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Enhancement of boresight radiation for leaky wave antenna array

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Abstract

An array of half-width microstrip leaky-wave antennas (HW-MLWAs) of two uniform elements was designed to obtain maximum boresight radiation. Achieve this, two uniform of HW-MLWAs are placed at 180◦ and fed by a probe located at the center between the elements, two uniforms of HW-MLWAs, loaded terminated by 50Ω lumped element. Two beams from two branches individual merge to form the resultant directive beam. The simulation represents the susceptibility of the proposed array of uniform HW-MLWAs to the radiation broadside direction effectively. The predict bandwidth matched of the array is 582 MHz (4.18–4.76 GHz). The direction of its main beam in boresight happens over a wide 13%, relatively (4.18-4.76 GHz) band. The proposed peak gain at the boresight direction of the array is 9.91 dBi.

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

1. Introduction

Leaky wave antennas (LWAs) are a class of traveling-wave antennas (T-WA) characterized by a wave propagating along a structure that is long compared with the wavelength. They are very similar to surface-wave antennas [1]. Like most T-WA, leaky-wave antennas are long in the propagating direction and possess a cross-section with dimensions on the order of the wavelength of operation. A characteristic feature of these antennas is that the electromagnetically field is exciting by a wave which is incident on the interior or on the exterior of the guiding structure which produces currents that propagate along its longitudinal direction. When transmitting, the input traveling wave, often a fast wave, progresses along the guide and leaks out the energy of the structure, so that only a negligible field is left at the termination end of the traveling-wave antenna [2-7].

Microstrip leaky wave antennas (MLWA) have been considered since the latest 1970s [8] also, spillage from higher order modes of lines microstrip was clarified in detail in the mid-1980s [9]. Microstrip leaky wave antennas (MLWAs) are alluring because of their planar is low profile arrangement, the simplicity of fabrication, and inborn pillar examining capacities [10]. The fundamental mode of higher order for a microstrip line does not radiation as the electric field is unequivocally joined between the ground and the microstrip, however some higher request modes radiation as leaky waves. By using a conducting vias array as well along with an edge of the microstrip line in order to make an electric field null at the edge, this way lead the microstrip line to work in the 1st higher-order mode, designing this way is called HW-MLWAs [11, 12]. Much research has been directed on MLWAs [2, 13]. The main beam direction of the MLWA is given by [14]:

$$\theta(f) = sin^{-1}\frac{\beta(f)}{k_0(f)} \qquad (1)$$

where k_o is the free-space wave, β is the constant phase number, and $\theta(f)$ is the angle from the perpendicular direction of boresight. In this state, the boresight is the direction to

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the substrate plane. The direction of main beam dependent on the phase constant β and the formal beam width dependent on the attenuation constant [15]. The main beam of uniform LWAs has been the steering between near endfire direction at higher frequencies and steered near boresight direction at lower frequencies where boresight, in this case, is the perpendicular direction to the array plane. Be that as it may, it has been discovered amazingly hard to accomplish a boresight main beam from a uniform LWAs Consequently this constraint of uniform LWAs to radiation towards boresight has pulled in enthusiasm from the exploration group [16].

An assortment of research has been led to influence the leaky wave to radiate at the boresight direction. The antenna has dual beam made out of a solitary microstrip line with the coplanar waveguide (CPW) nourish at the focal point of the microstrip antenna was proposed in the late 1990s [17]. This type of antenna can deliver boresight the main beam at the low frequency with a narrow beamwidth in the plane of the elevation and wide beamwidth in the azimuth plane. At high frequencies, it gets a double beam antenna one at the forward direction and another beam is backward direction. Two straightly enraptured full-width LWAs, each feed at the two closures, are put orthogonal to each other in the middle, to create a circularly captivated boresight polarized [18]. A spiral array exhibit made out of eight substrate integrated waveguides (SIWs) on a solitary substrate was shown to deliver radiation boresight [19]. Operational at direction broadside heading is gotten by the so-known part condition, happening when the leaky mode stage and spillage constants are equivalent ($\beta/k_o=\alpha/k_o$) and the MLWA is symmetrically encouraged [20]. a circuit model of LWA that is related to the model of the Menzel HW-MLWA in Figure 1 (a). Dielectric-filled parallel plate waveguide can be modelled as a of admission Y_{01} ended at one end by a short circuit and the other end by admission Y_t, see Figure 1 (b). The E null produced in the EH1 mode by vias is represented by a inductance or short circuit. The transverse resonance relative [21].

$$\Gamma_{left}(y).\Gamma_{left}(y) = 1 \tag{2}$$

The reflection coefficient Γ due to the admission of the edge of the microstrip patch antenna Y_t is unity with a phase shift P. Referring to Figure 1 (b), at a point $y = y_a$ just to the right of Y_t

$$\Gamma_{left}(y_a) = e^{jp} \tag{3}$$

$$\Gamma_{right}(y_a) = -e^{-j2kw/2} \tag{4}$$

where k=β-jα is the complex wave number in the substrate and w is the width of the structure. In (4) becomes:

$$-e^{j(p-kw)} = 1 \tag{5}$$

$$p - kw = \pm z\pi \quad \text{z=1,2,3......} \tag{6}$$

z=1 for EH1 mode:

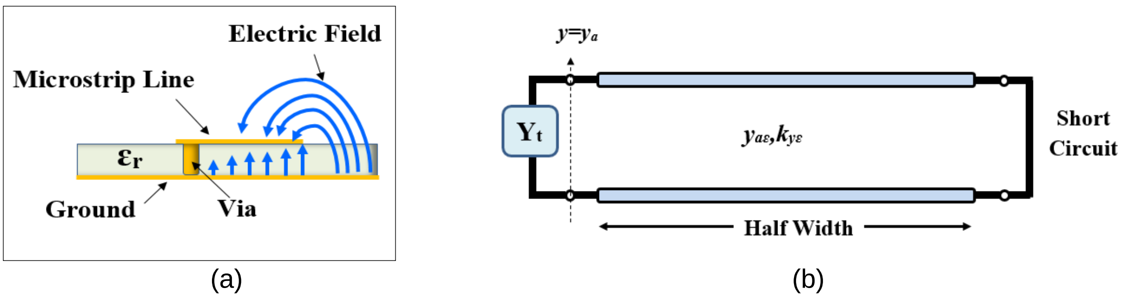

Figure 1. Menzel circuit model:
(a) Cross-sections of Menzel of HW-MLWA (b) equivalent circuit

This paper presents a novel design of an uniform HW-MLWAs array cluster made uncommonly to acquire boresight radiation over a wide bandwidth. Two HW-MLWAs elements are set at 180° displacements angular used to create the array and it is fed by a solitary probe at the center between two components.

2. Antenna Configuration

The proposed uniform array HW-MLWAs is shown in Figures 2 (a) and (b) represents the top view, and fed point with a matching load, respectively. Two HW-MLWAs elements are designed with 180° angular. The entire structure is on a solitary layer substrate Rogers RT5880 the and tanδ=0.0009, dielectric constant εr=2.2, with a height of substrate (h) of 1.575 mm. The width (W) and length (L) of the substrate are (3.234λ0) 231 mm, (0.658 λ0) 47 mm respectively where λ0 is the free space wavelength calculating at 4.2 GHz. The width (wp) and length (lp) of the radiating element is (1.54 λ0) 110 mm and (0.157λ0) 11.2 mm, respectively. The width (wf) and length (lf) of the radiating element end are (0.0.077 λ0) 5.5 mm and (0.075 λ0) 5.4 mm, respectively as shown in Figure 3 (a). The same dimension's feeder is used for the output ports of the antenna. The other output ports of the LWAs are terminated by using 50Ω lumped element loads as represented in Figure 3 (b). A gap (S = 0.6 mm) is the end of the feed line and the center of first via. The number of total vias is 70 vias in each element to connect between the ground and radiation elements. The metalized via holes diameter and distance between two vias adjacent can be calculated using the design rules from (7)

$$D > 0.2\lambda_0 \ , \ D/P \leq 0.5 \quad (7)$$

where D via hole diameter, λo free space wavelength and P is the distance between two adjacent vias. Referring to (7), the diameter of all vias is 0.8 mm and the distance between two adjacent vias, P is 1.5 mm, the radius of probe feed, R_f is 0.64 mm is used to feed the array at the center. This lumped element loading at output ports in order to prevent the reflected waves [22, 23].

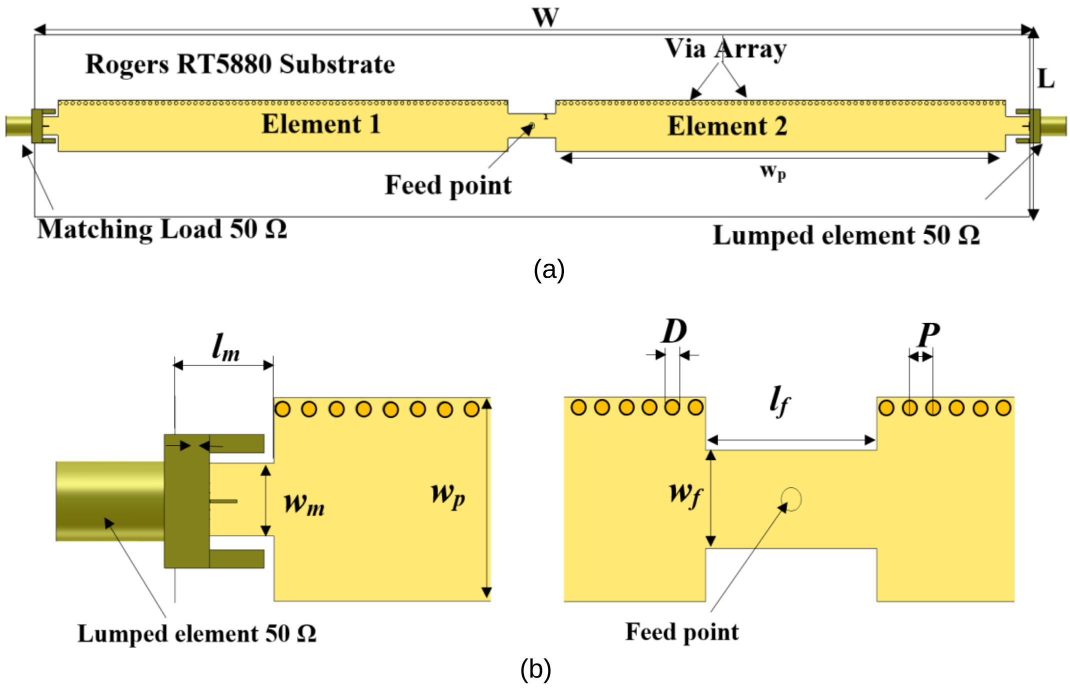

Figure 2. Proposed HW-MLWA array: (a) top view (b) feed point and matching load

3. Antenna Optimization

For planning of the design for the array half HW-MLWA exhibit the optimum estimation of every parameter for matching array antenna with all elements at the range frequency, parametric examinations were done utilizing CST Microwave Studio. The variation of substrate material with the reflection coefficient that shows in Figure 3 The dielectric constant steady at higher frequency laminates of Rogers RT5880 is the lowest of all items of substrates, and low dielectric misfortune influences them to appropriate for high frequency/wide band applications where scattering and misfortunes should be limited. A characteristic feature of these antennas is that the electromagnetically field is exciting by a wave which is incident on the interior or on the exterior of the guiding structure which produces currents that propagate along its longitudinal direction. leaky wave modes propagation energy along the longitudinal bearing in the dielectric substrate, with just the misfortunes and to be identified with the materials. the radiation pattern when used FR4 substrate is very small value and have two beam width because the mismatching between patch leaky wave antenna and FR-4 substrate.

The variation length of the substrate with the reflection coefficient that shows in Figure 4. The optimum value of the length of the substrate is λo/4 at operation frequency 4.2 GHz, because the substrate edge is effected of the antenna performance by unwanted result of cross polarization when choose the length quarter of a wavelength from the lowest frequency that is lead to not interfere the intrinsic pattern of the array antenna. The antenna is feeding on one end and the other side of end of the proposed antenna is terminated by a lumped element matching load 50Ω load to suppress any reflected wave and improvement matching impedance, see Figure 5. As shows in the figure, the reflection coefficient with matching load and without matching load, this variation of reflection coefficient with the impedance matching load dependent of (8) [24, 25]

$$\Gamma = \frac{Z_L - Z_S}{Z_L + Z_S} \tag{8}$$

where Γ is the reflection coefficient, Z_S is the impedance source, and Z_L is the impedance load.

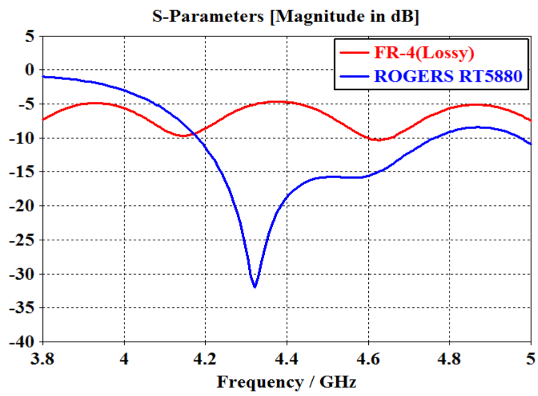

Figure 3. Variation of $|S_{11}|$ with the substrate material

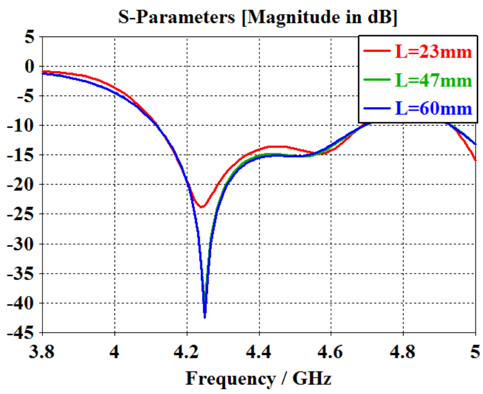

Figure 4. Variation of |S11| with length (L) of substrate

Figure 6 representing the variety of length (lp) of the radiation component with reflection coefficient parameter S_{11}. It is clearly show that the array of HW-MLWAs shift to the lower frequency when the length of the radiation component is increase, the optimum length of radiation element is (lp = 11.2 mm) at resonance frequency 4.2 GHz. Figure 7 represents the variation of reflection coefficient with (lf) length of feed point, the optimum length of feed point is (lf = 5.5 mm).

Figure 8 show that the reflection coefficient (S11) with gap S, and chose three values of S, S1 and S2, S1 = 2.1 mm when remove the first via and S2 = 3.1 mm when remove 2 vias an appropriate S is required between the end of the feed line and the center of first via to force the wave toward the microstrip edges, as well as to improve impedance matching at S = 0.6 mm.

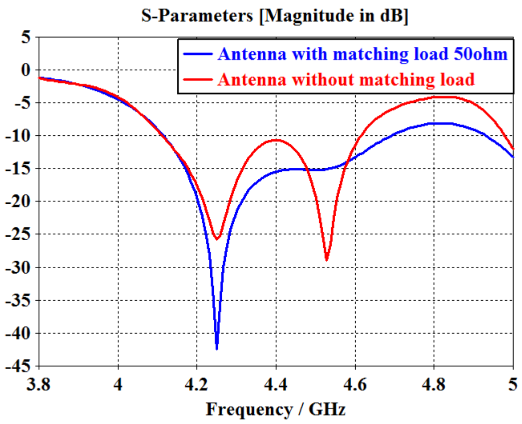

Figure 5. Variation of |S11| with matching load

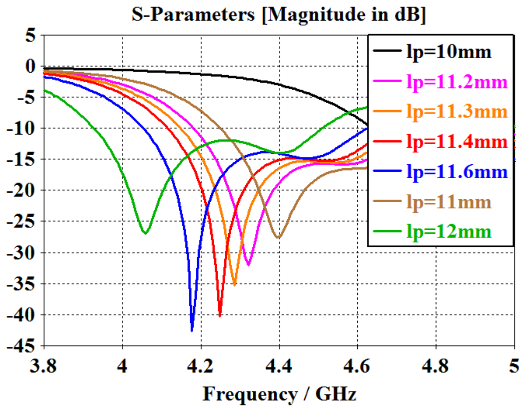

Figure 6. Variation of |S11| with (lp) length of radiation element

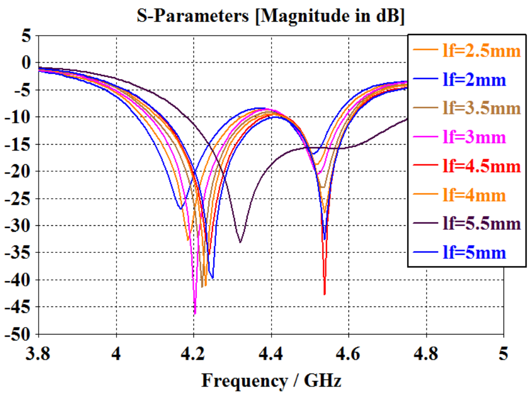

Figure 7. Variation of |S11| with (lf) length of feed point

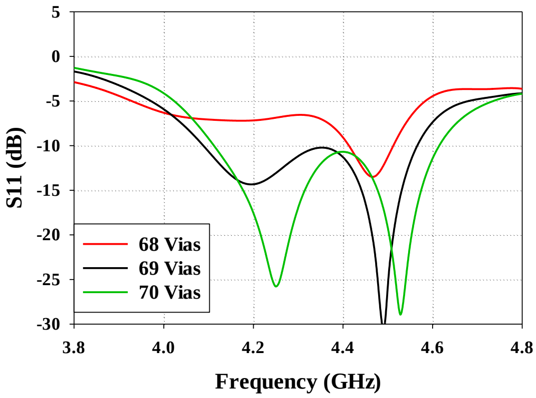

Figure 8. Variation of |S11| with the gap (S) between the end of feed line and the center of first via

4. Results & Discussion

Figure 9 shows the scattering parameters S_{11} of the array. It has a 10 dB return-loss with the bandwidth from 4.18 GHz to 4.76 GHz. Since the array is fed its center each element of LWAs, the two beams of two elements combine to produce one beam toward the boresight direction. The main beam of the leaky wave antenna in this approach radiated towards the boresight, which is given by (1). The array is contain three port left and right port is loaded by matching load 50Ω and prob fed at its center of proposed design. When the two identical beams are added together the result is a boresight beam. All the antennas radiate waves that are linearly polarized and the resultant beam is also linearly polarized. The array radiates toward the boresight from 4.18 GHz to 4.56 GHz with a gain greater than 9 dBi. Beyond 4.56 GHz the beam shifts away from the boresight. That is happened because the absolute value of propagation constant (β/ko) variation with frequency and consequently so does the main beam direction. When an increase of frequency, the main beams shifting away from the boresight direction. When the value of θ is high, the beams do not form a single beam on boresight. The peak gain within the boresight beam radiation band is 9.91 dBi and the bandwidth of the array is 482 MHz (4.18 GHz to 4.76 GHz). Although the return loss of the array is less than -10 dB below 4.25 GHz the array still radiates towards the boresight with a gain greater than 9 dBi. Figure 10 represents the 3D radiation pattern of the antenna at 4.2 GHz. The radiation efficiency of the HW-MLWA array is greater than 86% over the 3dB gain bandwidth. Above 4.2 GHz total efficiency is more than 85%. However, the total efficiency is lower at lower frequencies; for example, at 4.1 GHz and 4.18 GHz it is 63% and 52%, respectively, due to the poor impedance match at these frequencies.

Figure 11 demonstrates the deliberate E-plane standardized radiation pattern at 4.2 GHz. The main beam deliberately indicates towards boresight from 4.18 GHz to 4.3 GHz. In this HW-MLWA array, radiation waves are spellbound in the y-direction. Henceforth, the resultant radiating in the boresight course is a polarization in ϕ=0◦ direction, where ϕ is measured from the x-axis. It can be seen that the radiation pattern is symmetrical. This is because of the asymmetry rotational geometric of the structure, the value of deliberate sidelobe level is equal to -13.9 dB, yet as the increase in frequency, the side lobe level also increasing. It is pertinent to take note of that regardless of the debasement of side lobe level, the radiation pattern of the main beam still boresight towards at 4.56 GHz. With the increasing of frequency, the main lobe from each branch controls facilitates far from boresight. This is the purpose behind the corruption of side lobe level at higher frequency.

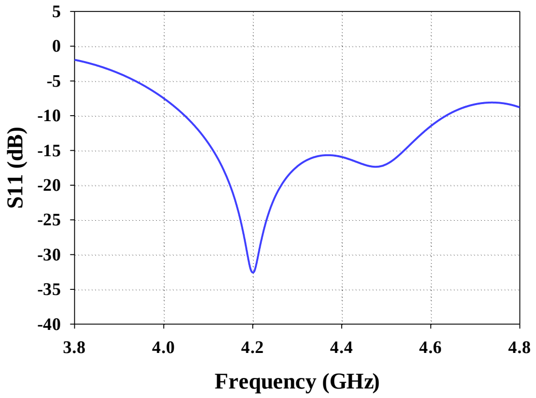

Figure 9. Predicted reflection coefficient |S_{11}| of the half-width microstrip leaky wave antenna array

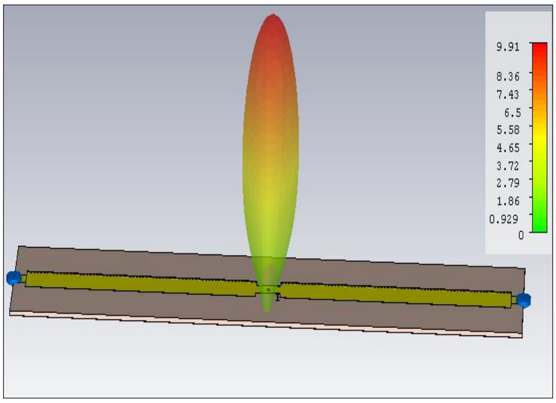

Figure 10. 3D Radiation pattern of the Half-Width microstrip leaky wave antenna array

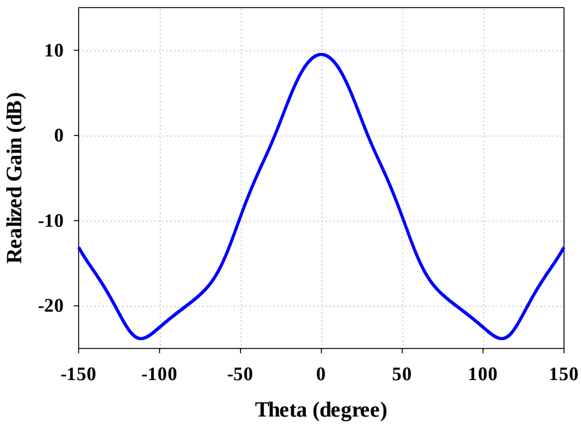

Figure 11. Radiation pattern of proposed antenna at 4.2 GHz (phi=0)

4. Conclusion

The two uniform HW-MLWAs array has been designed to achieve towards the boresight radiation for the main beam with good impedance matching. Uniform HW-MLWAs array usually radiate at a particular angle from the boresight, i.e. they do not radiate exactly at boresight. The configuration and designing of the proposed array is simple and requires only two uniform HW-MLWAs on a single feed with a single substrate. The maximum gain of the array is 9.91 dBi and the gain is >9 dBi over the band 4.18 to 4.56 GHz.

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