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# Hands-on 2.4 GHz RFID

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**Abstract**—This article presents a RFID system (i.e., tag and reader) allowing to experiment with the RFID technology at 2.4 GHz. The tag is a classical tag designed around 915 MHz whose antenna has been modified to operate at 2.4 GHz. The reader is based on an Arduino platform with a nRF24L01+ module and an envelope detector. This system is entirely compatible with the regulations (FCC and ETSI) and the Gen2 standard. All file design will be released in open source for the community. Finally the total cost of the prototype is under \$40 and can be built by students.

**Index Terms**—Arduino, nRF24L01+, Software Defined Radio.

## I. INTRODUCTION

The RFID technology as we know it has been standardized and deployed in the 860–960 MHz band. This band is also commonly known as the Ultra High Frequency (UHF) band. For example, in US, the unlicensed ISM band is defined between 902 and 928 MHz. In Europe, the UHF band has been chosen between 865–868 MHz (with a reduced power).

This choice seems so obvious today that it is difficult for younger researchers to imagine an RFID system operating outside the UHF band. However, before the adoption of the standards, the choice between the UHF (860–960 MHz) and the 2.4 GHz bands has been debated. At that time, the UHF band emerged as the preferred solution since it represents good tradeoff between the size of the antenna and the read range at which we can read a tag. This band also introduces some limitations since the exact frequency band and the maximum radiated power depends on local regulations and are different in each world region. This last remark leads to different reader types and different tag design depending on the world region.

Compared to the UHF band (860–960 MHz), the 2.4 GHz band (2400–2484 MHz) offers a reduction of the antenna size, an increased bandwidth of 84 MHz and most importantly the same band in any world region. The 2.4 GHz band also comes with significant drawbacks such as the reduction of the read range due to the higher path loss and a (slightly) lower efficiency for the CMOS circuitry.

Since the deployment of the RFID technology in the UHF band, the literature for 2.4 GHz RFID remains sparse. The only notable exception appears in [1] where the authors succeed to modify a UHF reader to operate at 2.4 GHz. The modification requires the use of a local oscillator and two mixers to upconvert and downconvert the signal. This approach allows them to maintain the functionalities of the reader (modulation, timing, anti-collision) and to translate them directly around 2.4 GHz. Moreover, the performance of this reader remains

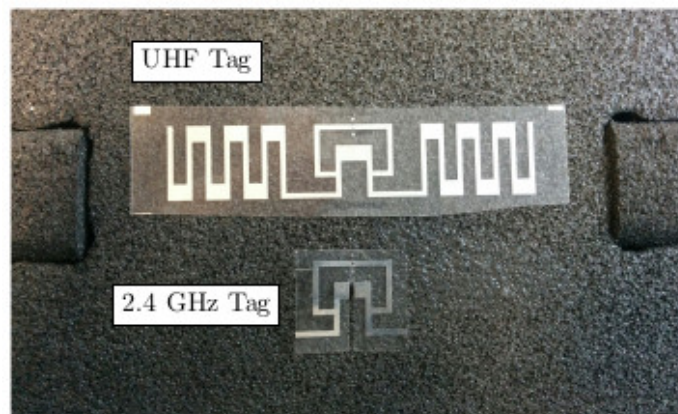


Fig. 1. Photograph of the proposed RFID tag: up, original design at 915 MHz, down: optimized for 2.4 GHz.

very good and was able to read tags at 2.4 GHz at a distance of 30 cm with an Equivalent Isotropic Radiated Power (EIRP) of 20 dBm. This read range can theoretically reach 3 m with the maximum EIRP. Compared to this approach, this paper presents a custom reader operating directly at 2.4 GHz. This 2.4 GHz RFID system is able to handle a small subset of the RFID protocol which is sufficient to read a tag at 2.4 GHz. This reader can be easily reproduced by students and represents a total cost lower than \$40. All file design will be released in open source for the community [2].

## II. TAG DESIGN

The proposed tag is based on a PID Explorer 70x14 designed by Paragon ID. This tag is based on a M730 chip from Impinj. The procedure to optimize the tag at 2.4 GHz has been largely inspired from the one described in [1] and requires the cutting of the two arms of the dipole to reduce the size of the antenna. Moreover the T-match has been cut to significantly reduce the imaginary part of the antenna impedance. The whole procedure can be realized with a simple pair of scissors. Note that, even if the tag is optimized for 2.4 GHz, all messages are compatible with the classical EPC Gen 2 protocol [3] since the tag is still based on a compliant UHF chip. A picture of the tag optimized at 2.4 GHz is presented in Fig. 1 with the original UHF tag.

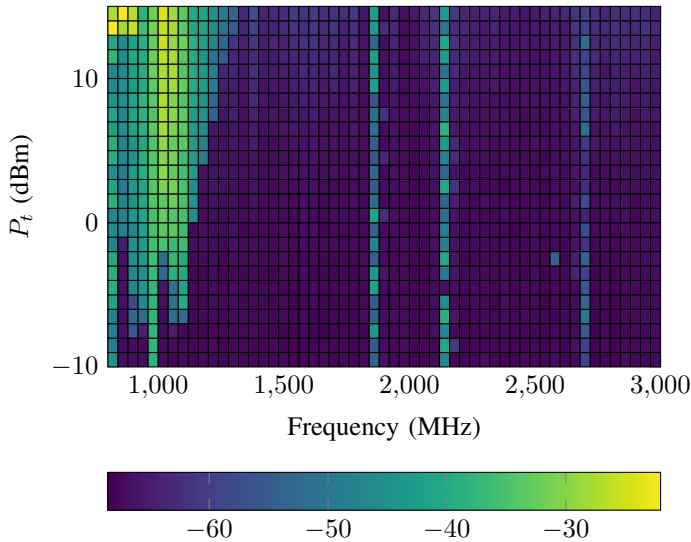


Fig. 2. Modulated power backscattered by the tag in dBm in real environment before cutting (vertical lines are other transmissions).

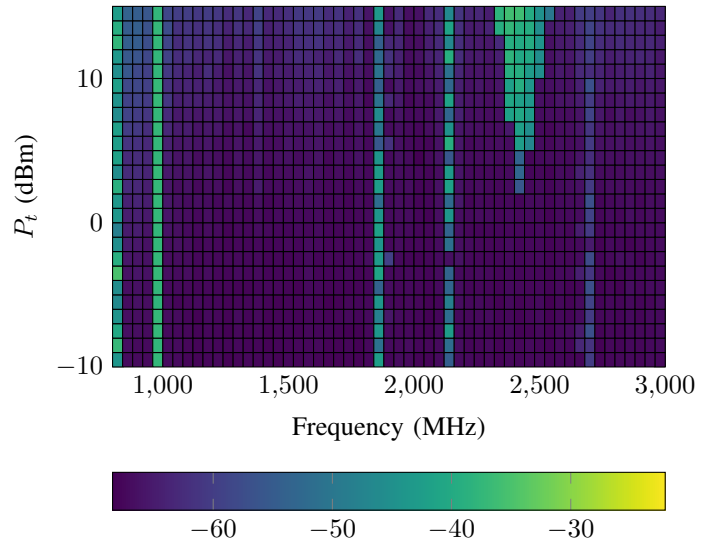


Fig. 3. Modulated power backscattered by the tag in dBm in real environment after cutting (vertical lines are other transmissions).

### III. READER DESIGN

The reader is based on the architecture presented in [4]. This reader can be considered as a SDR reader since all operations related to the RFID protocol are implemented in software and executed by the ATmega328p in the Arduino platform. The analog front-end of the reader is composed of a separate Tx and Rx. The transmitter is based on a nRF24L01+ module (generating a CW) and an SPDT switch (generating the ASK modulation). The receiver is based on an envelope detector and can be built on a protoboard. Note that the envelope detector used has been designed for the UHF band in [4] but can still operate at 2.4 GHz without any modification. Finally the price of the Arduino platform is \$20, the nRF24L01+ module and the switch can be found ant \$10 each. The total cost of the system is around \$40.

### IV. RESULTS

The performance of the tag before the cutting is presented in Fig. 2 and compared to the performance of the tag after the cutting in Fig. 3. Both figures present the modulated backscattered power as a function of the frequency and the transmitted power. These figures have been obtained using a custom bench composed of a signal generator and a real time spectrum analyzer. This bench is able to produce the same results as the Voyantic Tagformance Pro reader in read range mode [5]. Deep blue points correspond to a non-activation of the tag. Green and yellow points correspond to an activation of the tag. Note that vertical lines correspond to other transmissions present in the environment (GSM, EDGE, LTE). We can see that the cut tag is optimized at 2.4 GHz. At 2.4 GHz, the tag activation power has been estimated at  $-19$  dBm using the Friis equation. This activation power represents a reduction of 4.5 dB compared to the original UHF design. The delta RCS is equal to  $-28$  dBsm. Also by

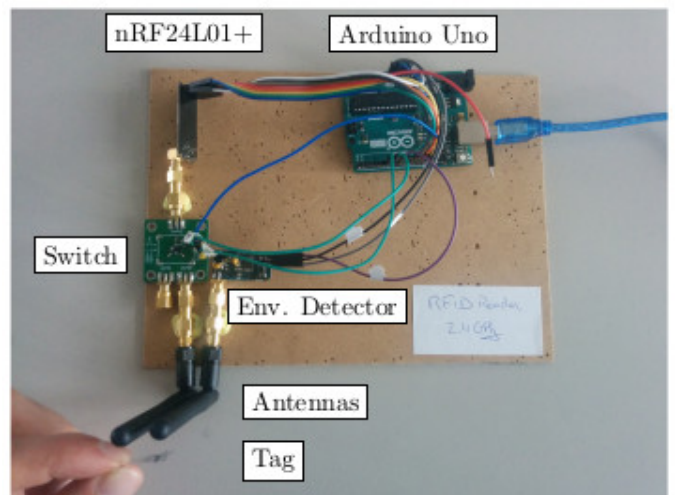


Fig. 4. Photograph of the proposed RFID reader and tag at 2.4 GHz.

observing the IQ signals of the real time spectrum analyzer, the proper functioning of the tag was verified.

The proposed reader has been used to read the optimized tag. Photograph of the proposed 2.4 GHz RFID system is presented in Fig. 4. Distance at which the tag can be activated represents a cylinder of 3 cm around the Tx antenna for a transmitted power of 0 dBm. Successful read range can be achieved at a distance of only a few millimeters but can be enhanced by increasing the transmitted power and by optimizing the envelope detector.

### V. CONCLUSION

In this paper, we present an open source 2.4 GHz reader system which can be built for less than \$40. This system is fully compatible with the standards and the Gen2 protocol.

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