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Open Testing and Measurement Bench for UHF RFID

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Abstract—In this article, we present an open testing and measurement bench allowing one to characterize the performance of any UHF RFID tag. The architecture is based on a vectorial generator and a real-time spectrum analyzer. Both instruments are controlled by a single script on a remote controller. The bench is able to extract the power on tag forward and power on tag reverse, the delta RCS and the read range of a UHF tag. This bench can offer similar functionalities compared to industrial solutions such as the Voyantic Tagformance Pro reader. All relevant design files will be released as open source to the community.

Index Terms—RFID, POTR, POTF, Delta RCS, read range.

I. INTRODUCTION

Since twenty years, the performance of the UHF RFID technology has been significantly increased. A classical UHF reader can read dozens of tags per second at a range upto 10 m in real environment. However tag characterization and optimization remain a complex challenge for every tag designer. Actually, the performance of a tag can be characterized by a set of different metrics such as the power on tag forward (POTF), the power on tag reverse (POTR), the delta RCS and finally the read ranges (forward and round-trip). These metrics are classically used to compare the performance of different UHF RFID tags or to characterize the performance of a tag in different environment [1]. The need for characterization benches allowing the designer to extract these parameters quickly and efficiently is a major concern.

Few years ago, custom characterization benches for UHF RFID tags were commonly designed by research labs. Authors in [2] present a detailed state of the art of these systems. First systems were reported since 2007 in [3] based on transmitter and receiver modules connected by a PXI bus. Systems were also reported based on proprietary reader such as [4] (based on a ThinkMagic reader) and [5] (based on a Alien reader) which significantly reduces the complexity of the bench since all critical operations are handled by the reader chip but also reduces the flexibility. Finally, prototypes have also been proposed based on SDR transceivers such as USRP [6] where the architecture has been proposed in [7]. A remarkable example appears in [8] where the authors designed a bench based on laboratory instruments and a FPGA to handle the complex timing requirement of the RFID protocol. Unlike all the other previously described benches based on laboratory instruments, this bench was able to extract the EPC of the

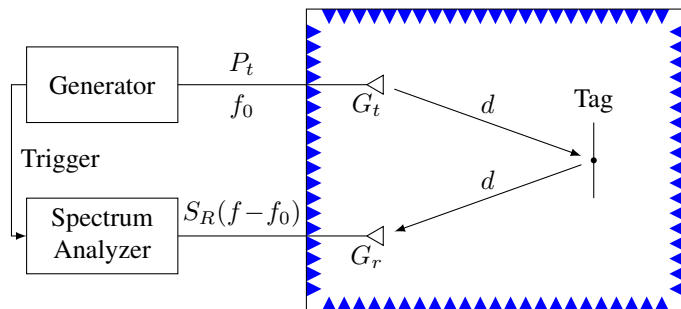


Fig. 1. Measurement bench based on a bistatic configuration used to characterize a UHF tag.

tag. Today, industrial solutions such as [9] have emerged as reference and have replaced almost all custom testbenches. These industrial benches have standardized the measurement of UHF tags so that performance of different tags can easily be compared. However, the flexibility of these benches remains in some cases limited due to the proprietary architecture.

This article presents an open measurement bench able to characterize the performance of any UHF tag. The bench is built around a signal generator and a real time spectrum analyzer controlled by a single Octave (or Matlab) script on a remote PC. This bench allows one to extract the POTF, the POTR, the delta RCS, the forward and reverse read range of any tag. This bench can provide similar capabilities as [9]. All relevant design files will be released as open source to the community [10].

II. MEASUREMENT BENCH ARCHITECTURE

The bench is composed of a signal generator Agilent MGX N5182A and a real time spectrum analyzer Tektronix RSA 3408A. The generator can modulate any carrier frequency up to 3 GHz over a bandwidth of 15 MHz. The spectrum can demodulate any signal up to 6 GHz over a bandwidth of 36 MHz. Both instruments are controlled by a remote PC using SPCI commands over VXI-11 protocol. Note that the generator and the spectrum are also connected using a trigger for accurate synchronization. The tag is placed at a fixed distance from the antenna in the farfield region. Fig. 1 presents the architecture of the proposed bench in bistatic configuration and Fig. 2 shows a picture of the bench in anechoic chamber using a monostatic configuration.

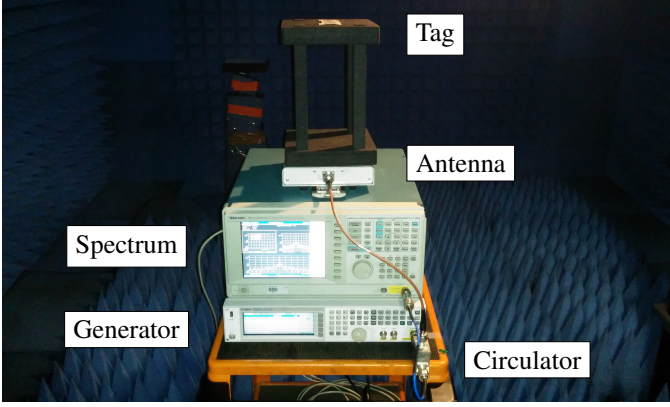


Fig. 2. Photograph of the proposed bench based on a monostatic configuration in anechoic chamber.

Note that the monostatic configuration uses the circulator and patch antenna of the Tagformance Pro reader to easily compare the results. The bistatic configuration using two UWB antennas allows to easily extend the bandwidth. More importantly, the instrument models can easily be replaced by other equivalent models and by simply modifying the associated SPCI commands. This architecture provides a natural flexibility to realize any UHF tag characterization.

III. PRINCIPLE OF OPERATION

A. Overview

The measurement bench's elementary operation is to generate a query command using the arbitrary generator and to capture the response of the tag. The query command, stored inside the generator memory, sets all parameters of the tag transmission including modulation and data rate. The response of the tag, which consists of the RN16, is captured by the spectrum analyzer. To achieve an accurate synchronization between the generator and the spectrum analyzer, a trigger from the generator to the spectrum is used. Contrary to other benches, the response of the tag is measured in the frequency domain using the procedure described in [11].

From the power spectral density $S_r(f)$ measured at the spectrum analyzer side, the modulated received power, $P_{r,d}$ is computed by [11]:

$$P_{r,d} = \lim_{\epsilon \rightarrow 0} \int_{f_0-\epsilon}^{f_0+\epsilon} S_R(f-f_0) df \quad (1)$$

The suppression of the power located around f_0 allows the bench to be insensitive to the leakage present in the setup (from the reader and the environment). This modulated power is computed iteratively for any frequency and power in the considered domain. All classical estimators such as POTR, POTF, delta RCS and read range (forward and round-trip) can be extracted using post processing after the measurement. Contrary to [9], note that EPC can not be extracted since successive reader commands can not be generated before the expiration of T2 [12].

B. Performance Metrics

The power on tag forward (POTF) is defined as the power received at the tag side needed to activate the chip. This parameter can be extracted from the minimum transmitted power by the reader $P_{t,min}$ which is able to activate the tag:

$$\text{POTF} = \frac{P_{t,min} G_t \lambda^2}{(4\pi d)^2} \quad (2)$$

where G_t is the gain of the transmitting antenna, λ is the wavelength used by the reader and d is the distance between the tag and the antenna.

The power on tag reverse (POTR) is defined as the modulated (effective) power backscattered by the tag and can be expressed as:

$$\text{POTR} = \frac{P_{r,d} (4\pi d)^2}{G_r \lambda^2} \quad (3)$$

where $P_{r,d}$ is the modulated received power by the reader and has been defined in (1). G_r is the gain of the receiving antenna of the reader.

The delta RCS σ_d , initially introduced in [13] and extended in [11] can also be used to characterize the modulation efficiency of the tag. This quantity can be expressed by:

$$\sigma_d = \frac{P_{r,d} (4\pi)^3 d^4}{P_{t,min} G_t G_r \lambda^2} \quad (4)$$

The forward read range corresponds to the maximum read range at which the tag can be activated in free space, assuming that the reader transmits the maximum EIRP allowed by the standard is given by:

$$d_f = \frac{\lambda}{4\pi} \sqrt{\frac{\text{EIRP}_{max}}{\text{POTF}}} \quad (5)$$

where EIRP_{max} but depends on the considered world region (e.g., 36 dBm in US).

The round-trip read range corresponds to the maximum read range at which the reader can detect the tag response in free space, assuming that the reader transmits the maximum EIRP allowed by the standard is given by [14]:

$$d_r = \sqrt[4]{\frac{\text{EIRP}_{max} G_r \lambda^2 \sigma_d}{(4\pi)^3 P_{r,min}}} \quad (6)$$

where $P_{r,min}$ is the reader sensitivity. Note that this round-trip read range is different from the reverse read range used in [9].

Finally, the real read range of the RFID system in free space is given by the minimum between the forward read range d_f and the round-trip read range d_r :

$$d = \min(d_f, d_r) \quad (7)$$

These parameters allow the tag designer to characterize any UHF tag and compare their performance.

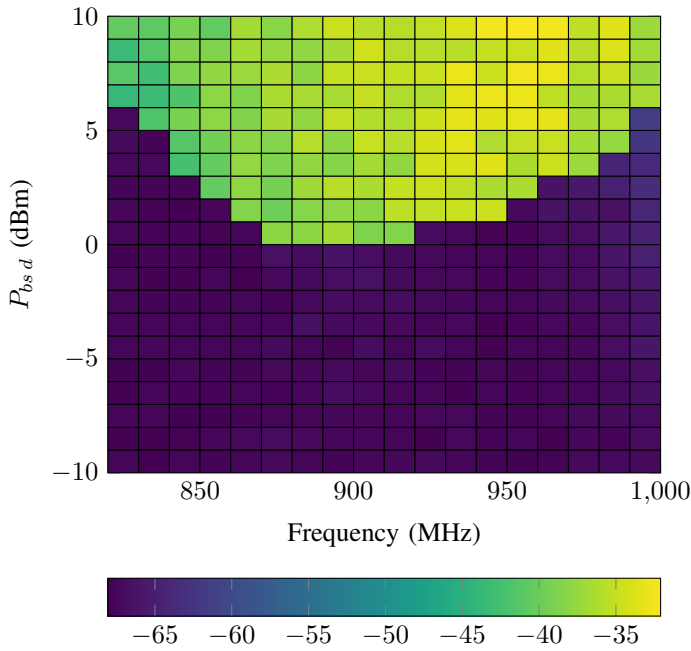


Fig. 3. Modulated backscattered power $P_{r,d}$ as a function of the frequency and transmitted power for the proposed measurement bench.

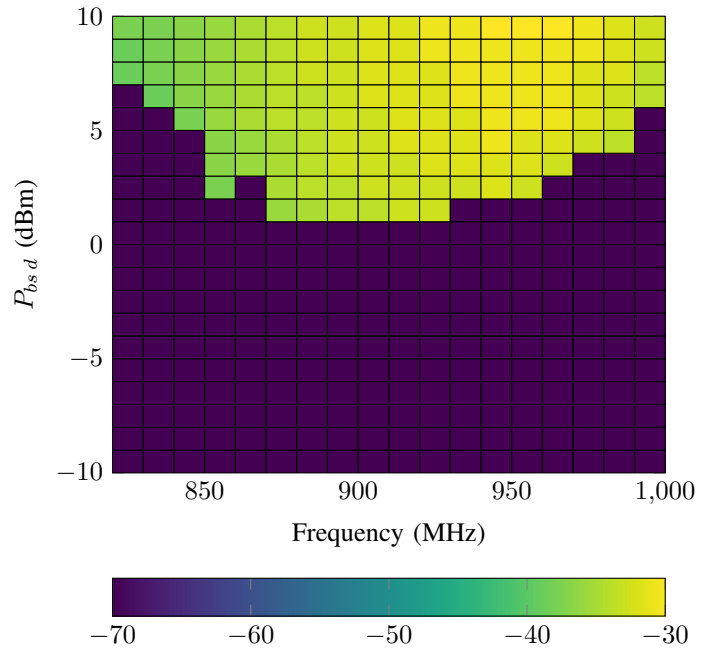


Fig. 4. Modulated backscattered power $P_{r,d}$ as a function of the frequency and transmitted power for the Voyantic Tagformance Pro.

C. Bench Calibration

Presented metrics do not take into account the different losses present during the transmission of the different signals. To realize an accurate measurement, calibration of the bench is needed to compensate for these effects. This calibration is done statically by estimating the losses along the transmit and receive path as a function of the frequency. These parameters can be accurately measured using a VNA and/or a power meter. For the antennas, the variation of the gain in the considered bandwidth needs to be known. Note that this calibration step is identical to the “calculated” calibration proposed by the Tagformance Pro reader.

IV. RESULTS

In this section we compare the performance of the same tag (Rafsec Dogbone, Monza 1 [15]) using the proposed measurement bench and the Tagformance Pro reader. Note that any tag can be used in practice. Both benches use the same monostatic configuration (same cables, circulator and antenna, distances, anechoic environment) and the same calibration. Modulated backscattered power is presented in both cases, in Fig. 3 and 4. Note that the same colorbar ranging from -70 dBm (blue) to -30 dBm (yellow) has been used to plot the two figures. Note that the measurement time for the Voyantic is less than 30 s, however our custom bench is much slower since it takes around 1 s to measure a single point. Thus complete measurement time for our system is around 7 min. Note that improvements can still be done by doing the acquisition during the transfer of the data or by processing the data directly on the spectrum analyzer.

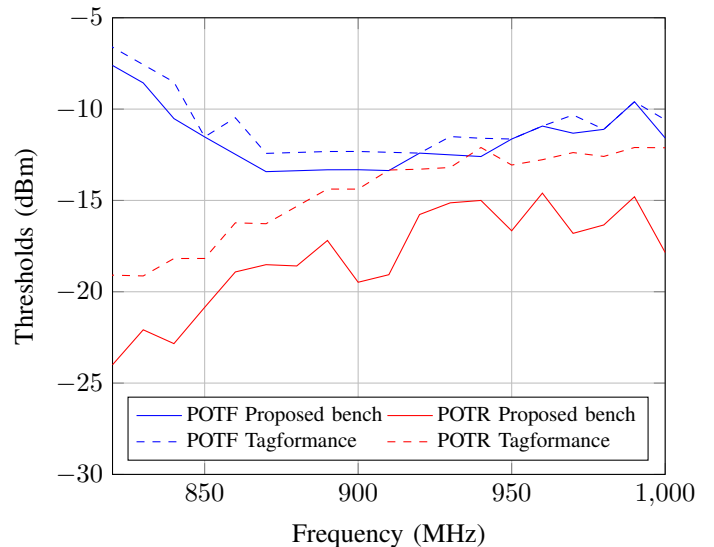


Fig. 5. Power on tag forward (POTF) and power on tag reverse (POTR) for the proposed bench and for the Voyantic Tagformance Pro.

Fig. 5 presents the POTF and the POTR for the Rafsec Dogbone tag. Note that the POTF for both benches are in very good agreement and the difference is below 2 dB over the whole bandwidth. The POTF is on average 4 dB lower for our bench and is more impacted by noise. The difference of 4 dB is at the time of the writing still under investigation. The sensitivity of the bench has been estimated at -70 dBm with a span of 2 MHz. Higher sensitivity can be achieved by simply reducing the span value.

Fig. 6 presents the delta RCS σ_d of the Rafsec Dogbone tag.

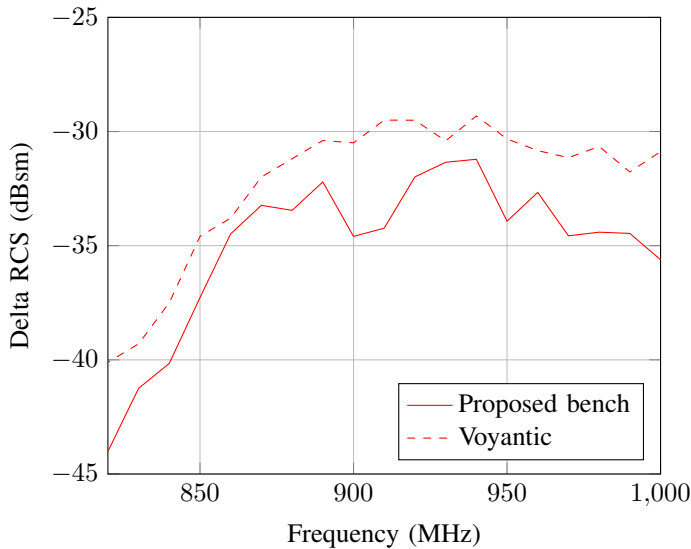


Fig. 6. Delta RCS σ_d for the proposed bench and for the Voyantic Tagformance Pro.

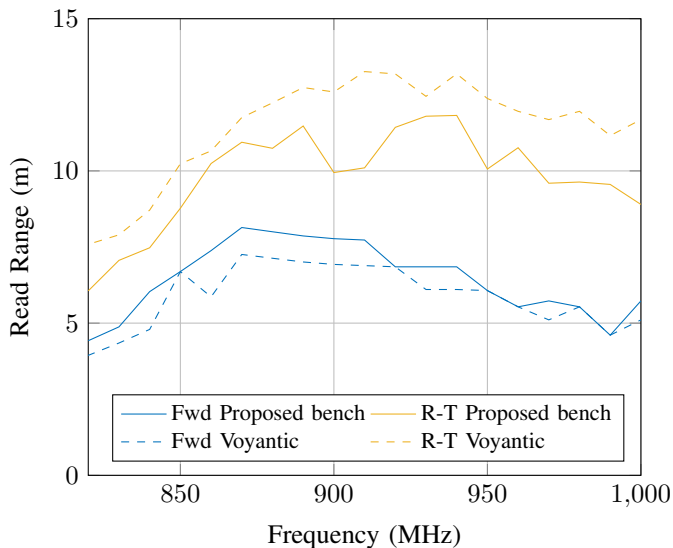


Fig. 7. Forward read range d_f and round-trip read range d_r for the proposed bench and for the Voyantic Tagformance Pro.

Note that these curves have been obtained using the definition presented in (4) for both benches. In theory, a passive tag operating at 915 MHz, can achieve a maximal delta RCS of -22.4 dBsm (57.5 cm²). However, for real RFID chips, impedance states are never perfect loads, thus delta RCS is generally lower than the maximum value. At 915 MHz, the delta RCS of the Rafsec Dogbone presents a maximum value of -30 dBsm (measured by the Voyantic) and -34 dBsm (measured by the proposed bench). The difference comes directly from the one observed in Fig. 5.

Finally, the read range of the RFID system assuming an EIRP of 36 dBm and a reader sensitivity of -75 dBm is presented in Fig. 7. Note that the forward and round-trip read

ranges have been computed by using (5) and (6). Since the Monza 1 is an old chip, we can check that the read range is limited by the forward read range.

V. CONCLUSION

In this paper, an open measurement bench is introduced to characterize the performance of any UHF RFID tag. The bench offers a higher flexibility compared to industrial testbenches in terms of operational bandwidth. However the system is limited by the measurement speed and can not satisfy the timing requirement to observe the EPC of the tag. We hope that this concept can be reproduced and improved by other researchers.

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