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Coupling in reflector arrays

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Coupling in Reflector Arrays

INTRODUCTION

For many applications, such as echo enhancement and satellite communication, reflectors which have a maximum of reradiation back in the direction of arrival of an incident wave are needed. In 1955, Van Atta [1] proposed a reflector with this property. The reflector consists of antenna elements properly arranged and connected by transmission lines. In order to reduce the space occupied by a reflector array, it is desirable to arrange the array antennas as close to each other as possible. However, in this case coupling between the array antennas will reduce the reflecting properties of the reflector array.

The purpose of the present communication is to demonstrate that this is true for a Van Atta reflector consisting of four half-wave dipoles arranged on a line. Some theoretical studies of the influence of coupling in Van Atta reflector arrays have been carried out previously [2]–[4]. In this communication, theoretical results obtained by using the methods described in [2]–[4] will be compared with experimental results. In contrast to previous experimental results [4] which have been presented as normalized, the results described here are absolute. Before the experimental results are described, some theoretical remarks will be given.

THEORY

For a linear Van Atta reflector consisting of n parallel half-wave dipoles, we will determine the maximum back-scattering cross section for an incident wave polarized parallel to the dipoles and propagating along the normal to the plane containing the dipoles. This back-scattering cross section will be determined when coupling is neglected. Then

there are two fields which add up to give the cross section. First, the field due to scattering from the dipoles when they receive the incident wave; second, the field due to the interconnections between the dipoles [4]. If the length of the transmission lines is chosen to be an unequal number of half a wavelength, these two fields add in phase and we have the maximum cross section for normal incidence. It is well-known that for one dipole, the back-scattering cross section of the field due to scattering is $0.20\lambda^2$ [5]. Since the field intensity due to the interconnecting transmission lines is of the same magnitude as the field intensity due to scattering, the maximum back-scattering cross section of one dipole is $4\times0.20\lambda^2$, i.e., the maximum back-scattering cross section for normal incidence is $0.80n^2\lambda^2$ for the

Van Atta reflector. This result shows that if a certain space is available, the cross section increases with the square of the number of dipoles arranged within the space. However, the cross section cannot be increased indefinitely, because coupling will reduce the back-scattering cross section when the dipoles are
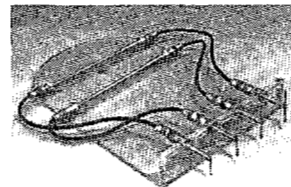

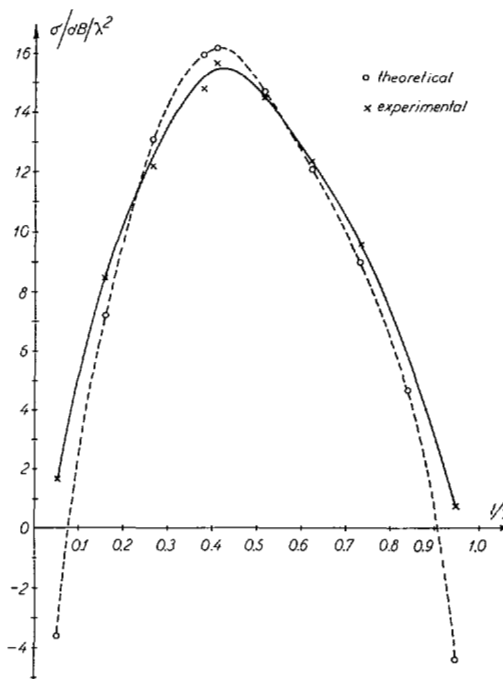Fig. 1. The experimental Van Atta reflector.

Fig. 2. Back-scattering cross section for normal incidence as a function of the length of the transmission lines. Distance between the dipoles equals 8 cm.
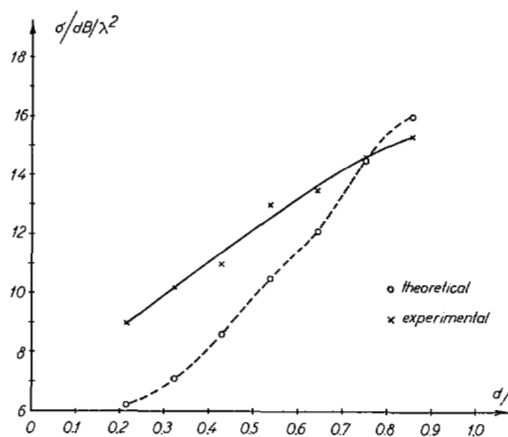

Fig. 3. Back-scattering cross section for normal incidence as a function of the distance between the dipoles. Length of the transmission lines is about $0.40\lambda + p\lambda$.

arranged close to each other. In this connection it is interesting to find the spacing (d) between the dipoles in the case of a linear reflector if we wish to arrange them within an area A and require them to possess a back-scattering cross section equal to that of a flat metallic plate of area A. Using as the back-scattering cross section of a flat plate $4\pi A^2/\lambda^2$ it is easily found that $n \simeq 4A/\lambda^2$. Since one half-wave dipole in the reflector occupies the area $\lambda/2 \cdot d$, this means that the dipoles should be arranged with an interspacing of about half a wavelength. In fact, as will be seen below, if the spacing is smaller than half a wavelength, then coupling reduces the back-scattering cross section below the value $0.80n^2\lambda^2$ derived by neglecting coupling.

EXPERIMENTAL RESULTS

Fig. 1 shows the experimental Van Atta reflector consisting of four parallel half-wave slot-fed dipoles with open-ended terminations. Line stretchers are inserted into the transmission lines connecting the dipoles. This is done in order to determine easily the length of the transmission lines for which the reflector has a maximum back-scattering cross section for normal incidence. This cross section is measured by using a conventional monostatic radar set up in an anechoic chamber. The measurements were carried out at 3.21 GHz.

First, for an equispacing of 8 cm between the dipoles, the cross section is measured as a function of the length of the transmission lines. The result is shown in Fig. 2 and is in agreement with the theory. It is seen that there is a maximum of reflection when the length of the transmission lines is about $0.40\lambda + p\lambda$, where λ is the wavelength and p is an integer. As explained in [4], it is due to coupling that the maximum does not occur for the length $0.50\lambda + p\lambda$.

Next, with the length of the transmission lines adjusted to about $0.40\lambda + p\lambda$, the cross section is measured when the equispacing is decreased in steps of 1 cm from 8 cm to 2 cm (i.e., from 0.86λ to 0.21λ). The results are shown in Fig. 3. The main reasons for the discrepancies between the theoretical and experimental curves are 1) that the reflections from the transmission lines, including the line stretchers, add to or subtract from those from the Van Atta array, and 2) that the line stretchers introduce VSWRs into the transmission lines. However, in agreement with theory, it is demonstrated experimentally that when the inter-element spacing in a Van Atta reflector array is decreased, then coupling reduces the back-scattering. Furthermore, it is seen that for some spacings larger than half a wavelength, coupling may increase the back-scattering cross section above the value 11.1 dB/λ^2 found by using the formula $0.80n^2\lambda^2$ derived above when coupling is neglected.

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A Note on the Radiation Characteristics and Forced Surface Wave Phenomena in Triangular-Grid Circular Waveguide Phased Arrays

Abstract—Forced surface wave resonances are shown to occur in dielectric-free 45-degree triangular-grid circular waveguide phased arrays. Similar surface wave phenomena were observed in an identical grid array of rectangular waveguides in the H-plane of scan. In the circular waveguide array, however, the resonance is observed in the E-plane and is shown to be an isolated point. This isolation is further illustrated by observing certain vector symmetries in the radiation patterns.

Considerable effort has been devoted towards developing an understanding of certain anomalous resonances [1]–[7] which occur in phased-array antennas. These phenomena are manifested by total internal reflection and consequently no radiation of power by the antenna at particular angles of scan. While the existence of these phenomena was, to a degree, expected for dielectric-covered phased arrays under certain conditions [1], [2], it has been shown that they can also occur in dielectric-free brick arrays of rectangular waveguides [3], [4] and in equilateral triangular arrays of circular waveguides [7]. The brick array of rectangular waveguides and a circular array with an identical grid both exhibit forced surface wave phenomena, but in different planes of scan.

The results to be described were obtained by numerically solving the vector two-dimensional integral equation for the planar array of circular waveguides [7]:

$$2\sum_{j=1}^{J} A_j Y_j \Phi_j = \sum_{j=1}^{\infty} Y_j \Phi_j \iint_A \Phi_j \cdot E_t da$$
$$+ \sum_{p=1}^{2} \sum_{(m)} \sum_{(n)} Y_{mnp}' \Psi_{mnp}$$
$$\cdot \iint_A (\Psi_{mnp})^* \cdot E_t da. \quad (1)$$

We solve for the unknown tangential electric field E_t at the aperture A of the circular wave-

guides. The $\{\Phi_j\}$ and $\{\Psi_{mnp}\}$ are, respectively, the circular waveguide modes [7], [8] and the periodic free-space modes required by Floquet's theorem ($p=1$ denotes a TE mode, $p=2$ a TM mode). The Y_j and Y_{mnp}' are the respective modal admittances. The mode of excitation of the array is specified by the $\{A_j\}$ which are the amplitudes of the incident waveguide modes (properly normalized to the total input power). (In the results presented here, we choose only the two degenerate circular TE_{11} modes.)

The reflection coefficients R_j of the jth incident mode are readily found from the aperture field solution by

$$A_j + R_j = \iint_A \Phi_j \cdot E_t da \quad (2)$$
$$(j = 1, \cdots, J).$$

The radiated fields (which are related to the far fields of the singly-excited waveguide element in the infinite array environment [9]) are found from the aperture field by

$$E_\theta = \frac{1}{\sqrt{1 - T_x^2 - T_y^2}}$$
$$\cdot \iint_A (\Psi_{002})^* \cdot E_t da \quad (3)$$

and

$$E_\phi = - \iint_A (\Psi_{001})^* \cdot E_t da,$$

where the angles θ and ϕ are the usual polar coordinate angles associated with the x, y, z coordinate system. T_x and T_y are the beam-pointing directional cosines with respect to the x and y axis (the ground plane). The transmission coefficients of the array-scattering matrix are proportional to the radiated field components

$$T_\theta = \sqrt{Y_{002}/Y_1} E_\theta \quad (4)$$

and

$$T_\phi = \sqrt{Y_{001}/Y_1} E_\phi,$$

when only a circular TE_{11} mode is incident on the aperture. The unitary condition for the scattering matrix determines the proportionality constants.

In the brick array analyzed earlier [3], [4], where only a single mode was propagating in the waveguide, surface wave resonances were observed in the H-plane of scan. In contradistinction, however, when an identical grid array of *circular* waveguides is excited as shown in Fig. 1, we note that a forced surface wave resonance is present in the E-plane of scan before the first grating lobe (denoted by the vertical arrows) appears. (The magnitude of the reflection is plotted versus the differential steering phases ψ_x or ψ_y along the x or y coordinates. They are proportional to T_x and T_y [7].) In the H-plane scan, no such resonance is observed although $|R_x|$ is very nearly one at grazing incidence (the heavy arrow). Small changes in the wavelength do not greatly alter the results except that total reflection *at grazing incidence* is observed in the H-plane at other wavelengths.

In addition, it is of interest to note that, unlike the results found for the brick array of rectangular waveguides, the surface wave resonances found here (in the E-plane here and for other planes in different grids [7]) occur at *isolated* points in the scan plane. This