Chirp Based Backscatter Modulation

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***Abstract*— The Internet of Things (IoT) envisions ubiquitous, cheap and low data rate connectivity between humans, machines and objects. The main technology that can satisfy this vision is wireless communication technology, but to embed this into objects at a large scale, some requirements like battery-free and long range communication should be considered.**

In this work we propose a modulator that can backscatter different chirps, based on Chirp Spread Spectrum (CSS) modulation which can achieve high sensitivities, meaning long range communication. Moreover, we prove with this design that we can reflect backscatter Long Range (LoRa) preamble symbols with a Spreading Factor (SF) of 7 and 125 kHz of bandwidth. Thus, it will be possible to reuse the LoRa receivers already developed.

***Keywords*— Backscatter modulation, chirp spread spectrum, internet of things, low power, .**

I. Introduction

In the Internet of Things (IoT) context, where billions of connected objects are expected to be ubiquitously deployed worldwide, the frequent battery maintenance of ubiquitous wireless nodes is undesirable or even impossible. The growth of the devices will be made possible only if the sensors battery needs are eliminated or reduced significantly. For low power sensors and devices, careful power management and power conservation are critical to device lifetime and effectiveness. One of the possible solutions is to change completely the paradigm of the radio transceivers in the wireless nodes of a IoT system. The backscatter communication, which consists in reflecting and modulating an incident radio signal, promises to be an excellent alternative to active radios, due to their low cost, low power and low complexity implementation.

In most Radio Frequency Identification (RFID) systems and passive sensors, the reader to tag communication is based on amplitude shift keying (ASK) or phase shift keying (PSK) that modulates either the amplitude, or both the amplitude and phase, of the reader's transmitted Radio Frequency (RF) carrier. However, the work [1] has shown that modulated backscatter can be extended to include higher order modulation schemes, such as Four-state Quadrature Amplitude Modulation (4-QAM). While ASK and PSK transmit 1 bit of data per symbol period, 4-QAM can transmit 2 bits per symbol period, thus increasing the data rate and leading to reduced on-chip power consumption and extended read range. In [2], [3] a 16-QAM modulator for backscatter communication was developed. Ambient radio waves can be used as a source to backscatter the data to a receiver, eliminating the need for dedicated RF transmitters. Several studies have shown the use of this technique to allow battery-free backscatter devices using broadcast FM stations [4], TV station [5] and Wi-Fi signals [6]. In [7] the authors present a tag that operates with ambient backscatter signals while featuring high-order modulation with ultra low power consumption.

As it is known, backscatter communication is a low power and low cost implementation, but it is limited to short ranges. Some recent studies implemented a backscatter modulator that can be compatible with Long Range (LoRa) hardware, and extend the range of communication [8]. The implementation can synthesize LoRa symbols, but has very low data rates which limits the scalability of the technology for other applications. In [9] the authors utilize ambient LoRa transmissions as the excitation signals, and shift the incoming active LoRa chirp by an amount of $BW/2$ and $-BW/2$ and then join them into a new chirp, respecting the LoRa standard. This implementation is totally dependent on LoRa communication, since it uses FSK modulation in an active LoRa chirp. Moreover, the data rate is very low, since the design can encodes only one bit per LoRa symbol.

In this work, we present a backscatter modulator that can synthesize Chirp Spread Spectrum (CSS) modulation or any kind of chirps and it is scalable for other type of applications due to its simple implementation. The modulator is composed by two transistors and a Wilkinson power divider and can achieve very low power consumption making it possible to adapt this technology into domains such as smart cities, precision agriculture and many others where backscatter is currently unfeasible.

The paper is organized as follows, Section II presents the operational principle of the system, Section III presents the results and Section IV the main conclusions.

II. Circuit Description

The circuit developed for this work is demonstrated in Fig. 1. The prototype implemented is composed by a Wilkinson power divider, two matching networks and two transistors (ATF-54143, Broadcom). This circuit was designed

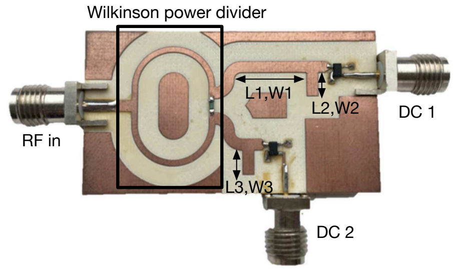


Fig. 1. Photograph of the backscatter circuit. Element values are L1 = 9.86 mm, W1 = 1.87 mm, L2 = 3.65 mm, W2 = 1.87 mm, L3 = 3.65 mm, W3 = 1.87 mm. Substrate for the transmission lines is Astra MT77, thickness = 0.762 mm, ε_r = 3.0, tan δ = 0.0017.

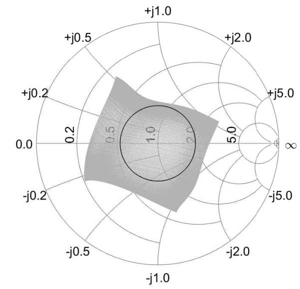
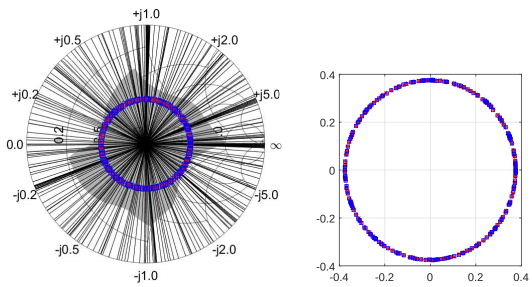


Fig. 3. Reflection coefficients obtained from measurements and a circle with a VSWR of 1.9. The voltages at each gate of transistor were swept from 0 V to 0.6 V with a step of 1 mV.



(a) (b)

Fig. 2. Simulations of the circuit developed. a) Reflection coefficients obtained from simulation and mapped with the intersection of 256 different phases with constant VSWR of 2.2. b) Detailed mapping of point obtained from simulations with the intersections.

for an operation frequency of 2.45 GHz and optimized with 0 dBm of input power. In Fig. 1 it is possible to observe the difference of line length which corresponds to 45°phase shift. The drain impedance of each transistor varies for different gate voltages, and it is possible to obtain different reflection coefficients. This means that is possible to determine different phases with a constant Voltage Standing Wave Ratio (VSWR).

As it was said previously, it is possible to alter the gate voltages at each transistor in order to achieve different reflection coefficients. Using ADS and through the Large-Signal S-Parameters (LSSP) simulation it was possible to characterize the circuit from 0 V to 0.6 V with a step of 1 mV, at each transistor. The result of this simulation can be seen in Fig. 2a represented by a gray shadow inside the Smithchart, with different reflection coefficients. Using this fine sweep of voltage it is possible to have a very accurate modulator, that can change, with a high precision, the phase of the reflected wave. In Fig. 2a it can be seen 256 different phases (represented with black lines in the Smithchart) and their intersection with a constant VSWR of 2.2 (represented in red in the Smithchart). Moreover, through our characterization, we match the reflection coefficients with the intersections (represented in blue in the Smithchart) and extract the voltages needed to the expected phases. These matching can be seen in more detail in Fig. 2b.

Considering an ideal chirp (signal whose frequency increases or decreases with time) it is possible to extract the phase of the time domain waveform at each time instant and based on the previous explanation of the circuit analysis we can obtain the regulated control voltage profiles in time domain to synthesize the chirp in the backscatered signal.

III. Results

Fig. 3 presents the results obtained from the measurements with voltages ranging from 0 V to 0.6 V with steps of 1 mV on each transistor at 2.45 GHz. Thus, it was necessary to determine a constant VSWR that fits into the mesh of the obtained reflection coefficients, as can be seen in Fig. 3, with a value of 1.9. The setup used for these measurements includes a Performance Network Analyzer (PNA) (E8361C, Agilent Technologies) and the Arbitrary Waveform Generator (AWG) (AWG5012C, Tektronix).

After acquiring the reflection coefficients it was possible to determine the control voltage profiles based on the chirp present in Fig. 4a.

Using the setup presented in Fig. 5 (composed by a Vector Signal Generator (VSG) (SMJ100A, Rohde & Schwarz), an AWG and an oscilloscope (DSO804A, Keysight)) and applying the voltages determined into the AWG a backscattered chirp signal was obtained, Fig. 4b, which is a linear chirp with 125 kHz of bandwidth and a duration of 2 ms.

This approach enables a large number of applications and the most important is the LoRa technology, which uses CSS modulation. LoRa can occupy three different bandwidth: 125 kHz, 250 kHz and 500 kHz. LoRa symbols are modulated over an up-chirp of 125 kHz bandwidth and different orthogonal Spreading Factors (SFs) (from 7 to 12) are used based on data rate requirements and channel conditions. The LoRa physical layer includes 8 preamble symbols, 2 synchronization symbols, physical payload and optional CRC.

Figure 6a presents a chirp which is based on one symbol from the LoRa preamble modulation with a SF of 7 and 125 kHz of bandwidth. Following the same procedure explained above the voltage profiles presented in Fig. 7 were obtained and synthesized using the AWG. The backscattered signal obtained can be seen in Fig. 6b.

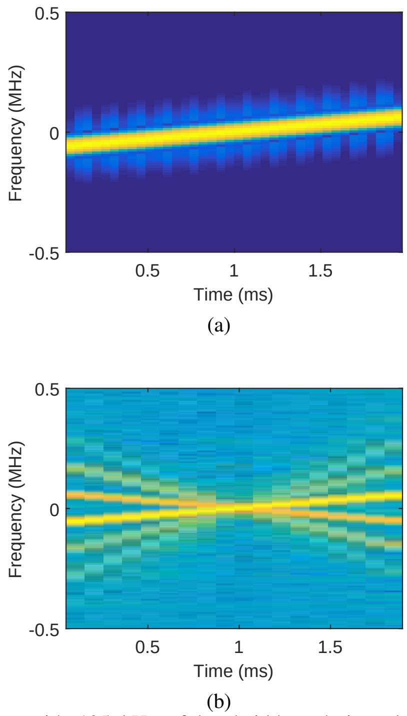


Fig. 4. Chirp with 125 kHz of bandwidth and time duration of 2 ms. a) Original chirp synthesized with our system. b) Obtained chirp from the measurement setup.

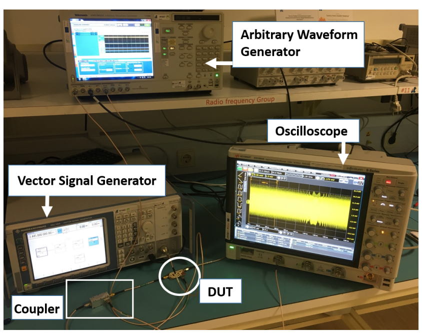


Fig. 5. Photograph of the measurement setup used to acquire the reflected chirps.

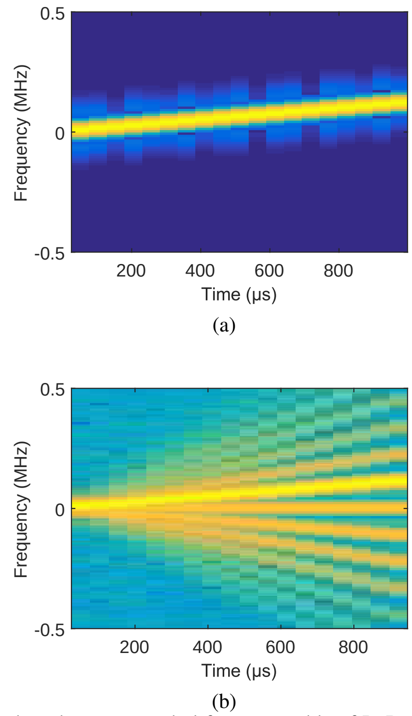


Fig. 6. Chirp based on one symbol from preamble of LoRa modulation with a SF of 7, with 125 kHz of bandwidth and time duration of 1 ms. a) Original chirp synthesized with our system. b) Obtained chirp from the measurement setup.

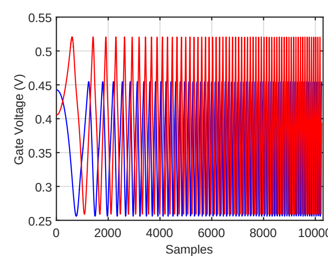


Fig. 7. Voltage profiles in time domain, obtained from mapping the phases synthesized from the chirp presented in Fig. 6 with reflections coefficients presented in Fig. 3.

Figures 4b and 6b present the obtained chirps from the measurements. As can be seen the chirps present some distortion that is caused by the transistors. There are some techniques to remove the harmonics, namely the backscatter harmonic cancellation presented in [8].

IV. Conclusions

In this paper, a novel approach for backscatter chirp signals was presented. The paper described a modulation technique that will enable long range reliable communication capabilities of radios at the low power and cost of backscatter hardware. Moreover, by synthesizing LoRa symbols it will be possible to use the already developed readers that offer sensitivities of -149 dBm and through this improve the range of communication of backscatter radios. As a future work we plan to build a LoRa frequency prototype including the digital logic that will be able to backscatter LoRa symbols.

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