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Fixed-Frequency Beam Steering from a Stub-Loaded Microstrip Leaky-Wave Antenna

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***Abstract*—A microstrip leaky-wave antenna (MLWA) is designed for fixed-frequency beam steering. The main beam direction of this antenna is controlled by changing the periodic reactive loading of a microstrip line. This reactive loading is provided by a set of periodic patches closely coupled to the stubs in the microstrip line. These patches can be selectively connected to the ground using PIN diodes. The proposed reconfigurable antenna can steer main beam from 40° to 64° in discrete steps at 6.2 GHz.**

I. INTRODUCTION

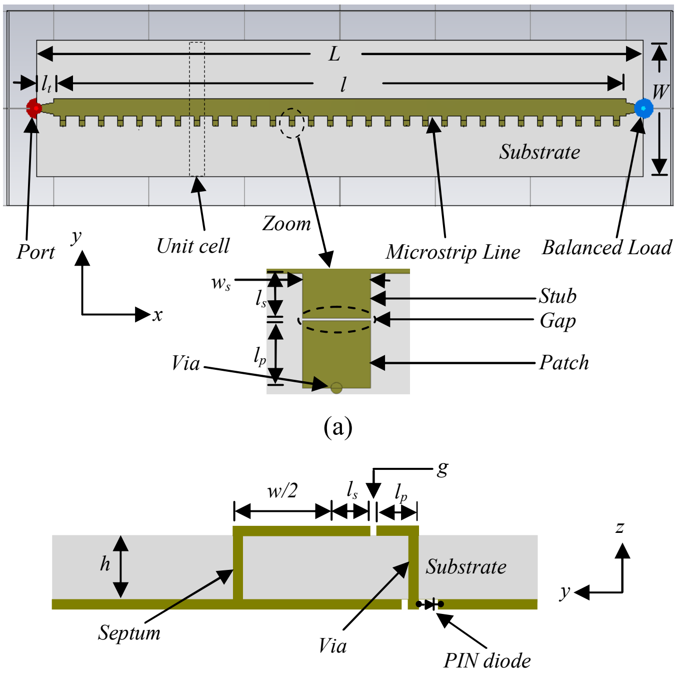
The leaky-wave phenomenon of a microstrip line has been utilised to realize beam steering in microstrip antennas [1]. The radiation in these microstrip leaky-wave antennas (MLWAs) is usually obtained from the first higher-order mode [2]. The radiation angle of the main beam θ_m from the broadside is given by $\sin^{-1}(\beta / k_0)$ where β is the phase constant in the propagation direction and k_0 is the wave number in free space. In the first higher-order mode of a microstrip line, β / k_0 increases with the increase in frequency [2]. Hence the beam scans from broadside to endfire as the frequency increases.

Beam scanning at a fixed-frequency is desirable in certain applications such as side-looking sensors in automotive applications [3]. In order to change θ_m at a fixed-frequency, β needs to be changed in the MLWA. This is usually achieved by using active switches such as PIN diodes and varactor diodes in the antenna [4-5] or changing the antenna feed point [6].

In this paper, a reconfigurable stub-loaded half-width MLWA (HW-MLWA) is presented. The HW-MLWA with periodic stubs in one side is loaded by a set of periodic patches that can be selectively connected to ground using PIN diodes. Changing the periodic loading on the microstrip line changes the effective β of the microstrip line. Therefore the beam can be steered by controlling the states (On and Off) of the PIN diodes.

II. ANTENNA STRUCTURE & DESIGN

The structure proposed is a modified HW-MLWA with periodic stubs as shown in Fig. 1(a). One edge of the printed microstrip is connected to the ground using a metallic wall referred to as a septum. The purpose of the septum is to avoid the propagation of the fundamental TEM wave and to support the propagation of first higher-order mode through the structure [7]. The free edge of the microstrip line contains 30 equally spaced stubs with a center-to-center separation of 10mm from one to another. Each stub has a width (w_s) and length (l_s) of 3mm and 2mm, respectively.



(a)

(b)

Fig. 1: Proposed MLWA (a) top view (x-y plane) and (b) side view (y-z plane).

A set of square patches, each 3mm x 3mm, are printed very close to the free edge of the stubs, leaving a narrow 0.1mm gap (g) between them, as shown in Fig. 1(a). Each patch contains a via that goes through the substrate to the ground level. This via is connected to the ground by a PIN diode. The side view of this arrangement is shown in Fig. 1(b). The n-terminal of the each PIN diode is connected with the ground plane while the p-terminal is connected to a via. The p-terminals of each diode are connected independently to the positive terminal of a dc supply using externally controlled switches. The ground plane is connected with the negative terminal of the dc supply. When a diode is forward biased i.e. in On state, the patch is connected to the ground. Similarly, when the diode is reverse biased i.e. in Off state, the patch is isolated from the ground. Having a separate connection to the p-terminal provides an individual control of the states of each diode. This way, the patches can be controlled individually.

The antenna is fed from one end using a standard SMA feed and terminated on the other end with a 50Ω matched load. A tapered transmission line of length (l_t) 9mm is used both at the feed and the termination in order to provide a good impedance match. This HW-MLWA is designed on Rogers RT5880 substrate with ε_r=2.2, and tanδ=0.0009. The length (L), width (W), and height (h) of the substrate are 318mm (6.572λ_o), 70mm (1.447λ_o), and 0.787mm, respectively, where λ_o denotes the free-space wavelength calculated at 6.2GHz. The length and width of the ground plane has the same respective dimensions of the substrate. The length (*l*) and width (w/2) of the microstrip line are 300mm (6.2λ_o) and 8mm, respectively.

III. Results & Discussion

The design of the proposed HW-MLWA was carried out using CST Microwave Studio [8]. The PIN diodes were simulated as ideal switches in this design. In the On state, the diode acts as a short circuit and in Off state the diode acts as an open circuit. Hereafter, these On and Off states are denoted as "1" and "0", respectively. Since each PIN diode can be individually controlled, a wide variety of switch configurations are possible.

The radiation of the HW-MLWA is tested for six selected switch configurations (SCs) given in Table I. The radiation patterns at 6.2GHz for these switch configurations are shown in Fig. 2. It can be seen that the main beam can be steered from 40° to 64° in discrete steps by switching between the selected SCs. The state of each PIN diode changes the reactance between the corresponding stub and ground. Having different SCs introduces different reactance profiles along the microstrip line. Each of these reactance profiles provides a distinct β for the HW-MLWA at a fixed frequency. As a result the main beam direction θ_m changes with the SC.

In SC1, all PIN diodes are in the On state i.e. the capacitance between the stub and the ground is larger compared to the SC6. By observing the radiation patterns for SC1 and SC6 it is clear that higher capacitance i.e. a smaller reactance results in a main beam directed away from endfire and smaller capacitance i.e. larger reactance results in a beam directed towards endfire. Further, this observation leads to conclude that turning the PIN diodes on results in a relatively smaller effective β_1 compared to the effective β_2 when all PIN diodes are off.

TABLE I
Selected Switch Configurations and Corresponding Main Beam Directions at 6.2 GHz

Switch configuration (SC)		Main Beam Direction (θ_m)
1	111111111111111111111111111111	40°
2	111101111011110111101111011110	44°
3	000001111100000111110000011111	51°
4	101010101010101010101010101010	54°
5	000001000001000001000001000001	59°
6	000000000000000000000000000000	64°

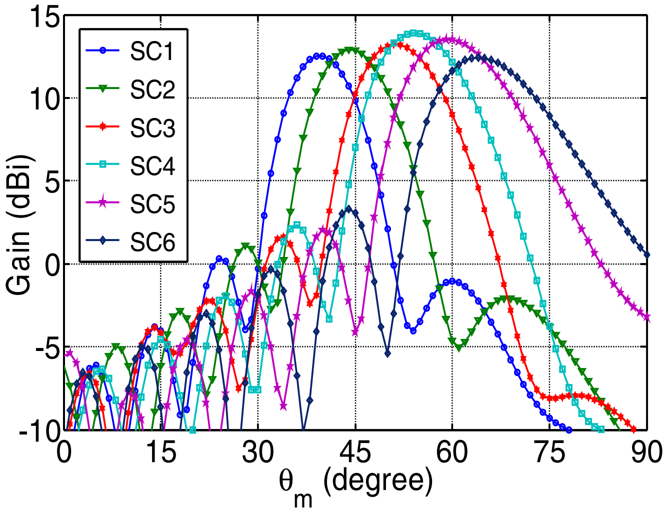


Fig. 2. Radiation patterns (dBi) of the proposed antenna at 6.2 GHz for selected switching configurations.

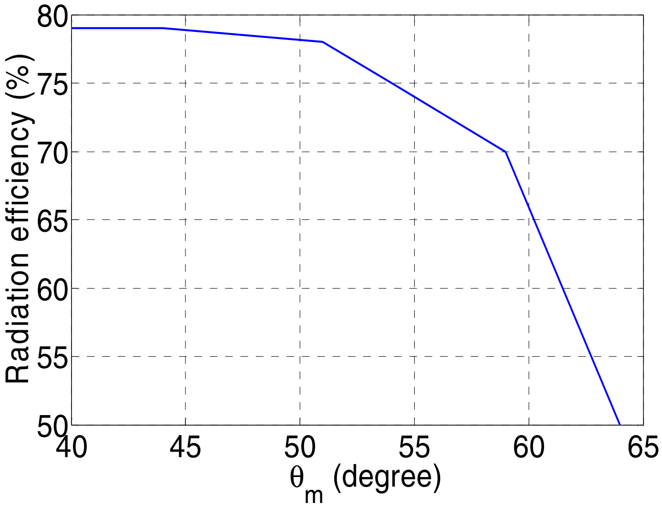


Fig. 3. Radiation efficiency (%) of the proposed antenna for different main beam directions at 6.2 GHz.

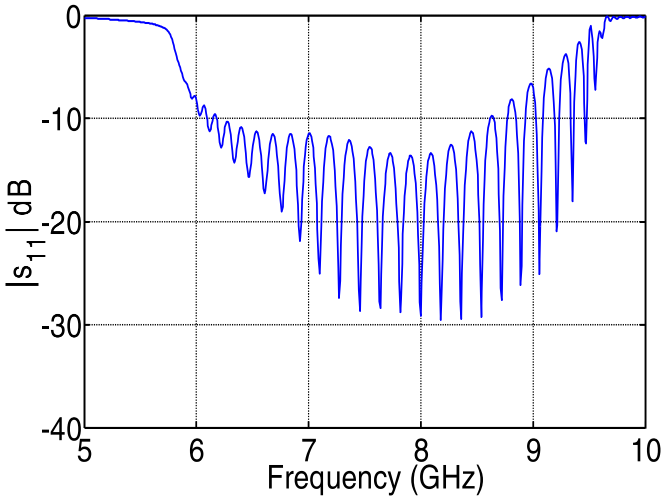


Fig. 4. $|s_{11}|$ for the switch configuration 1 (SC1) of the proposed antenna.

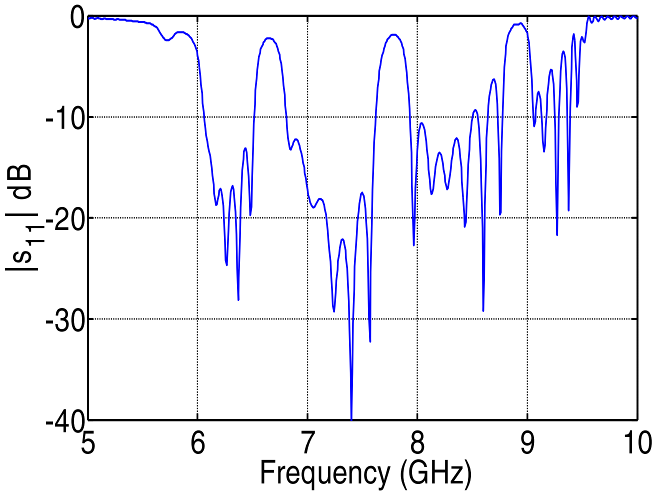


Fig. 5. $|s_{11}|$ for the switch configuration 2 (SC2) of the proposed antenna.

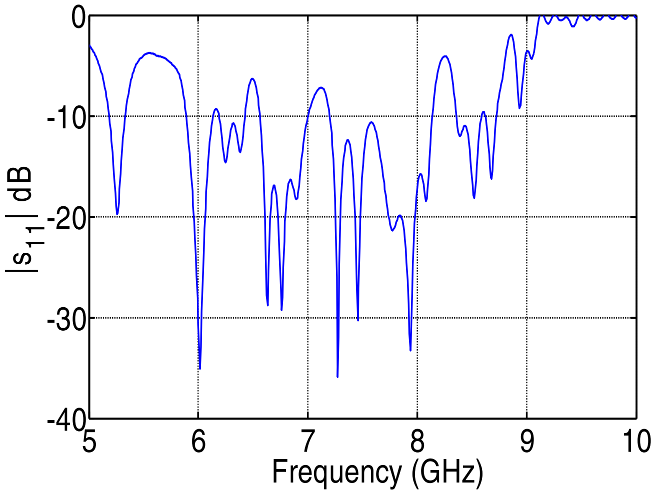


Fig. 6. $|s_{11}|$ for the switch configuration 3 (SC3) of the proposed antenna.

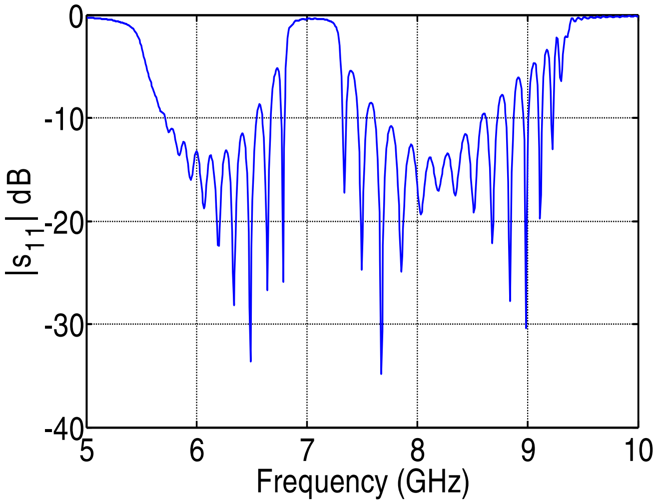


Fig. 7. $|s_{11}|$ for the switch configuration 4 (SC4) of the proposed antenna.

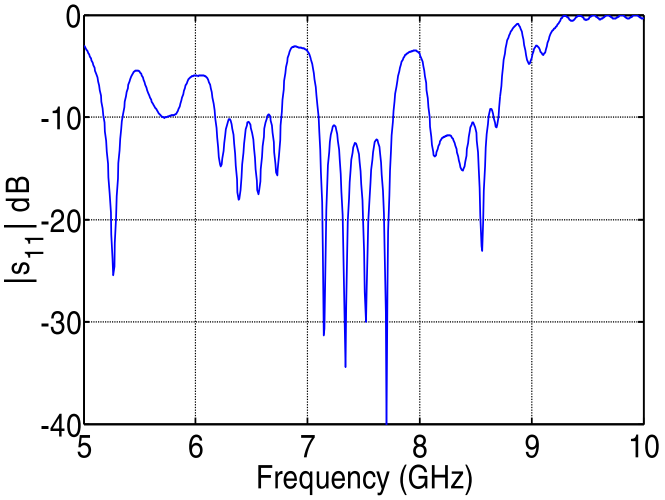


Fig. 8. $|s_{11}|$ for the switch configuration 5 (SC5) of the proposed antenna.

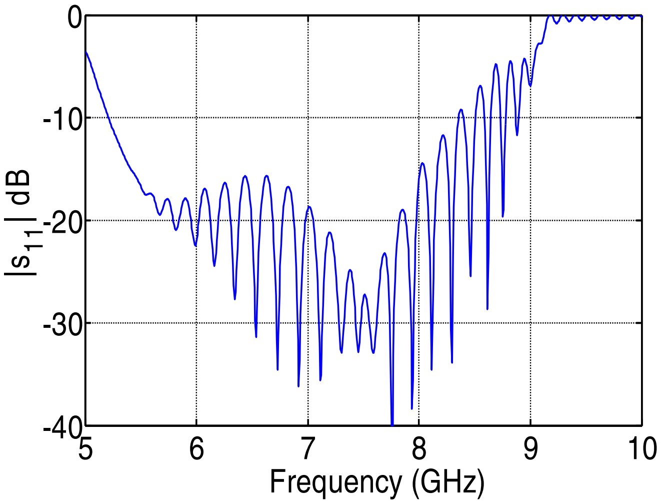


Fig. 9. $|s_{11}|$ for the switch configuration 6 (SC6) of the proposed antenna.

The radiation efficiency of this HW-MLWA is shown in Fig. 3 for different main beam directions. The radiation efficiency is high for the beams directed closer to 40^o and the efficiency decreases when approaching endfire. The input reflection coefficient magnitudes for the six main switch configurations are shown in Figs 4-9. It can be seen that the HW-MLWA has a return loss greater than 10dB at 6.2GHz for all listed switch configurations.

IV. CONCLUSION

A structure that allows dynamic modification of the phase constant is presented in this paper. The change in the reactance profile in a HW-MLWA changes the effective phase constant β at a fixed frequency. This can be used to achieve fixed-frequency beam scanning in a design where the fundamental TEM mode is suppressed while β is varied for the first higher-order mode. This design can provide a wide variety of switch configurations that can steer the main beam direction from 40^o to 64^o in discrete steps.

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