# Microwave Analysis and Experimentation for Improved Backscatter Radio

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***Abstract*—This work aims to improve the RFID RF front-end performance via microwave analysis. It is well known that the magnitude of the complex reflection coefficient difference, between two loads connected to the tag-antenna, is a crucial design parameter. On the other hand, the loads are usually considered ideal and there is no microwave analysis of electromagnetic interference between the antenna and the load control circuit. This study demonstrates through measurements that the assumption of ideal loads is not realistic and magnitude of reflection coefficient difference is reduced in practice, offering degraded backscatter radio performance (compared to the ideal case). A microwave analysis is utilized in order to assess coupling between the control circuit and the antenna/RF switch (that selects the loads). As a collateral dividend, the magnitude of reflection coefficient difference is increased with microwave analysis and experimental measurements and a specific methodology is proposed.**

***Index Terms*—RF identification (RFID), Backscatter.**

## I. Introduction

Backscatter radio technology is widely used today in many applications e.g. environmental monitoring [1], [2].A backscatter radio schematic for two terminating loads is depicted in Fig. 1. Switching between different loads, usually performed by a transistor located at the *RF front-end area*, is controlled by a circuit, located at the *circuit-control* area, and modulates the scatter signal [3]. Assuming that $Z_i$ is the load connected to the tag antenna when the tag is at stage "$i$", the reflection coefficient of the tag antenna system is [4],

$$\Gamma_i = \frac{Z_i - Z_a^*}{Z_i + Z_a}, \qquad (1)$$

where $Z_a$ is the tag antenna impedance. Hence, the amplitude of the complex reflection coefficient difference between the two states, or equivalently between two loads, $Z_1, Z_2$, connected to the antenna is,

$$D = |\Gamma_1 - \Gamma_2| \,. \qquad (2)$$

As $D$ increases, backscatter performance is improved [4]. In the ideal case, the term $D$ is equal to 2, achieved when $\Gamma_i$s are diametrically opposite on the unit circle (Smith chart). With given $Z_i$s, there is a complex $Z_a$ which maximizes $D$, although the optimal case, $D = 2$, is not always achieved.

This work proposes a design procedure in order to maximize term $D$. Specifically, a methodology is offered for:

- $Z_i$ selection which leads to diametrically opposite $\Gamma_i$s on the unit circle (Smith chart).
- RF front-end microwave design/analysis. Mutual coupling reduction between antenna and tag is needed.
- Maximization of term $D$ with $Z_a$ as a variable and $Z_i$s fixed.
- Estimation of $Z_a$ for which tag antenna should be designed with.

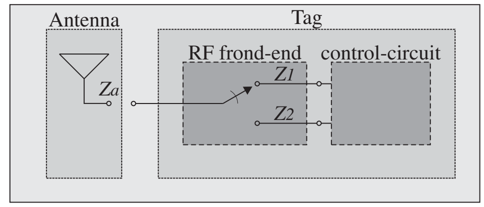


Fig. 1. Backscatter radio schematic for two terminating loads-states.

## II. Initial Analysis

In this section, the influence of term $D$ in backscatter radio performance is tested. More specifically, FM modulation is used. The sub-carrier (i.e switching) frequency signal with the value of Eq. (1) of [2], modulates the humidity measurement with frequency modulation (FM) of the carrier produced by an emitter, detached from the receiver (bi-static, dislocated topology). It is noted that as the sub-carrier amplitude increases, backscatter communication performance is improved. The overall procedure has been analytically described in [2].

### A. Antenna Design

A bow-tie tag-antenna at 868MHz has been designed, fabricated and measured. All simulation were performed via the Agilent Technologies ADS software. Initially, the antenna has $Z_a = 40.2416 - 4.6807i$. In order to have different $Z_a$ but exactly the same antenna gain and structural mode [4], the antenna is connected with an SMA connector through identical type of lossy coaxial cable with different lengths (three cases). The obtained antenna impedances after measurement are,

$$Z_a = [109.1 + 6.2i \quad 42.80 + 21.8i \quad 27.50 + 16.9i]. \qquad (3)$$

### B. Tag Design

In this work, it is assumed that the two different stages correspond to opened and shorted antenna terminals, respectively.

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In the ideal case, it is obvious that $Z_1 = \infty$ and $Z_2 = 0$ Ohm. Consequently, from (1)–(3),

$$D_{\text{ideal}} = [1.9968 \quad 1.7821 \quad 1.7040]. \tag{4}$$

Nevertheless, $Z_1$ and $Z_2$ are actually equal to $10 - 91.5i$ and $27.8 + 45i$ Ohm, respectively, as found after measurement. Hence,

$$D = [1.4027 \quad 1.2688 \quad 1.0650]. \tag{5}$$

The above procedure not only shows that backscatter performance is strongly influenced by parameter $Z_a$, but also that $Z_i$s should not be taken into account as ideal. Finally, it is noted that, for these values $Z_1, Z_2$, even when $Z_a = 62.4752 + 55.3889i$, which maximizes (2), the optimal $D$ is only equal to 1.5734, considerably different from the maximum 2.

### C. Measurement

For validation purposes, the antenna-tag performance is measured in terms of sub-carrier signal strength. The topology consists of an emitter, a battery-enabled (semi-passive [2]) antenna-tag and a reader. The distance between the emitter and reader was 50 m, while the antenna-tag was placed between them, at distance 5 m from the emitter. The received signal was sampled with a time window of 1.2 seconds and 200 samples were collected by the reader. The sub-carrier amplitude was measured for all three cases, i.e. for the antenna-tags with the three different $Z_a$ and consequently, different $D$. The mean value of the resulting signal strength in dBm are,

$$A_{\text{ideal}} = [-46.1547 \quad -51.9010 \quad -53.5390] \tag{6}$$

According to the above procedure it is obvious that the backscatter performance can be enhanced through antenna design, with appropriate impedance $Z_a$. More specifically, when $D$ increased from 1.0650 to 1.4027, the sub-carrier signal strength is increased by approximately 7.4 dB. The latter has obvious impact on the final distance between the emitter and the reader. It should be noted that even with the optimal $Z_a$, $D$ reaches 1.5734, i.e. far away from 2. Hence a better RF front-end microwave design is required.

## III. Design Optimized Antenna-Tag

In this section, RF front-end (Fig. 1) is electromagnetically analyzed in order to select $Z_i$s such that $\Gamma_i$s are diametrically opposite on the smith chart. The coplanar waveguide structure was chosen, since the latter is easily fabricated due to the absence of vias. The transistor, playing the role of switcher between $Z_i$s, is placed very close to the antenna, at the end of the RF front-end geometry in order to avoid introducing phase difference. The mutual coupling reduction, between the RF front-end and circuit-control area, is achieved due to the physical distance between them but and due to the utilization of RF chokes The latter, due to the very high impedance at high frequencies, act as low-pass filters. The final structure is fabricated and after measurement was found that $Z_1 = 1.3 - 221.2i$ and $Z_2 = 18.1 + 14.4i$, for $-20$ dBm power input. Hence, according to (2), the value of $Z_a$ which maximizes $D$, i.e. $D = 1.9161$, is equal to $56.6172 + 196.082i$. Fig. 2 depicts $\Gamma_i$s with the initial (dashed line) and improved (solid line) RF front-end. It is obvious that the backscatter performance is enhanced in terms of $D$.

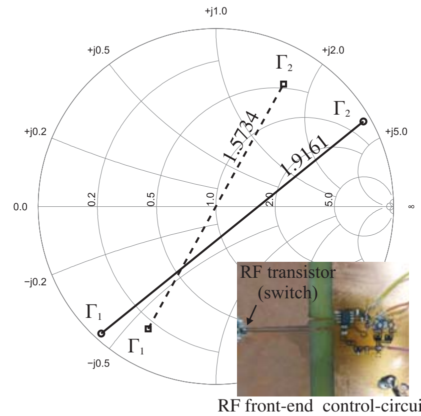


Fig. 2. $\Gamma_i$ with initial (dashed line) and improved (solid line) RF front-end. The difference $|\Gamma_1 - \Gamma_2|$ is increased by approximately 22%.

## IV. Conclusion

A versatile, microwave-based technique is presented, that maximizes backscatter performance in terms of $|\Gamma_1 - \Gamma_2|$. It was shown that, the loads which modulate the backscatter signal, must not be considered ideal. Instead, microwave analysis or measurement should be implemented. With appropriate loads, there exists an antenna with impedance which maximizes the difference between reflection coefficients $\Gamma_i$s. Hence, backscatter performance is enhanced. Future work includes the development of an optimized antenna-tag via the proposed design method and validation through measurement procedure, identical to the one presented at Section II-C.

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