Impedance Control and Radiation Properties of a 2.45 GHz ISM Band Wave Guide Antenna for Embedded Transponders in Metallic Objects

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1. Introduction

The recent development of low cost field-powered transponders has significantly increased the demand on identification of goods in industrial areas. Especially in factories where machines and metallic work pieces should be identified and monitored, the use of commercial tags fails because of the reflecting properties of metallic surfaces; an approach to solve this problem is presented in [1] where the transponder is not placed on the object to identify, but under its surface. The signal transmission between the transponder chip and the air interface occurs through a cavity working as cylindrical wave guide antenna, as shown in Fig. 1a). A planar wave guide-to-planar transition achieves the field coupling between the wave guide and the chip. To maximize the communication range, the chip should be matched to the wave guide antenna. Also optimal alignment of the reader and the transponder antennas is required [2]. This paper presents a method to tune the input impedance of the wave guide antenna by varying the transition geometry. Furthermore the radiation properties of the antenna excited by the transition are analyzed.

2. Impedance Control of the Cylindrical Wave Guide Antenna

The cylindrical waveguide antenna operates in the 2.45 GHz ISM band and has an inner diameter of 85 mm. The geometry parameters of the transition proposed in [1] have been sequentially tuned to vary the real and the imaginary part of the antenna impedance. It has been found that especially the lengths $a$ and $b$ depicted in Fig. 1b) cause the targeted effects.

Figure 1: a) Signal transmission mechanism in metallic objects; b) Geometry parameters of the wave guide-to-planar transition. All parameters are in mm

Reducing the length $a$ will increase the real part of the antenna impedance. At the same time, the imaginary part is decreased as shown in Fig. 2a). It should be mentioned that the lower the impedance real part is, the stronger the imaginary part vary over the frequency range, and thus only
narrow band impedance match can be achieved. Similarly, the reduction of the length $b$ decreases both the impedance real and imaginary part as shown in Fig. 2b). Even if these parameters do not allow tuning either the real part or the imaginary part independently, it is possible to realize a wide range of impedances by varying both of them. For example by setting $b = 5.4\, \text{mm}$ and sweeping the length $a$ between $32.5\, \text{mm}$ and $38\, \text{mm}$, the impedance real part has been tuned from $60\, \Omega$ to $32\, \Omega$ at the frequency $2.45\, \text{GHz}$ while the imaginary part remains almost unchanged as Fig. 2c) shows. Similarly, setting $a = 35\, \text{mm}$ and sweeping $b$ from $2.3\, \text{mm}$ to $10.5\, \text{mm}$ tuned the imaginary part from $-60\, \Omega$ to $110\, \Omega$, while the real part varied from $25\, \Omega$ to $130\, \Omega$ (Fig. 2d)).

In practice, the power matching could be easily achieved by tuning the impedance real part as mentioned above and by connecting a reactive component in series or parallel between the transition and the transponder module to adjust the imaginary part to the required value.

![Figure 2](image)

**Figure 2:** a) Influence of length $a$ and b) length $b$ on the antenna impedance; c) Antenna impedance real and imaginary part by $2.45\, \text{GHz}$ as function of length $a$ and d) length $b$

### 3. Radiation Properties of the Cylindrical Waveguide Antenna

The radiation characteristics of the antenna depend on the topology of the transition which performs the excitation. Due to their position to each other, the transition monopoles and loops generate a field distribution similar to the circular wave guide $H_{11}$ mode in the unambiguous frequency range. It is expected that the generated electromagnetic wave in this frequency range is linear polarized in the monopoles direction. To verify this assumption the antenna was measured in an anechoic chamber and fed using a balun since the transition has a differential input. The spatial distribution of the measured horizontal and vertical electric field magnitudes $|E_h|$ and $|E_v|$ are...
shown in Fig. 4a) and Fig. 4b). In the plane \( \theta = 0^\circ \), \( |E_\phi| \) is maximum and \( |E_\theta| \) is minimum by \( \varphi = 0^\circ \) and vice-versa every \( \Delta \varphi = 90^\circ \). This indicates a linear polarization in the plane \( \theta = 0^\circ \) and according to the coordinate system depicted in Fig. 3) the polarization plane is parallel to the transition monopoles, as expected.

Figure 3: Spatial orientation of the wave guide antenna during the field pattern measurement. The horizontal and vertical 3dB beam widths are depicted.

Figure 4: a) Normalized magnitude of \( E_\phi \) and b) \( E_\theta \) by 2.4GHz. c) Normalized magnitude of \( E_\phi \) and \( E_\theta \) at 2.4GHz in the plane \( \varphi = 0^\circ \)

Figure 5: Polar plot of \( |E_\phi| \) and \( |E_\theta| \) in the a) \( \varphi = 0^\circ \) and b) \( \varphi = 90^\circ \) plane at 2.45GHz

Furthermore, the magnitude of both \( E_\phi \) and \( E_\theta \) decreases with increasing \( \vartheta \), which indicates that the antenna radiates with a unique radiation lobe and the main direction is the positive z-axis. The
normalized magnitudes of $E_{\varphi}$ and $E_{\rho}$ in the plane $\varphi = 0^\circ$ are shown in Fig. 4c) and it can be seen that the axial ratio is about $11\,dB$ in the main radiation direction. Fig. 5a) -b) show the polar depiction of $|E_{\varphi}|$ and $|E_{\rho}|$ in the two perpendicular planes shown in Fig. 3. From Fig. 5 it can be seen that the horizontal and vertical $3dB$ beam widths are $\alpha_h = 66^\circ$ and $\alpha_v = 72^\circ$ respectively. These angles can be visualized in the 3-dimensional diagram of $|E_{\rho}|$ and $|E_{\varphi}|$ shown in Fig. 6). As argued before, the diagrams show that the electromagnetic radiation occurs with a unique lobe in the positive $z$-axis.

![Diagram of normalized magnitudes](image)

Figure 6: Three dimensional visualization of $|E_{\rho}|$ and $|E_{\varphi}|$

4. Conclusion

In this paper, a method to tune the impedance of a cylindrical wave guide antenna designed to feed $2.45\,GHz$ ISM band transponders embedded in metallic objects is presented. The antenna is excited by an incorporated planar waveguide-to-planar transition. Sweeping two geometry parameters of the transition permits to realize real and imaginary part in a wide range. As long as the operation frequency remains in the unambiguous frequency range of the wave guide, the antenna radiates mainly in its longitudinal axis with a unique lobe. The radiated wave is linear polarized and the polarization plane is parallel to the transition monopoles. The axial ratio is about $11\,dB$ in the main radiation direction and the horizontal and vertical $3dB$ beam widths are $66^\circ$ and $72^\circ$ respectively.

Acknowledgments

The authors wish to acknowledge the assistance of E. Batzdorfer and R. Behrend for providing experimental work pieces. Special thanks go to the German Research Foundation for the financial support of this work in the framework of the Collaborative Research Centre 653.

References