INCREASED EFFICIENCY AND REDUCED SIDELOBES IN REFLECTOR ANTENNAS USING LOADED SOFT-TYPE PANEL EDGES AND HARD-TYPE SUPPORT STRUTS

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Abstract
The paper shows that the scattering from blocking support struts and from gaps between reflector antenna panels can be reduced by loading the struts to make their surfaces artificially hard, and by loading the edges of the panels to make them artificially soft.

Introduction

In all aperture antennas there will be reduced antenna efficiency and increased sidelobes if the aperture-field distribution is uneven with "holes" in it. These holes can e.g. be caused by blockage from the struts supporting the primary-feed or the subreflector, or by slots in the surfaces of the reflectors. Such slots or gaps will e.g. be present in large reflector antennas that are realized by a number of reflecting panels. The reason is that such panels must be individually adjustable to obtain the required surface accuracy, and thereby they cannot touch each other.

The purpose of the present paper is to show how scattering from blocking struts and panel gaps can be reduced by loading the struts and the panel edges to obtain artificially hard and soft surfaces, respectively, as defined in [1] and [2]. The ideas have been presented in [3]-[6]. The present paper will present recent results of the work and show the similarity between scattering from struts and gaps.

Approximate formulas for struts

The scattering from cylindrical struts is characterized in terms of their induced field ratio (IFR) [7], which is a function of the strut width W, the cross-sectional shape of the strut, the angle of incidence with the strut, the wavelength and the polarization. We can define a complex equivalent strut blockage width by

$$W_{eq} = -\ \mathrm{IFR}\ \ W \qquad (1)$$

This is a very convenient definition, because the blockage efficiency η_{sb} and the relative sidelobe contribution due to scattering from one strut are approximately given by [8]

$$\eta_{sb}\ [\mathrm{dB}] \approx -8.7\ L\ \mathrm{Re}\{W_{eq}\}\ /\ A \qquad (2)$$

$$R\ [\mathrm{dB}] \approx 20\ \log(|W_{eq}|\ L/A) \qquad (3)$$

where L is the length of the strut and A is the aperture area of the reflector. The effect of illumination taper over the aperture is neglected in these formulas. The following asymptotic formulas show the polarization dependence of W_{eq}. For $W \ll \lambda$ we have approximately ($k = 2\pi/\lambda$)

$$W_{eq} = (\pi W/kW)\{[\ln(kW/2)]^{-2} + j[\ln(kW/2)]^{-1}\} \quad \text{(TM-case)} \qquad (4)$$

$$W_{eq} = j\pi kW^2/8 \qquad \text{(TE-case)} \qquad (5)$$

When $W \gg \lambda$ we have $W = W_{eq}$ for both the TE and TM cases. We see that $W_{eq} \gg W$ for the TM case and $W_{eq} \ll W$ for the TE case. This property will also be present when $W \approx \lambda$ if the cross-section of the strut is made rhombic or in other ways oblong [9].

Sidelobes from gaps

Scattering from gaps between reflector panels is equivalent to scattering from a narrow magnetic conducting strip. Thereby, the gap scattering can be characterized by equivalent blockage widths dual to those given in (4)-(5), so that now $W_{eq} \gg W$ for the TE case and $W_{eq} \ll W$ for the TM case. Thus, the gaps will scatter strongly when the E-field has a component orthogonal to them. Let us now try to estimate the level of these sidelobes. Let us assume that the reflector area is A and that the panel edges have lengths L. If we have circular polarization, each gap will scatter the field equally strong, and this level is given by R in (3) minus 3 dB due to the polarization. There is a total of about $N \approx A/L^2$ reflector panels. The gaps are distributed rather systematically over the reflector, but if there are enough of them we can add them together on a power basis to get the average sidelobe level. This gives an average relative sidelobe level due to the gaps of

$$R[\text{dB}] = 20\log(|W_{eq}|L/A) + 10\log(N) - 3\text{ dB} \qquad (6)$$

Typical values for an antenna with 100 m diameter is given in Table 1.

Invisible hard struts

We have seen that the struts can be made almost invisible for the TE case by letting $W \ll \lambda$ or by making the cross-section oblong. Unfortunately, W_{eq} for the TM case becomes worse when this is done. The reason is that strong currents easily can float along the strut, and not so easily transverse to it. Another explanation is that the E-field is orthogonal to the strut with a hard boundary condition for the TE case, and that it is tangential to it with a soft boundary condition for the TM case. We can change the boundary condition to the desired hard type for the TM case by coating the strut with a dielectric layer of thickness $t \approx d/(4\sqrt{\epsilon_r - 1})$ [4], and thereby, the equivalent blockage width can be reduced. If we want the blockage width to remain low for the TE case, we need in addition to load the dielectric layer with conducting strips or to use corrugations filled with dielectric material, where the strips and the corrugations must run orthogonal to the strut. The dielectric-loaded "invisible" hard strut is verified experimentally (Table 2). We have a significant reduction of the blockage width when the strut is coated, over a bandwidth of 10 to 20 %. A reduction factor 3 gives about 10 dB reduction of the blockage lobes according to (3). This is easily obtained.

Soft panel edges

We have seen that gaps between reflector panels give large sidelobes for the TE case but not for the TM case. For the TM case the E-field is tangential to the panel edge with a soft boundary condition, which make the gap under cut-off. Therefore, the soft boundary condition is desirable, and we can make it soft also for the TE case by locating grooves under the edge (Figure 1). Experiments have shown that one groove like in Figure 1 reduces the scattering by 10 dB over a 40 % bandwidth. Thus, the sidelobes caused by gaps can easily be reduced by 10 dB. More experimental results will be given in the oral presentation.

Conclusion

Experimental work has shown that the scattering from narrow support struts (TM case) easily can be reduced by 10 dB by coating the strut with dielectric material to obtain an artificially hard surface. The scattering from narrow gaps between reflector panels can easily be reduced by 10 dB by locating grooves or corrugation under the edges. The ideas originate from the concept of artificially soft and hard surfaces. This concept is based on impedance boundary conditions, which is an approximate boundary condition valid for large and almost plane loaded surfaces. Nevertheless, the concept has proven useful and gives results that are qualitatively correct even for struts and gaps that have small lateral extents in terms of wavelength.

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Table 1. Approximate sidelobes due to 3 mm gaps between panels in antenna with 100 meter diameter. The panel size is 2m x 2m. The sidelobes can be reduced by more than 10 dB below the table values over 40 % bandwidth by using corrugations under the panel edges.

Frequency	Antenna gain	$\lvert W_{eq} \rvert$	Sidelobes from gaps relative	dBi	
10 GHz	58 dBi	9 mm	- 63 dB	- 5 dBi	
20 GHz	64 dBi	6 mm	- 66.5 dB	- 2.5 dBi	
40 GHz	70 dBi	5 mm	- 69 dB	1 dBi	

Table 2. Experimental results for the equivalent blockage widths $\lvert W_{eq} \rvert$ of metallic struts and of dielectric-coated hard struts (TM case only) between 15 GHz and 16.5 GHz

Strut Cross-sections		Width	Blockage width W_{eq} Minimum		10 % bandwidth	
		W	$\lvert W_{eq} \rvert$	$Re\{W_{eq}\}$	$\lvert W_{eq} \rvert$	$Re\{W_{eq}\}$
Metal		6 mm	9,6mm	7,9mm	9,8mm	7,9mm
Metal		6 mm	19 mm	13 mm	20 mm	13 mm
Coated hard		11mm	3,2mm	3,1mm	8,3mm	5,4mm
Metal		6 mm	14 mm	10 mm	15 mm	10 mm
Coated hard		11mm	2,3mm	2,3mm	5,0mm	3,1mm

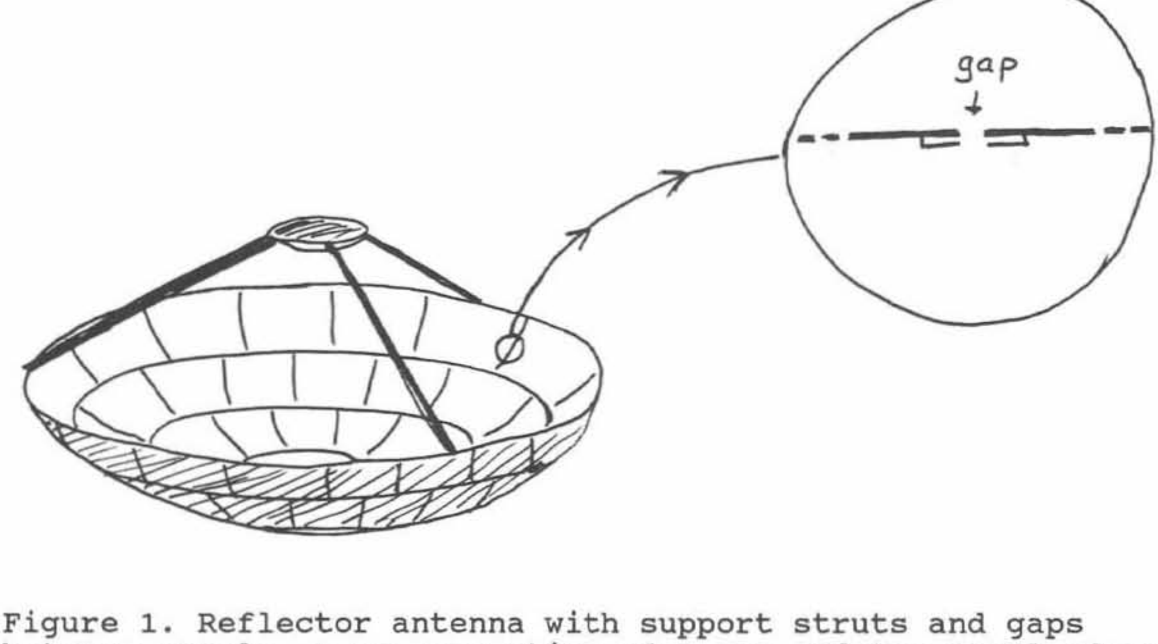

Figure 1. Reflector antenna with support struts and gaps between panels. A cross-section of a gap and two panel edges, both loaded with corrugations of the soft type, is shown in the circle.