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# Compact periodic leaky-wave microstrip antenna with periodic short circuits and forward-to-backward scanning capability

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#### Abstract

Compact size, elliptical polarization, a low-sidelobe-level microstrip leakywave antenna with short pins on one side of the sheet is described in the paper. The suggested antenna consists of 7 sheets that are periodically put on the antenna structure, with one of the edges of the sheet being incorporated with short-circuit pins. The proposed antenna has effective decrease in antenna size good scan capability, and reduction in sidelobe level In comparison with another types of antennas. A set of simple and effective equations is used to determine the operating range of the antenna. As elucidated by simulation results, the scanning process is carried out from 11° to  $-15^{\circ}$ , at the rate of 26% as the frequency changes from 22.8 GHz to 27.8 GHz.

#### Keywords

leaky wave antennas, Microstrip antennas, Beam steering, Antenna radiation patterns

#### For citation

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# Компактная периодическая микрополосковая антенна вытекающей волны с периодически установленными короткозамыкателями и способностью сканировать в прямом и обратном направлениях

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#### Аннотация

В статье описана компактная микрополосковая антенна вытекающей волны с излучающими элементами, имеющими с одной стороны короткозамыкатели, формирующая поле эллиптической поляризации с низким уровнем боковых лепестков. Предложенная антенна состоит из 7 прямоугольных печатных излучателей, последовательно возбуждаемых микрополосковой линией, каждый из которых замкнут с одной стороны проводящими штырями с экраном. По сравнению с другими антеннами, предложенная имеет меньшие размеры, хорошую способность частотного сканирования и уменьшенный уровень боковых лепестков. Для определения рабочего диапазона использованы достаточно простые выражения. Как показано в результате моделирования в среде Ansys HFSS, сканирование обеспечивается в диапазоне углов от 11 до -15 градусов при изменении частоты на 26 % от 22,8 до 27,8 ГГц.

#### Ключевые слова

антенны вытекающей волны, микрополосковые антенны, управление лучом, диаграммы направленности антенны

#### Для цитирования

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#### Introduction

Since 1979, several research groups have been working on the design of a microstrip leaky-wave antenna (MLWA) because of its attractive properties, such as easy feeding network, wide bandwidth, narrow beamwidth, and frequency scanning capability. In contrast to resonant antennas, radiation in leaky wave antennas are created by the leaking of traveling waves propagating along with the antenna [1]. As the frequency changes, the main beam direction changes, since the frequency depends on the phase constant, resulting in a frequency-scanning antenna. From the literature, several recent approaches use a different type of periodic LWA, such as sinusoidally modulated reactance surface antenna, the aperture illumination of which has an amplitude distribution that tapers cell by cell [2], several identical cells along the antenna structure are discussed in [3], a periodic leaky-wave array antenna with circular polarization on planar Goubau line is under consideration in [4], a half-width LWA is explained in [5]. The possibility of scanning from backward to forward of a half-width MLWA antenna is discussed in [6]. An analysis of the dispersion characteristics of the metal strips-loaded grounded dielectric slab is presented in [7].

The scanning capability of a small size MLWA and its side lobe level (SLL) reduction is under discussion in this paper. The suggested antenna (Fig. 1) is made up of a sequence of microstrip sheets. The main lobe may scan from forward to backward directions with a simplified structure. The return loss, radiation pattern (E-plane), and the propagation constant for this antenna are calculated and the results are presented. We try to improve several factors, including the size, which is one of the most important factors, as well as the simplicity of the feeding network, the amount of antenna gain, and the scanning range of frequencies. In Section II, the sequence of equations is obtained to compute the propagation constant, through which it is easy for us to calculate the parameters of the antenna as well as the frequency bands on which it works. Section III describes the design of the antenna that is proposed. In Section IV, simulation results are shown and described for various antenna characteristics. The proposed antenna gives similar scanning capabilities to its counterparts from other antennas, a good advantage despite its small size.

#### **Theory for periodic MLWA**

In this work, we minimized the structure of the antenna  $4.4\lambda_0$ . Metal strips are periodically placed on the microstrip line placed on the insulating board with short pins on one side edges of the metal strips as shown in Fig. 1. Floquet's theorem lists the complex propagation constant  $k_{zn}$  of periodic LWA is as follows [1; 8]

$$k_{zn} = k_z + \frac{2\pi n}{p}, n = \pm 1, \pm 2, \pm 3.$$
 (1)

When one of the space harmonics is a fast wave, the leakage process occurs indicating the disturbance period leakage. This is generally the n = -1 harmonic, and the outcome is the necessity of  $k_0 < \beta_{-1} < k_0$  by suitably changing the periodicity p. The main beam can be scanned up to the desired angle, and usually, it may be scanned from backward to forward. The fundamental Floquet wave has a uniform structure. The approximate wave number represented in (1),  $k_z = \beta_z + j\alpha_z$  with the microstrip LWA in half-width [9]. The approach for finding the complex propagation constant of the half-width microstrip LWA is described below [3; 5; 6; 10]:

$$\frac{\beta_{zn}}{k_{zn}} = \sin\left(\frac{\pi}{2} - \theta\right). \tag{2}$$

The variation of the operating frequency with the phase constant determines the angle  $\theta$  of the main beam. We also note the half-power beam-width  $\theta_{HPBW}$  for the main beam with attenuation constant  $\alpha_z$ 

$$\frac{\alpha_{zn}}{k_0} = 0.18\theta_{HPBW} \cos\left(\frac{\pi}{2} - \theta\right) \tag{3}$$

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for periodic units, the complex propagation constant can be calculated in the following way [8]:

$$k_z = \sqrt{\omega^2 \mu \varepsilon_r - k_x^2}, \qquad (4)$$

$$\exp(jk_x 2T) = \frac{k_x - \omega \mu y_\omega}{k_x + \omega \mu y_\omega},$$
(5)

$$y_{\omega} = \frac{h}{120\lambda_0} + \frac{k_0 \varepsilon_{eff} \Delta T}{120\pi}, \qquad (6)$$

where  $k_x$  the complex wavenumber concerning the *x*-axis and *T* in (5) represents the width of half-width MLWA of microstrip sheets and  $\Delta T$  in (6) shows the corresponding extension.  $\Delta T$ ,  $\Delta$ ,  $\varepsilon_{eff}$  is calculated as follows [6]:

$$\Delta T = 0.412h \frac{\varepsilon_{eff} + 0.3l/(h+0.262)}{\varepsilon_{eff} - 0.258l/(h+0.813)} + \Delta, \tag{7}$$

$$\Delta = \frac{a}{2\pi} \left[ \ln\left(\frac{1}{\pi r}\right) - \frac{4\pi^2 r^2}{a^2} + 0.601 \frac{a^2 \varepsilon_r}{\lambda_0} \right],\tag{8}$$

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r + 1}{2} \left(\frac{1 + 5h}{T}\right)^{-1/2},\tag{9}$$

where *a* represents the distance between the pins, *r* represents the radius of each of the pins, and  $\Delta$  indicated the sequence of short pins in a parallel-plate circuit architecture. The structure of the antenna  $4.4\lambda_0$  is minimized in the proposed antenna.



Fig. 1. The geometry of the proposed periodic leaky-wave antenna **Рис. 1.** Топология предложенной антенны вытекающей волны

As illustrated in Fig. 1 the antenna to be designed consists of the a microstrip line with 7 radiating segments of microstrip sheets placed periodically on the microstrip line. To improve the matching impedance, a series of short pins are added to end plates, for four pins for each plate arranged periodically. The antenna is designed with one port and a ground plane. In this design, a relative permittivity of the substrate is  $\varepsilon_r = 2.82$ , the substrate height is of h = 0.782 mm. The distance between shorting pins is a = 1 mm, and the shorting pins have a radius of r = 0.25 mm. Table 1 summarizes the parameters of the suggested MLWA.

Table 1. The antenna's parameter	fable	<b>1.</b> The	I. The antenna'	$\mathbf{s}$	parameters
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Таблица 1. Параметры антенны						
Symbol	Size in mm					
l_total	The substrate length	58				
2T	Width of the microstrip sheets	10.5				
W	The microstrip line width	2.2				
<i>l''</i>	The tail distance	2.6				
p	Spacing of microstrip sheets	7.8				
$W\_total$	The substrate width	31.5				
<i>l'</i>	Distance from the feed port	2.6				
la	The total length of the antenna	55				

Since short pins are located only on one side of the microstrip sheets, the appearance of a transverse component of the electric field should be expected. The radiated field will have elliptical polarization. From the point of view of communication and radar systems, this makes it possible to provide reception even with the orthogonal position of the antenna to the source. Optimization of the polarization properties of the considered antenna will be carried out in the further research.

## **Simulation Results**

Simulated results of the return loss of the antenna suggested are depicted in Fig. 2 Over the bandwidth, the return loss remains under -10 dB, which demonstrates good performance. The proposed antenna's propagation constants are depicted in Fig. 3.

From 22.8 to 27.8 GHz, *E*-plane radiation gains for the suggested antenna are shown in Fig. 4. With the gain variation of 0.9 dB, the gain of 13.1 is attained for the various frequency excitations on the bandwidth. Scanning ranges from 11° at 22.8 GHz to  $-15^{\circ}$  at 27.8 GHz, with a 26° scanning range.

To define the sidelobe level the normalized gain of the proposed antenna is shown in Figs. 5-7 at 22.8, 24, and 27.8 GHz, respectively. The SLL of the antenna at the broadside is equal to -10.88 dB.



Fig. 2. The reflection loss  $S_{11}$  for the suggested antenna Рис. 2. Частотная зависимость коэффициента отражения  $S_{11}$ предложенной антенны



Fig. 3. The attenuation constant  $\alpha/k_0$  and the phase constant  $\beta/k_0$  versus the frequency

Рис. 3. Частотная зависимость коэффициента затухания  $\alpha/k_0$ и коэффициента фазы  $\beta/k_0$ 



Fig. 4. The simulated antenna *E*-plane gain scanning for different frequencies





Fig. 5. The radiation pattern in the E-plane for the frequency equal to 22.8 GHz

Рис. 5. Диаграмма напроавленности в плоскости вектора *E* на частоте 22.8 ГГц



Fig. 6. The radiation pattern in the E-plane for the frequency equal to 24 GHz

Рис. 6. Диаграмма напроавленности в плоскости вектора *E* на частоте 24 ГГц



Fig. 7. The radiation pattern in the E-plane for the frequency equal to 27.8 GHz

Рис. 7. Диаграмма напроавленности в плоскости вектора *E* на частоте 27.8 ГГц

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From the graphs shown in Fig. 8, it can be seen that the difference between the right and left polarization radiation fields is not yet sufficient. The proposed antenna provides elliptical polarization. As can be seen from Fig. 8, the elliptical polarization variance is around -7 dB broadside and approximately -12 dB at 22.8 GHz and -4 dB at 27.8 GHz, which is acceptable for a variety of applications. This is due to the fact hat the amplitudes of the orthogonal field components are not equal as shown in Fig. 9. However, if compared with the radiation of the antenna without short-circuiters as shown in Fig. 10, the gain is 28–32 dB.



Fig. 8. The right-hand circular polarization (solid) The left-hand circular polarization (dash) simulations are performed at three frequencies (with short pins)

Рис. 8. Угловая зависимость коэффициента усиления для поля правой (сплошная) и левой (штриховая) круговой поляризации на шести частотах (с короткозамыкателями)



Fig. 9. The simulated radiation pattern  $E_{\theta}$  (solid) and  $E_{\phi}$  (dash) components of the antenna with shorting pins





Fig. 10. The simulated radiation pattern  $E_{\theta}$  (solid) and  $E_{\phi}$  (dash) components of the antenna without shorting pins

Рис. 10. Угловая зависимость коэффициента усиления для  $E_{\theta}$  (сплошная) и  $E_{\phi}$  (штриховая) компонентов поля на шести частотах без короткозамыкателей

It is found that the electric field remains normal and that the radiation pattern and impedance are not affected much. We would like to show that the goal is to have circular polarization, and this will be in the next stage. Simulations are performed using (Ansys HFSS) High-Frequency Electromagnetic Simulation Software.

To verify the results of our simulation, we use another software, AWR Design Environment. Good coincidence of the antenna parameters is noted.

In Table 2, several past studies are compared to the proposed antenna in this work. The compact length, reduction in SSL, elliptical polarization, and good continuous gain scanning performance is achieved.

	Table 2. Comparison with other MLWAS
Таблица	2. Сравнение с другими микрополосковыми антеннами
	вытекающей волны

Antenna	Operating band (GHz)	Total antenna length (mm)	Antenna gain (dBi)	Broadside SSL (dB)	ε <sub>r</sub>
[3]	20~29	91.5	12.1	-13	6.15
[10]	$5.7 \sim 11.7$	27.85	$3.72 \sim 5.9$	N/A	2.65
[11]	$11.1 \sim 17.3$	320	8~18	N/A	2.2
[10] Scanning range (-65°~-5°) (5°~65°)	10.6~16.45	320	$6{\sim}13$ 14 ${\sim}16$	N/A	2.2
[9]	$7.4 \sim 13.5$	175	$7.48 \sim 12.01$	-10	2.2
Current work	$22.8 \sim 27.8$	55	12.2~13.1	-10.88	2.82

#### Conclusion

The compact size, elliptical polarization, and a low-sidelobe-level leaky-wave microstrip antenna with short pins on one side of the sheet are suggested in this work. The suggested antenna consists of 7 sheets that are periodically put on the antenna structure, with one of the edges of the sheet being incorporated with short-circuit pins. The proposed antenna has effective decrease in the antenna size, good scan capability, and reduction in sidelobe level in comparison with another types of antennas. To determine the operating range of the antenna, a set of simple and effective equations is used. As elucidated by simulation results, the scanning process is carried out from 11° to -15°, at a rate of 26 %, as the frequency shifts from 22.8 to 27.8 GHz. The proposed antenna is very useful in organizing traffic or automobile radar the system. We will work on manufacturing it in near future to match the results and make practical measurements.

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