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A 77 GHz Series Fed Weighted Antenna Arrays with Suppressed Side-Lobes in *E*- and *H*-Planes

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Abstract—This paper proposes a 77 GHz microstrip series-fed patch antenna array for automotive radar applications. Based on the Taylor Distribution Principle, we designed a six-unit series-fed weighted antenna array. A Wilkinson 1 : 8 un-equal divider is employed to connect eight antenna arrays to form a whole planar antenna. In antenna far-field patterns, the *E*-plane side-lobe level is approximately below −20.15 dB, and the *H*-plane side-lobe level is about −15 dB. Good accordance is obtained between simulated and measured results. The designed antenna has great value in the application fields of 77 GHz automotive radar antenna.

1. INTRODUCTION

In the past few decades, great progress has been made in the frequency regulation for automotive radar [1]. As well known, the chaotic use of the automotive radar frequency band will lead to many unfavorable factors that limit the development of the automotive radar industry and will also waste a lot of manpower and resources. In the 1990s, the European Union published a set of standards, and the 76–77 GHz band had been identified [2]. Nowadays, in Europe, North America and Japan, this band is assigned to intelligent transportation services. In the automotive radars, 77 GHz millimeter-wave system exists for many years. In addition to car driving safety [3, 4], the 76 GHz radar system is also used in helicopter anti-collision [5], unmanned ground vehicle [6, 7], etc. The operation frequency is typically in the 76–77 GHz band for frequency-modulated continuous wave (FMCW) or pulse Doppler operation. The higher bandwidth allows for W-band ultra-wideband (UWB) systems with improved distance resolution, which were previously the main target of 24 GHz automotive radar development [8].

As a key component in 77 GHz radar systems, the antenna needs to have competitive advantages such as low cost, compact size, high gain, low side lobe and easy integration. Compared to traditional 24 GHz radar, radar at 77 GHz has a smaller antenna size which can greatly reduce the whole dimension of the radar. In conventional solutions, horn antennas are widely used in the radar system because of their high directivity, large bandwidth and simple structure. However, in millimeter-wave band, horn antennas have weaknesses such as high manufacturing costs and bulky size which cannot be accepted by commercial automotive manufacturers. So microstrip patch antenna becomes a good option due to the merits of small size, low cost, high gain and easy integration in front-end circuits. Moreover, the existing PCB processing technology can meet the high-precision requirements of 77 GHz antenna. In order to achieve a relatively high gain, the 77 GHz radar antenna needs to be in an array antenna form. As well known, in millimeter-wave band, series-fed method is better than parallel-fed one in consideration of the simple feeding network and low insertion loss. Therefore, series-fed method has been more widely adopted in 77 GHz radar, as can be seen in [9–11].

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This paper presents the design of a 77 GHz series-fed antenna array. Similar ideas have been shown in papers as in [12] and [13]. Side-lobe level is an important indicator of a radar antenna. It should be noticed that the series-fed patches in this paper are weighted in order to lower the E-plane side lobes. [12] reports a W-band 8×8 series-fed patch array pattern, but the E-plane side-lobe level is not good due to the unweighted patches. The E-plane side-lobe level in our work is almost 5 dB lower than the one in [12]. Similarly, [14] presents a 4×4 unweighted patch antenna array for 77 and 94 GHz frequencies. The side-lobe level is close to -10 dB. In [15], a ten-element antenna array with a Wilkinson divider feeding network is presented with a side-lobe suppression of nearly -15 dB. However, the complicated feeding network is not suitable for millimeter wave applications because it will bring quite a bit of losses along the unusually long microstrip line. In our research, a Wilkinson 1 : 8 un-equal divider is also adopted to obtain low side-lobe level in H-plane. So the side lobes in E- and H-planes are all suppressed in this paper.

2. ANTENNA ARRANGEMENT

The antenna is simulated in Ansoft HFSS, and the required operation bandwidth is from 76 GHz to 78 GHz. The single antenna array consists of six units series-fed microstrip patches on a Rogers 5880 substrate ($\varepsilon_r = 2.2 \tan\delta = 9 \times 10^{-4}$) with thickness $h = 0.127$ mm. This ultra-thin substrate will effectively suppress the surface wave in millimeter-wave antennas. Design configuration of the antenna array is shown in Fig. 1. The width and length of the middle patch in one array are calculated by transmission-line model of microstrip antenna [16]. In order to reduce the side lobe in E-plane pattern, the width of other antenna elements is chosen according to the current distribution on each antenna. Based on [17], by proportionally tapering the patch width with the normalized Taylor distribution amplitudes, finally we get the width of the other patches. The length of the feeding line between series fed patches is $\lambda_g/2$ (half wavelength in transmission line) to ensure the same phase. Actually, a lot of works have been done to improve the antenna performance. For example, the antenna resonance frequency changes when six patches are combined. So length of the patch should be optimized. Space between the patches of one array should also be parametricly swept.

In consideration of narrowing H-plane beamwidth, in this design, we use eight same single arrays in parallel with a spacing of $\lambda_0/2$ (λ_0 is the freespace wavelength at 77 GHz) to build the final antenna array. Meanwhile, a Wilkinson 1 : 8 un-equal divider is employed to connect the eight arrays. So each of the eight arrays is fed unequally by -20 dB Taylor's distribution excitation in order to reduce

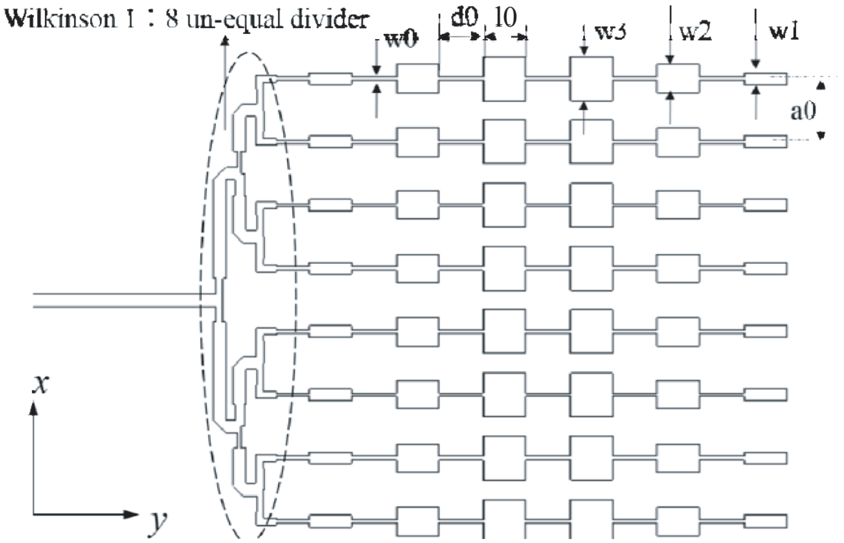


Figure 1. Antenna array design configuration. Structure parameters: $w0 = 0.1$ mm, $w1 = 0.35$ mm, $w2 = 0.85$ mm, $w3 = 1.32$ mm, $d0 = 1.35$ mm, $l0 = 1.265$ mm, $a0 = 1.9$ mm.

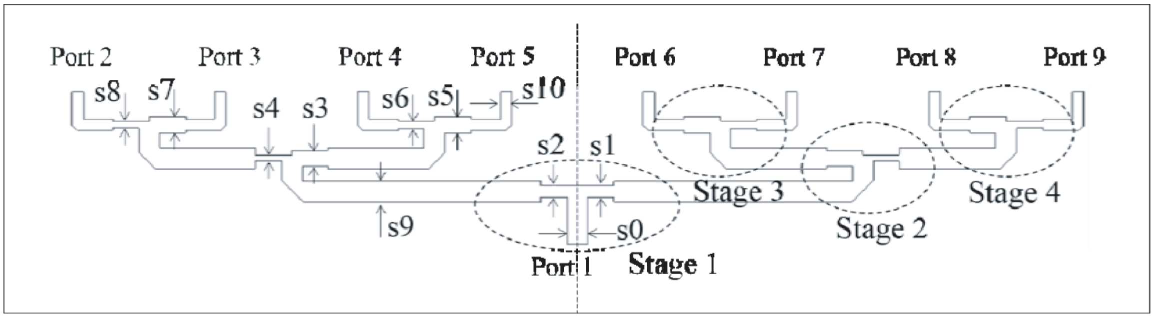


Figure 2. Configuration of the presented Wilkinson 1 : 8 un-equal divider. Structure parameters: $s0 = 0.38\,\mathrm{mm}$, $s1 = 0.208\,\mathrm{mm}$, $s2 = 0.208\,\mathrm{mm}$, $s3 = 0.268\,\mathrm{mm}$, $s4 = 0.14\,\mathrm{mm}$, $s5 = 0.23\,\mathrm{mm}$, $s6 = 0.186\,\mathrm{mm}$, $s7 = 0.219\,\mathrm{mm}$, $s8 = 0.197\,\mathrm{mm}$, $s9 = 0.38\,\mathrm{mm}$, $s10 = 0.208\,\mathrm{mm}$.

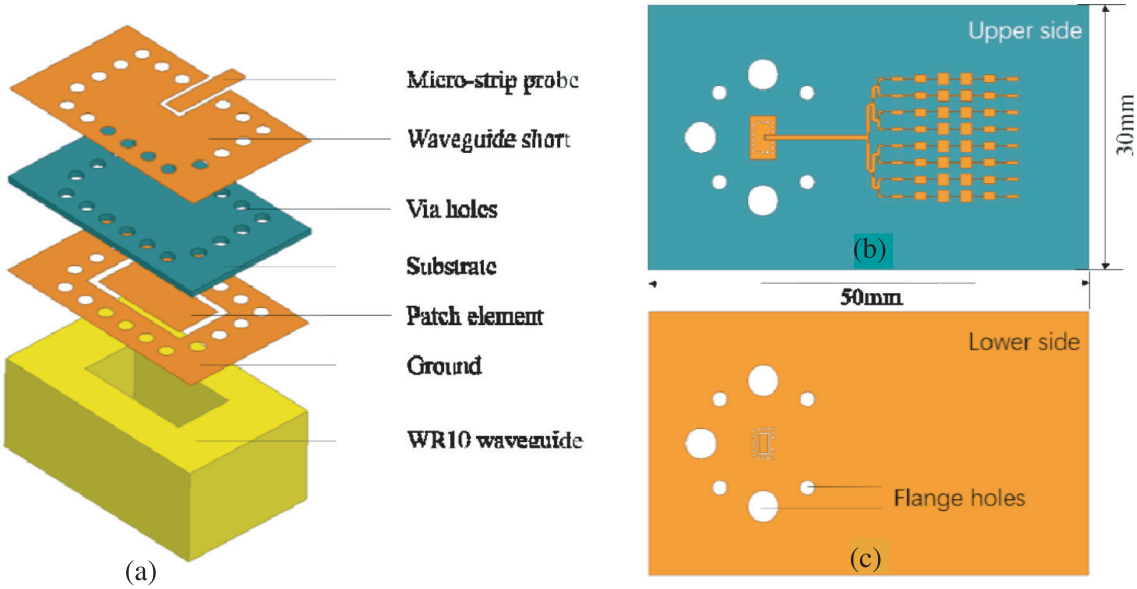


Figure 3. (a) Microstrip to waveguide transition. (b) Antenna upper side. (c) Antenna lower side.

the H-plane side lobe. Fig. 2 shows the presented compact microstrip Wilkinson 1 : 8 unequal divider. This microstrip divider consists of one equal T-junction divider (stage 1) and three unequal T-junction dividers (stages 2, 3 and 4) [18]. The current amplitude coefficients in this design are: $a_i = [0.53 : 0.623 : 0.832 : 1 : 1 : 0.832 : 0.623 : 0.53]$.

In millimeter-wave band, microstrip to waveguide transition is requested to have higher performance. Various solutions have been proposed such as quasi-Yagi type [19] and planar waveguide type [20], but the bandwidth is limited. In this paper, a wide-band microstrip to waveguide transition is adopted to feed the antenna array. In Fig. 3(a), we can see that a microstrip probe and a waveguide short are located on the upper side of the substrate. SIW like metallic holes are used to connect the upper side to the WR10 waveguide. In the lower side of the substrate, a patch element is placed to conduct the wave to the metal waveguide. The prepunched flange holes will make a precise connection between antenna and the WR10 waveguide, as shown in Figs. 3(b) and (c). According to HFSS simulation, reflection characteristic $|S_{11}|$ and the insertion loss $|S_{21}|$ of the transition model in Fig. 3(a) are presented in Fig. 4. We can see that the resonance occurs at 77.1 GHz; -15 dB impedance bandwidth is 5.91 GHz (from 74.5 GHz to 80.41 GHz) which is much more than the required operation bandwidth; insertion loss $|S_{21}|$ is less than 0.26 dB from 76 GHz to 78 GHz. The simulation results show that the proposed structure is fit for the millimeter-wave microstrip to waveguide transition.

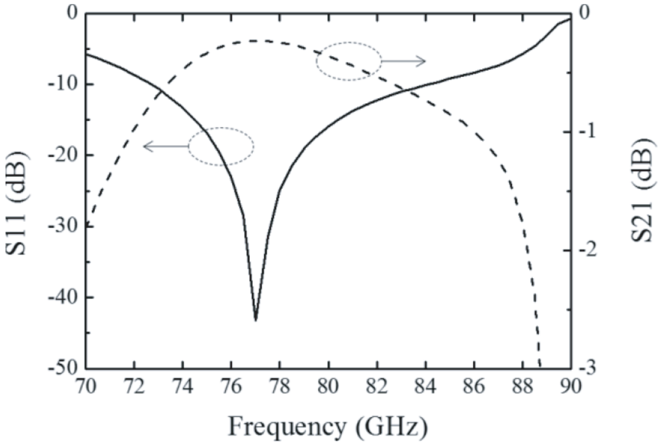
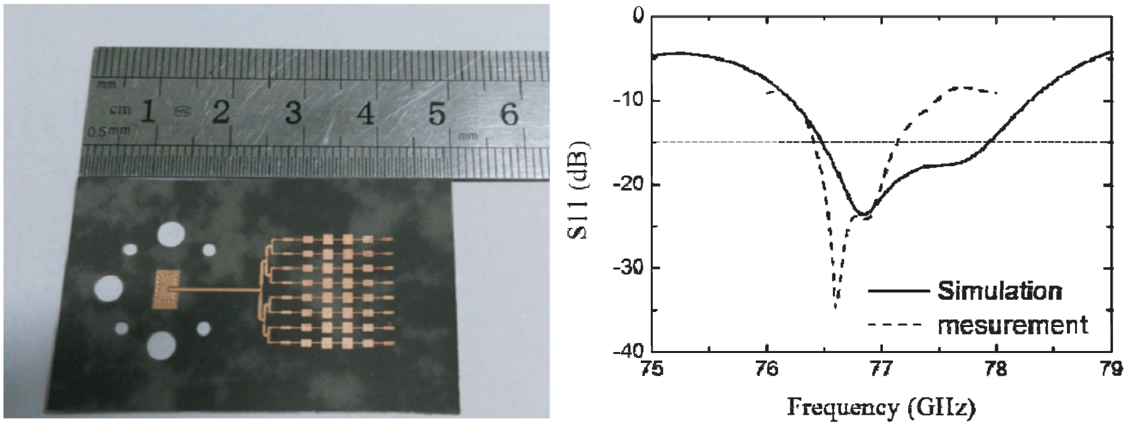
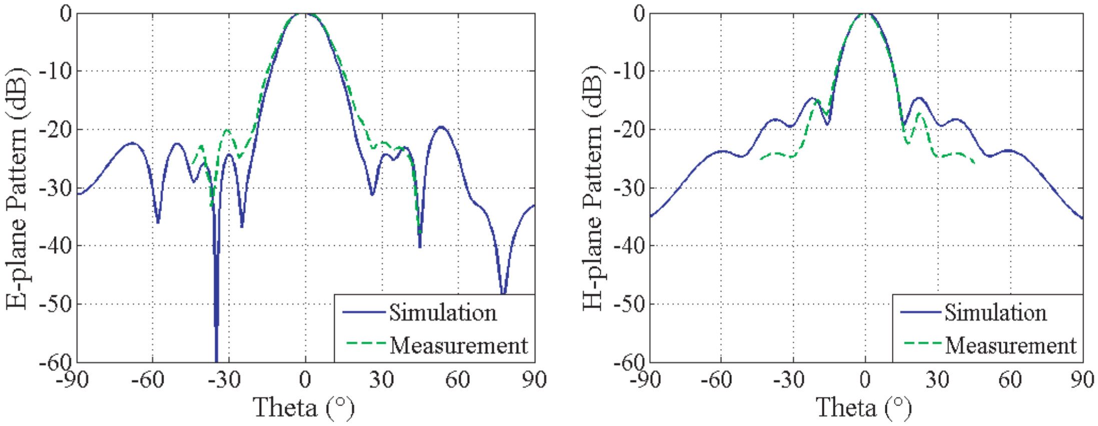


Figure 4. Reflection characteristic $|S_{11}|$ and the insertion loss $|S_{21}|$ of the transition model in Fig. 3(a).



(a) (b)

Figure 5. (a) Photograph of the proposed antenna with microstrip to waveguide transition. (b) The simulated and measured reflection characteristic $|S_{11}|$ of the proposed antenna.



(a) (b)

Figure 6. The simulated and measured far-field pattern: (a) *E*-plane, (b) *H*-plane.

3. ANTENNA FABRICATION AND MEASUREMENT

A photograph of the antenna array with WR-10 flange hole is shown in Fig. 5(a). Antenna size is just 50 × 30 mm. The result in Fig. 5(b) shows that the proposed antenna achieves a −15 dB impedance bandwidth of 730 MHz (from 76.47 GHz to 77.2 GHz) while the simulated impedance bandwidth is 1.8 GHz. The difference between the simulated and measured results may be due to the manufacture errors and the dielectric constant offset.

Figure 6 shows that the simulated 3 dB beamwidth of the designed antenna is 15.63° in *E*-plane and 13.6° in *H*-plane, respectively. In contrast, the measured 3 dB beamwidth is 16.7° in *E*-plane and 12.82° in *H*-plane. Good accordance is obtained between simulated and measured results. In addition, the *E*-plane side-lobe level is approximately below −20.15 dB, and the *H*-plane side-lobe level is about −15 dB. The designed series-fed weighted antenna shows good directivity in radiation pattern at 77 GHz, as can be seen in Fig. 7.

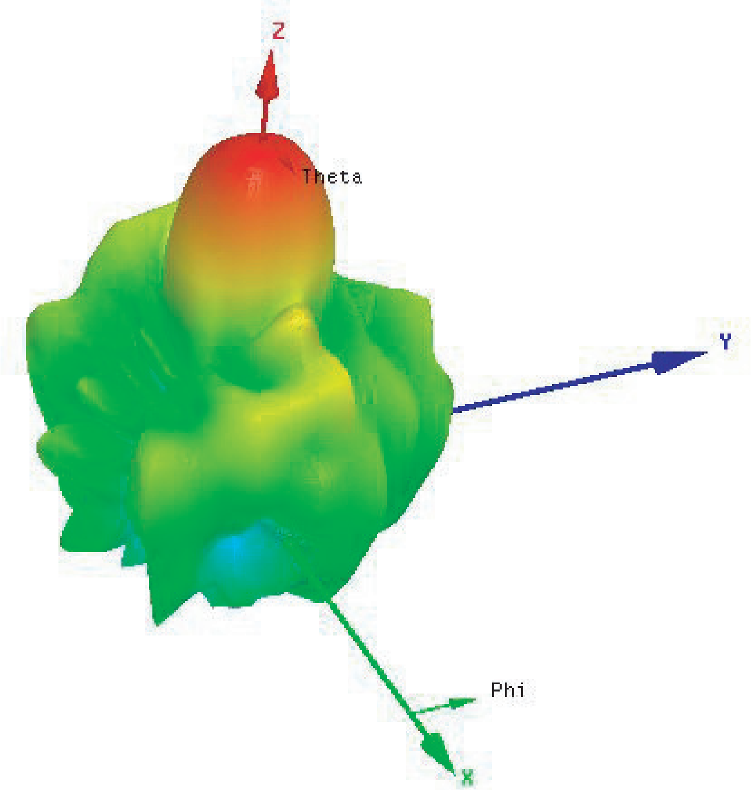


Figure 7. The 3D far-field pattern.

4. CONCLUSION

A 77 GHz microstrip series-fed patch antenna array with suppressed side-lobes in *E*- and *H*-plane is proposed in this paper. In the far-field antenna patterns, the *E*-plane side-lobe level is approximately below −20.15 dB, and the *H*-plane side-lobe level is about −15 dB. Results show that the designed antenna has great value in the application fields of 77 GHz automotive radar antenna.

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