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A Novel Design of 45° Linearly Polarized Array Antenna with Taylor Distribution

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Abstract—The growing interest in collision avoidance automotive radar systems in K-band necessitates the development of dedicated antenna systems with 45° inclined linear polarization (LP). In this letter, a 45° inclined LP array antenna with Taylor distribution is proposed, designed, and fabricated.

1. INTRODUCTION

With the rapid development of automatic driving technology, more and more attention has been paid to vehicle anti-collision radar [1, 2], in which the radar antenna has attracted a lot of research interests. For automotive anti-collision radar application, microstrip antenna array is one of the best choices due to many advantages such as low profile, light weight, and easy integration with a high frequency circuit.

In previous papers, we can find that most of the proposed antennas [3–5] are horizontal polarization antennas or vertical polarization antennas. But in reality, we often need an antenna that can transmit or receive two kinds of polarized signals with one channel, for that we do not know the polarization of the received signal. Zhang and Lu [6] and Chen et al. [7] have proposed a configuration of integrated 45° linearly polarized slot array antenna based on a substrate of integrated waveguide (SIW) technology. However, they synthesize the array with numerical optimization, which is very time-consuming, and the metallized vias will weaken the structure strength of PCB.

In this paper, a novel design of 45° linearly polarized array antenna with Taylor distribution is proposed. The antenna is analyzed by full-wave Finite Element Method (FEM) simulations using commercial software (Ansoft HFSS17 [8]). This 45° polarized array antenna has a wide application in microwave and millimeter wave systems, especially for auto-motive collision-avoidance radar.

2. ANTENNA CONFIGURATION AND DESIGN

In this section, both the radiation element and feeding network will be thoroughly illustrated. Fig. 1(a) shows the geometry of the proposed 45° linearly polarized array antenna with Taylor distribution. The proposed antenna consists of two major parts. One is 8×6 slant polarized patches, and the other is a set of series-fed microstrip feed network.

The microwave substrate used in the prototype antenna is Rogers RO4350(tm), with the dielectric constant $\varepsilon_r = 3.66$ and dielectric loss tangent $\tan(\delta) = 0.004$ at 10 GHz. The substrate thickness is 0.508 mm, and the copper thickness on the substrate is 17 μm. All the results are obtained by using the commercial software of Ansoft HFSS 17.

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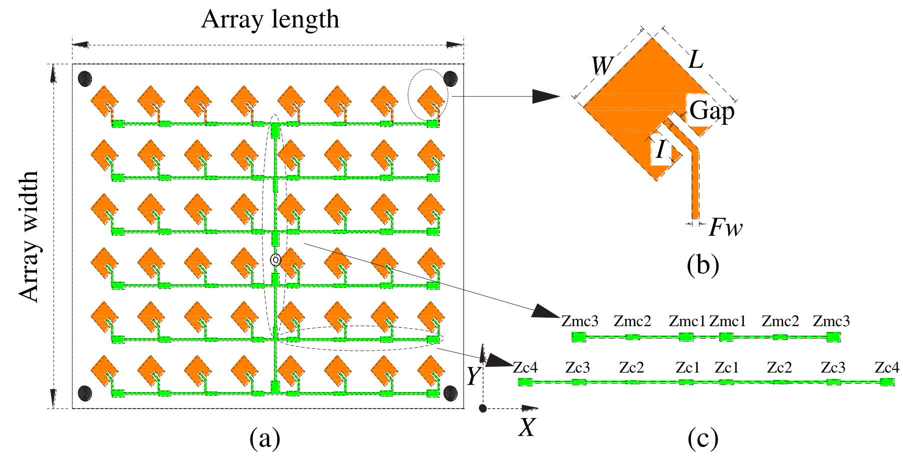


Figure 1. (a) The proposed 45° linearly polarized array antenna with Taylor distribution. (b) Configuration of radiation element. (c) Feeding network.

2.1. Radiation Element

Figure 1(b) shows the radiation element used in the prototype array antenna. The 45° inclined patch etched on the substrate together with the series-fed network can provide the required 45° polarization.

The size of the patch width W affects the radiation pattern and input impedance of the microstrip antenna. According to paper [9], W can be given by formula (1):

$$W = \frac{c}{f_r}\left(\frac{\varepsilon_r + 1}{2}\right)^{-1/2} \tag{1}$$

If the size of W is larger than the value above, the electric field could produce higher order mode, and the gain will be lowered.

Theoretically, the length L of the rectangular microstrip antenna is half the dielectric wavelength, and yet due to the influence of edge field, $2\Delta L$ should be subtracted from half dielectric wavelength, just like (2):

$$L = \frac{c}{2f_r\sqrt{\varepsilon_e}} - 2\Delta L \tag{2}$$

where c is the speed of light, f_r the resonant frequency, and ε_e the effective dielectric constant.

ΔL and ε_e can be expressed as follows [7]:

$$\Delta L = 0.412h\frac{(\varepsilon_e + 0.3)\,(W/h + 0.264)}{(\varepsilon_e - 0.258)\,(W/h + 0.8)} \tag{3}$$

$$\varepsilon_e = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + \frac{10h}{W}\right)^{-1/2} \tag{4}$$

Based on the theoretical value, the initial size of the microstrip patch can be obtained, and hence the final size can be obtained after further optimization.

It can be seen from Fig. 2(a) that the normalized input impedance at 24.5 GHz is equal to $1 + j0$. From the results of the impedance, we can readily make out how the resonant frequency is produced.

When the normalized input impedance is matched with the port, we can observe from Fig. 2(b) that the maximum radiation direction is in the positive Z-axis direction, and the gain achieves 6.7 dB.

2.2. Synthesis Technique

In order to suppress the sidelobe level effectively, Taylor synthesis method is used to obtain unequal amplitude distribution. A quarter wavelength impedance converter is added between the elements of the antenna array. By adjusting the ratio of the characteristic impedance of each section to the

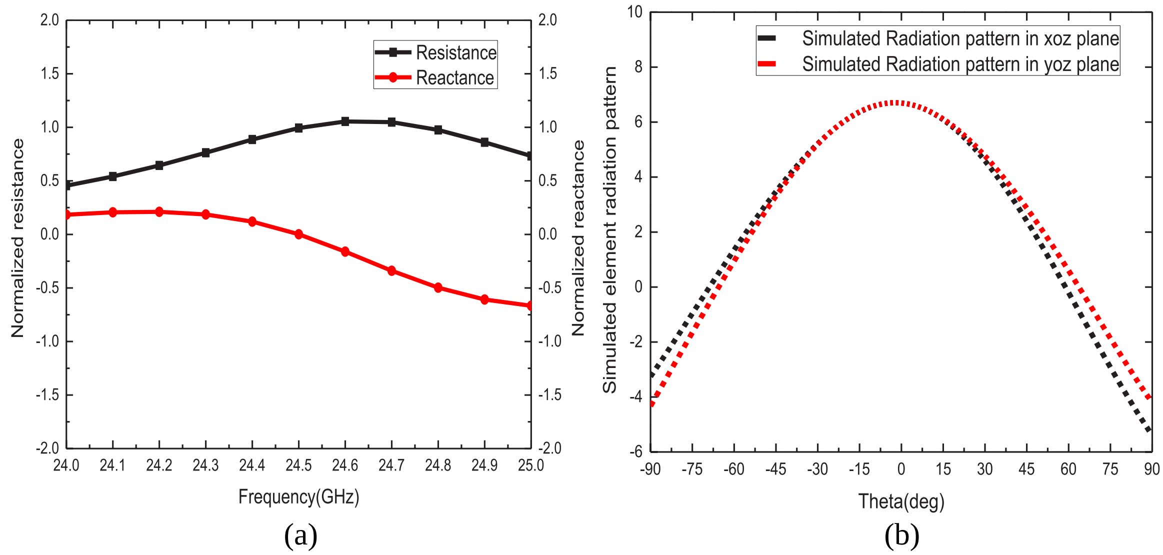


Figure 2. (a) The Normalized impedance of the element. (b) The radiation pattern of the element.

characteristic impedance of the transmission line, the current taper distribution is controlled to lower the sidelobe level and ensure the impedance matching with the port.

The impedance transformation section forms a $1 : n_i$ transformer. Assuming that the input current amplitude on the first radiation element is 1, we can obtain $I_0 = 1$; $I_1 = n_1$; $I_2 = n_2 n_1$; $I_i = n_i n_{i-1} \cdots n_2 n_1$. According to Taylor synthesis method, to achieve the sidelobe level of -30 dB shown in Fig. 3, the current distribution on one side of XOZ is $I_0 : I_1 : I_2 : I_3 = 1 : 0.82 : 0.53 : 0.29$. Similarly, the current distribution on one side of six elements is $I_0 : I_1 : I_2 = 1 : 0.69 : 0.32$.

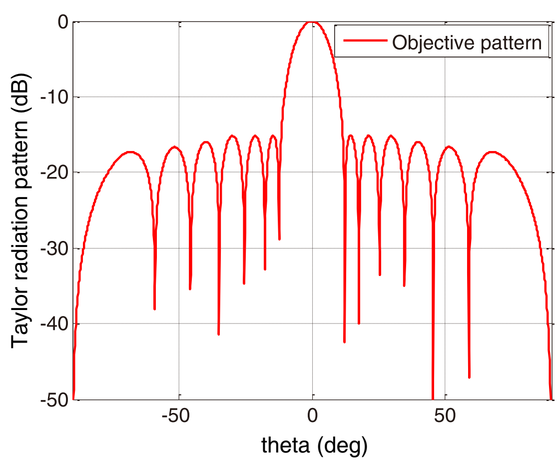


Figure 3. The objective Taylor pattern.

After obtaining the current distribution, we can obtain the characteristic impedance of the microstrip line by $z_i = n_i * z_0$, where z_0 is the characteristic impedance of the main feedline and matched to the input impedance of the element. Then the line width of the microstrip line can be calculated according to the formula of the characteristic impedance of the microstrip line [10]. The obtained feeding network is shown in Fig. 1(c), and the main parameters of the proposed array are shown in Table 1.

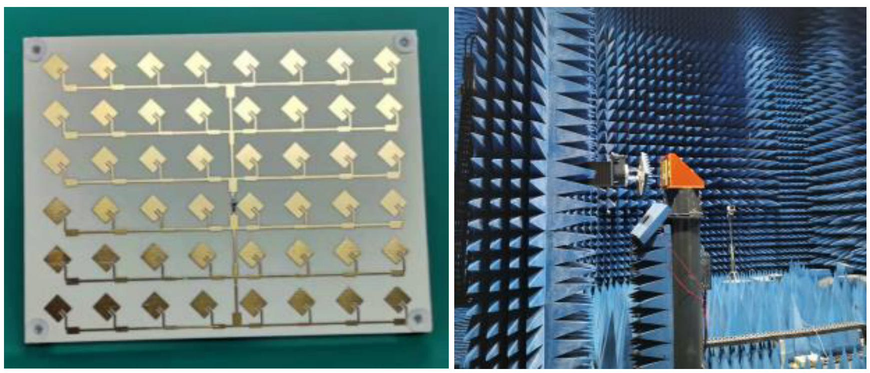
Table 1. Detailed dimensions of elements and feedline (unit: mm).

W_{c0}	W_{c1}	W_{c2}	W_{c3}	W_{c4}	W_{mc1}	W_{mc2}	W_{mc3}
0.28	0.61	0.45	0.72	0.96	1.2	0.625	1.26
F_w	Gap	I	W	L	F_{l0}	F_{l1}	F_w
0.2	0.27	1.05	2.85	3	1.29	2	0.2

3. EXPERIMENTAL VERIFICATION

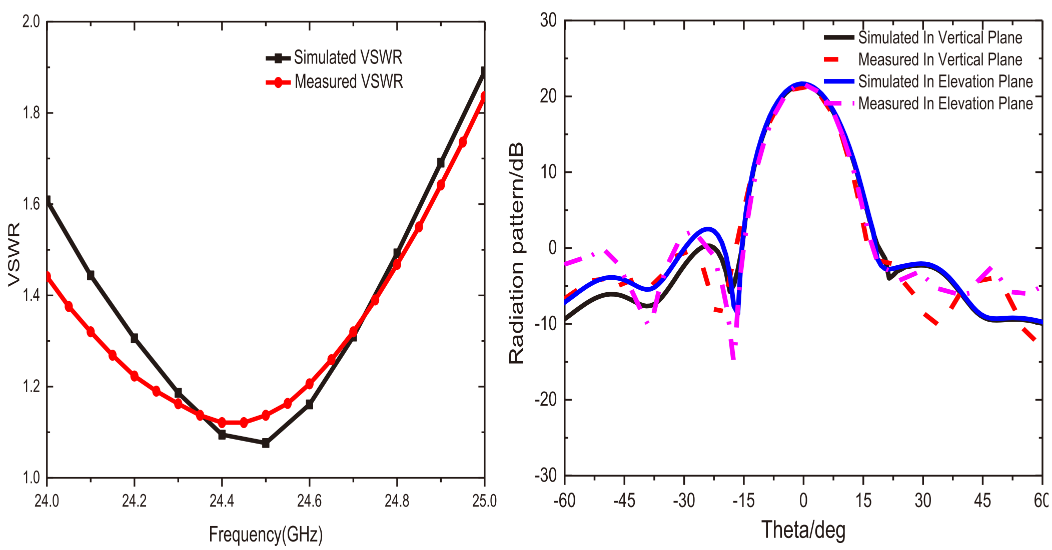
To verify the aforementioned design, the proposed antenna has been designed and fabricated. A photograph of the prototype is shown in Fig. 4(a), and the dimensions are 60.4 mm × 46 mm × 0.508 mm.

The Voltage Standing Wave Ratio (VSWR) has been measured prior to the radiation patterns, by Rohde & Schwarz ZVA 40. The measured data has been compared with the simulated one in Fig. 5(a).



(a) (b)

Figure 4. (a) The photograph of the prototype, (b) the array under test in the near-field chamber.



(a) (b)

Figure 5. (a) Reflection coefficient of the 2-D array. (b) Radiation patterns of the 2-D array at 24.5 GHz.

As illustrated in Fig. 5(a), the measured voltage standing wave ratio is below 2, from 24.0 to 25 GHz, and the measured center frequency is 24.42 GHz, which has a nearly 80 MHz deviation from the designed center frequency, i.e., 24.5 GHz. An analysis posterior to the measurement has revealed that the error of dielectric constant in the fabrication has caused the difference.

The 2-D array is tested in the near-field chamber, which is placed on one side of the triangular support plate.

The radiation patterns are shown in Fig. 5(b), where the measured curves are consistent with the simulated counterparts, and the measured SLLs in elevation plane and azimuth plane are −20 dB and −21 dB, respectively. Compared with the objective Taylor pattern, the measured Sidelobe Levels (SLLs) are higher by 8 dB, because the number of sampling units in each direction is relatively small.

4. CONCLUSION

This paper presents a 45° linearly polarized 8×6 array antenna in the K band with high gain, low sidelobes, and compact size. The simulation and measurement results show that the antenna has a bandwidth of 1 GHz from 24 GHz to 25 GHz, with VSWR smaller than 2. Meanwhile, a pencil beam with less than −20 dB sidelobe level in both the azimuth plane and elevation plane has been achieved at the center frequency (24.5 GHz).

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Data Availability Statement

Data sharing not applicable to this article as no datasets were generated or analysed in the current study.

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