Novel Size-Reduced Unit Cells for Uniplanar Chipless RFID Tags

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***Abstract*—The paper introduces the two new size-reduced unit cells/scatterers in the form of uniplanar resonators for application in frequency spectrum-based uniplanar chipless RFID tags. They are derived from U-folded dipole loaded by either meander line inductor or interdigital capacitor. Radar cross section, and resonant frequency has been evaluated by EM simulation and S-parameters have been measured and calculated when scatterers have been placed in parallel-plate waveguide. The results clearly show the trade-off between size-reduction and radar cross section proportional to read range of the proposed configurations. Their potential lies in the development of new smaller uniplanar chipless tags with higher information density.**

***Index Terms* — Chipless RFID, folded dipole, interdigital capacitor, meander inductor, radar cross section, reduced length resonator.**

I. Introduction

Although RFID technology has been known for more than three decades, it did not start to be used extensively until the last decade. Now, it has a broad field of applications in commerce, industry, medicine, science and other areas. Basic information can be found, e.g. in [1]. Within these systems, a new evolving branch, chipless RFID, promises the advantage of simplest and therefore cheapest structure comparing to current tags employing silicon chips. Thus it has a potential for optical barcodes replacement. A summary of early works in the field of fully-printable chipless RFID transponders can be found e.g. in [2], [3]. An important problem in the design of chipless tags is the attainable surface/volume density of stored information (in bits) which is still insufficient. Currently, today's RFID chipless tags thus still cannot compete with optical barcodes in the amount of stored information per unit area. A disadvantage of optical barcodes, however, is the need for direct unscreened contact between the code label and the reader. In the case of RFID tags, the reader can be screened, since detection is performed using radio waves.

The work presented here has been inspired and further evolve the structure of a chipless tag shown in [4] which is composed of a set of uniplanar scatterers in the form of U-folded printed dipole or alternatively viewed as a stub of coplanar strip transmission line. One of its ends is shortened, while the opposite side is open. This allows the excitation of a quarter wavelength standing wave transmission line mode, when irradiated by an incident electromagnetic wave with an electric field parallel to a shortening segment. The chipless tag designed in [4] is composed of 20 unit cells - resonators/scatterers and thus produces 20 resonant peaks. Significant coding capacity is achieved in the surface area of 70×25 mm^2.

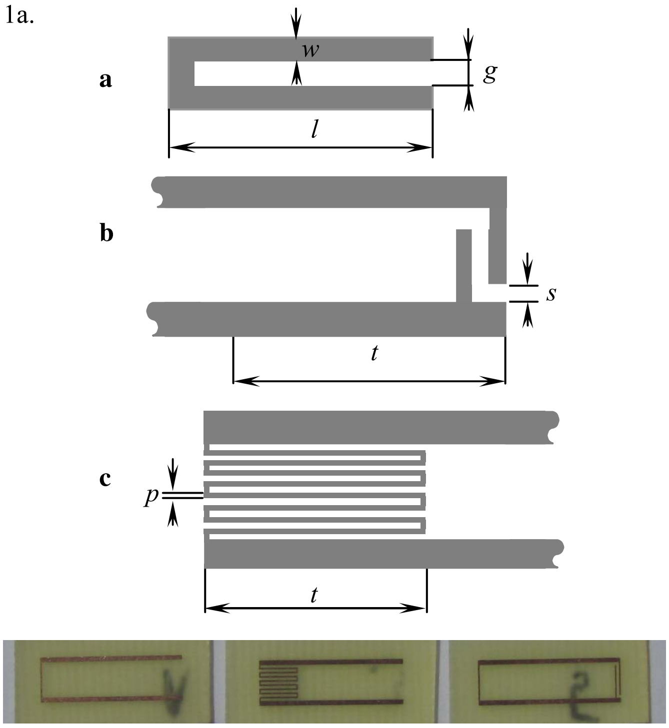
The aim of this work is to design, build and evaluate a unit cells that have smaller footprint area than the resonator presented in [4]. Such improved novel cells promise to build smaller chipless RFID tags with the higher information density. The two size-reduction concepts have been proposed: loading the U-folded dipole by an interdigital capacitor at its open end, or by inserting a meander line inductor in the middle vertical part of the dipole. Now we have one more parameter that can be used for tuning each of the resonators – capacitance C, and/or inductance L.

The proposed unit cells were simulated by CST Microwave Studio and measured in parallel plate waveguide to prove the validity of the proposed concepts. Radar cross section and resonant frequency have been evaluated. The results clearly show the miniaturization potential of proposed solutions as well as trade-off between size-reduction and radar cross section (RCS) of all, original unit cell as well as size-reduced modifications.

II. Size-Reduced, Inductively and Capacitively Loaded U-Folded Dipole

The tag presented in [4] is composed of resonators/scatterers in the shape of a U-folded dipole shown in Fig. 1a. The resonant frequency of this dipole is determined approximately by its extended length $2l+g$. Alternatively, the U-folded dipole may be considered as a quarter wavelength transmission line resonator shorted at one end and opened at the other and. The length of this resonator can be reduced by an interdigital capacitor placed at the open end; see Fig. 1b or by the meander line inductor placed instead of the shortening segment; see Fig. 1c.

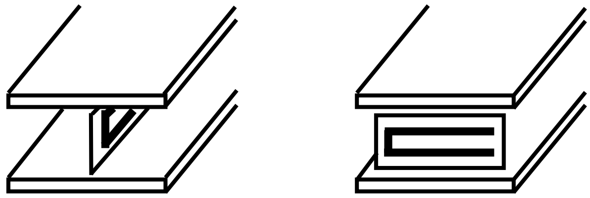
Three uniplanar folded dipole type resonators were designed, simulated by the CST Microwave Studio, fabricated and measured. These are: the U-folded dipole, see Fig. 1a, the folded dipole shortened by the meander inductor, see Fig. 1c and the folded dipole shortened by the interdigital capacitor composed of two fingers, see Fig. 1b. All these three resonators are 14 mm in length, 4.2 mm of total width. Width of their arms is 0.5 mm. The length of the inductor meander is $t = 4$ mm, width of the meander strips and gaps between them are 0.2 mm. Metallization thickness is 0.035 mm, and its conductivity is 10^7 S/m. The FR-4 substrate ($\varepsilon_r = 4.4$) of 0.5 mm in thickness supporting the resonators is 20 mm in length, and 9 mm in width. The resonators were analyzed and measured in an open parallel plate waveguide of width equal to 20 mm and height equal to 10 mm. Both longitudinal and transversal resonators positions are taken into account; see Fig. 2. The resonator in the longitudinal position, Fig. 2a can be excited both by the electric and magnetic fields, whereas the resonator in the transversal position, Fig. 2b, is excited by only the electric field. This transversal position is, however, more often used in the tag design [4]. Both newly proposed size-reduced resonators were compared with the same sized U-folded dipole resonator shaped according to the original in [4]; Fig. 1a.



d

Fig. 1 Layout of the resonator presented in [4] (a), schematic details of a two-finger interdigital capacitor terminating the resonator at the open end (b), a meander line inductor replacing the short (c), fabricated resonators (d).

The response of the U-folded dipole, Fig. 1a, and of the dipole shortened by the inductor, Fig. 1c depends only negligibly on the position in the waveguide. This is due to the fact that these resonators are dipoles excited only by the electric field parallel to the shortening strip with the very limited influence of the magnetic field. The response of the dipole shortened by the capacitor, Fig. 1b, depends on the position, as it represents a closed conducting loop sensitive to magnetic field perpendicular to its surface. Consequently, this dipole shows a better response in the longitudinal position, Fig. 2a.



a b

Fig. 2 Positions of resonators in the open parallel plate waveguide, longitudinal (a), and transversal (b).

Proposed resonators were measured in a quasi TEM waveguide designed with a small cross-section that ensures obtaining a measurable response. The line is fed through standard coaxial-rectangular waveguide transitions. An R32 waveguide was used. The waveguide passes the propagating wave via the TEM taper to the parallel plate waveguide with transversal dimensions 20 × 10 mm. The central re-assembled part of the waveguide is used for calibration, and the resonators are put in its center. The TEM waveguide is shown in Fig. 3. The fabricated resonators are shown in Fig. 1d.

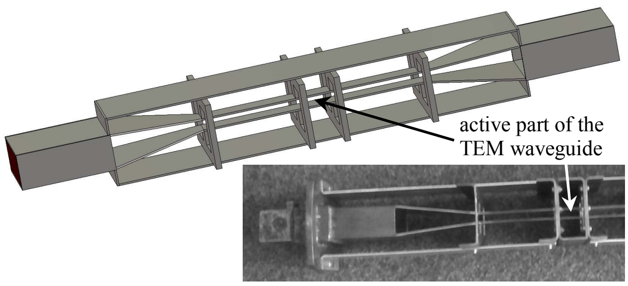


Fig. 3 The CST Microwave Studio model of the used TEM waveguide, and a detail of the fabricated line.

The scattering parameters of the U-folded dipole, Fig. 1a, are plotted in Fig. 4. The resonator is located in the transversal position; see Fig. 2b. The maximum RCS of -28 dBms calculated by the CST Microwave Studio of this resonator located in free space is at 3.37 GHz; see Fig. 5.

The maximum response of the dipole loaded by the inductor is shifted to lower frequency 2.67 GHz (which represents size reduction to 79 %) where RCS is -39 dBms. The scattering parameters of this resonator simulated by the CST and measured are plotted in Fig. 6, the resonator position in the waveguide is transversal; see Fig. 2b. The inductor of the length $t = 4$ mm moves the resonance to frequency 2.6 GHz; see Fig. 6. Comparing these results to the results obtained for the U-folded dipole, the dipole shortened by the inductor has smaller effective area so that its sensitivity is lower than the sensitivity of the U-folded dipole. The RCS is lower by about 10 dB, and S_{21} dip is about 3 dB less deep.

Finally, the RCS of the dipole loaded by the interdigital capacitor composed of two fingers is plotted in Fig. 5. This resonator is even less sensitive than the dipole shortened by the inductor. The maximum RCS of the resonator -42 dBms at 2.34 GHz for the longitudinal position; Fig. 2a, is by 3 dB higher than its response for the transversal position; Fig. 2b.

This is due to the contribution of the magnetic field to the resonator response in the longitudinal position. The measured scattering parameters of the resonator terminated by the capacitor are compared in Fig. 7 for the two resonator positions in the waveguide, Fig. 2. The resonant dip of S_{21} is -8 dB for the longitudinal position and only -5 dB for the transversal position. This resonator is shortened even more effectively (size reduction to 69 %) than the U-folded dipole with the inductor however at the expense of lower RCS.

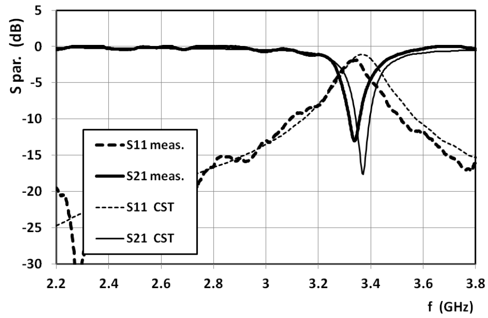


Fig. 4 Measured and simulated scattering parameters of the original U-folded resonator 14 mm in length.

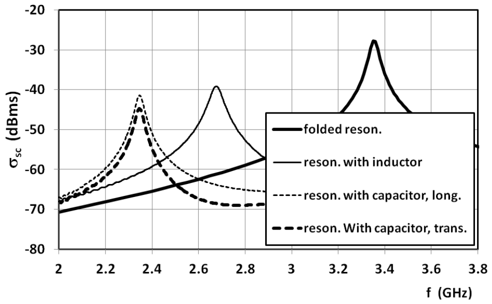


Fig. 5 RCS of the U-folded dipole of 14 mm in length, and the same length dipoles loaded by the inductor, and by the capacitor in the both longitudinal and transversal positions (simulated by the CST Microwave Studio).

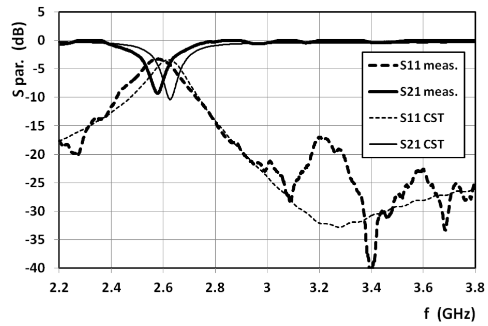


Fig. 6 Measured and simulated scattering parameters of the shorted U-folded resonator loaded by the inductor, Fig. 1c.

III. Conclusions

The two newly proposed unit cells/scatterers for application in the design of uniplanar chipless RFID tags of reduced size have been investigated. The tags composed of these resonators are able to store a higher amount of information per unit surface comparing to the reference unit cell. It has been shown that both inductive and capacitive loading of the original U-folded dipole reduce the resonant frequency while original outer size is maintained. For investigated configurations, inductively loaded U-folded dipole exhibited larger RCS then the dipole loaded capacitively. The resonator loaded by the capacitor exhibited the smaller resonant frequency and thus better miniaturization potential, however, at the expense of smaller read range. Thus trade-off exists between the requirements for size reduction and maximum read range.

The application of the array of such size-reduced unit cells/scatterers in chipless tag requires careful evaluation of frequency resolution of resonant peaks to achieve as high information density as possible. Mutual coupling may significantly affect this resolution. Further we may expect the influence of size-reduction versus read range trade-off affecting the short identification distance of small, high information density chipless tags. This will be a target of a future work.

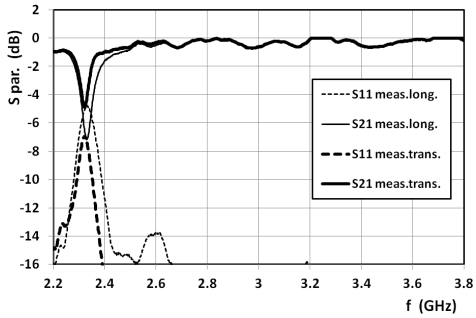


Fig. 7 Measured scattering parameters of the U-folded resonator shorted by the capacitor, Fig. 1b. The resonator is placed both in the longitudinal and in the transversal positions.

Acknowledgement

This work has been supported by the Grant Agency of the Czech Republic under project No. 13-09086S, and by the Czech Technical University in Prague under project No. SGS13/198/OHK3/3T/13.

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