

Electronically controlled radiation pattern leaky wave antenna array for (C band) application

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Abstract

This paper provides an insight of a new, leaky-wave antenna (LWA) array. It holds the ability to digitally steer its beam at a fixed frequency by utilizing only two state of bias voltage. This is done with acceptable impedance matching while scanning and very little gain variation. Investigation is carried out on LWAs' control radiation pattern in steps at a fixed frequency via PIN diodes switches. This study also presents a novel half-width microstrip LWA (HWMLWA) array. The antenna is made up of the following basic structures: two elements and reconfigurable control cell with each being comprised of two diodes and two triangle patches. A double gap capacitor in each unit cell is independently disconnected or connected via PIN diode switch to achieve fixed-frequency control radiation pattern. The reactance profile at the microstrip's free edge and thus the main beam direction is changed once the control-cell states are changed. The main beam may be directed by the antenna between 61° and 19° at 4.2 GHz. C band achieved the measured peak gain of the antenna of 15 dBi at 4.2 GHz beam scanning range.

Keywords: beam steering, control cell, double gap, HW-LWA array, LWA

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1. Introduction

Since the proposal of microstrip LWAs (MLWAs) in 1978, considerable interest in its research followed [1-6]. Due to their large bandwidth, ability to integrate easily with microwave and millimetre-wave circuits, planar low-profile configuration, inherent beam-scanning abilities with frequency and narrow beam [7-13], microstrip LWAs continue to be a popular choice. The equation $\sin^{-1}(\beta/k_0)$ gives the main beam's direction (θ) as measured from the boresight of a LWA, in which k_0 refers to the free-space wavenumber while β refers to the phase constant. In relation to this, the direction that lies at 90 degrees to the plane of the antenna is the boresight. The main beam direction changes as the value of (β/k_0) fluctuates with frequency. Usually, wireless communication systems function in predefined frequency band although the LWAs scan the beam via sweeping the operating frequency.

As such, beam scanning at a fixed frequency becomes the desired function. Several LWAs have been built for the purpose of fixed-frequency scanning, which includes a multiterminal MLWA [14], Fabry-Perot LWA [15-17], composite left/right-handed (CRLH) LWA [18], and half-width MLWAs [19]. Since there is a strong attachment of electric field between the ground plane and microstrip, the fundamental mode of a microstrip line never radiates. Leaky waves are radiated by some higher-order modes. An electric field-null makes up the first higher-order mode and a phase reversal along the center of the microstrip. Considerations of the first higher-order mode's properties led to the design of a MLWA in which the center of the microstrip is fixed with a shorting wall. This causes the microstrip line's width to be reduced by half. Such antenna is also termed as half-width (HW) microstrip LWA (HW-MLWA) [20].

The requirement of not exciting anything else apart from the first higher order mode complicates the feeding process of a traditional microstrip LWA. Beneath the microstrip, the electric field's normal component is the mode's peculiar aspect. As such, excitation can only be achieved by utilizing two offset feeds that are driven 180 out of phase. Vias that connect a half-width line with one edge to the plane of the ground and having a single offset feed was

recently suggested by Zelinski et al [5]. This arrangement creates an electric wall at a location in which full-width antenna's electric field becomes zero. In addition to utilizing a simpler feed system, this implementation benefits by having only one radiating edge. Lumped capacitors could be combined to such single edge as suggested by Laheurte and Luxey, in order to give the required reactance to potentially alter the main beam's direction towards any angle from broadside to endfire.

This paper provides an insight into the development of a method that allows a MLWAs to reach fixed-frequency beam scanning and also suggestions on a novel HW-MLWA array configuration because the high-gain and the highly directional antenna arrays at the transmitter (TX) and the receiver (RX) reinforces the suitability of wireless communications [21-24]. That eliminates the necessity of lumped capacitors. It has two new features: 1) building a systematic control cell based approach to assess and develop digitally controlled reconfigurable electromagnetic gadgets which includes antennas, 2) utilizing only two values of bias voltage needed to switch on and off towards getting impedance-matched fixed frequency beam scanning and high quality. A binary reconfigurable control cell (covetable between two states) forms the basic structure of the HW-MLWA. Stacking of some similar unit cells created the HW-MLWA. As detailed in the following part, alteration of the states of control cells allows fixed frequency steering of the antenna beam. A total of 12 control cells are used in proposed design each cell is contain two triangles.

2. Antenna Configuration

The structure proposed is a modified two elements of HW-MLWA with 6 periodic control cells in each elements as shown in Figure 1 (a). Each element of HW-MLWA is designed on Rogers RT5880 substrate with $\epsilon_r=2.2$, and $\tan\delta=0.0009$. Length (L), width (W), and height (h) of the substrate is 239 mm ($3.3347\lambda_0$), 100 mm ($1.4\lambda_0$), and 1.575 mm, respectively, where λ_0 denotes the free-space wavelength that is calculated at 4.2GHz. Length and width of the ground plane has the same respective dimensions of the substrate. The length (l_p) and the width (w_p) of microstrip line is 222 mm ($3.108\lambda_0$) and 12 mm ($0.168\lambda_0$), respectively. The proposed HW-MLWA array is fed from one end of the radiation element using a standard SMA feed and the outer free corner of each branch is shorted to the ground plane by a via to avoid reflection and to achieve good impedance matching as demonstrated in Figure 1 (b). Dimensions of the feed line are optimized according to some parametric studies. The optimum parameter values for the length (l_f) is 4.5 mm and width of the feed (w_{f1} , w_{f2} , w_{f3} and w_{f4}) are 8.5 mm, 6 mm, 4 mm and 31 mm, respectively. One edge of microstrip line is connected to the ground using a vias array, which is placed along the edge of microstrip line. Major purpose of the vias array is to avoid the propagation of the fundamental transversal electromagnetic (TEM) wave and to support the propagation of first higher-order mode through the structure [25-26]. The proposed antenna to shorten the edge of each element are used 145 vias. The design configurations of these structures have been presented in. The metallized diameter (d) and distance (S) between the two adjacent vias can be calculated using the following (1), that set the design rules [27-28].

$$d > 0.2\lambda_0, \frac{d}{s} \leq 0.5 \quad (1)$$

The distance (S) between the two vias is 1.5 mm, and the value of the diameter (d) of each via is 0.8 mm. The appropriate gap(n) between the feed and the first via and gap (m) between the feed and first control cell are 4.9 mm and 48.55 mm, respectively, as shown in Figure 1 (c). These gaps are required to force the wave toward the microstrip edges and improve matching impedance [29].

3. Control Cell Configuration

The concept of cascading multiple type of unit cells to create a larger cell has been previously studied by [30] for nonreconfigurable structures. Major drawback in that approach is that this design system is nonreconfigurable, which means large cells cannot be operated for other configurations after fabrication. In this paper, the idea of a reconfigurable control cell is

presented, which consists of small reconfigurable unit cells. The design allows to dynamically change the characteristics and size of the large-cell.

The free edge of microstrip line contains (6) equally spaced control cells of each element with a space separation between cells (A_3) of 9.8 mm. Each cell contains two triangular patches and the dimension of each triangle is (A_1) 20 mm and (A_2) 16 mm as shown in Figure 1 (b). A set of control cell patches, was putted very closer to the microstrip line's free edge, leaving a narrow 0.25 mm gap (g_1) between them, and the gap between the triangles in control cell (g_2) is 0.2 mm as shown in Figure 1 (b). Each control cell consists of two triangular patches, two PIN diodes are working as binary switch and two vias that goes through the substrate than connected to the ground level. The PIN diode is connected with the triangular patch plan through its p-terminal whereas the n-terminal is connected to a via as shown in Figure 1 (c). The p-terminal of every diode is attached independently to the positive terminal of DC power supply using externally controlled switches. The ground plane is connected with the other terminal (-ve) of the DC supply. When a diode is in ON state, i.e. forward biased, the patch is connected to the ground and when the diode is in OFF state, i.e. reverse biased, 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. In this way, the patches can be controlled individually. The total input impedance of the antenna when the PIN diodes are ON can be calculated as [31].

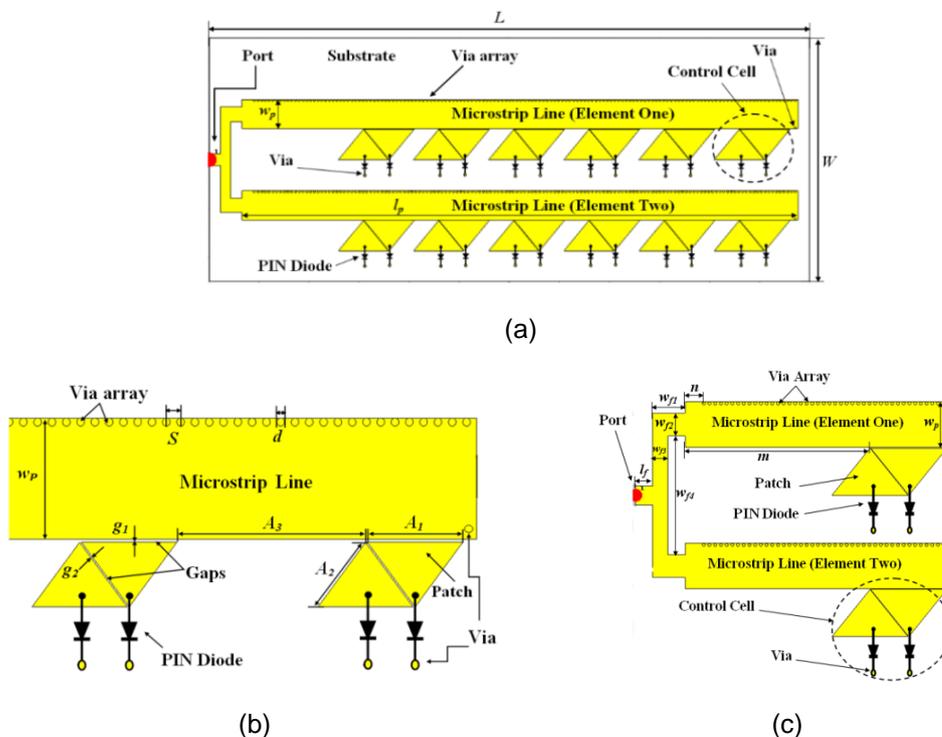


Figure 1. Reconfigurable HW-MLWAs array: (a) top view, (b) microstrip line with control cell, (c) port and feed line for two elements.

4. Results & Discussion

CST Microwave Studio was put into consideration for the development and study of the proposed antenna. The switches of PIN diode that are utilized for this test are taken as the best antenna. The diode is forward-biased switch (shown as '1') and the triangle patch lies directly joined to the ground as positive supply is placed to the PIN diode's p-terminal. A dc supply's positive terminal is joined separately to each PIN-diode's p-terminal. This permits the state of each PIN diode to be individually controlled ('Off' or 'On'). When the PIN diodes are in the Off state (represented as '0'), the capacitance between the ground and the free edge of the microstrip line is lower than when diodes are in the ON state. Lower capacitance causes a main beam that lies at a greater distance from broadside while the higher capacitance causes the

main beam to lie nearer to the broadside. Extra control over this reaction profile is attributed to having these control cells in the microstrip's free-edge.

In comparison to the effective capacitance without patches, the longer patches bring out a reduced effective capacitance between the radiating edge and ground. Thus, triangle patches cause the direction of the main beam to be moved towards the endfire. Alterations to the PIN diode switch configuration for a given patch length can further causes changes to the main beam's direction. The switch cases and corresponding direction of main beams at 4.2 GHz is represented by Table 1. Input reflection coefficients of the five distinct switch settings presented in Table 1 is represented by Figures 2, 3, and 4. They show that for these switch cases, the antenna is highly coordinated at 4.2 GHz. Compared to the capacitance as the switch is Off, the capacitance between the ground plane and free edge of the microstrip line is greater than when the switch is On (1). The admittance profile at the microstrip line's radiating edge is altered by the change of switch states, and thus causing alterations to the effective β of the structure in Table 1. Figure 5 shows the radiation pattern for the five distinct switch settings. It is observable that for state 1 when all diodes are (ON) than the vias is connected the patch cell with ground plane the main beam direction combine towards (19°) near of broadside. For state 5 when the all diodes are (OFF) than no any connected between patches cell with the ground plane the main beams are directed towards (61°) near of the endfire.

Table 1. Switch Configurations and Corresponding Main Beam Directions at 4.2 GHz

State No.	Switch cases	Main Beam Direction (θ_m)
1	11-11-11-11-11-11-11-11-11-11-11	19°
2	00-00-00-00-00-00-11-11-11-11-11	23°
3	10-10-10-10-10-10-10-10-10-10-10	36°
4	11-11-11-11-11-11-00-00-00-00-00	39°
5	00-00-00-00-00-00-00-00-00-00-00	61°

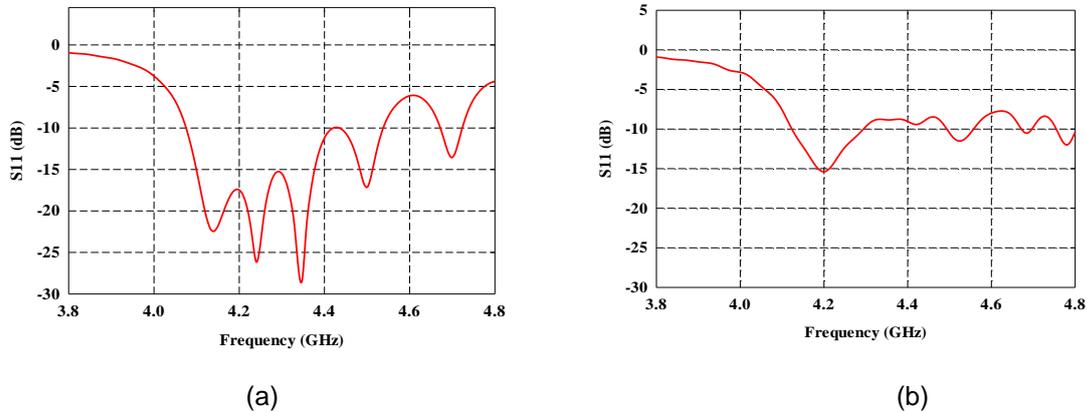


Figure 2. $|S_{11}|$ for the (a) state 1 and (b) state 2 of the proposed antenna

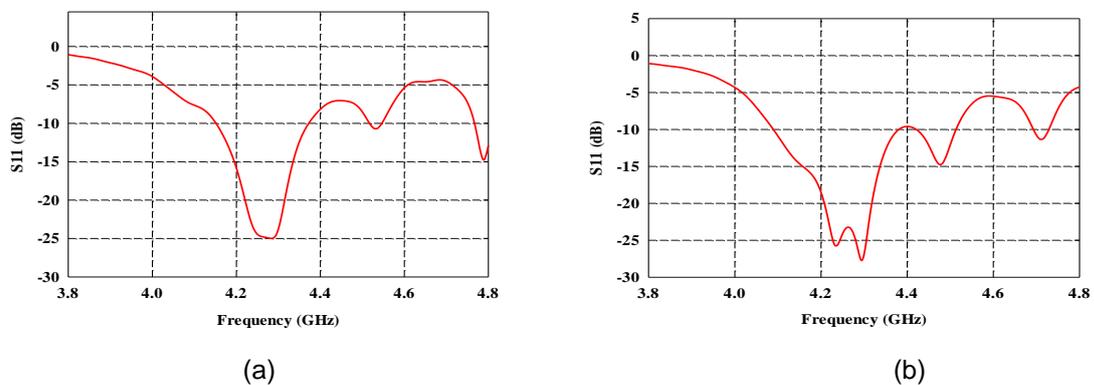


Figure 3. $|S_{11}|$ for the (a) state 3 and (b) state 4 of the proposed antenna

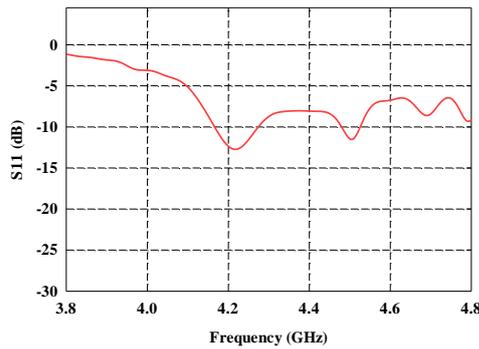


Figure 4. |S11| for the state 5 of the proposed antenna

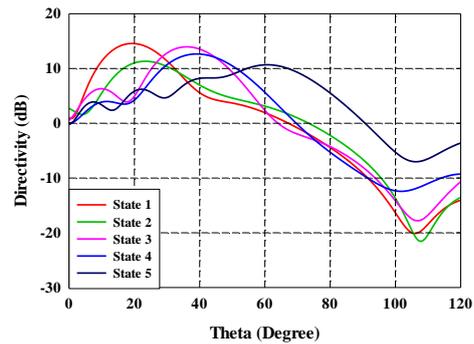


Figure 5. Radiation patterns of the proposed antenna at 4.2GHz for different switch cases in Table 1

The voltage standing wave ratio (VSWR) indicates the impedance matching of antenna. The value of VSWR should lie between 1 and 2. In Figure 6 shows the VSWR for proposed HW-MLWA antenna array for five states of switched and Table 2 is contain the value of VSWR at 4.2 GHz for switches configuration in Table 1, in state no. 1 the value of VSWR is low because the main beam near of the broadside and in state no. 5 the VSWR is high because the poor radiation when the main beam steering towards endfire.

As the beam points get nearer to the foresight, the efficiency of a MLWA's radiation is high. The radiation efficiency lowers as the beam move towards the endfire [32, 33]. Conversely, as the beam scans the same range at 4.2 GHz, the reconfigurable HW-MLWA's radiation efficiency lowers by only 4.181% from 95.6% to 91.479%. As the antenna is properly similar for all the selected control cell states, the reconfigurable antenna's total efficiency almost matches all those states' radiation efficiency. In both forms of LWA's, when the beam is steered towards the direction of end-fire, the lowering of radiation efficiency compensates for the rise in directivity. In this case, within the context of a proper LWA design, production by this gain variation may be lower than the industrial standard 3dB limit.

The radiation efficiency of this HW-MLWA is shown in Figure 7 for different main beam directions. The radiation efficiency is high for the beams directed closer to 39° and the efficiency decreases when approaching endfire at the main beam direction at 61°.

Table 2. Switch Configurations and VSWR at 4.2 GHz

State No.	Switch cases	VSWR
1	11-11-11-11-11-11-11-11-11-11-11-11	1.306
2	00-00-00-00-00-00-11-11-11-11-11-11	1.411
3	10-10-10-10-10-10-10-10-10-10-10-10	1.387
4	11-11-11-11-11-11-00-00-00-00-00-00	1.269
5	00-00-00-00-00-00-00-00-00-00-00-00	1.638

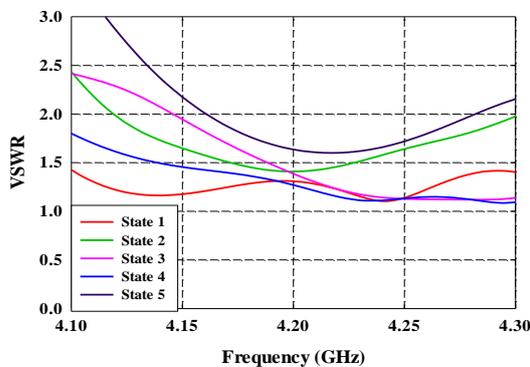


Figure 6. VSWA for the HW-MLWA array for the switches configuration for all cases in for the switches configuration for all cases Table 2

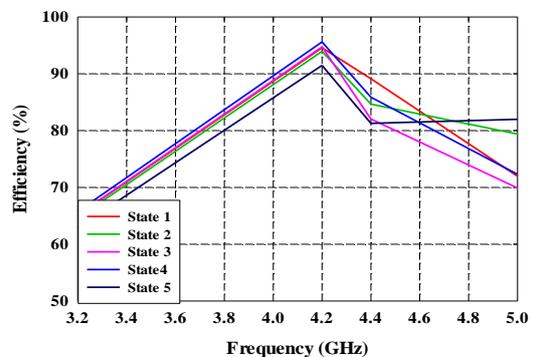


Figure 7. Efficiency for the HW-MLWA array for the switches configuration for all cases in Table1

5. Conclusion

A new technique to control the radiations of periodic HW-MLWAs array at a 4.2 GHz, using control cell containing two triangular patches with two PIN diodes, is presented in the article. The free edge of the microstrip line has been loaded by double gap capacitors, which are periodic, and PIN diodes has been used to control their connections with the ground plane. This design helps us to achieve beam scanning while there is no need of lumped capacitors and we also need not to change the frequency. We have developed a multi-state of control cell approach to analyses reconfigurable periodic structures and this approach is used for the design of microwave leaky wave antenna that is reconfigurable. Our current methodology is helpful for the design and analysis of reconfigurable periodic structure systematically. The scanning range of the designed antenna is 42° at 4.2 GHz while the peak gain at 4.2 GHz is 15 dBi beam scanning range is realized in C band.

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