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CIRCULARLY POLARIZED MICROSTRIP PATCH ANTENNA USING ARTIFICIAL MAGNETO-DIELECTRIC SUBSTRATE WITH GRID STRUCTURE

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Abstract—We propose a circularly polarized microstrip patch antenna that use an artificial magneto-dielectric (AMD) substrate. The proposed antenna has a square patch with dual feeding points and uses a Wilkinson power divider in order to achieve a circularly polarized radiation pattern. The AMD substrate is constructed with a two-dimensional array of single split ring resonators. The antenna has an axial ratio of less than 1.7 dB, peak gain of 0.55 dBic, and exhibits a right handed circular polarized radiation pattern at Korean UHF RFID service band. The size of the antenna is 100 mm × 100 mm × 5.2 mm and the radiating patch measures 65 mm × 65 mm ($0.199\lambda_0 \times 0.199\lambda_0$).

1. INTRODUCTION

Radio frequency identification (RFID) has attracted the attention of retailers and manufacturers for use in supply chain management. Several frequency bands have been assigned to RFID signals, including the 125 kHz, 13.56 MHz, UHF (860–960 MHz), and 2.45 GHz bands. As operating frequencies for RFID systems have shifted toward the microwave region, antenna design has become critical to overall performance of RFID systems [1, 2].

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Magnetic materials are useful in reducing the resonant frequency in patch antennas while retaining relative bandwidth. A substrate with $\mu > 1$ allows only a small increase in bandwidth over the same size patch with $\mu = 1$. Such a substrate offers an important advantage: the resonant length of a patch is reduced by a factor of $\sqrt{\mu}$, so that a much smaller patch will have roughly the same bandwidth as a patch using only a high permittivity substrate [3, 4]. However, general magnetic materials, such as ferrite composites, suffer from appreciable magnetic loss and high resistivity in the microwave frequency range [5]. Recently, artificial magneto-dielectric substrates (AMDs), that exploit periodic structures made of various resonators, have gained increasing attention. [6] introduced the method utilizing on the shorted microstrip line to implement of artificial magnetic materials. In [7], the impedance bandwidth characteristics of the planar radiators with different material filling such as air, high-μ, high-ε, and magneto-dielectric using split-ring resonators (SRRs) were compared and it confirmed that the impedance bandwidths of the patch antennas with high-μ and AMD substrate was broader than others. In contrast, densely packed arrays of SRRs were used as an AMD substrate in [8] to reduce the resonant frequency of a $\lambda/2$ patch antenna. AMDs have been employed to enhance the impedance bandwidth properties of planar radiators; in this scenario, the AMDs are typically arrayed along a single axis. Such a layout provides good performance only in linearly polarized antennas, however, since the AMDs exhibit different propagation characteristics along other axes.

We propose a circularly polarized patch antenna using an AMD substrate, which is laid out a two-dimensional array so as to achieve identical propagation performance in both directions. The proposed antenna consists of a square patch, an AMD substrate, a ground, and a Wilkinson power divider. The AMD substrate is constructed by using SRR. Each component of the antenna is printed on four FR-4 substrates of different thicknesses. The AMD substrate and the proposed antenna were designed by using Ansoft HFSS [9]. The overall dimension of the antenna is $100\,\text{mm} \times 100\,\text{mm} \times 5.2\,\text{mm}$. The designed antenna is applicable to UHF RFID handheld reader for Korean RFID standard (917–923.5 MHz).

In Section 2, the proposed antenna configuration, AMD substrate structure, and the characteristics of a single-fed square patch with the proposed AMD substrate are introduced and explained. In Section 3, the proposed circularly polarized antenna is fabricated and the measured results are presented.

2. ANTENNA DESIGN

2.1. Antenna Configuration

Figure 1 shows the proposed circularly polarized patch antenna. The antenna consists of a square patch, an AMD substrate, a ground, and a Wilkinson power divider. Each component is printed on four FR-4 substrates of different thickness, each with dielectric constant of 4.4, as shown in Figure 1(b). The square patch is printed on substrate #1, which has a thickness of 0.8 mm and is excited by using two via holes through four substrates. The AMD substrate is constructed by using SRRs in substrate #2, which has a thickness of 3.2 mm, as shown in Figure 1(c). The SRRs are arrayed in both the x and y directions. The ground and Wilkinson divider are printed on opposite sides of substrate #4, which has a thickness of 0.4 mm. Substrate #3, which is 0.8 mm thick, separates the ground plane from the AMD substrate. The Wilkinson divider is used to achieve wide bandwidth and good axial ratio characteristics using a dual-feed structure by exploiting the quadrature phase difference between two orthogonal feeds.

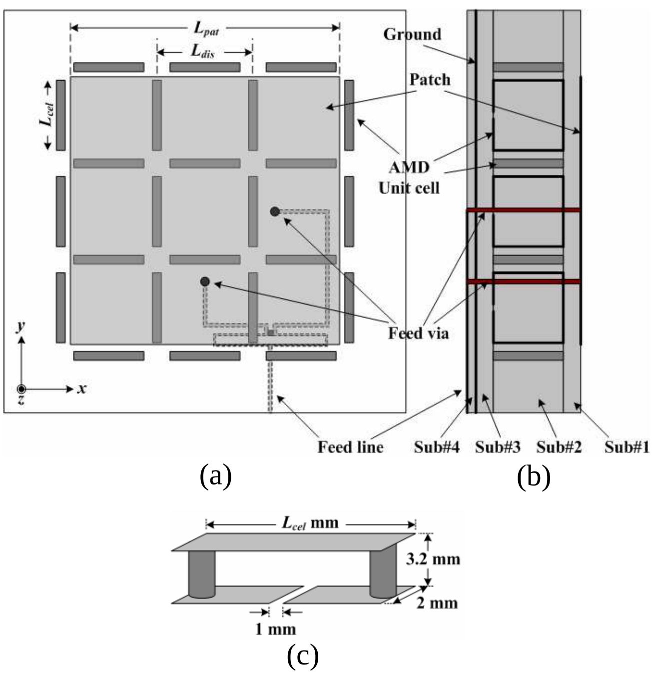


Figure 1. The proposed antenna structure in (a) top view, (b) side view, and (c) a unit cell.

2.2. AMD Substrate Design

SRR unit cells of AMD substrates are arrayed along only one axis, namely the x-axis (Figure 2(a)) or y-axis (Figure 2(b)). Because the two AMD substrates differ in permeability, as shown in Figure 3, there are difficulties in using a one-dimensional arrayed AMD substrate in a circular polarized microstrip patch antenna.

Figure 4 shows the proposed two-dimensional arrayed AMD substrate structure and the permeability characteristics of the designed AMD substrate. Because the grid structure of the proposed AMD substrate extends in both the x and the y directions, the electrical properties of the AMD along both axes are identical. Therefore, the proposed AMD substrate can be used in a circularly polarized microstrip patch antenna with an orthogonal feed network.

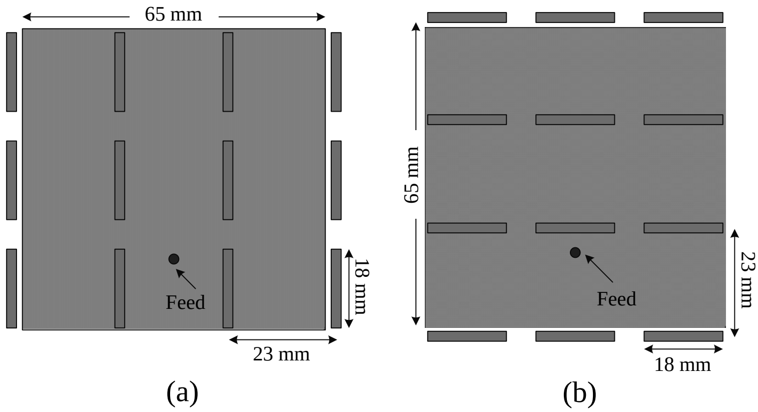


Figure 2. Arrayed AMD structure (a) x-axis and (b) y-axis.

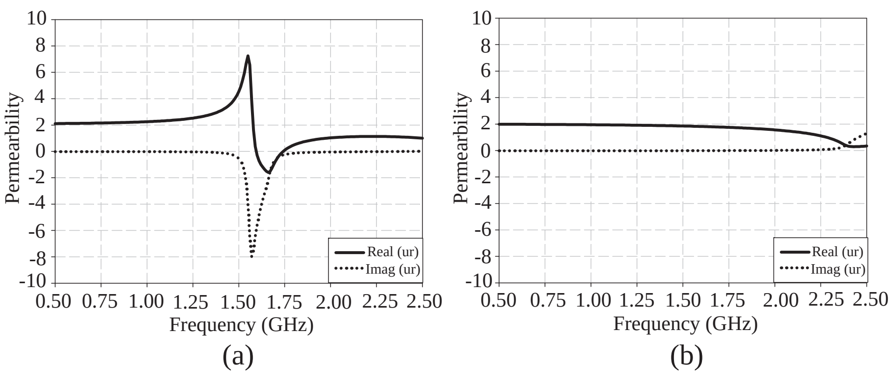


Figure 3. Permeability of AMD structure with (a) x-axis array and (b) y-axis array.

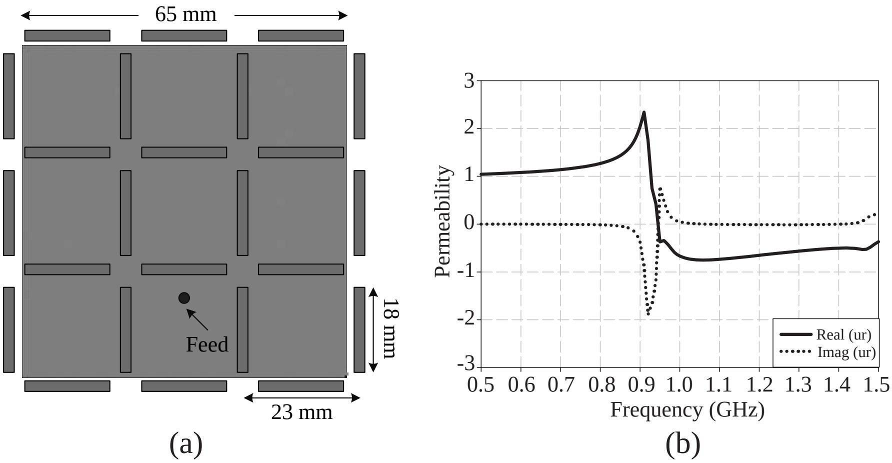


Figure 4. 2-D arrayed AMD substrate (a) structure and (b) permeability.

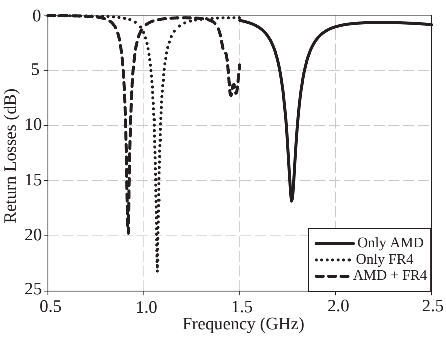


Figure 5. Return loss characteristics for three different substrates.

2.3. Antenna Design

In general, the resonant frequency of a microstrip is directly related to the guide wavelength (λ_g), which is given by

$$\lambda_g \cong \frac{\lambda_0}{\sqrt{\mu_r \varepsilon_r}} \tag{1}$$

The bandwidth can be written in terms of the permittivity and permeability as

$$BW = \frac{96\sqrt{\frac{\mu}{\varepsilon}}\frac{t}{\lambda_0}}{\sqrt{2}[4 + 17\sqrt{\mu\varepsilon}]} \tag{2}$$

As shown in Equation (1), the antenna size can be reduced by adjusting the permeability and/or permittivity values of the substrate. However, the use of a high permittivity dielectric only will narrow the bandwidth as shown in Equation (2). On the order hand, the use of a substrate with $\mu > 1$ can reduce the size of a microstrip patch without deteriorating the bandwidth performance [3, 4]. In this paper, we use AMD substrate to obtain permeability greater than unity and to achieve good CP performance.

To design and analyze the proposed AMD substrate, we use a 65 mm × 65 mm single-fed square patch printed on the AMD substrate. Figure 5 shows the return loss characteristics of the square patch for three different substrates: AMD only (solid line), FR-4 only (dotted line), and AMD + FR-4 (dashed line). The square patch on the AMD-only substrate has a resonant frequency of 1.77 GHz, while the resonant frequency of the patch on the FR-4-only substrate is 1.07 GHz. When the two substrates are combined, the resonant frequency of the patch is 0.92 GHz. Thus the electrical length of the patch is reduced from $0.233\lambda_0 \times 0.233\lambda_0$ to $0.199\lambda_0 \times 0.199\lambda_0$ (73%) of the value for the FR-4-only substrate. The relative impedance bandwidth of patch antennas with the same size on FR-4-only and on FR-4 with AMD substrate are 2.8% at the center frequency of 1.07 GHz and 2.7% at the center frequency of 0.92 GHz, respectively. Even with the size reduction of 16%, the bandwidth still remains almost the same.

Figures 6 and 7 show the return loss characteristics of the square patch for, respectively, varying unit cell lengths L_{cel} and varying inter-unit cell distances L_{dis}. The resonant frequency of the patch is determined by L_{cel} rather than by L_{dis}. Therefore, the resonant frequency of the square patch can be controlled by changing the length L_{cel} of unit cell as well as the patch size. The final values of the designed

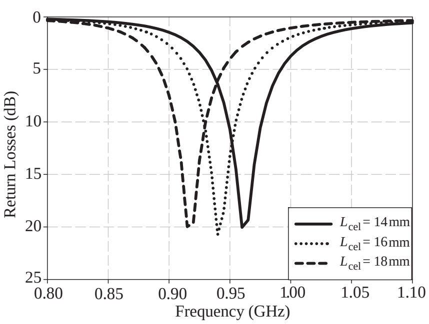


Figure 6. Return loss characteristics for various the length of a unit cell L_{cel}.

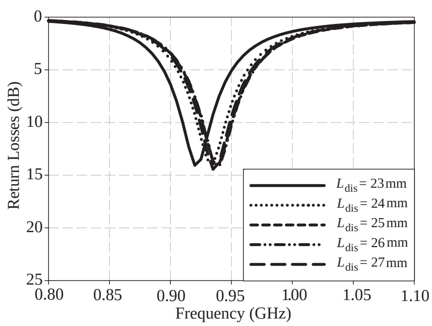
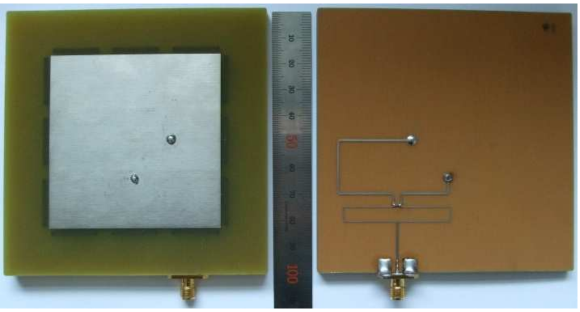


Figure 7. Return loss characteristics for the various distances between unit cells L_{dis}.

AMD substrate are $L_{\text{pat}} = 65\,\text{mm}$, $L_{\text{cel}} = 18\,\text{mm}$, and $L_{\text{dis}} = 23\,\text{mm}$. The overall size of the antenna is $100\,\text{mm} \times 100\,\text{mm} \times 5.2\,\text{mm}$.

3. MEASURED RESULTS

Figure 8 shows photographs of the fabricated antenna. The designed antenna is fabricated by stacking four FR-4 substrates, labeled #1 through #4, with respective thicknesses of 0.8 mm, 3.2 mm, 0.8 mm, and 0.4 mm. The designed antenna is excited by an orthogonally dual-fed structure (Figure 8(a)) and a Wilkinson power divider with quadrature phase difference (Figure 8(b)) in order to achieve wide bandwidth and good axial ratio properties. The measured and simulated return losses characteristics of the designed antenna are shown in Figure 9. There exists slight mismatch of the resonance



(a) (b)

Figure 8. Photograph of the fabricated antenna (a) top view and (b) bottom view.

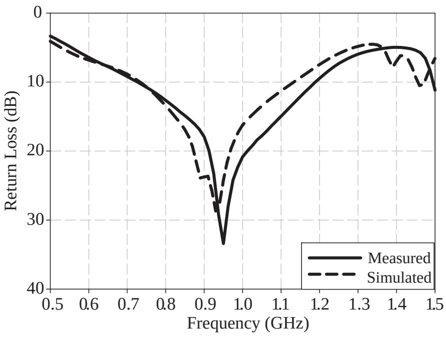
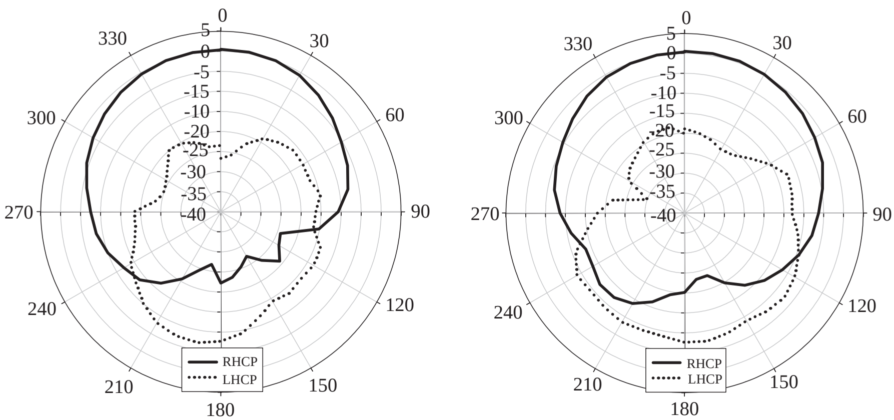


Figure 9. Measured and simulated return loss characteristics.

frequency but the overall return loss characteristics are very similar. The antenna has an impedance bandwidth of 460 MHz (48%) from 730 MHz to 1190 MHz, for a return loss of 10 dB. Figure 10 shows the measured radiation patterns in the two principal planes (the x-z plane and the y-z plane) at 920 MHz. The designed antenna exhibits right-handed circular polarization (RHCP) and a beam width at 3 dB of 110° in the x-z plane and 120° in the y-z plane. The cross-polarization level in the forward direction is very low, yielding a good axial ratio. However, the cross-polarization in the rear direction is rather high, because of the compact size of the proposed antenna (100 mm × 100 mm ($0.307\lambda_0 \times 0.307\lambda_0$)).

Figure 11 shows the measured RHCP gain and axial ratio of the designed antenna. The antenna's axial ratio is less than 1.7 dB, and the peak gain is 0.55 dBic in the Korea UHF RFID service band. The



(a) (b)

Figure 10. Measured radiation patterns (a) x-z plane and (b) y-z plane.

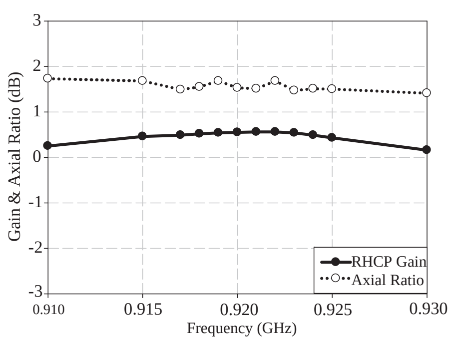


Figure 11. Measured peak gain and axial ratio.

gain of the designed antenna is less than that of typical microstrip patch antennas owing to the large magnetic loss ($\tan \delta_m$) in the AMD substrate (Figure 4(b)) and the compact ground size. Although the gain of the proposed antenna is less than that of aperture-coupled antenna using dielectric substrates with high relative permittivity [10] or of four-layer stacked antenna using air substrate [11], it has a lower profile and smaller size as well as reasonable peak gain of 0.55 dBic. The proposed antenna is thus well-suited to use in handheld RFID readers. However, the method to improve the gain needs to be investigated further for RFID systems required higher gain.

4. CONCLUSIONS

We proposed a circularly polarized microstrip patch antenna using an AMD substrate for use in RFID handheld readers. The AMD substrate was constructed with single SRRs arrayed in both x and y directions. The antenna consisted of a square patch, an AMD substrate, a ground, and a Wilkinson power divider. Each component was printed on an FR-4 substrates; four substrates had dielectric constant of 4.4 and different thicknesses. The designed antenna has an impedance bandwidth of 460 MHz (48%), a peak gain for right handed circular polarization of 0.55 dBic, and an axial ratio of less than 1.7 dB. The sizes of the antenna and radiating patch, respectively, are 100 mm × 100 mm × 5.2 mm and 65 mm × 65 mm ($0.199\lambda_0 \times 0.199\lambda_0$). Because of the designed antenna's compact size, good CP characteristics and suitable gain, it is appropriate for use in UHF RFID handheld readers operating in the Korea RFID band (917–923.5 MHz).

ACKNOWLEDGMENT

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