Reversed T-matching in RFID Tag Antennas

Pavel Nikitin(1), John Kim(1), Guilherme Berzagui(2), João Miguel Roehe(2) and KVS Rao(1)
(1) Impinj, Seattle, WA 98109, USA, http://www.impinj.com
(2) Impinj, Porto Alegre, RS 90680, Brazil, http://www.impinj.com

Abstract—— **In this paper, we analyze a reversed T-matching used in UHF RFID tag antennas. We investigate similarities and differences between T-match and reversed T-match using EM simulations and an equivalent circuit approach applied to a generic 70 x 14 mm RFID tag antenna for M700 IC.**

I. Introduction

A very common antenna used in UHF (RAIN) RFID tags is a T-matched dipole [1, 2]. This type of antenna consists of a loop and a dipole and provides a good broadband impedance match using only distributed traces. It is commonly used in tags that are designed for ARC specifications [3].

There exist many possible configurations of the loop shape and how exactly the loop can be coupled or connected to the main dipole [4]. Fig. 1 shows basic T-matched tag antenna structure with two possible IC locations. When IC is placed directly on the loop (position A) it is usually referred to as a T-match. When IC is placed directly on the dipole (position B), it is called a reversed T-match, a technique known both in RFID [5] and in general antenna engineering [6]. IC can also be placed elsewhere on the loop (off center line) which has certain advantages but results in non-symmetrical antenna pattern. In this paper we will concentrate on reversed T-match antennas.

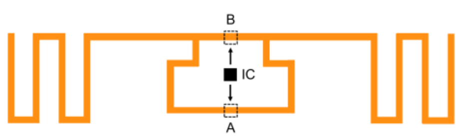

Fig. 1. RFID tag with a T-match (IC at location A) and a reversed T-match (IC at location B). Note: feed gap is assumed to exist at the location of IC.

Both T-matched and reversed T-matched tags typically have threshold POTF and POTR (tag sensitivity and backscatter) curves with very similar behavior characterized by three resonant frequencies: two minima in POTF (frequencies f_a and f_b) and one maximum in POTR (frequency f_c) as shown in Fig. 2.

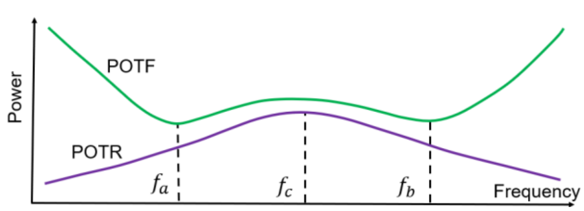

Fig. 2. Threshold POTF and POTR of a typical T-matched tag.

Previously, in [7] we derived closed form expressions for those frequencies based on equivalent circuit of a T-matched tag. In this work, we show that the same equivalent circuit topology can be re-used for reversed T-match analysis, but the physical meaning of circuit elements is different.

II. Equivalent Circuit

The equivalent circuit in Fig. 3 represents a T-matched tag and is well familiar to many researchers [2]. It is an equivalent T-network representation of a transformer-based circuit that represents a dipole inductively coupled to a loop with an IC.

A closer look at the antenna in Fig. 1 reveals that the same exact circuit can represent both T-matched and a reversed T-matched configurations but inductors L_a, L_b, L_c values and meanings are different depending on whether the IC is placed at location A or location B, as explained in Table I below. Components R_1, C_1 represent tag dipole resistance and capacitance, parallel Rp||Cp||Rmod combination represents RFID IC, and V_0 is RF voltage induced on the tag antenna.

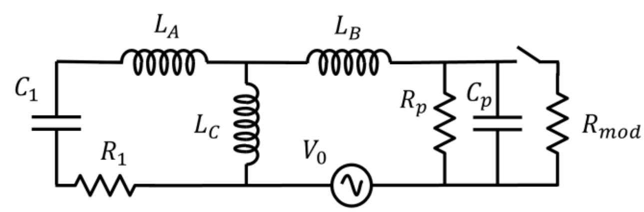

Fig. 3. Equivalent circuit of both T-matched and reversed T-matched tags.

TABLE I. Equivalent circuit elements for T-matched and reveresed T-matched tags and their interpretations

Element	Interpretation	T-match	Reversed T-match
L_a	1st inductor in T-circuit	$L_1 - M$	$L_1 - M$
L_b	2nd inductor in T-circuit	$L_2 - M$	M
L_c	3rd inductor in T-circuit	M	$L_2 - M$
L_1	Dipole inductance	$L_a + L_c$	$L_a + L_b$
L_2	Loop inductance	$L_b + L_c$	$L_b + L_c$
M	Mutual inductance	L_c	L_b

Since the circuit that represents both T-matched and a reversed T-matched configurations is the same, all closed-form expressions for resonant frequencies f_a , f_b and f_c that were derived in [7] remain valid. They can be applied directly to the reversed T-matched tags with the understanding that L_1, L_2, M that appear in those formulas need to be replaced with their equivalents $\widetilde{L_1}, \widetilde{L_2}, \widetilde{M}$ that can easily be found from Table I as $\widetilde{L_1} = L_1 + L_2 - 2M$, $\widetilde{L_2} = L_2$, $\widetilde{M} = L_2 - M$.

III. Example

Let us consider an example: a generic 70 mm x 14 mm meandered dipole tag antenna in two configurations: T-match and reversed T-match as shown in Fig. 4

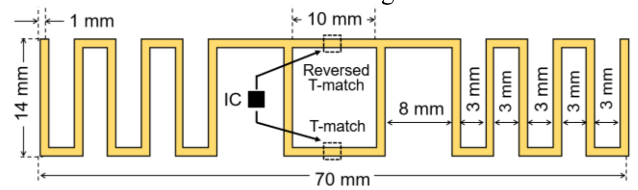

Fig. 4. RFID tag with a T-matched and reversed T-matched options.

We simulated this antenna using CST EM simulator [8] on 90 x 34 x 2 mm piece of a dielectric material (ε =2.57, tan δ =0.0717) which is a dense cardboard from Voyantic material set [9]. Then we calculated threshold POTF and POTR of both tag antennas when loaded with M700 series IC [10] (Rp=2.8 kOhm, Cp=1.04 pF, autotune feature is assumed to be disabled to make POTF resonances more visible).

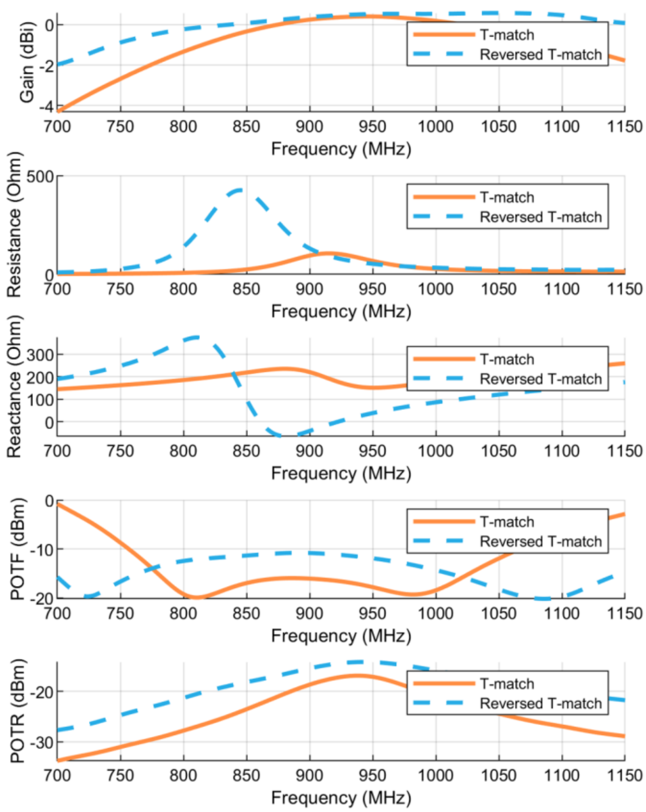

Fig. 5. Gain, resistance, reactance, threshold POTF and threshold POTR of a T-matched and reversed T-matched RFID tag variants from Fig. 4

Fig. 5 shows simulated characteristics of T-matched and reversed T-matched tag variants from Fig. 4. There are several things worth noting there. The peak gains of both antennas are identical but reversed T-matched tag has a wider gain bandwidth. The dipole resonance (resistance peak) of the reversed T-matched tag happens at the lower frequency. The POTF resonances of the reversed T-matched are further apart and POTR is higher due to stronger coupling in reversed T-matched tags, as we show below in Table II.

Due to all that, the first POTF resonance of the reversed T-matched tag occurs at the lower frequency which means that a smaller tag with the resonance at the desired band on a given material can be realized using reversed T-matching. This can be useful for RFID applications which require small tag size.

Table II shows equivalent circuit element values extracted for T-match and reversed T-match variants of a tag shown in Fig. 4. One can see that the mutual inductance (which is an indicator of the coupling between the dipole and the loop) is indeed more than two times higher in the case of the reversed T-match for the same tag antenna geometry.

TABLE II. Equivalent circuit element values for T-matched and reveresed T-matched tags and their interpretations

Element	Interpretation	T-match	Reversed T-match
L_a	1st inductor in T-circuit	33.46 nH	32.26 nH
L_b	2nd inductor in T-circuit	27.25 nH	14.32 nH
L_c	3rd inductor in T-circuit	6.85 nH	16.68 nH
L_1	Dipole inductance	40.31 nH	48.94 nH
L_2	Loop inductance	34.10 nH	30.99 nH
M	Mutual inductance	6.85 nH	14.32 nH
R_1	Dipole resistance	12.78 Ohm	15.29 Ohm
C_1	Dipole capacitance	0.75 pF	0.73 pF

IV. Conclusions

In this paper, we demonstrated that reversed T-matched UHF RFID tags can be analyzed using the same equivalent circuit as T-matched tags. Using an example 70x14 mm tag, we showed that reversed T-matched tags can have stronger coupling and thus exhibit higher backscatter and lower first sensitivity resonance. We hope that this paper will be useful to antenna designers developing tags for various applications.

References

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