# Permittivity of Vacuum and Speed of Light in Vacuum which Vary with Relative Speeds of Media in Uniform Rectilinear Motion with Respect to Each Other

**Namik Yener**
Technical Education Faculty, Umuttepe Campus, Kocaeli University
Izmit 41380, Kocaeli, Turkey

**Abstract**— Having determined in a series of articles that the principle of constancy of speed of light in vacuum of the Special Relativity Theory is false and has to be put aside because it cannot account for the loss in one of the two media which are in uniform rectilinear motion with respect to each other, it has become necessary to use different speeds of light in vacuum for different Galilean reference systems. In this paper this is demonstrated again by obtaining of a relation that relates the speed of light in vacuum $c$, constitutive parameters of the medium, frequency and the speeds of two media in uniform rectilinear motion with respect to each other. This in turn necessitates the revision of the concept of the permittivity of vacuum for different Galilean reference systems. Therefore first we determine the speed of light in vacuum for one of the two moving media, and define the permittivity of vacuum for that medium using the speed of light in vacuum found for that medium. We assume the permeability of vacuum is an invariant quantity given as $\mu_0 = 4\pi \times 10^{-7}$ [H/m]. The same procedure is repeated also for the second medium. The two media which are in relative motion with respect to each other and which are taken up in this paper, are a simple medium with loss and a perfectly conducting medium filling a half space. Their interface is an infinite plane perpendicular to the direction of the uniform rectilinear motion of the second medium which is constituted of the perfectly conducting half space. For simplicity we have assumed the incident wave that impinges on the interface has a wave vector that makes an angle of $\theta = \pi/2$ with the direction of the velocity of the moving medium and hence we can make use of the time dilation formula to transform the frequencies between the Galilean reference systems. The permittivity of vacuum and speed of light in vacuum results obtained are particular to this electromagnetic system.

## 1. INTRODUCTION

In a series of articles it has been established by the author that when there are two media in uniform rectilinear motion with respect to each other and one of which has dissipation the speeds of light in vacuum for the two media become dependent on the speeds of the media with respect to each other. This fact which negates the Special Relativity Theory has been proved and reported for the dissipative medium as general as a homogeneous and timeinvariant bianisotropic medium [1]. Therefore it has become necessary to redefine the concept of speed of light in vacuum for moving media. The objective of this paper is to achieve this and also redefine the concept of permittivity of vacuum as a parameter that depends on the reference frames in rectilinear and uniform motion while considering permeability of vacuum on the other hand as a universal constant equal to $\mu_0 = 4\pi \times 10^{-7}$ [H/m]. A simple dissipative medium at rest and a perfectly conducting medium in uniform and rectilinear motion constitute the electromagnetic system of this paper. Their interface is an infinite plane perpendicular to the velocity of the second medium [2]. For the two media the mentioned speeds of light in vacuum, and permittivities of vacuum are found in terms of the conductance, frequency, and permeability of the first medium and the relative speeds of the two media.

In this paper we assume that the incident wave vector makes an angle of $\theta = \pi/2$ with the direction of velocity of the rest medium ($Ox$ axis). In this case the Doppler shift formula reduces to the time dilation formula between the two media and the Doppler shift is solely attributable to the factor of $\frac{c'}{c}\frac{1}{\sqrt{1-v_1^2/c^2}}$ that appears in the said formula [3]. In this case speed of light in vacuum and permittivity of vacuum results for medium (I) depend solely on measurements made from the laboratory frame. The same results for medium (II) however require measurement of frequency in the rest frame in addition to the above quantities measured from the laboratory frame.

It is generally desired to make the measurements from the laboratory frame rather than the rest frame. To arrive at results that involve only such quantities, the frequency as it appears from the rest frame must be transformed. This involves the angle the incident wave vector makes with the velocity of the rest frame [2]. I.e., there is implicit dependence of $c$ on $\theta$. By setting $\theta = \pi/2$ we decrease the number of the independent parameters by one. Furthermore if $\theta = \pi/2$ assumption was not made, instead of the linear equation in $c^2$ that we have in (3) below, we would have a cubic equation in $c$ which would make the problem less amenable to analysis.

## 2. SPEED OF LIGHT IN VACUUM DEPENDENT ON GALILEAN REFERENCE FRAME

Taking $\varepsilon_c(\omega) = \varepsilon'(\omega) + j\varepsilon''(\omega)$ as the complex permittivity, we must have the condition that $\varepsilon''(\omega) > 0$ holds when $\omega > 0$. This is a physically necessary condition for the passivity of the medium. For reasons of causality $\varepsilon_c(\omega)$, where $\omega = \overline{\omega} + j\tilde{\omega}$ is true, must be analytic in the upper half plane. Indeed for metals at the lower frequencies up to infrared, one has $\varepsilon_c(\omega) = \varepsilon + j\sigma/\omega$ which is analytic in the whole complex $\omega$ plane except at $\omega = 0$ [4]. And it is this form of complex permittivity that we shall assume is true in this article. We shall use the nomenclature 'real part of permittivity' for the real part and 'conductivity' for $\sigma$.

Using Equations (21a) through (22b) of [2], and taking the difference of squares of the wave numbers for incident and reflected waves after setting $\theta = \pi/2$ one obtains: $k_i^2 - k_r^2 = (k_i \sin\theta)^2 - (k_r \cos\theta_1)^2 - (k_r \sin\theta_1)^2 = -\alpha^2(\omega' r/c' + \omega' r/c')^2 = 4\alpha^2\tilde{\omega}'^2(r/c')^2$ where $\omega' = j\tilde{\omega}'$. Now using time dilation relation $\omega'/\omega_i = \alpha(c'/c)$ in terms of the frequency [3], since we have transverse Doppler effect due to only the factor of $\frac{c'}{c}\frac{1}{\sqrt{1-v_1^2/c^2}}$ [5, 6] because we have set $\theta = \pi/2$, one obtains when the difference of dispersion relations for incident and reflected waves is taken, namely when Equations (26a) and (26b) of [2] are subtracted,

$$4\alpha^2\tilde{\omega}'^2\left(\frac{r}{c'}\right)^2 = \left\{\left(j\frac{\tilde{\omega}'}{\alpha}\frac{c}{c'}\right)^2\left[1 - \alpha^4(1 + r^2)^2\right]\right\}\varepsilon_1\mu_1 + j\sigma_1\mu_1\left\{\left(j\frac{\tilde{\omega}'}{\alpha}\frac{c}{c'}\right)\left[1 - \alpha^2(1 + r^2)\right]\right\}. \quad (1)$$

From (1)

$$2\frac{\tilde{\omega}'\alpha}{cc'}(1 - c^2\varepsilon_1\mu_1) = \sigma_1\mu_1 \quad (2)$$

follows which is now only in terms of real quantities as opposed to Equation (40) of [2] which includes imaginary quantities $j$ and $\omega' = j\tilde{\omega}'$. This is in fact the equation used in [2] to negate the Special Relativity Theory. If $\omega_i$ is the pure imaginary incident wave frequency observed from $K$, with $\omega_i = j\tilde{\omega}$ and again using the time dilation relation for the frequency under the $\theta = \pi/2$ constraint, from (2) one gets for the speed of light in vacuum for $K$

$$c^2 = \frac{2\tilde{\omega}}{(\sigma_1 + 2\tilde{\omega}\varepsilon_1)\mu_1} + \frac{\sigma_1 v_1^2}{\sigma_1 + 2\tilde{\omega}\varepsilon_1}. \quad (3)$$

## 3. $\varepsilon_0$, PERMITTIVITY OF VACUUM FOR $K$ THAT CHANGES WITH RELATIVE SPEEDS OF $K$ AND $K'$ AND SPEEDS OF LIGHT IN VACUUM FOR $K$ AND $K'$

The relative real part of permittivity $\varepsilon_{1r}$, the relative magnetic permeability $\mu_{1r}$ and the conductivity of medium (I), are the quantities that can be obtained as the results of measurements made from $K$ through comparisons with corresponding values for vacuum [7, 8]. Since medium (I) where these three quantities are measured is at rest with respect to $K$, they must not change with changing $v_1$ even though the real part of permittivity, $\varepsilon_1$ may change because of the change in $c$ due to (3). Therefore since $\varepsilon_{1r}\mu_{1r}$ is a constant quantity, by definition

$$c^2\varepsilon_1\mu_1 = \varepsilon_{1r}\mu_{1r}, \quad (4)$$

must also not change with changing $v_1$. If in (3) we note that $\varepsilon_1 = \varepsilon_{1r}\varepsilon_0$, $\mu_1 = \mu_{1r}\mu_0$ where $\varepsilon_0\mu_0 = 1/c^2$, one can write down

$$\frac{2\tilde{\omega}}{\sigma_1\mu_{1r}\mu_0 + 2\tilde{\omega}\varepsilon_{1r}\varepsilon_0\mu_{1r}\mu_0} + \frac{v_1^2\sigma_1}{\sigma_1 + 2\tilde{\omega}\varepsilon_{1r}\varepsilon_0} = \frac{1}{\varepsilon_0\mu_0}. \quad (5)$$

One should observe that in (5), $\mu_0 = 4\pi \times 10^{-7}$ [H/m] is an invariant quantity and all other quantities in (5) excluding $\varepsilon_0$ are determinable by measurements made from $K$. Hence we are in the position to compute $\varepsilon_0$ from (5). Indeed (5) will yield:

$$\varepsilon_0 = \frac{\mu_{1r}\sigma_1}{2\tilde{\omega}(1 - \varepsilon_{1r}\mu_{1r}) + v_1^2\sigma_1\mu_{1r}\mu_0}. \quad (6)$$

$\varepsilon_0$ will be dependent on $\tilde{\omega}$ and $v_1$. Now we can formulate the expression for $c^2$ in terms of parameters that can all be determined as explained above:

$$c^2 = \frac{1}{\varepsilon_0\mu_0} = \frac{2\tilde{\omega}(1-\varepsilon_{1r}\mu_{1r}) + v_1^2\sigma_1\mu_{1r}\mu_0}{\sigma_1\mu_{1r}\mu_0}. \tag{7}$$

For the particular choice of frequency and medium (I) and hence of $\tilde{\omega}$, $\sigma_1$, $\mu_{1r}$ and $\varepsilon_{1r}$, (7) gives a hyperbola in terms of variables $c$ and $v_1$.

Notice that the time dilation relation in terms of the frequency is $\frac{\omega'}{\omega_i} = \alpha(\frac{c'}{c})$. Here when medium (I) is simple but lossy, $c \neq c'$ has been proved in the previous series of articles and measurements that will yield $\omega'$ versus $\omega_i$ must necessarily accommodate a $c'/c$ ratio that is different from unity. Using this formula for time dilation in terms of the frequency, one can establish the expression for $c'^2$ also utilizing (7).

Indeed one then has:

$$c'^2 = \left(\frac{\tilde{\omega}'}{\tilde{\omega}}\right)^2 (c^2 - v_1^2) = \left(\frac{\tilde{\omega}'}{\tilde{\omega}}\right)^2 \left[\frac{2\tilde{\omega}(1-\varepsilon_{1r}\mu_{1r})}{\sigma_1\mu_{1r}\mu_0}\right]. \tag{8}$$

In this expression all the quantities on the far right hand side are obtained by measurements. Except for $\tilde{\omega}'$ which is measured from $K'$, all quantities are measured from $K$. Equation (8) can also be used to obtain $v_2$, which is the relative speed of $K$ with respect to $K'$, as follows:

$$v_2^2 = v_1^2 \left(\frac{\tilde{\omega}'}{\tilde{\omega}}\right)^2 \left[\frac{2\tilde{\omega}(1-\varepsilon_{1r}\mu_{1r})}{2\tilde{\omega}(1-\varepsilon_{1r}\mu_{1r}) + v_1^2\sigma_1\mu_{1r}\mu_0}\right]. \tag{9}$$

We can also find the expression for $\varepsilon_0'$ permittivity of vacuum in frame $K'$ using (8). Indeed if permeability of vacuum is again taken as $\mu_0' = 4\pi \times 10^{-7}$ [H/m] for frame $K'$,

$$\varepsilon_0' = \left(\frac{\tilde{\omega}}{\tilde{\omega}'}\right)^2 \frac{\mu_{1r}\sigma_1}{2\tilde{\omega}(1-\varepsilon_{1r}\mu_{1r})} \tag{10}$$

will be found.

## 4. CONCLUSION

It has become evident that since the principle of constancy of speed of light for all Galilean reference systems has to be put aside, the concept of permittivity of vacuum and hence the concept of speed of light in vacuum have to be structured as per Equations (6) and (7). Thus we have to define a new permittivity of vacuum and hence a new speed of light in vacuum in order to make Maxwell's equations compatible with the principle of relativity. This problem has been attempted to be solved. For the case of an incident wave vector with an angle $\theta = \pi/2$ with the velocity direction of the uniform rectilinear motion of one of the moving media, the results have been obtained for both Galilean reference systems.

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