$

For DC, only the even-order terms are important → Model can be restricted to even order terms and simplified to first 2 terms:



Consider a single tone at the system input:

$$x(t) = Bcos(\omega_1 t + \varphi 1)$$

The output is given by:

$$z(t) = \frac{B^2k_2}{2} + \frac{6B^4k_4}{16} + \frac{B^2k_2}{2}cos(2\omega_1 t + 2\varphi_1)$$

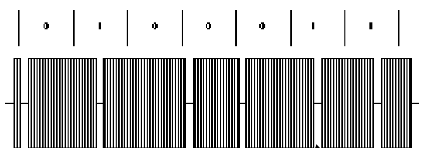
$$+\frac{B^4k_4}{2}\cos(2\omega_1 t + 2\varphi_1) + \frac{B^4k_4}{8}\cos(4\omega_1 t + 4\varphi_1)$$

After Low-pass filter, the RF components will be eliminated, the only DC component will remain:

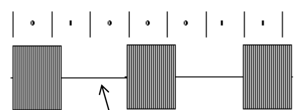
$$y_{DC} = \frac{B^2k_2}{2} + \frac{6B^4k_4}{16}$$

MODULATION AND CODIFICATION

- ❖ Reader-to-tag link has two goals: Communication and Energy transfer
- ❖ Data communication and Energy transfer can take place simultaneously
- ❖ In such cases the Modulation and Codification must be carefully designed, otherwise the Energy transfer will be degraded
- ❖ For instance: An inappropriate combination of Codification-Modulation with long dead periods (signal off) would lead the tag to fail



Good choice: signal is off for short periods of time



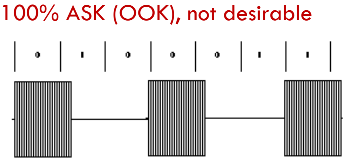
Bad choice: signal is off for long periods of time → At those periods tag has no available energy to operate

MODULATION AND CODIFICATION

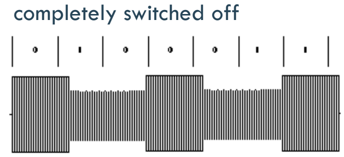
Modulation:

- ✓ ASK is the preferred Reader-to-tag modulation because it is simple allowing low-complexity tag design
- ✓ However, pure 100% ASK (OOK) modulation is not desirable

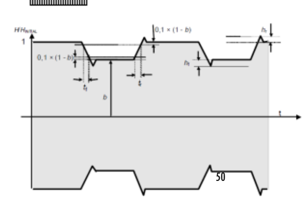
100% ASK (OOK), not desirable

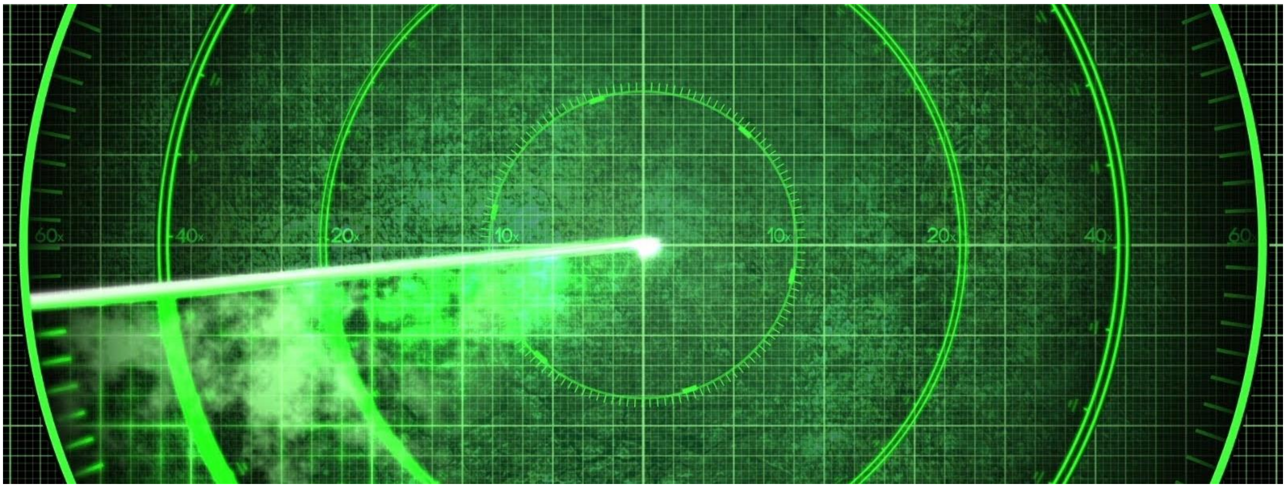


e.g. 15% ASK: Signal is never completely switched off



For instance, standard ISO14443-B uses 10% ASK Modulation in downlink



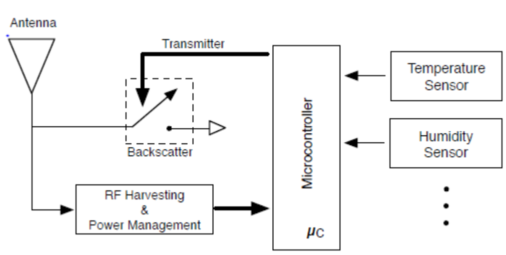


BACKSCATTER RADIO ALTERNATIVES

Dual Band Backscatter

DESIGNING BACKSCATTER WITH DUAL BAND

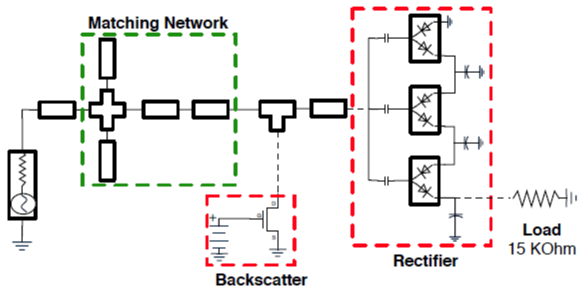
Combining WPT and backscatter can actually improve the coverage range in a clever way…



Correia, R.; Borges de Carvalho, N.; Fukuday, G.; Miyaji, A.; Kawasaki, S., "Backscatter wireless sensor network with WPT capabilities," in *Microwave Symposium (IMS), 2015 IEEE MTT-S International* , vol., no., pp.1-4, 17-22 May 2015

DESIGNING BACKSCATTER WITH DUAL BAND

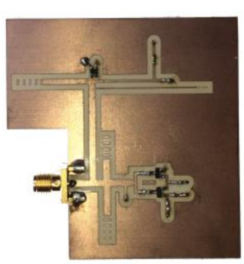
The backscatter is designed so that the input matching network is dual at harmonics …

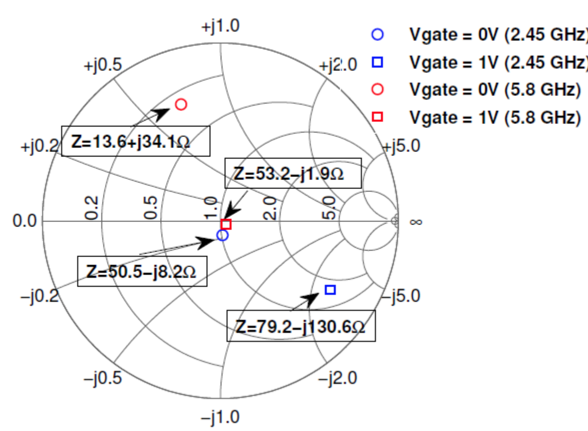


Correia, R.; Borges de Carvalho, N.; Fukuday, G.; Miyaji, A.; Kawasaki, S., "Backscatter wireless sensor network with WPT capabilities," in *Microwave Symposium (IMS), 2015 IEEE MTT-S International* , vol., no., pp.1-4, 17-22 May 2015

DESIGNING BACKSCATTER WITH DUAL BAND

The backscatter is designed so that the input matching network is dual at harmonics …

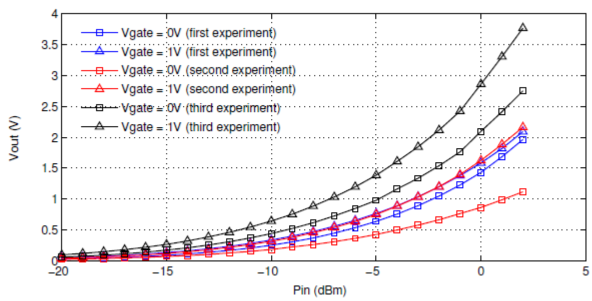




Correia, R.; Borges de Carvalho, N.; Fukuday, G.; Miyaji, A.; Kawasaki, S., "Backscatter wireless sensor network with WPT capabilities," in *Microwave Symposium (IMS), 2015 IEEE MTT-S International* , vol., no., pp.1-4, 17-22 May 2015

DESIGNING BACKSCATTER WITH DUAL BAND

The backscatter is designed so that the input matching network is dual at harmonics …



Correia, R.; Borges de Carvalho, N.; Fukuday, G.; Miyaji, A.; Kawasaki, S., "Backscatter wireless sensor network with WPT capabilities," in *Microwave Symposium (IMS), 2015 IEEE MTT-S International* , vol., no., pp.1-4, 17-22 May 2015

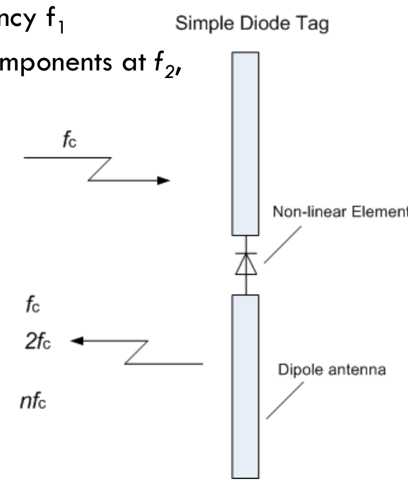
BACKSCATTER RADIO ALTERNATIVES

IMD Passive Radios

1-BIT TRANSPONDER USING HARMONIC EFFECT

- Transmitter illuminates the Tag with a signal at frequency f_1
- Due to Non-linear behavior, tag produces harmonic components at f_2, $2f_1$, … , Nf_1

  - TAG = Simple Diode + Antenna

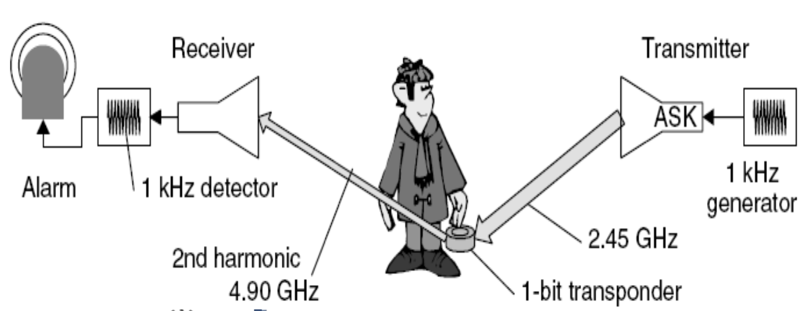


1-BIT TRANSPONDER USING HARMONIC EFFECT

Receiver detects one of the harmonics (e.g. second harmonic, $2f_1$)

- If harmonic is detected → Tag in the field
- If not → No tag in the field

  - Used in Anti-theft Systems



NONLINEAR DISTORTION

Non-linear System:

$$y_{NL} = \sum_{k=1}^{+\infty} a_k x(t-\tau_k)^k = a_1 x(t-\tau_1) + a_2 x(t-\tau_2)^2 +$$

$$+ a_3 x(t-\tau_3)^3 + \ldots$$

2 tone input:

$$x(t) = b_1 \times \cos(\omega_1 t) + b_2 \times \cos(\omega_2 t)$$

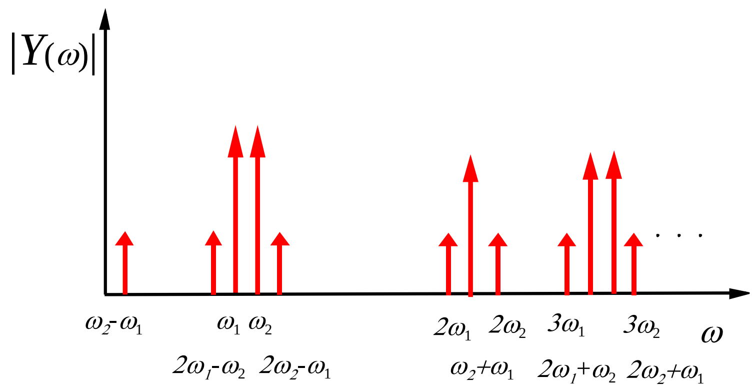
NONLINEAR DISTORTION

$$y_{NL} = \underbrace{a_1\left(b_1 \times \cos(\omega_1 t) + b_2 \times \cos(\omega_2 t)\right)}_{y_1 = 1^{a}\, ordem} +$$

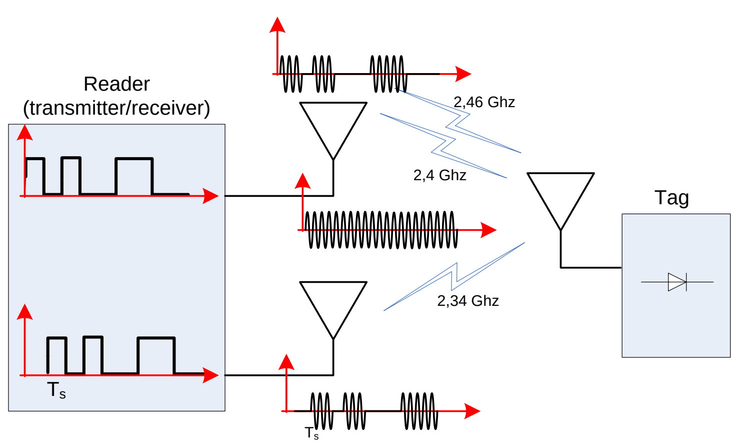
$$+ \underbrace{a_2\left(b_1 \times \cos(\omega_1 t) + b_2 \times \cos(\omega_2 t)\right)^2}_{y_2 = 2^{a}\, ordem} +$$

$$+ \underbrace{a_3\left(b_1 \times \cos(\omega_1 t) + b_2 \times \cos(\omega_2 t)\right)^3}_{y_3 = 3^{a}\, ordem} + \ldots.$$

NONLINEAR DISTORTION



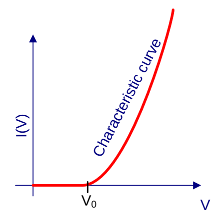
NL RFID PROPOSAL



Gomes, H.G. and Carvalho, N.B.C. , "RFID for Location Proposes Based on the Intermodulation Distortion", Sensors & Transducers Magazine, vol.106, n.7, pp.85-96, July, 2009

NONLINEAR DISTORTION

$$i_D(v_D) = I_S \exp\left(\frac{v_D - R_s i_D}{\eta V_T}\right)$$



$$\delta_{NL}\left[y(x)\right] = K_0 + \frac{1}{1!}\frac{d\delta_{NL}\left[y(x)\right]}{dx}\bigg|_{x(t)=x_0}(x-x_0) + \frac{1}{2!}\frac{d\delta_{NL}{}^2\left[y(x)\right]}{d^2x}\bigg|_{x(t)=x_0}(x-x_0)^2 +$$

$$\frac{1}{3!}\frac{d\delta_{NL}{}^3\left[y(x)\right]}{d^3x}\bigg|_{x(t)=x_0}(x-x_0)^3 + \dots$$

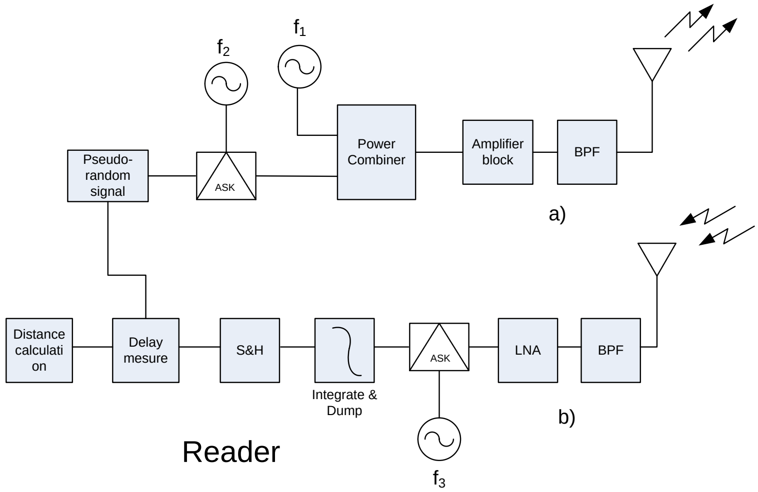
NONLINEAR DISTORTION

$$\delta_{NL}\left[i_D(v_D)\right] = K_0 + \underbrace{\frac{1}{1!}\frac{di_D}{dv_D}\bigg|_{v_D=v_0}}_{a_1}(v_D - v_0) +$$

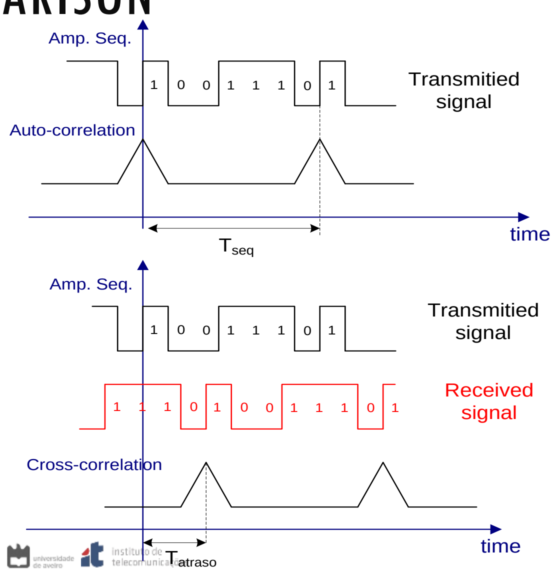
$$+\underbrace{\frac{1}{2!}\frac{di_D{}^2}{d^2v_D}\bigg|_{v_D=v_0}}_{a_2}(v_D - v_0)^2 +$$

$$+\underbrace{\frac{1}{3!}\frac{di_D{}^3}{d^3v_D}\bigg|_{v_D=v_0}}_{a_3}(v_D - v_0)^3 + \dots$$

BLOCK DIAGRAM

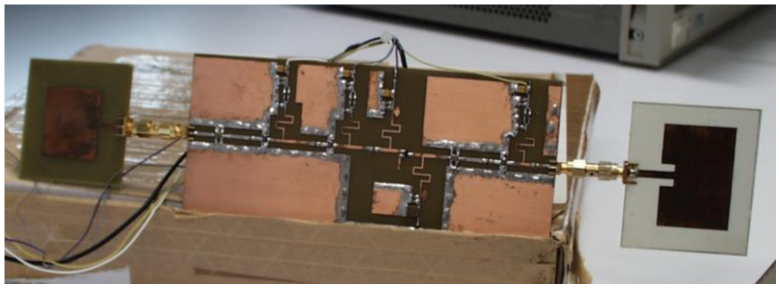


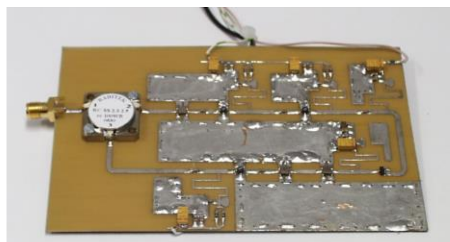
SIGNAL COMPARISON



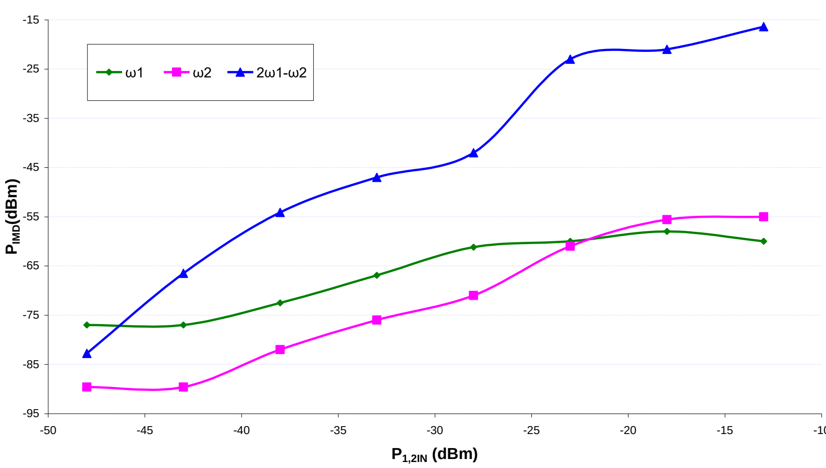
IT - DETI – Universidade de Aveiro (nbcarvalho@ua.pt)
RADIO SYSTEMS

PROTOTYPE





RESULTS



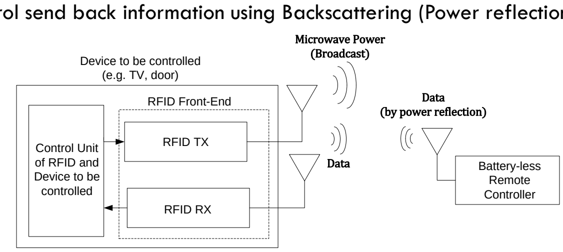
BACKSCATTER RADIO ALTERNATIVES

Remote Control

BATTERY-LESS REMOTE CONTROL

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)

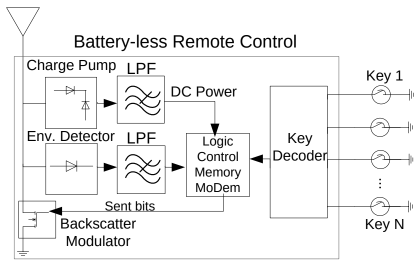


Advantages compared to conventional IR technology:

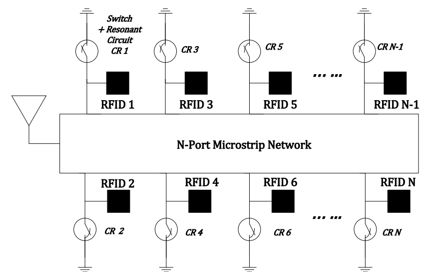
- ✓ **Elimination of costs** associated to battery maintenance and treatment of toxic waste
- ✓ **Long range and no line of sight communication** thanks to the use of radio waves
- ✓ **Cost-effective solution**, thanks to the use of a low-cost RFID technology (UHF EPC)

PROPOSED SOLUTIONS

Option I: Passive Wireless Sensor - alike



Option II: Multi-RFID scheme



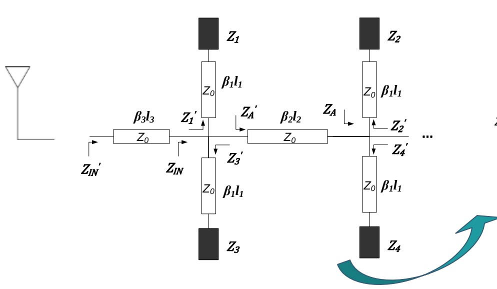
Multi-RFID scheme is implemented

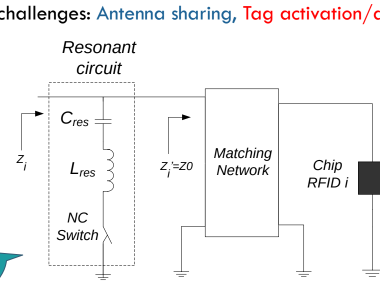
- Several RFID chips are used, each one associated to a key
- Only the chip associated to the pressed key should be read by the RFID reader to identify the key

MULTI-RFID SCHEME

Operating principle:

- N passive RFID tags associated to N keys/switchs
  - 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



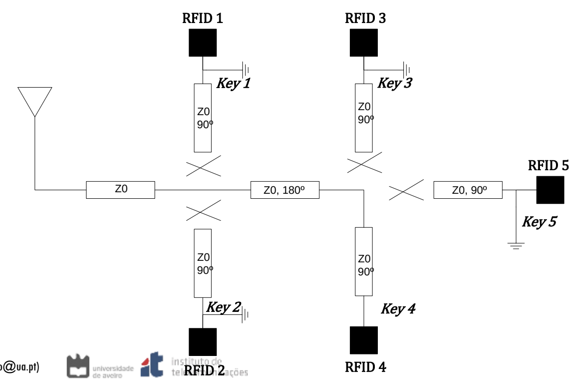


Port termination
= 0 Ohms by default
= 50 Ohms if user presses the key

Tags interconnection (N-port Network)

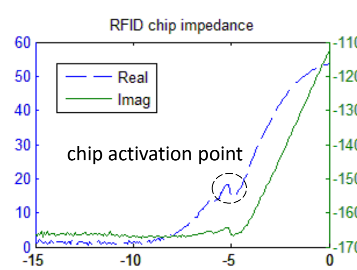
MULTI-RFID SCHEME

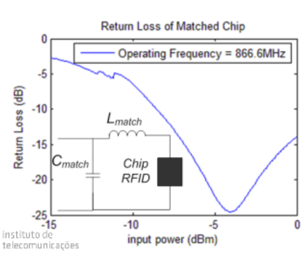
Example: key # 4 is pressed → RFID4 is routed to the antenna port without interference of idle tags



MULTI-RFID SCHEME - MEASUREMENTS

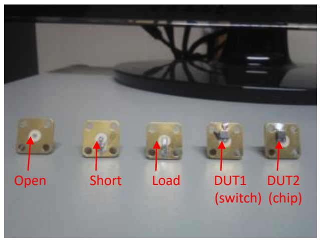
RFID chip measurement

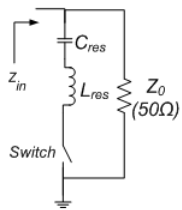




MULTI-RFID SCHEME - MEASUREMENTS

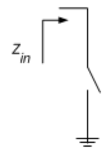
Switch characterization

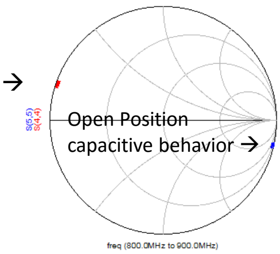




Port termination

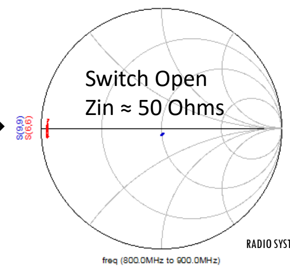
Closed Position
inductive behavior →





NC switch

Switch Closed
Zin ≈ 0 Ohms →

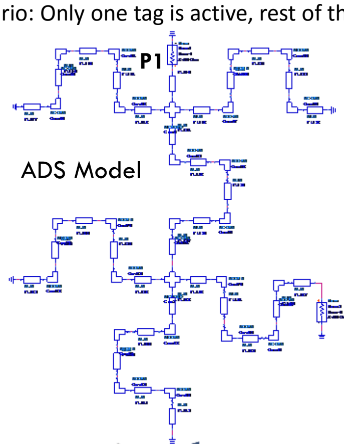


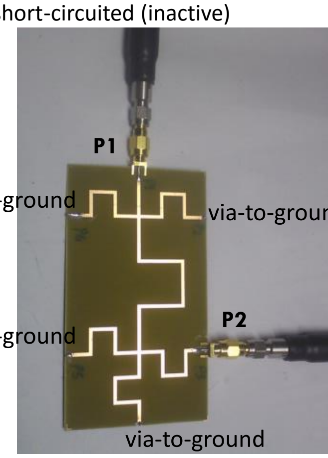
MULTI-RFID SCHEME - MEASUREMENTS

N-Port Network Simulation and Measurement

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

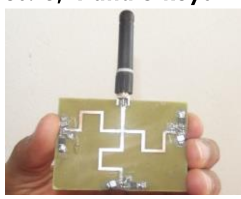
Scenario: Only one tag is active, rest of them are short-circuited (inactive)

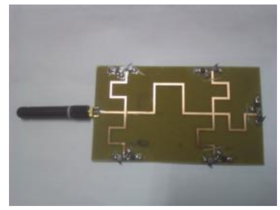




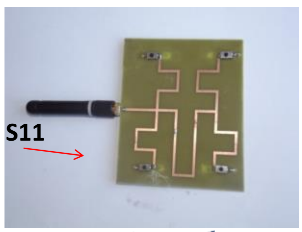
MULTI-RFID SCHEME - MEASUREMENTS

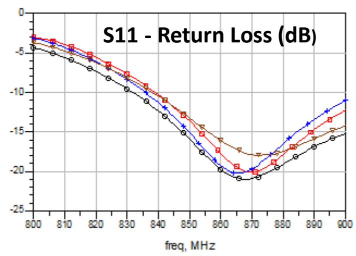
Remote control prototypes: 3, 4 and 5 keys





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

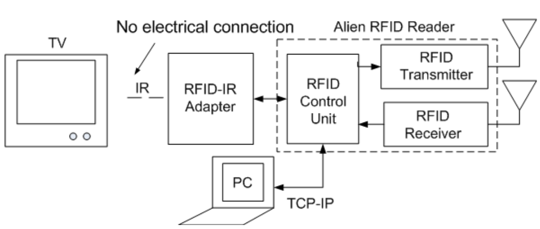


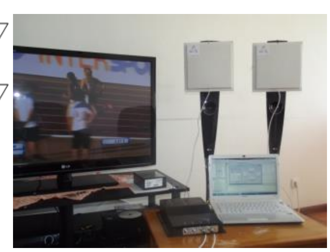


o – key 1 pressed
x – key 2 pressed
▪ – key 3 pressed
< – key 4 pressed

MULTI-RFID SCHEME - MEASUREMENTS

- ✓ 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.

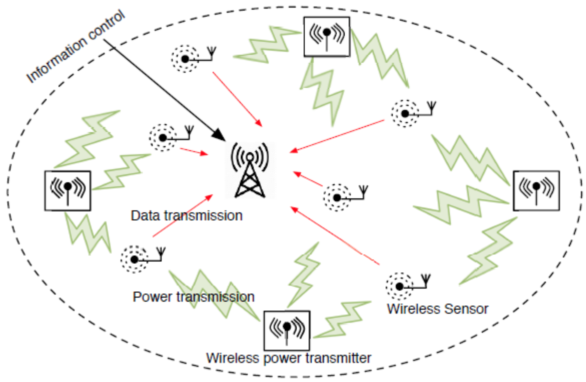


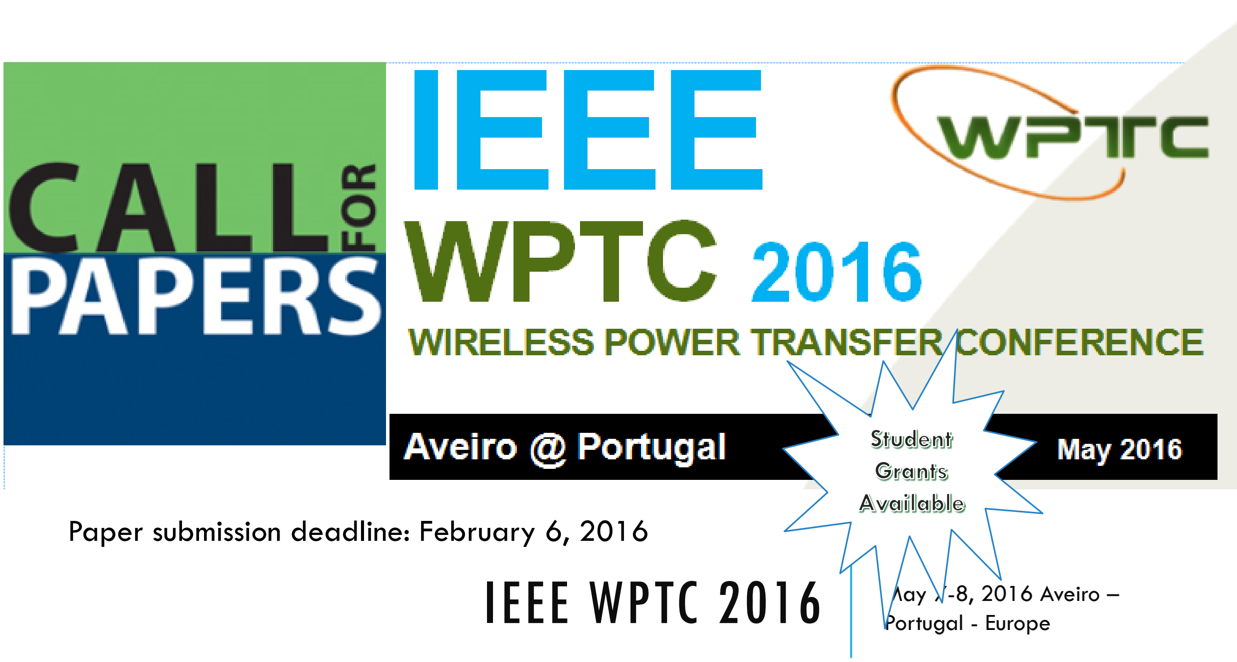


The prototype is composed by:

1) TV
2) RFID reader and Computer
3) RFID-IR adapter

FUTURE VISION





Paper submission deadline: February 6, 2016

IEEE WPTC 2016

May [illegible]-8, 2016 Aveiro – Portugal - Europe

www.wptc2016.org