RFID-based Backscattering for Wearable mIoT Sensors: A Feasibility Study Using a 5.8 GHz Cross-Polarized Patch Antenna

Raymond Jia, *Student Member, IEEE*, Tyler Lizzo, Annie Luo,
Charles Lynch, *Student Member*, *IEEE*, Manos M. Tentzeris, *Fellow*, *IEEE*
School of Electrical and Computer Engineering
Georgia Institute of Technology, Atlanta, GA, USA

***Abstract* — Developments in the medical Internet of Things (mIoT) field have led to an increase in the need for wearable sensors with small energy and physical footprints. In this paper, RFID backscatter communication is introduced as an alternative wireless communication technique to existing WiFi and Bluetooth systems. RFID backscatter communication is known for its extreme low power consumption and small physical footprint, potentially ideal for long-term wearables. The feasibility of transmitting data via backscatter communication is investigated through analysis of data bit-error rates at varying transmission rates and distances while power consumption is compared to known consumption values of WiFi and Bluetooth to verify the energy advantage of the system.**

***Keywords* — medical Internet of Things (mIoT), wearable sensors, RFID, backscatter communication, cross-polarized patch antenna**

I. Introduction

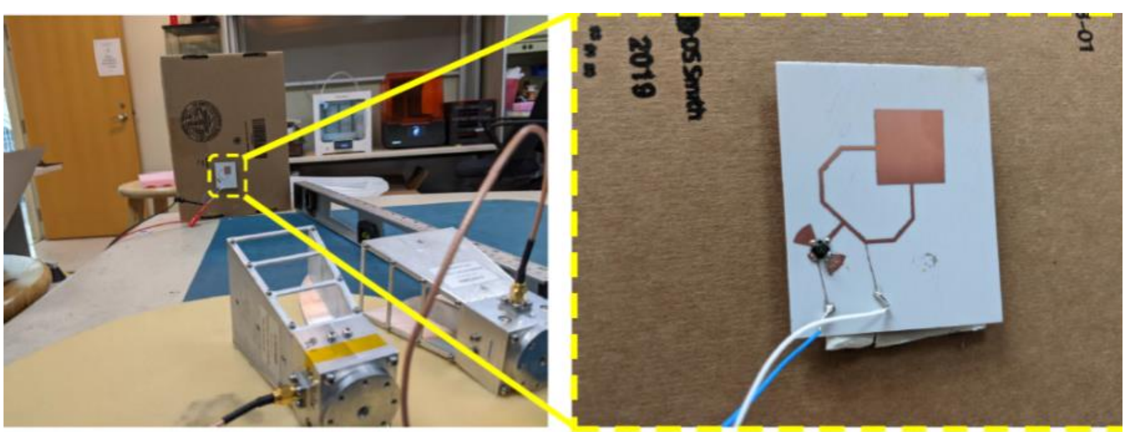
Chronic illnesses are the leading drivers of death and disease as well as the leading drivers of healthcare costs in the United States. Patients suffering from chronic illnesses often require frequent hospital trips for physiological exams to monitor their condition, trips that could easily be avoided with the development of medical grade wearable sensors for consumers. Research in the mIoT field serves to realize this vision, developing increasingly small and multi-functional wearable medical sensor prototypes for transmitting collected data to the Cloud. Unfortunately, existing prototypes of wearable sensors are bulky and power inefficient due to usage of existing wireless communication methods such as Bluetooth and WiFi, discouraging potential users from wearing them day and night, thereby preventing effective data collection.

Multiple alternative wireless communication methods to WiFi and Bluetooth exist, among which RFID backscatter communication is a particularly promising technique. Widely used in ID cards and tracking tags, backscatter technology communicates by modulating and reflecting waves from an external transmitter to an external receiver, thereby barely consuming any power on its own. A comparison of the low power capabilities of RFID backscatter communication technology with existing WiFi and Bluetooth setups reveals that the power consumption of backscatter systems is up to three orders of magnitude less than traditional setups [1]. Furthermore, backscatter solutions are also at least one order of magnitude cheaper to implement than conventional radios due to lack of requirements for analog RF components [2]. However, these features come with a tradeoff: backscatter communication suffers from environmental interference and relies heavily on the efficacy of the antenna system. Because backscatter relies on reflected signals, two-way path loss occurs across the roundtrip of the signal [1], increasing the probability of losing data due to noise, receiver limitations, and increased distances. The human body also attenuates RF signals, in particular muscles and intestines have high attenuation for RF signal strength [3], decreasing the return strength of backscatter signals even more if used for wearable applications.

Given the discussed advantages and limitations of backscatter communication, this paper seeks to verify the low power capabilities of backscatter communication and examine limitations of backscatter with respect to transmission rates and distances.

II. Experimental Setup

The patch antenna used to perform backscatter communication can be seen in Fig. 1(b) and is a 5.8 GHz cross-polarized RFID tag with a CE3520K3 low noise FET load modulator, designed on a Rogers 4003C substrate with a thickness of 0.508 mm and a relative permittivity of 3.55. The cross-polarized design was chosen due to its ability to reduce the self-interference of the signal, increasing the sensitivity of reading the tag. The chosen frequency of 5.8 GHz was selected due to recent developments by the FCC opening more bandwidth in the 5.8 GHz band, creating the potential for a dense implementation of multiple tag and sensor combinations for on-body applications. The interrogating end can be seen in Fig. 1(a), consisting of two cross-polarized horn antennas controlled by a Software Defined Radio (SDR), placed a measured distance away from the target 5.8 GHz RFID tag. The patch antenna is connected to a TI MSP 430 microcontroller generating a random bitstream to simulate sampled temperature data. The simulated random bitstream is output as a Pulse-Width Modulation (PWM) waveform to the RFID tag with frequencies of 9 kHz and 16 kHz selected to represent ‘0’ and ‘1’ bits respectively and 19 kHz as a signal preceding the data stream to indicate transmission. The resulting waveform is frequency shift keyed in the transmissions reflected back to the transmitter. Varying symbol rates (duration to transmit one bit) and distances are evaluated, and power consumption is measured through the MSP 430 microcontroller.



(a) (b)

Fig. 1: Hardware setup for experimental design. (a) Interrogating antennas. (b) 5.8 GHz cross-polarized RFID tag.

III. Experimental Results

When measuring the current of the MSP 430 to determine power consumption, it was immediately apparent that there were two main current values: current of the device in resting state and current of the device in data transmission state. The recorded values of the currents are displayed in Table 1. The equation used to calculate power consumption is as follows:

$$P = V_S \left[I_T \left(\frac{t_{message}}{t_{total}} \right) + I_R \left(\frac{t_{resting}}{t_{total}} \right) \right]$$

TABLE I. MSP 430 MEASURED CURRENT VALUES

Current Type	Current Value (mA)
Transmitting	1.32
Resting	1.12

where, P is the average power consumption, V_S is the supply voltage, I_T is the transmitting current, I_R is the resting current, $t_{message}$ is the duration of data transmission in time, $t_{resting}$ is the duration of between data transmissions in time, and t_{total} is the sum of $t_{message}$ and $t_{resting}$ or the data sampling period. For all samples taken, $t_{resting}$ was a constant 1 second while $t_{message}$ was variably adjusted in the variable transmission rate experiment. As $t_{message}$ is the only variable in the equation, increasing $t_{message}$ relative to $t_{resting}$ by increasing the symbol rate also increases the overall power consumption as the transmitting current is greater than the resting current in Table 1. By setting either $t_{message}$ or $t_{resting}$ to zero, the power consumption range of the sensor package can be calculated, giving a range of 5.6 mW to 6.6 mW.

To evaluate Bit-Error Rate (BER) of the system, the sensor package transmitted a random bitstream of 250 messages at 16 bits per message. BER was calculated as follows:

$$BER = \frac{N_{Err}}{N_{Bits}}$$

where, N_{Err} is the number of bits with erroneous value and N_{Bits} is the total number of bits received. The BER of varying transmission rates is displayed in Fig. 2(a) and the BER of varying distances is displayed in Fig. 2(b). Both graphs use a semi log scale for BER, and in the varying transmission rates graph, symbol rates beyond 75 ms are not displayed due to the recorded BERs being zero.

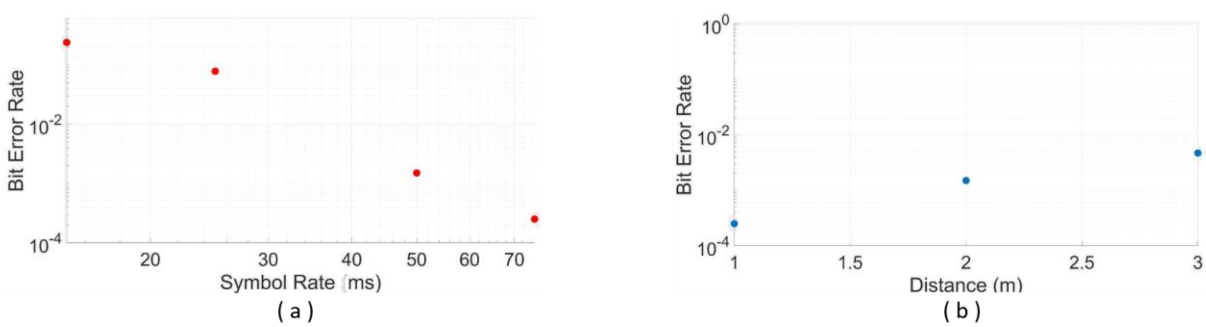


Fig. 2: System BER graphed on semi-log scale. (a) Varying symbol rates at a constant 2.0 m distance. (b) Varying distances at a constant 50 ms symbol rate.

IV. Results Analysis

When analyzing power consumption, it is noted that Bluetooth generally consumes on the order of 10 to 100 mW while WiFi consumes over 100 mW [2], both greater than the calculated consumption range of 5.6 mW to 6.6 mw for backscatter transmissions in this experiment. However, RFID backscatter generally consumes power in the range of 1 to 10 µW [2], three orders of magnitude less than the measured power consumption. It is likely that most of the power consumption comes from other operations constantly performed by the microcontroller. If the backscatter communication only consumes µW levels of power, any microcontroller operation will be orders of magnitude greater.

In terms of BER, an acceptable maximum BER for wireless communication is 10^{-3} [4]. When varying symbol rates at a constant distance of 2.0 m, only symbol rates greater than 50 ms were able to reach the requirement, with BER decreasing as symbol rates increased. Decreasing BER is expected with increasing symbol rates due to prolonged transmission of each bit giving the receiver a greater chance to accurately identify the indicated bit. When varying distances at a constant symbol rate of 50 ms, only distances less than 2.0 m were able to reach the required maximum BER of 10^{-3}, with BER increasing as distance increased. Increasing BER is expected with increasing distances due to increased two-way path loss causing greater noise and disruption of transmission clarity. The effective BER can be further decreased by several orders of magnitude using error-correcting code (ECC), however ECCs will contribute to slower transmission rates as well as more complex operations on both ends of the transmission.

V. Conclusion

In this paper, RFID backscatter communication was implemented as a communication system for a wireless sensor package. The RFID backscatter system utilized a 5.8 GHz cross polarized antenna connected to a sensor package managed by a low power MSP 430 microcontroller. Measurements of power consumption verified the efficiency of backscatter communication in comparison to conventional WiFi and Bluetooth benchmarks. BER measurements indicated symbol rates of 50 ms or greater at distances of 2.0 m or less were best suited for the system. The measured capabilities of the current system are sufficient for a passive wearable sensor collecting data frequently throughout the day, and physical improvements could be made to further reduce power consumption and increase transmission clarity at longer ranges.

References

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