Equivalent Circuit Analysis of Open-End Slot Type RFID Tag Antenna

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***Abstract*—— In this paper, we analyze open-end slot antennas commonly used in UHF (RAIN) RFID tags. We show that they can be analyzed using the same equivalent circuit that represents T-matched dipole tags. We explore the correspondence between circuit elements and open-end slot type tag antenna parameters. We also give a practical example of 80 mm x 25 mm tag with good agreement between simulation and measurement results.**

I. Introduction

One class of antennas used in UHF (RAIN) RFID tags are structures known in general antenna engineering as open-end slot antennas [1] or half-slot antennas [2]. Also, a similar looking antenna type is asymmetric coplanar strip folded dipole [3]. They are less common that T-matched dipole antennas but find a lot of use, especially in challenging applications that require good performance on variety of dielectrics such as ARC-approved baggage tracking tag products [4]. In RFID, such antennas are sometimes referred as antennas with "embedded T-match" [5,6], or "folded dipoles" [6,7], or "T-slot" antennas [8], or just "slot antennas".

In classic slot antennas the ground plane is typically large and slot needs to be of resonant length (half a wavelength). Slot length of open-end slot type RFID tags can vary and the ground plane is finite but can be made very compact (see tag example in section III). Open-end slot type tags typically have threshold POTF and POTR (tag sensitivity and backscatter) curves with very similar behavior as T-matched dipole tags, characterized by several resonant frequencies [9]. In this work, we show that the same equivalent circuit that represents T-matched dipole tags behavior can be used for open-end slot type tags analysis.

II. Equivalent Circuit of Open-End Slot Type Tag

While there are exist many variations of open-end slot type antennas for UHF RFID tags, we concentrate in this paper on one common symmetric geometry shown in Fig. 1 that can be found in many papers and products cited in the previous section. This antenna has T-shaped open-end slot. Its key parameters are ground plane with length L and width W, horizontal slot with length L1 and width W1, vertical slot with length L2 and width W2, and feed trace of width W3 located at height L3.

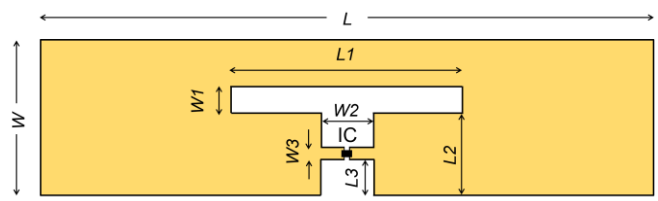

Fig. 1. RFID tag with open-end slot type antenna

The circuit that we use to model that antenna is shown in Fig. 2 and is well familiar to many researchers [5,9]. It is a transformer-based equivalent circuit that contains a series RLC-combo (components R_1, C_1, L_1) that represents tag dipole inductively coupled (with coupling coefficient k , 0<k<1) to a parallel RLC-combo (components R_p, C_p, L_2) that represents tag loop loaded with RFID IC. Parallel Rp||Cp combination approximates chip threshold impedance in absorbing state. While that equivalent circuit may not be ideal for modeling the impedance of open-slot antennas, it still replicates well the general resonance behavior of the tag and thus can be used for analysis and understanding.

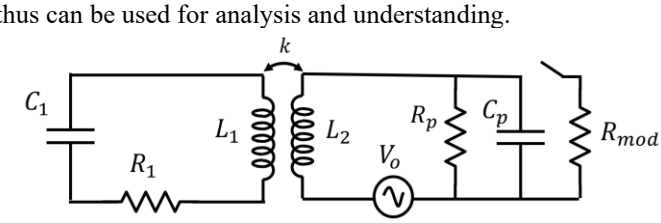

Fig. 2. Equivalent circuit for T-matched tags.

While all the parameters of antenna in Fig. 1 can be varied, in this short paper we focus on effects of L2. This is one of the critical geometry parameters in open-end slot type tag antennas because it controls the coupling.

The reference tag geometry is shown in Fig. 3. It is the antenna in Fig. 1 with the following parameters: L=135 mm, W=25 mm, L1=20 mm, W1=2 mm, L2=12 mm, W2= 2mm, L3=0 mm, W3=1 mm, feed gap at the RFID IC location is 140 um. The effect of L2 change is studied relative to this reference geometry.

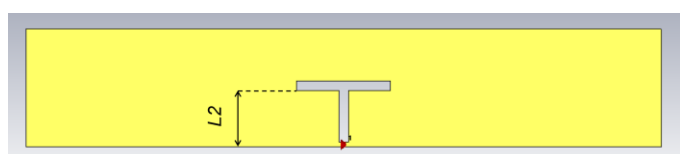

Fig. 3. Reference 135 mm x 25 mm tag geometry simulated in CST.

We used a CST simulator (integral equation solver) [10] to simulate the antenna shown in Fig. 3. Then we calculated threshold POTF and POTR of that tag with M700 series IC [11] (Rp=2.8 kOhm, Cp=1.04 pF, autotune feature is disabled to make resonances more visible). We varied L2 between 6 and 18 mm. As one can see, POTF resonances separate further when L2 is increased and POTR becomes higher due to stronger coupling.

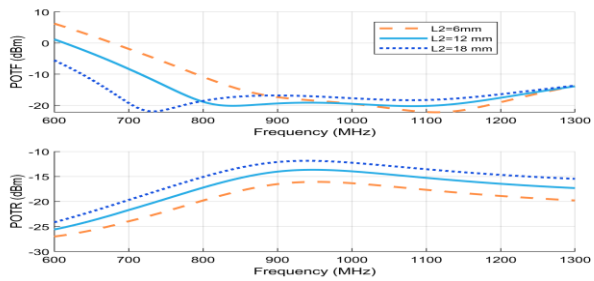

Fig. 4. Simulated POTF and POTR of the tag in Fig. 3 when L2 is varied.

We also extracted equivalent circuit parameters from CST simulation of antenna impedance. As one can see, varying L2 strongly affects the coupling parameter k. We also calculated equivalent loop and dipole resonant frequencies (even though technically there is no loop and dipole in analyzed antenna). They are both affected by L2 but the predicted frequency f_c of POTR resonance (calculated using eq. (8) in [9]) does not change, just as expected from model. The predicted location of

TABLE I. SOME EQUIVALENT CIRCUIT PARAMETERS VS L2

Element	L2=6 mm	L2=12 mm	L2=18 mm
k	0.24	0.34	0.49
f_{loop}	1124.7 MHz	1041.5 MHz	943 MHz
f_{dipole}	954 MHz	916 MHz	853 MHz
f_c	982 MHz	974 MHz	978 MHz

III. PRACTICAL EXAMPLE

As we mentioned in the introduction, the ground plane of open-end slot type antennas is finite but can be made very compact: just enough to have first tag sensitivity resonance fall into desired band of operation Let us consider a practical example: 80 mm x 25 mm open-end slot type tag antenna which fits, for example, into credit card. The other parameters are: L1=10 mm, W1=W2=3 mm, L2=17 mm, L3=0 mm, W3=1 mm. We simulated this antenna in free space using CST and calculated its threshold POTF and POTR for M700 series IC load.

We prototyped this tag using standard EMI copper tape with conducted adhesive. The IC was mounted on thin FR4 board and soldered as shown in Fig, 5. We measured the tag in anechoic chamber using Voyantic Tagformance Pro [12]. The tag was laid flat on foam and tested from the direction of IC.

Fig. 5. Example 80 mm x 25 mm RFID tag open-end slot type antenna

Measured threshold tag response is shown in Fig. 6. The POTR resonance of this tag lies beyond 1000 MHz but the fist POTF resonance is visible and located in FCC band. It agrees well with (using eq. (2) and (5) in [9]).

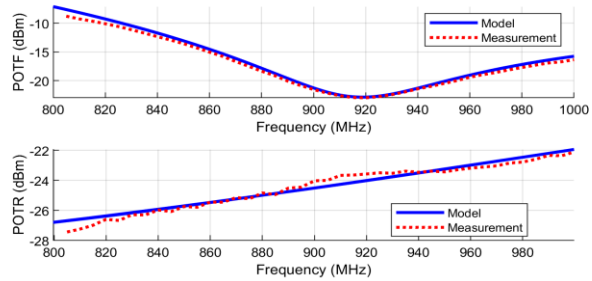

Fig. 6. Threshold POTF and POTR of example tag: model and data.

IV. CONCLUSIONS

In this paper, we discussed open-end slot type RFID tag antennas and showed that they can be analyzed using the same equivalent circuit that represents T-matched dipole tags. We also gave a practical example of 80 mm x 25 mm tag. We hope that this paper will be useful to antenna designers developing tags for various applications.

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[12] Voyantic Tagformance Pro: https://voyantic.com/lab/tagformance-pro/