Poster Abstract: HarmonicID- Identifying Analog Backscatter Tags with Harmonics

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ABSTRACT

Backscatter tags consume extremely low power and are activated by an external carrier for sensing and communication purposes. Analog backscatter tags achieve further power and cost reductions by moving digitization and computation overhead to a remote receiver. Such cheap tags may enable sensing for everyone. We present a novel fully analog tag identification mechanism inspired by musical instruments. Interestingly, they share the same concept connecting the two fields. Each instrument has a unique harmonic content and therefore the human ear can distinguish different musical instruments. By tuning the tags to reflect a unique harmonic content we enable identification of purely analog tags.

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1 INTRODUCTION

Backscatter communication is attractive as it is an extremely low power communication mechanism. Instead of generating an RF wave for transmitting data, they reflect or absorb the external carrier. Analog backscatter tags, simple in design further reduces the power budget by removing digital components on the tag [1, 4]. However, such analog tags lack methods to identify them when deployed at scale. Adding an identification would require more components on the tag which increases the power budget.

Our key idea is inspired by the way humans distinguish between instruments, using harmonic frequencies. When different instruments play the same musical note which has the same fundamental frequency, the different harmonics (overtones) form unique tonal characteristics. This is the reason why we can clearly identify their distinct sources such as a guitar or a piano [2]. We propose using this principle with analog backscatter tags where the data would be the 'music note' and the ID is the 'instrument'.

A common approach is to shift the frequency of the backscattered signal away from the carrier signal [3]. When performing this shift, multiple harmonics of the shifted frequency are also generated. By varying the duty cycle we assign specific harmonic content to a tag to identify them. We show that we can generate harmonics using purely analog components with zero overhead and demonstrate that we can identify the tags even when they are blocked by walls.

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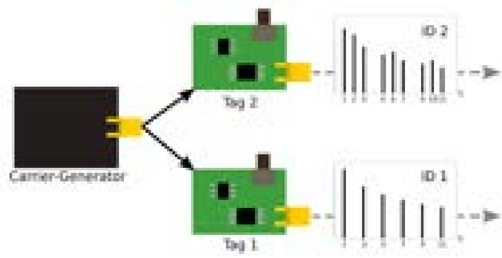

Figure 1: The carrier-generator provides an unmodulated carrier for the tags to backscatter the data as a frequency response. Tag 1 and Tag 2 have unique harmonic patterns. We identify Tag 1 when every second harmonic is below the noise floor and Tag 2, when every 4th harmonic is below the noise floor.

2 DESIGN

Backscatter tags have a switch that toggles between two impedance states of the antenna to reflect or absorb an external carrier signal. One can avoid the self-interfering unmodulated carrier signal at the receiver by shifting the backscatter signal. Consider an external unmodulated carrier signal of frequency f_c and a sinusoidal signal of frequency Δf. We can represent frequency-shifted backscatter as $2\sin(f_c t)\sin(\Delta f t) = \cos(f_c - \Delta f)t - \cos(f_c + \Delta f)t$. The frequency Δf can be approximated as the fundamental frequency of a square wave acting as the backscatter switching signal.

We assign a different duty cycle to each tag to form a unique harmonic sequence that we call the harmonic pattern. Duty cycles from 0% to 50% have unique harmonic patterns which are repeated for duty cycles higher than 50%. Hence we only assign duty cycles up to 50%. The uniqueness of this pattern makes it act as the tag ID.

Let the maximum number of harmonics for a given harmonic pattern be n. The basic pattern consists of all n harmonics having a non-zero power level. By changing the duty cycle in such a way that the ith and integer multiples of the ith harmonic power level for $i = 2..n$ are zero, we can form another $n - 1$ harmonic patterns.

The receiver detects peaks and deduces which tag the data is coming from by matching the peaks against the preassigned harmonic patterns. For more tags, we can assign more chunks of fundamental frequency bands to tags to use the bandwidth efficiently. This implies that a tag ID is a function of the fundamental frequency band, duty cycle and the number of harmonics.

Our tag design is fully analog, similar to analog tag designs such as RF Bandaid [4]. We use LTC6992, a COTS oscillator IC from Linear Tech., to map sensor data to frequency with a preassigned

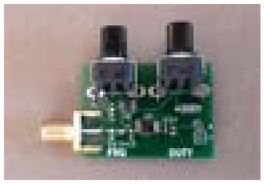

Figure 2: Fully analog tag design. The tag utilises a PWM generator to drive the RF switch. A voltage level between 0 V to 1 V sets the duty cycle of the PWM signal.

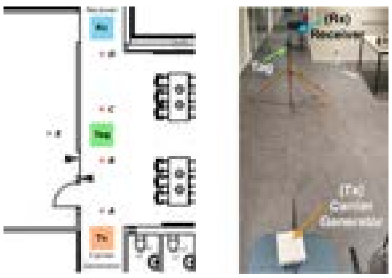

Figure 3: Indoor experimental setup. Two USRP devices act as carrier generator (Tx) and receiver (Rx). Positions A-E are reference points in the experiments.

duty cycle that determines its harmonic content. The output of the IC is a PWM waveform with frequency f_{out} derived from Eq. (1) that varies from 10 kHz to 1 MHz based on the resistance $\mathrm{R_{SET}}$.

$$f_{out} = \frac{1\ \mathrm{MHz}}{\mathrm{N_{DIV}}} \cdot \frac{50\ \mathrm{k}}{\mathrm{R_{SET}}}, \mathrm{N_{DIV}} = 1 \quad (1)$$

The tag directly maps the sensor output to a frequency to backscatter. Figure 2 shows our tag. We provide a minimum regulated 2.25 V for the ICs to operate. The total power consumption of the tag is 261 μW to 506 μW. As Δf increases the power consumption increases.

3 EVALUATION

We conduct a set of indoor experiments to measure the range where external interference and multipath are present. Figure 3 shows our experimental setup. We refer to the carrier generator as Tx and the receiver as Rx which are USRP B210 SDR devices. The carrier generator constantly transmits an unmodulated carrier at 868 MHz.

3.1 Impact of Receiver Distance on Harmonics

The range of analog backscatter systems is limited. As the higher harmonics are weaker than the lower harmonics, increasing the range would affect the harmonic pattern.

We choose a 50% duty cycle. At this duty cycle only odd harmonics appear and their power scales as $1/n^2$. For this experiment, we set the Tx power level to a baseline of 0 dBm. The Tx-to-tag distance is fixed at 1 m and we move the receiver away until only the first fundamental can be detected. We consider a harmonic as detectable if the SNR value is above 10 dB. At this value the receiver can clearly detect the peaks above the noise floor. The results in Figure 4 show that the number of visible harmonics decreases when distance to Rx increases. In order to detect more harmonics at higher distances, one can increase the carrier (Tx) power.

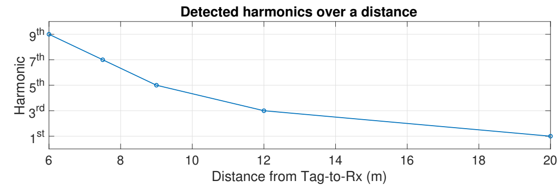

Figure 4: The highest harmonic peak that can be detected as the receiver (Rx) is moved away from the tag while Tx-to-tag distance is set to 1 m. As expected, the lower harmonics with higher power are detected from a longer distance.

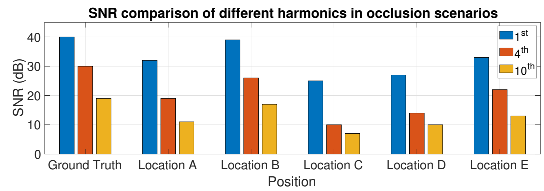

Figure 5: Occlusion Scenarios. The weakest signal occurs when the person is at position C, blocking the tag-to-Rx link. For all other scenarios including the through-wall, the SNR is above 10 dB for the 10th harmonic.

3.2 Non Line-of-sight

For real world applications, the line-of-sight from Tx-to-tag or tag-to-Rx may be blocked. We evaluate such occlusion scenarios and compare the impact of people, furniture and walls.

In the first experiment the line-of-sight is blocked by a person. The person is standing at locations A, B, C, and D between the carrier generator and the receiver as indicated in Figure 3. The results in Figure 5 show that the weakest signal occurs when the person is near the tag, at position C, blocking the tag-to-Rx link. For all other positions, the SNR is above 10 dB for the 10th harmonic.

In the second experiment the line-of-sight is blocked by furniture. Based on the worst case scenario from the previous experiment, we place the furniture in this experiment around the tag blocking both the tag-to-Rx and tag-to-Tx links at 50 cm distances from the tag. The experiment shows that even with such an occlusion, the harmonics have an SNR similar to that of the line-of-sight scenario.

In the third experiment we place the tag in a different room adjacent to the direct line-of-sight to Tx and Rx, blocked by a wall to represent a through-wall scenario. Position E in Figure 3 shows the tag's location. We place the tag at a distance at 5 m both from the Tx and Rx. Figure 5 shows that the SNR is above the 10 dB threshold for all harmonics.

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