Double-Layer High-Gain Microstrip Array Antenna

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***Abstract*—Novel double-layer microstrip array antennas are introduced for high-gain applications. In the proposed antennas, the complex and lossy feed network is not needed. Rather the double structure provides the field distribution at the aperture for the beam-focusing effect. A relatively simple design method based on a cavity model is presented.**

***Index Terms*—Array antenna, microstrip antenna.**

I. Introduction

MICROSTRIP antenna arrays have earned much attention due to their advantages over conventional antenna such as reflector antennas. In order to achieve a high antenna gain, however, the energy losses from the feeding structure must be reduced significantly. As reported in Henderson and James's design [1], the overall antenna efficiency drops to only 20% due to the large amount of feedline losses. In the Ka-band circularly polarized high-gain microstrip array presented by Huang [2], the efficiency is improved but still in the range of 55%. The main problem in a microstrip array has been the feed structure to the numerous radiating elements, which tends to become more complicated for a large array. In this paper, a simple feed structure is introduced to increase the antenna efficiency. The novel feeding scheme reduces the loss at the feed substantially.

The design concept is based on the double-layer microstrip structure, which was first introduced for the purpose of impedance matching [3], and has been used for a linear microstrip array [4]. Each array element is designed individually and integrated into an array configuration. The array element is defined such that the boundaries with its neighboring elements are enclosed with a perfect magnetic conductor (PMC) where the magnetic field component tangent to the interface vanishes [5]. When neighboring elements are connected, the boundary conditions at the element edges do not change and the array becomes a large resonant antenna. In this new structure, complex striplines to feed array elements are not needed. Since each element is designed separately, it is now possible to control the beam shape by varying the field strength at the radiating edges of the array elements.

Section II briefly describes the design scheme of the double-layer structure for an array antenna. The detailed formulation based on the cavity model is given in [5]. Section III compares numerical results with measured results to prove the design concept.

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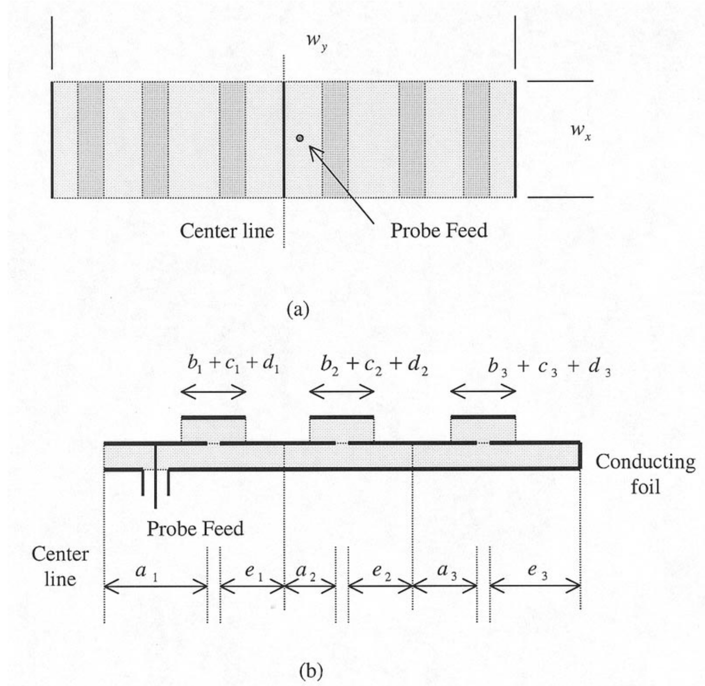

Fig. 1. A three-pair element rectangular microstrip array. (a) Top view. (b) Half of the cross-sectional view. The slot widths are c_1, c_2, and c_2. The dimensions of b_1, b_2, and b_3 indicate the widths of the overlapping regions between the top radiating patches and the middle metallic layer to the left sides of the slots and d_1, d_2, and d_3 are the widths of the overlapping areas to the right.

II. Design Scheme

A three-element linear array is shown in Fig. 1. One can design each array element individually to effectively control the distribution of an array element [4]. A conducting pin is connected at the center to ensure that the electric field vanishes and suppresses any unwanted mode excitations. The outer edge of the farthest element from the center is also shorted with a conducting patch to eliminate the unwanted radiation from the lower layer. For an optimum field distribution, one should choose proper sizes of gap and metallic patches at both of the upper and the lower layers as described in [3] and [5]. The altered field configuration can be achieved by shifting the location of the top patch or gap. Finally, a coaxial probe pin is placed where the amplitude of electric field is high enough to match the input impedance. When the array is large, the normalized field strength of the resonating mode around the feed is small and impedance matching becomes increasingly difficult. With a double-layer structure, it is possible to increase the field magnitude by varying the patch and gap sizes. Thus, the design scheme for the center element of the feed is different from those for the outer elements in which the field distributions are considered for the beam shape. In a given feed element design, the pin is placed usually at the point where the field is strongest because

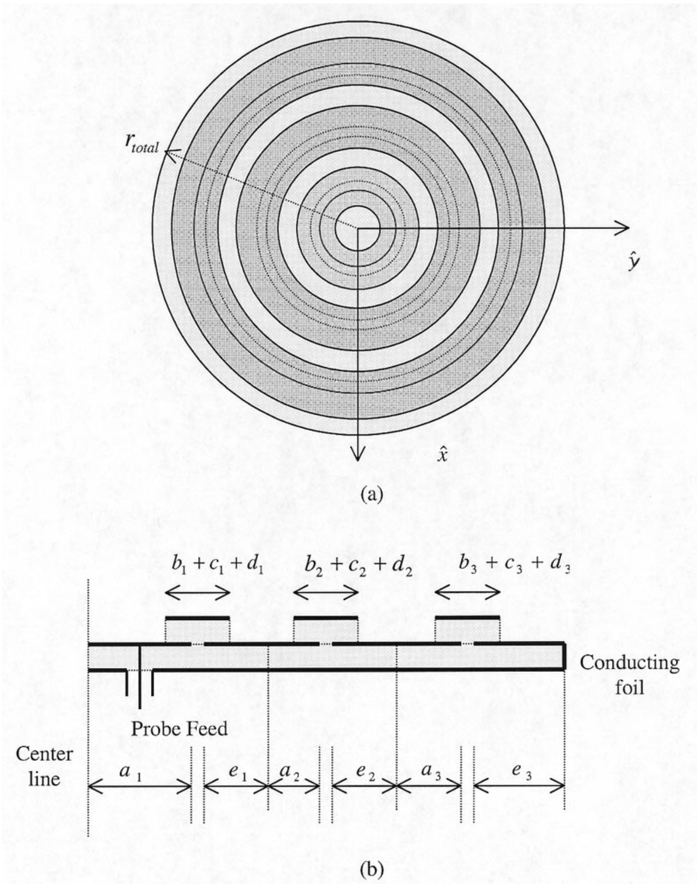

Fig. 2. A three-element circular microstrip array. (a) Top view. (b) Half of the cross-sectional view. The slot widths are c_1, c_2, and c_2 for the first, second, and third elements from the center, respectively. The dimensions of b_1, b_2, and b_3 indicate the widths of the overlapping regions between the top radiating patches and the middle metallic layer to the left sides of the slots and d_1, d_2, and d_3 are the widths of the overlapping areas to the right. Thus, $b_1+c_1+d_1$, $b_2+c_2+d_2$ and $b_3+c_3+d_3$ are the widths of the respective top radiating patches.

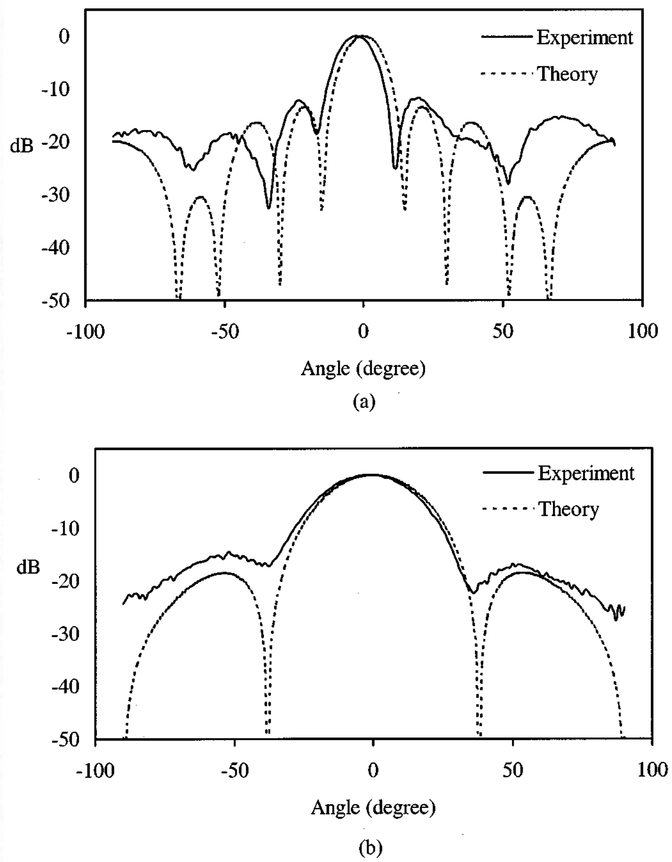

Fig. 3. The theoretical and the measured radiation patterns of the rectangular array in Fig. 1 at 4.96 GHz. (a) E-plane. (b) H-plane. The dimensions are $a_1 = 2.7$ cm, $e_1 = 1.3$ cm, $a_2 = 2.6$ cm, $e_2 = 0.8$ cm, $a_3 = 2.6$ cm, $e_3 = 1.7$ cm, $b_1 = 1.5$ cm, $b_2 = b_3 = 0.8$ cm, $c_1 = c_2 = c_3 = 0.2$ cm, $d_1 = 1.4$ cm, $d_2 = d_3 = 0.8$ cm, $w_x = 5$ cm, and $\varepsilon_r = 2.94$ and $t = 60$ mils. The feed is located 0.9 cm from the center line.

the antenna becomes less efficient as the field strength at the feed increases. In the design process, the resonant frequencies of the individual elements are made to be as close as possible.

III. Experimental and Theoretical Results

A three-element rectangular array antenna and a three-element circular antenna were fabricated with Rogers RT/duroid 6002, which are shown in Figs. 1 and 2, respectively.

For the rectangular array, a coaxial probe pin is placed 0.9 cm away from the centerline where the electric field is highest and the corresponding design resonant input resistance is 56 Ω. The total quality factor determines not only the bandwidth but also influences the input impedance. The higher Q value is, the narrower the bandwidth is but the resonant resistance increases for easy input impedance matching. The quality factor is designed to be around 100 to give an acceptable bandwidth, while the input impedance can be easily matched.

The measured resonant frequency is 4.96 GHz, which is very close to the computed value. Fig. 3 compares the numerical and measured results of the E- and H-plane radiation patterns, which shows excellent agreement between theory and experiment. The slight discrepancy of the E-plane patterns between the theory and measurement could be due to the tilt of the array axis during the measurement. The side lobe levels are below -13 dB. The measured antenna gain is 18.5 dB compared with the ideal value of 19.5 dB. The corresponding aperture efficiency is 79%.

For the circular array shown in Fig. 3, the design process is similar to that of the rectangular array, except that the basis functions are different [5]. Even though the antenna covers a two-dimensional (2-D) plane, the design process involves essentially one-dimensional (1-D) problem and is as simple as in the rectangular case. The coaxial cable is placed only 0.5 cm from the center to have the resonant input impedance slightly larger than 50 Ω.

The measured resonant frequency was 5.16 GHz, compared with the design frequency of 5.07 GHz. Fig. 4 shows the measured and computed radiation patterns of the E- and H-plane. Again the agreement between the theoretical and experimental values is excellent. The measured antenna gain is 15.9 dB, which is within experimental error from the computed ideal directivity of 17.3 dB. The resultant aperture efficiency is 23%. The low efficiency is mainly due to the unwanted radiation of cross polarization. In other words, the maximum possible aperture efficiency is only 50%. The high cross-polarization

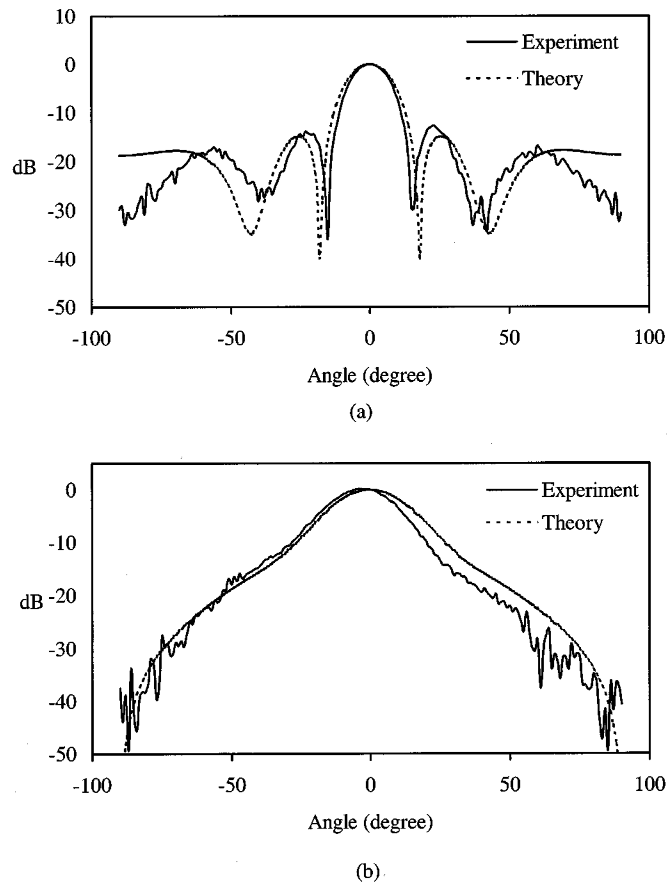

Fig. 4. The theoretical and measured radiation patterns of the circular planar microstrip array in Fig. 3 at 5.16 GHz. (a) E-plane. (b) H-plane. The dimensions used are: $a_1 = e_1 = 2.5$ cm, $a_2 = 1.3$ cm, $e_2 = 2.4$ cm, $a_3 = 1.3$ cm, $e_3 = 1.55$ cm, $b_1 = b_2 = b_3 = 0.5$ cm, $c_1 = c_2 = c_3 = 0.2$ cm, $d_1 = d_2 = d_3 = 0.5$ cm, and $\varepsilon_r = 2.94$ and $t = 30$ mils. The feed is located 0.5 cm from the center.

level is attributed to a circular shape of the radiating edges of the upper microstrip patches.

The circular geometry provides a convenient method for a 2-D microstrip geometry, but the aperture efficiency is much smaller than that of the rectangular array.

IV. Concluding Remarks

Novel microstrip array antennas are introduced. By utilizing a double-layer structure, the need of a complex feed network has been eliminated. A rectangular array is demonstrated to show high aperture efficiency. The maximum size, however, is limited due to the design constraint of input impedance matching. A circular array antenna is introduced to overcome such size limitation. One drawback of the circular array is its aperture efficiency substantially less than that of the linear array due to high cross-polarization levels.

References

[1] A. Henderson and J. R. James, "Improved microstrip flat-plate array for domestic DBS reception," in *IEEE Antenna Propagat. Symp.*, Philadelphia, PA, 1986, pp. 565–568.

[2] J. Huang, "A K-band circularly polarized high-gain mcirostrip array antenna," *IEEE Trans. Antennas Propagat.*, vol. 43, pp. 113–116, Jan. 1995.

[3] C. S. Lee, T.-H. Hsieh, and V. Nalbandian, "Impedance matching of a double-layer microstrip antenna," *Microwave Opt. Technol. Lett.*, vol. 14, pp. 295–296, 1997.

[4] C. S. Lee and T.-H. Hsieh, "Linear microstrip array antenna with a simply feed network," *Microwave Opt. Technol. Lett.*, vol. 23, pp. 25–27, 1999.

[5] T.-H. Hsieh, "Double-layer microstrip array antenna," Ph.D. dissertation.

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