Low Bit rate Ambient FM Backscattering for Low Cost and Low Power Sensing.

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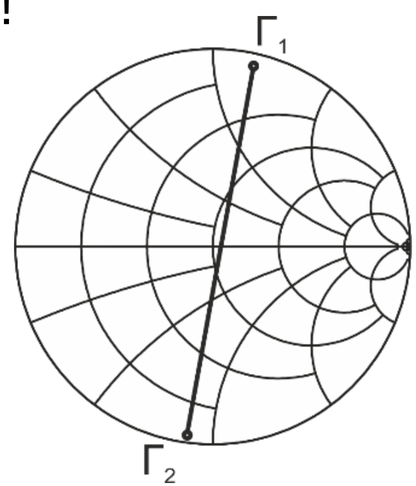
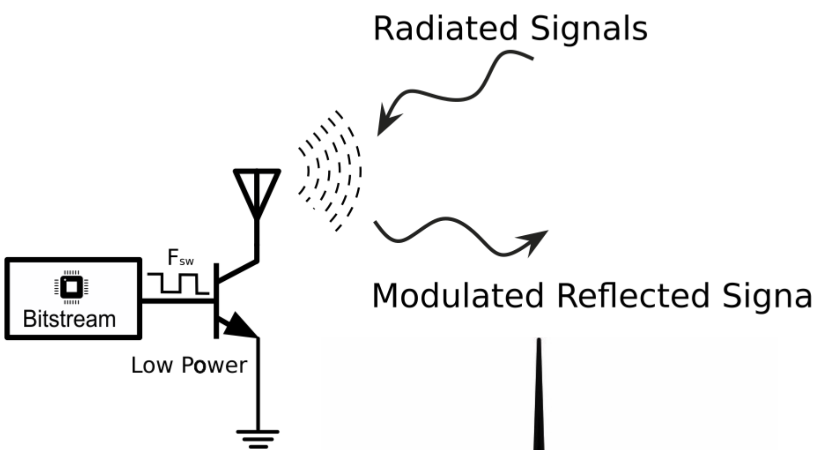
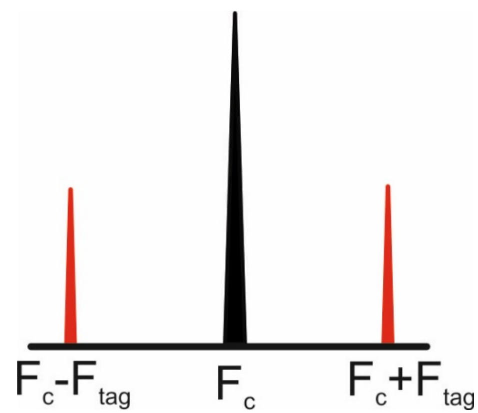
Backscatter Principles (1/2)

- Commercial WSN Radios → Cost and Power Constraints
- Solution: Backscatter Communication->RFIDs
- Single transistor communication
- Antenna load switching @ F_{tag}
- μW Power Consumption!
- Low Cost!

$$\Gamma_i = \frac{Z_i - Z_a^*}{Z_i + Z_a},$$

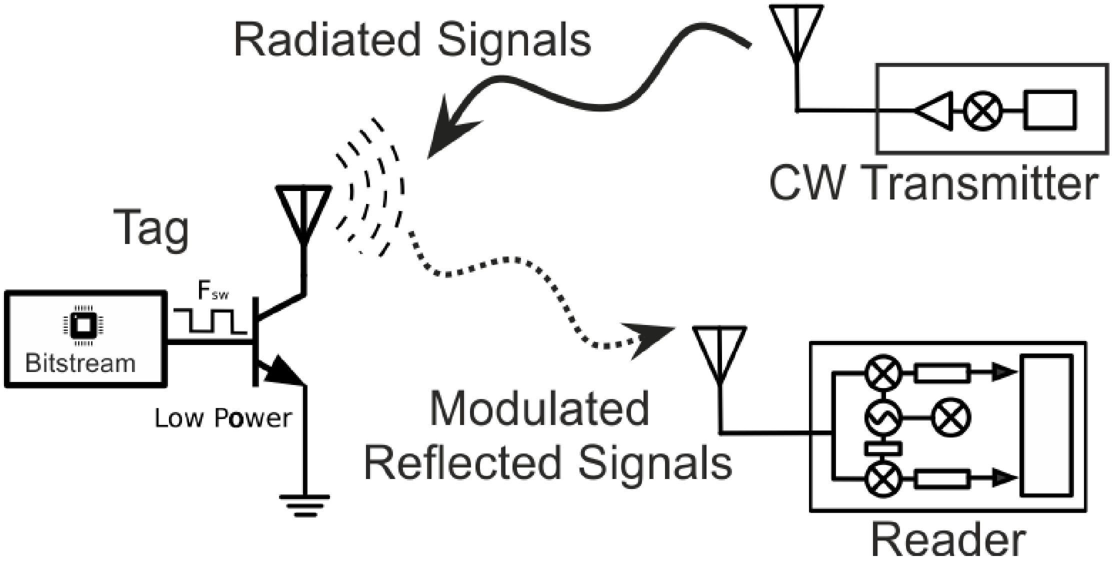






Backscatter Principles (2/2)

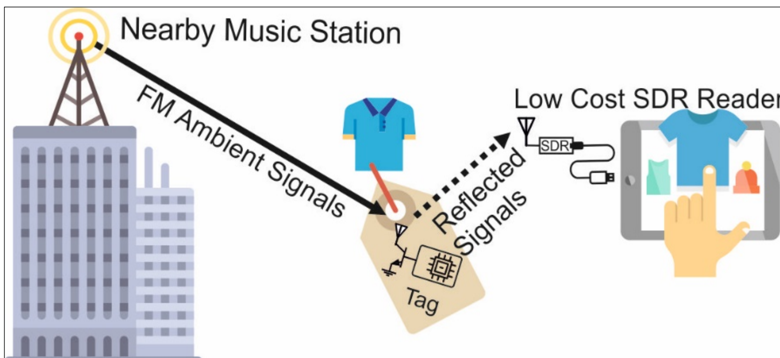
- Bistatic or Monostatic Architecture:
  - CW Transmitter and Reader → Collocated or not
- Emitter:
  - Dedicated CW Transmitter
  - Ambient Signals
- Tag:
  - MCU (control unit)
  - Multiple sensors
  - Simple RF front-end
- Reader:
  - Software defined radio
  - Smartphone

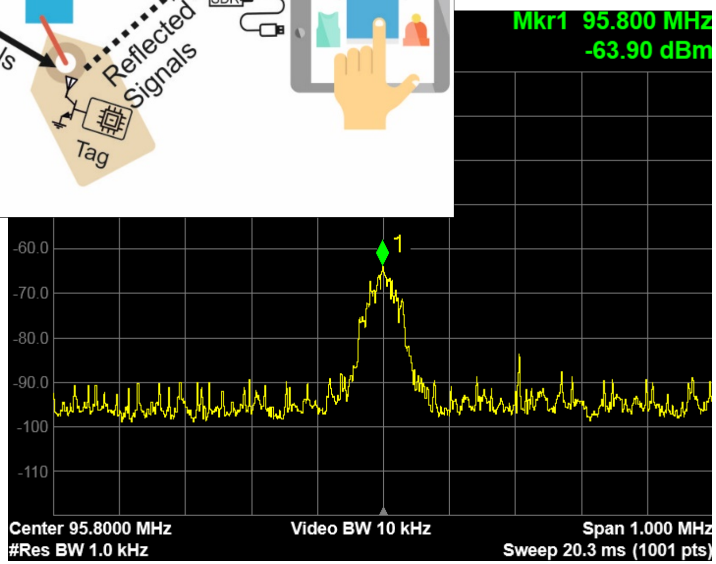


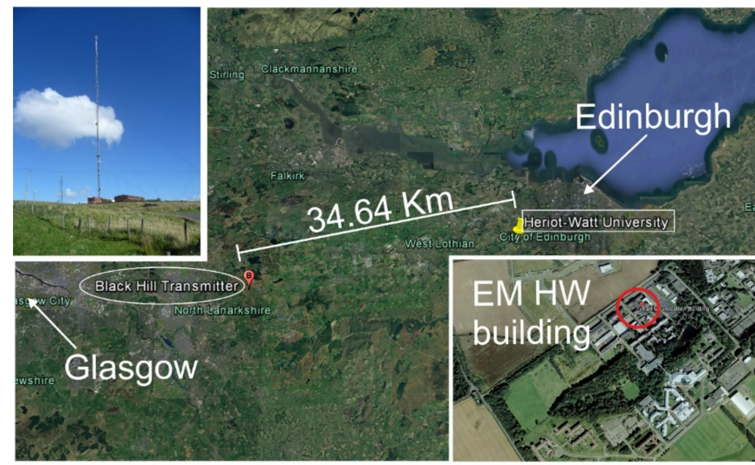
Ambient FM Broadcasting Backscatter

- Communication using reflected ambient music signals.

- Simplified scheme -> Only a receiver and a tag.



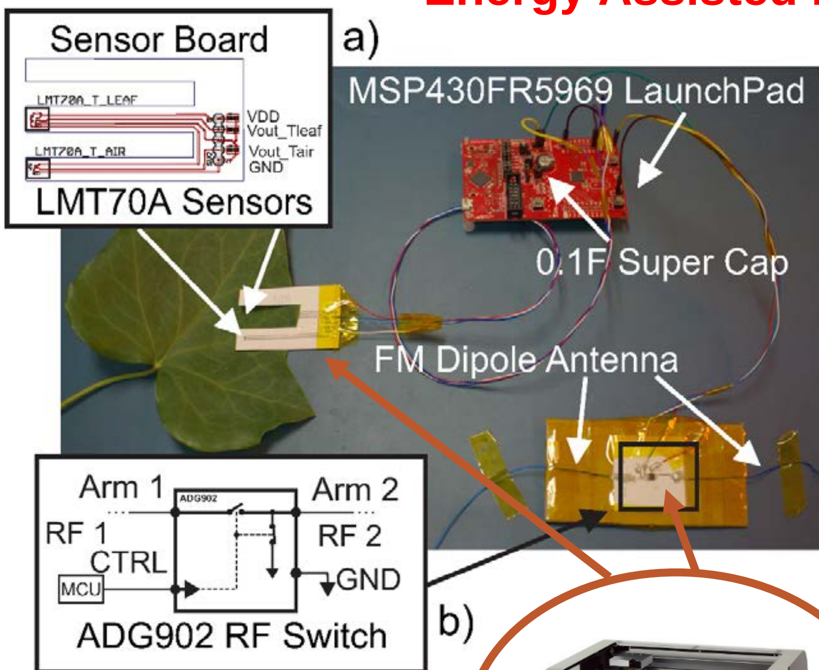


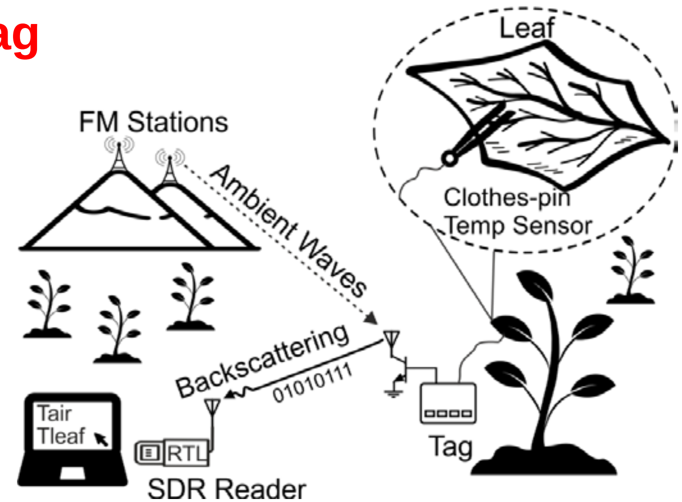


BBC 95.8 MHz
Transmission power: 250 KW
Measured indoor max power: -60 dBm

Ambient Backscatter for Agriculture

Energy Assisted Prototype Tag





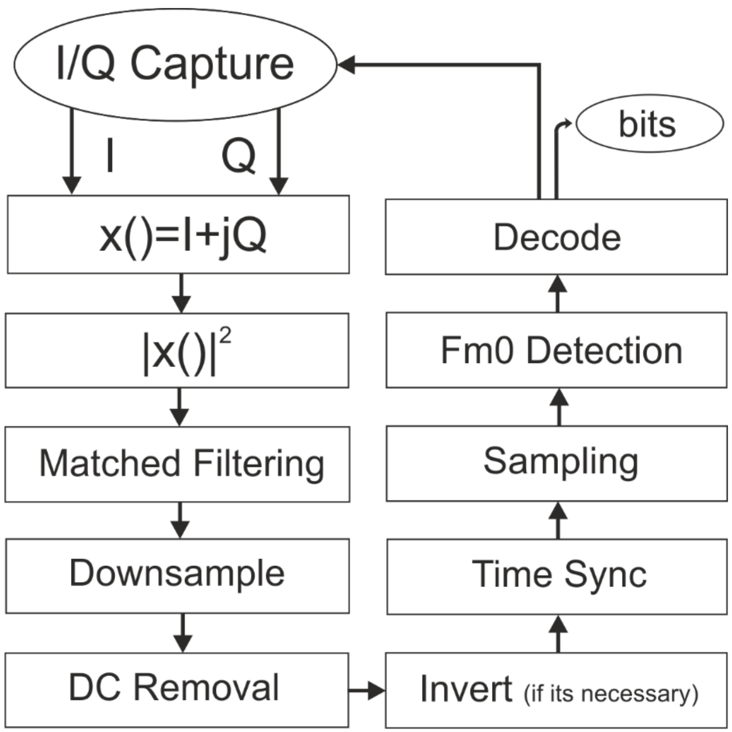
- Use FM broadcasting ambient signals.
- Temperature difference (T_{leaf}-T_{air}), related with the meteorological event of rainfalls

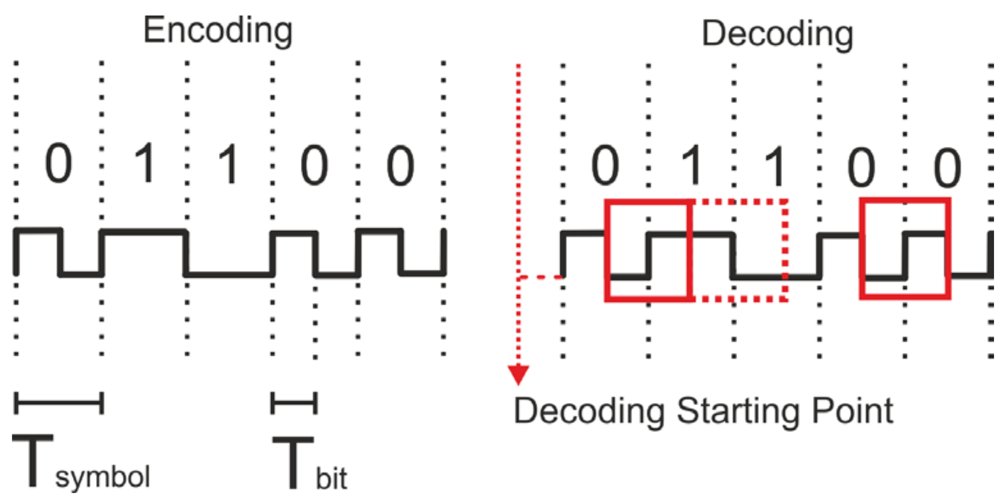
Resolution:
20 µm – 50 µm

Inkjet Printed
Nanoparticle Inks

OOK FM0 Receiver Algorithm

- RTL-GNU radio and MATLAB
- Received baseband signal

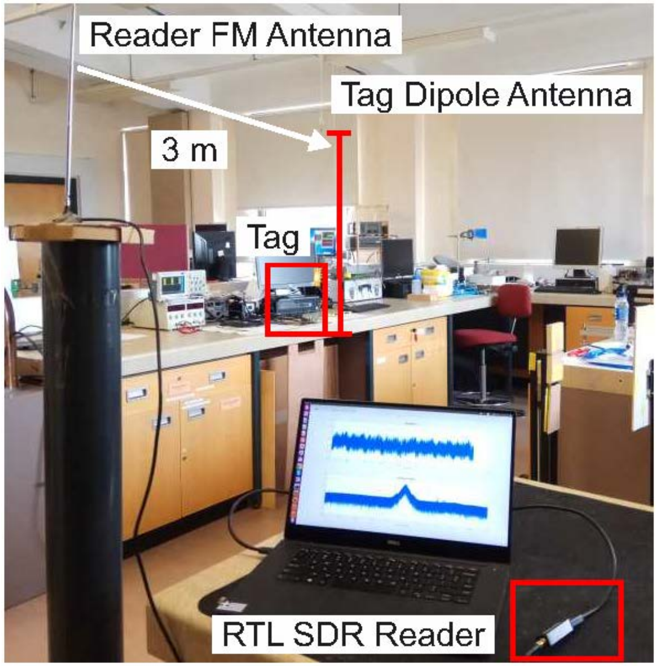


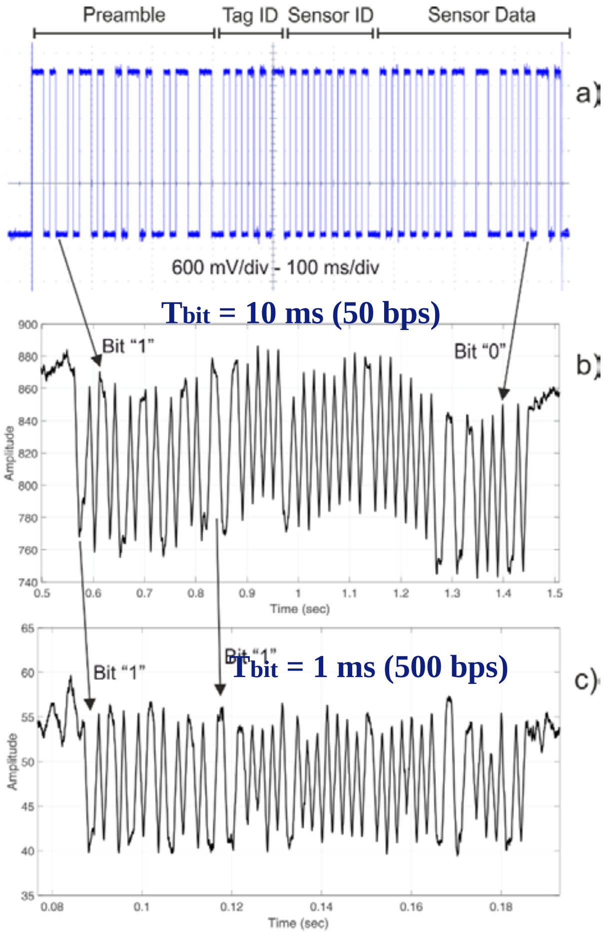


Binary Modulation Tag

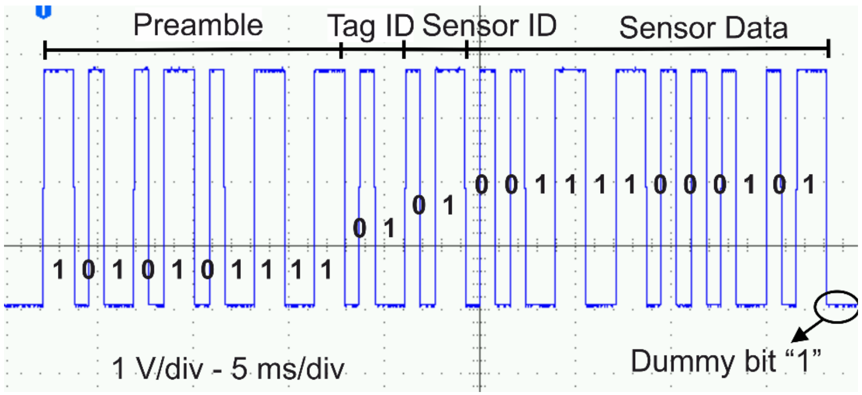
- Indoor implementation of sensing system
- Modulation ASK with FM0 encoding
- Channel fluctuation →

Trade off: Bit rate and Efficient filtering

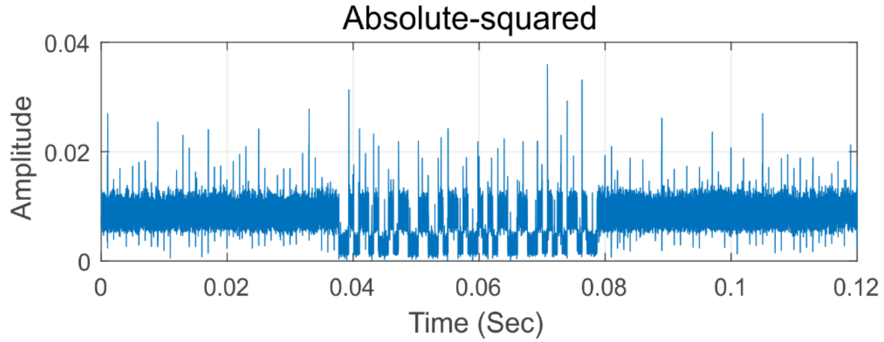


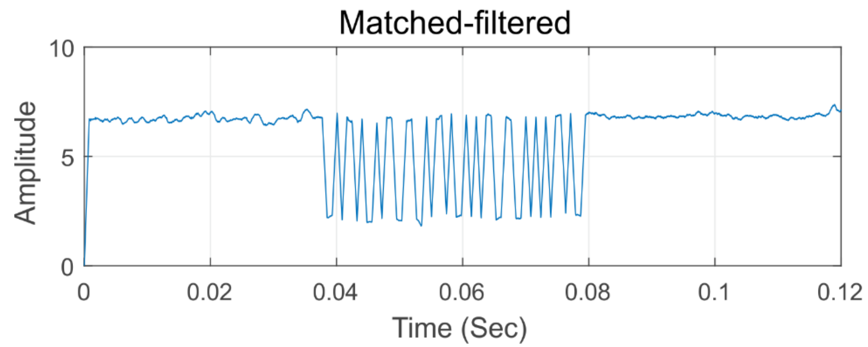


Some Receiver Plots!



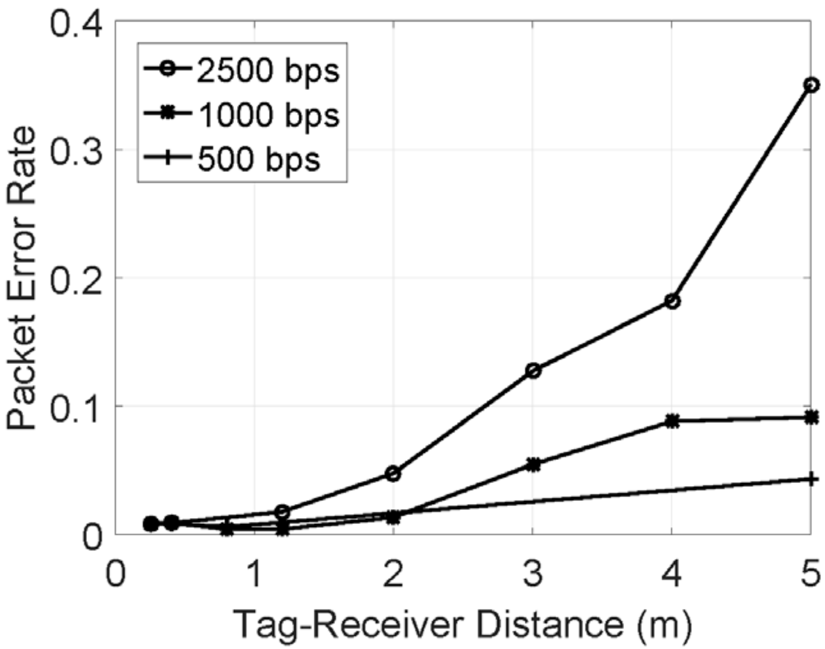
Tag Packet Waves

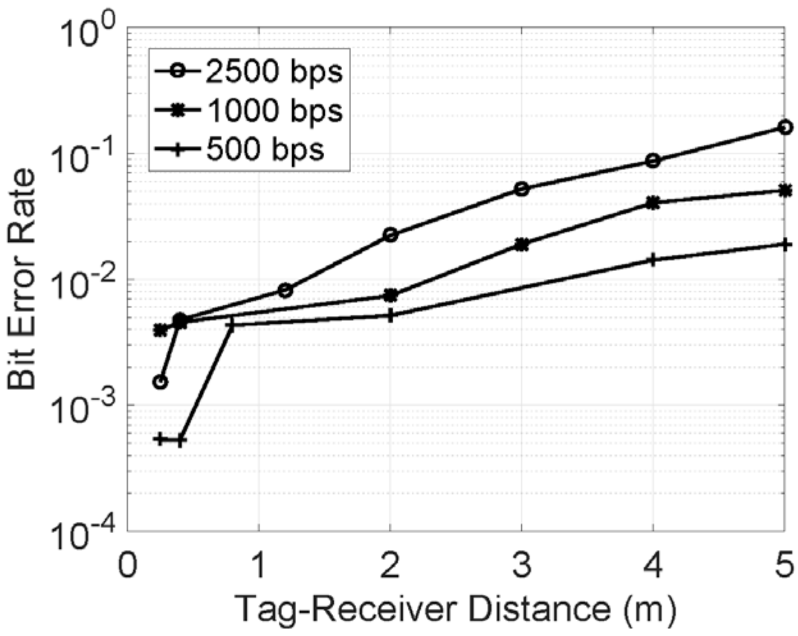




Receiver Packet Waves

Real Indoor Demo Results

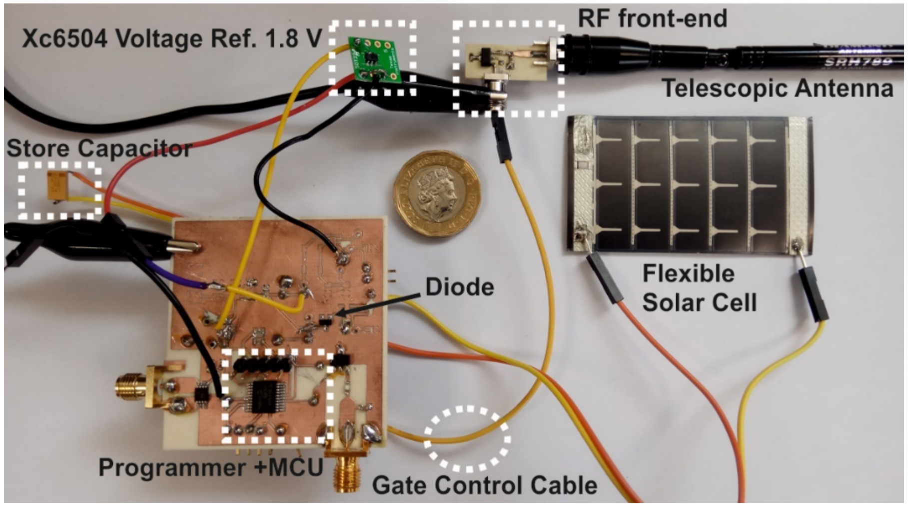


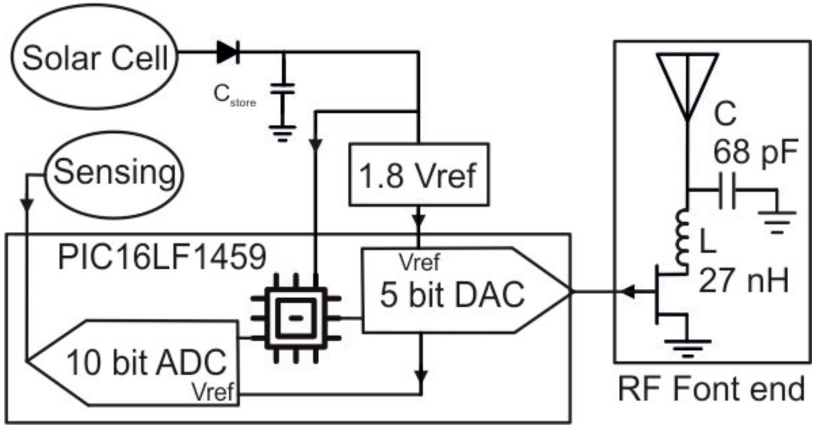


- Edinburgh Heriot-Watt University EMP lab
- GOAL: increase the "tag-reader" distance

Battery-less uW Tag

- 8-bit PIC16LF1459 MCU-> 25uA/MHz @ 1.8 V
  - 32 kHz clock
  - T_{symbol}=5.8 ms
- DAC for RF front-end control
- Solar panel + store capacitor
- ADC for sensing





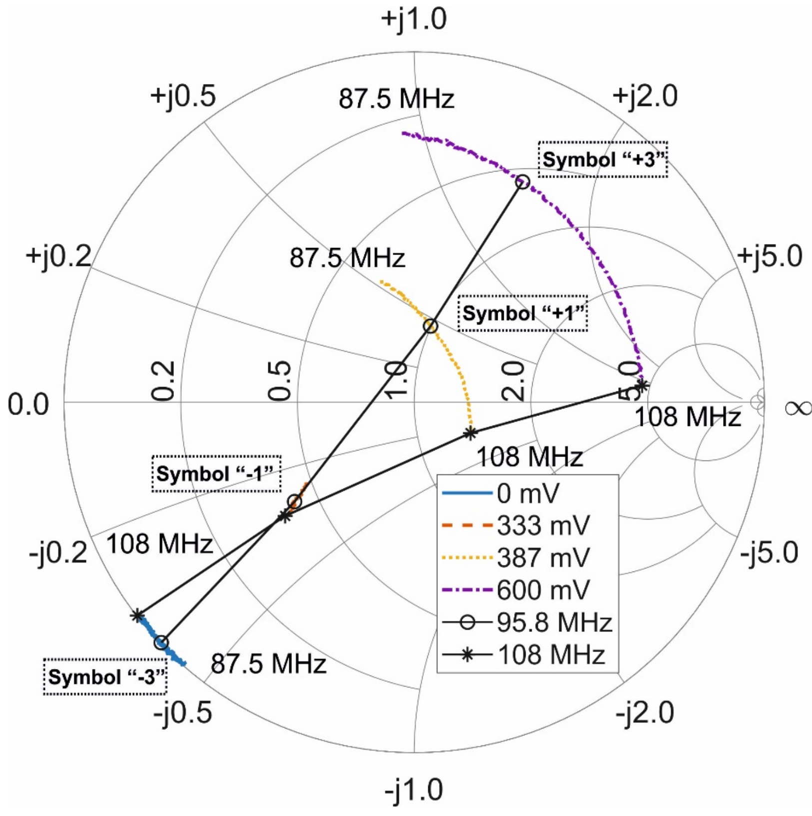
Tag Operation Mode @V_{DD} = 1.8 V	μA	Bit rate (bps)
Sleep: (no DAC, no ADC)	0.6	0
Active: OOK (no DAC, no ADC)	3.6	147
Active: OOK (no DAC, ADC)	220	147
Active: 4PAM (DAC, no ADC)	15	328
Active: 4PAM (DAC, ADC)	240	328

High Order Modulation Tag

- High order modulation on ambient backscatter
- 4 PAM -> 2 Bits/symbol
- Spectrally efficient low power applications
- FM band 87.5 MHz- 108 MHz
- Single transistor

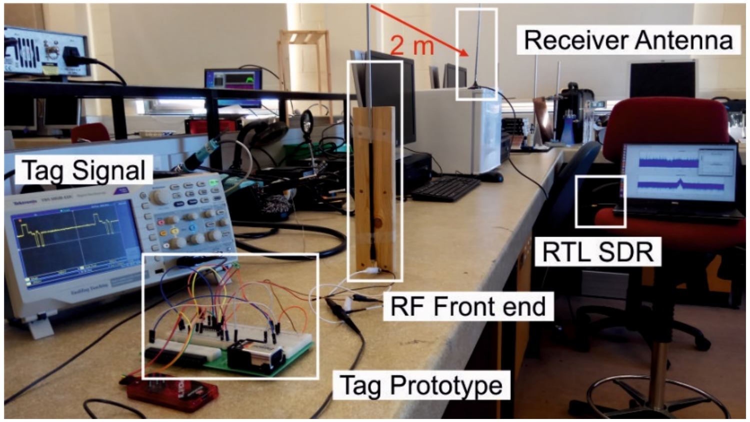
4 PAM MODULATION PARAMETERS

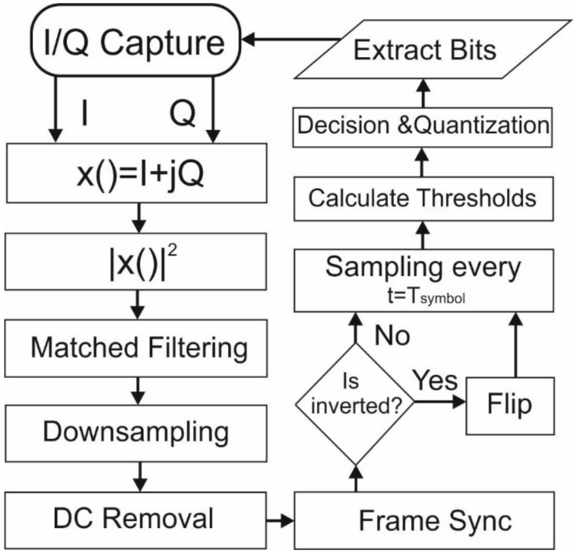
Γ	Symbol	Bits	V_{gate} (mV)
$-0.7245 - j0.6922$	-3	00	0
$-0.3414 - j0.2881$	-1	01	333
$+0.0223 + j0.1779$	$+1$	11	387
$+0.3079 + j0.6334$	$+3$	10	600



4 PAM Receiver

- Low cost RTL SDR (Cost: 18$)
- MATLAB+GNU Radio
- Real Time



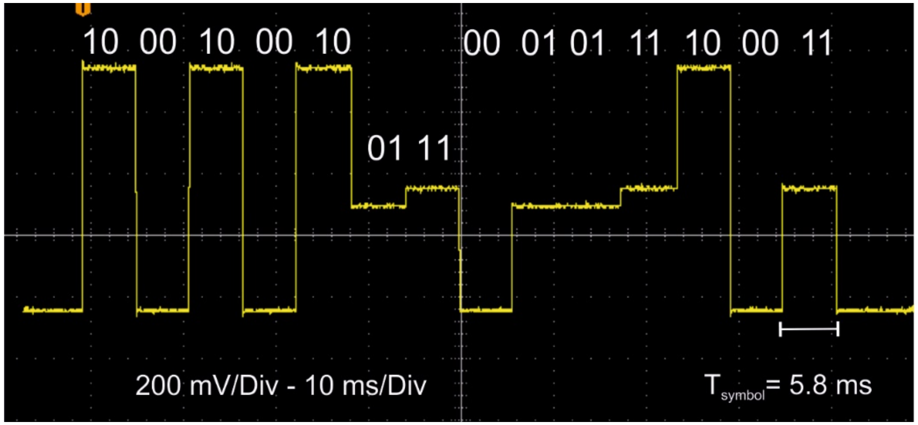


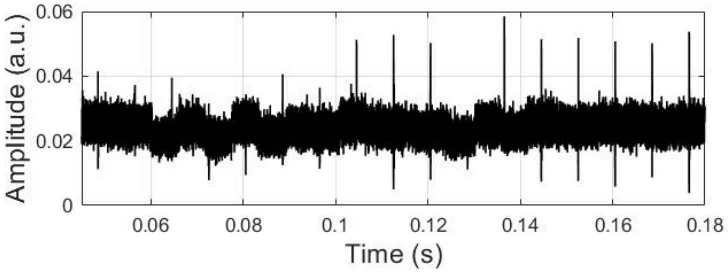
Receiver Algorithm:

- Envelope Detection
- <u>Correlation with square pulse (Duration=T_{symbol})</u>
- Dynamically calculated thresholds
- Quantize a signal to the nearest element of the set [-3, -1, +1, +3]

Receiver Results (1/2)

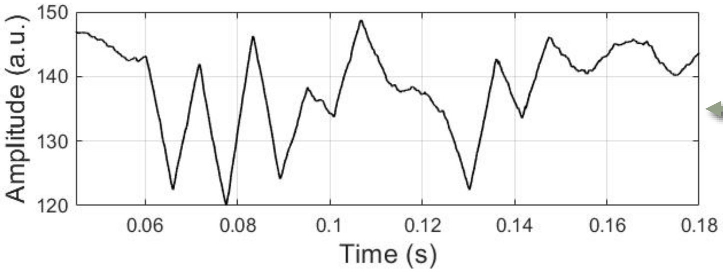
- Tag waveform (MCU):
  - Preamble
  - Training symbols
  - Data





- Packet: [10 00 10 00 10 11 11 00 01 01 11 10 00 11]

  [+3 -3 +3 -3 +3 -1 +1 -3 -1 -1 +1 +3 -3 +1]



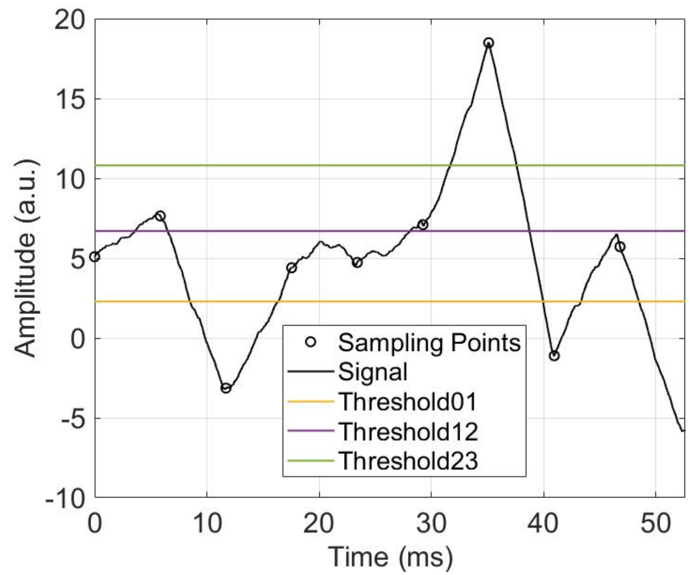
Receiver Packet Waves, Bit rate: 345 bps

Receiver Results (2/3)

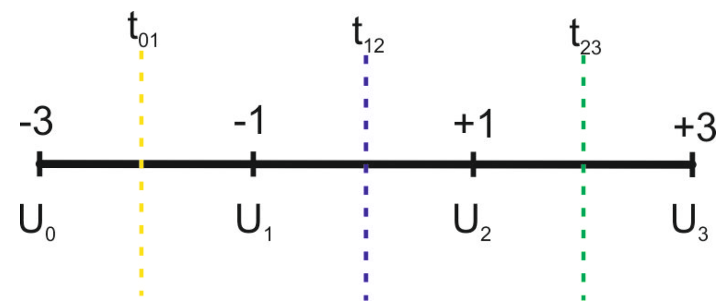
- Calculate three thresholds

from preamble & training symbols

- Packet data: [-1 +1 -3 -1 -1 +1 +3 -3 +1]



$$t_{01} = \frac{\sigma_1^2\mu_0 - \sigma_0^2\mu_1}{\sigma_1^2 - \sigma_0^2} \pm \frac{\sqrt{\sigma_1^2\sigma_0^2\left[(\mu_1 - \mu_0)^2 + (\sigma_1^2 - \sigma_0^2)\ln\frac{\sigma_1^2}{\sigma_0^2}\right]}}{\sigma_1^2 - \sigma_0^2}$$



$$t_{01} = \frac{\sigma_1\mu_0 - \sigma_0\mu_1}{\sigma_1 + \sigma_0} + \frac{\sigma_1(\sigma_1^2 - \sigma_0^2)}{2\sigma_0(\mu_1 - \mu_0)}$$

Summary

- Low cost, low power backscatter sensing system
- Low cost tag/receiver hardware
- Real time indoor demos (Ambient Binary and High Order Modulation)
- 5 meters wireless communication

Future Goals

- High order modulation measurements
- Better RF front end → Increase range
- Improvement of receiver algorithm

Thank you for your attention !

Questions ?

Acknowledgment

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