Anomalous wave scattering by a finite number of longitudinally slit cylinders of small wave dimensions

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In diffraction of a plane wave by a periodic array of circular cylinders with longitudinal slits, there is a total reflection of the waves in the long-wave region even if the elements of the array are far apart.[1] The reason is that the array elements have pronounced resonant properties.[2]

When a finite number of cylinders with longitudinal slits are excited by a lumped source, a new effect is observed: a directed emission by a comparatively small number of reflectors of small wave dimensions, which form a screen of complex geometric shape with transverse dimensions on the order of the wavelength. A screen of this sort can effectively form plane phase fronts.

We consider the excitation by a magnetic-current filament of a reflector formed by a finite number (N) of circular cylinders with a longitudinal slit (the angular size of the slit is θ) distributed uniformly over a circular arc of angle α and radius R_1 (Fig. 1). We assume that the cylindrical screens are infinitesimally thin and ideally conducting. This problem has been solved rigorously for an arbitrary arrangement of screens.[3,4]

The radiation resistance for an antenna system of this type is the sum of the intrinsic radiation resistance of the filament and the induced radiation resistances from the unclosed cylinders:

$$R_\Sigma = \frac{\pi k}{c}\left(1 + \mathrm{Re}\sum_{q=1}^{N}\sum_{m=-\infty}^{\infty}\mu_m^q J_m'(ka)\cdot H_m^{(1)}(kr_{q0})e^{im\varphi_{q0}}\right).$$

The coefficient of directed action can be determined from

$$\mathrm{CDA}(\varphi_0) = \left|1 + \sum_{q=1}^{N} e^{ikr_{q0}\cos(\varphi_{q0}-\varphi_0)}\sum_{p=-\infty}^{\infty}\mu_p^q J_p'(ka)e^{ip(\varphi_0-\frac{\pi}{2})}\right|^2 \cdot \frac{R_0}{R_\Sigma}$$

Here $J_m'(x)$ and $H_m^{(1)}(x)$ are the derivative of the Bessel function and the Hankel function, $k = 2\pi/\lambda$ (λ is the wavelength), a is the radius of the cylinders, and μ_m^q are the Fourier coefficients of the surface current density on the q-th cylinder. These coefficients are found from the solution[3,4] of coupled systems of linear algebraic equations of the second kind (r_{q0}, φ_{q0} are the relative coordinates of the q-th cylinder and the filament).

The effective solution which has been found for our diffraction problem raises possibilities for analyzing the field near this structure over a broad frequency range and for plotting two families of mutually orthogonal curves lines of constant phases of the H_z component of the electromagnetic field and energy flux lines.

Because of the small wave dimensions of the elements of the structure and their weak mutual effects away from the resonance, the radiation field of the magnetic-current filament is perturbed only slightly here; i.e., the radiated field passes freely through the discrete reflector (Fig. 2a), and the directional pattern is isotropic. In this case the scattering of the waves is analogous to the diffraction of an H-polarized field by closed circular cylinders.

At frequencies near the resonant value, determined by the condition $ka \approx [-2\ln\sin\theta/2]^{-1/2}$, on the other hand, the scattering of H-polarized waves by this structure is qualitatively different. The excitation of quasinatural Helmholtz-mode oscillations in the elements of the system[2] and the strong mutual effect of the scatters greatly distort the near-zone phase structure of the field. The formation of phase nodes near the scatters leads to the appearance of regions in which the energy flux is zero on the average over a period. These regions cause the effective dimensions of the scatters to increase, and this increase leads in turn to a cutoff of the perturbing field. The phase front becomes essentially flat over an angular sector of significant size near the structure.

The qualitative change in the near-zone field structure at resonance causes most of the energy of the electromagnetic field of the magnetic-current filament to be radiated in a certain direction. That there is a flat angular distribution of the radiated energy away from resonance and that most of the energy is radiated in a rather narrow angular sector in the resonant case can be seen from the distribution of the near field of the structure, i.e., from a

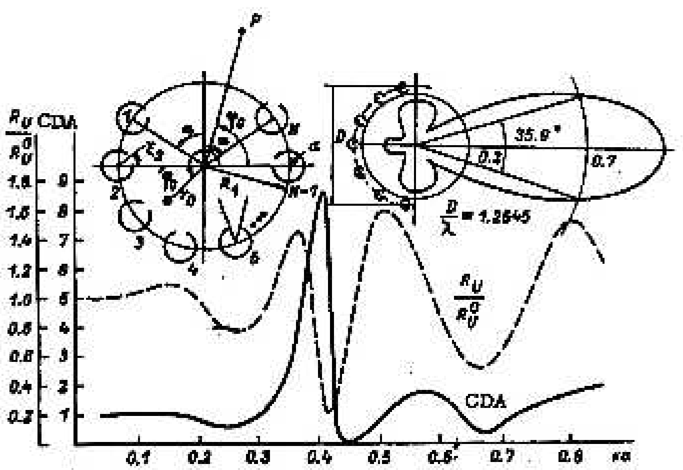

FIG. 1. The general structure. Frequency dependence of the coefficient of directed action (CDA) and of the radiation resistance, normalized to the radiation resistance of a filament in free space (R_Σ^0). Also shown here is the directional pattern at the maximum CDA.

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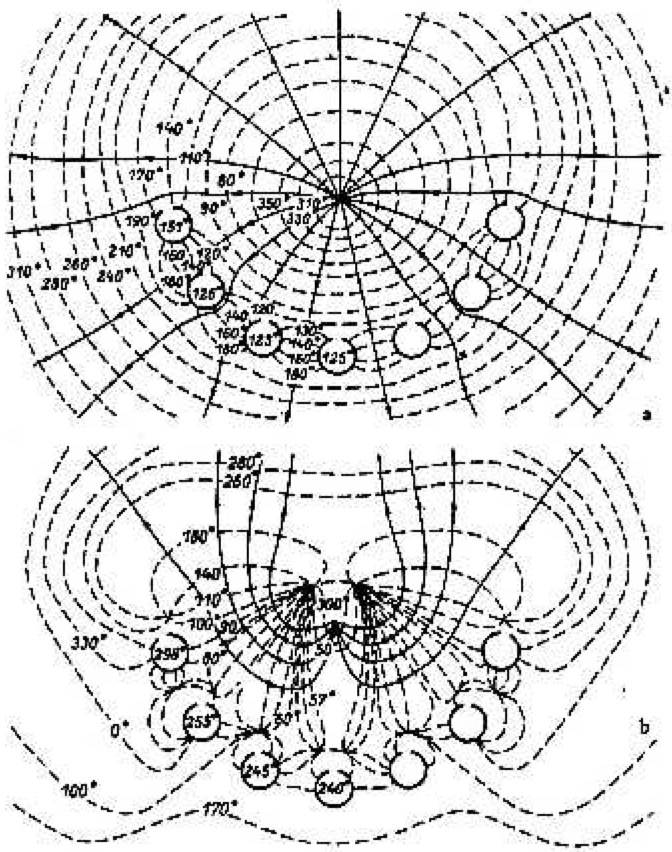

FIG. 2. Lines of constant phase (dashed curves) and lines of the energy flux averaged over the period. a) Away from resonance; b) at resonance.

family of lines of the Poynting vector flux, which is orthogonal in the two-dimensional case to the family of lines of constant phase of the field component H_z ($\arg H_z$ = const); (Figs. 2a and 2b).

Directional patterns with a clearly defined main lobe with a width of about 36° are formed by a system with wave dimensions of order λ through the formation of a region of a nearly flat phase front near the antenna (the relating size of the side lobes is less than 0.2).

Numerical analysis of the behavior of the parameters of an antenna formed by a magnetic-current filament and a discrete resonant reflector consisting of 3, 4, 5, or 7 elements has shown that the coefficient of directed action can reach values of 6, 7, 8.3, and 8.5, respectively, at resonance. It is particularly important to note that the geometric dimensions of the antenna did not exceed 1.2 λ.

The implementation of this diffraction effect in antenna technology would raise the possibility of developing structurally simple, small directional antennas.

It is important to note that (as a comparative study shows) the properties of this discrete reflector at intermediate wavelengths, i.e., for wavelengths comparable to the dimensions of the aperture, are similar to those of solid cylindrical mirrors in the short-wave region.

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Strong four-wave mixing with phase conjugation in a nematic liquid crystal *

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1. The parametric four-wave interaction with oppositely propagating waves (in the frequency-degenerate case) appears to be one of the most interesting laser effects associated with wave propagation in nematic liquid crystals having a large optical orientational nonlinearity (see, for example, Ref. 1 among the recent experiments). This arrangement, which is sometimes used in dynamic holography,[2] has the remarkable property of correcting the wavefronts of laser beams with complex wave profiles (see Ref. 4, for example). This property stems from the possibility of phase conjugation (or "wavefront inversion") with automatic satisfaction of the matching conditions.[3]

The high efficiency of this conjugation arrangement for nematic liquid crystals was discussed theoretically in Ref. 5. This arrangement was implemented experimentally in Ref. 6, through the use of a special transparency with a photosensitive semiconductor film under a static external field.

In this letter we report the first experiment for a purely optical nonlinearity of a standard nematic-liquid-crystal cell. We have taken some measurements, which we will interpret at a qualitative level.

2. The experimental arrangement is shown in Fig. 1.