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Low Power Secure Backscatter Communication Techniques Exploring Ambient Signals

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***Abstract*—In this article, we present the proof of concept of techniques exploring ambient signals for low power and secure backscatter communications. This real-time system operates by scavenging a crowded electromagnetic spectrum and recycling active incoming signals for secure quasi-passive wireless communications. This is achieved through a low power and efficient spectrum sensing approach to identify prominent communication channels and using this energy and spectrum, to backscatter a superimposed frequency shifted signal for secure communication, utilizing a semi-passive adaptive modulation approach. No new spectral energy is added to the system in this approach, demonstrating a net zero spectral crowding or a quasi-passive opportunistic communication.**

Keywords — Backscatter communication, spectrum sensing, chirp spread spectrum (CSS)

I. INTRODUCTION

Backscatter communications, dating back to the era of the Second World War, is utilized for several applications including navigation, communication, espionage, and so forth [1], [2]. One could achieve backscatter communication by controlled reflection of electromagnetic energy impinging on an engineered object. This could be as simple as reflection or not (or ON - OFF keying) in the time domain in correlation to a binary information to be transmitted, to more dense techniques like controlling the magnitude, phase, or frequency of backscattered ambient signals, which result in different modulation schemes as per the desired information capacity and channel availability [3], [4].

The present-day RFID techniques are a genius extension of this concept [5]. RFID systems are deployed pervasively at present in extensive domains from commercial labelling, sensing, assembly lines, tamper protection and security applications and similar. RFID technique is a simple yet versatile technique that could be easily adapted to real time communication with the integration of some data actuators that could be a sensor, or transducer like a microphone or a camera [6], [7]. However, a drawback of RFID system is the requirement of a dedicated interrogator and a dedicated spectrum, compliant with the legal emission regulations, and operating power.

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An alternative approach to conventional RFID approach is to rely on ambient signals, that are often always present in the modern environment including TV, Wi-Fi, radio communication including FM stations and cellular phones, and similar [8]–[10]. In this approach the communication system operates in a bistatic mode, in which the source of the signal includes channels that already occupy the communication spectrum, and the backscatter node could be as simple as an antenna connected to certain pre-determined loads (like open, short, and matched loads). Such that each time a different load is selected to backscatter the incoming ambient signals in correlation to the data to be transmitted, the backscatter modulation is achieved, as depicted in Fig. 1.

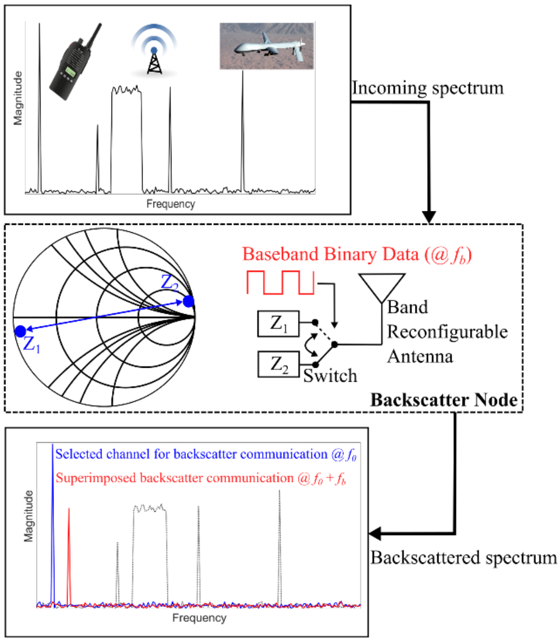

Fig. 1. Concept of backscatter modulation of ambient signals.

Such a transmission has various advantages as follows, which includes the simplicity achieved by not requiring a dedicated RF source, no energy addition to the existing RF spectrum, security aspects from the quasi-passive nature, and so on. The reader system for such a communication could be realized in most cases by minor alterations to the receivers used for the intended reception of ambient signals, like a smart phone receiving FM or Bluetooth signals[11], or a low-cost software defined radio (SDR) as a dedicated receiver. The security provided by such a communication is through the anonymity and range limit of such a data stream, since, often, it is very difficult to diagnose that such a communication is happening among the intended ambient signal brightness, unless one has an a-priori knowledge of its existence.

In this paper, we demonstrate the proof of concept of a secure and adaptive opportunistic backscatter communication system, using simple hardware, exploring ambient RF energy spectrum.

II. Proposed Technique

The block diagram of the proposed system is given in Fig. 2. Here the system scans the incoming spectrum using a tuned rectenna, interfaced to a microcontroller in real time, to identify the strongest channel of the ambient spectrum. Once a channel is identified, a backscatter communication is initiated at this frequency, by activating a narrow band reconfigurable antenna connected to a set of loads, controlled using digital baseband waveform, as explained above in Fig. 1. This way, limiting the bandwidth of the reconfigurable antenna, we make sure that there is no unwanted backscatter spill into unwanted frequency bands apart from the two side bands around the strongest incoming channel frequency.

Detailed explanation of each block of this system and the choice of hardware is given in the following paragraphs.

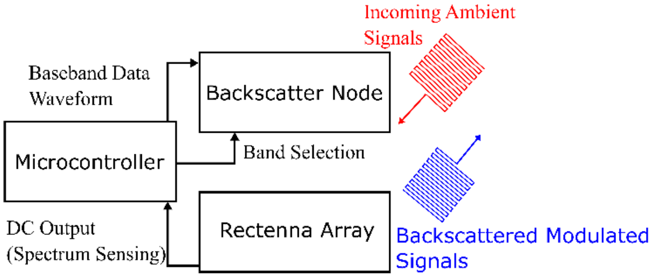

Fig. 2. Block diagram of backscatter modulation system used in this study.

A. Spectrum Sensing

Here a matched rectenna array with each rectenna being tuned to different bands covering a certain frequency spectrum is employed for spectrum sensing. The rectenna unit used in this technique is wired around a standard inset fed microstrip patch antenna [12], for a 50 Ω feed termination, connected to a SMS7630-079LF Schottky diode rectifier through a T match network composed of three inductors and two transmission line segments, as shown in Fig. 3.

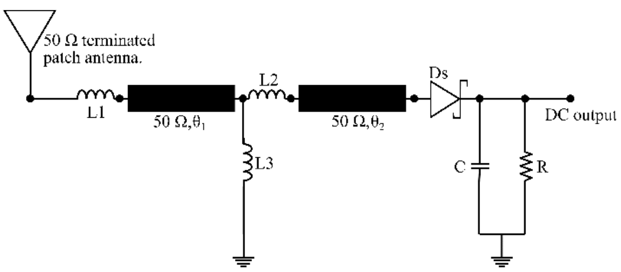

Fig. 3. Schematic of rectenna used in this study.

There are four rectennas in this array, tuned respectively to 1.8 GHz, 2.45 GHz, 2.7 GHz, and 3.5 GHz. The photograph of the fabricated rectenna array is given in Fig. 4. The circuit parameters for each of these antennas, optimized for an input power level of –10 dBm at the receiving antenna terminal is given in Table 1, with respect to Fig. 2. The DC output versus frequency of this rectenna array when excited using a broad band Vivaldi antenna with an average mid band gain of 7dBi and placed 20 centi-meters away from the array in boresight, for an input power of 19 dBm is depicted in Fig. 5.

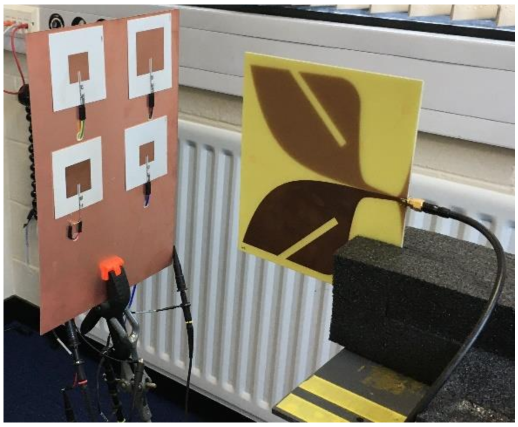

Fig. 4. Photograph of rectenna array used for spectrum sensing applications.

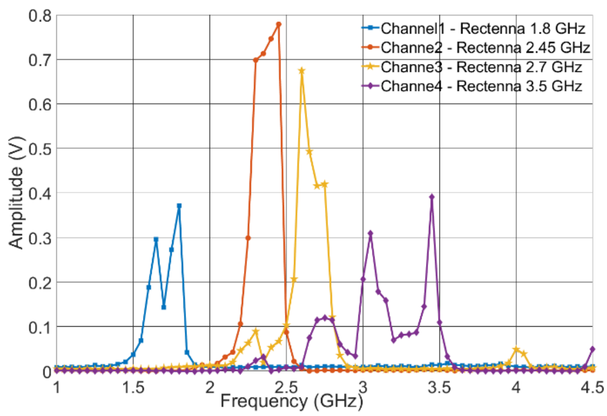

Fig. 5. Regulated DC output versus frequency for four rectenna elements in the array given in Fig. 4.

The DC output of the rectennas is fed to an ADC based comparator configured using Cypress PSoC4200 family microcontroller. This microcontroller is also employed as the logic controller of the backscatter system. It generates two signals, one for controlling the reconfigurable backscatter antenna and one for controlling the switch for backscatter modulation. As one could see from the Fig. 5, that the output levels of the rectenna array are not equal for different frequency bands. Hence, a linear scaling is performed in algorithm to normalize the received power levels and to make an un-biased decision on the strongest channel among the incoming peaks.

Table 1. Circuit parameters for the rectenna array used in this study, with reference to Fig. 3 and Fig. 4.

Parameter (right) Rectenna name (downward)	L1	L2	L3	θ_1	θ_2
1.8 GHz	12 nH	9 nH	4.1 nH	14.39°	10.79°
2.45 GHz	7.8 nH	3.9 nH	2.2 nH	19.58°	14.69°
2.7 GHz	3.1 nH	2.4 nH	1 nH	24.02°	18.02°
3.5 GHz	3 nH	2 nH	2.5 nH	27.94°	20.95°
Common parameters: C = 33 pF, R = 10 kΩ, Ds = SMS7630-079LF Schottky diode.					

B. *Backscatter Communication Node*

The concept of the backscatter node used in this study is depicted in Fig. 1. This is a simple arrangement in which two loads are connected to an antenna through an electronically controlled single-pole-double-throw (SPDT) switch such that the incoming signals received at the antenna port are reflected at two different phases with a significant separation in the Smith chart domain [8]. This way the depicted circuit acts as a frequency mixer that upconverts the binary data stream controlling the SPDT switch to the incoming frequency. In other words, the binary data stream is modulated/superimposed on to the incoming RF carrier. This could be considered as a conventional mixing operation that generates two side bands (sum and difference) from the baseband data frequency and the incoming ambient signal frequency, around the latter.

In practice such a node is realized by connecting a 50Ω terminated reconfigurable slot antenna to a commercial SPDT switch ADG918 terminated on a matched load and an open circuit, as shown in the inset of Fig. 10.

C. *Reconfigurable Antenna*

The narrow band reconfigurable antenna used for the backscatter node is adapted from [13]. This is a microstrip fed slot antenna whose radiating slot length is tuned with the help of MADP-042305-130600 PIN diodes, attached across the slots as shown in Fig. 6. Here the entire biasing circuit is integrated into the ground plane of this antenna, by effectively segmenting the ground plane using DC block capacitors.

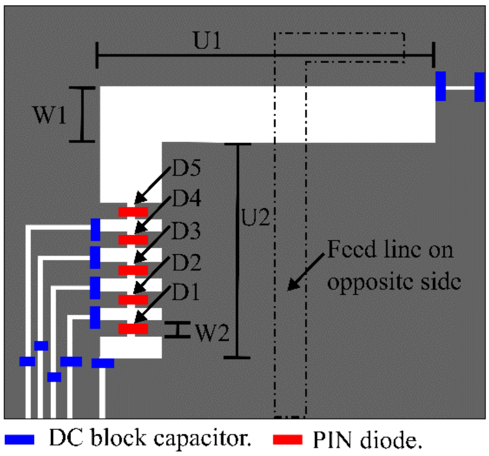

Fig. 6. Geometry of the band reconfigurable antenna. D1 to D5 are PIN diodes, U1 = 25 mm, U2 = 27 mm, W1 = 3.4 mm, W2 = 1 mm. DC block capacitor = 100 pF, PIN diode: MADP-042305-130600.

The photograph of the fabricated reconfigurable antenna and its input reflection coefficient characteristics are depicted respectively in Fig. 7 and Fig. 8.

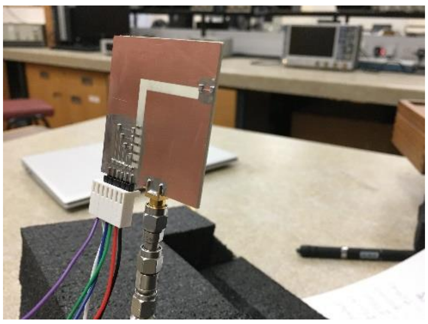

Fig. 7. Photograph of the fabricated band reconfigurable antenna.

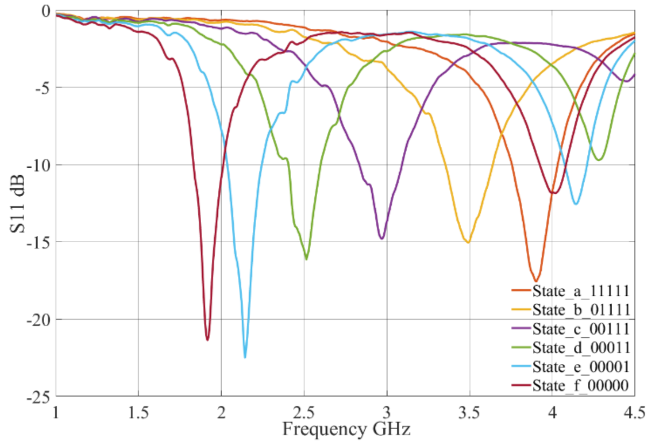

Fig. 8. Input reflection (S11) characteristics of the band reconfigurable antenna. '1' refers to diode switched ON (forward bias, 5V, 10 mA), and '0' refers to diode switched OFF (no bias). D5 = MSB, D1 = LSB (refer Fig. 6 for position of diodes).

III. Outcomes and Future Scopes

The photograph of the over the air (OTA) link of the proposed system is depicted in Fig. 10. Here we use a USRP N200 SDR form Ettus Research connected to a wide band Vivaldi antenna as the source of ambient signals, and an another USRP N200 configured as a receiver for receiving the backscatter modulated signals. Matlab 2021 is used to configure and control the USRP N200 as well as to process the received signals.

A chirp spread spectrum (CSS) communication scheme is used in the presented case for the backscatter modulation to prove the concept. Here, the backscatter node is programmed to transmit a burst of a pre-set combination of upchirps, and downchirps as shown in Fig. 9.

The parameters for the upchirp and downchirp are chosen as follows: Quantization levels = 128, Bit duration = 5 ms, Frequency start = F_c + 50 kHz, Frequency stop = F_c + 60 kHz, where F_c = 2.45 GHz in the presented case.

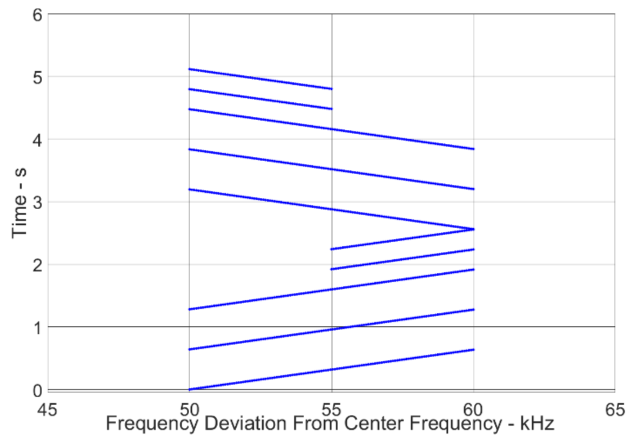

Fig. 9. Format of the CSS data frame burst transmitted using the backscatter modulation node.

Fig. 11 depicts the received spectrum showing the CSS modulated side bands (around ± [50 to 60] kHz) and the ambient peak at 2.45 GHz (indicated as 0 Hz in this down converted spectrum) ambient signals. Fig. 12 shows the frequency versus time (waterfall spectrograph) of the reception in which the modulated CSS signals could be easily identified as side bands. One could see here that a mirror side band is also seen at the negative side of the centre frequency, as this is a linear mixing scenario.

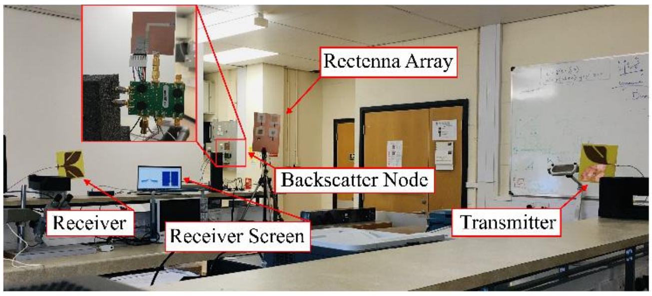

Fig. 10. Photograph of the backscatter OTA setup used in this experiment, showing the zoom image of backscatter node in the inset.

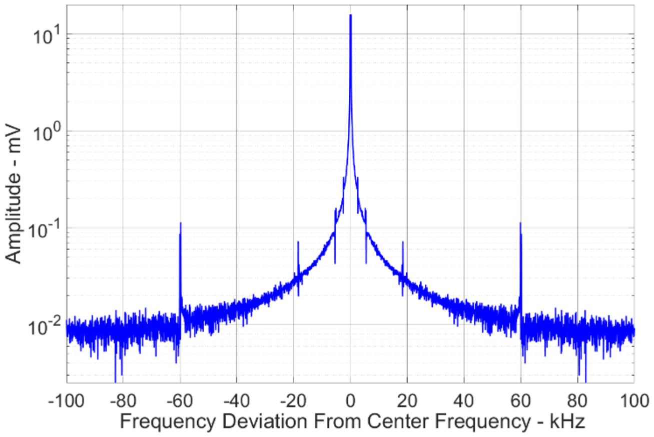

Fig. 11. A screenshot of the captured spectrum, centered at 2.45 GHz, backscattering CSS communication.

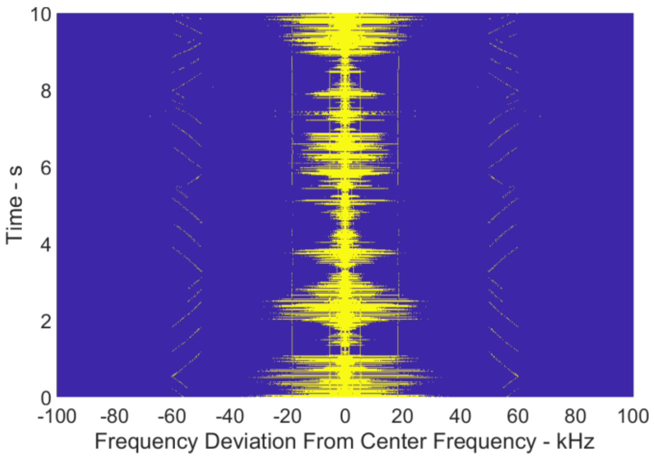

Fig. 12. Frequency versus time spectrograph (waterfall chart), displaying the CSS coded backscattered modulated side band around the center frequency at 2.45 GHz.

IV. Conclusion

We have successfully demonstrated the practical proof of concept of a secure and adaptive backscatter communication system exploring ambient signals. The only requirement of power in the presented concept (backscatter node) is to control the SPDT switch and for the spectrum sensing applications. At present the system is not optimized on a power consumption point of view, but just as a proof of concept of an adaptive backscatter system exploring ambient signals. Apart from the CSS, at present, the backscatter node is capable of transmitting two-state modulation types like frequency shift keying (FSK), amplitude shift keying (ASK), and binary phase shift keying (BPSK). However, this system could be easily modified to transmit other higher order modulation schemes like quadrature-PSK (QPSK), quadrature amplitude modulation (QAM) and similar, by choosing more switchable load termination states for the backscatter antenna.

The future perspectives of this idea include the utilization of a more power friendly microcontroller, replacing the ADC for spectrum sensing with a low power comparator logic, integration of an RF/renewable energy harvesting module to the system and further optimization to increase the bandwidth and security aspects.

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