Bridging Indoor RFID Localization and Long-Range Sensing: Exploring Energy-Efficient Backscatter Positioning

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Abstract

The evolution of backscattering communications has significantly advanced RFID-based localization, particularly in scenarios where cost-effectiveness and low power consumption in harsh environments are critical. Originally introduced during World War II with the concept of corner reflectors, backscatter-based localization has since progressed into ubiquitous indoor tracking and Internet of Things (IoT) applications. However, interference, energy harvesting limitations, and communication range constraints limit its full potential. Recent advancements in RFID-based localization have focused on techniques that optimize power allocation, extend range, and mitigate interference. One approach involves integrating sensing and communication (ISAC) systems with RFID, where Zero-Forcing and Convex Optimization minimize interference while enhancing power allocation. However, as tags move closer to user antennas, interference challenges remain. Another key development in backscattering communications has demonstrated long-range RFID localization by decoupling the carrier frequency from the receiver, achieving distances up to 3.4 km at 868 MHz with only 70 µW power consumption. However, this technique introduced unintended interference with nearby communication bands. More recent methods have addressed this issue by employing frequency shift keying (FSK) modulation, significantly extending reader-tag distances. Building upon these insights, we propose an auxiliary approach: integrating energy-harvesting receiving antennas within RFID localization networks, transforming them into self-powered sensor nodes. This approach opens opportunities for radio applications, where distributed low-power RFID beacons could support experimental localization networks. With backscatter localization techniques progressing in extended range, interference mitigation, and energy efficiency, this study explores their potential for passive RF sensing and citizen science applications. By bridging RFID localization and radio science, we investigate their feasibility in long-range sensing scenarios.

Introduction

The concept of Radio Frequency Identification goes that way since the World War-II, implementing the massive corner reflectors to collect the data from ground sources. Moreover, an encryption concept was exploited using the angular rotation with which the receiver can have its own received power.

Triple-turret reflector, in which each turret rotates with a predetermined speed. The result in the receiver is that particular reeds in the frequency meter become excited.

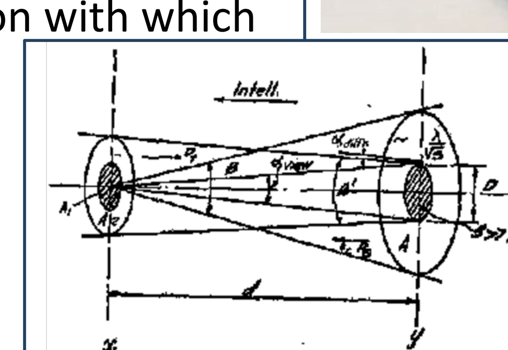


Fig. : The geometry of specular reflection, showing that for equal size antennas the reduction in power during the return path is only in a ratio of 1:4, [1]

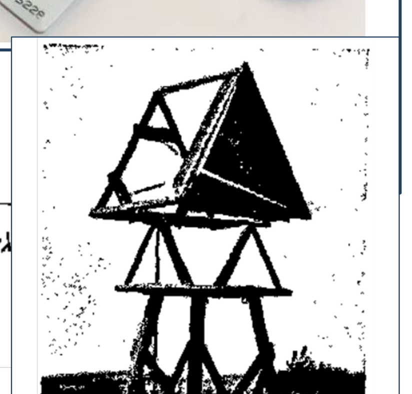
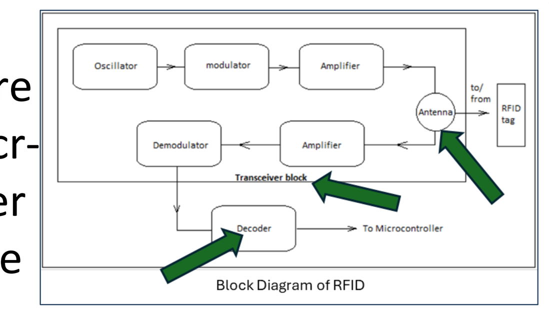


Fig. : In 1948, one of the largest corner reflectors used during the tests with a 2-foot free edge. The sides can be deviated manually or by means of a motor-driven device and readings taken of the response in the receiver

Method/Experiment

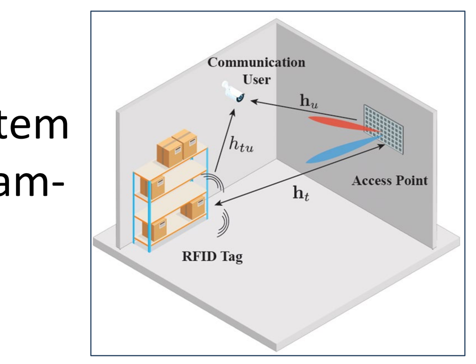
Main concept implies a low power transmitter and a (*corner reflector*) called Tag on which EM waves are harvested to operate the tag circuit and emit an encrypted message to the transmitter. So far, transmitter And receiver are the same unit, having the tag as the corner reflector.

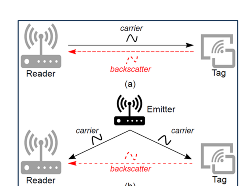


Block Diagram of RFID

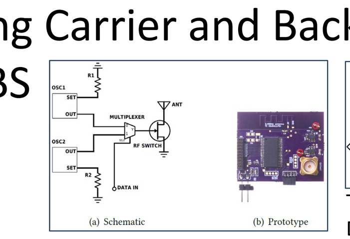
Various improvements have been taken:

1. integrated sensing and communication (ISAC) system with backscattering RFID tags (ZF+CVX(PA)+ Joint Beam-forming design)
2. Separating Carrier and Backscattered Signal
3. FSK to BBS

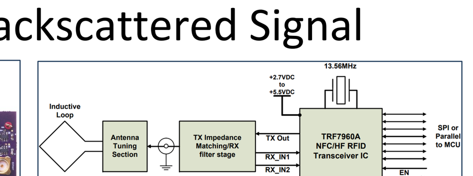




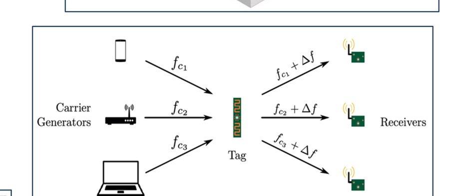
[3]



(a) Schematic (b) Prototype



TX Instruments' RFID Transceiver Reference Design Block Diagram



[2]

Frequency	Mode	Range	Transfer rate
125–135 kHz	Passive	Short range (up to 0.5 m)	Low
13.56 MHz	Passive	Medium range (up to 1.5 m)	Moderate
860–930 MHz	Passive	Medium range (up to 5 m)	Moderate to high
433 MHz	Active	Ultra long (up to 100 m)	High
2.45 GHz	Active	Long range (up to 10 m)	Very high

Data and Analysis

- [2] achieved 3.4 km(868 MHz carrier), 225 m (2.4 GHz carrier), consuming powers 70 µW and 650 µW. carrier-tag = 1m

Cons:

- discrete components
- selected high sensitivity reader/receiver (e.g., -110 dBm)
- high gain antennas at reader and emitter (e.g., 9 dBi)
- comm. dist. 1/d emitter-tag dist. (5~6m) L

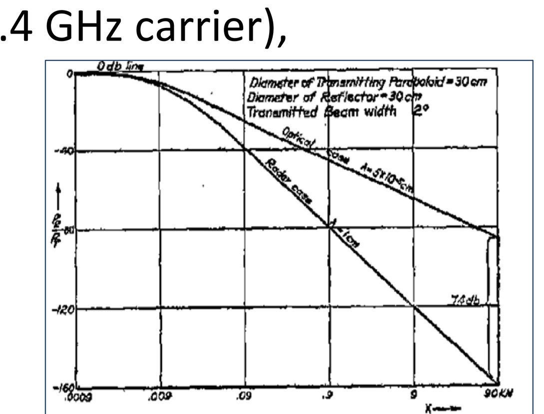
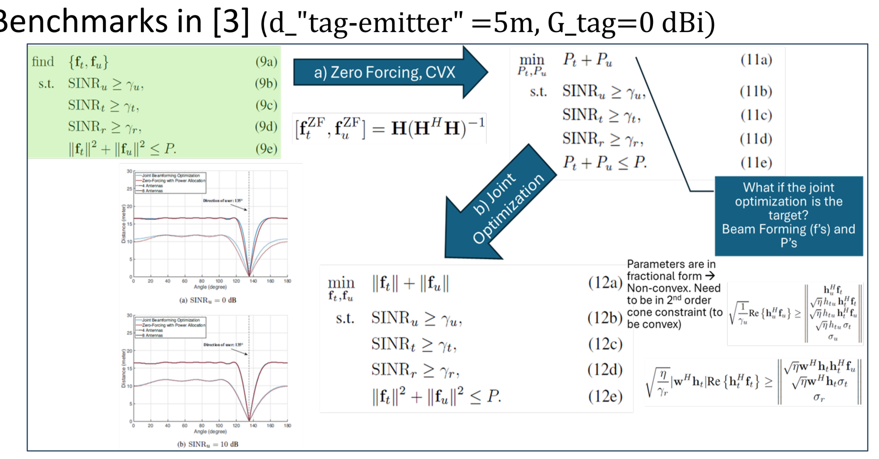
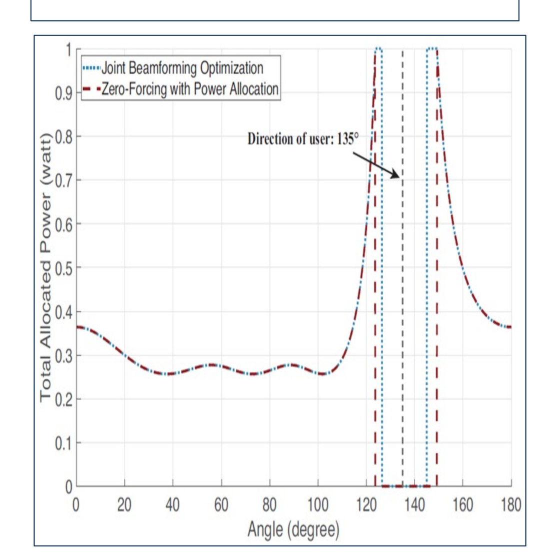


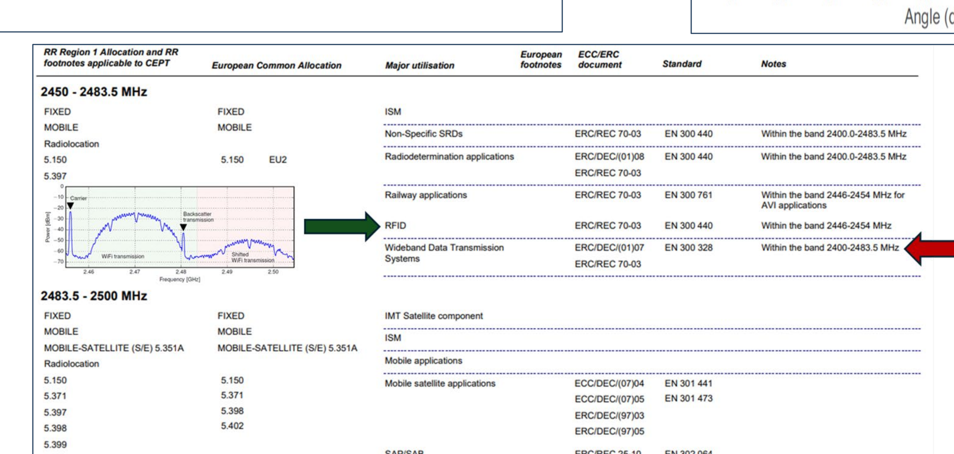
Fig. : Comparisons of light waves with microwaves, comparison of inverse-square-law and inverse-fourth-power law propagation, showing an advantage of 74 dB of the former over the latter at 90 km distance under assumed conditions

For the third solution:

- For the 2.4 GHz: d_"reader-tag" =60m
- For the 868 MHz: d_"reader-tag" =170m
- only 35 µW power consumption.
- Benchmarks in [3] (d_"tag-emitter" =5m, G_tag=0 dBi)







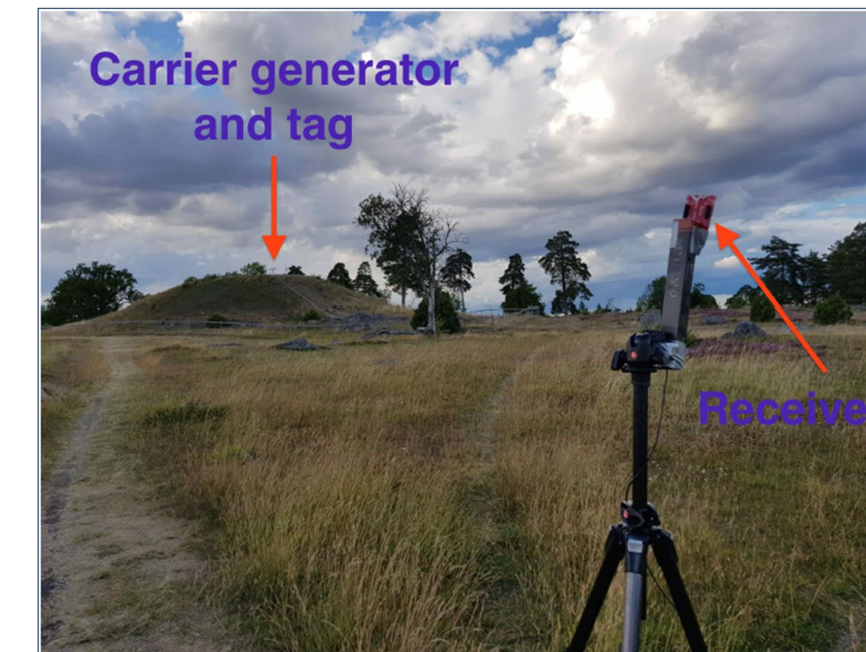


Fig. : 868 MHz architecture, [2]

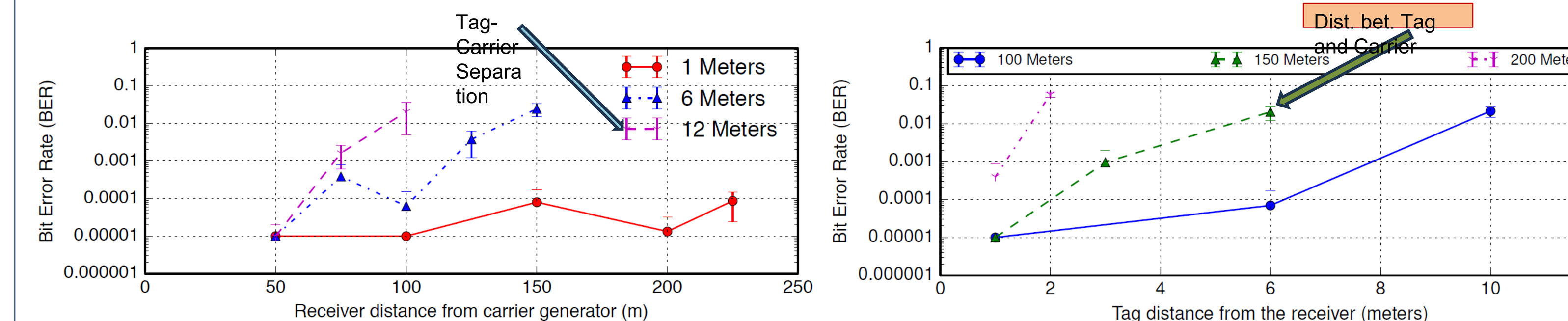


Fig. : 2.4 GHz, d= 12m, range = 100m, BER = 10^-2

Conclusion

The utilization of RFIDs has shown significant contribution in short range localization. However, there is a need to have broader coverage for RFID involvement. Our work suggests the involvement of High Frequency antennas that are able of capturing at least -23 dBm. This is correctly applied giving operating in Very Low Frequency (VLF) or even HF which lands to another band away form the GHz Wi-Fi. Moreover, interference due to unlimited background noise due to the atmospheric variable nature which affects the received HF power.

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