Comparison of UWB Chipless Tags on Flexible Substrates Fabricated Using either Aluminum, Copper or Silver

M. Barahona, D. Betancourt, and F. Ellinger

***Abstract* – In this paper, metals like aluminum, copper and silver are used to elaborate ultra-wide band (UWB) chipless radio frequency identification (RFID) tags either on bond paper or polyethylene terephthalate (PET) substrates. Up to 3 different UWB chipless tags designs with an amount of resonators ranging from 3 to 4 and a conductive strip width of 1 mm are fabricated. The tags are measured, its operation validated, and the performance comparisons between different fabrications are provided when available. The magnitudes of the radar cross section (RCS) calculated from the measurements of the scattering parameters, show that no major performance degradation is obtained for same tag designs fabricated with different metals and same substrate. According to market prices, replacing silver by copper a raw material cost reduction of at least 96% is expected, and at least 65% cost reduction replacing copper by aluminum.**

1 INTRODUCTION

Automatic radio frequency identification systems offer a technical advantageous solution to expedite processes over a wide range of markets and applications [1], [2]. However, it must offer both a reliable and an economically feasible solution to compete against the well-established barcode technology, especially on the item-level tagging currently deployed worldwide [3], [4]. This means that the investment cost of these systems should be comparable or cheaper than the current barcode one, in order to make this technology attractive to the end-users [4]. The fabrication cost of the tag is the main impediment to reach this goal and overtake a growing market of forecasted revenues of 8.3 billion USD for 2018 [3], and a wide range of applications that goes from asset tracking, access control, healthcare, military, etc.

To achieve this target, different approaches with their respective applications for item level tagging are currently being investigated [5], [6]. The UWB chipless RFID technology is one of the options to perform this task for short range operations, due its potential to significantly reduce the UWB chipless tag fabrication cost, by applying mass production techniques like the printed electronics on flexible substrates [7], [8].

Nowadays, silver ink is the most reported and utilized material in printed electronics [9], including the UWB chipless RFID tags on flexible substrates [7]. Although it is well known that copper is cheaper than silver, and aluminum cheaper than copper. According to up-to-date market prices calculated per pound, copper cost at least 96% less than silver, and aluminum cost at least 65% less than copper [10], [11]. Therefore, a major challenge in the field of printed electronics on flexible substrates is to replace silver with cheaper metals like copper or aluminum. This would depend on the success to avoid their oxidation at ambient conditions, especially for the aluminum case, and on controlling the temperatures required in the post printing process, which should not exceed 120-150 °C [9]. Methodologies to produce copper ink with sintering temperatures below 200 °C are being investigated [12]. Nevertheless, to the best of the author's knowledge, no UWB chipless RFID fabricated on flexible substrates like PET or bond paper using aluminum or copper and a mass production technique has been reported yet. And only a manually fabricated copper strip on bond paper tag can be found in [13].

Furthermore, regardless of the mass production technique to be used to achieve this industrial level manufacturing at the lowest cost possible, initial research on the types of raw materials that could be used to fabricate the UWB chipless tags needs to be conducted. To determinate their influence and differences on the radio frequency (RF) response of the tag and evaluate their impact in the tag's performance. Hence, the importance to exploit other approaches to fabricate tags using metals like aluminum or copper in order to conduct these studies.

In this paper, the first UWB chipless tags manually fabricated using aluminum strips on either PET or paper substrates are introduced. The first copper strip UWB chipless tags on PET are also presented. The UWB chipless tags prototypes are measured in an office under normal conditions, its functionality experimentally verified, and the materials influence in the tag's RF response evaluated. The results obtained are compared between equivalent designs and to their silver ink screen printed counterparts when available, assessing their RF performance differences.

2 UWB CHIPLESS TAGS DESIGNS

To perform this investigation and test the materials, the different UWB chipless tags designs presented in [7], [8], and [13] are chosen, due to their different geometrical shapes and signatures in the frequency domain. Figure 1(a) shows the different designs' shapes. For the proof of concept only one code per type of tag is needed, therefore the following codes are selected: The circular tag is based on 3 strip rings of 1 mm width and an 8 mm radius disk, with a separation of 1 mm between resonators [13]. The modified conical tag considering only 4 resonators of lengths 21.8, 18, 16, and 14.8 mm, a width of 1 mm and 10° of aperture angle [8]. And finally, the dipoles

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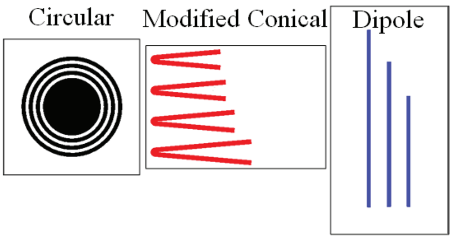
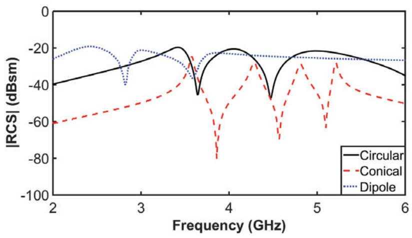
978-1-5090-0470-6/16/$31.00 ©2016 IEEE



(a)



(b)

Figure 1: (a): Circular, modified conical and dipole like UWB chipless tags designs shape. (b) Simulated |RCS| based on copper strips for Circular tag, modified conical tag, and dipole tag.

tag with resonators' lengths of 35, 45 and 55 mm, width of 1 mm, and a separation of 5 mm [7]. Figure 1(b) shows the |RCS| response of the circular, modified conical and dipole tags respectively, simulated using CST Microwave Studio. Peaks and dips of different bandwidths and central frequencies can be observed, as well as different |RCS| values for every design. The responses are simulated using a strip thickness of 35 µm in all cases, bulk copper with an electric conductivity σ of $5.8 \cdot 10^7$ S/m. And bond paper is used as a substrate with 100 µm of layer thickness, a relative permittivity of 2.31 and a density of 800 kg/m^3 [13].

3 FABRICATION AND TEST PROCEDURES

The materials used for the manually fabricated UWB chipless tags prototypes are commercial copper or aluminum tape for the conductive strips, and commercial bond paper or PET for the substrate. The acquisition prices of the raw materials are: 4 euros for a 50 mm x 15 m aluminum tape [14], 8.9 euros for a 30 mm x 15 m copper tape [15], 6.6 euros for 500 sheets of A4 bond paper [16], and 9 euros for 100 sheets of A4 PET [17]. Considering only the circular tags conductive area of 4.24 cm^2 and a 9 cm^2 substrate area, the copper tag was fabricated at an approximate cost of 8.4 euro cents, while the aluminum one at 2.3 euro cents and the rest of the designs at even lower costs.

To fabricate the UWB chipless tags, two pattern masks printed with the full scaled desired design on a sheet of bond paper using a commercial inkjet printer are required. The first mask pattern is used to provide the shape to the metal tape and the other one serves as a template in which the finalized strips are pasted. First, the paper substrate with the full scaled printed mask is fixed to the respective tape with an adhesive agent, this from the side where there is no metal, to avoid affecting the conductivity of the tape by adding other components to its surface. Then using a cutting tool, the metal tape is shaped to remove the undesired parts. Finally the strips are pasted to the second mask following its printed pattern; this is needed to improve accuracy, since a major change in the strip size or separation may lead to change of the desired resonance frequency.

For the fabrication of the circular printed UWB chipless tags, screen printing is used. For this purpose, the printing system explained in [7] is used. The silver ink circular tags were printed at an estimated ink cost of 1.5 euro cents for a 7 µm layer thickness. To make it comparable to the copper or aluminum fabrication, the cost rounds 7.5 euro cents for a 35 µm layer thickness without any production costs. However, silver ink has approximately 10% of the bulk silver density and 1 kg of ink cost as much as double of 1 kg of bulk silver according to the fabricant's provided prices list, which stills makes it cheaper than using bulk silver. The fabricated copper and aluminum tape as well as the silver ink based UWB chipless tags are shown in Figure 2.

In order to verify the functionality of both types of UWB chipless tags, scattering parameters measurements are done using the bi-static measurement set up described in [13] and mounted at one of the offices at the TU Dresden. The tags are placed at a distance of 40 cm from the antennas to guarantee a higher signal to noise ratio (SNR); the vector network analyzer (VNA) is configured within the frequency band of 2 – 6 GHz, a transmitted power of 3 dBm, an averaging factor of 20 sweeps, and a total of 400 samples are taken. The |RCS| values are calculated according to the technique discussed in [13].

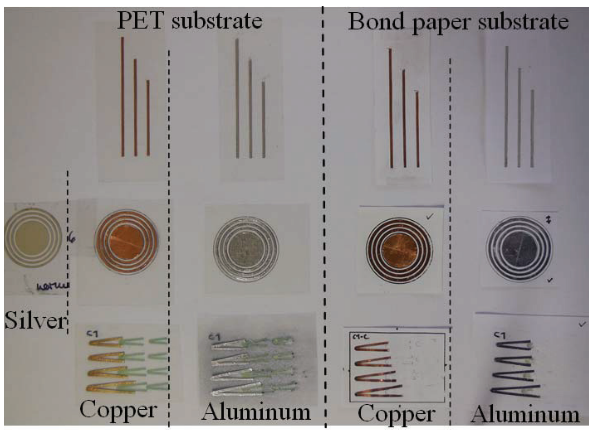


Figure 1: Fabricated UWB chipless tags using copper and aluminum tape on bond paper and PET, and single silver ink circular tag on PET.

4 RESULTS

Following the procedure described in the previous sections, the UWB chipless RFID tags are fabricated using either the copper or aluminum strips at the TU Dresden facilities and their silver ink printed counterparts at the TU Chemnitz ones. The measured layer thickness is around 7 µm for the silver ink tags, the calculated electrical conductivity based on the resistance measurements varies from design to design and is around $4 \cdot 10^6$ S/m for the dipole, and $2 \cdot 10^6$ S/m for the conical tags presented in [7] and [8] respectively. The silver ink circular tag presented in this paper has a conductivity value of $2.2 \cdot 10^6$ S/m. No tags using silver ink on commercial bond paper are fabricated for this investigation.

The measurements are performed and the results are resumed in Figure 3. In general the fabricated tags' |RCS| follow their simulated shape as shown in Fig. 1. The peaks are around the same order of magnitude for the different types of fabrications of the same design, and the dips sharpness which is caused by the resonance varies according to the difference in the conductivity of the strip material and the type of substrate of the tags.

In Figure 3(a) and (d), the measurement results correspondent to the circular tags on PET and bond paper are respectively shown, the printed silver ink on PET based tag presents a lower resonance due to its lower conductivity. The change of substrate from PET to bond paper also produces an additionally resonance loss of around 12 dB for this specific tag. Figure 3(b) and (e) presents the results corresponding to the modified conical tags on PET and bond paper, in this case a frequency shift for the two types of fabrication on each substrate is observed, this is due to the resonators lengths differences given that this particular tag is more sensitive to the accuracy of the fabrication process. Furthermore, this is the only design, in which the resonance generates peaks rather than the dips. A resonance loss of 3 dB is caused by the change of substrate from PET to bond paper, and a signal shape degradation especially visible in its last peak can also be observed for the bond paper substrate.

Finally, Figure 3(c) and (f) shows the measurement results correspondent to the dipole tags, as can be seen, there's a sound accordance between the |RCS| of the copper tape and the aluminum tag. A 3 dB difference due to the change of substrate is observed like in the modified conical case. Furthermore, the values can be compared to its silver ink counterpart in [7], whereas for the circular tag case, the silver ink based dipole tag produces a less sharp dips due to its lower conductivity.

The measurements results obtained confirmed that by fabricating the UWB chipless tags with materials like copper or aluminum, a cheaper UWB chipless tag can be achieved by reducing the raw material cost. And therefore these materials are suitable to be used for fabrication of UWB chipless tags on flexible substrates like bond paper or PET.

5 DISCUSSION AND CONCLUSION

Three different designs of UWB chipless RFID tags are fabricated and measured using aluminum, copper and silver. It has been experimentally demonstrated that it is possible to use these metals and obtain the desired RF characteristics of the tag at an almost negligible performance reduction while reducing the cost of fabrication. The manually fabricated chipless tags are able to produce an RF signature in accordance to the simulated values and comparable to the silver ink ones, fabricated using the printed electronics technology.

An automated stamping technique could also be used to mass produce chipless tags using copper or aluminum in order to reduce the tag's fabrication cost.

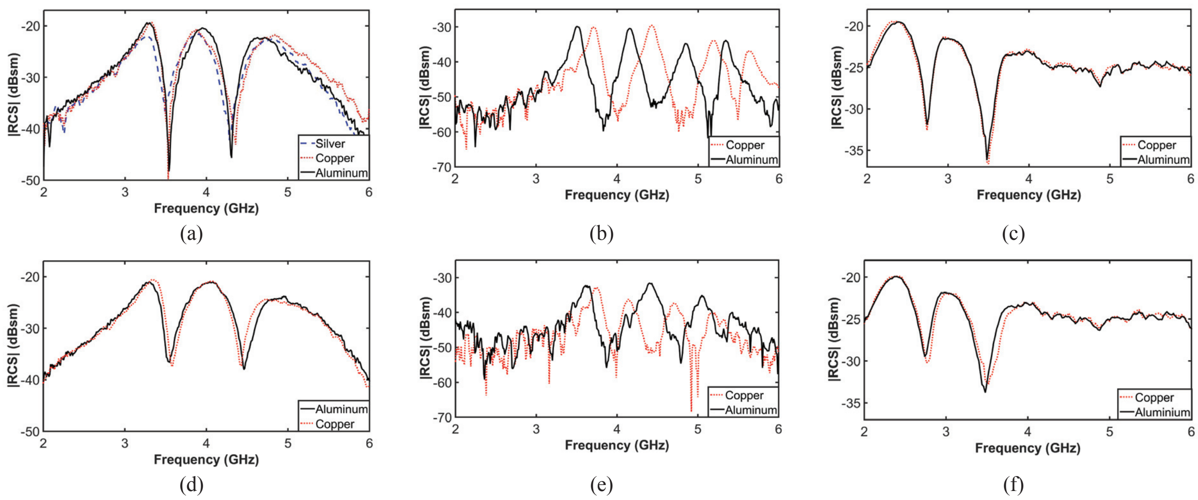


Figure 3: |RCS| Measurements results for (a) Circular tag on PET substrate, (b) Modified conical on PET substrate, (c) Dipole tag on PET substrate, (d) Circular tag on paper substrate, (e) Modified conical on paper substrate, and (f) Dipole tag on paper substrate.

Acknowledgments

The authors are grateful to Katherina Haase from TU Chemnitz, and P. K. Wolf from TU Dresden for their valuable support. The research leading to these results received funding from the European Union's Seventh Framework Program (FP7/2007-2013) under grant agreement No. 313161; eVACUATE Project (further info available at www.evacuate.eu).

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