Switchable Printed Yagi-Uda Antenna with Pattern Reconfiguration

Jung-Woo Baik, Seongmin Pyo, Tae-Hak Lee, and Young-Sik Kim

ABSTRACT—A switchable Yagi-Uda antenna prototype with radiation pattern reconfiguration is presented in this letter. The proposed reconfigurable antenna is based on the concept of switching between the reflector and director of a Yagi-Uda antenna using a radio frequency PIN diode. As a result, the minimum/maximum radiation can be steered towards desired signals or away from interfering signals in opposite directions. The measured 10 dB impedance bandwidth and gain are 210 MHz (7%) and 8.02 dBi at 3 GHz, respectively. Details of the antenna design and its performance are described and empirically analyzed.

Keywords—Yagi-Uda antenna, printed antenna, pattern reconfiguration, pattern switchable antenna.

I. Introduction

Interest in reconfigurable antennas has increased tremendously due to the potential for additional functionality and flexibility in modern communication applications. In particular, extensive research on multiple-input multiple-output (MIMO) techniques has resulted in studies on various reconfigurable antennas, the performance of which can be reconfigured by restructuring conventional antennas. The concept of the reconfigurable antenna was initially presented in Daniel H. Schaubert's patent [1], and it was greatly advanced by the Reconfigurable Aperture Program (RECAP) launched by the United States Defense Advanced Research Projects Agency (DARPA) [2]. In general, reconfigurable antennas can be classified into three types: resonant frequency, polarization, and radiation pattern reconfigurable [3]-[8]. In [3], frequency and polarization reconfigurability are achieved via a truncated microstrip patch antenna with a U-slot and PIN diode. In [4] and [5], an annular slot antenna with a PIN diode, and a single-turn square spiral microstrip antenna with a metal pad instead of a PIN diode are proposed for radiation pattern and frequency reconfiguration. The pattern reconfigurable antenna in particular has received much attention because manipulation of the radiation pattern enables avoidance of noise sources, improved security by directing signals only toward intended users, sensibility of signal, intentional jamming, improved beam steering capability of phased array systems, and diversity systems. In the pattern reconfigurable antenna, electrical binary switching mechanisms for pattern reconfigurability can be achieved by radio frequency (RF) PIN diodes, MEMS switches, and optical switches [6]-[8]. In [6], an antenna with a continuously varying radiation pattern direction utilizes a parasitic structure composed of a set of microstrip elements that can be electrically controlled via PIN diodes. The antennas reported in [7] and [8] are based on the concept of a basic Yagi-Uda antenna, designed on a dielectric substrate backed by a finite ground plane. Also, these antenna designs are implemented using a metal pad instead of RF switching devices, regardless of the effect of the bias lines. In this letter, we present an effective implementation of a pattern reconfigurable Yagi-Uda antenna with no ground plane, using an RF PIN diode to shift the minimum/maximum levels of the radiation pattern toward opposite side directions.

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Jung-Woo Baik (phone: + 82 2 929 9909, email: baik-jw@korea.ac.kr) is with the Research Institute for Information and Communication Technology, Korea University, Seoul, Rep. of Korea.

Seongmin Pyo (email: bryanpyo@korea.ac.kr), Tae-Hak Lee (email: taehaklee@korea.ac.kr), and Young-Sik Kim (email: yskim@korea.ac.kr) are with the Department of Radio Communications Engineering, Korea University, Seoul, Rep. of Korea.

II. Antenna Design

Figures 1(a) and (b) show the solid and side views of the proposed reconfigurable antenna, respectively. The designed antenna is fabricated on an RT/Duroid 5880 substrate with a

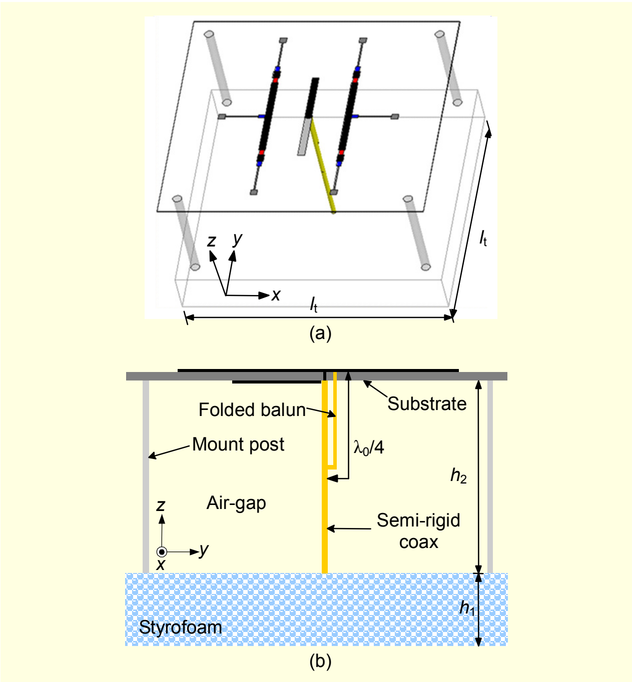

Fig. 1. Geometry of the proposed antenna: (a) solid view and (b) side view.

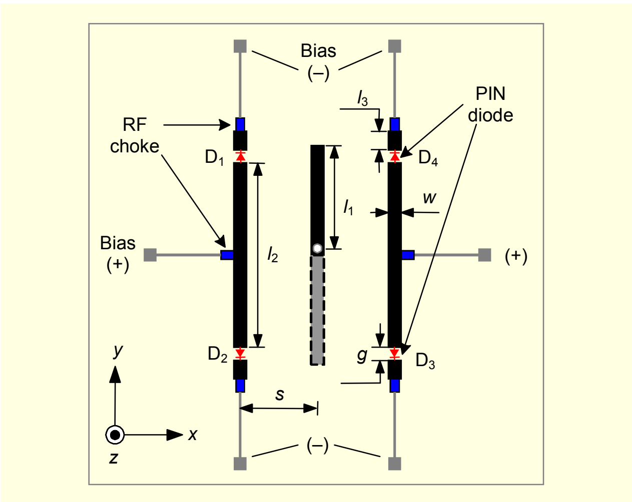

Fig. 2. Schematic of the proposed antenna using the PIN diode.

dielectric constant of 2.2 and a thickness of 0.508 mm. The substrate with the antenna and bias line patterns is fixed to the styrofoam using mount post which is made of teflon. There is an air-gap between the substrate and styrofoam. The two legs of a dipole serving as a driver of the Yagi-Uda antenna are printed on the two opposite sides of the substrate. Each leg of the dipole is connected to the inner core and outer shield conductor of a semi-rigid coaxial cable. The bias line is printed on the upper surface of the substrate. Usually, a ground plane at a distance of $\lambda_0/4$ from the driven dipole provides a balanced mode. However, since this is not in this design, a folded balun structure with a length of $\lambda_0/4$ (25 mm), where λ_0 is the free-space wavelength at the center frequency of 3 GHz, is used to excite a balanced mode. This is shown in Fig. 1(b). The heights of the styrofoam (h_1) and air-gap (h_2) are 25 mm and 75 mm, respectively. The dimensions of the antenna are 100 mm (l_t)×100 mm (l_t)×100.508 mm.

The schematic of the proposed reconfigurable antenna is shown in Fig. 2. The space *s* between the driver and reflector (director) is 18 mm, that is, 0.25λ_g, where λ_g is the guided wavelength at the center frequency of 3 GHz. The width *w* of the driver and reflector (director) is 1.5 mm. One leg of the dipole has a length of 21.45 mm (l_1), and the length of director (l_2) is 34.4 mm (0.478λ_g). The gap *g* for soldering the RF PIN diode is 1 mm. Therefore, the total length of the reflector is 47 mm, when the PIN diodes are in the ON-state. As shown in Fig. 2, a microstrip line with l_3 (5.3 mm) is added to one leg of the PIN diode for switching between the director and reflector. The RF choke inductors are used for isolation between the reflector (director) and the bias line. Its value is 100 nH. In this design, the PIN diode utilized for electrical switching is the Siemens BAR64-02W silicon diode [9].

III. Experimental Results

Figure 3 shows the measured and simulated return loss for the reconfigurable Yagi-Uda antenna when the diodes D_1 (or D_4) and D_2 (or D_3) are in the ON-state and the others are in the OFF-state. From the measured results, the 10 dB impedance bandwidth is 210 MHz (about 7% at 3 GHz) which is between 2.9 GHz and 3.11 GHz. Figure 3 also shows good agreement between the measured and simulated return loss. Simulation and optimization were performed using the commercial software of Ansoft HFSS based on the finite element method. Figures 4(a) and (b) show the measured and simulated radiation patterns in the *x*-*y* (*E*-plane) and *x*-*z* planes (*H*-plane),

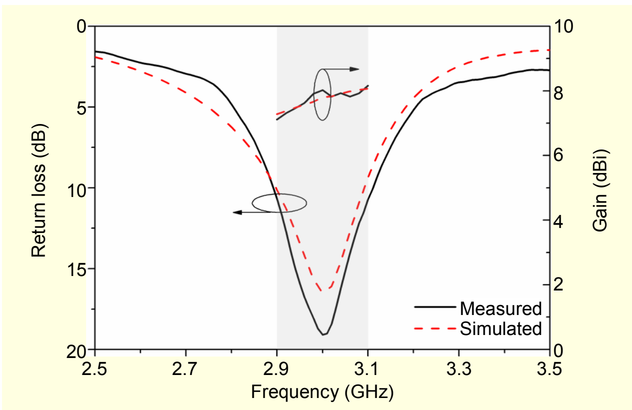

Fig. 3. Simulated and measured return loss of the antenna.

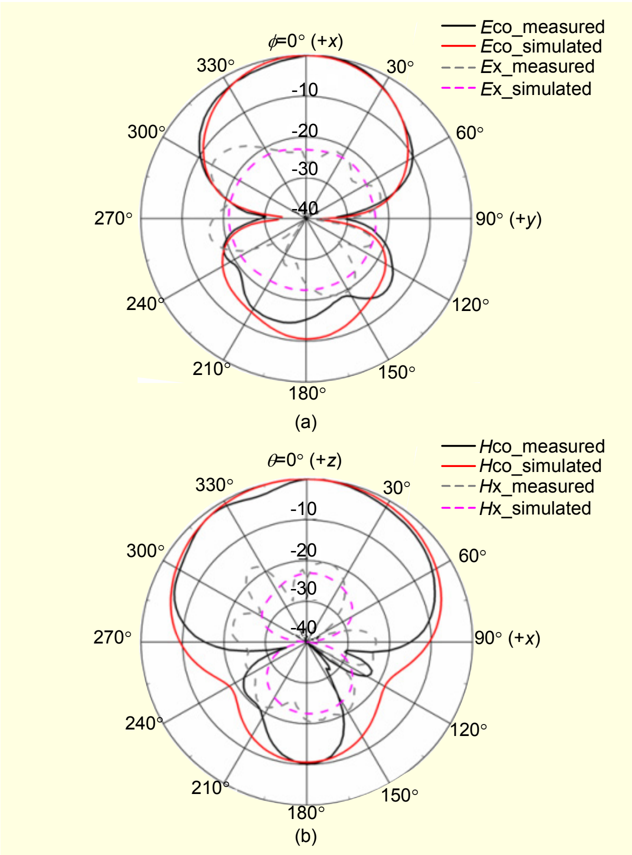

Fig. 4. Simulated and measured radiation patterns: (a) *E*-plane and (b) *H*-plane.

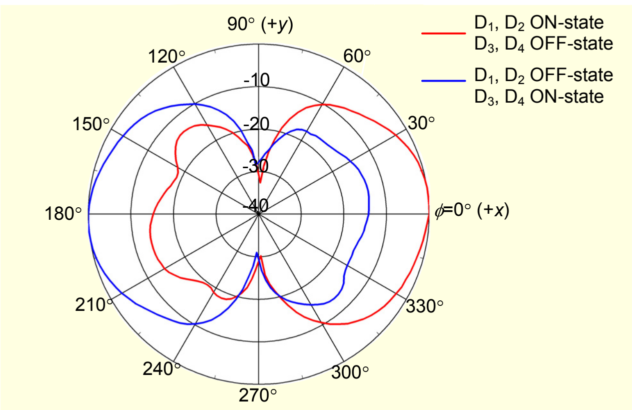

Fig. 5. Radiation patterns in each state.

respectively, when D_1 and D_2 are in the ON-state, and D_3 and D_4 are in the OFF-state. The front-to-back (F/B) ratio of the measured *E*-plane pattern is about 14 dB, which dominantly affects the spacing of the reflector with respect to the driven dipole. There is a slight difference between the measured and simulated back-lobe radiation patterns, which may be due to the bias lines and imperfect behavior of RF choke inductors. However, the electrically opened bias lines near the director have almost no effect on the main radiation. The measured and simulated peak gains are 8.02 dBi and 7.8 dBi, respectively, at the center frequency of 3 GHz. The measured *E*-plane patterns switched by each pair of RF PIN diodes are shown in Fig. 5. The radiation pattern when D_1 and D_2 are in the ON-state shown in Fig. 5 is equal to the co-polarized *E*-plane pattern shown in Fig. 4(a). Both radiation patterns plotted in Fig. 5 have almost the same F/B ratio of 14 dB and half-power beamwidth of 60°. From Fig. 5, it is clear that the main and back lobes of the radiation pattern are oppositely switched.

IV. Conclusion

In this letter, the switchable printed Yagi-Uda antenna is proposed for radiation pattern reconfiguration, which is achieved via electronic control of two pairs of RF PIN diodes. The minimum/maximum radiation directions of the designed antenna can be steered in opposite directions to select desired signals or avoid interfering signals, and this enables configuration of efficient wireless communication networks. Although the proposed antenna is operated at 3 GHz, this antenna model can be easily redesigned for other frequency applications by using the frequency scaling technique.

References

[1] D.H. Schaubert et al., *Frequency-Agile Polarization Diverse Microstrip Antennas and Frequency Scanned Arrays*, US Patent 4,367,474, to the United States of America as represented by the Secretary of the Army, Washington D.C. 1983.

[2] J.K. Smith, *Reconfigurable Program (RECAP)*, DARPA, 1999.

[3] K. Chung et al., "Reconfigurable Microstrip Patch Antenna with Switchable Polarization," *ETRI Journal*, vol. 28, no. 3, June 2006, pp. 379-382.

[4] S. Nikolaou et al., "Pattern and Frequency Reconfigurable Annular Slot Antenna Using PIN Diodes," *IEEE Trans. Antennas Propag.*, vol. 54, no. 2, Feb. 2006, pp. 439-448.

[5] G.H. Huff et al., "A Novel Radiation Pattern and Frequency Reconfigurable Single Turn Square Spiral Microstrip Antenna," *IEEE Microw. Wireless Compon. Lett.*, vol. 13, no. 2, Feb. 2003, pp. 57-59.

[6] M. Donelli et al., "A Planar Electronically Reconfigurable Wi-Fi Band Antenna Based on a Parasitic Microstrip Structure," *IEEE Antennas Wireless Propag. Lett.*, vol. 6, 2007, pp. 623-626.

[7] S. Zhang et al., "A Pattern Reconfigurable Micriostrip Parasitic Array," *IEEE Trans. Antennas Propag.*, vol. 52, no. 10, Oct. 2004, pp. 2773-2776.

[8] X.-S. Yang et al., "Yagi Patch Antenna with Dual-Band and Pattern Reconfigurable Characteristics," *IEEE Antennas Wireless Propag. Lett.*, vol. 6, 2007, pp. 168-171.

[9] http://www.infineon.com.