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Increasing radiation power in half width microstrip leaky wave antenna by using slots technique

Muhannad Kaml Abdulhameed[1], Sarah Rafil Hashim[2], Noor Kamil Abdalhameed[3], Ahmed Jamal Abdullah Al-Gburi[4]
[1]Information Technology Department, University of Kerbala, Karbala, Iraq
[2]Faculty of Education, Al-Zahraa University for Women, Karbala, Iraq
[3]Faculty of Medicine, University of Warith Al-Anbiyaa, Karbala, Iraq
[4]Faculty of Electronics and Computer Engineering, Universiti Teknikal Malaysia Melaka (UTeM) Durian Tunggal, Melaka, Malaysia

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ABSTRACT

The radiation power in the endfire is decreased while the main beam of half substrate integrated waveguide scan from broadside to endfire in a forward. The design of half-width microstrip leaky-wave antenna (HW-MLWA) has been presented in this work to increase the power radiation near endfire by using the slots technique in the radiation element. This slot leads to a decrease the cross-polarization. The proposed design comprises one element of HW-MLWA with repeated meandered square slots in the radiation element. One aspect of this antenna is generated by using a half substrate integrated waveguide with a full tapered feed line. The proposed antenna was terminated by load of 50 Ω, and feed on the other end of the antenna. Finally, the suggested design is simulated and acceptable results were found. The released gain is increased from 10.6 dBi to 12 dBi at 4.3 GHz. This design is suitable for unmanned aerial vehicle UAVs at C band application.

Corresponding Author:

Muhannad Kaml Abdulhameed
Department of Information Technology, College of Computer Science and Information Technology
University of Kerbala
Karbala, Iraq
Email: muhannad.k@uokerbala.edu.iq

1. INTRODUCTION

The invention of microwave technology related to linear leaky wave antennas can be used in radio engineering systems, including air traffic control systems, communications, radar, and radio navigation, based on both stationary and mobile objects, including aircraft. The first idea of leaky-wave antenna (LWA) introduced in 1978 with explaining the first higher-order mode for electromagnetic wave [1]-[3]. The planner low-profile antenna structure depending on the half-width microstrip leaky-wave antenna, become an attractive best choice for the researchers [4], [5]. The half-width microstrip leaky-wave antenna (HW-MLWA) is suitable for most applications, for example, point to multipoint communications, automotive aircraft radar. Most of the radiation leaky-wave antenna has been controlled by varying the operation frequency deadening of the frequency bands [6]-[8]. The direction of the beam scanning is directed by changing the operation frequency. The equation of the direct beam steering of the leaky-wave antenna is assumed by [9], [10]. Where $\theta(f)$ is the broadside angle, k_o is the wavenumber, and β is defined as the phase constant. So, the varying of the effective phase constant lead to varying of the main beam because of the change in the reactance of profile antenna [11]-[13].

$$\theta(f) = sin^{-1}[\frac{\beta(f)}{k_o(f)}] \quad (1)$$

The beam steering or scanning technique in most communication systems depends on the changing of operating frequency [14]. However, some methods of control radiation pattern by changing the feed position of the microstrip line. The radiation pattern is changed by using the slot technique. The radiation pattern control in the half-width microstrip LWA is changed by using the diode switch technique. Each case has a different angle of the main beam, and the radiation pattern change by changing the switch diode cases. When the change of lumped element of the microstrip line leads to a change in the main beam direction, this varying depends on the value of the lumped element (inductance, capacitance, and resistance) [15]-[18]. According to the short and open circuit for the microstrip line, the microstrip leaky-wave antenna is loaded by the stop lumped element to control the radiation pattern. One of the most important control techniques is using the varactor diode with a microstrip line and using the biasing voltage to control the varactor diode, leading to the head of the main beam direction [19], [20]. The space between the stub loads it's very effective for the direction of the main beam. The composite right left hand of microstrip leaky-wave antenna using the slots for controlling the pattern by altering the operation frequency [21]-[23]. Archbold *et al.* has used the transverse resonance in [24] for determining the suitable capacitance to achieve the main beam at a demanded angle. Over the operating frequency range, the main beam of (HW-MLWA) was steered at a fixed frequency. Using lumped capacitors to load the microstrip edge, the beam has been pointed in the wanted direction.

In this article, the half-width microstrip leaky-wave antenna was proposed to control the radiation pattern by using the zigzag slots technique. By changing the operation frequency, the direction of the main beam has been altered. Thus, a change in the operating frequency leads to a change in the antenna reactance instead of variation in the radiation pattern power direction.

2. CONFIGURATION OF ANTENNA

The proposed half-width microstrip LWA is shown in Figure 1(a) (perspective view). This design is modified for half leaky width wave with zigzag unit cell slots. The Rogers RT5880 uses as substrate and tan (δ)=0.00090, and (ε_r=2.2). The length (L) of the substrate is 230 mm (3.26 λ_o), and the width of the substrate is 45 mm (0.71 λ_o). The thickness of Rogers RT5880 is 1.575 mm, and the wavelength (λ_o) for the free space is 4 GHz for the application of the C band. The dimensions of the microstrip patch are 180 mm for the length of the microstrip line and 10 mm for the width of the microstrip patch. The proposed HW-MLWA is fed from one side by using a stander SMA connector, as shown in Figure 1(b) and 1(c). The feed line length l_{ps} and width w_{f1} are (4.54 and 4.1) mm, respectively. This type of connector has low losses at a higher frequency, and the impedance of this connector is very low [25], [26]. The other side of the microstrip line is terminated by the lumped element using the 50 ohms loaded to prevent any electromagnetic reflection. On the other hand, to get good impedance between connector and microstrip line. The proposed design of the microstrip line is connected with the ground by a vias connector in order to force the microstrip line for working in the first higher-order mode for electromagnetic wave [27] the dimension of via according to this equations.

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

The space between every two vias (P) is 2 mm, and the diameter of vias is 0.9 mm. Therefore, the distance between the first and the edge line towards the fed port (S) is 3 mm. This space is significant to reflect the electromagnetic wave towards the microstrip line. The input impedance of HW-MLWA can be calculated by using (3)-(5). The technical method is implementing electronic control for the maximum radiation pattern of the LWA according to the circular waveguide, which has a longitudinal slot.

$$Z_{in} = Z_w \left[\frac{Z_L + Z_w \tanh(\gamma L)}{Z_w + Z_L \tanh(\gamma L)}\right] \tag{3}$$

$$Z_w = 8Z_o sin^2\left(\frac{\pi y}{W_{eff}}\right)\frac{k_o h}{kW_{eff}}\sqrt{\frac{\mu_r}{\varepsilon_r}} \tag{4}$$

$$Q_f = \frac{1.23}{\left[1+0.12\left(\left(\frac{l_u}{w_p}\right)-1\right)^{0.9}\right]} \tag{5}$$

The leaky-wave antenna contains a round, dielectric-filled waveguide with a longitudinal slot, symmetrically tapering from the center to the edges, an absorbing load placed directly short-circuited end of the waveguide, open ring electrodes, thin compared to the operating wavelength, placed inside the waveguide on equal.

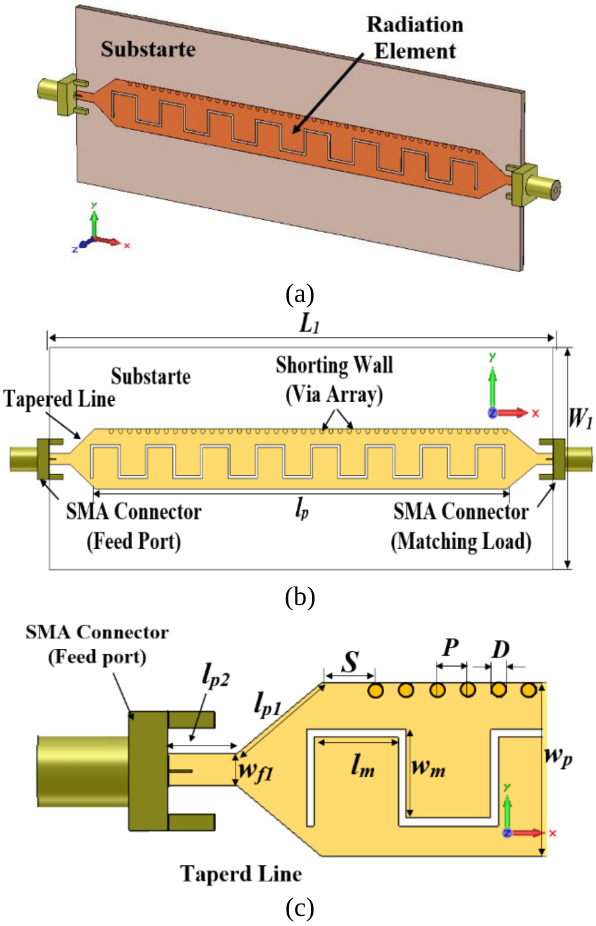

Figure 1. Half-width microstrip LWA; (a) perspective view, (b) top view matching load with slots, (c) port and slot dimensions

3. RESULTS AND DISCUSSION

The controlling of the main beam is dependent on the sweeping operating frequency. Each state of the frequency leads to change the reactance of the profile microstrip antenna, then change the phase constant of the microstrip leaky-wave antenna (half-width), which change the main beam according to (1). For example, the state 1 at 4 GHz, the main beam direction is $19^{o,}$ and the directivity is 11 dB, while state 2, when the sweeping frequency from 5 to 4.1 GHz, the direction is equal to $25^{o,}$ and the directivity is 11.5 dB. In-state 3, the directivity is increased when the operation frequency increased. Also, the radiation pattern direction is 29^{o}. The state 4, 5 and 6, the directivity increased with the operating frequency [28], [29]. In-state 7, the directivity was decreased because the radiation power loss in the endfire of the microstrip line is evident in Table 1 and Figure 2. An etched slot has been placed in the HW–MLWA radiation element for realizing a wideband antenna. The slots have a negligible effect on the radiation pattern and do not raise the antenna size. The slot shape and position have to be appropriate on the LWA. Hence, the meandering slot equivalent circuit has inductance, and it is a series joined to another shunt inductance.

Table 1. Selected seven case of sweeping frequency

State No.	Sweeping operating frequency (GHz)	Main Beam Direction (Degree) without meandering slots	Main Beam Direction (Degree)	Directivity (dB) without meandering slots	Directivity (dB)
1	4	17^{o}	19^{o}	10	11
2	4.1	22^{o}	25^{o}	10.3	11.5
3	4.2	25^{o}	29^{o}	11	12
4	4.3	27^{o}	30^{o}	11.4	12.6
5	4.4	29^{o}	33^{o}	11.9	13
6	4.5	35^{o}	39^{o}	12.4	13
7	4.6	41^{o}	45^{o}	11.9	12.4

In Figure 3, the radiation pattern (main beam direction) of state 1 and 2 are 19° and 25° respectively. The simulation result according to H- plane and the phi is equal to zero. When microstrip LWAs are designed by analyzing the complex factors of characteristic impedance input, all the value of these parameters depends on the antenna's reactance profile.

The optimum values of parameter antenna by using the parametric study method. In-state 6 and 7, the radiation pattern is 39° and 45°, respectively. The primary factor of the microstrip line is complex propagation constant change by changing the reactance between microstrip patch and ground plane. The electromagnetic file becomes zero between the patch microstrip line of the proposed antenna and the ground plane, that's means the antenna working in the first higher-order mode. The vias make a short circuit between the patch microstrip line of the leaky-wave antenna and the ground plane. According to phase constant, when getting the similar reactance of two cases that means to get the same main beam direction according to phase constant [30]-[33]. Each slot in the microstrip line led to increasing in the electric field then led to increasing the gain of the proposed antenna [34]. In Figure 4 the simulation of realized gain with the main beam direction-the recognized gain decrease when the operation frequency increase. The maximum realized gain at 4.4 GHz is equal to 13 dB, and the minimum gain is 11 dB at 4 GHz. In Figure 4 the realized gain decrease with an increase in the degree of main beam direction. The electric field of the microstrip leaky-wave antenna is decreased in endfire, leading to reduced radiation power.

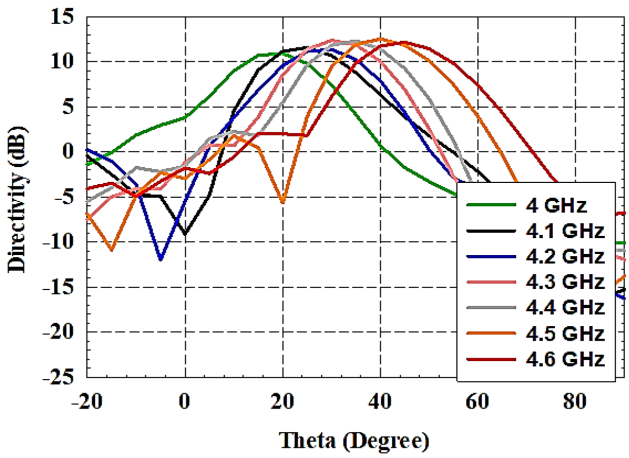

Figure 2. Directivity of suggested antenna with the main beam direction when sweeping frequency between 4 GHz to 4.6 GHz

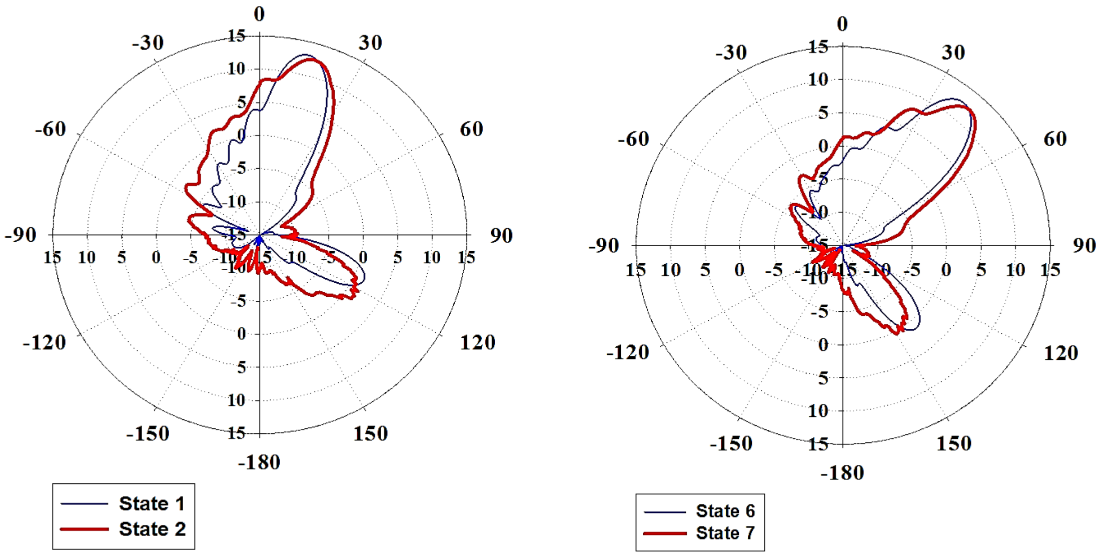

Figure 3. Radiation patterns of the proposed antenna on the H-plane (x-z plane) for states 1, 2, 6, and 7 (Phi=0)

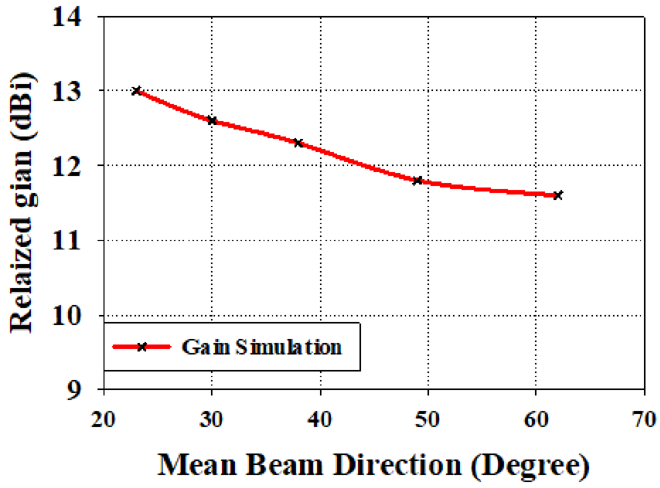

Figure 4. Simulated of proposed antenna gain of the half width microstrip LWA

The cross-polarization has been increased when the beam scans were neared to endfire [35], and beyond it to the forward direction, as shown in Figure 5. It is a central problem of a uniform HW-MLWA1 without using any slots. The radiation of the microstrip line is polarized in the x-direction, while the polarization in the y-direction is for the radiation of the uniform HW-MLWA1 in the free edge. So, it is necessary to find an appropriate way to reduce cross-polarization while keeping the distance between slots. For minimizing the cross-polarization, a slop shaped slot has been added periodically as the meandered square. The cross-polarization level of uniform HW-MLWA1 and periodic HW-MLWA2 at state 1 are –9.45 and –16.21 dB respectively, when the main lobe points close to the broadside. As a result, the maximum realized gain is equal to 13 dB for the beam direction at 33. Thus, the radiation efficiency of microstrip LWA is changing in changing the direction of the main beam. In Figure 6, the maximum value of radiation efficiency has been achieved if the main lobe direction is close to broadside. However, the efficiency is decreased when nearing the main lobe to the endfire, which means the electromagnetic field is attenuate near the endfire.

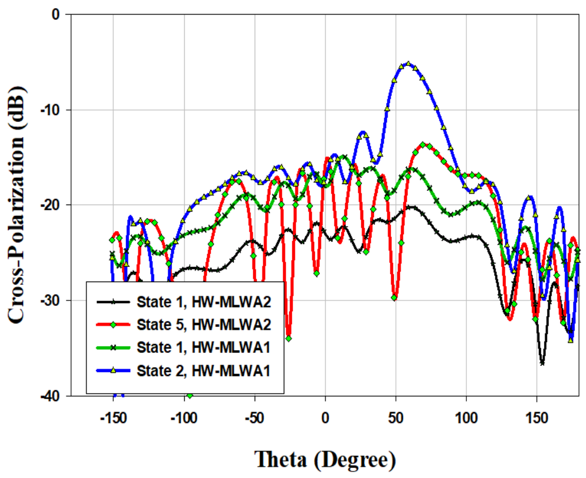

Figure 5. Cross polarization for the HW–MLWA1 and HW-MLWA2, concerning co-polarization level

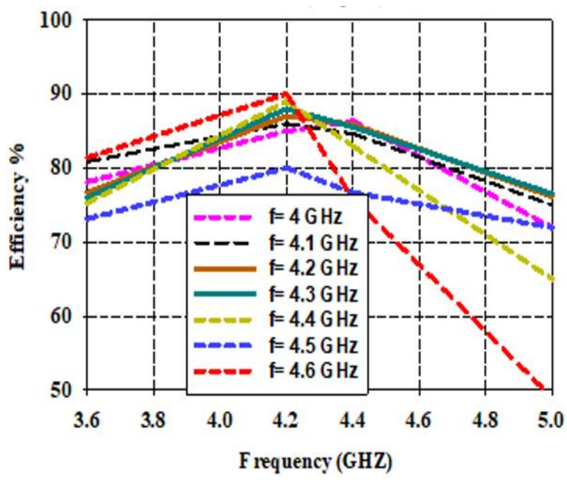

Figure 6. The efficiency of the suggested antenna for the seven states at 4.2 GHz

4. CONCLUSION

The practical phase constant in the half-width microstrip leaky-wave antenna is changed by changing the reactance profile of the microstrip antenna due to altering the operation frequency. The radiation power is increase by increasing the electric field in the endfire. The realized gain increase near broadside, the maximum value is 13 at 33^{o}, and its decrease at endfire is equal to 11 dB at 4 GHz. The controlling radiation pattern by sweeping the frequency between 4 GHz to 4.6 GHz led to main beam direction scanning between 19^o to 45^o. The proposed antenna is a non-reconfigurable periodic structure by using the unit cell is contain slots technique. The slots technique led to an increase in the electric field in the microstrip line, increasing the radiation power in the endfire. Thus, the proposed design provided control of the radiation pattern in the C band application.

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