which requires two L-shaped probes and one T-junction power divider. In this article, it is recommended to use one meandering probe to replace the twin L-shaped probes fed, which can simplify the antenna structure. Results demonstrated that the two feeding mechanisms provide the similar performance. It is obvious that the proposed antenna has simpler structure and lower manufacturing cost. The proposed antenna and the meandering probe-fed patch antenna in [3] have similar structure; the achievement of the gain enhancement is newly presented. The proposed antenna is suitable for constructing mobile base station antenna, such as GSM1800.

5. CONCLUSION
A meandering probe-fed long rectangular patch antenna has been proposed. The antenna has a high gain of 11 dBi and a wide impedance bandwidth of 26% (SWR < 1.5). The antenna has a low crosspolarized level, which is less than −15 dB across the operating bandwidth.

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LOW-PROFILE PLATFORM-TOLERANT RFID TAG WITH ARTIFICIAL MAGNETIC CONDUCTOR (AMC)

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ABSTRACT: A novel low-profile (~0.01λ) platform-tolerant passive RFID tag incorporated with artificial magnetic conductor (AMC) is proposed in this letter. It consists of a modified dipole antenna combined with an AMC ground plane and a tag chip attached on the feeding point of the antenna. The proposed tag shows long and stable read range from 4 to 6 m with a realized gain ranging from 4.1 to 5.3 dB for different platform materials such as metals and lossy liquids. © 2008 Wiley Periodicals, Inc. Microwave Opt Technol Lett 50: 2292–2294, 2008; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.23690

Key words: RFID; artificial magnetic conductor (AMC); tag antenna

1. INTRODUCTION
In recent years, an interest on radio frequency identification (RFID) technology has been growing enormously and RFID systems have been widely used in a variety of areas such as supply chain management (SCM), inventory control, and security management. Among various RFID systems, UHF passive RFID system has been employed widespread for these applications because of long read range, high data rate, and high read rate [1, 2]. An RFID tag antenna plays very important role in the RFID system because it receives electromagnetic energy and data from a reader and transmits data stored in a tag memory to the reader. A kind of dipole antenna has been commonly used for commercial RFID tags, but its performance varies unpredictably when it is placed on different materials such as cardboard, wood, plastic, or metallic object. Therefore, an antenna design of an RFID tag tolerant to different environments becomes crucial for successful implementation of passive RFID systems. Many different kinds of approaches have been reported in the literature, but many of them are not enough to be used in real applications with metals and liquids [3, 4].

In this letter, a new low-profile (~0.01λ) passive RFID tag with artificial magnetic conductor (AMC) tolerant to different platform materials without sacrificing its read range significantly is presented. An AMC is a type of electromagnetic band gap (EBG) material or artificially engineered material showing high-impedance behavior at a specified frequency band, and it can function as a new type of ground plane to effectively reduce an antenna profile by using its property of having a reflection coefficient of +1 (in-phase reflection) [5]. A modified dipole type antenna and an AMC ground plane composed of narrow rectangular patches are designed considering the frequency shift due to the coupling effect occurring when the antenna and the AMC ground plane are put together. Next, the return loss and gain characteristics of the designed tag antenna for different ground plane sizes and the read range measurement results for different platform materials are discussed. All simulation data are obtained using Ansoft HFSS.
2. ANTENNA AND AMC DESIGN AND RESULTS

The geometry and photograph of a proposed low-profile passive RFID tag antenna with an AMC ground plane are shown in Figures 1 and 2, respectively. A modified dipole antenna is separated from AMC patches by a foam spacer of 2 mm, whose relative permittivity is $\varepsilon_r = 1.10$. The length of the antenna is 114 mm and its width is 19 mm. The gap between the two feeding points of the antenna where a tag chip will be attached is 2 mm. The tag chip used for the proposed antenna is Alien class-1 chip with an input impedance of about $6 - j125$ at 910 MHz, which is highly capacitive. To model this chip in computer simulation, one 6-$\Omega$ resistor serially connected between two 2.8 pF capacitors are used.

In this design, the center operating frequency is assumed to be 910 MHz, but the antenna is designed at somewhat higher frequency than this operating frequency to consider the downward shift of the resonant frequency. This shift appears when the tag antenna is placed on the AMC ground plane by parasitic capacitance induced between them, which will affect the antenna input impedance, too. In fact, this has an effect of reducing the size of the antenna. For the same reason, an AMC surface with an infinite impedance frequency, i.e. a reflection phase zero frequency, of 985 MHz is modeled and the reflection phase response of the designed AMC is shown in Figure 3. The high impedance band shifts to around 910 MHz when the AMC ground plane is placed below the dipole antenna because of a coupling effect in-between. The designed AMC ground plane consists of a $5 \times 2$ array of $x$-directed narrow rectangular patches etched on 1.524-mm-thick Taconic RF-60 substrate of relative permittivity $\varepsilon_r = 3.55$ and loss tangent $\tan \delta = 0.0028$, which is backed by a copper ground plane. It is important to mention that since the dipole antenna placed above the AMC ground plane has mainly horizontal-directed current distribution, the strip type patch is used instead of a square patch to increase the number of unit cells in a vertical direction ($y$-direction). The strip patch has a length and width of $x_a = 58$ mm and $y_a = 4.69$ mm, respectively. The gaps between the strip patches in $x$- and $y$-directions are $g_x = g_y = 2$ mm. It is also worth noting that both the antenna and the AMC ground plane are designed to be symmetrical in $x$- and $y$-directions, which would yield symmetrical scattering patterns seen from a reader position.

We first investigate the variations of the antenna performance for different ground plane size. Figure 4 shows the $S_{11}$ character-
istics of the tag for finite and infinite ground planes. In this figure, the finite ground measures 121 mm\(a_x\) × 34.44 mm\(b_y\), while the infinite ground means the case when the ground plane is largely increased compared to the operation wavelength. For the measurement, a 800 mm × 800 mm Aluminum plate is placed underneath the AMC ground plane to be assumed as an infinite ground plane. We see that the resonant frequency moves to lower frequency as the ground plane size reduces. Though not shown here, resonant frequencies for the intermediate-sized finite ground stay between the lowest and highest resonant frequencies shown in Figure 4. The realized gain properties for the finite and infinite ground planes are also compared as shown in Figure 5. It is observed that the realized gain decreases from 5.3 to 4.1 dB as the ground plane size reduces, which is very small. The −3-dB gain bandwidths are about 12 and 10 MHz for finite and infinite ground planes, respectively, which corresponds to approximately −3-dB return loss bandwidth.

Next, the variations on read range when the proposed tag is placed on three different platform materials are investigated. For this purpose, the read range of a free-standing tag is compared with the cases when the tag is placed on a large conducting plate (800 mm × 800 mm) and a rectangular parallelepiped plastic water container (290 mm × 200 mm × 100 mm). The experiment is performed in a fully anechoic chamber under the transmitted equivalent isotropic radiated power (EIRP) of 33 dBm from commercial SAMSYS reader. The read range comparison results are summarized in Table 1. We observe that the read range of 4.2 m for the free standing case increases to 6.0 m for the large conducting plate and 4.8 m for the plastic water container. The read range of 6.0 m for the conducting plate is quite long compared to existing commercial passive metal tags. This also guarantees that the proposed tag is somewhat platform-tolerant and works well for harsh environments such as metals and lossy liquids.

3. CONCLUSIONS

We have proposed a novel low-profile RFID tag incorporated with an AMC ground plane whose performance is tolerant to various platform materials. A dipole-type antenna is designed to be combined with an AMC ground plane taking into account the frequency shift due to the coupling effect occurring when the antenna and the AMC ground plane are put together. A maximum read range from 4 to 6 m has been achieved for different materials where the tag is placed on, and this validates the platform tolerance of the proposed tag. It is expected that the proposed tag can be used for many different RFID applications with different platform materials.

TABLE 1 Measured Read Range for Three Different Platform Materials

<table>
<thead>
<tr>
<th>Platform Material</th>
<th>Read Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Free standing (air)</td>
<td>4.2 m</td>
</tr>
<tr>
<td>Large conducting plate (800 mm × 800 mm)</td>
<td>6.0 m</td>
</tr>
<tr>
<td>Plastic bottle with water (290 mm × 200 mm × 100 mm)</td>
<td>4.8 m</td>
</tr>
</tbody>
</table>

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AN INTERPOLATED SPATIAL IMAGES METHOD FOR THE ANALYSIS OF MULTILAYERED SHIELDED MICROWAVE CIRCUITS

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ABSTRACT: In this article, an efficient interpolation method is presented to compute the Green’s function associated with electrical sources, when they are placed inside cylindrical cavities. The interpolation scheme is formulated in the frame of the spatial images technique recently developed. The original idea was to calculate, for every location of a point electric source, the complex values of the electric dipole and charge images, placed outside the cavity, to impose the appropriate boundary conditions for the potentials. To considerably reduce the computational cost of the original technique, a simple interpolation method is proposed to obtain the complex values of the images for any source location. To do that, a rectangular spatial subdivision inside the cavity is proposed. Each new subregion is controlled by means of the exact image values obtained when the source is placed at the four corners of the region. The key idea is to use a bilinear interpolation to obtain the image complex values when the source is located anywhere inside this subregion. The interpolated images provide the Green’s functions of the new source positions fast, and with high accuracy. This new approach can be directly applied to analyze printed planar filters. Two examples with CPU time comparisons are provided, showing the high accuracy and computational gain achieved with the technique just derived. © 2008 Wiley Periodicals, Inc. Microwave Opt Technol Lett 50: 2294–2300, 2008.