Aperture-Miniaturized Antenna Loaded with Split Ring Resonator Array

Soon-Soo Oh, Wook-Ki Park, Suk-Youb Kang, and Hyo-Dal Park

ABSTRACT—In this letter, a novel antenna with a miniaturized aperture is proposed. The substrate including a split-ring resonator array is inserted into a size-reduced open-ended waveguide. For a low return loss and high radiation efficiency, the ring arrangement is optimized, and a stepped transition using H-plane discontinuity is proposed. The proposed antenna achieves a 70% aperture reduction compared to a conventional standard waveguide antenna of WR-187 (47.6 mm×22.2 mm). The return loss drops significantly at three frequencies, and a reasonable gain is achieved. The aperture-miniaturized antenna can be used in many antenna applications such as near-field measurement.

Keywords—Split ring resonator, aperture miniaturization.

I. Introduction

In the past decade, the split ring resonator (SRR) has been intensively investigated because it can build up a negative permeability (μ_r) around the resonant frequency (f_r) [1]. SRRs are placed parallel to the conductive thin rods, and the incident wave can propagate because the conductive rods have negative permittivity (ε_r); therefore, both μ_r and ε_r are negative [1]. Another structure has been proposed in [2] and [3], in which an SRR placed inside a waveguide enables wave propagation below the cutoff frequency. The reason for this is that the longitudinal component of permeability (μ_{lr}) is negative below the cutoff frequency. This phenomenon is very useful since the waveguide can be miniaturized. In [2] and [3], a miniaturized filter was proposed, but the insertion loss is serious due to mismatching between the SRR array and the feeding structure.

Generally, the near-field measurements are performed by separating the probe from the antenna under test (AUT) by at least 3λ, where λ is the wavelength in free space [4]. Although near-field measurements could reduce the chamber volume compared to the far-field measurements, this separation distance could be a few meters in a VHF band. If the probe is placed closer to the AUT, the mutual coupling and multiple reflection increase because of the high level of the radar cross section (RCS).

We propose a technique for SRR loading which is applied to a microwave antenna for the first time to the best of our knowledge. This novel antenna miniaturizes the radiating aperture so that the RCS is relatively small, and it can be utilized as a probe for near-field measurements.

II. Antenna Design

The antenna proposed in this letter comprises four parts as shown in Fig. 1(a): a square waveguide loaded with an SRR array substrate, a rectangular waveguide, a quarter-wavelength impedance transformer, and a rectangular waveguide to connect to the adaptor. The frequency was determined to be about 5 GHz due to the ease of fabrication and experimentation.

The ring has an inner radius of 2.2 mm, an outer radius of 3.8 mm, and a gap of 0.4 mm. The distance between the centers of the rings is 10 mm. The substrate containing the SRR array, which is called the SRR array substrate, is inserted vertically along the central line of the open-ended square waveguide as shown in Fig. 1(a). This substrate has a thickness of 0.508 mm, a tangent loss of 0.009, and a dielectric constant of 2.2. The height of the SRR array substrate is equal to the

Manuscript received Jan. 12, 2009; revised Mar. 12, 2009; accepted Apr. 13, 2009.

Soon-Soo Oh (phone: + 82 42 860 4974, email: ssoh@etri.re.kr) is with the Broadcasting & Telecommunications Convergence Research Laboratory, ETRI, Daejeon, Rep. of Korea.

Wook-Ki Park (email: wookkipark@hotmail.com) and Hyo-Dal Park (email: hdpark@inha.ac.kr) are with the Department of Electrical Engineering, Inha University, Incheon, Rep. of Korea.

Suk-Youb Kang (email: Int-ksy@hanmail.net) is with the Department of Radio Sciences and Engineering, Korea Maritime University, Busan, Rep. of Korea.

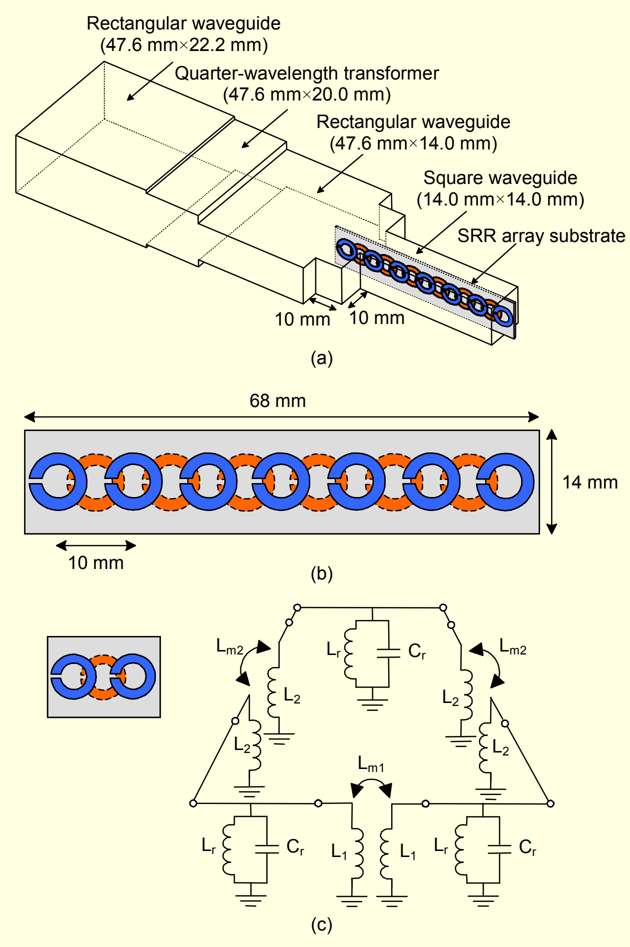

Fig. 1. Geometry of aperture-miniaturized antenna: (a) oblique view, (b) SRR array substrate, and (c) approximate equivalent circuit of three rings.

height of the square waveguide, 14 mm, and the length of the SRR array substrate is 68 mm. The square waveguide loading the SRR array substrate is 50 mm long, 14 mm wide, and 14 mm high. The aperture of the proposed antenna is reduced by about 70% compared to the aperture of a standard waveguide probe of WR-187 (47.6 mm×22.6 mm).

The SRR array has a partly overlapped placement as shown in Fig. 1(b). The seven rings marked with a solid line are positioned on one side, and the six rings marked with a dotted line are positioned on the other side, and they half-overlap each other. This configuration allows for dense placement of the rings so that the mutual coupling between rings and the transmission efficiency increase. An approximate equivalent circuit of the rings is shown in Fig. 1(c). For simplicity, only three rings are modeled. In the figure, L_r and C_r are the resonant inductance and capacitance of the ring, L_1 and L_2 are the self-inductance of the coupling between rings, and L_{m1} and L_{m2} are the mutual inductance. These mutual inductances are determined by the central spacing between rings so that the coupling level drops as the central spacing increases. The important fact to be noted is that these mutual inductances cause a multiple resonance, which is discussed in section III.

As shown in Fig. 1(a), the ring located at the left end of the array is placed half inside the rectangular waveguide with a dimension of 47.6 mm × 14 mm, which was presented in the filter structures [4]. In this study, the ring located at the right end of the array is also exposed to free space, and in our simulation, it was found to increase the radiation efficiency.

Another important design factor is a stepped transition using the *H*-plane discontinuity between the square waveguide and the rectangular waveguide, as shown in Fig. 1(a), with a lateral size of 10 mm. The optimization process was carried out as follows. First, the SRR array being inserted in an artificial TEM waveguide was simulated, and the central spacing between rings was optimized to have a low return loss. Then, the stepped transition and the SRR arrays in the rectangular waveguide were simulated simultaneously. The optimum size of the stepped transitions was found to provide a low return loss.

The designed antenna was connected to a network analyzer through a standard rectangular waveguide of WR-187. For impedance matching, a quarter-wavelength transformer was designed to be 47.6 mm wide, 20 mm high, and of 20 mm long.

III. Simulated and Measured Results

The proposed antenna was simulated using Ansoft HFSS finite element method (FEM) software. Figure 2 shows a photograph of the fabricated antenna.

The return loss from the simulation and measurement is shown in Fig. 3 with simulation results for the aperture antenna without SRR. As expected, the return loss was almost zero, which means that all waves were reflected.

Although the antenna was designed to have one resonant frequency (f_r), the simulated return loss drops significantly at three frequencies of 5.20 GHz, 5.35 GHz, and 5.52 GHz. The experimental return loss also shows three resonant frequencies of 5.09 GHz, 5.25 GHz, and 5.41 GHz. A frequency shift of about 0.1 GHz, as shown in Fig. 3, might be caused during the etching of the ring array. Our simulation found that the

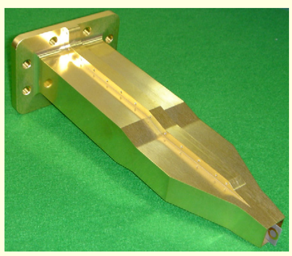

Fig. 2. Photograph of the fabricated antenna.

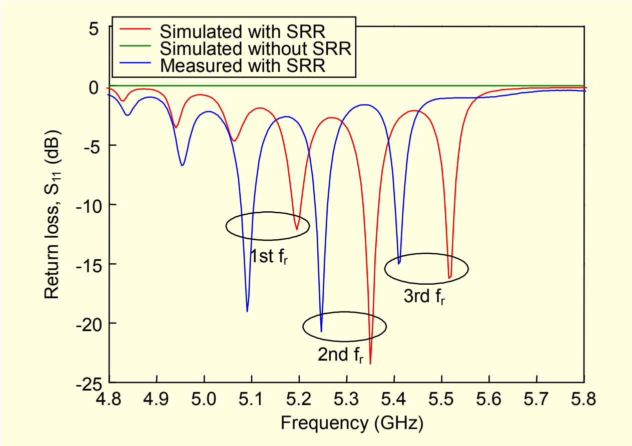

Fig. 3. Simulated and measured return loss, S_{11}.

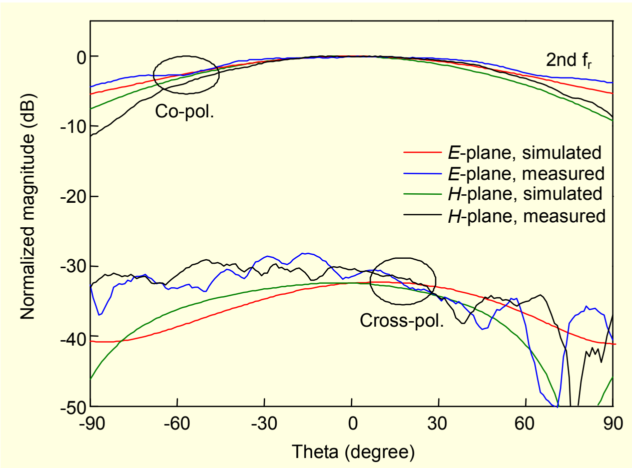

Fig. 4. Simulated and measured radiation patterns at the second resonant frequency.

decrement of gap spacing by 0.1 mm resulted in the frequency lowering by 0.08 GHz. Since the bandwidth of the proposed antenna is very narrow, a minor fabrication error could shift the resonant frequency away from the designed band as shown in Fig. 3. However, this narrow bandwidth could be broadened by adjusting the parameters of the ring such as the spacing and gap size, or by adopting multiple rings [5].

Figure 4 shows a normalized radiation pattern at the second resonant frequency. The designed antenna shows a broad radiation pattern. Since the patterns of the first and third resonant frequencies are similar to the pattern of the second resonant frequency, they are omitted. The 3 dB beamwidth in the *E*-/*H*-plane is summarized in Table 1. The simulated and measured cross-polar levels are low, below -30 dB.

The simulated and measured gain of the antenna is also summarized in Table 1. The relatively low gain is caused by the loss from the ring conductor and dielectric substrate [5]. The differences in beamwidth and gain are thought to result in

Table 1. 3 dB beamwidth in the *E*-/*H*-plane and gain from simulation and measurement.

	Beamwidth (degree)				Gain (dBi)	
	E, sim.	*H*, sim.	*E*, meas.	*H*, meas.	Sim.	Meas.
1st f_r	128	110	157	108	-1.59	-0.88
2nd f_r	126	109	148	110	-1.28	-0.94
3rd f_r	123	107	150	107	-2.62	-4.24

the broad beam patterns. A microwave absorber was placed behind the AUT during measurement. This absorber disturbs the field so that the pattern shape fluctuates. A similar phenomenon can be observed during the measurement of a dipole antenna.

IV. Conclusion

We proposed a waveguide antenna with a miniaturized aperture. An SRR array substrate was inserted into the central part of an open-ended waveguide. The ring placement was optimized, and *H*-plane discontinuity was proposed to decrease the return loss. The simulated and measured results showed three resonant frequencies around 5 GHz and a reasonable gain. The reduction of the aperture size is about a 70%. Although the gain is relatively low and the bandwidth is narrow, the proposed antenna can be used in many applications such as near-field measurement due to its miniaturized aperture.

References

[1] J.B. Pendry et al., “Magnetism from Conductors and Enhanced Nonlinear Phenomena,” *IEEE Trans. Microwave Theory Tech.*, vol. 47, no. 11, Nov. 1999, pp. 2075-2084.

[2] R. Marques et al., “Left-Handed-Media Simulation and Transmission of EM Waves in Subwavelength Split-Ring-Resonator-Loaded Metallic Waveguides,” *Phys. Rev. Lett.*, vol. 89, no. 18, 2002, pp. 183901-183904.

[3] S. Hrabar, J. Bartolic, and Z. Sipus, “Waveguide Miniaturization Uniaxial Negative Permeability Metamaterial,” *IEEE Trans. Antennas Propag.*, vol. 53, no. 1, 2005, pp. 110-119.

[4] D. Slater, *Near-Field Antenna Measurements*, Artech House, Boston, 1991.

[5] D. Kim, J. Yeo, and J. Choi, “Compact Spatial Triple-Band-Stop Filter for Cellular/PCS/IMT-2000 Systems,” *ETRI Journal*, vol. 30, no. 5, Oct. 2008.

[6] S.S. Oh and L. Shafai, “Artificial Magnetic Conductor Using Split Ring Resonators and Its Applications to Antennas,” *Microwave Optical Tech. Letts.*, vol. 48, no. 2, 2006, pp. 329-334.