PERFORMANCE DEGRADATION OF RFID SYSTEM DUE TO THE DISTORTION IN RFID TAG ANTENNA

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Abstract--In some Radio-Frequency IDentification (RFID) applications, the RFID tag antennas will be printed onto flexible substrates. After sticked onto different objects, possible distortion to the tag antenna such as bending of the tag will be caused due to the flexibility. In this paper, performance degradation of passive RFID systems due to bending of the RFID tag antenna is investigated. The antenna used is the basic folded dipole. Simulation results show that the performance of a passive RFID system, characterized by operating range, can be degraded significantly due to distortion. Thus, antenna structures less sensitive to this should be considered for RFID systems where this kind of effect might occur.

I. Introduction

RFID has been used for identification of different objects for several years. Advances in cost effective low power electronics now makes RFID a qualitative option for applications like replacing barcodes. In some RFID applications, tag antennas printed onto a flexible substrate are highly desired so that the tags can be applied simply by sticking them onto the objects [1]. When RFID frequency rise into the microwave region, the tag antenna must be carefully designed to match to the free space and to the following Application-Specific Integrated Circuit (ASIC) in the tag. This must be made to maximize the transfer of power in and out of the tag circuit and thus enhance the operating range of the RFID system [2]. This is especially important in a passive RFID system where the ASIC's only power supply is from the interrogating radio wave.

Attached to a flexible substrate, the tag antenna is affected by various distortions such as bending if sticked onto goods with soft package (e.g. plastic bags and papers), the bending due to the lose efficiency of the glue under the tag and damages caused by transportation. Also, in some cases it might be necessary to stick the tag over a corner of an object. The distortion in the structure will generally change the performance of the tag antenna and thus cause performance degradation to the RFID system, especially when operating in microwave frequency.

In many RFID systems, dipole antennas are the basic structures adopted for RFID tags operating in the microwave region [3]. In this paper we discuss the performance degradation by simulating several possible cases of distortion to a tag antenna modeled as a folded dipole. Bending at different angles at different positions on one arm is simulated. The input return loss and change in directivity due to bending at different angels at different positions on one arm are calculated. These calculations are carried out both for a printed folded dipole by using Finite Element Method (FEM) techniques and for a thin wire folded dipole by using Method of Moments (MoM) techniques.

With the simulated results, the performance degradation to the RFID system is further illustrated. It is shown how the operating range depends on the antenna distortion.

II. Performance of Bent Dipoles

The bent dipole is not a new topic [4] but we will study it more closely related to the RFID applications and only consider bending along one of the arms.

Let us consider the case with a folded dipole as the RFID tag antenna. For simplicity, the antenna structure is assumed to be perfectly conducting and surrounded by free space. The operating frequency is set to 2.45GHz, which is one of the available frequency bands for RFID. The dipole is fed in the middle and one of the dipole arms is bent at different angels α and at different distances d from the feed as shown in Fig. 1.

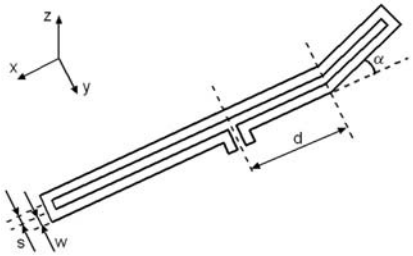


Fig. 1. Folded dipole bent towards the z-axis.

First, the effects of bending a printed folded dipole were simulated with the Finite Element Method. The simulated printed folded printed dipole has a total length of $\ell = 0.449\lambda$ for free space wavelength $\lambda = 0.1224\,m$, spacing $s = 0.0082\lambda$ and printed line width $w = 0.0082\lambda$. The input return losses of the bent printed folded dipole for different α and d are shown in Fig. 2 where we see that the input return loss increases as the antenna is bent at a point closer to the feed. The maximum Voltage Standing Wave Ratio (VSWR) obtained is about 2.3 which occurs when $\alpha = 90°$ and $d = 0$.

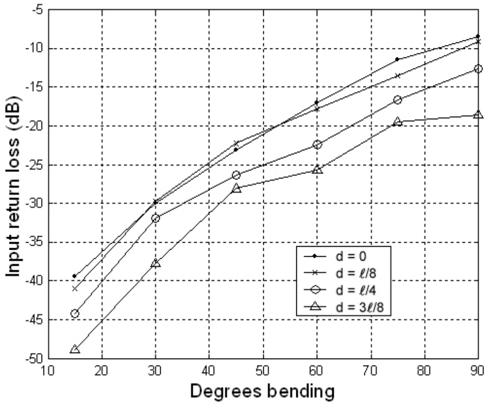
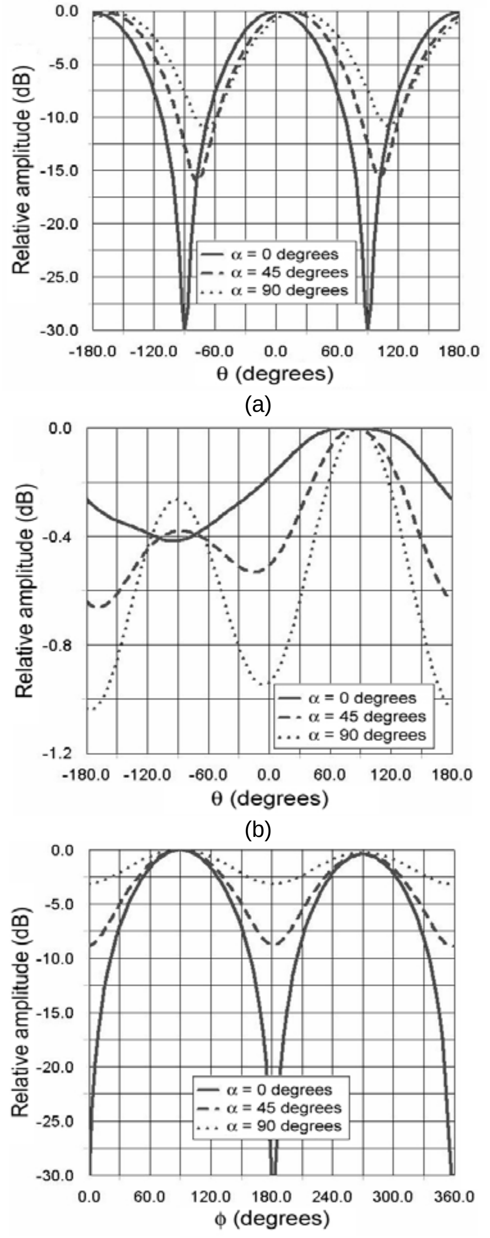


Fig. 2. Input return loss of printed folded dipole bent with different α at different positions.

Fig. 3 shows radiation patterns for different angles of bending when $d = \ell/8$. Each radiation pattern is normalized to its corresponding directivity. It can be observed that in the $\phi = 0°$ plane the angle of maximum directivity is tilted a degree, which is proportional to the bending angle, away from the z-axis. Also, the characteristic dipole end-side zero disappears with more bending, allowing a wider beam-width and no actual blind spot, thus lower directivity, $1.94\ dBi$ vs. $2.33\ dBi$ for the undistorted printed folded dipole. The same behavior in change of the radiation pattern has been observed for other values of d as well. The smaller d is, the greater impact the bending has on the radiation pattern.



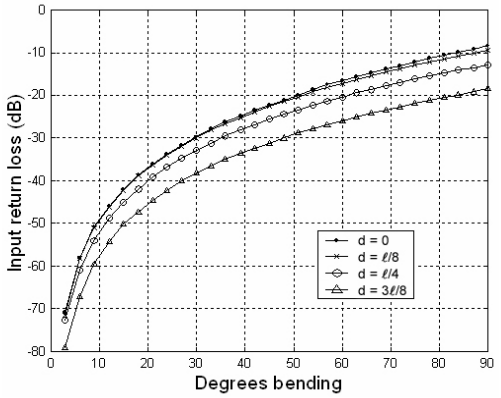
(a)

(b)

(c)

Fig. 3. Normalized radiation patterns of printed folded dipole in the (a) $\phi = 0°$ plane, (b) $\phi = 90°$ plane and the (c) $\theta = 90°$ plane for different *α* when $d = \ell/8$.

The bending effect on a thin wire folded dipole has also been simulated with the Numerical Electromagnetic Code (NEC-2) for thin wire antennas [5]. Dimensions for the thin wire folded dipole is $\ell = 0.460\lambda$, $s = 0.0082\lambda$ and wire radius $a = 0.00182\lambda$. Fig. 4 shows the input return loss due to bending of the thin wire folded dipole. As seen in the figure, the input return losses are similar to those obtained from the printed dipole. Also, the radiation patterns show great similarities with the results from the printed dipole.



(b)

Fig. 4. Input return loss of folded thin wire dipole bent with different *α* at different positions.

III. RFID System Performance

The distortion to the carefully designed RFID tag antenna will no doubt result in performance degradation to the whole RFID system. This can be further illustrated by studying the operating range of the RFID tag. In this analyze we define operating range as the passive tag's maximum distance from the interrogator in order to satisfy the ASIC's power consumption.

Power received in the tag can be calculated using the well-known *Friis-transmission formula*

$$P_r = \frac{(P_t \cdot G_t) \cdot G_r \cdot \lambda^2}{(4\pi R)^2}, \qquad (1)$$

where R is the distance between tag and interrogator, $P_t \cdot G_t$ is the Effective Radiated Power (ERP) transmitted by the interrogator (in EU, the transmitted power allowance is 0.5W ERP), G_r is the gain of tag antenna. For the non-distorted case (i.e. the antenna is not bent), assuming perfect match between the tag antenna and the following circuit and no ohmic loss, the gain will be the same as the directivity

$$G_r = D_r\ . \qquad (2)$$

For the distorted case, the gain will suffer from both the impedance mismatching and directivity change, which can be evaluated as

$$G'_r = \left(1 - |\Gamma|^2\right) \cdot D'_r\ , \qquad (3)$$

where D'_r is the distorted directivity and Γ is the reflection coefficient due to mismatch.

Generally, there is always a minimum power threshold to drive the ASIC in the tag. Therefore, the operating range must be reduced to obtain the power necessary to operate the ASIC with the allowed ERP when the tag antenna is distorted. The ratio of operating range with and without distortion, R' and R, is calculated as

$$\frac{R'}{R} = \sqrt{\left(1-\left|\Gamma\right|^2\right)\frac{D'}{D}} \tag{4}$$

For the tag with a folded dipole antenna, the performance degradation due to antenna distortion can be evaluated from (4) with the results obtained in section II. In practical applications the interrogator is likely to be directed along the z-axis when the tag antenna is oriented as in Fig. 1. The directivity in that direction is $D = 2.18\ dBi$ for the undistorted printed folded dipole. The corresponding RFID performance degradation for this antenna when bent with different α and d is provided in Fig. 5. It can be observed that the operating range will reduce almost 40% when the dipole is bent 90° at the feed. When bent at $d = 3\ell/8$ the reduction of operating range will be almost unaffected. Similar results have been obtained for the thin wire folded dipole.

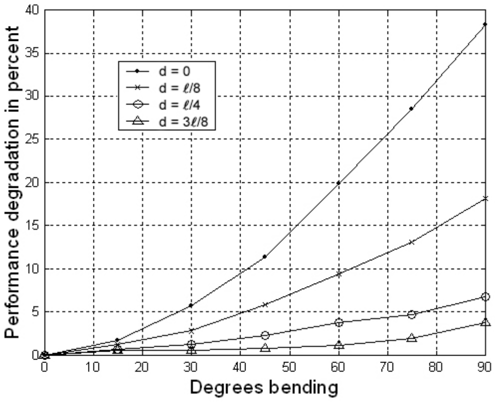


Fig. 5. Performance degradation of RFID system for a dipole tag antenna bent with different α at different d.

IV. Conclusion

An investigation of performance degradation in passive RFID systems due to the distortion of the tag antenna caused by geometrical bending of the antenna has been presented. This bending is likely to occur when attaching tags to flexible substrates. Distortion to basic tag antenna structures, such as printed/wire folded dipole antennas, has been simulated. It is shown that the performance of an RFID system, characterized by operating range, can be degraded significantly due to the distortion. Further work should be done in developing antennas more suitable for RFID applications where such distortion is likely to appear.

V. References

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