A Novel Fully Printed 28-bits Capacity Chipless RFID Tag Based on Open Conical Resonators

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Abstract— A novel fully printed 28-bits capacity chipless RFID tag using conical resonators is proposed here. The angle of aperture of these resonators is adjusted to suppress high order modes allowing an efficient use of the UWB frequency bandwidth. By using 12 resonators within a reduced dimension of $4.2 \times 3\,\mathrm{cm}^2$, a coding capacity of 28 bits is achieved, which is the highest coding capacity reported for a fully printed chipless tag. Several chipless tags are printed on flexible substrate and validated experimentally.

1. INTRODUCTION

Printed Chipless RFID owing to the elimination of both batteries and silicon chip provides a feasible method to obtain a wireless identification solution to the conventional barcode cost. Researchers all over the world have added numerous features to the chipless tags like, polarization diversity, tag detuning, coding capacity comparable to barcode, etc. [1, 2]. Even though it is easy to find "fully printable" tags on flexible substrate, most of the tags are developed using the conventional photolithography process and a "fully printed" passive chipless tag with high coding capacity can be seldom found. Besides the design of the chipless tag could be done without any surface mounted devices (SMD) on it, but simply using some conductive strips so as to reduce the cost and simplify its fabrication.

The highest reported coding capacity of a chipless tag comparable to the barcode is 49 bits [1], where multiple circular ring patch resonators are used. However, the chipless tags are developed on Rogers's substrate using conventional photolithography process. The same authors have also developed printed chipless tags on paper substrate using the high speed flexography process [3]. Here, 19 bits are achieved within a reasonable size of $7 \times 3\,\mathrm{cm}^2$.

A fully printed chipless tag on flexible substrate can be seen in [4], where a prototype of the tag is printed on a photo paper. Several capacitive discontinuities are placed at different distances and the reflected signals from these discontinuities are used for encoding. Nevertheless, it uses some discrete localized components and the conductivity of the metallic strips is approximately $3 \times 10^6\,\mathrm{S/m}$ due to the metallic thickness ($\approx 1\,\mu\mathrm{m}$). In order to rectify this, a linear tapered microstrip line is used which in turn increases the overall size of the tag, achieving a final coding capacity of 10 bits. Moreover, the prototype demands the use of external antennas and SMA connectors.

Thus, in short a fully printed passive chipless tag with coding capacity higher than 19 bits has not yet been developed. In this paper, a novel fully printed 28-bits capacity chipless tag based on open conical resonators is proposed. The chipless tag is developed on flexible substrate using screen-printing process which enables the fabrication of low cost tags for mass production applications. The proposed chipless tag can encode 28 bits within a compact size ($4.2 \times 3\,\mathrm{cm}^2$). The Radar Cross Section (RCS) of the chipless tag is encoded using the frequency shift generated by changing the physical length of each resonator.

2. CHIPLESS TAG DESIGN

The classical way of encoding in chipless tag is to create some resonance peaks or dips in the backscattered signal from the tag 1. To do so, the RCS of the tag is exploited. The proposed chipless tag is based on multiple open conical resonators which are able to produce RCS with sharp peaks at particular frequencies corresponding to the physical dimension of the resonator. Basically two different types of conical resonators can be seen, one with open end and the other with short circuited end. Figure 1 shows the simulated RCS of these two types for a given length 'l' and a cone angle 'φ'. CST Microwave Studio is used as the simulation tool. PET with $100\,\mu\mathrm{m}$ thickness is chosen as the substrate which has an effective permittivity of 2.9 and loss tangent of 0.0025.

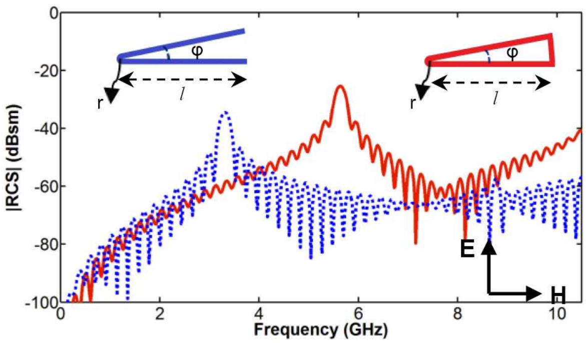

Figure 1: |RCS| of open and short circuit conical resonators along with the design parameters. 'l' is the length, 'φ' is the cone angle and 'r' is the radius of the curvature nose edge. In this example $l = 24\,\text{mm}$, $r = 1\,\text{mm}$ and $\varphi = 10°$.

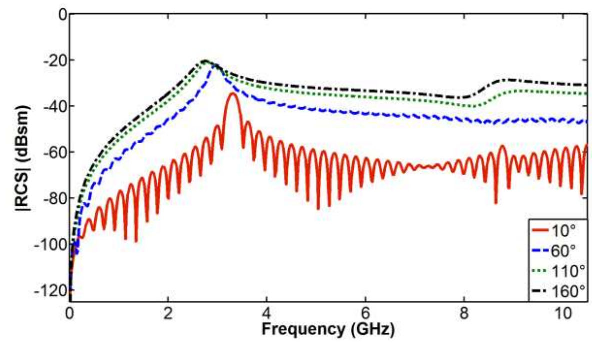

Figure 2: Simulated |RCS| of open conical resonator for different aperture angles φ and $l = 24\,\text{mm}$.

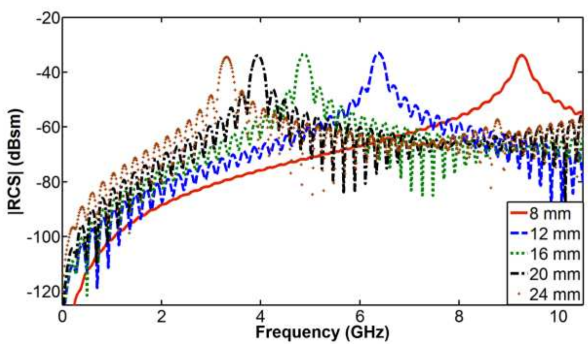

Figure 3: Simulated |RCS| of open conical resonator for different lengths l and $\varphi = 10°$.

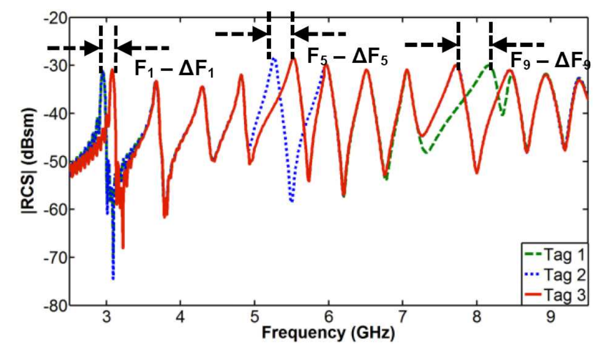

Figure 4: Simulated |RCS| response of different chipless tag combinations with 12 resonators.

When a vertically polarized electromagnetic wave is impinged on the surface of the resonator, it can backscatter energy peaks at certain resonance frequencies depending upon the physical length of the resonator. Even though the short circuited conical resonator produces better RCS, the open conical resonator can achieve a more compact size and better frequency selectivity ($\sim 25\%$). Since we are interested in high coding capacity, better selectivity allows increasing the number of resonators. Thus, a choice can be taken depending on the application and open resonators is chosen for this particular tag design.

Simulations have been done in order to verify the effect of each design parameter. One of the significant design parameter which determines the performance of the conical resonator is the cone angle 'φ'. It has been found that while decreasing the cone angle, the frequency peaks become highly selective with suppression in the even mode, while generating an odd mode. This suppression allows an efficient use of the frequency bandwidth. The reason for highly selective RCS is due to the increase in coupling between the two arms while cone angle is decreasing. Several simulations were done and it has been found that both 'l' and 'φ' influences the frequency of operation. The simulation results are shown in Figures 3 and 4.

A 10° cone angle 'φ' is chosen in order to have highly selective RCS peak. Several tag combinations are designed by changing the number of resonators in order to have the proof of concept. The designs are made on a single layer and no ground plane is included in the proposed case. Tags are simulated using 12 resonators. It has been found that when several resonators are used, third order modes can be observed which may be due to the coupling produced between the resonators. Hence the frequency of operation has been limited between 3.1 GHz and 9.3 GHz, since an odd mode is observed at 9.4 GHz; this means that for the used UWB frequency range, one resonator could be placed per almost 500 MHz bandwidth. Figure 2 shows the simulated RCS response of different tags with 12 resonators.

Frequency shift coding is implemented here, as explained in [1], and in order to assess the tag

encoding capacity for the selected bandwidth of 6.2 GHz, the number of possible frequency slots needs to be determined. For this purpose, the 3 dB bandwidth of each peak is considered. With this, the amount of frequency slots per resonator can be calculated by simple dividing the resonator's assigned bandwidth by its 3 dB peak bandwidth.

Furthermore, the total chiplesstag combinations without repetition 'N' in the case that the resonators are being able to take any frequency slot can be calculated using the following equation [5],

$$N = \frac{n_s!}{(n_s - n_r)!} * \frac{1}{n_r!} \tag{1}$$

where n_s is the number of slots and n_r is the number of resonators. The capacity of coding can be calculated as [6],

$$C = \log_2(N) \tag{2}$$

3. RESULTS AND PRINCIPLE OF ENCODING

In order to validate the design, the simulated chipless tags are fabricated on flexible PET substrate with a thickness of 100 µm. Screen printing with silver particle based ink is used for printing the metallic strips. The printed tags have a metallic thickness of approximately 8 to 10 µm and are able to produce a conductivity of 2×10^6 S/m. The width of the strip is chosen as 1 mm and the cone angle as 10°. Several tag combinations are printed and a bi-static measurement set-up is used for the tag characterization as shown in Figure 5. The tests are conducted in an anechoic chamber. An Agilent Performance Network Analyzer (PNA E8364B) is used to record the backscattered electromagnetic response from the tag. Two horn antennas with an average gain of 10 dBi in the frequency band from 1 GHz to 18 GHz and separated a distance of 45 cm from each other are connected to the two ports of the network analyzer.

The horn antennas are horizontally polarized, since this polarization provides the best radiation pattern to measure the higher frequencies components of the backscattered signal from the tag at shorter distances. In this case, the chipless tags are placed vertically in order to be interrogated with the horizontally polarized wave. Due to the antenna limitations, in order to efficiently extract the RCS high frequency peaks with a reduced noise level, the power delivered by VNA is set to 6 dBm and thechipless tags are placed at a distance of 50 cm from the horn antennas. In the practical case, the FCC and ETSI regulated power can be used to interrogate the tag [7] and it will also be detectable. A complex S_{21} has been measured using this configuration with the technique explained in 1. In order to validate the concept, 7 different chipless tag combinations are measured. The RCS of each chipless tag has been calculated using the formula explained in 1.

The measured |RCS| for chipless tags with 12 resonators is shown in Figure 6. All the 12 peaks are easily detectable in the figure but the |RCS| level is less than the simulation which may be due to the poor conductivity of the printed chipless tag. A simulation has been conducted with a conductivity of 2×10^6 S/m and it has been found that the |RCS| level decreased as in the case of measurement.

Even though simulations results permit more number of peaks and therefore bits, coding capacity is calculated based on the obtained measurement results since the measured RCS peaks have a wider

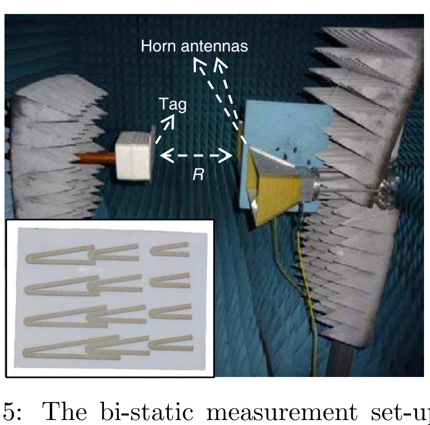

Figure 5: The bi-static measurement set-up used. The horn antennas are horizontally polarized. Inset: chipless tag with 12 resonators printed on transparent PET. The dimension of the tag is $4.2 \times 3\,\text{cm}^2$.

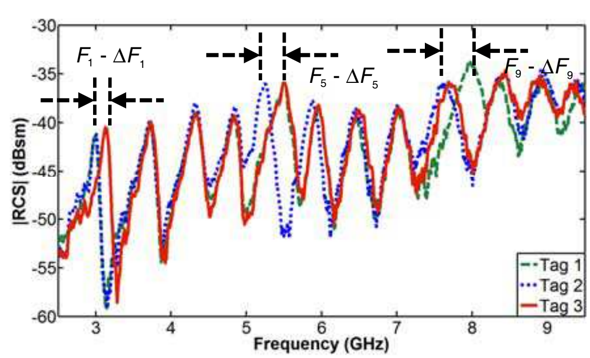

Figure 6: Measured |RCS| response of different tag combinations with 12 resonators.

bandwidth. As explained previously, the 3 dB peaks generate a total of 32 frequency slots for the 12 resonators tag and the given bandwidth as shown in Table 1. Thus for 12 resonators (n_s) with 32 slots (n_r), the capacity (C) of coding is calculated using (1) and (2) as 28 bits.

Table 1: 3 dB bandwidth and number of frequency slots per resonators.

Resonator	Frequency Range (GHz)	3 dB Bandwidth (MHz)	Frequency Slots per Resonator
1	3.1–3.6	100	5
2	3.6–4.2	150	4
3	4.2–4.8	150	4
4	4.8–5.4	150	4
5	5.4–5.8	200	2
6	5.8–6.2	200	2
7	6.2–6.6	200	2
8	6.6–7.0	200	2
9	7.0–7.6	300	2
10	7.6–8.2	300	2
11	8.2–8.8	300	2
12	8.8–9.3	500	1

4. CONCLUSION

In this paper, a novel fully printed chipless tag with high coding capacity is proposed. The tag consists of open conical resonators and the RCS of each resonance peak is used for encoding. A coding capacity of 28 bits is achieved within the unlicensed UWB from 3.1 GHz to 9.3 GHz, which is the highest coding capacity reported yet for a fully printed tag. The tag is printed on flexible PET substrate with a thickness of 100 μm using screen printing process and has a compact dimension of $4.2 \times 3\,\text{cm}^2$. The proposed design is validated experimentally and the obtained results proved the concept.

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