ISSN: 2278 – 909X
International Journal of Advanced Research in Electronics and Communication Engineering (IJARECE)
Volume 5, Issue 1, January 2016

Design and Parametric Analysis of Pattern Reconfigurable Patch Fed Ring Slot Antenna

M. Chinmayarangaraj, Dr. R. V. S. Satyanarayana, H. Mopidevi

Abstract— **A pattern reconfigurable patch fed ring slot antenna capable of yielding the following tilt directions: θ={-30°,0°,30°} in φ=90° plane at 2.4 GHz has been presented in this paper. Common bandwidth of ~1% is obtained around 2.4 GHz for all the tilt modes. Parasitic layer with ring slot metallization housing four switches is responsible for the beam tilting capability of the antenna. The parasitic layer is fed by a patch antenna in a different layer. A combination of parasitic layer based technology and Yagi-Uda beam steering has resulted in a robust design.**

Index Terms—**Reconfigurable Antennas, Pattern reconfigurability, ring slot antennas, parasitic antennas**

I. Introduction

An antenna which can perform multiple functions by changing its geometrical properties dynamically with the goal to support robust communication in rapidly changing environment is called a reconfigurable antenna. Change in geometrical properties can be accomplished by a variety of ways namely, electrical [1, 2], optical [3], physical [4, 5], and smart materials [6, 7]. Antennas which make use of Radio Frequency Micro Electronic Mechanical Systems (RF-MEMS), PIN diodes and varactors for their surface currents to be redirected are called electrically reconfigurable. Antennas based on photoconductive switching elements are known as optical reconfigurable antennas. Antennas that rely on altering the structure of the antenna are called physically reconfigurable. Finally, by use of the smart materials like ferrites and liquid crystals reconfigurable antennas can also be implemented. The properties of antenna such as frequency, radiation pattern, and polarization are dynamically reconfigured to handle the growing demands of wireless voice, video, and data transfers at gigabit speeds. Frequency reconfigurability involves change in the length of antenna whereas pattern and polarization reconfigurability relies directly or indirectly on change in phase of signal, or using well known antenna design methods. In this work, a well-known technique which is a yagi-uda beam steering methodology is employed. A variety of methods are used to feed reconfigurable antennas broadly classified as contacting and non-contacting. In contacting method, using a connecting element like microstrip line, the radiating patch is fed with RF power. In the non-contacting scheme, the power transfer between the microstrip line and the radiating patch is achieved by electro-magnetic (EM) field coupling. The popular contacting schemes are microstrip line and coaxial cable. Non-contacting schemes like aperture coupling and proximity coupling are well known. In this work, a patch antenna couples EM field to a parasitic ring slot structure in a non-contacting fashion.

In this paper, the pattern reconfigurability of the of parasitic layer based antennas using known design methods has been explored. First, a patch antenna has been designed to provide basic antenna structure for reconfigurability. Then, a patch fed reconfigurable ring slot antenna has been designed. Finally, switches are placed on the parasitic ring slot structure for pattern reconfigurability facilitating tilt three directions at IEEE 802.11 ac [8] band around 2.4 GHz for wireless fidelity applications. This technology could vastly improve wireless router connectivity to wireless devices such as laptops, smart phones, tablets, etc.

Pattern reconfigurability using parasitic layer based technology [9] became famous due to the following reasons: Improved power handling capability of switches as are exposed to less Radio Frequency (RF) power on parasitic layer, and ease of fabrication and integration of interconnecting switches on a separate layer. However, using a number of electrically small patches with quite a number of interconnecting switches (40) between them and using genetic algorithm to find the switching modes of operation is an innovative but time-consuming way to accomplish beam-steering. Also, there is the danger of genetic algorithm converging to a local minimum to yield poor results. Instead, using yagi-uda beam steering technique [10] on parasitic layer can yield the same results with much less number of switches. In this work, 4 switches employed on a patch fed ring slot provide beam-steering in the following directions: θ={-30°,0°,30°}; φ=90° plane.

II. Design Equations

A. Ground Plane

The ground plane is a square sheet which is assigned a Perfect E material in HFSS. The length of each side of ground plane is equal to the operating wavelength (λ) of the antenna which is calculated below.

$$\lambda = c / f$$

Where, c (=3 × 10^8 m/s) is the speed of the light in vacuum and f (= 2.4 GHz) is the operating frequency. Substitute these values in above equation and then we get

$\lambda = (3\times10^8) / (2.4\times10^9) = 0.125\text{m} = 125\text{mm}$

Manuscript received Jan22, 2016.

M. Chinmayarangaraj*, M.Tech, Department of ECE (Communication Systems), SVU College of Engineering, Tirupathi, Andhra Pradesh, India-517502.*

Dr. R. V. S. Satyanarayana*, Department of ECE , SVU College of Engineering, Tirupathi, Andhra Pradesh, India-517502*

H. Mopidevi*, Etch Engineering, Lam Research, Fremont, California, USA,*

Therefore the length of square ground plane is 125mm.

B. *Patch*

The patch is a rectangular sheet made of perfect E material. The length P_y of the patch is given by the below equation.

$$P_y = \lambda / (2\times\sqrt{\varepsilon_r})$$

Where λ is the operating wavelength and ε_r is the relative permittivity of the substrate. Substitute the values of λ and ε_r in above equation. Therefore the value of P_y is

$$P_y = (125mm) / (2\times\sqrt{2.2}) = 42.137mm$$

C. *Coaxial Cables' Diameter*

Coaxial cables' inner and outer conductors are made of copper metal and dielectric between them is made of Teflon (ε_r = 2.1). The diameter of the coaxial cable is determined from the equation below.

$$Z_0 = (138/\sqrt{\varepsilon_r}) \times (\log_{10}(D/d))$$

Where Z_0 is the characteristic impedance of coaxial cable which is assumed to be 50 ohms and ε_r is the relative permittivity of the dielectric between the two conductors of the coaxial cable.

Also d is the inner conductor diameter which is equal to 1mm. Substitute all the known values in the above equation then we get the value of outer conductor diameter D as shown below.

$$50 = (138/\sqrt{2.1}) \times (\log_{10}(D/1))$$

$$D = 10^{((50\times\sqrt{2.1})/138)} = 3.35mm$$

D. *Ring Slot Radius*

The material used as a substrate for the parasitic ring slot structure is Duroid(tm) (ε_r=2.2). It is at a height of h = 10 mm from the patch antenna which is found to be optimum in HFSS. The slot circumference is equal to the operating wavelength and the ring slot radius R is calculated as follows.

Ring slot circumference C = 2πR = λ

The free space wavelength λ at 2.4 GHz = 125mm.

Hence, ring slot radius R = λ / (2π) = 125mm / (2π) = 19.89mm.

E. *%Bandwidth of Patch Antenna*

The operating frequency is in the range of 2.35-2.45 GHz with 4.16 %BW. The %BW is calculated as shown below.

$$\%BW = ((F_H - F_L)\times 100)/F_R$$

We know that F_H=2.45GHz, F_L=2.35GHz, F_R=2.4GHz. Substitute these values in the above equation.

Therefore %BW = ((2.45-2.35)×100)/2.4 = 100/24 = 4.16%

III. Constructional Features

The reconfigurable antenna (see fig.1) consists of patch antenna, parasitic ring slots fabricated on two dielectric substrates namely: Rogers 4003 (ϵ_r = 3.55) and RT duroid (ϵ_r = 2.2) respectively and 4 switches placed on passive ring slot. Beam steering performance is enhanced if geometrically the patch metallization comes within the ring slot circumference. Hence, a higher dielectric constant substrate is chosen for the patch antenna which is primarily used as a feed for the ring slot. Four blocks of Rogers 4003 substrate are placed on four corners of patch antenna to support the parasitic layer on top. The circumference of the ring slot R is chosen to be ~ λ at 2.4 GHz.

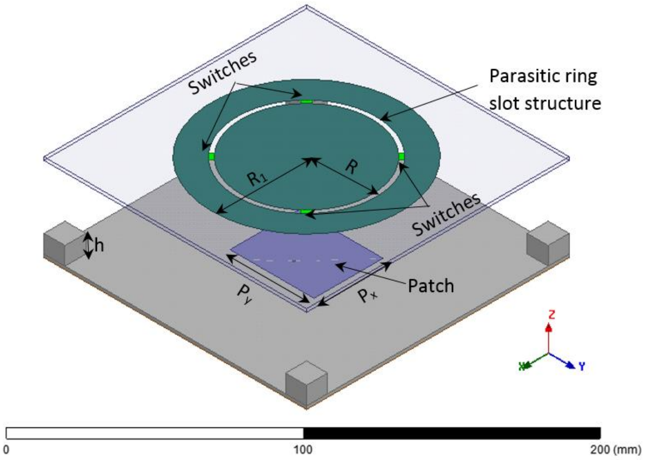


Fig. 1. Schematic of patch fed pattern reconfigurable ring slot antenna(for the sake of illustration parasitic ring slot is suspended at a distance from patch antenna)

The circular patch metallization on which the slot is etched has a radius R1 which is also important in impedance matching the antenna along with the height h of the blocks to support the parasitic layer. Coaxial feeding is used for patch antenna. The outer and inner conductors of coaxial cable are connected to the ground plane and patch metallization, respectively.

IV. Antenna Design and Optimization

Initially we parameterize the position of the coaxial cable by assuming it as (C_x, C_y, 0) mm with initial values C_x = 0 and C_y = 0. Then we parameterize the dimensions of the patch by assigning P_x and P_y as the width and length in X and Y directions respectively.

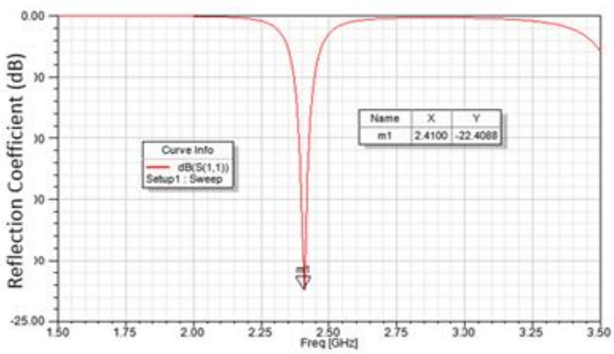


Fig. 2. Reflection coefficient of patch antenna in HFSS

The patch antenna offers a realized gain of 8.63 dB as shown in fig.3 below.

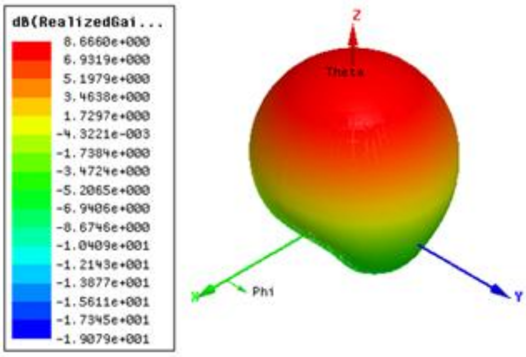


Fig. 3. 3D radiation pattern of patch antenna at 2.41 GHz

We optimize the patch length and width for the patch to operate at resonant frequency. We increase the width in Y direction and reduce the length in X direction for optimization. At 55mm width and 40mm length the patch resonates at 2.41 GHz. We also optimize the location of coaxial cable feeding for impedance matching between the coaxial cable and the patch. At Cx = 0mm and Cy = 8mm the antenna has a reflection coefficient S_{11} of -20dB approximately (see fig.2) which is enough for good impedance matching at resonant frequency. A waveport is used for the excitation of patch antenna in HFSS.

The patch dimensions (Px, Py) and coaxial cable location (Cx, Cy) are varied along with slot radius (R) and height (h) from patch antenna with the goal of obtaining dual resonance. Initial optimization yields Cx=0mm, Cy=10mm, Px=55mm, Py=40mm, R=19.89mm at 2.4GHz resonant frequency. Accordingly, the patch resonance occurs at 2.37GHz with S_{11}=-15.11dB and the slot resonance occurs at 2.58GHz with S_{11}=-5.13dB as shown in fig.4.

The radiation patterns at slot and patch resonances are shown in fig.5 below. From the plot below, it is evident that the square sheet on the parasitic layer containing the slot is obstructing radiation from patch structure.

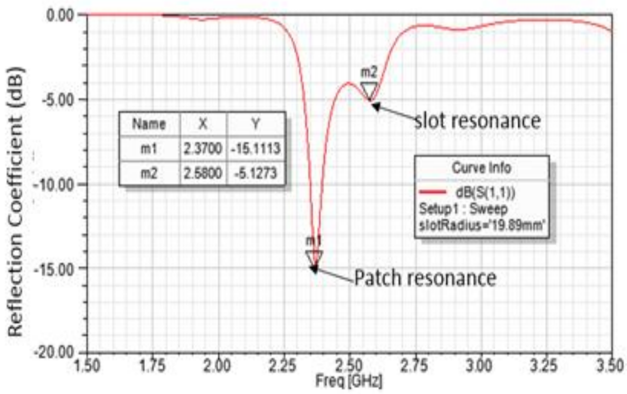


Fig. 4. Initial dual band resonance of patch fed ring slot structure

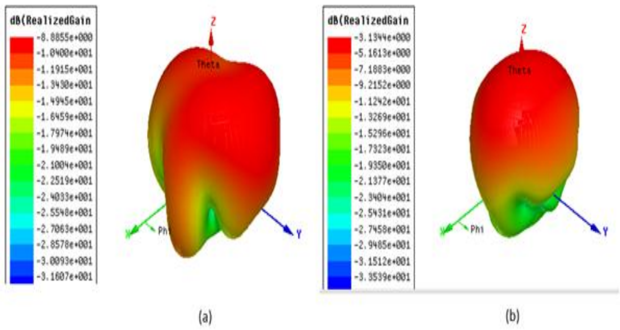


Fig. 5. Radiation pattern at (a) patch resonance (2.37 GHz) (b) slot resonance (2.58 GHz)

V. SWITCHES AND RECONFIGURABILITY

Perfect on/off switches are used in this work, i.e., presence or absence of copper strips are used to emulate the on or off statuses of switches. The switch locations are carefully chosen to accomplish switchable yagi-uda beam steering as shown in fig.6. When two of the switches are on and the other two off, the shorter slot (<λ/2) disconnected from the larger slot (>λ/2). The shorter slot acts like a director with the longer slot becoming the reflector and accordingly, in modes 1 and 2 the beam tilts towards θ={-30°, 30°}; φ=90° plane. In mode 3, when all switches are off, the beam is in the broadside direction i.e. θ=0°, φ=90° plane.

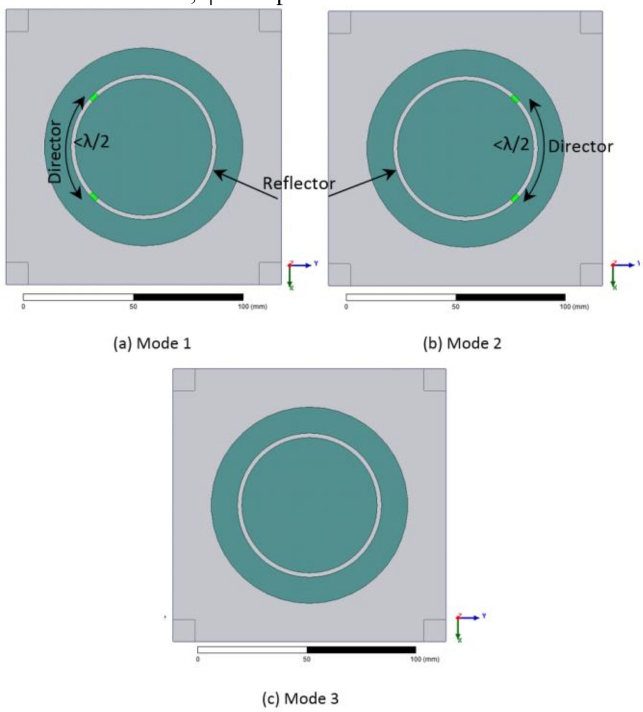


Fig. 6. Top view of reconfigurable modes of operation (a) Mode 1: θ=-30°; ϕ=90° (b) Mode 2: θ=30°; ϕ=90° (c) Mode 3: θ=0°; ϕ=90°

VI. PARAMETRIC ANALYSES

To validate the dual resonance behavior of the structure, a parametric analysis is performed to control the slot resonance with minimal effect on patch resonance. In this analysis, the slot radius (R) is varied as $R_{i=1to2}$ = {14.89mm, 19.89mm} and correspondingly the slot resonance is shifted along $f_{i=1to2}$ = {2.86GHz, 2.58GHz} as shown in fig.7. Please note, the parameter R is defined as slotRadius in HFSS and hence is shown in this way in the plot. As the slot resonance approached the patch resonance (on left) the impedance match of the both resonances improve as is evident from the plot.

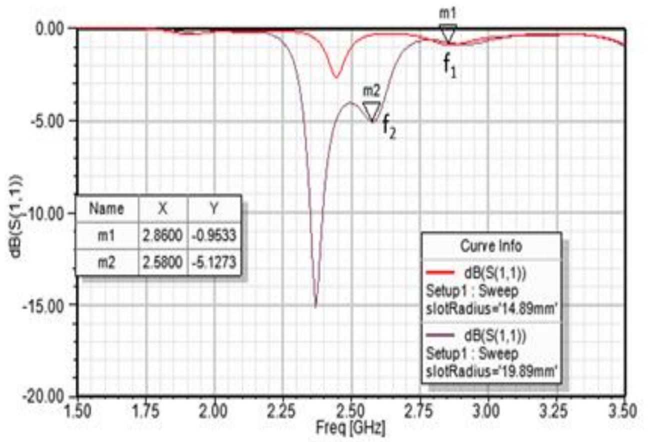
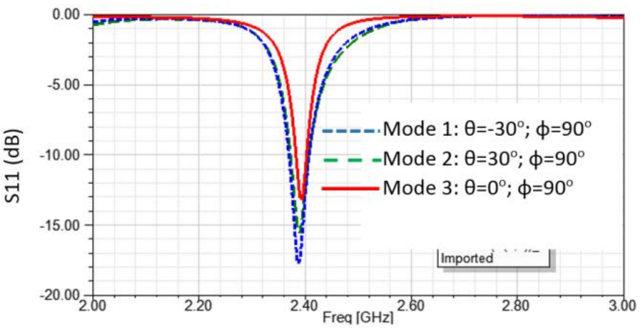


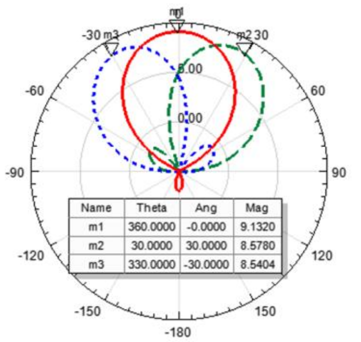
Fig. 7. Parametric analysis controlling slot resonance

VII. ANTENNA PLOTS

The optimized results of reflection coefficient and radiation pattern are shown in fig.8 for 3 different modes of operation: Modes 1, 2, and 3. A common BW of ~1% is obtained around 2.4 GHz. The max realized gain obtained was in the range 8.5-9 dB which indicates strong radiation performances.



(a) Reflection coefficient



(b) Radiation Pattern at 2.4 GHz

Fig. 8. (a) Reflection coefficient and (b) radiation pattern of 3 modes of operation.

VIII. CONCLUSION

A pattern reconfigurable antenna has been designed in HFSS with the goal to provide three different beam directions using only 4 switches at 2.4 GHz for wireless fidelity applications. The presented antenna uses a patch antenna as primary antenna and a patch fed ring slot antenna as parasitic element. A combination of parasitic layer based beam steering and yagi-uda beam steering has been utilized to design this antenna. This technology can be used on broadband base antenna designs to obtain wider common bandwidths. Careful optimizations of switch locations on the parasitic ring slot in conjunction to using broadband base antenna designs can increase the number of beam steering modes with minimum number of switches. For example, tilt angles in $\phi = 0^o$, 45^o, -45^o, -90^o can also be obtained by using additional switches on parasitic ring slot. Future work comprises of using real pin-diode switches on this antenna and building a prototype to take measurements of the antenna.

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REFERENCES

[1] E. Erdil, K. Topalli, M. Unlu, O. Civi, and T. Akin, “Frequency tunable microstrip patch antenna using rf mems technology,” *IEEE Transactions on Antennas and Propagation*, vol. 55, no. 4, pp. 1193 –1196, Apr. 2007.

[2] J. Kiriazi, H. Ghali, H. Ragaie, and H. Haddara, “Reconfigurable dual-and dipole antenna on silicon using series mems switches,” in *Antennas and Propagation Society International Symposium*, *IEEE*, pp. 403–406, June 2003.

[3] C. Panagamuwa, A. Chauraya, and J. Vardaxoglou, “Frequency and beam reconfigurable antenna using photoconducting switches,” *IEEE Transactions on Antennas and Propagation*, vol. 54, no. 2, pp. 449–454, Feb. 2006.

[4] G. H. Huff and J. T. Bernhard, Reconfigurable Antennas. Hoboken, NJ: John Wiley and Sons, Inc., 2007.

[5] M. Kohl, Shape Memory Microactuators, ser. Microtechnology and MEMS. Heidelberg, Germany: Springer, 2004.

[6] S. Gevorgian and E. Kollberg, “Do we really need ferroelectrics in paraelectric phase only in electrically controlled microwave devices?” *IEEE Transactions on Microwave Theory and Techniques*, vol. 49, no. 11, pp. 2117–2124, 2001.

[7] P. Rainville and F. Harackiewicz, “Magnetic tuning of a microstrip patch antenna fabricated on a ferrite film,” *IEEE Microwave and Guided Wave Letters*, vol. 2, no. 12, pp. 483–485, Dec. 1992.

[8] Eng Hwee Ong; Kneckt, J.; Alanen, O.; Zheng Chang; Huovinen, T.; Nihtila, T., "IEEE 802.11ac: Enhancements for very high throughput WLANs," *Personal Indoor and Mobile Radio Communications (PIMRC), 2011 IEEE 22nd International Symposium on* , vol., no., pp.849,853, 11-14 Sept. 2011.

[9] Li, Z.; Mopidevi, H.; Kaynar, O.; Cetiner, B.A., "Beam-steering antenna based on parasitic layer," *Electronics Letters*, vol.48, no.2, pp.59,60, January 19 2012

[10] Kitamura, C.K.Y.; Morishita, A.M.; Chun, T.F.; Tonaki, W.G.; Ohta, A.T.; Shiroma, W.A., "A liquid-metal reconfigurable Yagi-Uda monopole array," *Microwave Symposium Digest (IMS), 2013 IEEE MTT-S International* , vol., no., pp.1,3, 2-7 June 2013