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On "superluminal" effects

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Abstract

It is shown that the "superluminal" effects reported recently by Mugnai et al in Phys. Rev. Lett. **84** 4830 (2000) are geometrical artefacts.

"Superluminal" effects have recently been reported[1] for Bessel-type beams

$$\sim e^{i(zk\cos\theta-\omega t)} \tag{1}$$

of a microwave field produced by a circular slit in a horn antenna of cone angle θ. The propagation of the beam is measured along the z-axis, and a "superluminal" velocity $v = dz/dt = \omega/k\cos\theta = c/\cos\theta$ is reported, where ω is the frequency of the field, k is the wavenumber, and $c = \omega/k$ is the light speed in vacuum. Such a measurement implies a geometric artefact by including distances along the wavefronts. The wavefronts are indeed given by $z\cos\theta = r_{\parallel} = const$, such that the signal propagates along distances $dr_{\parallel} = dz \cdot \cos\theta$ with the phase velocity $u = dr_{\parallel}/dt = \omega/k = c$, *i.e.* the light speed, as expected.

Beside distances $r_{\parallel}$ along the wavevector $\mathbf{k}$, the phase of a plane wave includes arbitrary distances $r_{\perp}$ perpendicular to the wavevector $\mathbf{k}$, such that $\mathbf{kr} - \omega t = kr\cos\theta - \omega t = kr_{\parallel} - \omega t$; hence, the phase velocity is $u = dr_{\parallel}/dt = \omega/k$. If one choses to define an arbitrary velocity by $v = dr/dt = u\sqrt{1 + v_{\perp}^2/u^2} = u/\cos\theta$ such a velocity is always greater than the phase velocity u, due to the transverse "velocity" $v_{\perp} = dr_{\perp}/dt$; if $u = c$ such arbitrary velocities will always be "superluminal". They are easily visualized as corresponding to the wavefronts "motion" along a direction which is tilted at an angle θ with the wavevector. The "false" distances $r_{\perp}$ may appear by geometric constraints like $r = z$ in Ref.1, or by $z = \sqrt{r^2 - L^2}$, for instance, corresponding to a point-like source placed at distance L from a screen; the "velocity" along the screen is $v = dz/dt = cr/z > c$, and $c^2/v^2 = 1 - L^2/r^2$ is a parabollic law with respect to the L-dependence, similar with the one reported in Ref.1

The geometric artefacts in wave propagation are related to the wave delocalization. A larger-size detector (receiver) placed behind the one in Ref.1 will indicate "acausal effects" too, beside "superluminal" ones, as wavefronts of larger aperture are forerunners with respect to wavefronts of smaller aperture for such X-shaped Besssel-type beams. Similar effects arise also for evanescent waves in tunneling experiments.[2]

In conclusion, in contrast to the claim made in Ref.1, the results reported therein contribute nothing to "answering the question on the luminal limit of the signal velocity", and they could not in fact contribute anything; these results are simply wrong results. There can not be any discussion regarding "the meaning to be attributed to the demonstrated superluminality", since there has been demonstrated nothing of the kind, and there could not have been.

References

[1] D. Mugnai, A. Ranfagni and R. Ruggeri, Phys. Rev. Lett. **84** 4830 (2000).

[2] See, for instance, references in Ref.1.