

# A Planar Van Atta Array Reflector with Retrodirectivity in Both $E$ -Plane and $H$ -Plane

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**Abstract**—A planar antenna array reflector with retrodirectivity in both the  $E$ -plane and the  $H$ -plane is analyzed and demonstrated at  $X$  band. The reflector consists of six pairs of slot-coupled patch antennas arranged using the Van Atta approach. The total reflected field from the reflector is separated into three primary components; that is, the reradiation field from the patch antennas (RFPA), the scattering field from the patch antennas (SFPA), and the scattering field from the ground plane (SFGP). The first two components are calculated by using the method of moments together with a mixed potential integral equation and the last one is by the physical optics (PO) method combined with the method of equivalent currents (MEC). By tuning the microstrip-line lengths, the total reflected field contributed by the three components is designed to possess a broad-beamed pattern in both the  $E$ -plane and the  $H$ -plane. The measured patterns show good agreement with the designed ones.

**Index Terms**—Microstrip antennas, retrodirectivity, Van Atta array.

## I. INTRODUCTION

AFTER the proposal of the Van Atta retrodirective array reflector [1] in 1959, many related investigations have been reported due to its broad reflected-field pattern, which was useful for applications in enhancing the radar cross sections of ships and airplanes [2] and in satellite communications [3]. In these investigations, the dipole or horn antennas were used to implement the array reflector and the coaxial cables were chosen to connect the antennas. Recently, the authors have used planar antennas and printed transmission lines to implement the array reflectors [4], [5]. Due to the conformability of the structure, these planar retrodirective reflectors may be suitable for use in vehicle collision avoidance systems to enhance radar echoes from vehicles or roadside obstacles [4]. They are also suitable for use in beacon communication systems to increase the communication range of an on-board unit in a vehicle [5]. However, these planar array reflectors were with retrodirectivity in one dimension. They could only reflect high fields to the source points in the  $E$ -plane or the  $H$ -plane of the antenna array. In addition, the reflected fields were analyzed in conjunction with the experimental results.

In this paper, a  $3 \times 4$  planar Van Atta array reflector with two-dimensional (2-D) retrodirectivity is implemented. A more

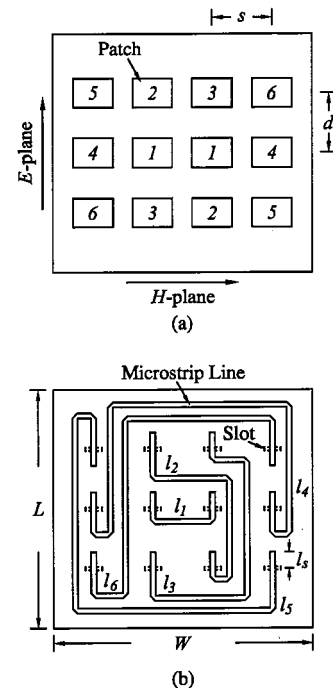


Fig. 1. (a) Top view and (b) bottom view of a planar retrodirective reflector using six pairs of slot-coupled patch antennas.  $L \times W = 72 \times 78 \text{ mm}^2$ .

rigorous analyzing method, which combines the method of moments and physical optics (PO) together with the method of equivalent currents (MEC), is used to analyze the scattering characteristics of the retrodirective reflector. Numerical and measured results are presented, which show good agreement with each other.

## II. ANALYSIS

Fig. 1 shows the top and bottom views of the proposed 2-D retrodirective reflector, which includes six slot-coupled patch antenna pairs on the antenna substrate [Fig. 1(a)] linked by  $50\text{-}\Omega$  microstrip lines of lengths  $l_1$  to  $l_6$  on the circuit substrate [Fig. 1(b)]. The dielectric constant ( $\epsilon_{ra}$ ) and the thickness ( $h_a$ ) of the antenna substrate are chosen as 2.33 and 0.7874 mm, respectively, and those ( $\epsilon_{rc}$ ,  $h_c$ ) of the circuit substrate are 2.2 and 0.508 mm. The sizes of the antenna patch and the coupling slot are designed to be  $8.73 \times 12 \text{ mm}^2$  and  $4 \times 1 \text{ mm}^2$  with a tuning stub length  $l_s$  of 5 mm. With this design, the antenna possesses a measured 10-dB return-loss bandwidth of 3% and a return loss of  $-18.3 \text{ dB}$  at the center frequency of 10 GHz. According to the Van Atta arrangement, the paired antennas are located symmetrically with respect to the reflector's center

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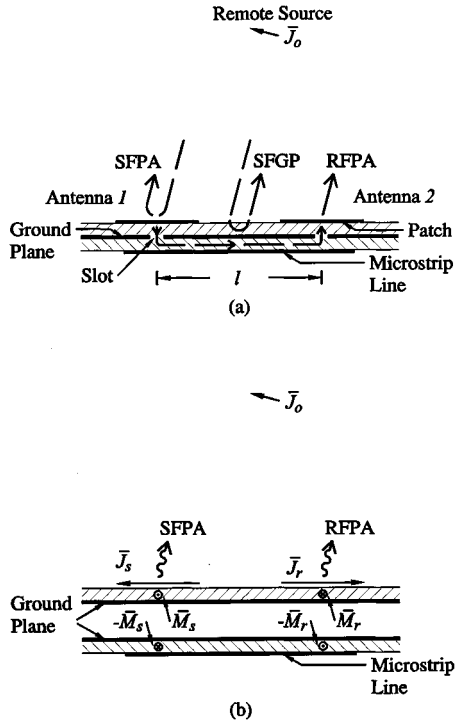


Fig. 2. (a) A slot-coupled patch antenna pair connected by a microstrip line of length  $l$ . (b) The induction equivalence of (a).

and the differences of  $l_1$  to  $l_6$  are multiples of a microstrip-line wavelength. The interelement distances in the  $E$ -plane ( $d$ ) and in the  $H$ -plane ( $s$ ) are both chosen as  $0.6\lambda_0$  to reduce the coupling effect between antennas [6]. In the following analysis, the mutual coupling between antennas and those between antennas and the ground plane edges are neglected.

The scattering mechanism of this reflector can be comprehended through Fig. 2(a), where one antenna pair with antennas 1 and 2 connected by a microstrip line of length  $l$  is shown. As the wave from a remote source ( $\vec{J}_0$ ) is incident upon antenna 1 (2), an electric current  $\vec{J}_s$  is induced on the patch and an electromagnetic field is distributed over the slot. By the equivalence principle, the slot can be closed off and replaced by equivalent magnetic currents above ( $\vec{M}_s$ ) and below ( $-\vec{M}_s$ ) the ground plane, as shown in Fig. 2(b). The magnetic current below the ground plane excites a modal field traveling through the connecting microstrip line toward the coupling slot of antenna 2 (1), which also induces a patch electric current  $\vec{J}_r$  and slot equivalent magnetic currents above ( $\vec{M}_r$ ) and below ( $-\vec{M}_r$ ) the ground plane. Therefore, by the equivalence principle, the total field above the ground plane is contributed by three sets of current sources; that is, the remote source  $\vec{J}_0$ , the currents ( $\vec{J}_s, \vec{M}_s$ ) and the currents ( $\vec{J}_r, \vec{M}_r$ ). All these currents radiate under the presence of the patch-free, slot-free, but substrate-loaded ground plane [Fig. 2(b)]. The field produced by the currents ( $\vec{J}_s, \vec{M}_s$ ) is denoted as the *scattering field from the patch antenna* (SFPA) and that by the currents ( $\vec{J}_r, \vec{M}_r$ ) is the *reradiation field from the patch antenna* (RFPA). The scattering field from the substrate-loaded ground plane due to the remote source  $\vec{J}_0$  is expressed as the *scattering field from the ground plane* (SFGP).

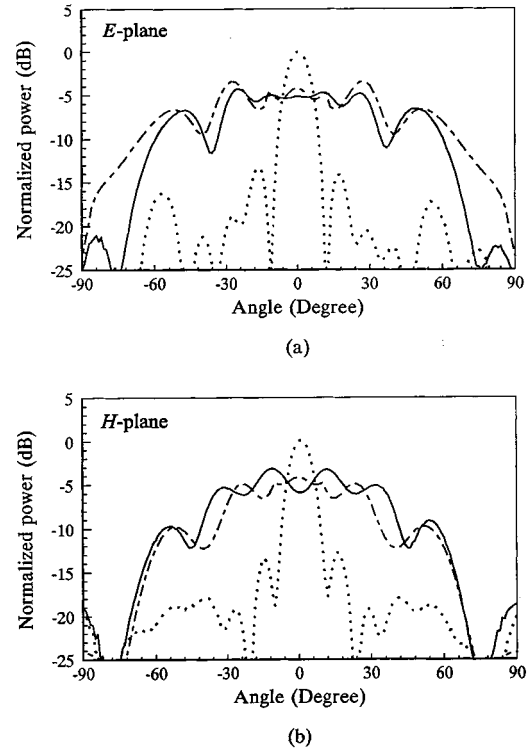


Fig. 3. Measured (—) and calculated (---) reflected-field patterns in (a)  $E$ -plane and (b)  $H$ -plane for a retrodirective reflector with a microstrip-line phase delay of  $37^\circ$ . Dotted lines ( $\cdots$ ) represent the measured patterns of a metal plate with the same size.  $f = 10$  GHz.  $(l_1, l_2, l_3, l_4, l_5, l_6) = (24, 67.5, 89.3, 154.6, 143.7, 121.9)$  mm. The microstrip-line wavelength is 21.76 mm.

These three field components make up the reflector's total reflected field.

The method of moments together with a mixed potential integral equation (MPIE) is used to solve the unknown currents ( $\vec{J}_s, \vec{M}_s$ ), ( $\vec{J}_r, \vec{M}_r$ ) and modal coefficient of the excited quasi-TEM mode at the feed point of the microstrip line. The solving procedure was similar to that shown in [7] except that when obtaining the MPIE for ( $\vec{J}_s, \vec{M}_s$ ), the total tangential field on the patch and over the slot included the incident field from the remote source, the specular reflected field from the ground plane, and those from the currents ( $\vec{J}_s, \vec{M}_s$ ). The SFPA and RFPA from the currents to the remote source are then obtained using the asymptotic substrate-loaded Green's functions [8]. To simplify the analysis of the scattering field (SFGP) from the finite ground plane, the substrate above the ground plane is first ignored. The PO method together with the MEC is used to calculate this field component [4]. The influence of the substrate on the ground plane is then considered by adding an extra phase delay due to the roundtrip wave propagation in the substrate.

### III. RESULTS

Since the phase of the RFPA would change as the phase delays in (or the lengths of) the connecting microstrip lines are varied, the total reflected-field patterns would thus alter due to the interference among the three-field components. (Note that the phases of the SFPA and SFGP are not related to the

microstrip-line phase delay.) A planar retrodirective array reflector with a phase delay of  $37^\circ$ , whose simulation patterns displayed small ripples and wide beamwidths in both  $E$ -plane and  $H$ -plane, was fabricated and measured. Fig. 3 shows the comparison of the measured and calculated monostatic reflected-field patterns of the reflector. The propagation loss and the bend loss of the connecting microstrip lines, which were measured as 0.014 dB/mm and 0.06 dB, respectively, have been incorporated in the calculation of the RFPA. The results are normalized to the reflected field at the normal direction of a metal plate with the same size as the array reflector. It is observed that the measured patterns agree well with the calculated ones. The discrepancy in the  $E$ -plane for angles larger than  $60^\circ$  and smaller than  $-60^\circ$  may come from the ignoring of the ground plane edge diffraction due to SFPA and RFPA. The measured relative 10-dB beamwidth is about  $130^\circ$  in both planes. As a comparison, the measured pattern of a metal plate with the same size is also presented. The retrodirective reflector offered smoother patterns than the metal plate did. Outside the angles near the normal direction, the reflected fields produced by the retrodirective reflector are, on average, 9 dB higher than those by the metal plate.

#### IV. CONCLUSION

In this paper, a  $3 \times 4$  planar Van Atta retrodirective array reflector with 2-D retrodirectivity has been implemented using slot-coupled patch antennas. The reflector was analyzed and designed by dividing the monostatic reflected field into three components, i.e., the RFPA, the SFPA, and the SFGP, which were then calculated using the method of moments and the PO method coupled with the MEC. It has been found that the design of the phase delays in the microstrip lines connecting the paired antennas was needed to smooth out the reflected-field patterns and to increase the beamwidths. The 10-dB beamwidths of the retrodirective reflector in the  $E$ -plane and the  $H$ -plane were both  $130^\circ$ , which were much wider than those ( $18^\circ$ ) of a metal plate with the same size. Finally, it is noted that due to the space limitation, larger Van Atta 2-D arrays would be difficult to implement by using coplanar transmission lines. Multilayer routing of the connecting transmission lines may be needed for a larger array.

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