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A Pattern Reconfigurable Microstrip Dipole Antenna with PRS Gain Enhancement

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Abstract— **This paper investigates a low complexity high gain structure that can switch the radiation pattern from boresight to almost endfire direction. The principles of Fabry Perot, reconfigurable parasitic reflectors and partially reflective surfaces are combined to achieve the pattern reconfigurability. Two different Fabry-Perot cavity spacings are assessed and a maximum gain of 18.8 dBi is achieved at boresight which can be reduced by over 12dB with the use of PIN diode switches. Radiation towards the endfire directions has a maximum gain of 7.1dBi which can be reduced by almost 17dB with the use of the PIN diode switches. The paper presents numerical simulations of the proposed antennas.**

Index Terms—**Beam steering,pattern reconfigurable, high gain, reconfurable antenna, partially reflecting surface.**

I. INTRODUCTION

Reconfigurable antennas have been of research interest to address the challenge of the achieving high quality of service, spectrum allocation and improving overall system performance by consuming low levels of energy for mobile communications systems [1]-[3]. Reconfigurable antennas have the ability to change their properties such as operating frequency, radiation pattern and polarization that makes them a potential candidate for future communication systems. Pattern reconfigurable antennas can be used to modify the coverage by directing the signal towards the intended direction which will reduce system energy consumption, avoid noisy environments and hence increase the spectrum efficiency [4-6]. Conventional ways of achieving pattern reconfiguration involves mechanical tuning and using phased arrays which can be bulky, high cost and complex for the use of many applications.

In [2], [3], [7], [8], the current paths on the parasitic radiating elements are altered with the use of PIN diodes where changing the length of the parasitic elements, changes the behavior from being a ‘Director’ or a ‘Reflector’. As a result, up to 60^0 of beam steering have been achieved with such models but the directivity at these angles are relatively small which will affect the variety of applications that can be used. More recently in [9] and [10], variable capacitance diodes and photo-conducting switches have been used to alter the current distribution along the parasitic elements and achieve pattern reconfiguration. However, a different way of achieving radiation pattern reconfiguring has been presented in [11] where the physical angle of the radiating arms of the antenna have been rotated with the aid of micro-electro-mechanical systems (MEMS). The variation of mutual coupling between two radiating strips causes the main beam to change direction. Within the research mentioned, various main beam directions have been achieved with different designs. According to the results achieved there is a noticeable reduction in gain whilst beam steering is obtained. A widely known Fabry-Perot resonant condition has been used in order to enhance the antenna gain where a partially reflective surface (PRS) is placed at a particular distance from the antenna and the ground plane to form a cavity including multiple reflections In order to enhance the antenna gain as proposed in [12] and [13]. More recently an anti-resonant mode of Fabry-Perot have been proposed in [14] and [15]. With this method where partial reflectors are placed on each side of a hairpin dipole where up to 12 dBi of gain has been achieved at the boresight direction. A recent publication [16], relying on the theory of [12], shows a beam steering structure that is formed of a ground plane, radiating patch and a partially reflective surface (PRS) loaded with PIN diodes which are attached in between each unit cell forming the partially reflecting surface. Varying the PIN diodes between “ON” and “OFF” states, beam steering was achieved up to 15^0 with 11.7 dBi of gain at the corresponding direction. However large amount of active components and complicated biasing have been used in order to control the direction of the beam.

In this paper a low complexity high gain beam switching dipole antenna is proposed. Compared to the previously explored models, a low complexity design with minimal additional components is presented to achieve beams that can be switched from boresight to close to end fire directions. The approach uses a combination of a Fabry-Perot implementation with reconfigurable parasitic reflectors.

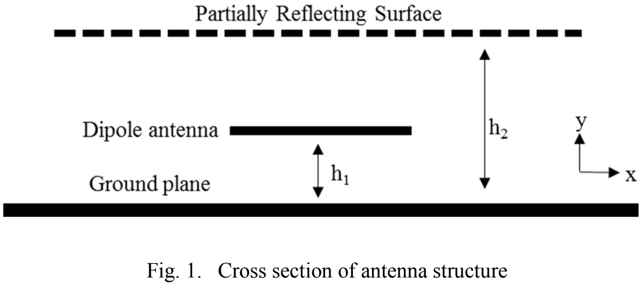

Fig. 1. Cross section of antenna structure

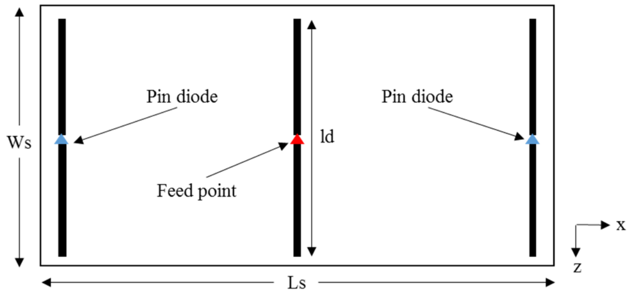

Fig. 2. Plan view of radiating element and reconfigurable reflectors

II. ANTENNA DESIGN AND FABRY-PEROT UNIT CELL TOPOLOGY

A. *Configuration of the structure*

The design approach of interest is shown in Fig. 1 and Fig. 2. A ground plane with dimensions of 550x550mm^2 is used. The radiating dipole antenna is placed a distance of h_l=38.2mm away from the ground plane in order to generate constructive reflections in phase with the radiated waves. The spacing between the ground plane and the partially reflecting surface (PRS), h_2, is varied between 84mm and 167.7mm (approximately $\lambda/2$ & λ) in order to evaluate the capabilities for beam reconfiguration. Fig. 2 shows that the dipole antenna incorporates two reconfigurable reflectors on each side which include PIN diodes at the center of each reflector. The length of the dipole and reflecting elements are l_d=58.55mm and 1mm wide on a 0.8mm thick FR-4 substrate (ϵ_r =4.3, tanδ = 0.025) of dimensions L_s=161mm and W_s=80mm. The PIN diodes were modelled using the electrical parameters of BAR64-02V where the equivalent circuit of the diode was modelled as a series RL circuit for the "on" state and a series RLC circuit in the "off" state. The resistance, inductance and capacitance of the diode was R_{PIN}=1.35Ω, L_{PIN}=0.6nH and C_{PIN}=0.17pF. The inclusion of the reflectors is to vary the radiation pattern from either high gain in the boresight direction or to an endfire radiation pattern by varying the state of the PIN diode. This will produce a very low complexity reconfigurable antenna compared to other methods where many reconfigurable elements are placed in the PRS.

B. *Unit cell analysis and PRS structure*

The structure illustrated in Fig.1 is considered. A cavity with a thickness of h_2 is formed by placing a PRS above a ground plane. The electromagnetic waves induced by the dipole antenna structure will undergo multiple reflections in the formed cavity. The cavity thickness determines the path length of the reflected waves where the ground plane introduces a phase shift of (π) as stated in [13] and [14]. In order to achieve maximum directivity at the boresight direction ray tracing theory can be used, [13], and the cavity thickness to achieve peak directivity can be expressed as

$$h_2 = \frac{\lambda}{4\pi}\left(\phi_H + \phi_L - 2N\pi\right), \qquad N = 0, 1, 2\ldots \qquad (1)$$

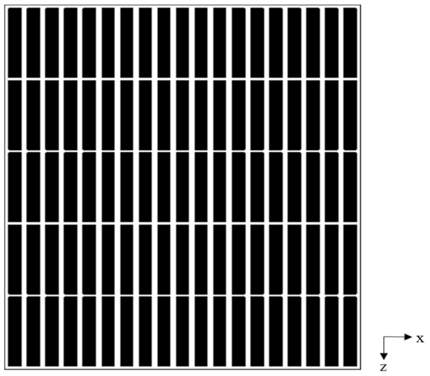

Fig. 3. Partially reflecting surface structure formed of 19x5unit cells

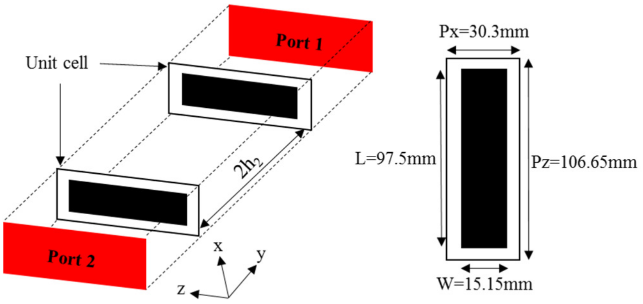

Fig. 4. Unit cell of PRS for waveguide analysis.

where ϕ_H and ϕ_L represents the reflection phases of the partially reflecting surface and the ground plane, λ is the free space wavelength at the resonant frequency. In order to achieve identical phase within reflections, the phase difference should be 2πN (N is an integer) as stated in [16]. Furthermore, the directivity of the cavity at the boresight can be determined with

$$D = \left(\frac{[1-R^2]}{1+R^2-2R\cos[\Delta\phi]}\right) \qquad (2)$$

where R is the magnitude of PRS reflection coefficient and the reflection coefficient phase difference between the ground plane and PRS is $\Delta\phi = \phi_H - \phi_L$.

The structure was designed by examining the unit cell behavior using a waveguide model, Fig. 4, where the boundary conditions were configured using perfect electrical boundaries at the z-axis and perfect magnetic boundaries at the x-axis. The structure was simulated using CST Microwave Studio®. The magnitude of the transmission coefficient of the unit cell, Fig. 5, shows that with a cavity thickness, h_2, of approximately $\lambda/2$, the cavity is transparent at a frequency of

1.842GHz. However doubling the cavity thickness (λ), decreases the resonant frequency to 1.815GHz.

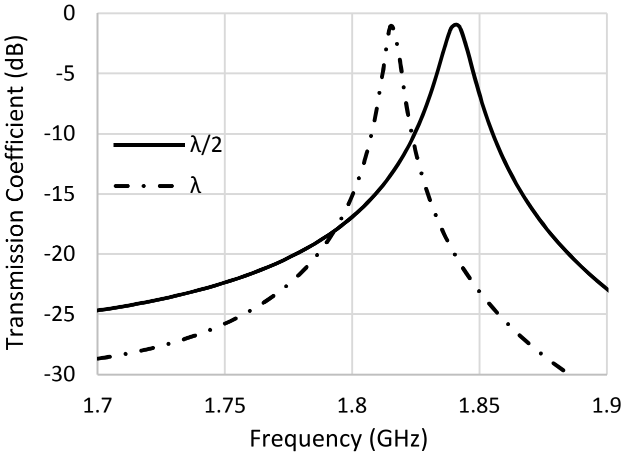

Fig. 5. Simulated transmission coefficients of a PRS unit cell for h_2, λ/2 and λ distance.

III. RECONFIGURABLE ANTENNA SIMULATIONS

The simulated realised gain patterns (H-plane/xy-plane) for the cases where the spacing between the PRS and the ground plane, h_2, is varied between either λ/2 or λ are shown in Fig. 6 and Fig. 7 respectively for both the "on" and "off" PIN diode states. Fig. 6 shows that the maximum gain occurs at boresight ($\phi = 90^0$) with a magnitude of 18.8dBi which is reconfigured to -11.39dBi when the PIN diode state is changed. Short circuiting the elements hence increasing the size, changes the null and lobe positions resulting in high gain 13.7dBi, beam switching at an angle of $\pm 20^0$ along the H-plane (x-axis) where "+ is referred as a positive and — is a negative direction respectively".

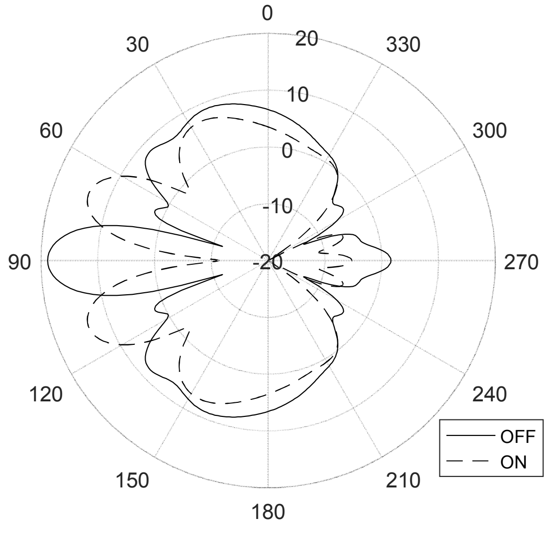

Fig. 6. Simulated farfield gain pattern (H-plane/xy-plane) at 1.842GHz, when h_2= λ/2, for the "on" and "off" PIN diode states.

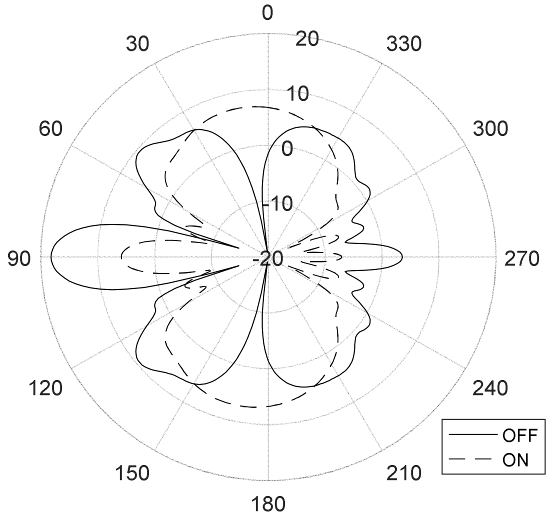

Fig. 7. Simulated farfield gain pattern (H-plane/xy-plane) at 1.815GHz, when h_2= λ, for the "on" and "off" PIN diode states.

In order to achieve a design that is capable of switching from boresight to endfire radiation, the cavity spacing, h_2, was changed to ~λ, which resonates at 1.815GHz. From Fig.7, it is observed that, with "off" state PIN diodes i.e. shorter parasitic elements, a gain of 18.2dBi is achieved at the boresight direction ($\phi = 90^0$). Changing the diode states results with a beam switch to 5.846dBi at the boresight. When the PIN diodes are "on", the power distribution within the cavity changes and it is observed that the main lobe direction is switched towards the edges (endfire) with an angle of $\pm 78^0$. The beam switching at this angle between the "off" and "on" states are -9.828dBi and 7.14dBi which proves that a gain enhancement of 16.96dBi is achieved at the edges.

IV. CONCLUSION

In this paper a low complexity approach of a high gain beam switching structure is presented. A microstrip dipole antenna with two reconfigurable parasitic elements employing PIN diodes are used in combination with a PRS to control the radiation pattern that can be switched from boresight to endfire directions. It is observed that with a cavity spacing of ~λ/2, the beam magnitude of 18.8dBi is reconfigured to -11.39dBi which shows a significant change where the beam steered $\pm 20^0$ relative to the boresight ($\phi = 90^0$). At this angle 15.5dBi of gain enhancement is attained. However with a cavity spacing of ~λ, the steering angle is increased up to $\pm 78^0$ (H-plane) and the maximum gain observed at this direction is 7.14dBi with a gain enhancement of approximately 17dBi. The validation of the structure with measurement results will be the next step and higher frequency operation of the structure will be investigated in the future work.

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