WFS05: Energy challenges in RFIDs and wireless sensors
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Powering and readout electronics of RFID sensors

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Outline

- Powering UHF RFID
  - Fundamental equations
  - Scaling in distance and frequency
- Sensors
  - Limitatins of passive RFID
  - Different Read-out strategies
  - Calibration
- Examples
  - Capacitive humidity sensor
  - Analog sensor: Ferroelectric varactor

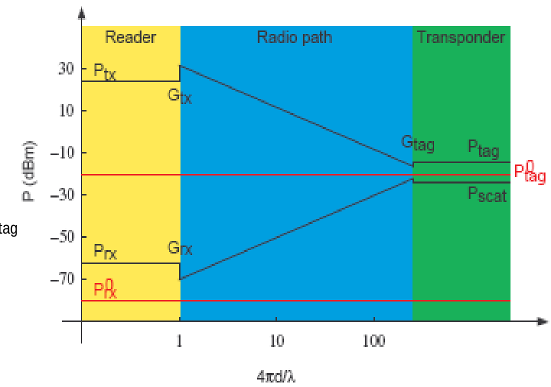
Power Budget

- Two critical power levels
  - Tag IC sensitivity P^0_{tag}
  - Reader sensitivity P^0_{rx}
- Actual range is the shorter of
  - Downlink range $P_{tag} > P^0_{tag}$
  - Uplink range $P^0_{rx} > P^0_{rx}$
- Friis equation

$$P_{tag} = A_e^m \frac{G_{tx} P_{tx}}{4\pi d^2}$$

- Radar equation

$$P_{rx} = \sigma_m \frac{\lambda^2 G_{rx} G_{tx} P_{tx}}{(4\pi)^3 d^4}$$

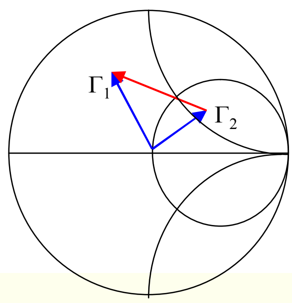


Fundamental Equations

- The load connected (Γ) to the transponder antenna affects both the transferred power and the scattered power.
- The power transferred to the transponder is described by the antenna effective aperture (A_e^m) and Friis equation.
- The scattered power received by the reader is described by the radar cross section (σ_m) and the radar equation.

$$A_e^m = \frac{G_A \lambda^2}{4\pi}\left(1 - \frac{1}{2}\left[|\Gamma_1|^2 + |\Gamma_2|^2\right]\right),$$

$$\sigma_m = \frac{G_A^2 \lambda^2}{16\pi} |\Gamma_1 - \Gamma_2|^2 .$$

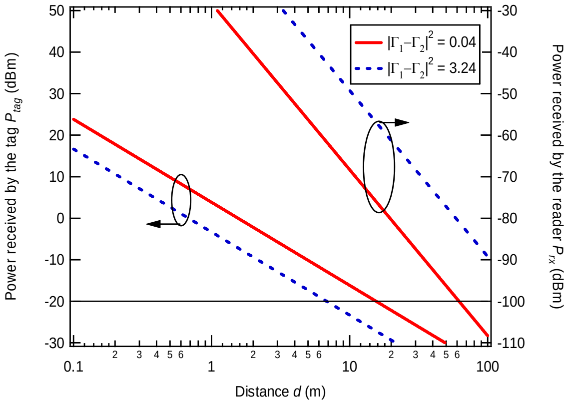


Range of passive UHF RFID

- f = 869 MHz
- $G_{tx}P_{tx}$ = 33 dBm (erp)
- G_{tag} = 0 dBi
- G_{rx} = 8 dBi
- P^0_{tag} = -20 dBm
- P^0_{rx} = -100 dBm

- The lower the P^0_{tag}, the better must P^0_{rx} be.

- What about at higher frequencies?



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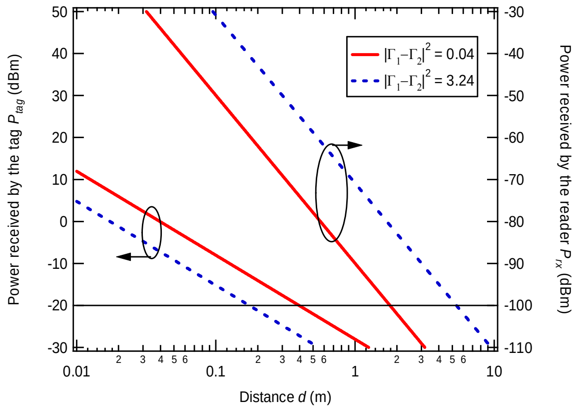
Range of passive Millimeter Wave RFID (MMID)

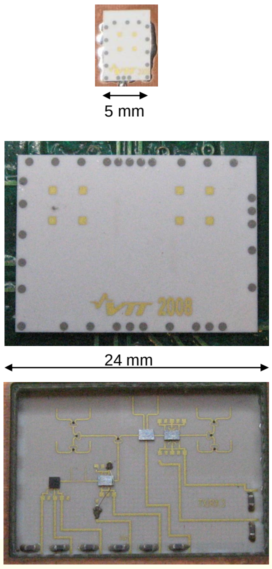
- f = 60 GHz
- $G_{tx}P_{tx}$ = 33 dBm (erp)
- G_{tag} = 0 dBi
- G_{rx} = 20 dBi
- P^0_{tag} = -20 dBm
- P^0_{rx} = -100 dBm

- Range is lower, so why go to higher frequencies?



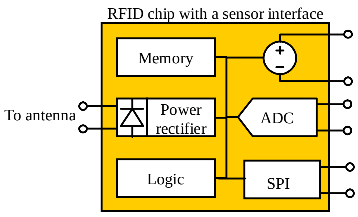
MMID at 60 GHz

- Use of millimeter wave frequencies enables all new features, including
  - miniaturized tags and readers
  - high data rate short range communication
- Demonstrator system at VTT
  - Semipassive tag
  - Reader IF bandwidth over 200 MHz
  - Range up to 15 mm
  - Power consumption 130 mW

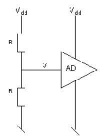
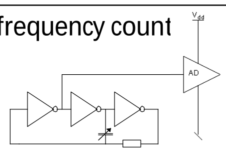
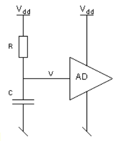


RFID and sensors

- An interface in the tag IC needed
- Commercial chips:
  - SL900A (http://www.ids-microchip.com)
  - PE3001 (http://www.pe-icdesign.de/)
- External interfaces for sensors and µC
- Power is critical: a few hundred 100 µA is available to a range of about a meter
  - Low current means high impedance, which makes the circuitry sensitive to external noise and paracitics
- Readout takes more time than ID query
- Operating voltage may fluctuate because of tag moving relative to reader
  - Rejection towards fluctuations are provided e.g. by a bridge measurement
- Fluctuations also in clock, temperature, paracitics



Comparison of readout strategies

	Resistive sensor	Capacitive sensor
Bridge 	• Provides rejection to fluctuations in V_{dd} • Needs high R	• Needs high f, which consumes power
RC frequency count 	• Slow • Needs a reference oscillator to account for fluctuations in T and V_{dd}	• Slow • Needs a reference oscillator to account for fluctuations in T and V_{dd}
RC loading 	• Provides rejection to fluctuations in V_{dd} • C can be tuned to fit the sensor R	•Provides rejection to fluctuations in V_{dd} • R can be tuned to fit the sensor C

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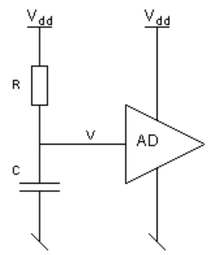
RC loading

- Load a capacitive sensor through a know R for a known time t and measure the voltage.
  - Simple circuitry
  - Provides rejection for fluctuations on operating voltage
  - Stability of clock required
- Sensor usually 10 – 100 pF
- Parasitics in the order of 1-10 pF
  - E.g. human equivalent to about 100 pF to ground
- Calibration *in situ* is important
  - In case of capacitive sensor, measuring reference capasitors $C_{low} < C_{sensor} < C_{high}$ is required.
  - Eliminates paracitics
  - Diminishes clock stability requirements
  - Need for several sensor inputs or an external µC handling the measurement

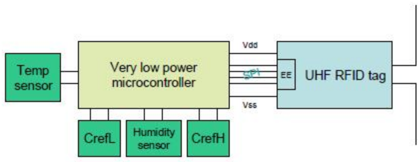


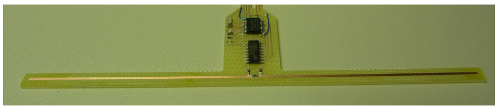
$$V = V_{dd} \frac{t}{RC}$$

UHF RFID temperature and humidity sensor

- External µC controls the measurement of temperature (resistive) and humidity (capasitive)
- Current consumption:
  < 100 µA (Vdd=2V)
  - Writing of tag IC EEPROM limits the range.
- In situ calibration: With 200pF and 400pF reference capacitors, resolution ~ 1pF
- Read range 0.5 meter demonstrated

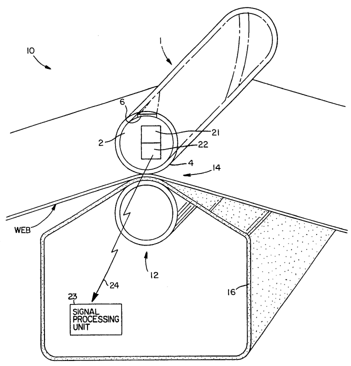
- If functionality is so limited, where to use it?





- Measurements in moving machine parts
  - Several patents on sensors and RFID in e.g. paper machines
- Measurements in long lifetime applications
  - E.g. Moisture in structures, lifetime of a building is decades

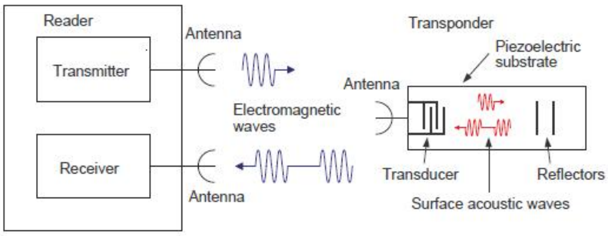
- Can range be extended?



Patent US5592875, Roll having means for determining pressure distribution, 1997

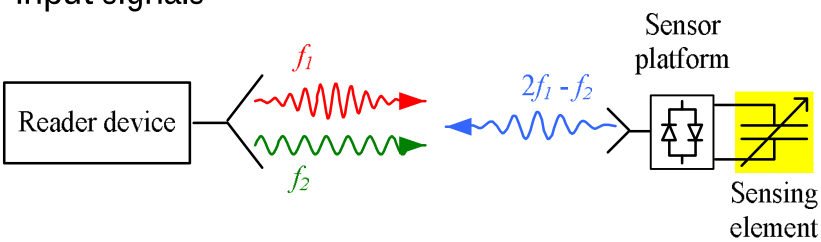
Analog sensor

- AD conversion takes place in the reader, not in the tag
  - E.g. Saw tags and sensors
- Allows longer range with sensors
- Drawbacks
  - Anticollision problematic, no rewritable memory, limited ID space

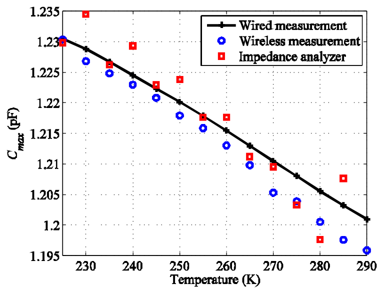


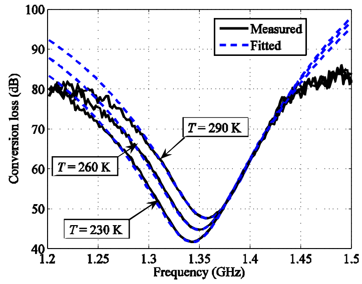
Intermodulation Communication Principle

- Sensor is illuminated at two closely located frequencies
- Sensor replies the sensor data at an intermodulation frequency
- Sensor utilizes electrical or mechanical mixing of the input signals



RFID Ferroelectric Temperature Sensor at VTT





- Ferroelectric varactor used simultaneously as a mixer and a sensor element
- Temperature measured wirelessly at 1.35 GHz
- 8 m read-out distance
- Low-cost manufacturing possible, e.g., using printed electronics

V. Viikari, H. Seppä, T. Mattila, and A. Alastalo, "Wireless ferroelectric resonating sensor," submitted to *IEEE Transactions on Ultrasonics, Ferroelectrics and Frequency Control*, 2009.

Conclusion

- RFID powering
  - UHF is a compromise with range, functionality and size
  - Millimeter waves enable high data transfer at short range
- Passive sensors with UHF RFID
  - Low power means high impedance, and sensitivity to paracitic capacitance.
  - In situ calibration required
- Optimal for long life time applications, with few tags and short range
  - Humidity in structures
  - Measurements in rotating machine parts
- Analog sensors provide longer range, but less functionality