Querying Analog Backscatter Tags

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Abstract

Analog backscatter tags communicate sensor data by directly modulating a carrier signal. Processing and computation of data is offloaded to a remote receiver, enabling simpler tag designs consuming much less power compared to digital backscatter. These tags embed sensor data typically as frequency variations. However, deploying multiple tags causes them to activate simultaneously, leading to overlapping frequencies and harmonics that make it difficult to identify each tag's data. Although using different carrier frequencies is an option, tags are frequency agnostic and reflect any carrier. To address this, we propose integrating a band-pass filter and a capacitor into each tag's front-end as a pluggable module, to limit activation frequencies. This approach allows individual querying of tags without modifying their backscatter modules, achieving a five-fold improvement in frequency selectivity compared to using only a band-pass filter.

CCS Concepts

• Networks → Sensor networks; **• Hardware → Wireless devices**.

Keywords

Analog backscatter, Querying, Multi-tag networks

1 Introduction

Analog backscatter tags are attractive for sensing because they require ultra-low power and are cost-effective. These sensor tags can be envisioned as stickers placed on walls, windows, and even in challenging environments such as underwater or inside the human-body for monitoring various physical parameters such as temperature and humidity [3]. These tags use resistive and capacitive sensors to modulate voltage levels, which are then directly transmitted using analog modulation without the need for power-hungry digital processors. Data processing is offloaded to a remote receiver, enabling simpler tag designs. To avoid interference from the strong carrier signal, analog tags shift their transmissions to a different frequency, where they encode sensor information in the frequency [1–3]. Reading this shifted frequency is enough to retrieve the sensor data value for the receiver.

Backscatter tags exhibit frequency agnostic behavior, meaning they backscatter signals across various frequencies. This creates significant spectral noise especially due to wideband harmonics generated during frequency shifting [2, 3]. Analog backscatter tags are simple and always active when powered, lacking MAC protocols or IDs. Therefore, when multiple analog backscatter tags are deployed, they all backscatter sensor data when a carrier is provided, synchronizing their transmissions, which makes it challenging to query a specific tag and its associated data. Assigning different switching frequencies to each tag is a common solution but is impractical for analog tags for two reasons. The first reason is that the tags generate wideband harmonics which spread for across 50 MHz [1, 2], requiring large frequency separations for the other tags. Secondly, higher switching frequencies increase power consumption, which undermines their low-power design goals [1].

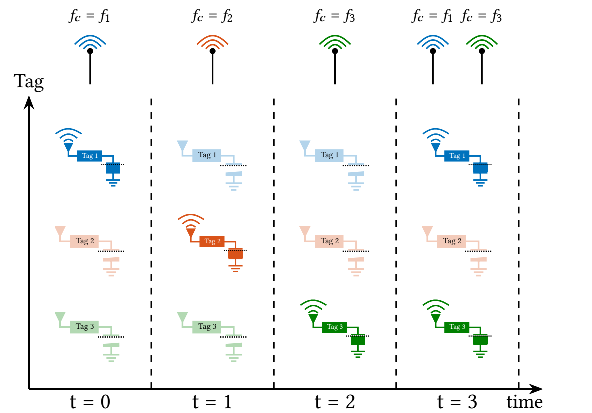

Figure 1: Overview of the analog tag querying system. In a single time slot, the reader transmits a carrier signal (f_c) in a specific frequency (f_1,f_2,f_3). Only tags tuned to the carrier frequency charge their capacitor to the threshold to activate backscattering.

We propose a novel solution enabling individual querying of analog backscatter tags (as in Fig. 1) by enhancing their frequency selectivity. This is achieved by extending the tag's RF front end with a pluggable module comprising a matched band-pass filter and an energy-storing capacitor. Achieving sharp band-pass filtering is impractical due to design complexity and component imperfections. Band-pass filters produce a higher voltage output when the RF source frequency is close to its center frequency. We use this idea to enable a tag to wake up via capacitor charging. Adding a capacitor after the filter enables voltage thresholding to differentiate carrier frequencies, allowing tags with overlapping filter ranges but different center frequencies to operate independently. This approach provides narrowband functionality using wider, easier-to-implement filters.

This approach enables tags to operate within narrow frequency bands, preventing unintentional activation by other frequencies. The system achieves (i) enhanced frequency selectivity with a five-fold improvement over filters alone, (ii) concurrent operation of multiple tags through carrier scheduling or multiple carriers, and (iii) non-intrusive integration without modifying the tag's original backscatter design.

2 System Design and Results

This tag design extends existing backscatter systems like RFBandaid [3]. by adding a pluggable module to the standard backscatter module. The backscatter module reflects data by modulating antenna impedance, while the pluggable module activates the tag only when an RF source at a specific frequency is detected. To activate the tag within narrower frequency ranges, we use a capacitor after the band-pass filter. To trigger the module we use a Schmitt trigger, a comparator with hysteresis, which has two threshold voltages. When the capacitor voltage reaches the upper threshold, the tag turns on and backscatters data; it then turns off as the capacitor discharges to the lower threshold. The Schmitt trigger output is the control signal for the RF switch to enable the tag to stay active for a finite amount of time for backscattering data, preventing rapid toggling.

Figure 2 shows capacitor charge voltages for different carrier frequencies at the same power level. Capacitor charge voltage is highest at the center frequency of the band-pass filter. Setting the threshold at 700 mV restricts the tag's response to carrier frequencies within a 20 MHz range, although the filter width is 100 MHz which otherwise triggers both Tag1 and Tag2. This shows that we can narrow the tag response frequency range by five times. The sharpness of the filter determines the width of the voltage peak. Sharper filters create narrower peaks, allowing for a lower activation threshold. Broader filters require a higher threshold.

By using this mechanism, we can individually query analog backscatter tags shown in Figure 3. This extension is compatible with both analog backscatter systems like RF-Bandaid and digital systems like WISP. The number of tags that can be queried depends on the bandwidth use per tag.

3 Future Work

An exciting direction for future work is the integration of analog backscatter sensing into Massive IoT deployments in 6G networks. One of the key visions of 6G is to support an unprecedented number of IoT devices, far exceeding the capabilities of current networks such as 4G and 5G. Ultra-low-power analog backscatter tags can massively enhance 6G's

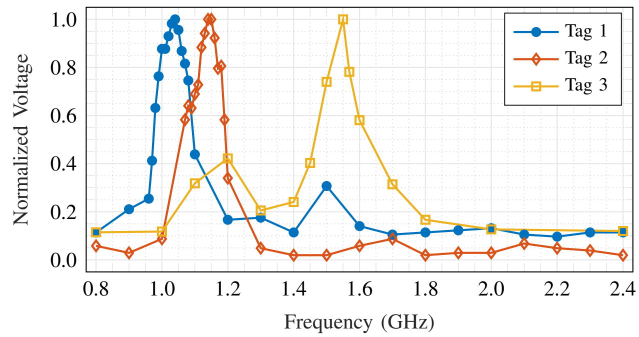

Figure 2: Normalized capacitor charge voltage levels for different carrier frequencies for three tags with three different band-pass filters.

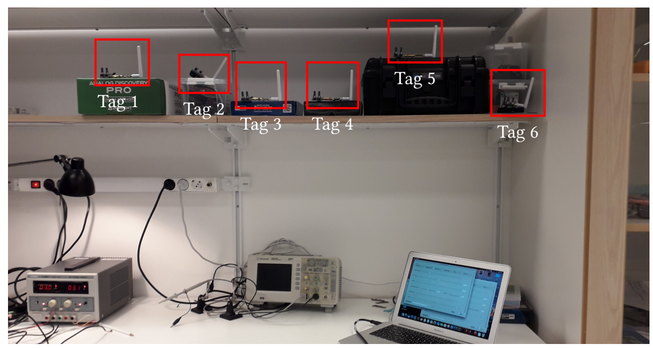

Figure 3: Tag distribution for the experimental setup. Multiple tags are attached to objects on the shelf. Each tag has a proposed plugged module. Tags can be queried in different time-slots or simultaneously without interference from one another.

data collection capabilities by enabling the deployment of a large number of extremely energy-efficient sensors within the network infrastructure. Emerging applications such as digital twins and machine learning model training require vast amounts of real-world data, which analog tags can collect at minimal cost. Moreover, as 6G expands into mmWave frequencies (>24 GHz), the availability of larger bandwidths offers advantages for analog backscatter systems in terms of allocating frequency bandwidths to tags and allow concurrent querying of multiple tags using FDMA.

References

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