Screen-Printed Depolarizing Chipless RFID Tag Based on Asymmetric Configurations

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Abstract—A novel compact cross-polar chipless RFID tag with a ground plane is proposed in this paper. The proposed tag has multiple unbalanced resonators, i.e., the two arms of U-shaped with unequal length. These unequal arms are employed to generate the depolarizing (cross-polar) radar cross-section (RCS) response. The ground plane with the help of depolarizing identification enables this tag to be attached to highly reflective or absorptive background media such as metal or the human body. Low-cost screen printing has been adapted fabrication of the tag. The proposed tag presented in a 2×2 array configuration can encode 6-bits with a total size of $80 \times 80 \times 1 \text{ mm}^3$.

Keywords—chipless tag, cross-polar, screen printing

I. INTRODUCTION

Nowadays, chipless radio frequency identification (RFID) tags are more competitive because of their unique low-cost advantage compared to passive RFID tags with integrated circuits (IC) [1]. Recently, the cross-polar chipless tags received widespread interest from researchers due to their robust detection ability in a dynamic environment [2]. This is because the co-polar chipless tags cannot be detected when they are attached to some strongly reflective material (e.g. metal) [3], [4]. Nevertheless, the cross-polar chipless tags can be adopted for tagging the items robustly because they can depolarize the emitted electromagnetic (EM) plane wave avoiding the inference of the co-polar reflected wave from the attached objects [5].

In this work, a novel depolarizing (cross-polar) chipless tag using the polyethylene terephthalate (PET) substrate is designed based on the unbalanced U-shaped scatters. This tag uses a double layer configuration (i.e. a metal ground) for avoiding the resonant frequency deflection due to the permittivity change of the attached dielectric [6] or the substantial interference of the metal background body in a real unknown environment.

II. THE PROPOSED DESIGN

The conventional U-shaped chipless RFID tags illustrated in Fig. 1(a) cannot produce the cross-polar RCS response when they are illuminated by an incident wave polarized in the parallel or orthogonal direction with the tags' arms. The reason is that

the traditional U-shaped resonator is a symmetric structure that

Fig. 1. (a) The traditional co-polar U-shaped resonators. (b) The proposed cross-polar unbalanced U-shaped resonators. The size parameters: $l = 38 \text{ mm}$, $w = 2 \text{ mm}$.

Fig. 2. The co-polar and cross-polar RCS response magnitude of both balanced and unbalanced U-shaped resonators.

the induced current cannot generate an orthogonal component in the backscattered wave. A slightly modified structure is proposed to change the current path in arms of the resonators as illustrated in Fig. 1(b). As a result, the depolarizing response is obtained. Figure. 1 exhibit the specific dimensions of the outermost ring, and the parameters of the remaining five resonators could be easily gained by the scaling factor (SF) demonstrated in Table I. The screen printing method is used in the fabrication process. Six resonators are made of conductive

Fig. 3. The surface current distribution at 3.33GHz (a) The proposed cross-polar unbalanced U-shaped resonators (b) The balanced U-shaped resonators.

TABLE I. SCALING FACTOR OF THE REMAINING RESONATORS

Length difference	SF ₁	SF ₂	SF ₃	SF ₄	SF ₅
$l/2$	0.84	0.71	0.60	0.50	0.42
$l/4$	0.86	0.73	0.61	0.52	0.44
$l/16$	0.86	0.72	0.61	0.52	0.44

Fig. 4. The simulated cross-polar RCS response of the proposed configuration with different length variations of two arms and the photograph of the fabricated prototype unit displayed in the inset.

ink etched on a PET substrate with permittivity of 2.3 and loss tangent of 0.002.

III. SIMULATION AND ANALYSIS

The proposed tag is simulated in the CST Microwave Studio, where the model is illuminated with an EM plane wave in the horizontal polarization. The comparison of the RCS response between the symmetric U-shaped resonators and the proposed unbalanced U-shaped resonators is exhibited in Fig. 2. It is clear that the co-polar RCS signature of these two scatters could not be deployed to identification since the response is interfered by the bottom ground plane. But the proposed configuration could create a depolarizing signature compared with a negligible cross-polar response generated from the balanced resonators. For the proposed tag, each resonator could produce a resonant peak in the cross-polar RCS spectrum shown in Fig. 2. The appearance of a peak can be encoded as '1', then the digital signature of this tag including 6 bits as 1 or 0 can be generated.

The simulated surface current distribution at the resonant frequency of the third outer ring (i.e. 3.33 GHz) is shown in Fig. 3(a), which indicates that the unbalanced vertical currents in the proposed tag could contribute to cross-polar RCS reflection. To further explain the generation of the cross-polar response, the surface current of a balanced tag with optimized dimensions at the same frequency is demonstrated in Fig. 3(b), which shows the first-order resonance of the innermost ring and the third-order resonance of the outmost ring, respectively. But both of these two resonances have resulted from the balanced current distribution that cannot create the cross-polar components.

The impact to the cross-polar RCS caused by the various degrees of unbalance is also researched. A 2×2 tag array with a substrate thickness of 1mm is performed considering the practical readability of the proposed tag. The total length of these resonators is almost the same but with unequal two arms. Table I gives the detailed SF of the remaining resonators of these three tags. Accordingly, the cross-polar RCS response of these tags is provided in Fig. 4, which shows the cross-polar RCS response increases with the extension of the length difference. It should be noted that even a slight difference between two arms (i.e. $l/16$) could also produce the cross-polar signature that proves the depolarizing response derives from the unbalanced surface current. Finally, a prototype of the proposed chipless tag unit has been fabricated employing the screen-printed technique shown in the inset of Fig. 4. The measured results of the array configuration will be presented at the conference.

IV. CONCLUSION

A novel depolarizing chipless tag using the PET substrate with a ground plane is investigated. This tag is made of six unbalanced U-shaped resonators. The proposed tag is suitable for massive production with cross-polar detection capability because of the low-cost screen printing. The cross-polar characteristic of the proposed tag with a ground plane enables the tag to be identified when attached to a strongly reflective or absorptive surface for practical applications.

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