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Enabling Multicarrier Backscattering Communications

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***Abstract*—We demonstrate for the first time that a multicarrier signal, and in particular an OFDM signal, can be generated by backscattering a single carrier incoming electromagnetic wave. This is achieved by utilizing a semi-passive IQ backscatter modulator involving two transistors with varying biasing in a Wilkinson power divider architecture that has previously been proposed and demonstrated for Quadrature Amplitude Modulation (QAM) and Chirp Spread Spectrum (CSS) modulation schemes. The multicarrier backscattering signal is synthesized in time domain. This capability enables low-cost and low-power consumption tags to significantly improve the transmission data rate and potentially communicate with the commercial wireless networks such as WiFi and LTE.**

***Index Terms*—Backscattering communications, Internet of Things (IoT), multicarrier modulation.**

I. Introduction

The World around us is becoming increasingly 'intelligent', featuring smart homes, smart buildings and smart cities, etc. A key underpinning technology is the Internet of Things (IoT) networks that are able to sense the environment, convey the information (usually in a wireless fashion) and, in some applications, take actions [1]. This massive scale of IoT nodes, commonly called tags, bring major challenges with regard to their costs, power consumption and maintenance (e.g. replacing batteries). These requirements promote backscatter communication technology as a promising solution to enable wireless communication between IoT tags and centralized readers, as it replaces the costly and power-hungry radio frequency (RF) frontends, e.g. mixers and power amplifiers, which exist in every conventional wireless transmitter. Instead, in order to convey information, a backscattering tag relies on modulating the scattered incoming electromagnetic (EM) waves. A prevailing example is commercial RFID systems.

Backscattering modulation can be achieved by changing the impedance loads that the tag antenna is terminated with. This 'semi-passive' transmitter architecture is capable of reducing the power consumption by several orders of magnitude, i.e. down to the order of μW [2]. Here the term 'semi-passive' refers to the fact that the tag does not actively radiate but instead any power consumed is used for modulating an impedance load. Borrowing from commercial RFID systems, several backscattering communication links employ the Amplitude Shift Keying (ASK) scheme, which in its simplest form leads to On-Off-Keying (OOK). OOK is performed by connecting a matching load or a full-reflection circuit (i.e. open or short) to the tag antenna, so that incoming EM waves received by the antenna are absorbed or scattered in a sequence that depends on the data to be transferred [3]. This has further been extended to higher order ASK modulations, such as 4PAM in [4].

Since modulation in the frequency domain is more resilient to noise compared with modulation in the amplitude domain, the Frequency Shift Keying (FSK) based backscattering modulation was developed for different orders, for example 2FSK in [5] and 4FSK in [6]. This is commonly achieved by toggling among different loads connected to the tag antenna with a frequency that matches the modulation frequency shifts. This brings the possibility for backscattering tags to communicate with Bluetooth devices [7].

Phase modulation can be more challenging for backscattering communications since it requires coherent detection at receiver end. Its differential form, however, can help eliminate this requirement. In [8] and [9] a universal Quadrature Amplitude Modulation (QAM) backscattering tag design was proposed, which comprises two ultra-low power transistors operating as variable loads. It has been demonstrated that when connected in a Wilkinson power divider configuration, the reflection coefficient from the circuit can cover a large continuous area on the Smith Chart. Recently, this IQ backscatter modulator has been exploited to create Chirp Spread Spectrum (CSS) modulated LoRa waveforms, increasing the backscattering communication range to hundreds, or even thousands, of meters [10], [11].

Despite the significant progress in backscattering systems over the past few years, to the best of our knowledge a scheme that enables multicarrier backscattering modulation has yet to appear in open literature to date. We note that although FSK-based frequency hopping and the CSS modulation [11] generate backscattering signals that occupy a frequency bandwidth, at any time instant the signals only have a single frequency component. Instead, a multicarrier signal would involve backscattering multiple frequencies simultaneously.

In this paper, we report for the first time that a multicarrier backscattering signal can be synthesized by exploring the IQ modulator tag, once developed for QAM and CSS modulations [9], [11]. It is worth mentioning that this work intends to generate multicarrier backscattering signals when the incoming EM wave is a single carrier. This is distinct to the system presented in [12], wherein the tag is performing ASK upon incoming multicarrier waveforms.

This paper is organized as follows; In Section II the IQ backscatter modulator is briefly described, followed by its operation principle for multicarrier signal generation in Section III. The future work is presented in Section IV. Finally, conclusions are drawn in Section V.

II. Dual-transistor Based IQ Modulators

To facilitate study and discussion hereafter in this paper, the architecture of the dual-transistor based IQ modulator proposed and designed in [9] and [11] is illustrated in Fig. 1. The incoming signals captured by the tag antenna is firstly 3-dB divided into two paths which are terminated by impedance loads that is controlled by a transistor each. The two paths are characterized by 45º phase difference, achieved by means of a transmission delay line. With reference to Fig. 1, the reflected signals at ports B and C are therefore characterized by phase difference of 90º, since the signal in the *I*-path passes through the delay line twice. This 90º phase difference in two paths makes the impedance manipulation by the two transistors orthogonal in IQ plane.

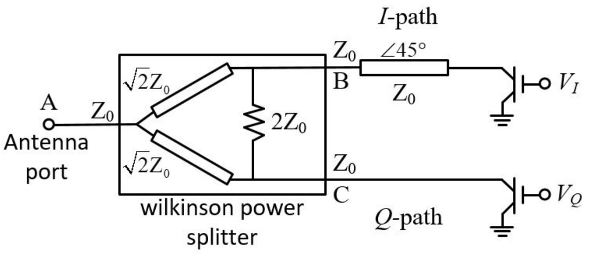

Fig. 1. Dual-transistor based IQ backscatter modulator.

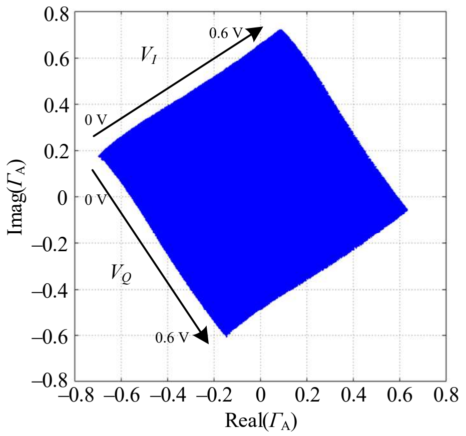

Fig. 2. Reflection coefficient observed at antenna port A when V_I and V_Q of two transistors (ATF-54143) are swept from 0 to 0.6 V. Measured Transistor impedance at 2.45 GHz and an ideal Wilkinson power splitter are used for the plot.

In practical designs, the transistor ATF-54143 from Broadcom is selected due to its ultra-low current of 0.2 µA (measured) when the gate voltage is below 0.6 V. Fig. 2 depicts the reflection coefficient at the antenna port A, denoted as Γ_A, when the gate voltages of two transistors, i.e. V_I and V_Q in Fig. 1, are swept from 0 to 0.6 V in steps of 1 mV. As expected, these two control voltages are able to span the reflection coefficient along two orthogonal directions.

III. Synthesis of Multicarrier Backscattering Waveforms

In this section, we demonstrate the synthesis of multicarrier backscattering waveforms from a continuous wave (CW) incidence using the dual-transistor based IQ modulator described in Section II.

As an illustrative example, the authors synthesize the preamble of IEEE 802.11g (WiFi 3), which has 64 OFDM subcarriers, each of whom is BPSK modulated. The preamble last

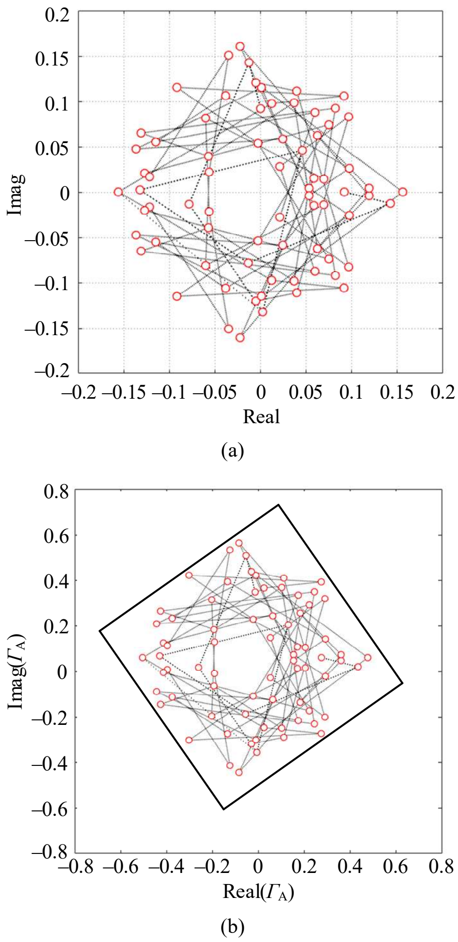

Fig. 3. (a) 320 preamble samples in IQ plane in the IEEE 802.11g. (Some samples are overlapped); (b) the scaled 320 samples to fit into the shaded area in Fig. 2.

for five OFDM symbols, therefore, comprises 64×5 = 320 samples in the time domain. Considering the baseband signal, each sample is characterized by its magnitude and phase and therefore is a complex number. This complex sequence, which consists of 320 samples in the time domain with the sampling period being the inverse of the OFDM subcarrier frequency spacing, is plotted in Fig. 3(a). The magnitude of samples is small due to power normalization. The sample sequence, which has already contained 64 subcarriers, is then frequency upconverted in order to generate OFDM RF signals, ready to be radiated.

As pointed out these baseband time-domain samples are used to modulate the OFDM fundamental RF carrier. This in fact is the same function that the IQ backscatter modulator applies on the incoming EM continuous wave. By applying the IQ values associated with this sequence, it is thus possible to backscatter an OFDM signal from an incoming single carrier signal.

In order to illustrate this, we first scale the samples within the shaded area shown in Fig. 2, see Fig. 3(b), in order to maximize the backscattering signal power. Each sample (circle dot) in Fig. 3(b) corresponds to a pair of transistor control voltage (V_I, V_Q). In other words, when a correct sequence of 320 (V_I, V_Q) is applied at the IQ backscatter modulator at the OFDM sampling rate, the incoming single carrier EM wave is converted/backscattered into the OFDM modulated IEEE 802.11g preamble. Using the same procedure, the OFDM payloads can be generated, thus, equipping this low-cost low-power tags the capability of communicating with WiFi, (or others, e.g. LTE), devices.

IV. Future Work

Future work is planned to fully validate and demonstrate the proposed concept in this paper. This includes:

- Design and implement the IQ backscatter modulator at 2.45 GHz for IEEE 802.11g operation;
- Backscattering OFDM waveform measurement in both time and frequency domains;
- Over the air test to validate the compatibility with WiFi devices;
- Over the air BER versus SNR measurement to quantify the backscattering communication data rate and range.

The results are expected to be included in the extended paper for the IEEE T-MTT mini-special issue.

V. Conclusion

This paper presented the use of an IQ backscatter modulator to generate multicarrier backscattered signals. In particular, an IEEE 802.11g OFDM preamble was synthesized by simulation. The tag consists of only two transistors with current consumption no larger than 0.2 μA at voltage of less than 0.6 V. This proposed low-power multicarrier backscatter tag is able to significantly enhance the transmission data rate and, more importantly, enable the tags to directly communicate with other commercial devices that have the Internet access. The advancement made in this paper opens a new area for low-cost low-power (or even batteryless) IoT devices to intelligentize the world around us in a greener fashion.

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