Absence of the Relativistic Transverse Doppler Shift at Microwave Frequencies

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***Abstract*—An experiment is described showing that a 33-GHz microwave signal received by rotating antennas is not exhibiting the frequency shift ("transverse Doppler effect") predicted by the relativistic Doppler formula. The sensitivity of the apparatus used has been tested to be sufficient for detecting frequency shifts as small as 10^{-3} Hz which corresponds to the value of $(v/c)^2 = 5.10^{-14}$ used in the transverse Doppler shift experiment reported here. From the observed absence of the transverse Doppler shift it is concluded that either the time dilation predicted by the standard theory of special relativity does not exist in reality or, if it does, is a phenomenon which does not depend on relative velocities but may be a function of absolute velocities in the fundamental frame of the isotropic microwave background radiation.**

***Index Terms*—Doppler radar, interferometry, Ka-band frequencies, relativistic Doppler shift, time dilation.**

I. Introduction

MODERN LASER and microwave interferometric techniques have been very successful in improving the accuracy of experiments designed to measure, for example, length, distance, or speed of targets [1], [2]. In fact, recently reached accuracies seem to be sufficiently high for testing one of the fundamental predictions of special relativity (SR), namely the transverse Doppler effect which is one of the few direct consequences of SR as it follows directly from time dilation [3]. Up until now, no conclusive measurement of the transverse Doppler shift at microwave frequencies has been reported, whereas results obtained with laser techniques have already been published, for example, by Kaivola *et al.* [4], Klein *et al.* [5], and Davies and Jennison [6]. Since Davies and Jennison [6] did not observe any relativistic Doppler shift for a reflected laser beam incident on a transversely moving mirror, whereas Kaivola *et al.* [4] and Klein *et al.* [5] did observe relativistic frequency shifts by studying spectra emitted by fast ion beams, it was thought that performing a similar rotating disk experiment at microwave frequencies might help to solve this discrepancy. Moreover, such an experiment could clear up the question whether or not time dilation is a really existing phenomenon and, if it is, whether it depends on relative velocities or perhaps "only" on an absolute velocity in a fundamental reference frame such as the microwave background radiation [7], [8], as discussed in [9] by this author and by many others (for example, in [10]). The instrumentation and measurement method employed in this work is innovative in concept as a microwave interferometer has never been used before to test special relativity. Microwave signals exhibit high spectral purity and a well-defined polarization plane.

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II. Experimental Setup

The experiment reported in this paper is a very simple and straight forward measurement of the Doppler effect using a microwave signal transmitted through a rectangular wave guide with a well-defined polarization plane. The experimental setup is shown schematically in Fig. 1. A 33-GHz signal generator (Wiltron Sweeper 6640A) with very low phase noise (residual FM $<$ 40 kHz pk measured in 30 Hz–15 kHz bandwidth) is connected to a circulator using a Ka-band rectangular wave guide which guides the microwave signal toward a monopole antenna mounted in the center of a metallic disk. Opposite to this radiating monopole antenna a rotating disk (disk 1) with eight monopole antennas mounted at its rim is placed in such a way that each monopole antenna receives an (in magnitude and phase) identical signal from the stationary transmitter. The receiving monopole antennas are connected to each other by a circular metallic strip line, which forms a resonator. In addition, the disk 1 is covered by another circular metallic layer forming a "coplanar wave guide" together with the circular strip resonator connecting the receiving antennas. The waves received by the monopoles mounted on the rim of the rotating disk 1 should exhibit a transverse Doppler frequency shift when the disk is in rotation. No Doppler shifts are, of course, expected when the disk is stationary. The Doppler frequency shifted waves are picked up by a similar rotating disk (2) positioned near rotating disk 1. The signal received by disk 2 should again exhibit a transverse Doppler frequency shift when the two disks are rotating in opposite directions. The waves being transmitted from the rotating disk 2 into the wave guide pickup antenna located near the rim of disk 2 might be subject to another transverse Doppler shift. The overall frequency shift can then be measured by standard mixer and interferometer techniques. In this experiment (see Fig. 1), this is achieved by feeding both the Doppler frequency shifted signal and the reference signal into a mixer diode via a magic tee which acts as an interferometer. Phase and magnitude of the interfering signals are adjusted by the sliding short and by the variable attenuator. Since the transverse Doppler frequency shift is expected to be extremely small due to the small available rotational speeds, it is important to employ the interferometer technique with its extremely high sensitivity. The high sensitivity of the apparatus has been verified experimentally as will be discussed in Section IV.

A similar experiment, with only one rotating disk, has been carried out recently [11] with essentially the same result (absence of transverse Doppler shift). Since compensating shifts

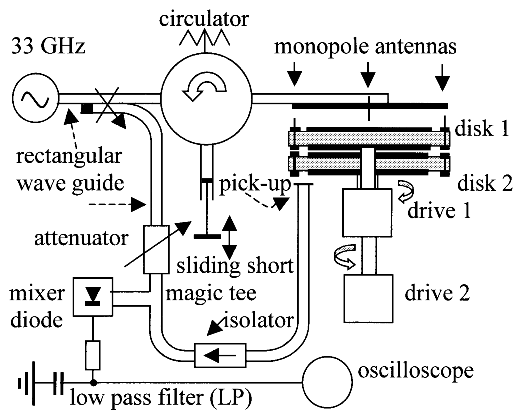

Fig. 1. Experimental setup.

could be possible with only one disk in rotation, the experiment was repeated with two disks with coinciding rotation axes in (opposite) rotation. With two disks in rotation, compensating shifts do not occur as shown in Section IV.

III. Doppler Shift Formula

From textbooks [3], [14] or Einstein's 1905 paper [12], one can easily derive the relativistic Doppler shift formula relevant for the used experimental setup. This will be done with the help of the paths of the involved waves as shown in Fig. 2. There the signal emitted by the stationary transmitter T is shown to be received by a receiver at R' moving at velocity v.

The associated angle φ' is related to the angle φ via the well known expression [3], [12]

$$\cos\varphi' = \frac{\cos\varphi - \left(\frac{v}{c}\right)}{1 - \left(\frac{v}{c}\right)\cdot\cos\varphi}. \tag{1}$$

c is the velocity of light. The frequency f' measured at R' is shifted according to the expression [3], [12]

$$f' = f\frac{1 - \left(\frac{v}{c}\right)\cdot\cos\varphi}{\sqrt{1-\left(\frac{v}{c}\right)^2}}. \tag{2}$$

This is the standard formula for the "one-way" relativistic Doppler shift. According to (2) a "red shift" occurs as is expected for a receiver moving away from the transmitter (in Fig. 2 in the x-direction). However, for $\varphi = 90^\circ$, the linear term in v/c disappears but a small "blue shift" still remains. This is the (up to now) generally accepted "transverse Doppler effect" [3], [12].

Identical expressions can be obtained by using the more elegant method employing wave vectors [13], [14]

$$k'_x = \frac{k_x - \omega\cdot\frac{v}{c^2}}{\sqrt{1-\left(\frac{v}{c}\right)^2}} \tag{3}$$

$$\omega' = \frac{\omega - k_x v}{\sqrt{1-\left(\frac{v}{c}\right)^2}}. \tag{4}$$

With the well-known relation

$$|\vec{k}| = \frac{k_x}{\cos\varphi} = \frac{\omega}{c} \tag{5}$$

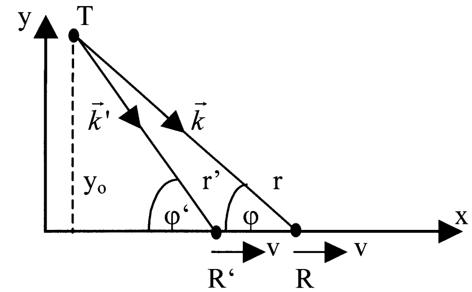

Fig. 2. Paths of transmitted and received waves.

the expressions (3) and (4) can be easily converted to the two (1) and (2) [14].

It should be emphasized that the distances between transmitter and receiver, i.e., r and r', do not explicitly appear in these equations. Standard textbooks [3], [13], [14] usually neglect them as being of no relevance for the calculation of the relativistic Doppler shift which is calculated via (2) or (4). However, (1) and the other usually quoted equation

$$\sin\varphi' = \frac{\sin\varphi\cdot\sqrt{1-\left(\frac{v}{c}\right)^2}}{1-\left(\frac{v}{c}\right)\cdot\cos\varphi} \tag{6}$$

both of which being derived from the Lorentz transformations are incompatible with the geometrical relation following directly from Fig. 2

$$y_o = r'\cdot\sin\varphi' = r\cdot\sin\varphi. \tag{7}$$

Combining (6) and (7) yields an expression for r/r'

$$\frac{r}{r'} = \frac{\sqrt{1-\left(\frac{v}{c}\right)^2}}{1-\left(\frac{v}{c}\right)\cdot\cos\varphi} \tag{8}$$

which is related to the Doppler frequency shift given by (2), i.e.

$$f' = f\frac{r'}{r}. \tag{9}$$

One could be tempted to claim that (9) is a new and correct expression for the Doppler frequency shift which precludes a transverse shift from occurring in a rotating disk experiment $(\mathrm{r} = \mathrm{r}')$ such as that reported here (where no transverse shift has been observed indeed). Unfortunately, (8) is wrong which becomes evident for v approaching c making r/r' equal to zero (for $\varphi = 90^\circ$) rather than equal to unity as it should be in a rotating disk experiment. The obvious conclusion drawn from this contradiction is that the Lorentz transformations are unrealistic transformations, which are not suited for deriving Doppler frequency shifts (see also Section V). This inconsistency already indicates that the relativistic derivation of the Doppler shift expression might be incorrect.

Up until now, relativistic Doppler shifts have been calculated using exclusively (2) or (4). Ives and Stilwell [15], [16] were the first to test time dilation via (2) or (4) by measuring the difference in the Doppler shift of spectral lines emitted in the forward and backward directions by a uniformly moving beam of hydrogen atoms. Their results and others will be discussed and compared with the findings reported in this paper in Section V.

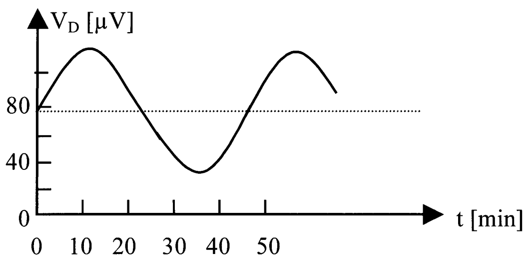

Fig. 3. Detector diode voltage versus time.

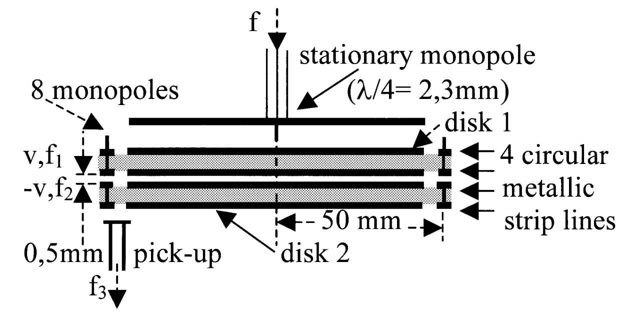

Fig. 4. Two rotating disks.

IV. Experimental Results

The experiment was carried out in two steps. First, the apparatus was tested with respect to its sensitivity to signals of very small frequency differences without rotation of the disks. The frequency of the wave being emitted by the center monopole antenna was slightly increased by moving the sliding short (Fig. 1). The reading on the oscilloscope corresponded to the difference frequency f_D according to the formula

$$f_D = |f' - f| \approx f \cdot \left[\frac{2v}{c}\right] \tag{10}$$

which has been derived by applying (2) twice (in order to take into account the reflection by the moving short) with $\varphi = 0°$. Of particular interest was the value $2v/c = 10^{-14}$, as this value was chosen close to the value of $(v/c)^2$ used in the subsequent crucial experiment with the disks in rotation. The sensitivity of the apparatus was found to be sufficiently high to detect $v/c = 10^{-14}$. In fact, it was even possible to measure the position of the nonmoving short (corresponding to $v/c = 0$) with micrometer resolution due to the interferometer principle this apparatus is based on. The result is illustrated in Fig. 3, where the detector diode voltage has been plotted versus time when the sliding short was moved at a velocity of about 1, 5 μm/s corresponding to $2v/c = 10^{-14}$.

After this test, the second and crucial part of the experiment—the measurement of the transverse Doppler shift by verifying (2) or (4) with the disks in rotation—was carried out. In order to do this, the angular velocities of the disks were increased from zero up to the highest possible value ensuring mechanical stability. 250 rev/s turned out to be a safe value. At this speed the predicted Doppler frequency should assume a value equal to about (the radius of the disk is 0.05 m, see Fig. 4)

$$\begin{aligned} f_D &= f \cdot \left[\frac{1}{\sqrt{1-\frac{v^2}{c^2}}} - 1\right] \approx f \cdot \frac{1}{2}\left[\frac{v}{c}\right]^2 \\ &\approx 33 \cdot 10^9 \cdot \frac{1}{2}\left[\frac{2\pi \cdot 250 \cdot 0,05}{3 \cdot 10^8}\right]^2 \\ &\approx 10^{-3}\ \text{Hz} \end{aligned} \tag{11}$$

if only one blue shift would occur, i.e., if only disk 1 is rotating and disk 2 stationary. In this case, an uncertainty exists, as one could argue that the blue shift the wave experiences during propagation from the stationary monopole to the rotating antennas mounted at the rim of disk 1 could possibly be compensated by an equal red shift occurring during transfer of the signal from the rotating disk (1) through disk (2) into the stationary pickup antenna. In order to avoid this uncertainty, both disks must rotate in opposite directions. For the case of equal speeds of the two disks ($v = -v$), the overall transverse Doppler shift consists of three shifts which can easily be derived by referring to Fig. 4 using the relativistic theorem for adding the velocities of the two disks:

$$f_1 = f\frac{1}{\sqrt{1-\left(\frac{v}{c}\right)^2}} \tag{12}$$

$$f_2 = f_1\frac{1}{\sqrt{1-\frac{(2vc)}{(c^2+v^2)^2}}} = f_1\frac{1+\left(\frac{v}{c}\right)^2}{1-\left(\frac{v}{c}\right)^2} \tag{13}$$

$$f_3 = f_2\sqrt{1-\left(\frac{v}{c}\right)^2} = f\frac{1+\left(\frac{v}{c}\right)^2}{1-\left(\frac{v}{c}\right)^2}. \tag{14}$$

In these equations, the "worst" case has been assumed that the first blue shift (f_1/f) is compensated by a red shift (f_3/f_2) of equal amount. On the other hand, the principle of relativity would call for another blue shift at the pickup or, if a red shift would occur for (f_1/f), then a red shift should also occur for (f_3/f_2). Anyway, an overall second order shift given by (14) or by a similar expression containing only quadratic terms of v/c should definitely remain if two disks rotating in opposite directions are used.

Admittedly, the amount of the expected shift is extremely low but the apparatus was indeed capable to detect such a low frequency as was demonstrated before in the test experiment. In fact, the low frequency is even advantageous as it allows to filter out longitudinal Doppler shifts caused by an off-axis displacement of the emitting stationary monopole or by geometrical irregularities of the rotating disks corresponding to the angular velocity of the disks, i.e., to about 250 Hz, which is orders of magnitude higher than the expected transverse Doppler frequency. The low-pass filter (LP in Fig. 1) is doing this job. However, the transverse Doppler shift can be detected even without the use of the low pass filter because the longitudinal Doppler shifts average out during each revolution of the disks whereas transverse shifts remain as they add up over their period of about 40 minutes (see Fig. 3). This was experimentally verified by deliberately introducing a low frequency shift of 1 mHz with the disks in rotation by moving the sliding short at a speed of about 2 μm/s. Anyway, longitudinal shifts have been minimized by keeping off-axis displacements small compared to the wavelength of the 33-GHz signal ($\lambda = 9{,}1$ mm) resulting in a longitudinal shift detector voltage of about 3 μV which is less than 10% of the expected transverse Doppler shift detector voltage.

Surprisingly, the detector diode voltage measured during the rotation of the disks was found to be constant at all speeds. It did not show an ac voltage of frequency predicted by (11) or (14). The expected transverse Doppler shift thus could not be observed. Instead, a null result was measured which was not due to instrumental deficiencies as a frequency shift of the same amount had been detected before during the first part of the experiment as described above. This result thus confirms the findings of Davies and Jennison [6], who found that a light pulse reflected from a rotating mirror did not show relativistic frequency shifts. However, other authors have observed transverse Doppler shifts, in particular Champeney *et al.* in their experiments performed with Mössbauer source and absorber mounted on a rotating disk [17], [18]. This discrepancy is not understood as will be discussed in the next section.

V. Discussion and Conclusion

Since the transverse Doppler shift has been derived directly from the Lorentz transformations, it thus is a direct consequence of the time dilation factor given by

$$\Delta t' = \Delta t \cdot \sqrt{1 - \left(\frac{v}{c}\right)^2} = \Delta t \cdot \gamma^{-1} \quad (15)$$

which appears in the relativistic Doppler shift formulae of (2), (4) and (8). In fact, time dilation is sometimes used to explain the transverse Doppler shift [17], [18]. From the observed absence of the transverse Doppler shift, one could be tempted to draw some very audacious conclusions such as the following.

1) Time dilation does not exist implying that the Lorentz transformations are not applicable (at least to rotating transmitters, antennas and detectors).
2) Time dilation exists only in a preferred frame of reference (microwave background) but cannot be detected by the used experimental setup as is the case with many other experiments which attempt to test local Lorentz invariance of time, length or mass.

Although similar statements have previously appeared in the literature [9], [19]–[23], it is nevertheless advisable to carefully compare the reported findings with other experimental results before such conclusions are drawn.

Doppler shift measurements have been performed in the past either by studying the spectra of fast ion beams [4], [5], [15], [16], [24] or by measuring the Mössbauer effect with source and absorber mounted on a rotating disk [17], [18]. In some of the ion beam experiments, the measured shifts were so small as to be close to the limits of observation [15], [16]. As far as the rotor experiments are concerned, centrifugal effects due to the rotation could not be eliminated [17], [18] but are thought to have no effect on the measurements. Perhaps the Sagnac effect [3] has played a role in these experiments. Nevertheless, in several experiments [15], [16], [18], [24], observation of time dilation has been claimed, in contrast to the findings reported in this paper. Whether or not this discrepancy can be resolved remains to be seen.

If one trusts the experimental results reported here, he can choose one of the two above mentioned conclusions. Clearly, both of them are in conflict with the principle of relativity: the first one fully denies the existence of time dilation; the second conclusion considers time dilation to be a real physical phenomenon only with respect to the preferred frame of reference as defined by the microwave background radiation [7], [8]. This implies that v in the Lorentz factor (15) is the absolute velocity of the laboratory with respect to the microwave background (390 km/s [8]) rather than the much smaller relative velocity as special relativity predicts. The preferred frame of reference is so to speak [9] the basis for calculating the (absolute!) velocities of all masses in the universe after acceleration (by the "big bang") had come to an end. The mass increase, like time dilation also related to the Lorentz factor given by (15), can be understood as the result of energy (and, hence, mass) transfer into the accelerated masses of the universe. Mass increase thus is not a relativistic effect [9].

The second conclusion is in good agreement with other theories such as that recently published by R. Pabisch [25], who has derived time dilation from two fundamental properties of photons which carry an inertial component $\vec{u}$ in the direction of the absolute velocity $\vec{u}$ of the emitter in the preferred frame of the isotropic microwave background radiation and have an absolute constant velocity c in the preferred frame. That leads to a contraction of the $\vec{u}$-component. He concluded that time dilation and quite visibly the synchrotron effect like all the other basic effects treated by special relativity depend on the absolute velocity $\vec{u}$ of a body with respect to the preferred frame of the isotropic microwave background radiation rather than on relative and, hence, equivalent velocities $\vec{v}$ and $-\vec{v}$.

Both conclusions lead to the resolution of all well-known paradoxa introduced by special relativity. However, there is no doubt that a quantum mechanical approach of the absorption and emission of photons would describe experiments of this type much more realistically than Maxwell's theory and the special theory of relativity which both neglect the atomistic structure of matter with the well known consequence that at least the special theory of relativity is incompatible with quantum mechanics. This fact and the experimentally observed absence of the transverse Doppler shift (time dilation) both suggest that the theory of (special) relativity should be revised or, at least, the Lorentz (gamma) factor should not appear in transformation equations. Thus, the Galilean principle of relativity is describing physics much more realistically. And, as far as calculating the Doppler shift is concerned, the classical formula valid for sound waves should rather be used.

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