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A Wideband Leaky-Wave Antenna Using Cylindrical Dielectric Resonators

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***Abstract*—This paper proposes a wide-band leaky-wave antenna (LWA) based on cylindrical dielectric resonators (DRs). Rogers TMM10i cylindrical DRs, excited by transverse thin slots on a microstrip line, are used as the antenna's leakage element. The DRs offer leaky-wave radiation in the $TE_{01\delta}$ mode. The resulting open stop-band (OSB) issue is fixed by using elliptical slots that are placed asymmetrically. The presented LWA operates within a 51.3% bandwidth, covering 12.6 to 21.3 GHz, with a gain mostly spanning from 14 to 16 dBi and a radiation efficiency average of 75%. The backward-to-forward continuous beam-scanning range of the proposed LWA is -60° to 20°. The proposed antenna may be an intriguing option for new DR-focused LWA research and radar applications.**

***Index Terms*—beam scanning, dielectric resonator, leaky wave antenna, microstrip, wideband.**

I. Introduction

It is increasingly challenging for conventional resonant antenna types to satisfy the performance requirements specified by next-generation communication technologies and radar systems. Leaky-wave antennas (LWAs), a category of travelling-wave antennas, have garnered significant research interest due to their enhanced radiation properties [1]. LWAs work based on the principle of ongoing leakage of the travelling wave, which enables steerable, high-gain beam-scanning functionalities [1]. The key distinctive feature of LWAs is their frequency-dependent beam-scanning capability [2]. It offers significant advantages over beam-steering antennas with complex feed networks [2]. Previously, LWAs utilised leakage cells such as slots [3], [4], patch loadings [5], [6], and composite right/left-handed (CRLH) structures [7], [8] to achieve broadband [9], [10], high-gain [11], [12], wide angle beam-scanning [13], [14], and multi-beam capabilities [15], [16]. Recently, dielectric resonator (DR) cells were studied as a novel leakage approach for planar LWAs [17], [18]. The ability to excite many DR modes at once enables the design of LWAs with a diverse set of features. High-gain and circularly polarized LWAs with rectangular DR cells and excitation through longitudinally tilted and cross-slots were demonstrated in [17] and [18], respectively. However, the use of a substrate integrated waveguide (SIW), high production costs, and a gain variance of 8 dBi in the operational range all present significant disadvantages.

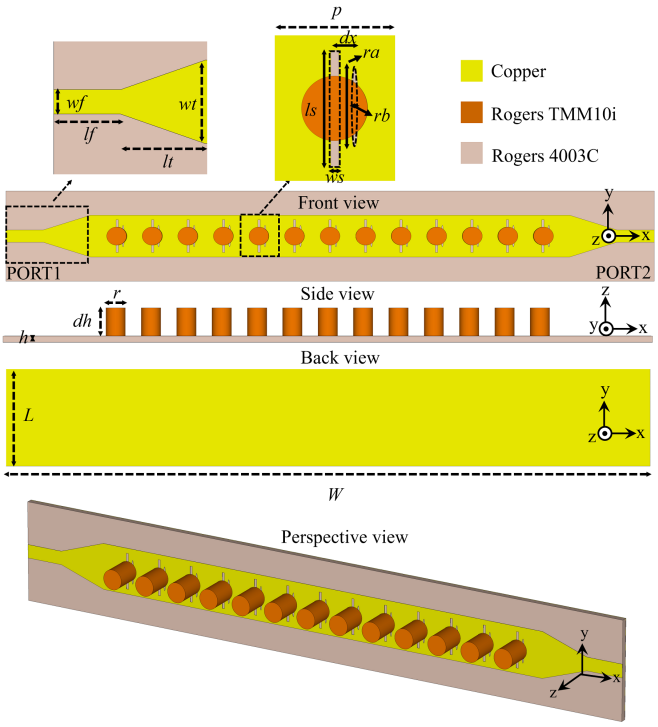


Fig. 1. The configuration of the proposed LWA. The dimensions in mm are $W = 164.5$, $L = 25$, $wf = 3.4$, $lf = 9.5$, $wt = 11.6$, $lt = 12$, $ws = 0.6$, $ls = 9$, $ra = 6$, $rb = 0.6$, $p = 9$, $dx = 1.5$, $r = 5$, $dh = 7$, $h = 1.524$.

In this study, a broadband microstrip LWA using cylindrical DRs is introduced. The DR cells are excited through thin transverse slots, while leakage is facilitated via the DRs' magnetic coupling. Elliptical slots create asymmetry, which mitigates the resulting OSB issue. The antenna operates with

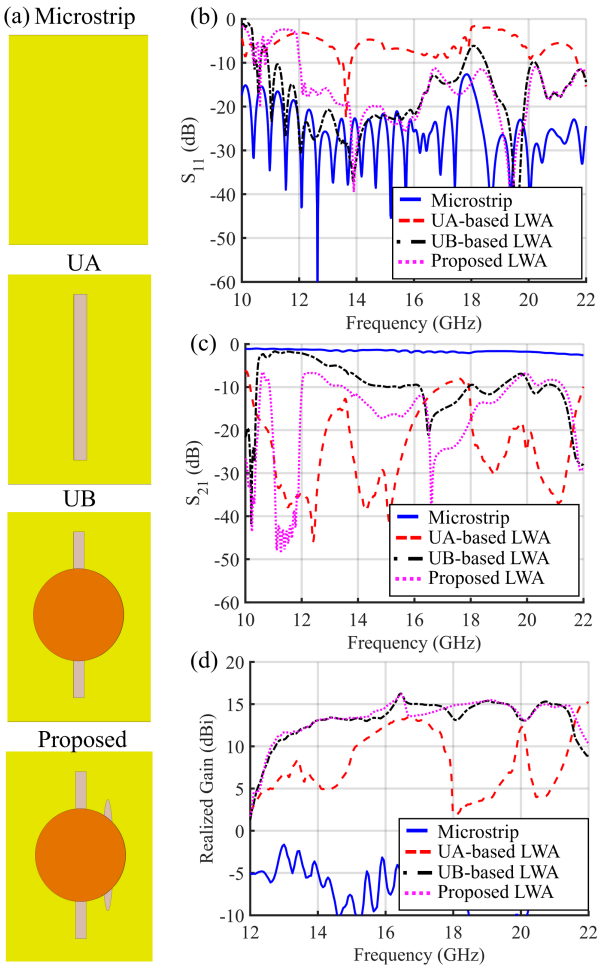


Fig. 2. The evolution of the proposed unit-cell's geometry. (b) Reflection coefficients (S_{11}), (c) transmission coefficients (S_{21}), (d) gain comparisons of the evolution stages of the proposed LWA.

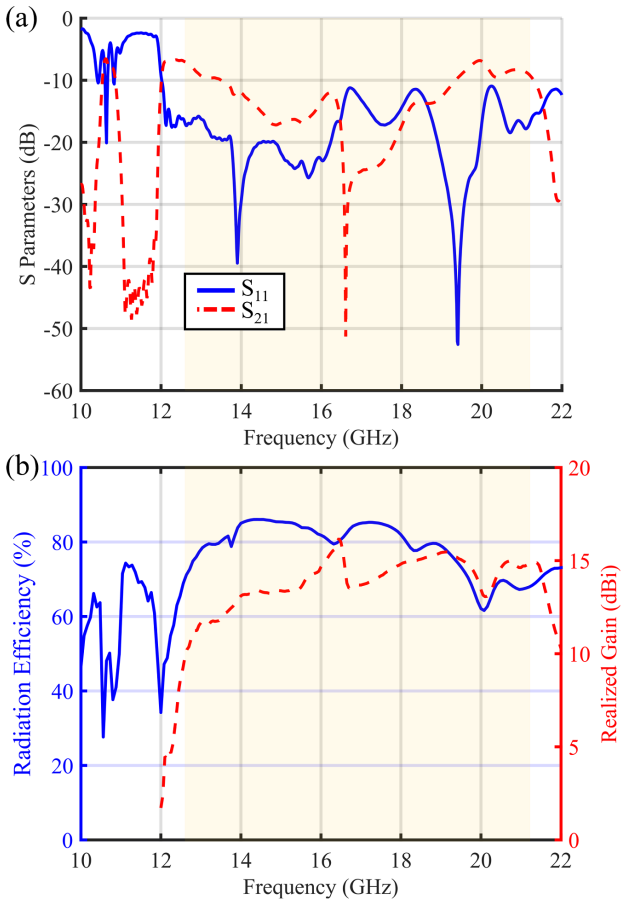


Fig. 3. (a) Scattering parameters (S-parameters), (b) realized gain and radiation efficiency results of the proposed LWA.

a bandwidth of 51.3%, and its gain ranges from 14 to 16 dBi throughout the majority of its working frequency band. The proposed LWA scans a total of 80° beam and is well-suited for radar sensors due to its cost-effectiveness, vialess architecture, wide bandwidth, and high-gain radiation performance.

II. ANTENNA DESIGN

Fig. 1 depicts the proposed LWA configuration, whereas Fig. 2(a) depicts the developmental phases of the unit cells of the proposed antenna. The proposed LWA is built on a Rogers 4003C substrate with a thickness of h = 1.524 mm, a dielectric constant of $\epsilon_r = 3.55$, and a loss tangent of $\tan\delta = 0.0027$. A 50Ω microstrip line with a tapered transition is utilized to feed the antenna. All dimensions of the proposed LWA are given in Fig. 1. To introduce powerful LWA characteristics in the antenna, 13 DRs are periodically arranged along the slotted microstrip transmission line. Conventional cylindrical DR design rules [19] are employed for the proposed DR dimensions. Cylindrical DRs are excited by thin transverse slots inserted into the transmission line ('UA' and 'UB' configurations). The DRs are made up of Rogers TMM10i, which has a dielectric constant of $\epsilon_r = 9.9$ and a loss tangent of $\tan\delta = 0.002$. The proposed LWA design addresses the OSB issue during LWA construction by implementing asymmetrically placed transverse elliptical slots.

Fig. 2(b)-(d) show the important numerical analyses referring to the transformation of the microstrip line into the proposed LWA. Fig. 2(b) and 2(c) demonstrate the reflection coefficients (S_{11}) and transmission coefficients (S_{21}), respectively, corresponding the evolution of the proposed LWA. Fig. 2(c) illustrates that the 'UA' configuration creates leakage, resulting in a reduction of the S_{21} values from -1 dB to -10 dB. However, the 'UA' is unable to sustain its operational capabilities (S_{11}> -10 dB) across the desired frequency band. To enhance leakage and propagation, cylindrical DRs are integrated into the 'UA' topology. As shown in the Fig. 2(b), the 'UB' design operates within the 11-22 GHz band, with a minor OSB issue observed in the 18 GHz region. Finally, Fig. 2(a) depicts that the OSB issue is solved through the incorporation of asymmetric elliptical slots into the proposed antenna. Fig. 2(d) presents gain comparisons across the various evolution phases of the proposed LWA to facilitate a more comprehensive analysis. The substantial enhancement in gain

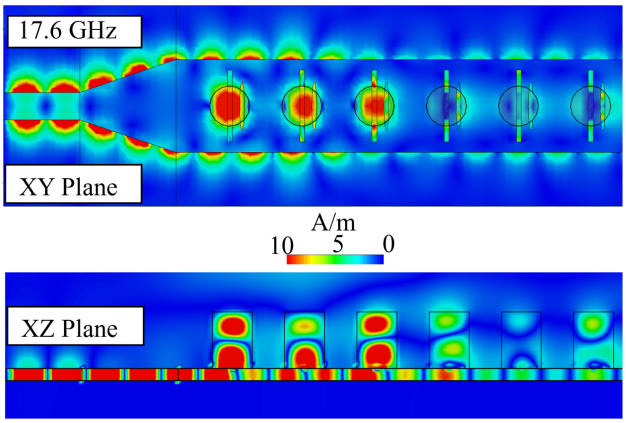


Fig. 4. Magnetic field distributions of the proposed LWA at 17.6 GHz.

TABLE I
CHARACTER COMPARISON BETWEEN THE PROPOSED ANTENNA AND PREVIOUS DR-BASED LEAKY-WAVE ANTENNAS.

Refs.	T. Line / DR Type	Operating Range(GHz)/ Frac. BW	Gain (dBi) / variation	Beam-Scan. Range(°)	Complexity
[17]	SIW Rectangular DR	26-40/42.4%	9-17 8	-60 to 21	High
[18]	SIW Rectangular DR	26-40/42.4%	8.7-17 8.3	-55 to 23	High
Prop.	Microstrip Cylindrical DR	12.6-21.3/51.3%	10.5-16 5.5	-60 to 20	Low

observed in the 'UB' design relative to the 'UA' design serves as another crucial indication of improved leaky-wave radiation. In addition, since the OSB problem is at low levels, no significant gain difference is observed between 'UB' and the proposed LWA at the broadside point (θ=0°, at 18.3 GHz). The numerical optimizations of the proposed LWA were performed with the full-wave electromagnetic solver CST Microwave Studio Software.

III. RESULTS AND DISCUSSION

Fig. 3(a) shows the simulated S-parameter results for the proposed LWA, and Fig. 3(b) illustrates the realized gain and radiation efficiency values. The antenna works in the frequency range of 12.6 GHz to 21.3 GHz, enabling for beam-scanning with changes in frequency. The total fractional bandwidth in this range is 51.3%. The antenna's gain changes from 10.5 dBi to 16 dBi, which is a variation of 5.5 dBi. For the majority of its operational band, the antenna works at more than 70% efficiency, and at most 85% efficiency Fig. 4 depicts how the magnetic field distributes out across the antenna's XY and XZ planes at 17.6 GHz. It is evident that the DRs induce magnetic coupling with the $TE_{01\delta}$ mode, hence enabling leakage and propagation. Fig. 5 exhibits the proposed LWA's radiation patterns in the XoZ plane and 3D at different operating frequencies. The antenna scans beams continuously from backward to forward direction, between -60° and 20°. Table 1 compares the characteristics of the proposed LWA with previous DR-based LWAs. The table shows that the The offered wide bandwidth and simple hardware architecture of

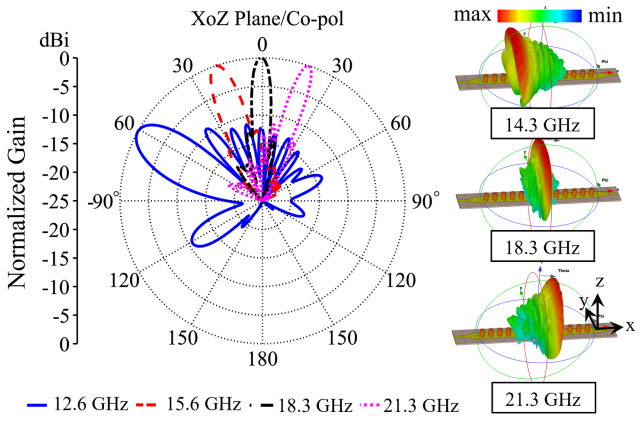


Fig. 5. XoZ plane and 3D radiation patterns of the proposed LWA for the various operating frequencies.

the proposed antenna make it a promising candidate for future radar and wireless communications technologies.

IV. CONCLUSION

A wide-band LWA using cylindrical DRs was proposed. The DR cells were excited by tiny transverse slots in the microstrip line, generating leakage via magnetic coupling. The consequent OSB problem was overcome using asymmetrically placed elliptical slots. The proposed LWA offers a 51.3% bandwidth between 12.6 and 21.3 GHz, with a maximum gain of 16 dBi. The antenna's efficiency ranges from 63% to 85%, and it can continuously scan the beam from -60° to 20°. The antenna's wide operating band and simple design features make it a suitable choice for Ku (12-18 GHz)-band radar and communications applications, as well as parts of the K (18-27 GHz)-band.

V. ACKNOWLEDGMENT

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