Miniature RFID tri-band CPW-fed antenna optimised using ISPO algorithm

H.H. Li, X.Q. Mou, Z. Ji, H. Yu, Y. Li and L. Jiang

A novel tri-band CPW-fed antenna designed for RFID applications is reported. Limited to 30 × 30 mm^2 area on a PCBoard with $\varepsilon_r = 4.4$, the antenna has four U-shaped, two F-shaped and two L-shaped slots as additional resonators to achieve multi-band operation. The intelligent single particle optimisation (ISPO) algorithm is used to determine the optimised slot configuration for the best return loss at 0.92, 2.45, and 5.8 GHz simultaneously. The performance of the designed antenna was characterised through simulations using the finite element method.

Introduction: Radio frequency identification (RFID) is a contactless automatic identification technology [1]. It has been used extensively in a variety of applications, such as supply chain management, logistics tracking, access control and public transportation card. Considering its immense potential, several bands ranging from 125 KHz to 5.8 GHz are allocated to RFID related applications, with 0.92, 2.45, and 5.8 GHz among the most popular frequencies. Recently, the need for a multi-band antenna has gained attention since it is more desirable for a single system to support multiple RFID standards simultaneously. However, most of the reported multi-band antennas, such as [2], [3] and [4], can either only operate at two frequency bands, or require relatively large areas.

In this Letter, we report a miniature tri-band CPW-fed antenna for 0.92/2.45/5.8 GHz applications. Limited to 30 × 30 mm area on a PCBoard with $\varepsilon_r = 4.4$, the antenna geometric configuration was optimised by the intelligent single particle optimisation (ISPO) algorithm [5]. The return loss and the radiation pattern of the finalised design are verified by finite element method (FEM) simulations.

Design methodology: The antenna is implemented on a low-cost FR-4 substrate with dielectric constant $\varepsilon_r = 4.4$, loss tangent $\tan\delta = 0.02$ and thickness $h = 1.52$ mm (Fig. 1). A 50 Ω CPW transmission line is used for the antenna feed. The width of the feeding line is fixed as $S = 2.6$ mm, and the gap between the feeding line and the ground plane is $G = 0.2$ mm. To achieve multi-band resonance, the antenna has four U-shaped, two L-shaped and two F-shaped slots. The slots, including the two symmetric L-, two symmetric F- and the two larger U-shaped branches ($L_5 \times W_4$) are introduced to increase the antenna electrical length at the two lower frequency bands (0.92 and 2.45 GHz), and the two smaller U-shaped branches ($L_6 \times W_7$) are utilised as refiners to slightly adjust the antenna frequency response [6].

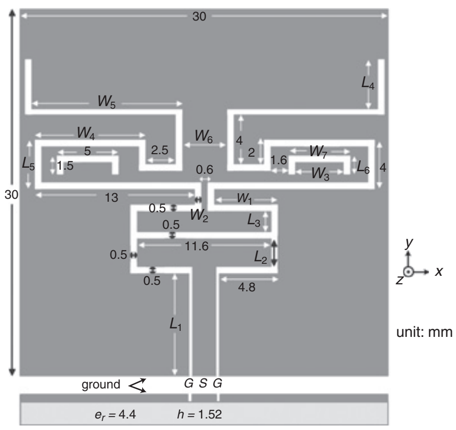

Fig. 1 *Geometry of proposed tri-band antenna (top view and side view)*

To optimise the antenna input impedance within the targeted frequency bands simultaneously, the geometric configurations of the slots are determined using the ISPO algorithm. The ISPO method is based on an analogy with models of the social behaviour of groups of simple individuals, and it is a method specialised for solving complicated multidimensional problems [5]. Using this algorithm, each potential solution is represented as a particle with a velocity vector and a position vector, which is partitioned into sub-vectors with a smaller number of dimensions. During the updating process, the velocity vector required for updating the position vector will be increased or slowed down depending on the fitness value; when the fitness value is not improved after several iterations in the sub-vector updating process, the particle will increase the diversity of velocity in order to escape from the local optimum. Detailed discussion of the ISPO algorithm can be found in [5].

Applying the ISPO algorithm to the antenna optimisation, the target of the optimisation process is set to achieve better than −10 dB impedance matching at 0.92, 2.45, and 5.8 GHz at the same time. For this purpose, a total of nine physical dimensions (L_1, L_2, L_3, L_4, W_1, W_2, W_3, W_4, W_5) of the antenna are defined as variables, which form the position vector described in the algorithm. As shown in Table 1 (upper part), for each of these variables, appropriate minimum and maximum values are specified. Based on [7], the fitness function (FF) for this optimisation process can be derived as

$$FF = 0.33\frac{S_{11}(0.92\,\text{GHz})}{-10} + 0.34\frac{S_{11}(2.45\,\text{GHz})}{-10} + 0.33\frac{S_{11}(5.8\,\text{GHz})}{-10} + \sum_{i=0}^{3} G_i \qquad (1)$$

$$G_i = \begin{cases} 1, & \text{if } S_{11} \le -10\,\text{dB} \\ 0, & \text{if } S_{11} > -10\,\text{dB} \end{cases}$$

where $i = 1$, 2, and 3 are used to represent 0.92, 2.45, and 5.8 GHz, respectively.

Table 1: Design parameters for multi-band antenna

Ranges of nine physical dimensions in ISPO algorithm

Parameter	L_1	L_2	L_3	L_4	W_1	W_2	W_3	W_4	W_5
Range (mm)	3–9	0.5–5	0.5–5	0.5–5	4–8	0.2–1.5	1–6	8–10	2–12.5

Physical parameters of finalised antenna

Parameter	L_1	L_2	L_3	L_4	L_5	L_6	W_1	W_2	W_3	W_4	W_5	W_6	W_7
Values (mm)	8.7	2.3	1.4	3.8	4	1.5	5.4	0.6	4	9	12.5	3.8	5

The convergence progress of this ISPO optimisation is shown in Fig. 2. It appears that the algorithm is extremely effective. Initially, the vector composed of the nine aforementioned variables is randomly positioned in the solution space. As the optimisation process goes by, the return loss within the two higher frequency bands quickly reaches the targeted value. But to achieve −10 dB impedance matching at the lowest band, the antenna performance at the two higher bands has to be compromised. As the fitness value becomes more stabilised, after five iterations, the return loss within all three frequency bands reaches the design target. The physical parameters of the finalised antenna are summarised in Table 1 (lower part).

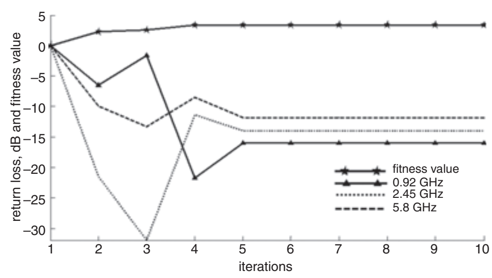

Fig. 2 *Progress of ISPO method with fitness function value and results of return loss at 0.92, 2.45, 5.8 GHz, respectively*

Simulation results: The ISPO-optimised multi-band antenna is verified using the FEM. As shown in Fig. 3, the simulated return losses are −15.96, −13.98, and −11.83 dB at the targeted frequency bands, all better than the design target. The bandwidth of the finalised antenna, which is defined as the frequency range within which the antenna achieves better than −10 dB matching (VSWR ≤ 2), is 10 MHz at the 0.92 GHz band, 30 MHz at the 2.45 GHz band, and 710 MHz at the 5.8 GHz band.

The radiation patterns of the antenna are also characterised, as shown in Fig. 4. It appears that the antenna radiates nearly omnidirectionally in the *xz*-plane, but the radiation patterns at all three bands show two nulls in the *yz*-plane at $\theta = \pm 90°$. Note that the antenna has relatively strong cross-polarised radiation (∼20 dB below the co-polarised radiation), which is advantageous for RFID applications since the tag-reader orientation is not strictly limited. The antenna gain at the simulated frequencies is −12.1, −1.7, and 5.2 dBi, respectively.

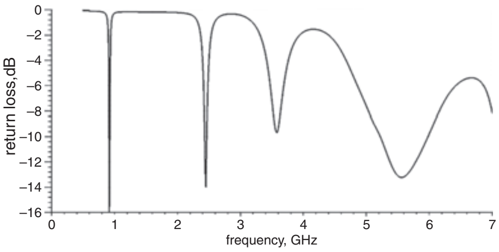

Fig. 3 *Return loss of proposed tri-band antenna obtained by FEM*

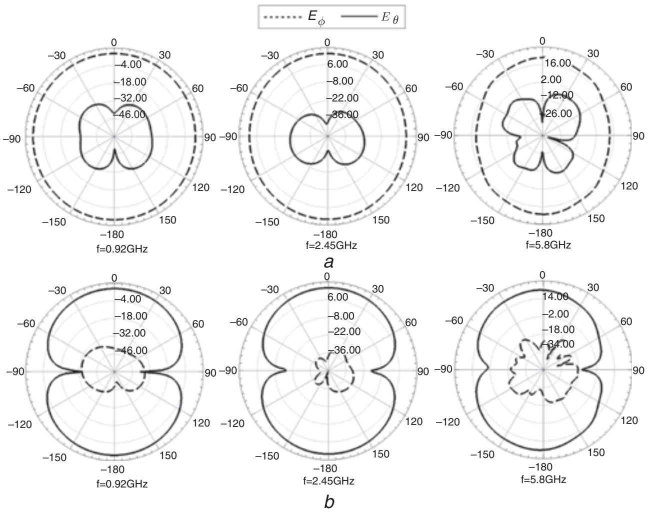

Fig. 4 *Radiation patterns of proposed antenna in xz-plane and yz-plane*
a Radiation patterns in *xz*-plane
b Radiation patterns in *yz*-plane

Conclusion: A novel tri-band RFID tag antenna designed for RFID applications is reported. Limited on a substrate of 30 × 30 mm^2 with $\varepsilon_r = 4.4$, the antenna is resonated to multiple frequency bands by introducing four U-shaped, two F-shaped and two L-shaped branches as additional resonators. To achieve impedance matching at 0.92, 2.45, and 5.8 GHz simultaneously, the ISPO algorithm is utilised to help determine the slot geometric configurations. The performance of the ISPO-optimised antenna is characterised using the FEM method, and simulation results show that the return loss within all the targeted frequency bands is better than −10 dB.

Acknowledgments: The authors thank the National Natural Science Foundation of China (NSFC) under grant numbers 60872125 and 60901016, the Fok Ying-Tung Education Foundation, the Guangdong Natural Science Foundation, Shenzhen City Foundation for Distinguished Young Scientists, SRF for ROCS, SEM and the SZU R/D Fund.

17 November 2010
doi: 10.1049/el.2010.3065

H.H. Li and X.Q. Mou (*School of Electronics and Information Engineering, Xi'an Jiaotong University, Xi'an 710049, People's Republic of China*)

Z. Ji, H. Yu, Y. Li and L. Jiang (*College of Computer Science and Software Engineering, Shenzhen University, Shenzhen 518060, People's Republic of China*)

E-mail: jizhen@szu.edu.cn

Z. Ji: W. Yu, Y. Li and L. Jiang: Also with the Shenzhen Key Laboratory of Embedded System Design, Shenzhen, China

References

1 Finkenzeller, K.: 'RFID handbook: fundamentals and application in contactless smart cards and identification' (John Wiley and Sons Inc., UK, 2003, 2nd edn)
2 You, B., Lin, B., Zhou, J., and Xu, W.: 'Dual-frequency folded dipole antenna with PBG structure', *Electron. Lett.*, 2009, **45**, (12), pp. 584–588
3 Hu, S.M., Zhou, Y., Law, C.L., and Dou, W.B.: 'Study of a uniplanar monopole antenna for passive chipless UWB-RFID localization system', *IEEE Trans. Antennas Propag.*, 2010, **58**, (2), pp. 271–278
4 Abu, M., Rahim, M.K.A., Suaidi, M.K., Ibrahim, I.M., and Zhang, F.H.: 'A meandered triple-band printed dipole antenna for RFID'. Proc. Asia Pacific Microwave Conf., Singapore, 2009, pp. 1958–1961
5 Ji, Z., Liao, H.L., Wang, Y.W., and Wu, Q.H.: 'A novel intelligent particle optimizer for global optimization of multimodel functions'. Proc. IEEE Congress on Evolutionary Computation, Singapore, 2007, pp. 3272–3275
6 Wong, K.L.: 'Compact and broadband microstrip antennas' (John Wiley and Sons Inc., New York, 2002)
7 Liu, W.C.: 'Design of a multiband CPW-fed monopole antenna using a particle swarm optimization approach', *IEEE Trans. Antennas Propag.*, 2005, **53**, (10), pp. 3273–3279