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DESCRIPTION OF THE SURFACE RADIATION OF NON-EQUILIBRIUM MEDIA USING TRANSFER FUNCTION

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The paper justifies the possibility of applying the concepts of transfer function to the description of the radiation of non-equilibrium media surface. Fourier optics terms allow you to reason about the comparison of perturbations magnitudes. These perturbations are inherent in the non-equilibrium radiating surfaces. As a comparison, the magnitudes that actually characterize elementary radiators are used. This conclusion can be applied to smooth surfaces of arbitrarily complex shape.

Keywords: non-equilibrium media, transfer function, perturbations magnitudes, Fourier optics.

Fourier optics is a part the theory of optical systems, considering the field of a monochromatic wave of arbitrary configuration (with minor limitations for real cases) as a superposition of separate plane waves. It is increasingly used in solution of various physical and applied problems [1]. Historically, Fourier optics has emerged as a discipline that applies the methods of research of passive radio engineering circuits to optical systems [1]. One of the basic concepts of Fourier optics is the transfer function of free space, which is a multidimensional analogue of the transfer function of a linear electronic element. Application of the terms of transfer functions in optics is extremely useful for the analysis of multi-beam interference [2], short and ultra short pulses propagation [3], etc. Gradually specialists in the field of optics begin to think in terms of spatial optical spectra in exactly the same way as experts in the field of radio electronics think of categories, the mathematical reasoning of which is implied in the use of temporal Fourier transform. The phrases like "high frequency left in the ground", "to tune in» have become conventional wisdom long ago. The expression "lens performs the Fourier transform" is no surprise in optics.

However, the terms of transfer function has so far been applied mainly to the analysis of passive optical systems so far (some exceptions are nanosecond pulses, but they are a very specific object). This paper will argue that concepts of transfer functions can be applied to the description of the radiation of non-equilibrium media surface as well.

The question of the transfer function of the surface of various objects has long been raised in the theory of radar. However, it could not be resolved completely by means of the classical Fourier optics. Indeed, the traditional statement of Fourier optics is a consequence of the theory of Huygens-Fresnel principle formulated by Kirchhoff [1], so the general definition of the concept of transfer function of a surface cannot be given without the involvement of a specific mechanism for the propagation of radiation through a non-equilibrium medium. This difficulty can be overcome by using the generalized Fourier optics [4,5], which, in particular, allows you to obtain the transfer function of a free space independently.

Substantiation of the Huygens-Fresnel principle, stated in the Kirchhoff theory, permits us to speak of "natural" transfer function of a free surface. To be more exact, the solution of the classical diffraction problem is connected with the degenerate transfer function, which is identically equal to one. This statement assumes a simple interpretation: the Huygens-Fresnel principle, solving the problem of diffraction, suggests that secondary sources, concentrated within holes, emit secondary waves. In the case of a real radiant (and especially non-equilibrium) surface, its directional diagram can be quite complicated. The solution of a diffraction problem in Fourier optics can be extended to the case of such surfaces, if you introduce a surface transfer function which allows you to describe the transition from the directional diagram of Huygens emitters to a real one.

Propagation of radiation from the support plane (1) to (2) the support plane (2) in Fourier optics is described by the transfer function of a free space as

$$A_2(\boldsymbol{\xi}) = \exp[-ik(\alpha x+\beta y\pm\gamma z)]\ A_1(\boldsymbol{\xi}) \tag{1}$$

where $A_1(\boldsymbol{\xi})$, $A_2(\boldsymbol{\xi})$ are angular spectra of radiation in planes (1) and (2); $\boldsymbol{\xi}=(\alpha;\beta;\gamma)$ is the unit vector characterizing the direction of propagation of a separate component of an angular spectrum in space; $\gamma=(1-\alpha^2-\beta^2)^{1/2}$; k is the module of a wave vector, the sign indexes a positive and negative angular spectrum branches.

It is significant that the calculation of angular spectrum in each of the planes can be made directly by using the Fourier transform as:

$$A(\boldsymbol{\xi}) = \int (u\boldsymbol{\xi} \pm(ik)^{-1}\partial u/\partial \mathbf{n})\exp[-ik(\alpha x+\beta y\pm\gamma z)]\ d\mathbf{S} \tag{2}$$

The possibility of applying of the transformation (2) corresponds to the identity transfer function of the surface. This assertion is directly derived from the main provisions of Fourier optics, but has not previously been emphasized. Let’s try to find an analogue of transformation (2) for an arbitrary non-equilibrium radiating surface.

The function u_0 we understand as the real distribution of the radiating sources fields. It is this quantity that is available for direct measurements in most practical applications (see, for example, [6,7]). Application of the operation (2) to this magnitude cannot provide the actual angular spectrum: otherwise, it would turn out that the directional diagram of the surface under consideration coincides with the directional diagram of free space.

Consider the following problem. Let the emitting surface coincide with the support plane (1), (see fig. 1), which restricts the free half-space Ω_1. We consider it along with another parallel plane (1`). This plane is already known to be related to the free half-space. The ratio (2) is obviously applicable to the distribution of the field created on it. The apparatus of the generalized Fourier optics allows (at least formally) to find the angular spectrum related to an arbitrary plane, regardless of whether the plane lies within a physically accessible to the radiation of the field Ω_1 or not. This situation is quite common for optics: just in the same way imaginary focuses and light sources are usually said about. On the basis of the spectrum according to [8]

$$u(\mathbf{r}) = \int A(\boldsymbol{\xi})\exp[ik\boldsymbol{\xi}\mathbf{r}]\ d\Sigma$$

where Σ is the unit sphere in the space of wave vectors. You can find some support distribution of the field relating to plane (1).

This function allows a simple interpretation: the field is a field that would be established in the area of Ω_1 if Huygens sources of secondary waves would be concentrated on the plane (1). Consider the relation of distribution of the field $u(\mathbf{r})$ with the field distribution of actual emitters $u_0(\mathbf{r})$. Without specifying the type of the directional diagram, the following conclusions can be drawn. If each of the actually existing on the surface of emitters is of a "point" nature (for example, the radiation of water surface is mainly determined by the surface layers), the spatial distribution of the field satisfies the isoplanarity condition: a shift of the "signal" to an arbitrary vector in the support plane (1) would result in a shift to the same vector in response. Application of direct and inverse (2,3) Fourier transforms cannot brake isoplanarity. Therefore, in the most general case, the auxiliary field $u(\mathbf{r})$ can be associated with the original field $u_0(\mathbf{r})$ only by the integral transformation that satisfies the condition in translation symmetry:

$$u(x,y) = \int K(x-x_0,y-y_0)\, u_0(x_0,y_0)\, dx_0\, dy_0,$$

where K is the function that characterizes the elementary emitter.

Thus, we can say that each of the really existing emitters creates an effective "spot" directly on the support plane. Indeed, considering a point emitter (the δ-like distribution of the field u_0 corresponds to it) it is easy to see that the effective distribution of the field will have the distribution which exactly matches the kernel of an integral transform (4). Note that now instead of the spatial characteristics of the emitter (directional diagram) we now have a characteristic relating only to the support plane.

It remains to take the final step. Ratio (4), expressing the condition of isoplanarity, mathematically is nothing more than a convolution transform. Therefore, we could argue that spatial spectra of real and auxiliary distribution of fields are related to each other by a multiplier, which is the Fourier transform of an integral transform kernel (4). This factor, which depends on the angular variables we should consequently consider to be the transfer function of the surface transmission. In other words, in the Fourier optics radiating surfaces can likewise speak of the transfer function of an extended space, and the transfer function of an infinitely thin object (of a surface). In particular, the study of wave disturbances in the disturbed water surface has long been a subject of study of experts in the field of remote sensing of the underlying ocean surface. Some experimentally confirmed theories allowing to conclude on the existence of so-called "critical phenomena" are worked out here [6]. These phenomena were observed in the works as the existence of apparent peaks in the diagrams, recorded by the analog of Michelson’s Fourier-spectrometer operating within the millimeter range [7]. The physical meaning of these phenomena is very simple: the resonance phenomena occur when the wavelength of the own thermal radiation of the water surface (or any screening radar) radiation coincides with the wavelength of the perturbation, which is implemented on the target surface [7].

The next opportunity arises. In the study of properties of the interphase complexes one should reject the use of previously developed methods of "bulk" analyzes however well proved in the past. Attention should be focused on the study of the interaction of radiation with the surface.

Further, as instead of the spatial characteristics (directional diagram) a planar one is used, then it is appropriate to speak of the typical spatial scale. In particular, according to the most general propositions of Fourier optics it can be stated that if the spatial scale of inhomogeneity of the distribution of emitters on the support plane (1) is smaller than the size of a "spot", defined by the type of K-function, then their existence is undetectable by means of optical or radioelectronic control. This fact can be interpreted as the existence of the lower boundary of "resonance phenomena", recorded in the study of the own radiation of the disturbed water surface.

Thus, terms of Fourier optics allow us to speak about the mapping of perturbations scale inherent in non-equilibrium radiating surfaces with the scales that characterize the actual elementary radiators. On the basis of the apparatus of generalized Fourier optics it can be stated that this conclusion may be applied to the smooth surfaces of an arbitrarily complex shape. This raises two possibilities. The first is a qualitative analysis of non-equilibrium multi-level structures arising from natural or man-made perturbations of radiating surfaces. The second is the application of the theory of multidimensional holography to the analysis of data obtained in the study of the state of water surface. An example of the latter is the detection of underwater objects based on an analysis of perturbations generated at the sea surface.

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