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Enhancement of elevation angle for an array leaky-wave antenna

Abstract. *A new design for array leaky-wave antenna to achieve high elevation angle and obtain high radiation pattern on boresight is proposed in this study. Two half-width microstrip leaky-wave antennas are placed horizontally and used one fed probe between them. The other side of the half-width used lumped element (matching load 50 ohm). An array of vias was used to connect the radiation element with the ground plane to make the microstrip line work in the first high order mode. The main beam direction can be changed by control the reactance of the microstrip line with the free edges of radiation elements and the ground. This controlling led to the use of two vertical vias array alone the radiation element of each antenna. The simulated result produced a high matched bandwidth of the array of 800 MHZ (4.2- 5) GHz. The direction of the main beam scanning towards in boresight with maximum gain 12.9 dBi. The elevation angle can be scanning between 22^o to 65^o. The proposed antenna is promising to the C-band applications.*

Streszczenie. W opracowaniu zaproponowano nowy projekt anteny z falą wyciekającą w celu uzyskania dużego kąta elewacji i uzyskania poprawy charakterystyki promieniowania podczas celowania. Dwie mikropaskowe anteny z falą wyciekającą o połowie szerokości są umieszczone poziomo i umieszcza się między nimi jedną sondę zasilaną. Druga strona półszerokości zastosowano pasujące obciążenie 50 omów. Do połączenia elementu radiacyjnego z płaszczyzną uziemienia zastosowano szereg przelotek, aby linia mikropaskowa działała w pierwszym trybie wysokiego rzędu. Kierunek wiązki głównej można zmienić, kontrolując reaktancję linii mikropaskowej ze swobodnymi krawędziami elementów radiacyjnych i uziemienia. To sterowanie doprowadziło do użycia dwóch pionowych szyków przelotek, które same stanowią element radiacyjny każdej anteny. Symulowany wynik dał wysoką dopasowaną przepustowość macierzy 800 MHz (4,2-5) GHz. Kierunek skanowania wiązki głównej w kierunku celownika z maksymalnym wzmocnieniem 12,9 dBi. Kąt elewacji może być skanowany w zakresie od 22o do 65o. Proponowana antena jest obiecująca dla zastosowań w paśmie C. (***Zwiększenie kąta elewacji dla anteny z falą wyciekającą***)

Keywords: Leaky-wave antenna (LWA), HW-MLWA, Control cell, Radiation pattern, Gap capacitor.
Słowa kluczowe: antena mikrofalowa, kąt elewacji

Introduction

The microstrip line leaky-wave antenna has been an attractive choice since 1970 [1] due to its ease of fabrication, low planer profile, high gain, low cost, and comprehensive capabilities of beam scanning [2]. The leakage of microstrip leaky-wave antenna from higher-order mode starts to study in 1980 [3]. The radiation pattern on the boresight of the planar low-profile leaky-wave antenna makes it a suitable choice for researchers and designers. The beam scanning ability of LWAs makes them an appropriate choice for several uses like multipoint communication and radar applications [4]-[7]. Many kinds of LWAs were designed to control the radiation pattern by altering the operation frequency [8]-[16]. The main lobe direction of a leaky-wave antenna is offered by [8], as given in the equation below:

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

The free space wavenumber is k_o, θ(f) is the angle, and the phase constant is β. By altering the reactance profile, the direction lobe can be changed due to altering the effective β [9]-[14]. The characteristics of the microstrip line in the fundamental mode does note any electric field radiated between the patch element and the ground plane. In order to radiate the electric fields, need to introduce the conducting wall between the microstrip patch and ground along the edge of the radiation element (microstrip line) by using the array of vias, so this conducting wall forcing the microstrip line to work in the first higher-order mode, then the electric field radiating in far-field on boresight. However, the radiation on boresight is complicated to achieve in a uniform leaky-wave antenna. The research community attractive attraction of leaky-wave antenna radiate on boresight because of the limitation of uniform microstrip leaky-wave is radiated on boresight. However, the researchers in [15-18] proposed a dual-beam antenna using a single radiation element with CPW fed. This antenna has narrow beam scanning on boresight at a lesser frequency and a wide elevation angle at a higher frequency. Achieving wide beam scanning of half-width microstrip LWA by utilizing some technique of double gaps capacitor, this antenna can be controlling the radiation pattern on boresight by using switch diodes is connecting the microstrip patch with the ground plane by an array of vias [19]-[21]. The authors in [22] proposed a new design for half-width LWA for steering on boresight for two main beams, and this design used the array of vias located on the middle of the proposed antenna. The main beam on boresight can be controlled in a microstrip leaky-wave antenna using the capacitor lumped element it put between the radiation element and the ground plane and connected by using the switch. However, the proposed design in [23] used two feed points on the edge of the microstrip line with T junction divider power and the main beam steering by changing the fed point of the proposed antenna. The main beam can be scanning wide elevation angle with high gain at high frequencies.

In this paper, a new array design of two elements of microstrip leaky-wave antenna is presented to radiate on boresight and scanning the primary beam by changing the operating frequency with a wide elevation angle and high gain. The proposed design used the power divider between two elements and fed from one side. The last used the matching load of 50 ohms to match characteristic impedance between the radiation and the ground. The proposed antenna is simulated using a microwave CST program.

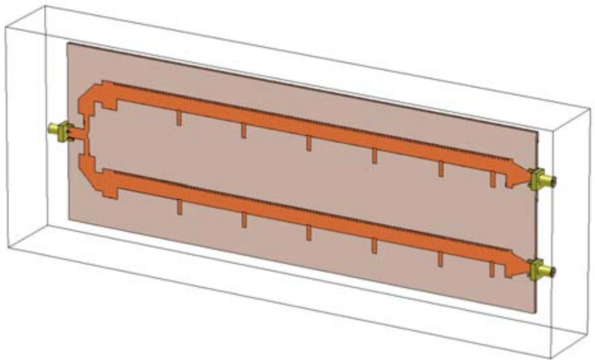
Antenna configuration

The new design array of LWA with rectangular cells for increasing the electromagnetic fields on the edge of the proposed antenna is shown in Fig. 1 (a), (b). This array is constructed on a substrate of RT5880 Rogers, with tan δ of 0.0009, εr=2.2, and substrate height (h), width (W), and Length (L) are 1,585 mm, 39 mm (0.598λ_o), and 240 mm (3.42λ_o), respectively. The proposed new design of array is fed from one side of microstrip line by SMA connector with standard commercial dimension and the former of microstrip line terminated by matching load 50 ohm in order to attenuation of reflecting wave and achieve the excellent matching impedance of the profile antenna as demonstrated in Fig. 1(c), and Fig. 1(d). The length (lp) of the microstrip line is 213 mm, and the width (wp) is 10 mm. By using the microwave CST program. The better values for the length (L4 = 3.4 mm) and width (L6=3.5 mm) of the feed end. Using the array of vias along the edge of the microstrip line to avoid the propagation of the fundamental transversal electromagnetic (TEM) and then to connect with the ground plane. The major aim of these vias for supporting the first higher-order mode propagating [24-26]. The proposed antenna has been presented to shorten the edge to applied 120 vias. The distance (S) and diameter (d) can be designed using the rules in the below equation [27].

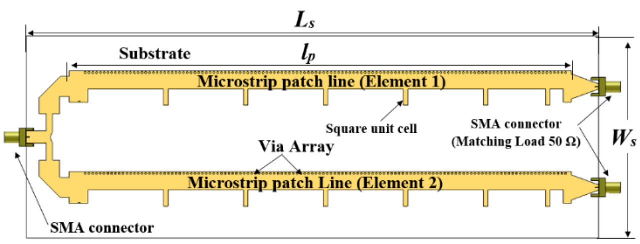
(2) $$d>0.2\lambda_o \quad ,d/S\leq 0.5$$

The space between the vias (S=1.4 mm) and vias diameter (d) is 0.9 mm. Therefore, the distance between the first via and feed is (n=3.8 mm), as shown in Fig. 1(c). these distances are wanted for improving matching impedance [28]-[32].

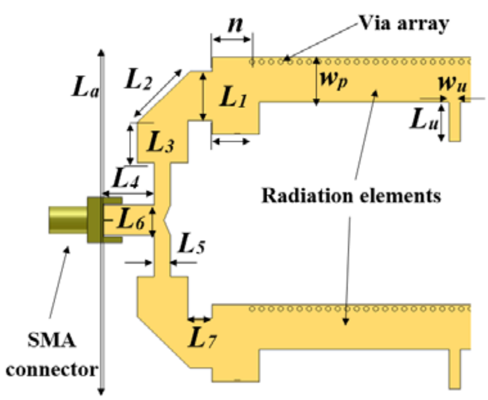
The edge of the microstrip line has six equidistant rectangular unit cells with (wu =4 mm) and (lu =10.8 mm), and the space between each of them is 28mm.



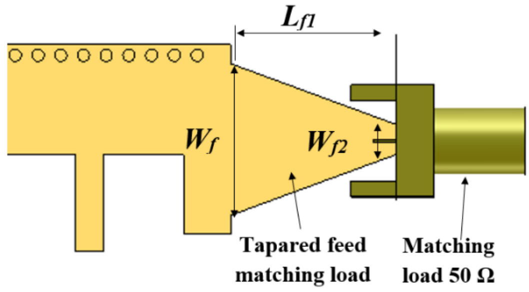
a)



b)



c)



d)

Fig. 1. Uniform LWA array: a) perspective view, b) top view, c) matching load with the rectangular unit cell, d) feed line with the port.

A 90° bend adds lower capacitance in the transmission line, as shown in Fig. 2. At the same time, some of the capacitance can be eliminated using equations (3-5) to mitring the bend. If the frequency was more than1 GHz, the power divider in the proposed array needs a V groove to avoid reflected in some power. We are using equation (6) to achieve the groove angle.

(3) $$M = L_5\sqrt{2}$$

(4) $$N = M\left[0.52 * 0.65e^{(-1.35*\frac{L_5}{h})}\right]$$

(5) $$P = \left\{N - \left(\frac{M}{2}\right)\right\} * \sqrt{2}$$

(6) $$\theta_{T\,junction} = tan^{-1}(\frac{L_5}{L_6})$$

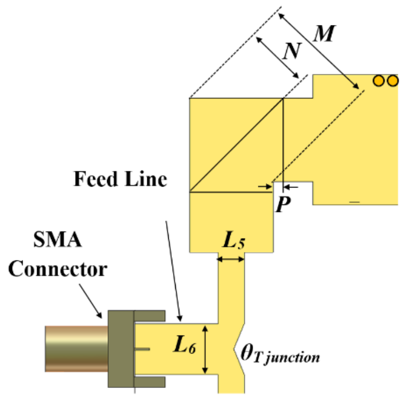


Fig. 2. A 90° bend in the transmission feed line.

Results and discussion

The array leaky-wave antenna radiation is verified for five values operation frequencies as in Table 1. Fig. 3 shows the switch arrangements in the frequency of 4.2 GHz. The beam radiation can be varying from +22^o to +65^o in discrete steps by changing the operation frequency. The altering of operating frequency leads to the variation in the reactance between the ground plane and the radiation microstrip elements. The main lobe direction has been changed with each new phase constant (β).

The realized gain has been decreased if the main beam is near the endfire due to the weak efficiency of radiation at the endfire for microstrip leaky-wave antenna. From Table 1, the gain alteration is 1.36 dB, and the ranges of scanning are from +22^o to +65^o. The side lobes level is increased at higher frequencies [33]. In contrast, the side lobe is reduced at low frequency, especially in scanning the beam at broadside direction due to the high radiation pattern efficiency.

Table 1: Main lobe scanning at 4.2 GHz for different cases.

State No.	Operation frequency	Direction of lobe (degree)	Gain (dB)
1	4.2	+22	12.9
2	4.4	+27	12.8
3	4.6	+44	11.9
4	4.8	+60	11.8
5	5	+65	11.54

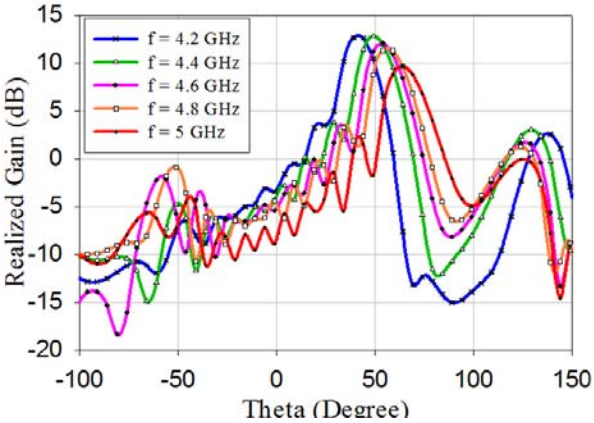


Fig. 3. Realized gain of the proposed antenna with main lobe direction.

The direction of the main beam (θm) alters with each operating frequency. The main factor that should be considered is the propagation constant, which is counted by using k=β-αj [34]. The direction of the main lobe in the leaky wave array is correlated to β as in equation (1). From the radiation for all cases of different operating frequency, the higher capacitance and a more negligible reactance simultaneously result in smaller capacitance and more significant reactance for the radiation directed away from endfire. Moreover, this situation leads to the understanding that rectangular cells have a comparatively smaller effective 1β at high frequency than effective 2β. Fig. 4 shows the radiation efficiency of the proposed antenna for different beam direction at varying operating frequency.

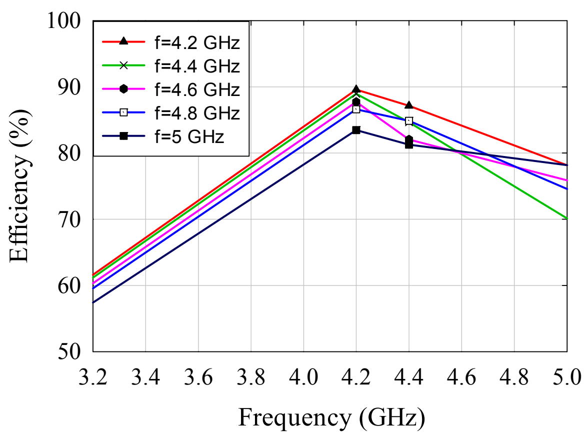


Fig. 4. The radiation efficiency of the array LWA for different operating frequencies.

The reflection coefficient in terms of S11 for the uniform array leaky-wave antenna is shown in Fig. 5. The proposed array antenna has (S11) less than -10 dB at 4.2 GHz for all cases. Also, it is possible for steering the beam in the different frequencies. Any altering in the frequency will change the reactance profile of the microstrip line, and then the impedance bandwidth was altered for each state. For example, the case of 4.2 GHz has a wide bandwidth due to reduced characteristics impedance in the array antenna edge. While in the case of 5 GHz, the impedance is high on the array antenna edge, which resulted in narrow bandwidth.

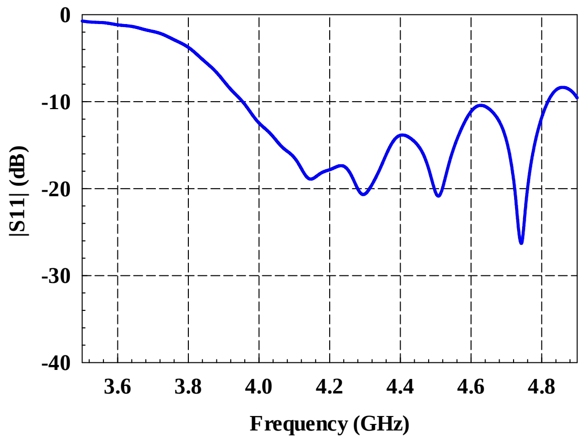


Fig. 5. |S11| proposed array leaky-wave antenna.

Fig. 6. Shows the radiation simulated results for uniform array antenna x–z-plane. The main lobe is steered in separate steps from +22° to +65° by changing the operation frequency. The main lobe direction at 4.2 GHz lies near the broadside (+22°), while the main beam direction is +65° at 5 GHz.

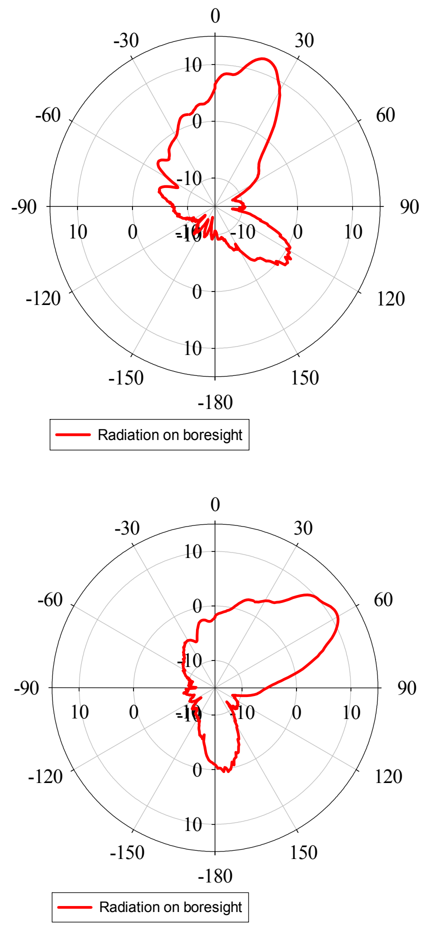


Fig. 6: Simulated radiation pattern of the non-reconfigurable array on the x-z plane at 4.2 GHz and 5 GHz.

The gain for all cases has been listed in Table 1. At higher frequency, the gain is low because of the weak impedance matching and also due to the high side lobes. Fig. 7 shows the stable gain for the proposed array antenna within a good range of scanning. The antenna has a peak value of gain (12.9 dBi) at 4.2 GHz. While the minimum gain is equal to 11.54 dBi at 5 GHz, and the other range for gains varying between (12.9 and 11.54) dBi. Moreover, the main lobe direction of the antenna has only 1.3 dB variation between the minimum and maximum gain. Additionally, the beam scanning range from +22^o to +65^o.

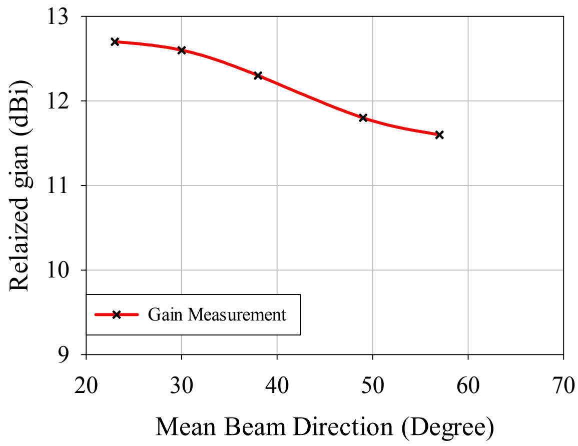
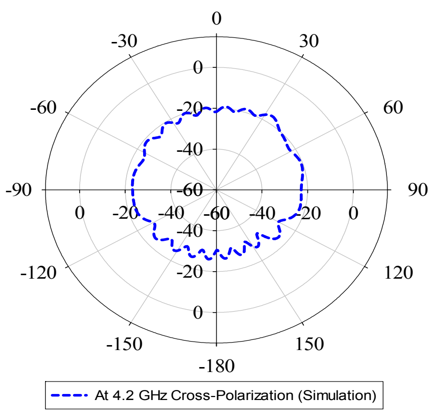


Fig. 7: Simulated gain of the uniform array antenna.

Cross–polarization is increased if the beam is directed from the broadside to the endfire side [35]. In the leaky wave array structure, the polarized is in the y-direction. Moreover, the gap between each two rectangular unit cells is polarized in the direction of x–y. The cross-polarization and weak radiation in the endfire cause the degradation in the gain. Use of the extended Hansen–Wood (H-W) is one of the potential solutions for the weak radiation in the endfire of the leaky-wave antenna to maximize the directivity of endfire [36]. The proposed antenna length is constant, and the configuration of the rectangular cell in the microstrip line has been developed periodically to decrease the cross-polarization in the patch edge. The slot dimensions were calculated and optimized by using the CST program for achieving a similar operating frequency. The simulated cross-polarization level is –18 dB at 4.2 GHz, and for 5 GHz is –16 dB, as can be seen from Fig. 8. The cross-polarization is increased when the main lobe scans from the broadside, where the lower frequencies move forward at higher frequencies.



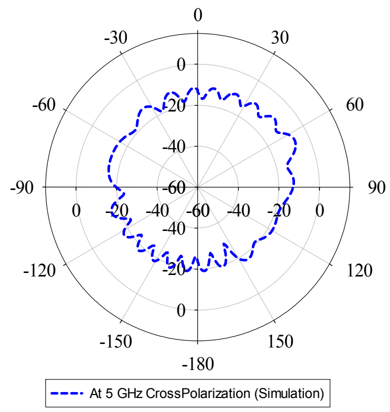


Fig. 8: Simulated Cross–Polarization of the non-reconfigurable array on the x-z plane at 4.2 GHz and 5 GHz

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Conclusion

In this work, a new design for improvement of elevation angle (scanning range) in the uniform leaky-wave antenna array at a varying operation frequency from (4.2 to 5) GHz is presented using the rectangular unit cell. The beam scanning has been achieved without using the lumped capacitors. Two half-width microstrips leaky-wave antennas are placed horizontally. An array of vias is used to connect the radiation element with the ground plane to make the microstrip line works in the first high order mode. The simulated resulted high matched bandwidth of the component of the array 800 MHZ (4.2- 5) GHz. The direction of the main beam scanning towards in boresight with maximum gain 12.9 dBi. The elevation angle can be scanning between 22^o to 65^o. The proposed antenna is promising to the C-band applications and also the concept of leaky-wave can be applied for Ultrawide band to enhance their radiations [37]-[39].

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