2.4 GHz Passive Gen2 RFID System

Pavel Nikitin, Joshua Ensworth, K. V. S. Rao, Alberto Pesavento, John Kim

Impinj, Inc.
400 Fairview Ave N, Ste 1200, Seattle, WA 98109, USA
nikitin@ieee.org , jensworth@impinj.com , kvsrao@ieee.org , apesavento@impinj.com , jkim@impinj.com

***Abstract*— This work presents an experimental implementation of a passive Gen2 RFID system operating in 2.4 GHz band. The system re-uses existing off-the shelf RFID hardware: Impinj Speedway reader and Monza R6 IC. We analyze system performance and discuss various aspects of operating passive RFID in 2.4 GHz band.**

I. INTRODUCTION

At the dawn of UHF RFID, in early 1990s, both 860-960 MHz and 2400-2483.5 MHz bands (to which we will refer as 915 MHz and 2.4 GHz bands) were seriously considered for passive RFID systems. The choice of 860-960 MHz band for passive UHF RFID was largely dictated by longer desired read range for tag IC sensitivities of that era. At 2.45 GHz frequency, the wavelength is approximately 2.7 times smaller than at 915 MHz, thus the read range for the same EIRP and tag sensitivity is approximately 2.7 times shorter:

$$r_{tag} = \frac{\lambda}{4\pi}\sqrt{\frac{EIRP}{P_{tag}}} \qquad (1)$$

Assuming the RFID system range is limited by the forward link (powering the tag), Figure 1 shows maximum possible read range vs. tag sensitivity for both frequencies for a reader radiating 36 dBm EIRP. A good discussion of tradeoffs and advantages of higher frequencies for RFID is given in [1-2].

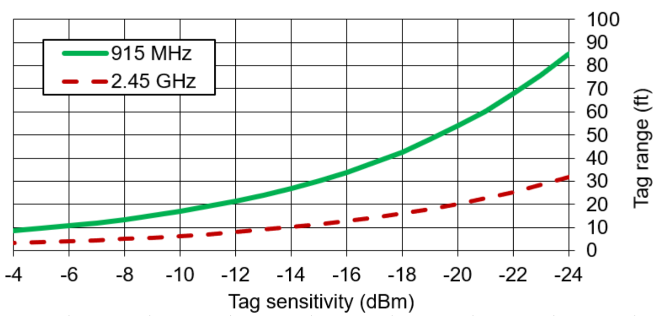

Figure 1 – Maximum tag read range vs. tag sensitivity in free space for 36 dBm EIRP.

Reference [3] presents a good comprehensive comparison between four different UHF RFID standards that existed in early 2000s. Since then, Gen2 became a prevailing UHF RFID standard. The performance of RFID readers and tag ICs have also dramatically improved [4]. There are many interesting works that use custom discrete microcontroller tags and software defined radios (SDR) for backscatter communication in 2.4 GHz and higher bands [5-7]. In this work, we demonstrate a fully functional passive RFID system that operates in the 2.4 GHz band but at the same time re-uses existing off-the shelf Gen2 RFID hardware (reader and tag IC).

II. THE READER

We used Impinj Speedway R420 FCC reader [8] in bistatic configuration with an addition of an external RF source and a few other RF components for properly upconverting the reader transmissions and downconverting the received tag signals as shown in the block diagram presented in Figure 2.

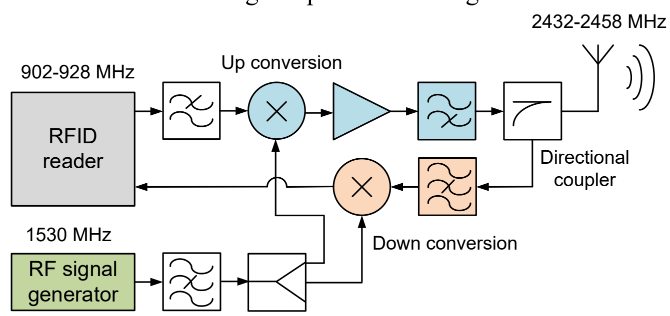

Figure 2 – Block diagram of RF front end of 2.4 GHz reader based on existing 915 MHz reader.

Our assembled reader system is shown in Figure 3. We used Agilent E4432B Signal Generator (providing 1530 MHz carrier signal), 2 dBi antenna (W1010 from Pulse Electronics), and several Mini-Circuits components: 3 dB power splitter ZN2PD-20, RF mixers ZX05-25MH, 20 dBm RF power amplifier ZRL-2400LN+ (to compensate for the large conversion loss of passive mixers), and various filters to filter unwanted harmonics: lowpass filter VLF-800+, bandpass filters VBF-1525+, high-pass filter ZFHP-2100.

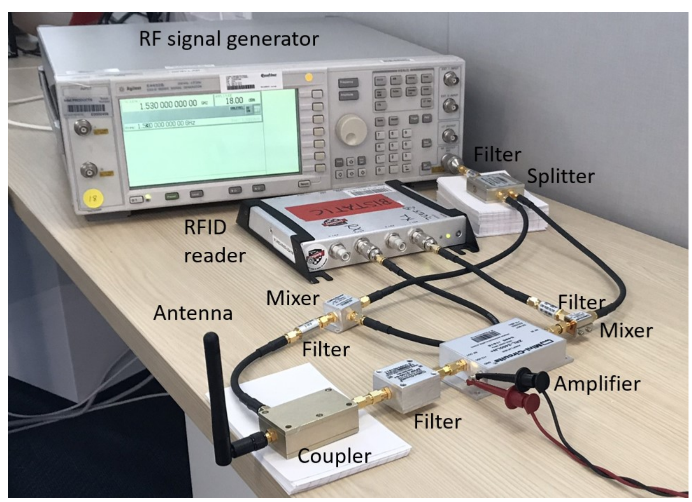

Figure 3 –2.4 GHz RFID reader system.

978-1-7281-1210-7/19/$31.00 ©2019 IEEE

III. THE TAG

There are currently no commercially available passive RFID ICs for 2.4 GHz band, thus we used available UHF Gen2 IC, Monza R6 [9]. Its simplified impedance model is a parallel RC circuit with the values R_p=1560 Ohm, C_p=1.44 pF. For modeling simplicity, we assumed that this model holds for 2.4 GHz band but due to lower rectifier efficiency and changes in impedance the tag sensitivity will be 3 dB worse than expected.

For prototyping simplicity we used an existing RFID tag with Monza R6, ER62 [10], and modified it using iterative analysis with CST [11] to make tag resonant in 2.4 GHz band. The modification is simple and can be done only by trimming as seen in Figure 4. Figure 5 shows tag sensitivity modeled from simulated antenna impedance and gain and tag IC model parameters. The impedance matching is not perfect but is sufficient for the verification of our system operation. The tag is expected to have a peak sensitivity of about -11 dBm in the middle of 2.4 GHz band. The modified tag size is 32 x 15 mm.

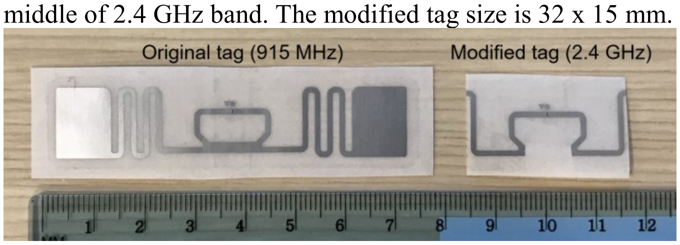

Figure 4 – 915 MHz RFID tag and its 2.4 GHz modification.

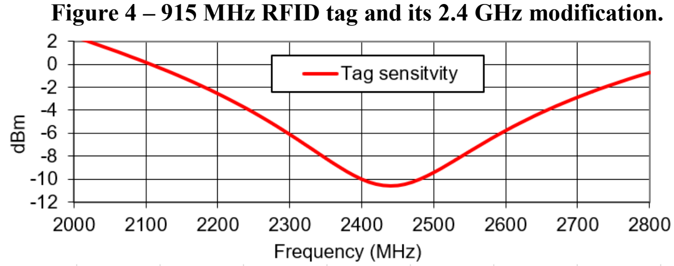

Figure 5 –Simulated 2.4 GHz tag sensitivity.

IV. EXPERIMENTAL RESULTS

The assembled testbed is shown in Figure 6. It was controlled using Impinj Item Test software. We found that at 17 dBm transmit power (into the antenna) we were able to read our 2.4 GHz tag using standard Gen2 commands at a maximum distance of approximately 1 ft. We also successfully read multiple tags.

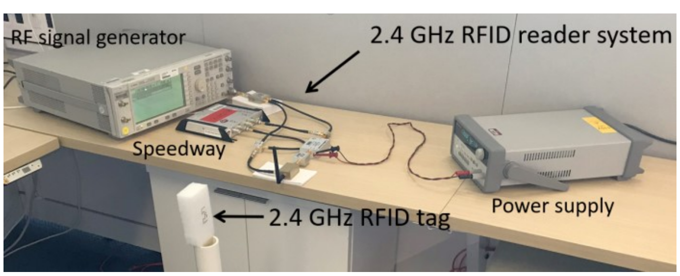

Figure 6 – Experimental 2.4 GHz RFID testbed.

For the transmit power of 17 dBm and antenna gain of 2 dBi, the radiated EIRP is 19 dBm. At 1 ft distance (which is in far field region for our 2.4 GHz reader antenna), the path loss at 2.4 GHz is 30 dB, and hence -11 dBm power is incident on the tag which agrees well with our simulations (see Figure 5).

V. DISCUSSION AND CONCLUSIONS

The maximum EIRP of our system is currently limited by the characteristics of its external RF components. We expect that by improving those to bring the EIRP to the maximum allowed 36 dBm (same FCC limitation for both 915 MHz and 2.4 GHz bands) and using a better matched tag antenna, the range of our experimental system can increase by at least a factor of 10.

Currently, the 915 MHz band is still undoubtedly the best band to use for UHF RFID in terms of longer read range and fewer in-band interference sources (the 2.4 GHz ISM band is very crowded). However, 2.4 GHz band has its own advantages. Interference sources (such as WiFi) can also be used to harvest extra power for tags [7]. Miniature 2.4 GHz tags can be used for tagging smaller items. Smart steerable RFID antenna arrays (such as [12]) can be made smaller at 2.4 GHz. Simpler 2.4 GHz antennas can be easily integrated or re-used in smartphones and handheld devices which already use 2.4 GHz band for Bluetooth and WiFi. Wider frequency bandwidth (83.5 MHz) available in 2.4 GHz band may require a different air protocol, coding, and modulation schemes but can result in significantly higher tag read rates and better tag localization accuracy.

To conclude, UHF RFID is very attractive technology because of its long read range (compared to LF and HF RFID) and the lowest endpoint radio (tag IC) power requirements and cost compared to all other existing wireless technologies. We demonstrated that Gen2 RFID system can operate in 2.4 GHz band using existing readers and tag ICs and we hope that the simple system described here can serve as a good educational experimental platform to allow students and researchers to study various aspects of using UHF RFID at higher frequencies.

REFERENCES

[1] J. D. Griffin and G. D. Durgin, "Complete link budgets for backscatter-radio and RFID systems", IEEE Antennas and Propagation Magazine, vol. 51, no. 2, pp. 11-25, April 2009

[2] D. Paret, "RFID at ultra and super high frequencies: theory and application", Wiley, 2010

[3] R. Glidden et al., "Design of ultra-low-cost UHF RFID tags for supply chain applications," in IEEE Communications Magazine, vol. 42, no. 8, pp. 140-151, Aug. 2004

[4] P. Nikitin, K. V. S. Rao and S. Lam, "UHF RFID tag characterization: overview and state-of-the-art," in Antenna Measurement Techniques Association Conference (AMTA), Seattle, 2012

[5] L. Catarinucci et al.,"A cost-effective SDR platform for performance characterization of RFID tags," in IEEE Transactions on Instrumentation and Measurement, vol. 61, no. 4, pp. 903-911, April 2012

[6] J. F. Ensworth and M. S. Reynolds, "BLE-backscatter: ultralow-power IoT nodes compatible with Bluetooth 4.0 (BLE) smartphones and tablets," in IEEE Transactions on MTT, vol. 65, no. 9, pp. 3360-3368, Sept. 2017

[7] N. Van Huynh et al., "Ambient backscatter communications: a contemporary survey," in IEEE Communications Surveys & Tutorials, vol. 20, no. 4, pp. 2889-2922, 2018

[8] Impinj Speedway R420 RFID reader, https://www.impinj.com/platform/connectivity/speedway-r420

[9] Monza R6 RAIN RFID endpoint IC, https://www.impinj.com/platform/endpoints/monza-r6/

[10] ER 62 UHF RFID tag, http://junmptec.com/index.php?m=content&c=index&a=show&catid=71&id=64

[11] CST 3D EM simulation software, https://www.cst.com

[12] xArray RAIN RFID Gateway , https://www.impinj.com/platform/connectivity/xarray