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Discussion

Comment on "Do evanescent waves really exist in free space?"

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Abstract

In a recent paper [A.B. Katrich, Opt. Commun. 255 (2005) 169], Katrich has claimed that in a 2D free space evanescent waves do not exist because they are not exact solutions of the free space wave equation. We show that his conclusions are not valid, and that evanescent can indeed exist in free space.

Katrich [1] has claimed that evanescent waves are not solutions of the homogeneous free space Helmholtz Rayleigh–Sommerfeld diffraction integrals give only approximate solutions. These statements are in contradiction to what is found from near-field optics and frustrated total reflection. Also, evanescent waves are known to play a key role in diffraction from cylinders, gratings, half-planes, etc.

The main error in Katrich's argument is in Eq. (1), where he claims that any field within a two-dimensional free half-space can be expanded into Bessel functions of the first kind, J_n. It is well known that these functions (unlike the Bessel function of the second kind Y_n, or the Hankel functions $H_n^{(1,2)}$) do not contain any evanescent components, as Katrich proves in the paper. Therefore, he has ignored the evanescent components straightaway, and it is therefore not surprising that he can then carry on to show that the evanescent components vanish. The functions J_n are not a complete set for a source-less 2D half-infinite space. Of course, an appropriate basis in this case is that of forward-propagating plane waves $\exp\{ik[px+(1-p^2)^{1/2}z]\}$, where the positive imaginary value of the square root must be chosen when $p^2>1$. Clearly, these waves are well-behaved solutions of the Helmholtz equation for all $z \geqslant 0$ and for any real p. While they carry infinite power, they can be combined to give fields of finite power.

In the first column of the second page, the author states that the distribution at the source plane must satisfy the free space Helmholtz equation. This is a confused statement and the source of other errors in the paper. It does not make sense to say that a boundary condition satisfies the Helmholtz equation, as this equation involves a second derivative in z. We would need to know both the field at the boundary and its second normal derivative to test if they are consistent with the Helmholtz equation.

On page 2, line 53, Katrich states "If evanescent waves do not contribute to the far-field then they must be transferred to propagating waves near the source". Actually the evanescent waves propagate sideways, so they do contribute to the far-field, but only very close to the boundary plane. As the radius r becomes large, the contribution at any angle θ decreases. They are not "transferred to propagating waves near the source".

On page 2, line 66, Katrich [1] comments on the "strange results" of Zeng [2], that the angle of divergence

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for a small planar source is limited to 65°. This result is not really strange, and is caused by two factors:

1. If width is defined as the cylindrical distance from the axis for the intensity to fall to one half for a particular fixed axial distance z, then even a uniform spherical wave has a limited divergence because of the inverse square law.
2. The assumption of a planar source that tends to zero in width is not the same as a point source, as a planar source behaves as a dipole source. This effect was first described by Darwin in the early 1900s [3] in the connection of X ray diffraction. See also [4].

On page 2, line 84, Katrich [1] states "Conventionally it is assumed that in the source plane any field distribution can be specified". This is a valid criticism of the Kirchhoff boundary conditions, which are known to be not self-consistent. There are therefore issues regarding Kirchhoff boundary conditions (which are an approximation) when studying problems of diffraction by apertures. However, the first Rayleigh–Sommerfeld diffraction formula (which should really be called a "propagation" formula rather than a "diffraction" one) is an exact formula for scalar wave propagation in free space, where given the field at a planar boundary (and the knowledge that there are no sources to the right of the boundary), one can unambiguously determine the field elsewhere to the right of the boundary exactly. Therefore, one can specify the boundary field distribution arbitrarily for the sake of wave propagation. Where this boundary field comes from and how we found it is a separate issue.

There exist also many cases, e.g. diffraction by a small aperture or by a grating, or scattering by a cylinder or half-plane, where there are evanescent components, and these are predicted by rigorous diffraction theory. The case of diffraction of a plane wave by a cylinder is one of the best known and simple examples where an expansion in terms of Bessel functions (both of the first and second kinds, in a combination that satisfies Sommerfeld's radiation condition) is used. In such a case the diffracted field, as well as its spectrum across any plane parallel to the axis of the cylinder, can be found rigorously, in analytical terms, and the presence of evanescent waves is undeniable. In the case in which the cylinder radius is much smaller than the wavelength, in particular, the diffracted field is proportional to the outgoing Hankel function of zero order and then its plane-wave spectrum turns out to be proportional to $\exp(ikd\sqrt{1-q^2})/\sqrt{1-q^2}$, where d is the distance of the plane from the cylinder axis, and q is the normalized spatial frequency, which takes values from ∞ to $-\infty$.

Katrich also criticizes the results of Porras et al. [5], presumably on the grounds that they found a phenomenon in which Gaussian light pulses propagate at a group velocity greater than the speed of light, attributing this "strange" result to the use of evanescent waves. Actually, superluminal phenomena like this are not unusual. In fact, they occur for any pulsed field that is composed of plane waves traveling in more than one direction. They do not violate causality or any other physical principle. This effect is particularly evident in the propagation of the so-called X-waves, which propagate faster than c along the mean propagation axis. Of course, such pulses cannot carry information at a speed faster than c. Most of all, this effect has nothing to do with evanescent waves, but rather with the scissors effect of different homogeneous wave components going in different directions, which give intensity distributions that "move" faster than light. X-waves are composed of homogeneous waves exclusively.

In conclusion, the mathematical arguments presented in Ref. [1] that prove the inexistence of evanescent waves are flawed. The existence of these waves in free space is strongly supported both theoretically and experimentally.

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