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Two possible interpretations of the near-field anomaly in microwave propagation

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ABSTRACT

Microwave propagation experiments, over a short range, demonstrated that the ratio $b = c/v$ of the light velocity c to the observed one v resulted to be less than unity. The various results are here interpreted and compared with the theoretical predictions according to a classical electromagnetic model and to an alternative model based on the assumption of a broken local Lorentz invariance. In any case, the observed superluminal behavior is found to be peculiar to near field.

Introduction

Microwave and optical experiments have been demonstrated to be a powerful tool for observing anomalies in wave propagation. The observation of superluminal behavior, has been of particular interest both in tunneling processes of evanescent waves and in propagation in air with non evanescent (complex, X-shaped, Zenneck-type) waves [1–7]. A detailed analysis of the arrival time of the front-edge in microwave propagation has recently been reported demonstrating the possibility of observing superluminal effects: that is, the first beginning of the pulse may result in advance with respect to the propagation at the light velocity in vacuum [8,9]. We should note that, even if non-evanescent like-complex or X-shaped waves can survive over distances much greater than evanescent ones (typically, up to distances of the order of one meter for centimeter wavelengths), the results observed are essentially confined to -or, better, originated in- the near-field region (see [10] where even a path-integral approach to the problem was considered).

However, in special cases, the issues relative to the above mentioned waves were detectable even at distances (up to ~80 m) for Zenneck-type waves, that are much greater than those typical of the near field [11–13].

In a recent work [14], the angular dependence of the advancing in the arrival time relative to microwave propagation experiments was derived from previously performed measurements. It was found that an anticipation in the arrival time tends to be most extreme for angles of around 30°. The results were interpreted according to a model based on fast-complex waves, suitably modified by a bidimensional treatment. As a matter of curiosity, in the same paper the issue of some experiments, performed over metal bars stimulated by ultrasounds, was mentioned due to the fact that the emission of nuclear particles was evidenced with an angular dependence, with respect to the longitudinal axis of the bars, which privileged angles again of the order of 30°. More precisely, with the use of cylindrical steel bars 2 cm in diameter and 20 cm in height, and subjected to compression along the longitudinal axis, the emission of alpha particles was observed with angles between the strain direction and the alpha track direction that ranged from 34° to 38° [15]. The latter phenomenon, could be interpreted in the framework of the "deformed space-time" (DST) theory, as reported in [16].

The purpose of the present work is a careful analysis of the results already reported in [14] by considering the angular dependence – not merely in an average way – as well as the wave intensity (or its energy) as a function of the distance separating the launcher-horn antenna from the receiver-horn antenna. The results will be interpreted according to the model based on complex waves [8,9], but also in consideration of the DST theory [16], by taking into account a first approach made in this direction [17]. Other experimental results to be considered are those reported in [18].

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Complex-wave model [19]

An exhaustive description of the model is given in [9], where the arrival of the pulse is described by considering both contributions given by a pole and also the one due to a saddle point. However, for our purposes it is sufficient to consider the pole contribution, as presented early in [3], in addition to the saddle-point contribution, as results from the use of the more realistic bidimensional treatment of [14]. The results obtained can be summarized as follows. The resulting field u at the receiver is expressed as the sum of two contributions, one representing a spherical wave and the other representing a complex wave, namely

$$u = \frac{\lambda}{\rho} \exp\left[i\left(k\rho - \frac{\pi}{2}\right)\right] + 2\pi i \exp\left[ik\rho\cos(\alpha+\beta)\right], \tag{1}$$

where ρ and α are the polar coordinates of the observation (receiver) point, $k = 2\pi/\lambda$ is the wave number and the complex-value angle $\beta = \beta_r - i\beta_i$ determines the pole-position in the plane of the complex-direction angles [9,14]. The first term in (1) represents a spherical wave that propagates at light velocity c and with an intensity that attenuates as $(\lambda/\rho)^2$. The second term in (1) is a fast wave that propagates with a phase-path velocity v_{pp}, to be identified with a "signal-path" velocity [3], given by

$$v_{pp} = \frac{c}{\cos(\alpha+\beta_r)\cosh\beta_i} \tag{2}$$

and that attenuates with an intensity that is

$$4\pi^2 \exp\left[-4\pi\frac{\rho}{\lambda}\sin(\alpha+\beta_r)\sinh\beta_i\right]. \tag{3}$$

Data relative to microwave propagation experiments between two horn antennas, which operates at a frequency of about 10 GHz ($\lambda = 3.158$ cm), as taken from Refs. [14,18], are shown in Fig. 1, as a function of ρ which represents the distance separating the two antennas. There, $b^2_{em} = (c/v_{pp})^2$ and $b^2_s = (\tau_\alpha/\tau_0)^2$, where τ_α is the measured delay at the maximum value α_M and $\tau_0 = \rho/c$. We have to note that the two series of b^2_s values reported have the same origin in the experimental results of time delay taken from Ref. [3], in addition to other two determinations reported in Ref. [9]. The two series of b^2_s values in Fig. 1 and b_s in Figs. 2 and 3 are obtained by two slightly different definitions adopted in Refs. [14,18] respectively, and attributed to two slightly different evaluations of the effective distance ρ. The two determinations of b^2_{em} depend on two different choices of α_M and β_r. In the same graph we also report

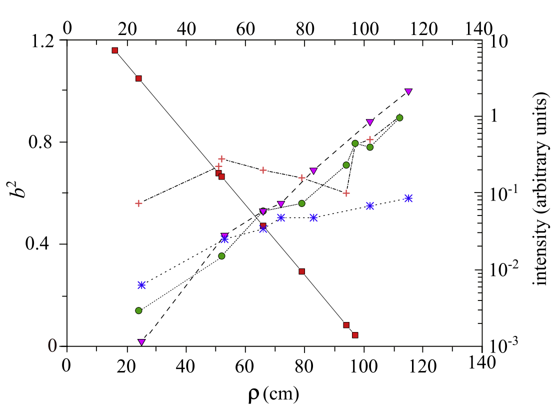

Fig. 1. Experimental values of b^2_s, as taken from [14] (full triangles) and [18] (full circles), compared with the theoretical ones b^2_{em1}, from [18] (stars), and b^2_{em2} from [14] (crosses), together with the intensity of the complex wave (full squares). For clarity of representation no fiducial bars are given. However, the spread of the data can give an idea about their uncertainty estimated to be $\Delta b^2 \simeq \pm 0.1$.

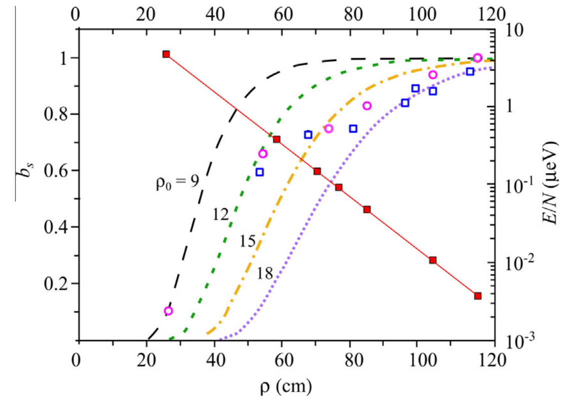

Fig. 2. Experimental values of b_s as taken from [14] (open squares) and [18] (open circles), compared with the theoretical curves as given by Eq. (7) for some values of ρ_0 (in cm), and residual unitary energy as given by Eq. (4) (full squares).

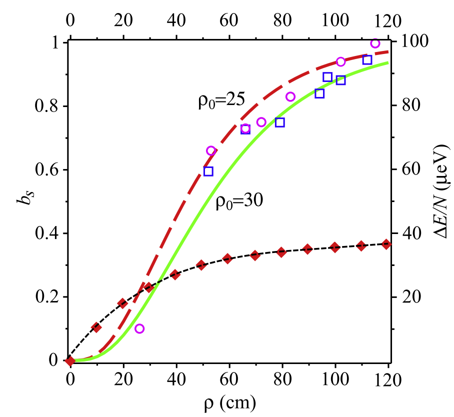

Fig. 3. Same as Fig.2 for $E_0 = h\nu = 37$ μeV, and $\rho_0 = 25$ and 30 cm. The curve of the lost energy ΔE, as given by Eq. (5) (full squares), is also shown.

the ρ-dependence of the intensity as given by Eq. (3), which in [14] is given for values of β_i comprised between 11.5° and 2.9°. However, as discussed in [14], it is the smaller value of β_i that makes possible to have a plausible situation, with an intensity of the complex wave prevalent over the normal-wave one, up to ρ of about 1 m, as required by the experimental evidence. Apart from the value of b^2_s at the minimum ρ value, i.e ~26 cm, the different determinations of b^2 can be considered to be in reasonable agreement and to demonstrate an evident superluminal behavior ($b^2 < 1$) which tends to disappear ($b^2 \rightarrow 1$) when ρ becomes of the order of 1 m. This latter value can be considered to be the maximum extension of the near field for the experimental set-up adopted [20].

An alternative model

A different interpretation of the results already reported in [1,3] was given in [17] within the framework of a deformed special relativity (DSR) that hypothesizes a situation of broken local Lorentz invariance. Indeed, an interpretation of this kind was already invoked in order to interpret an anomalous effect resulting in the near field of crossed microwave beams [18]. The effect consisted of an unexpected transfer of modulation from one beam to the other which could not be fully interpreted in terms of the usual electromagnetic framework. However, this type of approach (which was already adopted in [18]) deserves to be considered in more detail before any serious conclusion can be safely drawn.

Returning now to the analysis of superluminal behavior in microwave propagation as given in [17], a question arose since in this particular context, it was considered that a threshold energy $E_0 \simeq 5\ \mu\text{eV}$ is the energy value at which the metric parameters become constant, hence $b^2(E) = (E/E_0)^{1/3}$ for $0 \leqslant E < E_0$, while $b^2(E) = 1$ for $E \geqslant E_0$ (subminkowskian electromagnetic metric [17]). This assertion, therefore, appears to be in contradiction with our results as shown in Fig. 2 where, in addition to the values of $b_s(\rho)$, the curve of the residual unitary energy (which is divided by the number N of the photons) is reported and clearly demonstrates, similarly to the intensity illustrated in Fig. 1, a net decrease with increasing ρ. The corresponding numerical values, as taken from [18], are obtained from the relation

$$E/N = h\nu e^{-2A_{att}} \tag{4}$$

where the attenuation constant $A_{att} = (2\pi\rho/\lambda)\sin(\alpha + \beta_r)\sinh\beta_i$ and $h\nu = 37\ \mu\text{eV}$ is the quantum energy of the carrier. Note that, in this way, the energy variation starting from the maximum value at $\rho \simeq 26$ cm, turns out to be $\sim 5\ \mu\text{eV}$, which is coincident with the threshold value E_0 mentioned previously. The apparent contradiction is indeed explained when we consider that the energy mentioned in [17] has to be considered as the energy ΔE *lost* by the signal after traveling a distance ρ from the emitting antenna according to the relation (see footNote 5 in [17])

$$\Delta E = E_{in} - E = h\nu\left(1 - e^{-\rho/\rho_0}\right) \tag{5}$$

which is, evidently, a quantity that increases with ρ, while the energy considered in our treatment is given by Eq. (4) which can be rewritten (omitting the N^{-1} factor) as

$$E = h\nu e^{-\rho/\rho_0}, \tag{6}$$

which shows an evident decrease with ρ.

In this scheme, by recovering the energy dependence of $b^2(E)$ as given in [18], namely $b^2(E) = (1 - E/E_0)^n$, where the exponent was taken $n = 7$, by substituting (6) we obtain

$$b(\rho) = \left[1 - \frac{h\nu}{E_0}e^{-\rho/\rho_0}\right]^{n/2}. \tag{7}$$

The decay constant ρ_0 can be determined from the values reported in [18], from which we find $\rho_0 \simeq 12$ cm. Some curves relative to Eq. (7) are reported in Fig. 2 for $h\nu = 37\ \mu\text{eV}$, $E_0 = 5\ \mu\text{eV}$, $n = 7$ and some values of ρ_0. In the same graph, we report the values of $b_s(\rho)$ as resulting from two determinations: one taken from [18] and the other from [14], as given by $b_s(\rho) = (\tau_o - \Delta\tau)/\tau_0$ where $\tau_0 = \rho/c$ and $\Delta\tau$ the measured advancing in the delay time. What clearly emerges from the comparison is that the function represented by Eq. (7) gives a reasonable description of the experimental results with ρ_0 values, which are comparable with the one previously determined, but should be considered as increasing with ρ from $\rho_0 \simeq 9$ cm to $\rho_0 \simeq 18$ cm. This means that relation (7) would need to be perfected in order to obtain a better description of the experimental results.

Still on the basis of relation (7), a more accurate description of the experimental results can be obtained by adopting a different value for the quantity E_0. In relation to Eqs. (5) and (6), the threshold energy in the present case should be considered to be different from the one assumed in [17,18]. A more convenient value for this threshold should be $E_0 = h\nu = 37\ \mu\text{eV}$, rather than $5\ \mu eV$, as previously considered. Also the constant ρ_0 has to be modified. As can be deduced from the data reported in Fig. 3 of Ref. [18], a more plausible value is given by $\rho_0 = 30.5$ cm. This latter value has been re-obtained by measuring the intensity behavior as a function of ρ, from which we obtained $\rho_0 = (32 \pm 2)$ cm. In Fig. 3 we report the new representation of Eq. (7) for $E_0 = 37\ \mu\text{eV}$ and $\rho_0 = 25$ and 30 cm [21], which supplies a better description of the same experimental results. In the same figure we report the (new) representation of the lost energy ΔE, as given by Eq. (5), which correctly demonstrates a close correspondence between its variation and the one relative to the b_s values.

It is rather surprising that it is just this approach to the problem that allows for a better representation of the experimental behavior, even if the model is based on a relatively free assumption of parameter values. The classical electromagnetic model previously considered is found to be less capable of obtaining agreement with the experimental data, especially in the initial region of distance ρ. In conclusion, even if the problem of the interpretation of the experimental behavior remains without a definitive answer, the anomaly of the superluminal behavior is without doubt peculiar to the near field in microwave propagation. When this work was accomplished, we became aware of an interesting article [22] which deals with the anomalous delay in the UHF range of frequencies, that is with wavelengths of few meters, still in the near field over distances of the order of one meter, in analogy with our results in the microwave range.

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