Could Battery-less Scatter Radio Tags Achieve 270-meter Range?

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***Abstract*—This paper studies whether increased ranges of bistatic scatter radio communication are possible, especially when low-cost, embedded receivers, originally designed for conventional radio (and not for scatter radio) are employed. Wireless power transmission and bistatic scatter radio are closely related, and thus, this work aims to highlight a new exciting, potentially interesting, key-enabling research direction. It is found that for 13 dBm emitter transmission power, 246 meters scatter radio tag-to-reader distance is possible, with packet error rate (PER) less than 1%, while 268 meters are possible at the expense of increased PER, in the order of 10%.**

I. INTRODUCTION

Recent advances in backscatter communication have enabled the development of ultra-low-cost and low-power wireless sensor/tags. Examples include large-scale environmental monitoring of air humidity [1] and soil moisture [2], which are both critical in agriculture, as well as short-range telemetry applications [3].

One key architecture for scalable backscatter communication is based on bistatic principles; the tag/sensor is illuminated by a carrier emitter and modulates information on its reflection coefficient; the signal is reflected by the sensor's antenna and received back by another unit, the reader. Thus, in bistatic architecture there are in principle three different entities involved, the carrier emitter, the tag/sensor and the reader, offering flexible setups. Bistatic scatter radio communication was first offered in [4]–[6] focusing on either on-off keying (OOK) or frequency shift keying (FSK) for scatter radio signals, highlighting the fundamental differences compared to conventional (Marconi) radio and also addressing issues relevant to the bistatic setup (e.g., carrier frequency offset between emitter and receiver). Ranges in the order of 140 meter were achieved, using commodity software-defined radios, while work in [7] further increased range by 10 more meters with careful coherent processing and small-block length channel codes. Work in [8] offered an example of bistatic scatter radio FSK received by the bluetooth module of a smartphone.

This paper studies whether increased ranges of scatter radio communication are possible, especially when low-cost, embedded receivers, originally designed for conventional radio (and not for scatter radio) are employed. If the answer is found positive, then a new avenue for battery-less, possibly remotely-powered sensor network applications will be opened, exploiting conventional embedded radios as low-cost scatter radio receivers. Wireless power transmission and bistatic scatter radio are closely related, and thus, this work aims to highlight a new exciting, potentially interesting, key-enabling research direction.

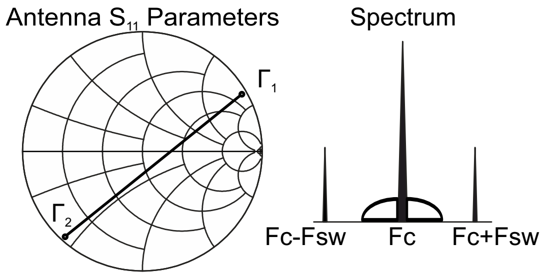

Fig. 1. FSK scatter radio communication principle: single, low-cost RF switch is utilized that alternates the antenna termination load between two values (Z_1 and Z_2) with switching frequency F_{sw}. Different antenna termination loads offer different reflection coefficients (left) that modulate a carrier signal with different amplitude and phase. For carrier frequency F_{c}, two subcarriers appear with frequencies $F_{\text{c}} \pm F_{\text{sw}}$.

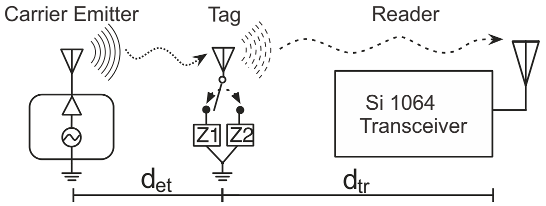

Fig. 2. Range measurements were implemented in the bistatic topology. Carrier emitter was far from the receiver. d_{et} denote the emitter-to-tag distance and d_{tr}, the tag-to-reader distance. Carrier emitter produces the signal which is modulated by sensor nodes and finally, the reflected signal is received by the reader.

II. IMPLEMENTATION

A. Bistatic Backscatter Radio

The BF1118 switch changes the termination of the antenna between two loads. By altering the termination load Z_i, the

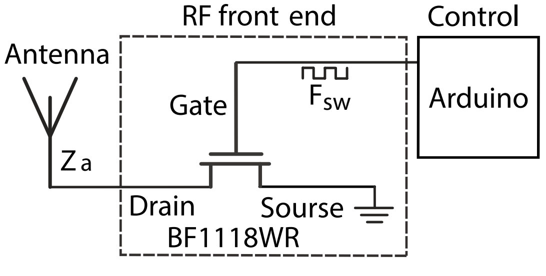

Fig. 3. Design of a scatter radio RF front end. On the right, the control unit produces the (switching) square pulse signal. On the left-hand side the RF front-end is depicted, implemented with the single RF switching transistor BF1118.

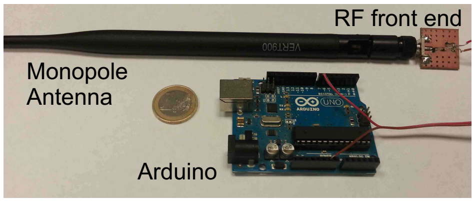

Fig. 4. The backscatter RF front end prototype. An arduino board was used as the control unit. The printed circuit board is directly connected though a SMA connector to a monopole antenna.

reflection coefficient

$$\Gamma_{\mathrm{i}} = \frac{Z_{\mathrm{i}} - Z_{\mathrm{a}}^{*}}{Z_{\mathrm{i}} + Z_{\mathrm{a}}}, \tag{1}$$

also changes, where Z_a is the sensor's antenna impedance and i represents the switch state. When the sensor's control circuit alters the state of the switch at a specific frequency F_{sw} and a carrier signal with frequency F_{c} impinges on the sensor's antenna (bistatic topology), two subcarriers are generated, with frequencies $F_{\mathrm{c}} \pm F_{\mathrm{sw}}$ (Fig. 1). By changing the switching frequency F_{sw} between two values F_{sw0}, F_{sw1}, we can create a binary-FSK modulated signal, so that "0" is represented by the subcarrier set resulting from F_{sw0} and "1" from F_{sw1}. If each signal controlling the sensor/tag switch, has a duration of T sec then the BFSK modulated, reflected signal will have a baud rate of $1/T$ bits per sec (bps). The bistatic architecture is shown in Fig. 2, while the design of the tag front end is shown in Fig. 3.

B. Control Circuit

The proposed tag is based on the widely available arduino development board due to the ease of making proof-of-concept systems. The microcontroller on the arduino board generates the frequencies that drive the BF1118 RF switch, so that BFSK can be realized via backscatter radio. To achieve a certain bit-rate, the duration of the generated signals can be altered. Special attention was given on implementing at the tag the control packets required by the protocol of the embedded receiver. Duty-cycled operation of the control circuit is possible, allowing for battery-less operation with appropriate RF (or other ambient source) energy harvesting.

C. RF Front End

The RF front end consists of a 3 dBi, omni directional monopole antenna and the BF1118 RF switch (Fig. 3). The PCB was designed in Agilent's ADS to minimize coupling loses and was fabricated in-house (Fig. 4). The measured S11 of the antenna at 868 MHz is offered at Fig. 5.

D. Receiver

On the receive side, a Silicon Laboratories SI1064 ultra-low power micro-controller unit (MCU) with integrated transceiver was configured to receive the BFSK-modulated, reflected signal coming from the RF front end. The RF configuration of the receiver is listed at Table I.

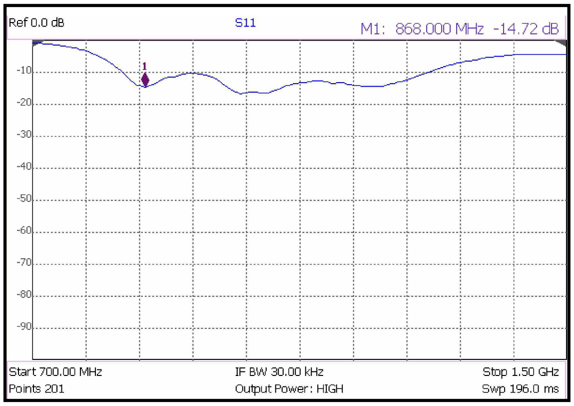

Fig. 5. Measured reflection coefficient for the monopole antenna, (S_{11}), with marker at 868 MHz.

TABLE I
RECEIVER RF CONFIGURATION

Parameter	Value
Modulation	2-FSK
Data Rate	1.2 kbps
Center Frequency	868 MHz
Frequency Deviation	±5.157 kHz
RX Bandwidth	45 kHz

TABLE II
COMMUNICATION ACCURACY.

#	d_{et} (m)	d_{tr} (m)	PER (%)
1	3	69.7	0.1
2	3	145.4	0.1
3	3	246	0.9
4	3	268	10.6
5	8.4	40.7	15.5
6	25.2	24.8	1

The frequency deviation resulting from the tag is not the ideal. This is due to a) the limitation of the arduino to produce and maintain a stable frequency and b) the frequency deviation of the carrier emitter. A Texas Instruments CC1101 transceiver IC with similar configuration was used to verify the tag, as well.

Using such commercial, embedded modules, completely eliminates the need for a computer at the receiver side and dramatically reduces the overall reception cost of scatter radio signals.

III. EXPERIMENTAL RESULTS

To test the setup, the tag control circuit was configured to produce switching frequencies, so that the resulting subcarriers fell within the receive bandwidth of the SI1064, centered at 868 MHz. Considering the configuration parameters of Table I and $F_{\mathrm{c}} = 867.9$ MHz, the appropriate subcarrier frequencies were $F_{\mathrm{sw0}} = 95$ kHz, $F_{\mathrm{sw1}} = 105$ kHz. The carrier emitter was another SI1064 configured as a continuous wave (CW)

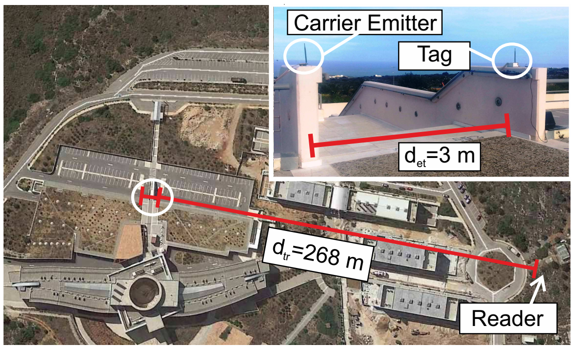

Fig. 6. Outdoor setup for communication range measurements of the described backscatter architecture.

source with $P_{\text{tx}} = 13$ dBm. Packet error rate (PER) tests were performed using packets with 8 bytes of preamble, 4 bytes of sync words and 6 bytes of payload without any form of line coding applied. A long stream of preamble/sync bytes was selected to minimize the likelihood of detecting noise as useful signal at the receiver. A set of 1000 packets was transmitted per measurement and a packet was transmitted every 500 ms. Resulted PER for a set of d_{et}, d_{tr} combinations is offered in Table II. It can be seen that 246 meters tag-to-reader distance is possible, with PER less than 1%, while 268 meters are possible at the expense of increased PER, in the order of 10%. The experimental setup utilized is shown in Fig. 6.

IV. CONCLUSION

This work offered a concrete proof-of-concept of how existing low-cost, embedded radio, invented for conventional wireless sensor networks can be exploited to receive bistatic scatter radio signals, with ranges as high as 268 meters, at 13 dBm emitter power. Battery-less, potentially remotely-powered devices, such as sensors, could vastly benefit from this line of research.

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