A Reconfigurable Radiation Pattern Annular Slot Antenna

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Abstract – This paper contemplate a theoretical analysis of a pattern reconfigurable antenna using annular slot antenna operating in low frequency. A shorting pin is inserted to allow the annular slot antenna to have an omnidirectional radiation pattern like a monopole antenna. The reconfigurable antenna consists of numerous metal cylinders arranged around the annular slot antenna. By controlling pin diodes associated with the metal cylinders, the antenna is capable of working up in different directions with a maximum working beam angle of 11.25° at a frequency of 1.05 GHz.

Keywords—pin diodes; annular slot antenna; pattern reconfigurable antenna.

I. INTRODUCTION

The need for reconfigurable antenna has increased proportional to the development of communication technology nowadays. Reconfigurable provides the ability to adjust the beam directions, working frequency and polarization upon command. If the desired operating characteristics of the antenna change, then the antenna must be reconfigured or rebuilt to meet the new specification. As a result, reconfigurable antenna is designed to be able to change frequency, pattern and polarization. Frequency reconfigurable antenna allows the antenna to be working in different frequency band, for example in [1][2][3].

Recently, pattern reconfigurable antenna has received much attention especially by using metamaterial-inspired concept[4][5][6][7] and antenna arrays[8][9]. A reconfigurable antenna can be achieved by incorporating more than one antenna in a structure. For example, radiation pattern of an antenna switches between a Vivaldi-shaped slot mode and a monopole mode when the two antennas are incorporated together in [10]. A central circular patch with multiple parasitic patches, each connected with switches can gives six beam of radiation pattern which can cover all directions in azimuth plane[11]. Another technique for reconfigurable antenna is by installing reflector and director in the structure. A monopole antenna in [12][13]attained multiple radiation pattern by incorporating pin diodes which connect the antenna to either a director or a reflector. In [14], [15], Yagi patch antennas are built with parasitic element which act as reflector and director by manipulation of switches.

In [16], both RF pin diodes and photodetector were tested for their switching functions. Both are analyzed for their advantages and limitations. The photodetector allows a good insertion loss but has a poor isolation, while the pin diodes give less interference in dc control with low loss and less cost. For a continuous reactive tuning, varactor is employed in [17]. Four parasitic patches antenna with embedded varactor diodes is designed to enable continuous changes in match frequency for the reconfigurable null scanning antenna. However, varactor suffers from poor linearity. The engagement of RF MEMS switch has been demonstrated in [18]. RF MEMS switch has the advantage of low power consumption, low insertion loss, high isolation but then again, it has a limited power handling capability and high-priced. Over the past decade, most research in reconfigurable antenna has emphasized the use of pin diodes. By referring to [19][20][21][22][23][24][25], different types of antenna had employed pin diodes in the antenna structure to attain diversity in radiation pattern.

This paper proposed an annular slot antenna operating in DC mode with a monopole radiation which offers bigger room for reconfigurability in terms of radiation directions. The antenna consisted of metal cylinder which is controlled individually using pin diodes to provide diversity in the radiation pattern of the antenna.

II. ANTENNA DESIGN AND OPERATION

A. Annular slot antenna in DC operating mode

Monopole antenna has been the subject of many classic studies for diversity in radiation pattern of an antenna. A monopole antenna has an omnidirectional radiation pattern which is essential for wide range of technologies. The omnidirectional pattern can be used to broadcast and receive the signals from almost all directions. However, one of the greatest challenges for radiation pattern reconfigurability in [12] is the direction of the beam. Therefore, the proposed annular slot antenna in this paper is designed to have the same omnidirectional radiation pattern with a wider possibility in

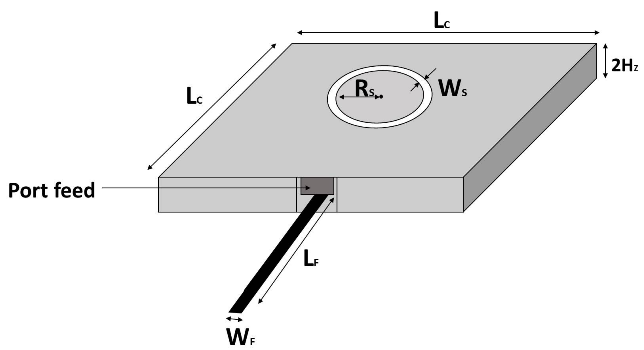


Fig. 1. Layout of the proposed antenna

making the antenna reconfigurable.

The construction of annular slot antenna was prepared according to the procedure in [26]. The shorting pin is inserted between the central resonating element and ground which causes an additional resonant mode occurs below the first-order mode. The additional mode has a uniform current distribution about the aperture, which normally happens at DC only and causes the antenna to operate in a low frequency area, in this case would be around 1.05 GHz. The shorting pin with a radius of 0.4 mm is inserted in the middle of the circular conductor of the antenna, right through the substrate to the metal back plane behind the substrate.

Fig. 1 illustrates the layout of the cavity backed annular slot antenna. The length and width of the substrate is set to 120 mm with a thickness of 1.6 mm. Two substrates of the same dimension are coupled together with the strip line feeds implanted in the middle of the substrates. The substrates are sealed off with metal sheet in front and back of the annular slot antenna. The width of the annular slot is 1 mm and the length of strip line feed is set to 46 mm to give maximum gain.

In this experiment, the RT 5880 is used as the antenna substrate. The substrates are enclosed with metal sheet like a cavity to prevent the antenna from radiating through the substrate. The dimensions of the elements are as follow: W_f = 2.6 mm, L_f = 46 mm, R_s = 19 mm, W_s = 1 mm, L_c = 120 mm and H_z = 1.6 mm. All the dimensions were selected to optimize the gain of the antenna

B. Pattern reconfigurable principle

In this paper, pattern reconfigurable antenna is constructed by placing thin metal cylinders around the slot antenna pin diodes in the middle. Pin diode is employed as switch to make them half wavelength. The distance between the metal cylinder and the center of resonating conductor is put into test to obtain the maximum gain. Different distances were examined starting from 19.5 mm to 50 mm away from the center of the antenna. Fig. 2 shows the maximum gain of radiation pattern for different distance. Based on the graph, 27 mm is selected as it gives highest gain. Other components of the antenna are also verified to find the most favorable dimension. The radius of the metal cylinder as well as the length of metal cylinders is also contributed to the performance of the antenna. Each metal cylinder has a radius of 0.5 mm to give maximum gain. The metal cylinder has a total length of 148.8 mm extended from the substrate.

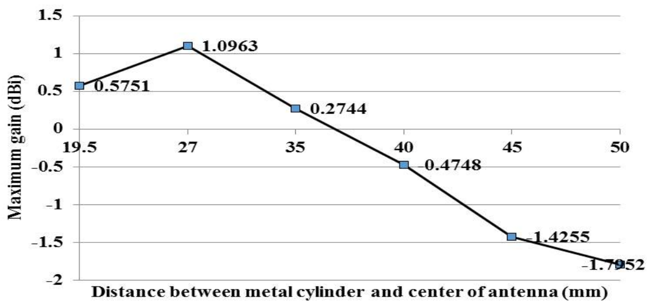


Fig. 2. Maximum gain for different distance of metal cylinder

The theoretical analysis of the annular slot antenna is conducted in Ansys High Frequency Structural Simulator (HFSS). For the purpose of simulation, the metal cylinder is divided into two and separated by an empty cylinder to signify when the switch is off. When the switch is activated, the two metal cylinders are united which gives a total length of λ/2. Fig. 3 shows the construction of the antenna in HFSS.

A pin diode serves to open or close a current path connecting two metal cylinders, which leads to radiation pattern reconfigurability. Pin diodes are less susceptible to electrostatic discharge damage compared to other switches. Forward biasing a pin diode creates a very low resistance at high frequencies, while reverse biasing results in an open circuit.

The different position of the activated metal cylinder around the annular slot antenna will determine the shape of the radiation pattern accordingly. When the pin diode is triggered, the metal cylinder will act as a director where the gain of the radiation pattern increased in that particular direction compared to other direction. In this paper, the proposed antenna is simulated continually to find maximum tilted beam angle of the antenna. Table 1 shows the number of metal cylinders attached to the antenna for different cases.

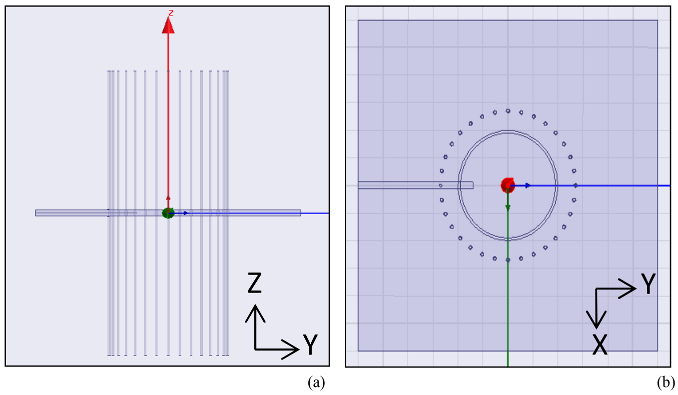


Fig. 3. The construction of annular slot antenna with metal cylinders in HFSS a) side view b) top view

TABLE I. NUMBER OF METAL CYLINDERS IN DIFFERENT CASES

Case	Number of metal cylinder	Minimum beam separation	Reconfigurable direction
Case 1	No metal cylinder attached	360°	All direction
Case 2	8	90°	4
Case 3	16	45°	8
Case 4	32	22.5°	16
Case 5	64	11.25°	32

III. Result and Discussion

The proposed antenna was simulated and optimized by Ansys HFSS 15.0. In each case, a metal cylinder is switched on and the resulted radiation pattern is analyzed. The simulated result for the return loss response (S_{11}) is demonstrated in Fig. 4. The value of return loss for the proposed annular slot antenna at 1.05 GHz is -10.14 in Case 1 and the result is getting better as more metal cylinders attached to the antenna.

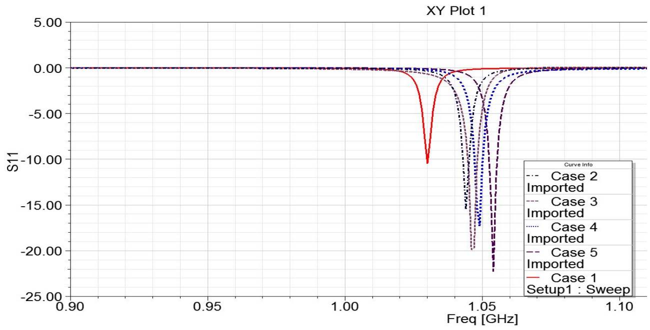


Fig.4. Return loss for 5 different case

The gains for different metal cylinders attached to the antenna are shown in Table II. The simulated result shows that the proposed antenna provides maximum gain in different direction depending on which metal cylinder is switched on. The proposed annular slot antenna gives an omnidirectional maximum radiation of -2.32 dBi at 1.05 GHz when no metal cylinders attached to the antenna. The results show the radiation pattern when the metal cylinder is activated with specific beam angle respectively. The exact value of maximum gain in the specific direction as each cases is studied is shown in Table II. However, there is a direction error occurs in Case 4 and Case 5, as the result shows the imprecision of beam direction. Fig. 5 shows the relation between the directional error and reconfigurable direction.

The maximum gain for each cases increase as the antenna working in more reconfigurable directions. The maximum gain of the antenna without metal cylinder is -2.32 dBi and increases as more metal cylinders attached to the antenna. The relation between the maximum gains and reconfigurable directions for five different cases is shown in Fig. 6.

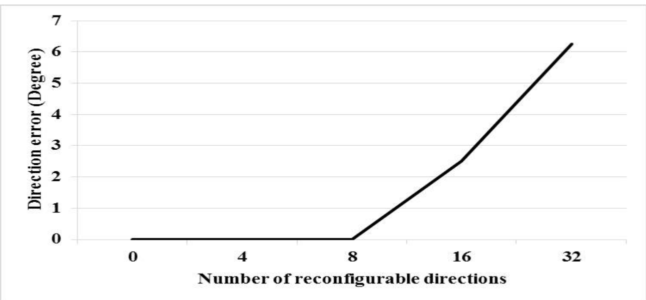
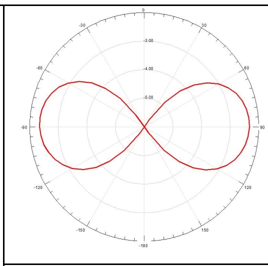
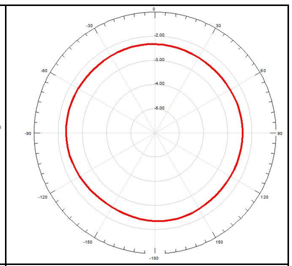
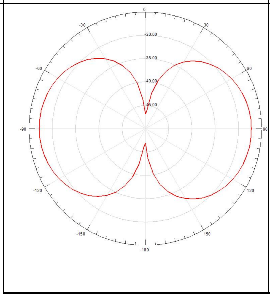
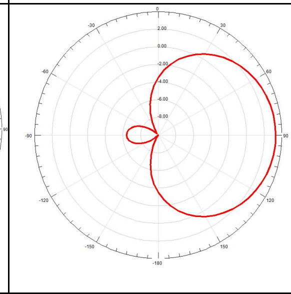
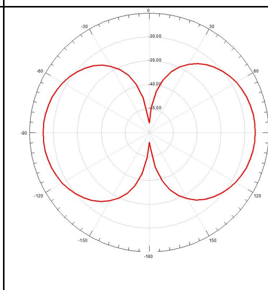
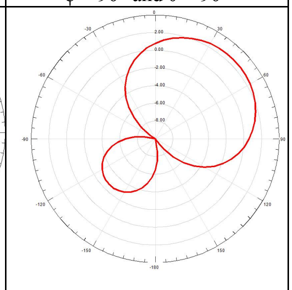
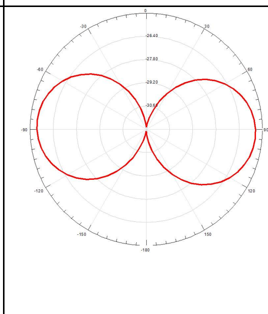
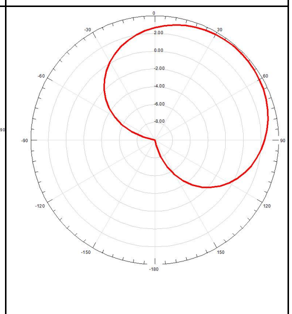
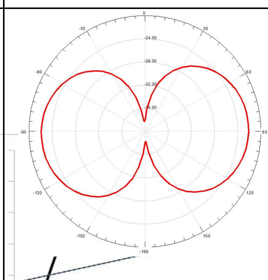
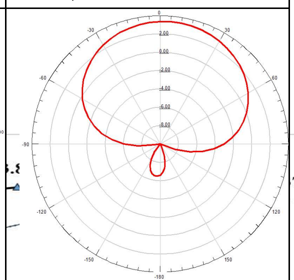


Fig. 5. Directional error vs Reconfigurable direction

Table II. Beam direction for different cases studied

Case 1		
	$\phi = 90°$ and $\theta = 0°$	Maximum gain: -2.32 dBi at ϕ = All direction and $\theta = 90°$
Case 2		
	$\phi = 90°$ and $\theta = 0°$	Maximum gain: 3.29 dBi at $\phi = 90°$ and $\theta = 90°$
Case 3		
	$\phi = 90°$ and $\theta = 0°$	Maximum gain: 2.59 dBi at $\phi = 45°$ and $\theta = 90°$
Case 4		
	$\phi = 90°$ and $\theta = 0°$	Maximum gain: 3.81dBi at $\phi = 20°$ and $\theta = 90°$
Case 5		
	$\phi = 90°$ and $\theta = 0°$	Maximum gain: 3.37 dBi at $\phi = 5°$ and $\theta = 90°$

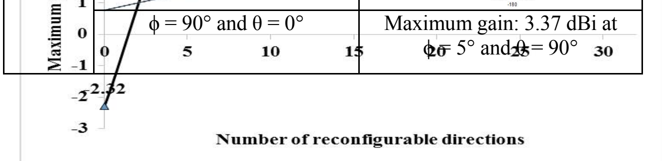


Fig. 6. Maximum gain vs Reconfigurable direction

CONCLUSION

A pattern reconfigurable annular slot antenna that can switch beams in numerous directions has been designed and tested using Ansys HFSS. By controlling pin diodes, the beam direction of the antenna can be switched accordingly. The design is working at low frequency with limited bandwidth and has a high profile structure restricting it's usability in small communication devices. Future work will consider these issues and look into low profile wide bandwidth designs.

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