Slotted Triangular Monopole Antenna for UHF RFID Readers

Khaled ElMahgoub [1,2]

[1] Autoliv ASP, Inc.
1001 Pawtucket Blvd, Lowell, MA 01854, USA
[2] Auto-ID Labs, Massachusetts Institute of Technology
77 Massachusetts Avenue, Cambridge, MA 02139, USA
kelmahgoub@ieee.org

Abstract **─** A new compact slotted triangular monopole antenna for ultra-high frequency (UHF) radio frequency identification (RFID) applications is presented. The antenna exhibits an omnidirectional radiation pattern and has a bandwidth (BW) of more than 13%. It covers the global UHF RFID band and has a maximum gain of around 2.6 dBi. An overview of the antenna design along with the full wave simulation is provided. A prototype of the antenna is fabricated and tested. Good agreement is obtained between simulated and measured results. Moreover, the antenna is used with a UHF RFID reader in real use cases where read range and read rate with different commercial tags are used to evaluate the antenna performance.

Index Terms **─** Monopole antenna, Radio Frequency Identification (RFID), read range, read rate.

I. INTRODUCTION

These days' radio frequency identification (RFID) use cases have increased considerably. RFID is a technology which uses RF signals for automatic identification of objects. It is utilized for several applications as a part of different territories, for example, electronic toll gathering, retail administration, access frameworks and numerous others [1]. In spite of the fact that these applications are important around the world, diverse districts have distinctive administrative standards for ultra-high frequency (UHF) RFID frameworks. In China the UHF RFID bands are 840-845 MHz and 920-925 MHz, while for North America, Europe 902-928 MHz band, 865-868 MHz band are used respectively, while for Japan up till 2018 two bands can be used 916-924 MHz and 950-956 MHz. So for an UHF RFID item to work all inclusive it should be reconfigurable or has enough band to cover the whole UHF RFID band (840-960 MHz). This adds a challenge in designing a global UHF RFID antenna. Many broadband UHF RFID reader antennas have been proposed in literature [2]-[5].

In this paper, a new compact omnidirectional broadband antenna for UHF RFID is proposed. The antenna is based on a triangular monopole antenna structure with triangular slot [6]. It has an impedance matching (<10 dB) BW over 13% and covers the global UHF RFID band (840-860 MHz). The antenna has a maximum gain of 2.6 dBi, and a gain around 2.5 dBi over the entire band. The antenna is small (dimensions $< \lambda/3 \times \lambda/3$ at the center frequency of the band $f = 900$ MHz) and is suitable for small or handheld UHF RFID readers. The antenna was fabricated and different properties were measured, simulation and measured results showed good agreement. Moreover, the antenna was used with a commercial reader and real uses cases were tested.

The paper is organized as follows: In Section II, the antenna design is described, a parametric study is conducted to examine the effect of the slot dimensions and the final dimensions of the antenna are stated. In Section III, the antenna simulation and measurements results are provided. Conclusions are provided in Section IV.

II. ANTENNA DESIGN AND PARAMETRIC STUDY

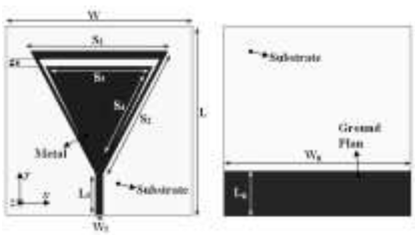
In this section, the design process of the antenna is described. The final design is shown in Fig. 1 and the final dimensions are stated. First step of the design process is using an equilateral triangular monopole antenna for wide band operation [7]; the antenna perimeter is chosen to be equal $\lambda/2$ where λ is the wavelength at 900 MHz. A microstrip line is used for feeding, and the antenna is mounted over a Roger RT/droid 6006 substrate with $\varepsilon_r = 6.15$, $\tan\delta = 0.0019$, and thickness of 1.9 mm. Second step is adding a triangular slot to enhance the matching, and to study the effect of such slot a parametric study was conducted on the dimensions of the slot using high frequency structural simulator (HFSS) [8]. Two parameters are studied, first the slot gap size g, which is changed while other dimensions are kept fixed. As shown in Fig. 2 (a), it is clear that the gap size can be used to shift the

Submitted On: August 23, 2015
Accepted On: December 13, 2015

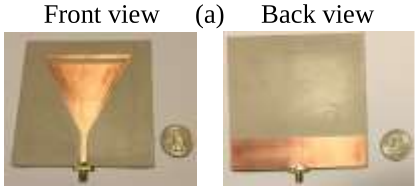
matching BW toward the required center frequency. Based on the parametric study g = 4.215 mm was chosen for this design. The second parameter is the slot width S_3, the slot width is changed while other dimensions are kept fixed. It could be noticed from Fig. 2 (b) that the slot width also causes a shift in the center frequency, S_3 = 60.415 mm was chosen. Moreover, genetic algorithm optimization was used to finalize the rest of the dimensions. The default parameters of HFSS genetic algorithm were used as follows: maximum number of generations is 1000, and number of individuals for parents, mating pool, children, next generation is set to 30, the number of survivors is set to 10, the goal was set that $|S_{11}|$(dB) at 900 MHz is ≤ -25 dB.

III. SIMULATION AND MEASUREMENTS RESULTS

In this section, the full wave simulations are carried out using HFSS. Moreover, measurement results are provided for the fabricated antenna shown in Fig. 1 (b). There is good agreement between the simulation and the measurement results.

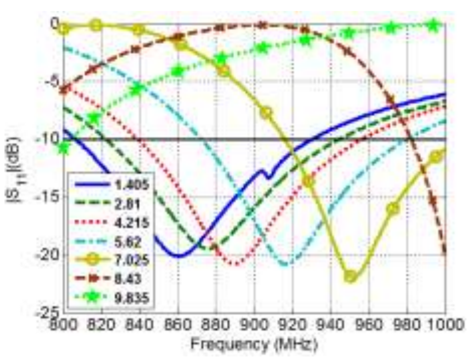


Front view (a) Back view

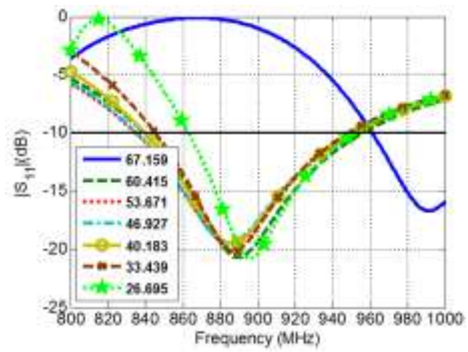


(b)

Fig. 1. (a) Antenna design, and (b) fabricated antenna (all dimensions in mm) [L = W = W_g = 105, S_1 = 77.275, S_2 = 77.553, S_3 = 60.415, S_4 = 56.55, L_f = 22.914, W_f = g = 4.215].



(a)



(b)

Fig. 2. Parametric study (units in mm): (a) g and (b) S_3.

A. Return loss

First the return loss is simulated and measured, and the results are shown in Fig. 3. As shown in the figure, the antenna is matched ($|S_{11}|$ < -10 dB) for the entire UHF RFID band (840 MHz to 960 MHz) with BW of more than 13%. Good agreement between simulated and measured results can be noticed.

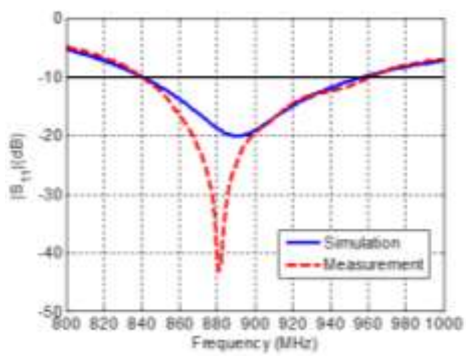


Fig. 3. Simulated and measured $|S_{11}|$ in dB.

B. Maximum gain

The maximum gain (at $\varphi = \theta = 0$) of the antenna is simulated and measured for different frequencies, the measurement setup is shown in Fig. 4 (a). The antenna has a gain around 2.5 dBi for the entire RFID UHF global band as shown in Fig. 5.

C. Radiation pattern

The radiation patterns of the antenna are simulated and measured at 915 MHz (center frequency for North America band). Measurement setup is shown in Fig. 4 (b), the radiation pattern are measured using what is defined in this paper as active measurement technique (measurement is done while reading a real tag). In this measurement technique the antenna is connected to M6e-M reader [9] (commercial UHF RFID) and the reader is set to the required frequency, the reader software is used to read a real tag (Alien Higgs 3 ALN-9640-Squiggle [10]) and report the tag received power.

The antenna is set at a fixed distance from the tag (1 meter) and the antenna is rotated using the 2 stepper motors as shown in the Fig. 4 (b). The received power at different angles is used to plot the measured radiation pattern (normalized to maximum received power). Figure 6 shows the different plane cuts for the radiation pattern, as shown the antenna exhibits an omnidirectional radiation pattern. Moreover, there is good agreement between the simulated and measurement results.

D. Read range

The Friis equation is used to calculate the theoretical maximum read range of an Alien Higgs 3 ALN-9640-Squiggle tag as follows:

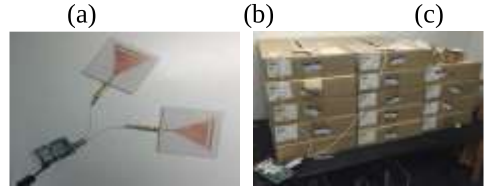
$$r = \frac{\lambda}{4\pi}\sqrt{\frac{P_t G_t(\theta,\varphi) G_r(\theta,\varphi)\, p \left|T_{antenna}\right|^2 \left|T_{tag}\right|^2}{P_{th}}}\,, \qquad (1)$$

where, r is the read range in meters, λ is the wavelength in meters, P_t is the transmitted power by the reader in watts, G_t the gain of the transmitting antenna, G_r the gain of the receiving tag antenna, p the polarization efficiency, $T_{antenna}$ is the power transmission coefficient of the antenna (account for mismatch), T_{tag} is the power transmission coefficient of the tag and P_{th} is the minimum received power necessary to turn on the chip in watts. For maximum theoretical read range the following parameters are used: P_t is used as 1 W, which is the maximum allowed transmitted power in USA, p is used as 1 for polarization matching, P_{th} is used as -14 dBm (39.8107 µW) as provided by the chip vendor [11] for the measured equivalent circuit, λ is set for each frequency from 800 MHz to 1 GHz. As for the return loss and the transmitting maximum gain they are calculated from the HFSS simulation, the maximum gain (at $\varphi = \theta = 0$) is used for maximum read range. While the receiving gain is used as 2 dBi for small dipole and T_{tag} is assumed as 1 for matching case. The read range is around 7.5 meter on average, and it has a maximum value of 8 meter in the 840 MHz China band. Moreover, the read range was measured using the M6e-M reader and two commercial tags Alien Higgs 3 ALN-9640-Squiggle, and Monza 4 Frog 3D tag [12]. The measurement setup is shown in Fig. 4 (c), the reader is set to 5 different frequencies (866.3, 915.25, 918.5, 919.2 and 922.625 MHz) to cover most of the UHF RFID global band, and the reader power was set to 30 dBm. The theoretical result is compared with the measurement results in Fig. 7. As shown in Fig. 7, the measured read range for the ALN-9640-Squiggle tag is 6 meter for EU band and around 6.5 meter for USA band, which is less than the maximum theoretical read range, and this is due many factors such as the return loss of the tag in real case can't be neglected, also polarization mismatch factor should be added due to misalignment, in addition the tag antenna gain might be less the 2 dBi used in the theoretical read range calculation. Moreover, the read range of the Frog 3D tag is less than the ALN-9640-Squiggle due to polarization mismatch, the Frog 3D tag is dual polarized while the other tag is linear polarized which is in alignment with the proposed antenna polarization.

E. Read rate

The read rate is measured using two fabricated prototypes of the proposed antenna connected to the M6e-M reader as shown in Figs. 4 (d) and 4 (e). The universal reader assistant (URA) software [13] is used to read a large tag population of 230 GEN2 Tags with several chips and antennas. The default profile is used with the following configuration: region is set to USA with band 902 to 928 MHz with 50 hopping frequency, transmitted power of 30 dBm, two antenna ports 1 and 2, Miller 4 encoding, backscattered Link Frequency (BLF) of 250 kHz. As shown in Fig. 8, the reader reads 221 unique tags per second (tags/sec), while the reader reads 220 tags/sec when using two 6 dBi commercial antennas set underneath the table as shown in Fig. 4 (e). The result proves that the proposed antenna can be used in real life use cases.

(a) (b) (c)



(d) (e)

Fig. 4. Measurement setup: (a) antenna gain, (b) radiation pattern, (c) read range, (d) commercial reader, and (e) read rate.

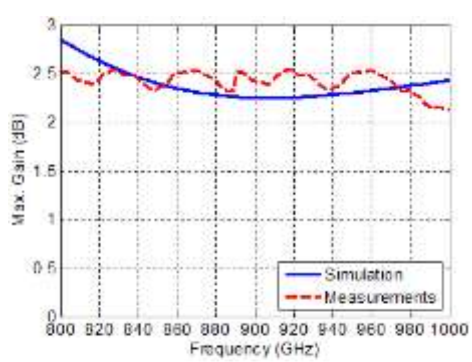
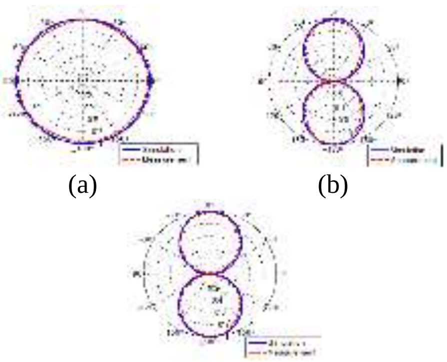


Fig. 5. Simulated and measured maximum gain versus frequency.



(a) (b)

(c)

Fig. 6. Simulated and measured radiation patterns normalized E_{total} at 915 MHz: (a) x-z, (b) y-z, and (c) x-y planes.

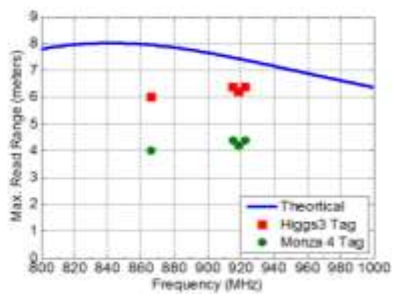


Fig. 7. Transmission coefficient for sandwiched composite-FSS structure under oblique incident TE^z plane wave ($\theta = 30^o$, $\varphi = 60^o$).

Fig. 8. Read rate measurements.

IV. CONCLUSION

A compact slotted triangular monopole antenna for universal UHF RFID applications is presented. The antenna exhibits an omnidirectional radiation pattern and has a bandwidth (BW) of more than 13%, and a maximum gain of around 2.6 dBi. The antenna design process was introduced and a prototype of the antenna was fabricated and measured. Good agreement is observed between the full wave simulation and measured results. Moreover, the antenna performance was evaluated with a UHF RFID reader in real use cases where read range and read rate with different commercial tags were measured. The antenna is suitable for small or handheld global UHF RFID readers.

REFERENCES

[1] K. ElMahgoub, T. Elsherbeni, F. Yang, A. Elsherbeni, L. Sydänheimo, and L. Ukkonen, “Logo–antenna based RFID tags for advertising applications,” *ACES Journal, Special Issue on Computational and Experimental Techniques for RFID Systems and Applications*, part I, vol. 25, no. 3, pp. 174-181, Mar. 2010.

[2] J. Lu and S. Wang, “Planar broadband circularly polarized antenna with square slot for UHF RFID reader,” *IEEE Transaction on Antennas and Propagation*, vol. 60, no. 1, pp. 45-53, Jan. 2013.

[3] Z. Wang, S. Fang, S. Fu, and S. Jia, “Single-fed broadband circularly polarized stacked patch antenna with horizontally meandered strip for universal UHF RFID applications,” *IEEE Transaction on Microwave Theory and Techniques*, vol. 59, pp. 1066-1073, Apr. 2011.

[4] X. Liu, Y. Liu, and M. M. Tentzeris, “A novel circularly polarized antenna with coin-shaped patches and a ring-shaped strip for worldwide UHF RFID applications,” *IEEE Antennas and Wireless Propagation Letters*, vol. 14, pp. 707-710, Dec. 2014.

[5] C.-C. Lin, L.-C. Kuo, H.-R. Chuang, and Y.-C. Kan, “A universal UHF RFID reader antenna,” *IEEE Transaction on Microwave Theory and Techniques*, vol. 57, pp. 1275-1282, May 2009.

[6] K. ElMahgoub, “Omnidirectional triangular antenna for UHF RFID readers,” *IEEE Antennas and Propagation Society International Symposium (APSURSI)*, pp. 1296-1297, Jul. 2014.

[7] C.-C. Lin, Y.-C. Kan, L.-C. Kuo, and H.-R. Chuang, “A planar triangular monopole antenna for UWB communication,” *IEEE Microwave and Wireless Components Letters*, vol. 15, no. 10, pp. 624-626, Oct. 2005.

[8] HFSS: http://www.ansys.com/Products/Simulation+Technology/Electromagnetics/Signal+Integrity/ANSYS+HFSS

[9] ThingMagic M6e-Micro reader, http://www.thingmagic.com/embedded-rfid-readers/m6emicro/1-embedded-rfid-readers/394-m6emicro

[10] ALN-9640-Squiggle: http://www.alientechnology.com/wp-content/uploads/Alien-Technology-Higgs-3-ALN-9640-Squiggle.pdf.

[11] Higgs3 IC: http://www.alientechnology.com/wp-content/uploads/Alien-Technology-Higgs-3-ALC-360.pdf.

[12] https://www.smartrac-group.com/files/content/Products_Services/PDF/Frog3D_M4.pdf

[13] ThingMagic Universal Reader Assistant (URA), http://www.thingmagic.com/images/Downloads/software/URABonjourSetup64.zip