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MILLIMETER WAVE OMNIDIRECTIONAL QUASI-YAGI ARRAY

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Abstract—A novel planar omnidirectional array based on Quasi-Yagi antenna is proposed in this paper. The modeling of this antenna and design method based on equivalent circuits have been developed. An eight-unit planar array has been designed, fabricated and measured. Measured results exhibit good performance of the return loss and radiation pattern in horizontal plane. The gain of the array in horizontal plane was about 0 dBi. The un-roundness of the radiation pattern in horizontal plane was about 5 dB.

1. INTRODUCTION

Smart antennas are used more and more commonly in wireless communication system as more and more components are arranged in a given space simultaneously for dimension restriction. In these systems, very limited space is used for antenna; it promotes the development of smart antenna to some degree. In some UMTS or small base station systems, omnidirectional radiation pattern antennas are usually used as operating antenna. In these systems $\lambda/4$ monopole or other kind of vertical polarization antennas are usually used. Monopole antenna is characterized with good performance of H-plane omnidirectional pattern and easily designed. Unfortunately, antennas with vertical polarization usually have a large profile; it results in intolerable large profile of the overall system. In some military or special application base station systems which have strict restriction for antenna profile, omnidirectional pattern antennas with horizontal polarization are needed. The un-roundness of radiation pattern in operating plane is also an important factor when high accuracy of the subsequent signal processing is needed. Many antennas with characteristics of omnidirectional radiation pattern and horizontal polarization have been demonstrated in [1–3]. In [1], the antenna structure is unsuitable for printed antenna; in [2], the ground and the fed line are arranged in two layers of the substrate; RF-signals is easily interfered by the antenna when it is fixed in the upper of the RF-circuit; in [3], the complex feeding structure is not easily fabricated. In this paper, a new kind of 8-unit planar omnidirectional array based on Quasi-Yagi antenna is presented; the planar Quasi-Yagi antenna is used as the unit of the array. Feeding point is located in the centre and feeding network is used to divide the input power and feed every unit equally. The bandwidth and un-roundness of horizontal plane of the array are about 1 GHz and 5 dB, respectively.

Planar Quasi-Yagi antennas are used commonly in point to point communication system or as unit of array. This kind of antenna has large front-to-back ratio. The structure of the planar Quasi-Yagi antenna and its application as the unit of 3D array can be found in [4]. The example of printed planar Quasi-Yagi antenna array can be observed in [5]. [6] analyzes the BALUN effects in design of the antenna. Planar array iss established in [7] for adaptive wireless system applications, but not suitable for base station system. The unit of the array we proposed is shown in Fig. 1. The black area is the top and the other area is the bottom ground; it has no difference in traditional planar Quasi-Yagi antenna. The length of one arm for the Quasi-Yagi antenna is about $\lambda_g/4$ and the dimension of the BALUN is adjusted to ensure the 180 degree difference between two out ports. Some other kind of omnidirectional antennas can be found in [8–11]. They are all

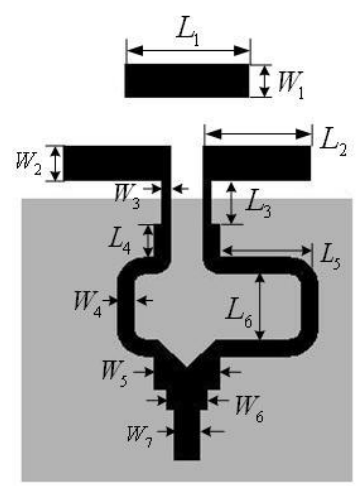

Figure 1. Unit of the array.

vertical polarized corresponding to H-plane omnidirectional radiation pattern and have large profile when the H-plane is used as operating plane.

Equivalent circuits of antenna are always needed for system simulation. Broadband equivalent circuit of a dipole antenna is proposed in [12]. The equivalent circuit of Quasi-Yagi antenna has the same form as dipole antenna. The only difference is the additional coupling occurred between the arm and director of printed Quasi-Yagi antenna; it can be included in resonant circuit-2 (composed of C_2, L_2, R_2). The values of the capacitance and inductance in Fig. 2 are different with the normal dipole for the different application frequency and fabrication process, but the circuit model is available for the contractible-scaled theory.

The equivalent circuit of the Quasi-Yagi array unit is shown in Fig. 2.

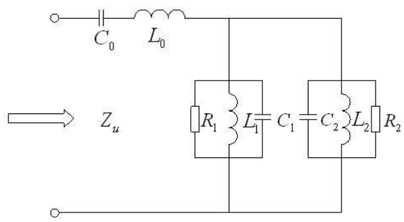

Figure 2. Equivalent circuit of the unit.

The equivalent-circuit approach, similar to that of [12], can be taken to determine reasonable values for the characteristic impedance of each unit and the overall array. Considering Fig. 2, let Z_0, Z_1 and Z_3 be the impedance brought by the three resonant circuits respectively. The impedance of the unit seen from the centre feeding point can be calculated as (Fig. 1):

$$Z_u = \frac{Z_1 \cdot Z_2}{Z_1 + Z_2} \tag{1}$$

where

$$Z_0 = j\omega_0 + \frac{1}{j\omega C_0} \tag{2}$$

$$Z_1 = \frac{j\omega R_1 L_1}{R_1 + j\omega L_1 - \omega^2 R_1 L_1 C_1} \tag{3}$$

$$Z_2 = \frac{j\omega R_2 L_2}{R_2 + j\omega L_2 - \omega^2 R_2 L_2 C_2} \tag{4}$$

Let $Z_u = 50\,\Omega$, when ω are selected, it can return to calculate the value of $\frac{l}{\omega}$ according to the method of [12]. For different ω, the corresponding l can be obtained. The result can be regarded as the initial value for optimization. Once suitable initial is used to realize the desired return loss and determine the final dimensions of the structure.

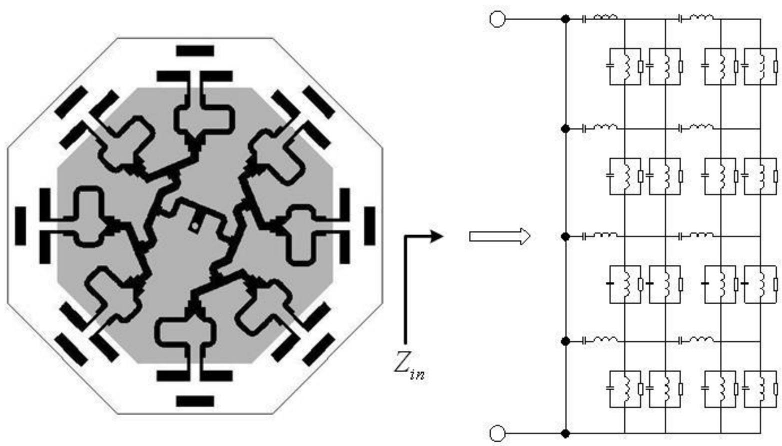

Figure 3. Array and its equivalent circuit.

2. DESIGN OF THE ARRAY

Figure 3 shows the proposed eight-unit planar Quasi-Yagi array and its equivalent-circuit. It is composed of eight units and a feeding network. The feeding point is located in the centre of the array. It can be fed by coupling fed line in other layers or by a coaxial line. Three stage 3-dB power divider is used to divide the input power to eight units equally. Widths of every microstrip line in the feeding network are calculated by ADS Line calculator under guidelines of power divider theory. The impedance of the array seen from the centre feeding point is:

$$Z_{in} = \frac{1}{8} Z_u = \frac{1}{8}\left[Z_0 + \frac{Z_1 \cdot Z_2}{Z_1 + Z_2}\right] \tag{5}$$

3. EXPERIMENT AND RESULTS

In order to verify the validity of the above method, an 8-unit array for operating in 37.5 GHz is designed and built in RT/Duroid 5880.

Figure 4. Photo of the array.

The permittivity and loss tangent of the dielectric material are 2.2 and $\tan\delta = 0.009$, respectively. The optimized dimensions of the unit are shown in Table 1. The thickness of the substrate is 0.254 mm and the corresponding width of the 50 Ω input microstrip line is 0.8 mm. The photo of the array is shown in Fig. 4.

Table 1. Dimensions of the unit.

W_1	W_2	W_3	W_4	W_5	W_6	W_7
1 mm	1 mm	0.2 mm	0.4 mm	1.6 mm	1 mm	0.8 mm
L_1	L_2	L_3	L_4	L_5	L_6	
1.5 mm	1.5 mm	1 mm	1 mm	2.4 mm	2 mm	

The return loss and radiation pattern of horizontal plane are shown in Fig. 5 and Fig. 6, respectively. We can see from Fig. 5 that the measured return loss is very similar to the simulated one. There is a small offset of the lowest point introduced by misalignment or manufacture problem. The bandwidth of the array is very narrow for the resonant $\lambda_g/4$ length arm. There are also many methods can be used to improve the bandwidth such as adding slot or patch on two arms; it is not the primary problem this paper focuses. Fig. 6 shows that the simulated and measured un-roundness of the radiation pattern in E-plane is around 5 dB. The un-roundness of the array can be improved by a more complicated feeding network and increasing the number of the Quasi-Yagi element at the cost of gain reduction for dielectric loss. The average gain of the array in horizontal plane is about 0 dBi. It is almost equal to theoretical gain.

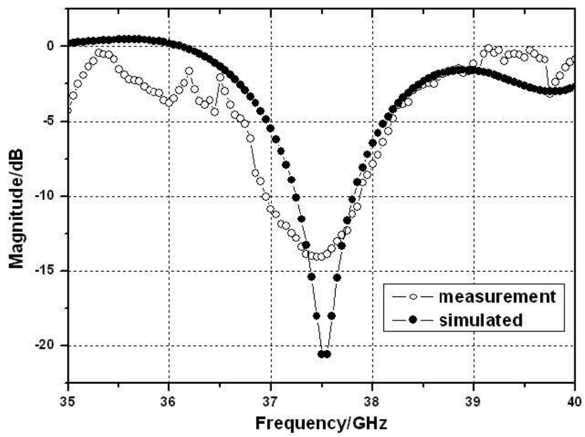

Figure 5. Return loss of the array.

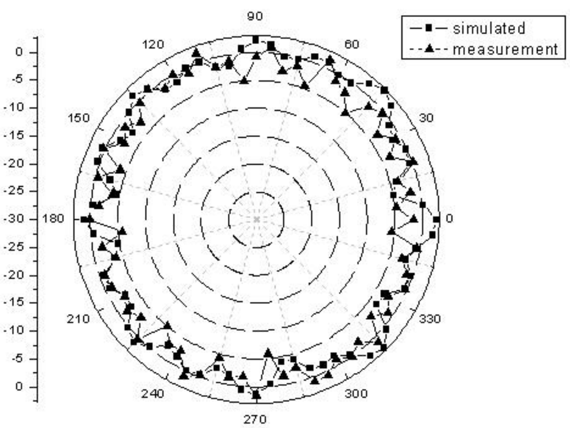

Figure 6. Radiation pattern for $\theta = 90°$.

4. CONCLUSIONS

A novel planar millimeter-wave omnidirectional array based on Quasi-Yagi antenna has been developed in this paper. Printed Quasi-Yagi antenna is used as the unit of the array and feeding network based on three-stage 3-dB power divider which is used to feed every unit equally. The design method for perfect planar array has been analyzed based on equivalent circuits. An 8-unit array is designed, simulated and fabricated to validate the design method. Good performance of return loss and un-roundness of horizontal plane radiation pattern is observed. This 8-unit planar omnidirectional array demonstrates the advantages of low profile, lightweight and easy fabrication.

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