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A Compact Beam Scanning Leaky Wave Antenna with Improved Performance

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***Abstract*—A compact microstrip leaky wave antenna (MLWA) with reduced side lobe level and increased linear frequency scanning capability is proposed in this article. Symmetric Yagi-like elements are introduced, which reduce the side lobe level by radiating the remaining power at the physical end of MLWA, and make the radiation plane (XZ plane) symmetric. Defected ground plane is used to optimize the working of Yagi-like elements. Measured results show that the side lobe is suppressed about 16 dB at 4.8 GHz. To further reduce the side lobe level, improve frequency scanning capability, and increase the gain., the leaky section of the antenna is tapered, and two slots of equal dimensions are introduced. The frequency beam scanning is improved compared with conventional MLWAs by achieving a total beam scan of 78° (from broadside [12°] to end fire [90°]). The measurements performed on the fabricated prototype exhibit good agreement with simulations.**

***Index Terms*—Microstrip leaky wave antenna, side lobe level, beam scanning, peak gain.**

I. INTRODUCTION

Since W.W. Hansen invented the first known leaky wave antenna in 1940 [1], it has attracted an increasing attention in the research community because of their simple feeding network, high radiating directivity, and frequency scanning capability [2]. Different types of uniform, quasi-uniform, and periodic leaky wave antennas with one-dimensional and two-dimensional radiation characteristics have been investigated and reported in literature [3]-[5]. Despite owning many advantages, LWA still faces a major problem, which is the tradeoff between the back lobe and the length of the LWA. The first microstrip leaky wave antenna (MLWA) proposed by Menzel [6] based on exciting first higher-order mode (TE01 mode) has a length of $2.23\lambda_o$ and radiates 65% of the power. The remaining power reflects from the open end of the LWA, resulting in a large back lobe. The length must be increased to $4.85\lambda_o$ to radiate 90% of the power. To radiate the power more efficiently and suppress the back lobes, the length must be increased to 5λo. The array topology in [3], suppresses back lobes up to 10.5 dB with a length of $2\lambda_o$. The back lobes are further suppressed to 15 dB, but with a length of 3λ by tapered loaded LWA [4]. By adding parasitic elements to LWA [5], the back lobes can be suppressed to 12 dB at 6.9 GHz while the length is $2\lambda_o$. All of the aforementioned designs require a large length, at least $2\lambda_o$, and complicated structure hindering their use in practical applications.

Beam steering is often required in many scenarios. It can be achieved using different antenna types, like phased arrays, and electronically steered parasitic array radiator (ESPAR); however, such structures require phase shifters or complex feeding structures. Because of their strong beam-scanning capability, different beam-scanning LWA designs have been reported in the literature [7-15].

High beam steering in Fabry-Perot leaky wave antenna is claimed in the study of Ghasemi et al [7]. Continuous beam scanning from backward to forward is realized using substrate integrated waveguide (SIW)-based LWAs [8]. A leaky wave antenna with beam steering capability based on metamaterial transmission line concept has been designed in the study of Symeonidou and Siakavara[9]. A compact bidirectional LWA based on TE20 mode SIW is proposed for operation at X-band [10]. Recently, a periodic-LWA based on SIW has been proposed for the beam scanning of circularly polarized waves [11].

In this article, our objective is to design a MLW antenna with the following features:

a. Reduced side lobe level (SLL)
b. Increased frequency scanning capability
c. Compact and smaller size
d. Symmetric radiation pattern

The remaining article is organized as follows: section II, design and theory of the three designs: LWA with asymmetric Yagi element, LWA with symmetric Yagi elements and tapered LWA with slots is discussed. In section II, simulation and measurement results for all three designs are presented and compared. Conclusion is drawn in section IV.

II. THEORY AND DESIGN

A microstrip leaky wave antenna with asymmetric Yagi-like elements was reported in Chiou et al [15]. The design consists of a typical microstrip leaky section which is amended with a monopole and directors. This whole structure can be seen as a microstrip leaky wave antenna with asymmetric Yagi elements. This structure along with its ground plane is depicted in Fig. 1(a). When a simple leaky wave antenna is excited, without monopole and Yagi elements, the power leaks out of the leaky section but not a hundred percent. The remaining power reflects back and causes the side lobes to grow larger. By using a monopole, the

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reflected power can be minimized through radiation from monopole. However, it makes the radiation pattern in the XZ plane asymmetric. To restore this plane and to reduce side lobes and back lobes, we introduce a leaky wave antenna with symmetric Yagi elements as depicted in Fig. 1(b).

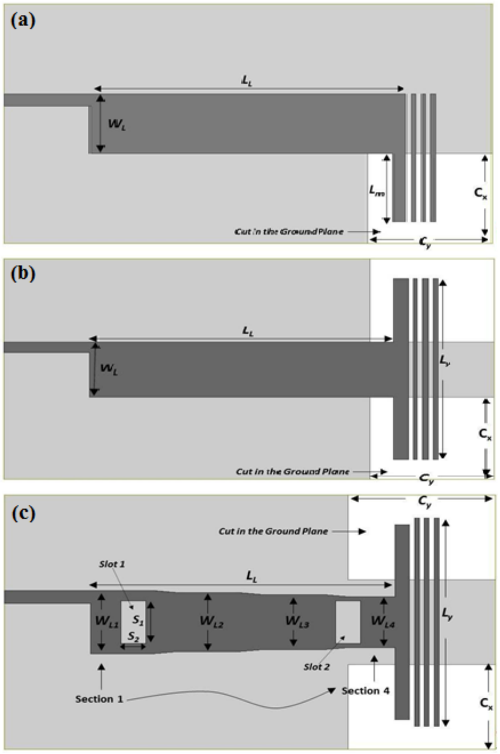

Fig. 1. MLWA (a) with asymmetric Yagi elements (b) with symmetric Yagi elements (c) with tapered leaky section and slots

The ground plane is also cut symmetrically. The symmetric Yagi elements along with modification in the ground plane result in a symmetric XZ-plane (E-plane) radiation pattern as shown in Fig. 2. As can be seen from Fig. 2, the radiation pattern for MLWA with symmetric Yagi elements is more symmetric than MLWA with asymmetric Yagi elements.

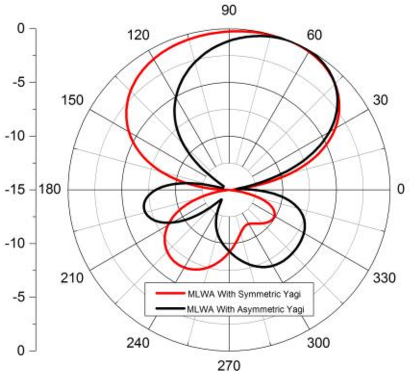

Fig.2. XZ-plane (E-plane) radiation pattern for MLWA with symmetric and asymmetric Yagi elements

To further enhance the performance of the leaky wave antenna, we optimize the design of the antenna by tapering the leaky wave section and bring two rectangular slits of equal dimensions as shown in Fig. 1(c). The rectangular slits help to break the path of surface currents and hence reduce the side lobe levels further. The overall dimensions of the antenna are 60 mm in width and 100 mm (1.8λ_o) in length. All of the antenna designs shown in Fig.1 are designed over 1.6-mm-thick FR4 substrate, having relative permittivity of 4.4 and loss tangent 0.02. Copper having conductivity of 7.8 ×10^7 S/m is used for the metallic part of the structure both in simulations and experiments. The proposed designs were approached through Ansoft HFSS numerical simulations, and the optimized structural parameters are shown in Table 1. The designs shown in Fig. 1(b) and (c) were fabricated using standard PCB techniques. The fabricated prototypes are shown in Fig. 3.

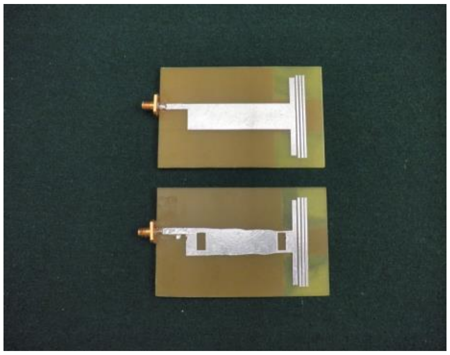

Fig. 3. Fabricated prototypes

TABLE 1 THE STRUCTURAL PARAMETERS OF LWAS

Parameters	Values (mm)
L_L	75
L_y	49
L_m	17
C_x	20
C_y	30
S_1	10
S_2	05
W_{L1}	15
W_{L2}	14
W_{L3}	13
W_{L4}	12

III. RESULTS AND DISCUSSIONS

The proposed antenna structures are designed for operation in C band. The reflection coefficients for all three MLWA designs are presented in Fig. 4. As can be seen from Fig. 4, the reflection coefficient for LWA with asymmetric Yagi elements is less than -10 dB over frequency range of 4.5 to 5.1 GHz. On the other hand, reflection coefficient is less than -10 dB over frequency band 4.6 to 5.5 GHz for LWA with symmetric Yagi elements. The bandwidth is further enhanced by tapering the leaky-wave section of the antenna resulting in an extended operating 4.5 to 5.5 GHz.

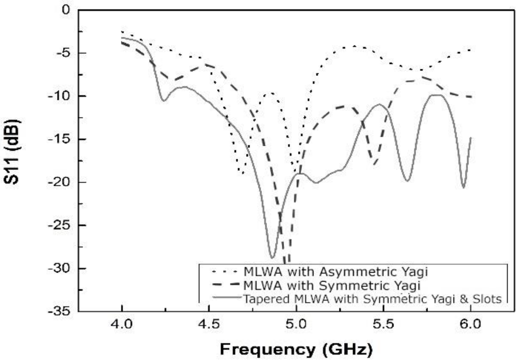

Fig. 4. Reflection coefficients for all three LWAs.

The SLL of MLWA designs is shown in Fig. 5. It can be seen from Fig. 5 that the SLL with symmetric Yagi elements is reduced compared with that of MLWA with asymmetric Yagi elements [15]. For asymmetric case beyond 4.8 GHz, the SLL starts to increase and reaches to more than -2 dB at 5 GHz, whereas for symmetric case, it remains less than -5 dB throughout the working frequency band of 4.6 to 5.5 GHz. SLL is further suppressed and goes below -10 dB from 4.5 to 4.9 GHz when the symmetric LWA is tapered and slots are introduced. The measured values for the SLL of the optimized design (tapered LWA with slots) are less than -10 dB for the whole operating frequency band (4.5–5.5 GHz).

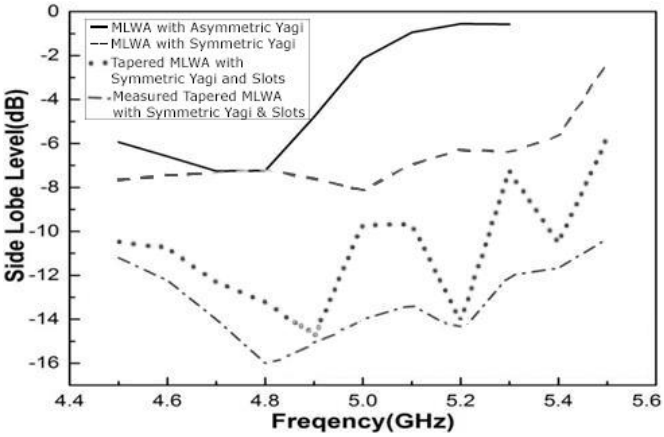

Fig. 5. Side lobe level of LWA designs.

The simulated radiation pattern in the YZ plane for the MLWA with symmetric Yagi elements for different frequencies is shown in Fig. 6. It is clear from Fig. 6 that the beam scans from 22° to 70° over a frequency range of 4.7 to 5.4 GHz.

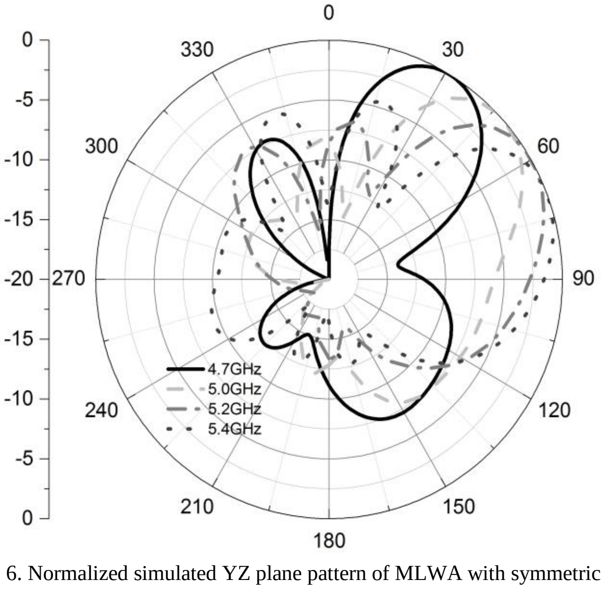

Fig. 6. Normalized simulated YZ plane pattern of MLWA with symmetric Yagi elements.

Measured results for frequency scanning of MLWA with slots and symmetric Yagi elements are shown in Fig. 7. The polar plot shows that the beam scans from 17° at 4.9 GHz to 90° at 5.5 GHz.

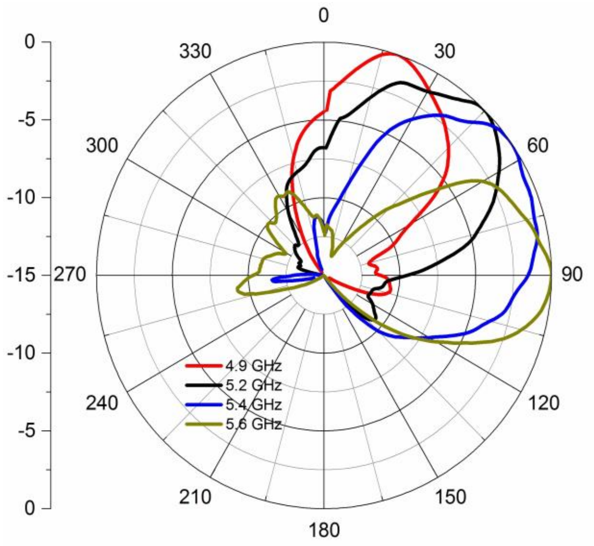

Fig. 7. Measured YZ-Plane of Tapered MLWA with slots and symmetric Yagi Elements

The beam scanning capability of all three LWAs has been presented in Fig. 8 for comparison. It can be seen from Fig. 8 that the widest beam scanning capability is demonstrated by the tapered leaky wave antenna with slots. The beam scans almost linearly from 12° to 90° when the frequency goes from 4.5 to 5.5 GHz, achieving a total scan of 78°.

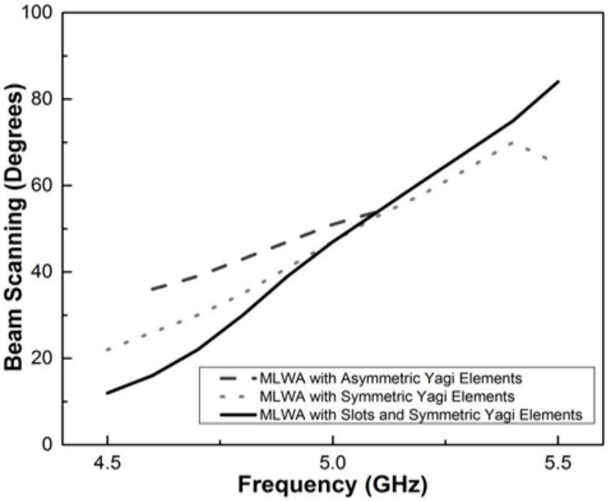

Fig. 8. Beam scanning comparison of different MLWAs.

The realized gain of all three antenna designs is presented in Fig. 9. It can be seen from Fig. 9 that the gain of the MLWA with symmetric Yagi elements is larger than the gain of MLWA with asymmetric Yagi elements for frequencies beyond 4.6 GHz. The gain is further improved for the tapered MLWA with slots and symmetric Yagi elements. Fig. 9 shows that the peak gain of the said antenna remains in acceptable range of 3.8 to 6.1 dB throughout the working frequency band of 4.5 to 5.5 GHz. The efficiency of the tapered LWA ranges from 70% to 80%. The gain of the prototype antenna is measured in Anechoic Chamber using three antenna method given in the study of Balanis [16].

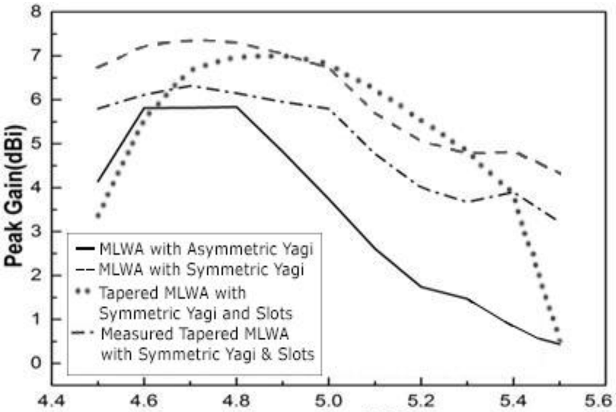

Fig. 9. Gain of different LWAs.

All three designs are compared in Table II. It is clear from Table II that the bandwidth, beam scanning capability, and average side lobe level are significantly improved as we optimize the design from LWA with asymmetric Yagi to the tapered LWA with slots and symmetric Yagi elements.

TABLE 2
OVERALL PERFORMANCE OF MLWA S

Antenna Type	Working Frequency Band (GHz)	Beam Scanning (Degrees)	Average SLL (dB)
MLWA with asymmetric Yagi Elements	4.6─5.1	36^{o}─54^{o}	-4
MLWA with asymmetric Yagi Elements	4.6─5.5	22^{o}─70^{o}	-6
Tapered MLWA with slots and symmetric Yagi	4.5─5.5	12^{o}─90^{o}	-10

IV. CONCLUSION

A compact microstrip leaky wave antenna (MLWA) with reduced side lobe level and increased linear frequency-scanning capability was proposed. Symmetric Yagi elements were used to reduce the side lobe level and make the radiation plane symmetric. The frequency-scanning capability was further enhanced in addition to reduction in side lobe level by tapering and introducing two slots in the leaky section. MLWA with slots and symmetric Yagi elements exhibits an almost linear and broader beam scanning (12^{o} to 90^{o}) behavior with increasing frequency from 4.5 to 5.5 GHz. Antenna gain remains in an acceptable range of 3.8 to 6.1 dB throughout the working band. Measured results showed that the side lobe is suppressed to less than -10 dB in the whole operating band (4.5–5.5 GHz). All these improvements were achieved by keeping the overall size of the antenna smaller by $1.8\lambda_{o}$. The fabricated design was validated through experimental measurements which were consistent with simulations.

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