A Simple Single-Feed Array of Uniform Half-Width Microstrip Leaky-Wave Antennas for Boresight Radiation

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***Abstract*—A simple leaky-wave antenna (LWA) array is presented here radiates in the boresight direction. It is based on uniform half-width (HW) microstrip leaky-wave antennas (MLWAs). Uniform HW-MLWAs usually radiate a fan-shaped beam with a beam direction near boresight at lower frequencies and near endfire at higher frequencies. One of the main challenges of uniform LWAs is to make them radiate toward the boresight. Six uniform HW-MLWAs are used in this array to overcome this limitation. The whole array is on a single substrate and is fed at the centre by a single probe. The peak gain of the array is 10.9 dBi and its 3dB gain bandwidth for boresight radiation is 270 MHz.**

I. Introduction

The first leaky-wave antenna (MLWA), proposed in 1940, was based on a slotted rectangular waveguide [1], [2]. Microstrip leaky-wave antennas (LWAs) were proposed in the late 1970s [3]. Since the invention of MLWAs they have attracted considerable attention due to their planar low-profile configuration, ease of integration with microwave and millimeter-wave circuits, narrow beam, and inherent beam scanning capabilities [2], [4]. Much research has been conducted on MLWAs [5]–[12]. The direction of the main beam of a LWA is given by [13]

$$\theta(f) = \sin^{-1}\left[\frac{\beta(f)}{k_0(f)}\right], \quad (1)$$

where β is the phase constant, k_0 is the free-space wave number, and $\theta(f)$ is the angle from the boresight. In this case, the boresight is the direction perpendicular to the plane of the substrate.

The dominant mode of a microstrip line does not radiate. However, some higher-order modes are leaky waves and can radiate. A MLWA was designed in [14] considering the properties of the first higher-order mode by creating a shorting wall at the center of the microstrip. In this way the width of the microstrip also was halved. This antenna is known as a half-width microstrip leaky-wave antenna (HW-MLWA).

The main limitation of uniform LWAs, that they cannot radiate toward the boresight, has attracted considerable interest in the research community and a variety of research has been conducted to achieve boresight radiation [15]–[17]. An array of uniform HW-MLWAs is presented in [18], where one end of each mcirostrip is connected to the feed through a matching line and the other end is terminated in a 50 Ω load through a matching line of the same dimensions. A much simpler array is proposed in [19] for the same purpose, and does not require any matching line or coaxial load. Each of these arrays used four HW-MLWAs arranged at 90° angular displacement.

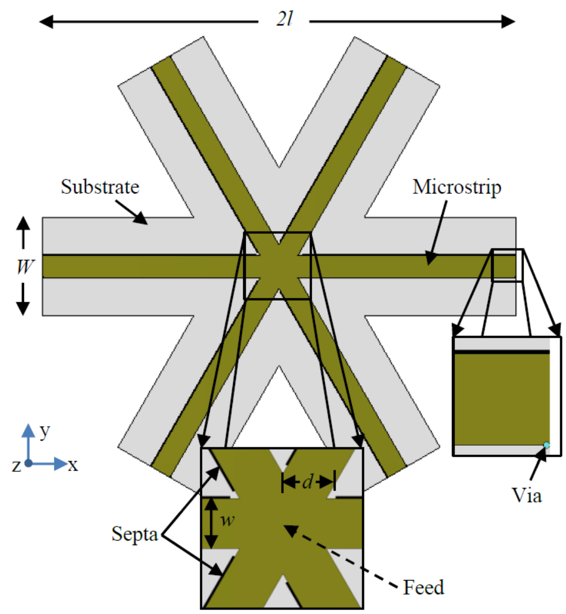

Fig. 1. Top view of the proposed uniform HW-MLWA array.

This paper presents a circular array of uniform HW-MLWAs specially designed for boresight radiation. Six microstrip lines are placed at a 60° angular displacement in an hexagonal outline arrangement around a central single probe.

II. Array Configuration

The array, shown in Fig. 1, was designed and analysed using CST Microwave Studio. The predicted 3D radiation pattern produced by the array is shown in Fig. 2. The array has been designed for fabrication on a Rogers RT5880 substrate, which has a thickness of 1.575 mm, dielectric constant of 2.2, and loss tangent of 0.0009. It consists of six uniform HW-MLWAs as shown in Fig. 1. The radius of the array is the

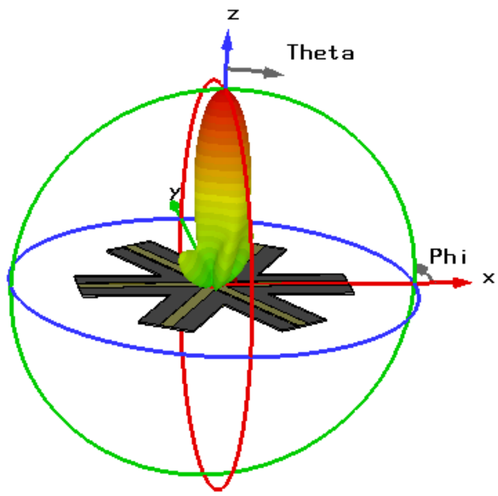

Fig. 2. 3D radiation pattern of the HW-MLWA array.

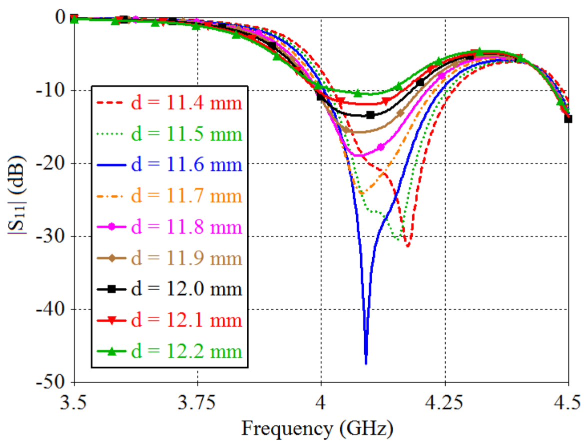

Fig. 3. Variation of reflection coefficient with the distance (d) between septa and feed point of the HW-MLWA array.

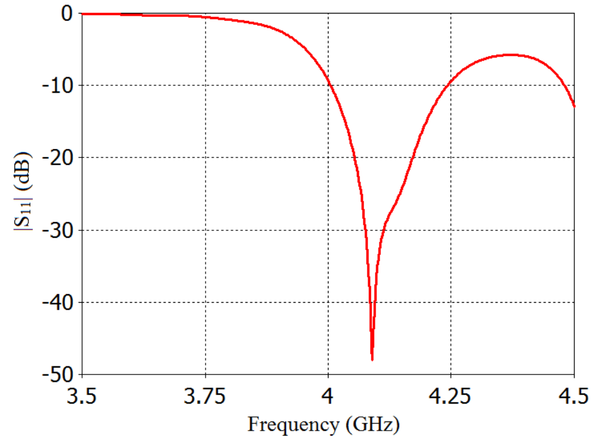

Fig. 4. Predicted reflection coefficient of the HW-MLWA array.

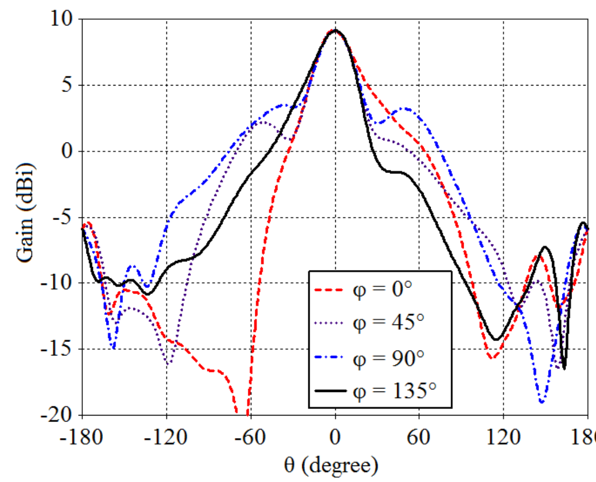

Fig. 5. Predicted radiation pattern cuts of the HW-MLWA array on constant-ϕ planes at 3.95 GHz.

same as the length (l) of the radiating microstrip, which is $1.6\lambda_0$, where λ_0 is the free-space wavelength at 4 GHz. The width of the substrate (W) and the microstrip line (w) of each LWA are $0.667\lambda_0$ and $0.1467\lambda_0$, respectively. One edge of the microstrip is shorted to the ground plane by a conducting wall (septum). The outer free corner of each microstrip is shorted to the ground plane with a via (right inset of Fig. 1) of radius 0.4 mm. The length of the septa in each case are the same, which was obtained by optimizing the input match of the array with CST Microwave Studio. Fig. 3 depicts the effect of the septa distance (d) from the centre point (feed) on the reflection coefficient of the array. For good matching, the optimum value of d was found to be 11.6 mm.

III. Results and Discussion

Fig. 4 shows the predicted reflection coefficient of the array. It has a 10 dB return-loss bandwidth from 4.005 to 4.24 GHz. Figs. 5 to 7 show radiation pattern cuts on four different 'constant-ϕ' planes at 3.95, 4.05, and 4.1 GHz, respectively. It can be seen that the array radiates a single beam directed exactly at the boresight. Since the array is fed its center each LWA produces a beam and the six beams together combine to produce a resultant beam toward the boresight.

Each LWA produces a beam at an angle to the boresight, which is given by Eqn. (1). The array is fed at its center by a single probe so all the LWAs are excited simultaneously. When the six identical beams are added together the result is a boresight beam. All the antennas radiate waves that are linearly polarised and the resultant beam is also linearly polarised. The array radiates toward the boresight from 3.92 to 4.19 GHz with a gain greater than 8 dBi. Beyond 4.19 GHz the beam shifts away from the boresight. This is because the value of β/k_0 changes with frequency and consequently so does the beam direction. With an increase of frequency the beams from individual antennas shift further away from the boresight as the angle θ increases. Due to this large θ, the beams do not form a single beam on boresight.

The peak gain within the boresight beam radiation band is 10.9 dBi and the 3dB gain bandwidth of the array is 270 MHz (3.92 to 4.19 GHz). Although the return loss of the array is worse than 10 dB below 4.005 GHz the array still radiates towards the boresight with a gain greater than 8 dBi. The gain at 3.92 GHz is 8 dBi. The radiation efficiency of

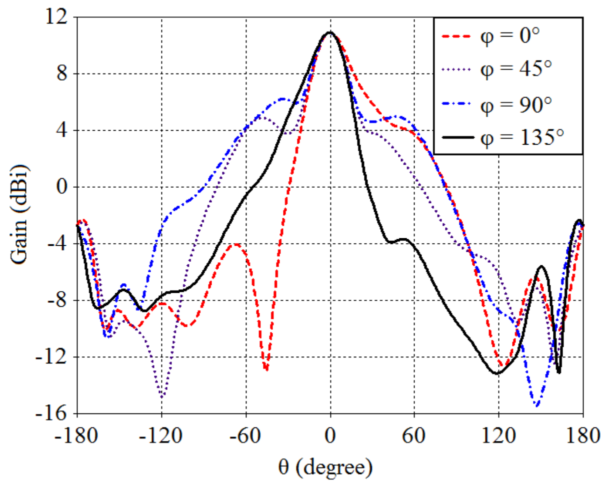

Fig. 6. Predicted radiation pattern cuts of the HW-MLWA array on constant-ϕ planes at 4.05 GHz.

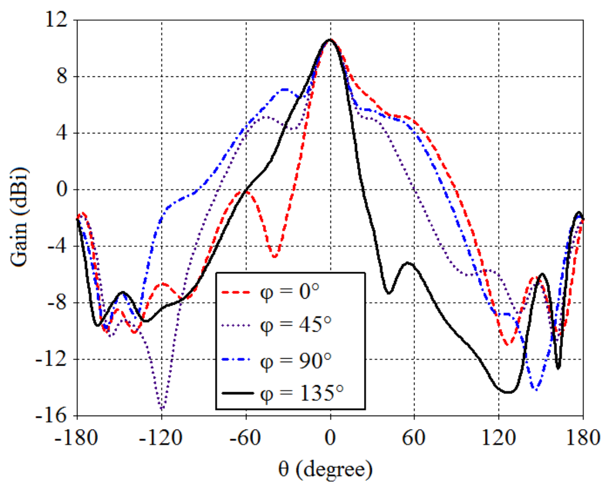

Fig. 7. Predicted radiation pattern cuts of the HW-MLWA array on constant-ϕ planes at 4.1 GHz.

the array is greater than 95% over the 3dB gain bandwidth. Above 4 GHz total efficiency is more than 85%. However the total efficiency is lower at lower frequencies; for example at 3.95 and 3.92 GHz it is 65% and 51%, respectively, due to the poor impedance match at these frequencies.

IV. Conclusion

An array of six uniform half-width MLWAs has been designed to achieve a single beam towards the boresight. Uniform HW-MLWAs usually radiate at a particular angle from the boresight, i.e. they do not radiate exactly at boresight. The configuration of the array is simple, and requires only six uniform HW-MLWAs on a single substrate with a single feed. The array provides a peak gain of 10.9 dBi and the gain is $>$ 8 dBi over the band 3.92 and 4.19 GHz.

Acknowledgment

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