Design and Development of an Annular Slot Antenna (ASA) with a Reconfigurable Radiation Pattern

Symeon Nikolaou$^{*(1)}$, George E. Ponchak$^{(2)}$ *Senior Member IEEE*, John Papapolymerou$^{(1)}$ *Senior Member IEEE* and Manos M. Tentzeris$^{(1)}$ *Senior Member IEEE*

Abstract: This paper discusses the use of pin diodes to modify the radiation pattern of an Annular Slot Antenna (ASA) keeping constant the frequency of operation. The planar antenna is fabricated on the top side of a Duroid substrate and the microstrip feeding line with the matching network is fabricated on the back side of the board. The design frequency is 5.8 GHz. Pin diodes are used to short the ASA in pre-selected positions along the circumference. As a result of the short, the direction of the null in the plane defined by the circular slot changes. As a proof of concept two pin diodes are placed symmetrically to the feeding line and 45 degrees away from the feeding line direction. As a result, the direction of the null shifts and is aligned with the direction defined by the circular slot center and the diode. Consequently a reconfigurable radiation pattern is accomplished. Return loss and radiation pattern measurements and simulations are presented and demonstrate a very good agreement.

Key Words: Annular slot antenna (ASA), pin diode, reconfigurable radiation pattern, reconfigurable antenna

I. INTRODUCTION

The recent trends in modern cell phones and other personal mobile devices within highly interfering environments require smart and reconfigurable antennas with easily controlled radiation patterns. The Annular Slot Antenna (ASA) proposed in this paper operates at 5.8 GHz and the use of pin diodes along the slot circumference allows the radiation pattern to be directed in a number of different directions while the operation frequency remains constant. It is fabricated on inexpensive material and is a compact design suitable for integrating in mobile devices. The annular slot antenna on dielectric material has been described explicitly in [1]. The effect of one shorted point along the circumference has been explored in [2] and the effect of capacitive loading is investigated in [3]. The use of shorting pins to maintain the radiation pattern constant while operating in different frequencies has been used in [4]. In the present work, pin diodes are used to control the radiation pattern of a planar annular slot antenna keeping constant the operation frequency.

II. DESIGN CONCEPT

The annular slot antenna consists of a circular slot on a square, metal ground plane that is fed by a microstrip line, fabricated on the bottom of the Duroid substrate as can be seen in Figs 1a and 1b.

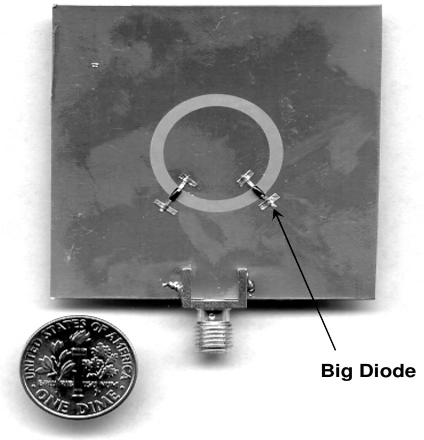

Fig. 1a ASA front side

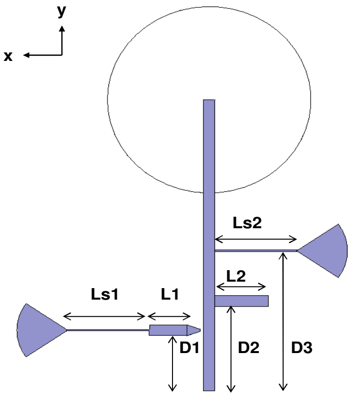

Fig. 1b Matching network schematic

The mean length of the slot circumference is approximately $3\lambda s/2$ at the design frequency where λs is the equivalent

---

Manuscript received July 31. This work was partially supported by the Georgia Electronic Design Center.

S. Nikolaou, J. Papapolymerou and M. Tentzeris are with the School of ECE at Georgia Institute of Technology. Atlanta Atlanta, GA 30332-0250, U.S.A (e-mail: simos@ece.gatech.edu).

G. E. Ponchak is with NASA Glenn Research Center, Cleveland, OH 44135, U.S.A. (e-mail:george.ponchak@ieee.org).

wavelength in a slot transmission line with width w, which is the design slot width [5]. The slot width w needs to remain small compared to λ_s. The microstrip feed line terminates in an open circuit that is approximately λ_s /4 from the ring where λ_s is the guided wavelength on the microstrip line. At the intersection of the microstrip line and the slot, magnetic coupling occurs, which, due to the 3λs/2 ring circumference, creates a null in the radiation pattern in the direction of the microstrip feed line. To change the direction of the null, short circuits are placed appropriately on the slot. Generally the null appears opposite to the position where the short is placed. The short in the slot results in a reformation of the electric field distribution along the slot (Fig. 2a) leading to a shift of the null in the short direction. The equivalent load at the input of the microstrip transmission line also changes when a short exists on the slot compared to the case when no short exists; therefore, reconfigurable matching stubs (Fig. 1b) are required to keep the antenna matched at the design frequency. The shorts are implemented by forward biasing pin diodes which are soldered along the slot circumference.

Based on the field distribution, the dipole model presented in Fig. 2a is proposed, which consists of three dipoles of length λ/2. The three dipoles are used in equilateral triangle orientation. The amplitudes and phases of the current excitations are estimated based on numerical simulations. The superposition of the E fields from the three dipoles is plotted and is compared to the numerical solution derived from the simulator, whereas good agreement is observed as can be seen in Fig. 2b, indicating the validity of the model. For each dipole's E field computation (1) is used as deduced from [6]

$$E(\theta) \simeq j\eta \cdot \frac{I_o \cdot e^{-jkr}}{2\pi r} \cdot \frac{\cos\left(\frac{\pi}{2} \cdot \cos\theta\right)}{\sin\theta} \qquad (1)$$

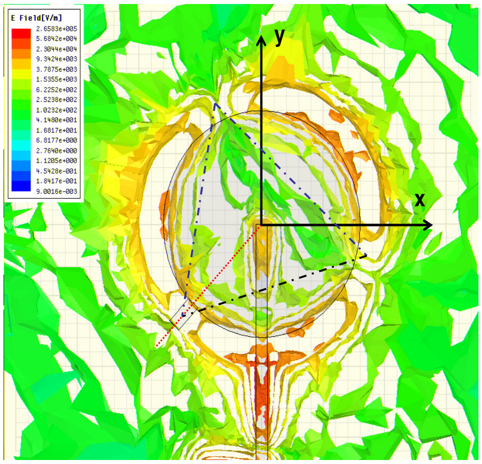

Fig. 2a E field distribution

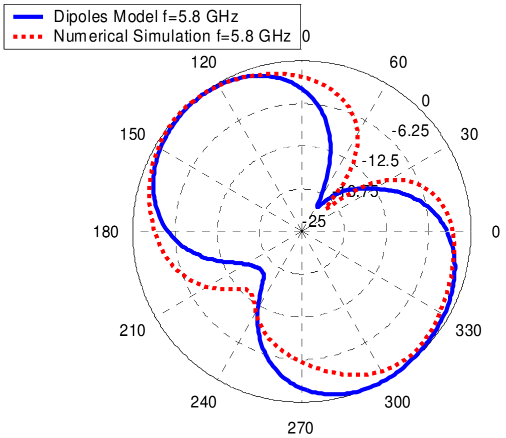

Fig. 2b Eφ polarization plot on x-y plane

III. ANTENNA DESIGN AND FABRICATION

The Annular Slot Antenna (ASA) design is presented in Fig.1. Two pin diodes which will be referred to as "big" diodes are soldered on the front side, and the feeding line with the matching stubs, are printed on the back side of the board, using standard photolithography. The antenna is fabricated on a 635 μm thick, low loss (tanδ=0.0025) Rogers RO3006 with ε_r=6.15 and a copper thickness of 18 μm. The antenna is fed by a 50 Ω microstrip line with width of 0.92 mm and the matching stubs are also 0.92 mm wide. The slot has an outer radius R=10 mm and an inner radius 8 mm resulting a slot width of 2 mm. The feeding line is 25 mm long and the end of the line is at the slot center. The outer part of the slot is used as the ground plane for the microstrip line on the back side. The whole board used is 50 mm x 50 mm. Two stubs are used to match the antenna for two cases; when only one of the diodes soldered at 45° away from the feeding line, is biased, and when both diodes are unbiased. Consequently one small diode is used for the activation of the matching stubs and two big diodes for the null control. The diode (ASI 8001) connected to the matching stub is considerably smaller than the diodes (MBP-1035-E28) on the slot, therefore is referred to as small diode. The stub that is constantly connected to the microstrip line is positioned at D2=7.27 mm and it has length L2=4.21 mm while the stub connected to the diode is positioned at D1=4.75 mm with length L1=2.97 mm. For biasing the small diode dc bias lines are fabricated with 70° radial stubs at the ends. Ls1=Ls2=6.50 mm and D3=12.08 mm. When the small diode is not biased and one of the two big diodes is biased, the antenna is matched at 5.8 GHz and appears a null in the direction of the diode. When none of the big diodes are biased and the small diode is biased, the antenna is matched at 5.8 GHz and a null appears in the direction opposite to the feeding line. As a result, for a fixed frequency at 5.8 GHz a null in three different directions can be created.

IV. NUMERICAL AND EXPERIMENTAL RESULTS

For the experimental validation of the design, return loss and radiation pattern measurements are taken. A small shift in the resonance frequency from 5.8 to 5.65 GHz is consistently observed when a big diode is biased along the slot. The downward shift in the resonant frequency is due to the capacitive load on the circumference as discussed in [7]. In addition, the coexistence of two real-size diodes on the slot with one of them forward biased and the second one reverse biased results in a parasitic resonance close to 6.5 GHz, as seen in Fig. 3a. For the simulation, the reverse biased diode was modeled as an ideal open circuit, and as seen in Fig. 3a, there is no parasitic resonance at 6.5 GHz. Therefore, the additional capacitive load as a result of the reverse biased diode is believed to cause the parasitic resonance, which can be filtered with a cascaded microstrip passband filter. The radiation pattern measurement presented in Fig. 3b clearly shows the pattern reconfigurability by orienting the null position in the desired direction. The plot in Fig. 3b presents the Eφ component on the x-y plane which is the plane of the antenna.

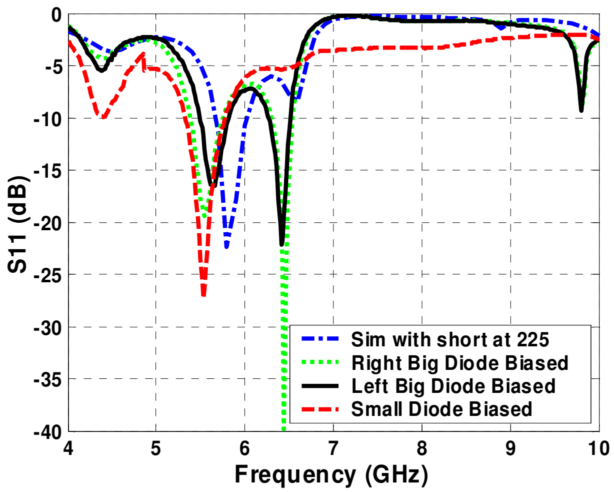

Fig. 3a Return loss simulation and measurement

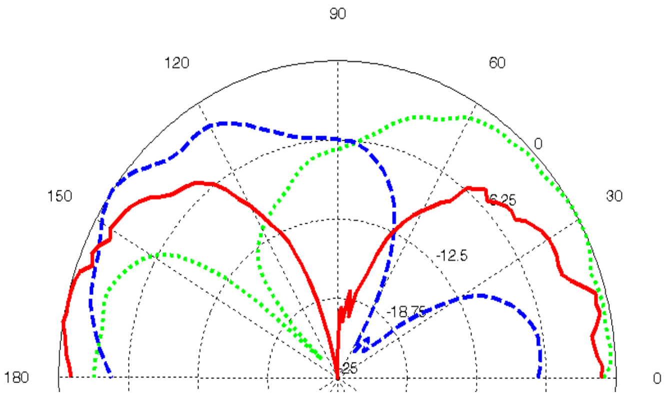

Fig. 3b Radiation pattern measurement

V. CONCLUSION

A reconfigurable annular slot antenna with a constant-frequency controlled radiation pattern using pin diodes was presented. The proposed antenna is fabricated on inexpensive material, has compact size, radiates with high efficiency and can be easily integrated with other components. The controlled radiation pattern can be used to dynamically minimize the interference of nearby radiators or to control the mutual impedance when the antennas are used as closely-spaced array elements.

REFERENCES

[1] Tong, C.E.and Blundell, R., “An annular slot antenna on a dielectric half-space”, IEEE Trans. Antennas and Propagation vol 2, no.7, pp.967 – 974, July 1994.

[2] Morishita, H., Hirasawa, K, Fujimoto, K.,” Analysis of a cavity-backed annular slot antenna with one point shorted” Antennas and Propagation, IEEE Trans. Antennas and Propagation, vol.39, no.10, pp.1472 – 1478, October 1991.

[3] Cheng-Shong Hong,” Small annular slot antenna with capacitor loading”
Electronics Letters, vol.36, no.2, pp.110 – 111, January 2000.

[4] P. R. Urwin-Wright, G.S. Hilton, I. J. Craddock, and P. N. Fletcher, “An electrically-small annular slot operating in the 'DC' mode”, Twelfth International Conference on Antennas and Propagation, vol. 2, pp. 686 – 689, April 2003.

[5] K.C. Gupta, R. Garg, I. Bah, and P. Bhartia, “Microstrip Lines and Slotlines”, Artech House, Second Edition, pp. 282 – 286.

[6] C. A. Balanis, “Antenna Theory Analysis and Design”, John Wiley & sons, Second Edition, pp. 152 –157