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Frequency-Coded mm-Wave RFID Tags Using Cross Polarization

Yuting Zhao(1)(2), Simone Genovesi (2), Guliano Manara (2) and Filippo Costa*(2)
(1) College of Information and Communication Engineering, Harbin Engineering University, Harbin, China
(2) Department of Information Engineering, University of Pisa, Pisa, Italy

Abstract

A frequency selective surface (FSS) based chipless RFID tag is designed at mm-Wave range. It is shown that the proposed design methodology can provide a multiresonant cross polar spectral signature while exhibiting a significant Radar Cross Section(RCS). Encoding in the cross-polar component of the RCS allows reader to detect the signal from surrounding scatters more easily when presence of metallic objects occurs. The unit cell of employed tag consists of five dipole resonators printed on a grounded dielectric slab, which realized a frequency position coding of 5-bit from 60 GHz to 90 GHz.

1 Introduction

Chipless Radio Frequency IDentification (RFID) offers great potential for wide application in green Internet of Things (IoT) thanks to low power consumption and low complexity. In conventional RFID system, the information is carried within the time modulation sequence of the backscattered. The time modulation is obtained by the presence of a chip on passive tags which are fed by RF interrogating signal emitted by the reader. The RF signal supply enables battery-free devices to transmit information, which simplifies manual maintenance such as charging or replacing batteries [1]. RFID tags operate at sub-GHz band and are characterized by a footprint which is a fraction of a wavelength (roughly 10 cm). Moreover, the presence of the chip makes the tags not suitable for application in extreme environment, on small and low cost packages. Chipless RFID tags can be easily scaled up in frequency due to their passive nature and can be a suitable candidate as a replacement or integration of barcodes for small packages. Chipless RFID tags are also capable to operate in harsh environment with extremely high temperature/toxic gases, or embedded in items [2].

However, most of the previous works on chipless RFID tags are designed at relatively low frequency bandswhich inevitably causes the size of the tags unit cell to be large, many of which are in centimeter scale. Scaling up to mm-wave frequency range allows both for footprint miniaturization and substrate thickness reduction. The use of standard single resonator approach does not provide a sufficient Radar Cross Section (RCS). A chipless tags for a novel indoor self-localization system operating at high mm-wave frequencies is proposed in [3, 4] by using dielectric resonators (DRs) arrays, dielectric lens and corner reflectors to boost the RCS. This approach is not suitable for bi dimensional tag design and is not flexible neither suitable for packaging. In [5] a Van-Atta reflectarray configuration was proposed to increase the RCS. In [6], single bit or two bit mm-wave tags were proposed and measured. However, the number of bit is usually vary small and only one or two bits are encoded. In printed tags, the amount of the backscattered power obviously depends on the geometric area of the tag, thus periodic tag configuration can be adopted to increase the RCS level [7]. If the tag is designed in mm-wave range the unit cell size of a single unit cell is is the order of a 1 or 2 mm and thus, even the use of 5×5 or 10×10 unit cells is compatible with practical applications. Moreover, the mm-wave design allows for reduction of tag substrate thickness below 0.1 mm, making tags flexible and suitable for packaging applications.

In this work, a frequency selective surface based chipless RFID tag works from 60 GHz to 90 GHz is investigated, which can be fabricated with printed circuit board technology or inkjet printing. Since the reflection that the interrogating signal undergoes is essentially operated by the finite tag reflection coefficient profile [8]. To explore the possibility of saving computation time of RCS, we investigated a fast semi-analytic method based on the work in [7].

2 The designed chipless tags

The proposed tag comprises a periodic surface printed on a thin grounded substrate. The unit cell of the periodic surface is composed by 5 dipoles with different lengths. The unit cell of the FSS-based tag consists of five dipoles with gradient lengths to obtain a 5-bits tag. In order to guarantee a reflected signal level above the surrounding clutters, the tag is designed to convert the polarization of impinging wave [9]. The incident wave, as is shown in Fig 1, is 45 $^\circ$ polarized with respect to the orientation of the dipole. The substrate is a 50 μm layer of Kapton backed by a metallic plane as shown in Fig 1. The Kapton layer is characterized by a dielectric permittivity of 3.5-j0.002.

Since in the case of chipless RFID system, tags are not capable to modulate the retransmitted signal, the informa-

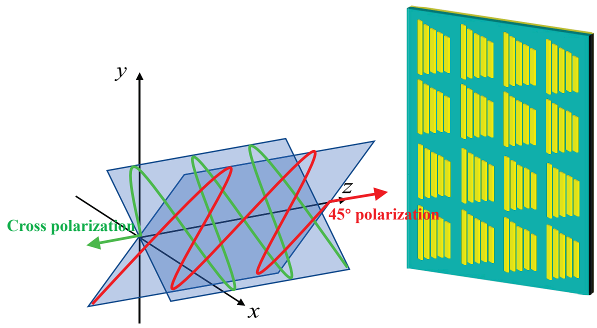

Figure 1. Chipless tags with 4×4 unit cells and the polarization of incident wave and desired reflection signal. The size of the unit cell is $1.6mm \times 1.6mm$, the lengths of the dipoles are $1.25mm, 1.2mm, 1.15mm, 1.2mm, 1.05mm$ respectively, both the width of and the gap between dipoles are $0.15mm$.

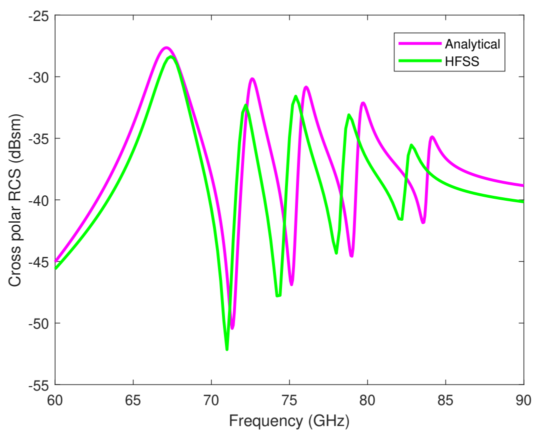

Figure 2. Analytical and full wave simulated cross polar RCS of tag with 5×5 periodic unit cells.

tion is encoded in the presence or absence of frequency peaks at predetermined frequencies. The cross polar reflection amplitude of unit cell with metallic dipoles and lossless substrate provides a perfect polarization conversion of the inpinging EM wave at 5 frequencies. The RCS of the finite tag can be computed by a HFSS but it requires a large amount of time and also a high requirement in terms of memory allocation. For this reason a semi-analytical method proposed in [7] is employed to assess the RCS property of the tag. In the case of normal incidence, cross-polar scattered field of tag with $M \times N$ unit cells can be computed as:

$$\vec{E}^r_{cr}(f) = \sum_{m=1}^{M} \sum_{n=1}^{N} |\Gamma^{m,n}_{cr}(f)| \, e^{-j\left(\angle \Gamma^{m,n}_{cr}(f)\right)} \tag{1}$$

The terms $|\Gamma^{m,n}_{cr}(f)|$ and $e^{-j(\angle \Gamma^{m,n}_{cr}(f))}$ represent the amplitudes and phases of the reflection coefficient of each unit cell of the tag. Being the tag formed by a periodic surface, these coefficients are all identical and can be evaluated by a periodic unit cell simulation in HFSS. Then, the RCS of the tag with a geometric area of $A = ND \times MD$, where D represents the unit cell side length, can be computed as follows [7]:

$$\text{RCS}^{tag}_{cr}(f) = \frac{4\pi A^2}{\lambda^2} \left(\frac{\left|\vec{E}^r_{cr}(f)\right|}{MN} \right)^2 \tag{2}$$

The RCS of the tag with 5×5 periodic unit cells computed with the proposed semi-analytical approach and by HFSS is reported in Fig. 2. The two results are in good agreement, even if a slight frequency shift for the last four peaks is observed.

It is obvious that the amount of the scattered power depends on the geometric area of the tag that gives contributes. In order to assess the impact of the tag unit cells in the level of cross-polar backscattered signal, the cross polar RCS value of three tags with different sizes are evaluated by using the proposed analytical approach. The results are reported in Fig. 3. The RCS value can be improved significantly with the increment of tag size. It worth to be noted that a 20×20 tag is only $3.2 \times 3.2cm^2$ in size with the RCS maximum value up to -5 dBsqm, which shows a great potential in chipless RFID system.

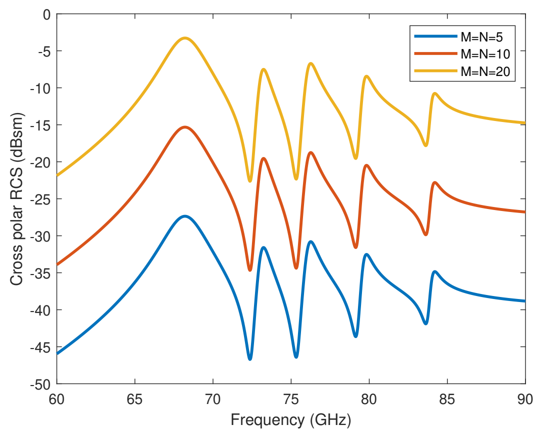

Figure 3. Analytical cross polar RCS results of tags with $5 \times 5, 10 \times 10, 20 \times 20$ periodic unit cells.

3 Quality factor of the peaks

The proposed chipless tag layout can be fabricated by using different technologies like for instance photolithography technique, inkjet printing or thermal printing. In the former case, a copper layer on top of the kapton substrate is patterned. In the latter case silver nanoparticle ink is employed to obtain the conductive pattern [10]. The inkjet printing or thermal printing approaches are suitable for fabrication on paper substrate. In these cases, the metallic pattern is characterized by a finite sheet resistance. The sheet impedance can be characterized with a simple waveguide setup in the desired frequency range [11]. A finite value of the sheet resistance clearly determines a decrease of the resonator quality factor; the lower is the real part of the sheet impedance of the deposition, the higher will be the quality factor of the resonant peaks. In order to assess the maximum tolerable level of sheet resistance, R_s, the unit cell with five dipoles is simulated in HFSS with different level of sheet resistance (copper metal, 0.3 Ω/sq and 0.5 Ω/sq). The amplitude of the cross polar reflection coefficients for the unit cell with copper and Ohmic sheet dipoles are reported in Fig. 4. The quality factors for different resistance surfaces are given in Table 1, which is calculated by f_0/Bw. f_0 is the resonant frequency, BW is considered as the $-3dB$ bandwidth, which is relative to the maximum value of S11 at the center resonant frequency of each band. As expected, the amplitude of reflection coefficient obtained with copper dipoles is characterized by a higher Q-factor with respect to the finite resistance cases. However, we can state that a sheet resistance of 0.3 Ω/sq is the minimum necessary to obtain detectable resonant peaks.

Table 1.
QUALITY FACTORS FOR DIFFERENT RESISTANCE SURFACES

	Band 1	**Band 2**	**Band 3**	**Band 4**	**Band 5**
Copper	29.2	66	76	61.3	35.6
Rs= 0.3 Ω/sq	25.9	42.1	39.4	30.1	<20
Rs= 0.5 Ω/sq	30	<20	26.7	30.1	<20

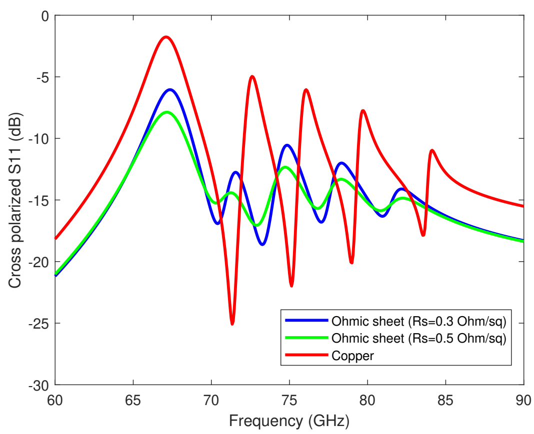

Figure 4. Cross polar reflection coefficients of a periodic tag configuration whose dipoles are modelled with copper or with finite sheet resistances.

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5 Conclusions

A mm-Wave chipless RFID tag based on frequency selective surface printed on thin grounded kapton slab is analyzed by using using semi-analytical and full wave simulations. The relationship between tag size and cross polar RCS value has also been reported. The unit cell of the proposed chipless tag is $1.6mm \times 1.6mm$ which is suitable for applications on small tagged objects. The tag comprises five dipoles arranged at 45° with respect to to the incident electric field. In this way the tag operates in cross-polarization and thus the presence of nearby metallic object does not deteriorate its performance. The tag is formed by a finite number of replica of the unit cell in order to obtain a considerable RCS. The realization of prototypes is ongoing and the experimental results will be presented at the conference.

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