2004 The “Big Bang” of Internet of Things

The Electronic Product Code (EPC)

- EPC provides unique* numbering scheme for physical objects
- EPC is only an ID, the information is stored on the network

<table>
<thead>
<tr>
<th>EPC-96 TYPE 1</th>
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<tbody>
<tr>
<td>01.00000A89.00016F.000169DC0</td>
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</tbody>
</table>

- Header: 8 bits
- EPC Manager: 28 bits
- Object Class: 24 bits
- Serial Number: 36 bits

96 bit = 10^{29} different codes

- Age of Earth is 10^{17} s
- Diameter of universe is 10^{29} cm
- 10^{19} ID’s available per person in this world
- Total capacity of chip manufacturers is 10^{13} tags/year

* Uniqueness by EPC and data behind in EPCIS
Different Frequencies in Use

**LF**
- 125 KHz
- 118 turns
- 2.4 cm

**HF**
- 13.56 MHz
- 7 turns
- 7.5 cm

**UHF**
- 900 MHz
- 14.8 cm

**EPC Gen2 HF**

**EPC Gen2**
IOT Simple passive UID Tag

- **Antenna**
- **RF**
- **DC**
- **Diode**
- **Capacitor**
- **FET**
- **Reader Data**
- **Logic**
- **UID**
- **Memory**
- **Modulation**
- **Simple Passive Tag**

- **1**
- **0**
- **Vdd**
- **Out**
- **User**
UHF Tag Zoo

- Plastic inlay
- Antenna structure
- Strap
- IC (other side)

9 cm
IOT Semi-passive Sensors

DC power

reader data

modulation

antenna

semi-passive tag

logic

\( V_{dd} \)

\( \mu C \) Memory

Sensor

\( 1 \ 0 \ 1 \)
Example of Semi-passive Sensor

- Flexible Temperature & Humidity Logger for Cold Chain
Passive UHF RFID Link Budget:

- Read Tags up to 8m Distance
- Limited by Tag Power Consumption

\[ Pr = \frac{Pt \cdot Gt \cdot Gr \cdot \lambda^2}{(4\pi)^2 \cdot d^2 \cdot L} \]

Gain = 7 dB

Path Loss 49 dB @ 8 m

+ 33 dBm (2 W)

Path Loss 49 dB @ 8 m

- 71 dBm (0.1 nW)

S/N = 35 dB

- 16 dBm received at tag

Receiver Noise: -99 dBm

(\( F = 25 \) dB, \( B = 100 \) kHz)

EPC Class 1 Gen 2

-13…-17 dBm

-22 dBm (6 μW) backscatter signal

Reality: Additionally orientation losses, system losses, fading, \( n > 2 \) ...
Additional noise sources, amplitude phase, TX to RX coupling
Multi-path reflections from metal (reinforced floors/ walls and other objects), cause nulls and peaks that get worse with distance from the antenna.

Power Distribution at 868 MHz


-3 dBm

-14 dBm
RFID EPC Gen2 UHF: Reader

Reader (Lesegerät)

- TX antenna
- RX antenna
- Power amp
- Modulation switch
- Synthesizer
- Direct conversion receiver
- Filter
- Signal processor

Passive Tag (Etikette)

10 mm
120 mm
Modern 4 Watt EPC Gen2 Reader

Software Defined Radio (SDR) Architektur
SDR Architecture: 3 System Parts

**RISC Processor**
- MAC
- Reader Protocol
- Interfaces

**Signal Processing**
- Sample Level on FPGA
- Symbol Level on DSP
- Air Protocol on DSP

**UHF Frontend**
- Direct Conversion Receiver
- Carrier Suppression
- Multi Antenna

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**Embedded Controller (Linux / CE)**
- Flash / RAM
- RISC CPU (XScale)
- Optional WiFi, Firewire, Ethernet, USB, RS232

**Base Band Signal Processing**
- DSP
- FPGA CPLD
- A/D
- D/A

**RF Front End**
- LNA
- PLL
- VCO
- PA
Tag to Reader Com: Sub Carrier Encoding

- ASK or PSK modulation: 5 kbps < data rate < 640 kbps
- Baseband-FM0 for **single** reader per frequency channel → saves bandwidth
- Miller sub carrier encoding for **dense** reader environment → no reader - tag collisions if massive filtering is used
Reader related risks
- Mutual interference among readers:
- Co-channel interference
- Adjacent channel interferences

Multi Carrier and Miller Coding
- Organize frequency plan
- $D = 4 \text{ m}$ adjacent interferer distance
- $D = 9 \text{ m}$ co-channel interferer distance

Carrier Frequencies
- Channel e.g. Nr. 4
- Channel e.g. Nr. 10

Nr. 7 and 13 assumed to be blocked by interferer
Example: Dock Door Application

Metro Germany Logistic Centre

Swiss Post Härkingen

Metro RFID Dock Door Portal

Swiss Post Härkingen
Filtering UHF RFID Reader (Europe)

-240 kHz ± 80
DC
240 kHz ± 80

Tag response
Frequency

Interrogator commanding
Interrogator listening
Tag response
Filter

Up to 4 W
Base band filter must cancel all 4 carriers
Europe:
RF band filter
LP
HP

Interrogator signal
Tag response

Up to 2 W e.r.p.
Up to 10 μW e.r.p.

Channels
865 MHz
888 MHz

RF Front End
Interferer has advantage over victim tag because its signal decreases with $1/d^2$ versus $1/d^4$ of the passive tag.

$$P_{Rx,dBm} = P_{EIRP,dBm} + G_{Rx, dBi} + 20 \cdot \log \left( \frac{\lambda}{4\pi D} \right)$$

**First Filter Spec Assumption:**
Adj. carrier level = weakest tag level

$fp = 320 \text{ kHz}, \quad Ap = 3 \text{ dB}$  
$fs = 600 \text{ kHz}, \quad As = 62 \text{ dB}$

→ 7th order CH

plus HP 2.O. against DC from own carrier

Countermeasure
1st idea: Integrated Active Filter

I-,Q-Filter: N = 6, Butterworth

- unfortunately above 1 MHz
- Attenuation insufficient
- IM3 spectral lines too high, as IM is generated mainly by interferers
Matched pair of programmable filters

- Continuous gain control range: 72 dB
- Digital gain control: 30 dB
- Filter bypass mode bandwidth (BW)
- $-3$ dB small signal bandwidth: 1100 MHz, VGA2 and VGA3 21 dB/12 dB
- 6-pole Butterworth filter: 1 MHz to 63 MHz in 1 MHz steps, 0.5 dB corner frequency
- IMD3: $>65$ dBc for 1.5 V p-p output
I-/Q- Basisband Filter

2nd idea: Active RC failed due to GBP (Qmax =11 @ 320 kHz)

3rd idea:
LC Filter Design selected
- Noise free
- No IM

7. Order LP
3 dB Chebyshev
f_c = 320 kHz
I-/Q- Basisband Filter

Transmission, dB

Carrier CH1
Tag
Carrier CH2

LP Design shows most hardest Spec
Modern Characterization of ADC: Dynamic Range, Spurious

- Speed and power constraints:
  - 14 Bit ADC 5 Msps
  - Fading Margin 10 dB
  - Max input level: -10 dBFS
  - Tag signal dynamic range: 40 dB
  - Nr. of Bits for Min input level: 4 Bit
  - Spurious min 10 dB lower

-10 dBFS

Tag Dynamic Range 40 dB

-50 dBFS

Min SNR 4 Bit

-74 dBFS

-84 dBFS
Integrated dual 14-bit ADC

Single 3 V supply operation (2.7 V to 3.6 V)
SNR = 74 dB (to Nyquist, AD9248-20)
SFDR = 86 dBc (to Nyquist, AD9248-20)
Low power: 90 mW/channel at 20 MSPS

Example: $f_s = 5$ Msps, FFT 16k-point
no averaging
MAMXSS0011 uses FET Switch for mixing

High IIP3: 20 dBm

I/Q - Downconversion

Interrogator commanding
Interrogator listening

Mixes the User Carrier In CHx to DC
Synthesizer for European (868 MHz, 4 channels) and US Regulations (902-928 MHz)

PLL:
Modulus Divider
Phase/Frequency Detector
Charge Pump

TCXO
20 MHz

VCO
850-950 MHz

Clock Buffer

Loop Filter 3. Ordnung
B = 4 kHz
Upcoming: Adaptive Carrier Suppression

- 32 x 32 impedances $\Gamma$
  
  Goal: Adaptively find the impedance to maximize suppression

- Patented under US 8456283, EP2118812
Adaptive Carrier Suppression
Measurement Results

- Results: Suppression of min. 47 dB

only Circulator and Antenna RL = 20 dB

Carrier Suppression approx. 50 dB

30 dB

Tag response