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Radiation beam scanning for leaky wave antenna by using slots

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ABSTRACT

This paper provides an insight of a new, microstrip leaky wave antenna. It holds the ability to continue steer its beam at a swapping frequency. 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 band frequency via vertical and horizontal slots. The enhancement is realized by etching horizontal and vertical slots on the radiation element. This study also presents a novel half-width microstrip leaky wave antenna (LWA). The antenna is made up of the following basic structures group's vertical and horizontal slots. 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 radiation pattern direction changes by sweeping the operating frequency between 4 GHz to 6 GHz.The main beam may be directed by the antenna between 15° and 55°. C band achieved the measured peak gain of the antenna of 10 dBi at 4.3 GHz beam scanning range.

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1. INTRODUCTION

Since the proposal of microstrip LWAs (MLWAs) in 1978, considerable interest in its research followed [1-9]. Wireless waves with different frequencies have different characteristics that could be more suitable for a certain type of wireless device [10-12]. 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 [13, 14], microstrip LWAs continue to be a popular choice. The equation $\sin^{-1}(\beta/k_o)$ gives the main beam's direction (θ) as measured from the boresight of a LWA, in which k_o 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_o) fluctuates with frequency. Usually, wireless communication systems function in predefined frequency band although the LWAs scan the beam via sweeping the operating frequency. Much research activities have targeted the topic of beam steering by changing the operating frequency such as. However, a huge number of applications utilized fixed frequency while beam scanning. Therefore, there is a lack of study to provide fixed frequency–beam steering based on an HW–MLWA.

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 [15], Fabry-Perot LWA, composite left/right-handed (CRLH) LWA [16], and half-width MLWAs [17]. 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) [18].

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. 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 beam scanning and also suggestions on a novel HW-MLWA configuration because the high-gain and the highly directional antenna at the transmitter (TX) and the receiver (RX) reinforces the suitability of wireless communications. Used two group of slots vertical and horizontal in order to can control radiation pattern by sweeping the operation frequency. This new design is suitable for C band application in radar system.

2. ANTENNA CONFIGURATION

The structure proposed is a modified one elements of half width microstrip leaky wave antenna with 24 periodic control unit slot cells in element as shown in Figure 1 (a). The proposed antenna of half width microstrip leaky wave antenna (HW-MLWA) is designed on Rogers RT5880 substrate with $\varepsilon_r = 2.2$, and $\tan\delta = 0.0009$. Length (L), width (W), and height (h) of the substrate is 250 mm ($3.3347\lambda_o$), 100 mm ($1.33\lambda_o$), and 1.575 mm, respectively, where λ_o denotes the free-space wavelength that is calculated at 4 GHz. 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 ($3.108\lambda_o$) and 12 mm ($0.168\lambda_o$), 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_p and l_{p1} are 4 mm and 6.32 mm, respectively. The width of the feed w_{fl} are 7.6 mm. 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 [19]. The proposed antenna to shorten the edge of each element are used 60 vias. The design configurations of these structures have been presented in. The metallized diameter (D) and distance (P) between the two adjacent vias can be calculated using the following equations, that set the design rules [20].

$$D > 0.2\lambda_o, \frac{D}{P} \leq 0.5 \tag{2}$$

The distance (P) between the two vias is 1.5 mm, and the value of the diameter (D) of each via is 0.8 mm. The appropriate horizontal slot (S_1) and the vertical slot (S_2) control cell are 3.2 mm and 8.5 mm, respectively, as shown in Figure 1 (c). These slots are required to force the wave toward the microstrip edges and improve matching impedance [21]. The concept of cascading multiple type of slots unit cells to create a larger cell has been previously studied by [22] 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 horizontal and vertical slots is presented. The design allows to dynamically change the characteristics and size of the large-cell. The microstrip line contains (24) equally spaced unit control cells of each element with a space separation between cells (g_1) of 4.6 mm.

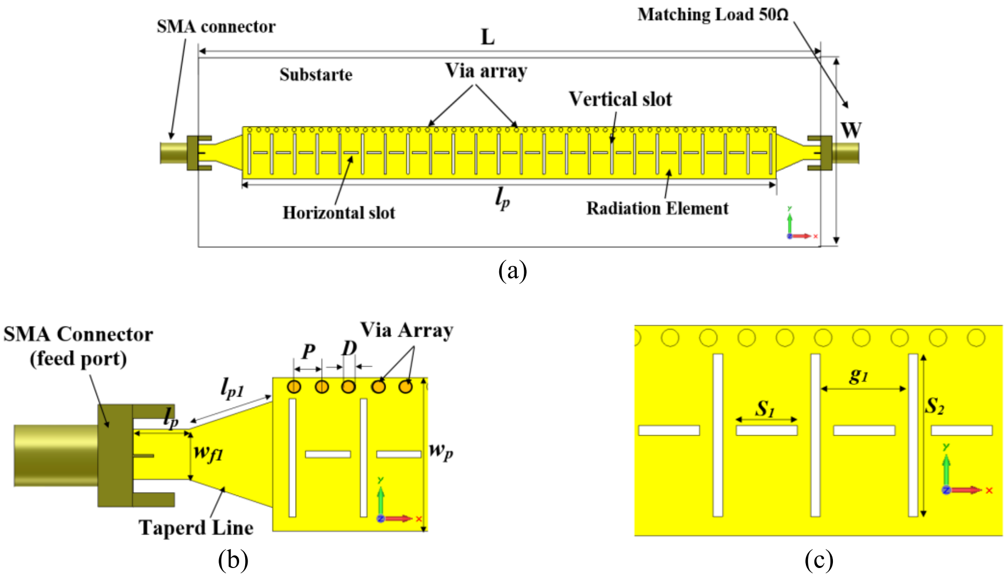

Figure 1. Reconfigurable SIW antenna: (a) top view, (b) microstrip feed line, (c) control unit slot cell

3. RESULTS & DISCUSSION

The unit cell slots that are utilized for this test are taken as the best antenna and the slot in microstrip patch is represented by capacitance. Extra control over this reaction profile is attributed to having these control cells in the microstrip's free-edge. CST Microwave Studio was put into consideration for the development and study of the proposed antenna. 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.The gain decreases when the beam is near the end fire because of the poor radiation in the end fire. The radiation power is dependent on the HW–MLWA length lp and leakage rate (α). As observed in Figure 2, the leaky wave propagation has an exponential function when the beam scanning is from the broadside towards end fire.

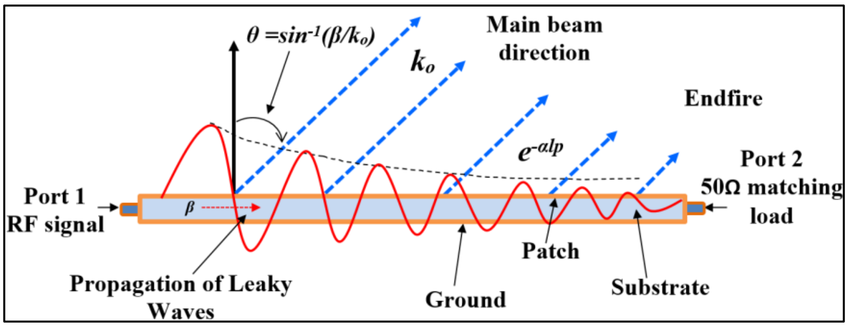

Figure 2. Propagation of leaky wave in HW-MLWA

In comparison to the effective capacitance without patches, the longer patches bring out a reduced effective capacitance between the radiating edge and ground. Thus, slots cause the direction of the main beam to be moved towards the endfire. Alterations to the slots configuration for a given patch length can further causes changes to the main beam's direction. The sweeping frequency cases and corresponding direction of main beams at 4 to 6 GHz. The return loss of the proposed antenna get it wideband and wide scanning range, as shown in Figure 3. They show that for these sweeping frequency case, the antenna is highly coordinated at 5GHz. Compared to the capacitance of the slots, the capacitance between the ground plane and free edge of the microstrip line is greater than at 5 GHz. The admittance profile at the microstrip line's radiating edge is altered by the change of operating frequency, and thus causing alterations to the effective β of the structure.

Figure 4 shows the radiation pattern for the five distinct operating frequency settings. It is observable that for state 1 when operation frequency is 4.3GHz the main beam direction combine towards (15°) near of broadside. For state 5 when the operating frequency is 5.5 GHz the main beams are directed towards (55°) near of the endfire. The gain decreases when the beam is near the end fire because of the poor radiation in the end fire. The radiation efficiency of the proposed design decreases gradually when the main beam direction becomes closer to the endfire and is high near broadside.

The proposed HW–MLWA was tested using the CST Microwave Studio. The scanning range of HW–MLWA is realized by vertical and horizontal slots on the the radiation element. The etching slots in the radiation part did not increase the size of the antenna, and the radiation pattern had a small effect. The slots technique on the radiation elements led to an increase in the bandwidth, whereas the etching of vertical slots close to the matching load is used to increase the current surface field in the entire and to match the impedance for proposed antenna. The shape of the slot on the radiation element is very critical. The proposed design used a vertical and horizontal slot to increase the bandwidth with good matching impedance and decrease the cross polarization of the antenna.

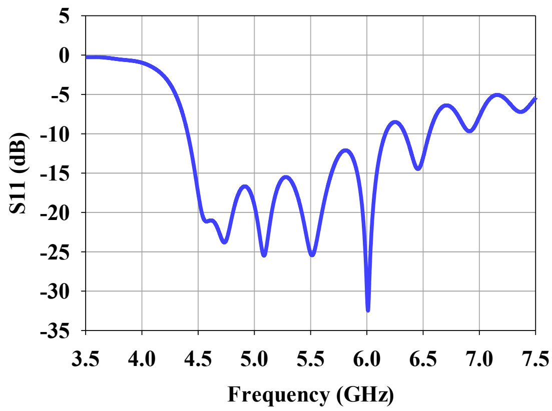

Figure 3. Return loss for proposed HW-MLWA without horizontal and vertical slots

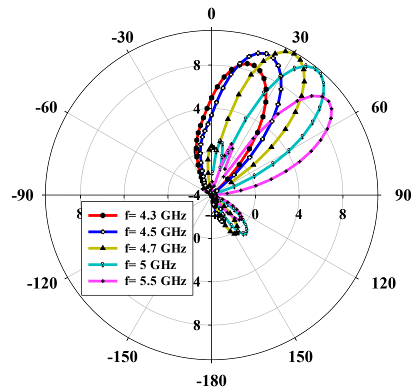

Figure 4. Radiation patterns (x-z-plane) of the proposed HW–MLWA (Phi = 0)

The VSWR is the ratio between the maximum RF voltages to a minimum along the transmission line. The standing wave is the companion of the original signal propagated in the antenna and reflected wave. The ratio between these waves is known as the voltage standing wave ratio (VSWR). This parameter is used to measure the characteristic impedance of the transmission line and matches the terminal impedance of the proposed antenna. It is also used to describe the performance of the proposed antenna with a transmission line. Figure 5 shows that the VSWR is ≤ 2, which means the proposed antenna has good matching impedance. The voltage standing wave ratio (VSWR) indicates the impedance matching of antenna. The value of VSWR should lie between 1 and 2.

The main beam for the proposed antenna can scan by changing its operating frequency, when a change in the operating frequency results in a change in the value of β/k_o then the main beam direction changes. Various studies have explored LWAs beam scanning by changing the operation frequency. Although most of these studies have focused on beam scanning, few studies have focused on increasing the bandwidth lead to obtaining wide range beam scanning. The boundary bandwidth of the proposed antenna is 4.3 GHz to 6.3 GHz. When the operation frequency between this band and the main beam direction is changed, such as when the elevation angle of the main beam is +15° at 4.3 GHz and the main beam direction is +55° at 5.5 GHz, the main lobe is scanned between the broadsides towards endfire direction. The realized gain is decreased when the beam scan is close to endfire because of the poor radiation efficiency in 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 [23-25]. Conversely, as the beam scans the same range at 4.3 GHz, the reconfigurable HW-MLWA's radiation efficiency lowers by only 4.4%- from 94.6% to 90.2%. As the antenna is properly similar for all the selected operation frequency 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.

This is the main problem with a periodic HW-MLWA1 that is designed not using any slots. This is because the radiation from the microstrip line is polarized in the x-direction whereas radiation from the free edge of uniform HW-MLWA1 is polarized in the y-direction. So, an effective way is necessary to reduce the cross-polarization while maintaining the distance between slots. Figure 6 shows the cross polarization of proposed HW–MLWA.It can be observed that the cross–polarization increases when the main beam moves to forward direction, from lower frequencies to the higher frequencies. It is observed in the previous design that the cross-polarization increases significantly when the beam scans close to endfire and beyond it into the forward direction.

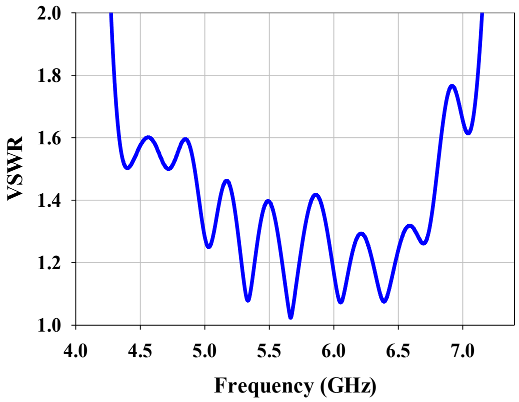

Figure 5. VSWA for the proposed uniform HW–MLWA

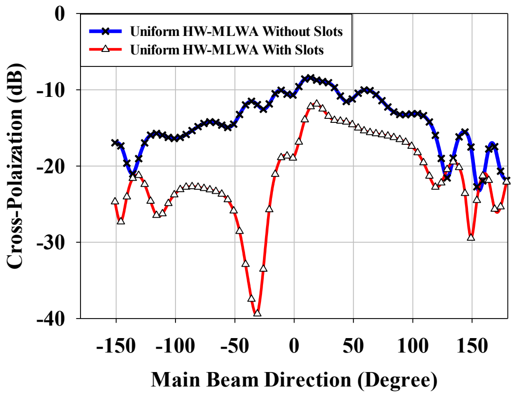

Figure 6. Cross-polarization level of proposed uniform HW-MLWA with vertical and horizontal slots

4. CONCLUSION

A new design to control the radiations of periodic HW-MLWAs at a wideband range scanning, using using two type of vertical and horizontal slots, is presented in the article. The proposed antenna has generally high radiation efficiency, and the main beam can scan continuously in a forward direction by changing only the operating frequency. The one of edge antenna is connected with ground plane by using vias connector, which are uniform half width mictostrip leaky wave antenna, and this slots has been used to increase the scanning rang of the proposed antenna. This design helps us to achieve beam scanning while there is with change the operating frequency. We have developed a multi-state of range frequency approach to analyses of this approach for the radar system. Our current methodology is helpful for the design and analysis of uniform HW-MLWA structure systematically. The scanning range of the designed antenna is 40^{o} between 4 to 6 GHz while the peak gain at 5 GHz is 10 dBi beam scanning range is realized in C band applications.

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