# Experimental detection of superluminal far-field radio waves with transverse plasma antennas



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# Experimental detection of superluminal far-field radio waves with transverse plasma antennas

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***Abstract*—The predictions of Maxwell's equations depend on the reference frame in which they are solved. If one solves Maxwell's equations in the rest frame of the transmitter, which is the common approach, one obtains Lorentz-Einstein electrodynamics by adding the special theory of relativity. Here, for formal reasons, no information velocities greater than the speed of light in vacuum are possible. If, however, one solves Maxwell's equations rigorously in the rest frame of the receiver, one comes to a field-theoretical generalization of Weber electrodynamics, which differs from Lorentz-Einstein electrodynamics. Although Einstein's postulates are also fulfilled in this Weber-Maxwell electrodynamics, in a specifically designed experimental setup of two mutually stationary and very distant antennas, electromagnetic waves may travel at velocities that exceed the speed of light in vacuum. This effect, previously predicted only theoretically, has now been experimentally investigated and confirmed. This finding indicates that Lorentz-Einstein electrodynamics is incorrect and that Maxwell's equations should instead be interpreted in terms of Weber electrodynamics. As a subsidiary result, these findings can enable remarkable new technologies, such as a highly compact method for radio direction finding (RDF).**

***Index Terms*—Maxwell equations, Electromagnetic forces, Electromagnetic propagation, Radio communication, Direction-finding, Speed measurement, Plasma devices**

## I. Introduction

Since their origin approximately 150 years ago, Maxwell's equations have almost always been solved in the rest frame of the transmitter because, at that time and still today, this is thought to be the natural approach due to its simplicity and the similarity to electro- and magnetostatics. With this approach, however, the problem arises that electromagnetic waves travel at the speed of light $c$ only with respect to the transmitter. Yet, it is known from numerous experiments that this does not agree with reality. Instead, Einstein's postulates apply, which are often referred to as postulates of special relativity[1]. These postulates can be formulated in different ways. For example, as follows:

1) *Principle of relativity:* Every velocity value requires a reference. Every uniformly moving receiver is allowed to be used as such a reference.
2) *Constancy of the speed of light:* An electromagnetic wave in vacuum travels from the perspective of any uniformly moving receiver at the speed of light in vacuum, $c$.

These postulates together state that the *same* electromagnetic wave travels at the speed of light in the frame of reference of *every unaccelerated* receiver, independent of the relative speed of these receivers with respect to the transmitter and *among themselves*. Aiming to solve this contradiction, Hendrik Antoon Lorentz developed the Lorentz transformation, which is named after him. In 1905, Albert Einstein provided a philosophical-mathematical interpretation with the special theory of relativity. This interpretation, as well as its accompanying mathematical formalism, is accepted today by the majority of physicists as a necessary evil and is ignored by almost all electrical engineers as irrelevant to their field. In contrast to most scientific theories, the special theory of relativity is very popular outside of science and is passionately adored by some and vehemently rejected by others.

Few are aware that Maxwell's equations can also be solved in the receiver's rest frame. In this case, the property of being in motion is transferred from the receiver to the transmitter. This approach produces additional current density terms, which must be considered when solving Maxwell's equations. At the same time, the magnetic field $\boldsymbol{B}$ loses its meaning, as the receiving antenna is now at rest, and thus, the velocity $\boldsymbol{v}$-dependent term $\boldsymbol{v} \times \boldsymbol{B}$ in the Lorentz force is obsolete.

Mathematically, solving Maxwell's equations in the receiver's rest frame is highly challenging due to the additional velocity-dependent current densities. For a single point charge, this solution is called the Liénard-Wiechert potential [1]. Remarkably, for small relative velocities, this solution is a rather simple equation called the Weber force [2].

The Weber force is older than Maxwell's equations and originates from André-Marie Ampère, Wilhelm Weber, and Carl Friedrich Gauss. Some decades after the introduction of Maxwell's equations, the Weber force had already been nearly forgotten and was known only to a few specialists (e.g., [3]). Over the past few decades, the Weber force has been investigated and studied again by a small group of scientists, largely unnoticed by the mainstream (e.g., [4]–[14]). Experiments and theoretical investigations have revealed that the reasons for which Weber electrodynamics fell into disuse are unjustified [15], [16] and that Weber electrodynamics is superior in some respects to standard electrodynamics in terms of experimental predictions [11], [17].

Recently it was demonstrated that Weber electrodynamics is closely related to Maxwell's equations [2]. In fact, Weber electrodynamics is much closer to Maxwell's equations than Lorentz-Einstein electrodynamics because the latter requires

[1]Literature references to the special theory of relativity are largely omitted, as it is the subject of countless articles and textbooks.

numerous ad hoc extensions such as the Lorentz transformation, Lorentz force, and relativistic dynamics to satisfy Einstein's postulates listed above. However, these additional assumptions are unnecessary if one solves Maxwell's equations rigorously and uncompromisingly in the receiver's rest frame.

This can be recognized in the electromagnetic force $\boldsymbol{F}$, which a uniformly moving Hertzian dipole, i.e., a point-like elementary antenna, with trajectory

$$\boldsymbol{r}_s = \boldsymbol{v}\, t \tag{1}$$

exerts on a point-like charge $q_d$ resting at location $\boldsymbol{r}$. The solution of Maxwell's equations for this special case is

$$\begin{aligned}\boldsymbol{F} = &\frac{q_d\, q \left(1 + \frac{\boldsymbol{r}_h \cdot \boldsymbol{v}}{r_h\, c}\right)}{2\,\pi\,\varepsilon_0\, c^2\, r_h} \left(\frac{\boldsymbol{r}_h}{r_h} \times \left(\frac{\boldsymbol{r}_h}{r_h} \times \ddot{\boldsymbol{s}}\,(t-\tau)\right)\right) + \\ &\frac{q_d\, q \left(1 + \frac{\boldsymbol{r}_h \cdot \boldsymbol{v}}{r_h\, c}\right)}{2\,\pi\,\varepsilon_0\, c^2\, r_h} \left(\left(\frac{\boldsymbol{v}}{c} \times \frac{\boldsymbol{r}_h}{r_h}\right) \times \ddot{\boldsymbol{s}}\,(t-\tau)\right)\end{aligned} \tag{2}$$

in the far field, where the definition

$$\boldsymbol{r}_h := \boldsymbol{r} - \boldsymbol{r}_s \tag{3}$$

is employed to shorten the notation [2]. The time constant $\tau$ is defined by the following approximation:

$$\tau \approx \frac{r_h}{c} + \frac{\boldsymbol{r}_h \cdot \boldsymbol{v}}{c^2}, \tag{4}$$

where the relative velocity $\boldsymbol{v}$ should be small[2] compared with the speed of light in vacuum $c$.

The function $\boldsymbol{s}(t)$ is the spatial displacement of the two point charges $+q$ and $-q$ in the Hertzian dipole as a function of time $t$. It should be noted that in textbooks (e.g., [18]), it is usually assumed that $\boldsymbol{s}(t) = \boldsymbol{e}_z\, p_0/(2\,q)\, \sin(\omega\, t)$, where $\boldsymbol{e}_z\, p_0$ is the electric dipole moment. Furthermore, in all textbooks, one can find only the solution for the Hertzian dipole at rest[3], i.e., for the case $v = 0$. The force (2) divided by the charge $q_d$ corresponds in this specific case to the electric field $\boldsymbol{E}$. In addition, textbooks provide the magnetic field $\boldsymbol{B}$.

Lorentz-Einstein electrodynamics [1], [18]–[20] postulates that the fields $\boldsymbol{E}$ and $\boldsymbol{B}$ calculated for a *resting* Hertzian dipole and a *resting* receiver can be substituted into the formula of the Lorentz force

$$\boldsymbol{F} = q_d\, \boldsymbol{E} + q_d\, \boldsymbol{v} \times \boldsymbol{B} \tag{5}$$

to obtain the force experienced by a receiver with charge $q_d$ *moving* at velocity $\boldsymbol{v}$. This is an ad hoc assumption, and it is a matter of fact that the force calculated by Equation (5) for $v \neq 0$ is significantly different from the force in Equation (2).

In particular, the wave (5) moves at the speed of light $c$ only for the transmitter, i.e., with respect to the Hertzian dipole. As previously mentioned, because this result contradicts reality and Einstein's postulates, Hendrik Antoon Lorentz and others[4] were motivated to develop Lorentz force and Lorentz transformation.

[2]E.g., a velocity of 1% of the speed of light $c$ is small in the sense of this approximation.

[3]Even when Liénard-Wiechert potentials are used because the authors consider the retardation only for the acceleration part.

[4]Woldemar Voigt [3]

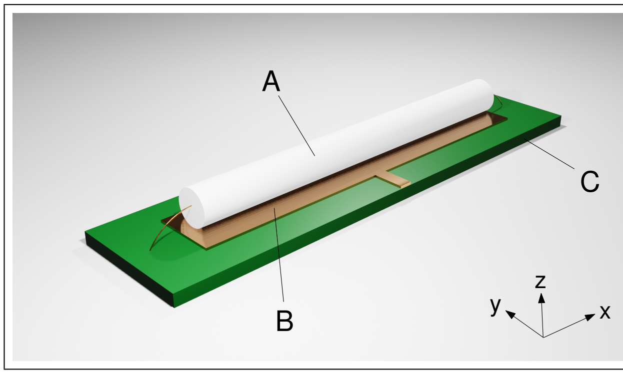


Figure 1. Structure of a transverse plasma antenna. A: cold cathode fluorescent lamp, B: external electrode with a connector, C: substrate material of the PCB (e.g., FR4).

The objective of this article is to assess the force in Equation (2) experimentally. For this purpose, a specialized type of antenna – the transverse plasma antenna – is applied. In the following section, its construction and operation are described.

## II. Transverse plasma antenna

Figure 1 shows the principal construction of a transverse plasma antenna. The antenna consists of two essential components: a tube containing an ionizable gas (A) and an electrode (B). For mechanical reasons, it is useful to mount tube and electrode on a printed circuit board (PCB) (C).

If a high DC voltage is applied across the tube (A), the contained gas is ionized. This creates an electrically conductive plasma, and a current flow occurs in which electrons move in one direction and ions in the other. The drift velocities of the electrons can be very high; for example, it can be close to 1% of the speed of light in vacuum. In contrast, the ions move much more slowly because they are considerably heavier.

The principle of operation of a transverse plasma antenna can be visualized by imagining that the tube is penetrated by a transverse electromagnetic wave moving in the x-direction. If we further assume that the transverse wave is polarized in the z-direction, it becomes clear that the electrons in the tube experience a force in the negative z-direction due to the electromagnetic force. In turn, a space charge zone is formed, and electrons come out of the electrode underneath, provided that the antenna is connected to the reference ground via a resistor.

If the direction of polarization of the incident electromagnetic wave changes, then the direction of current in the measuring resistor also changes. Thus, a transverse plasma antenna is, at least in principle, suitable for the reception of electromagnetic waves.

Notably, a transverse plasma antenna is different from typical antennas and linear plasma antennas [21] because the alignment in a linear plasma antenna is parallel to the polarization of the electromagnetic wave (the z-direction in this case). Furthermore, when using an ordinary antenna, one measures the signal in the longitudinal direction rather than at a measuring electrode, as with the transverse plasma antenna. The transverse plasma antenna is instead similar to a tube-

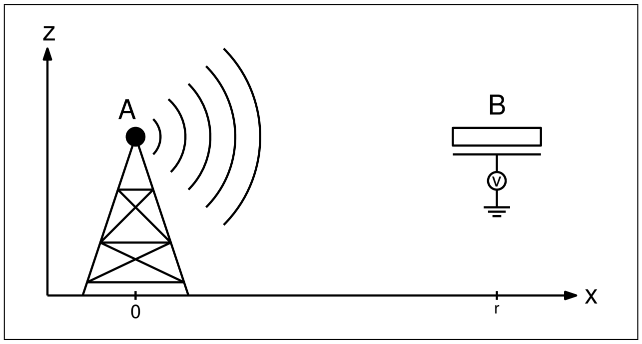


Figure 2. Radio tower A emits a z-polarized wave propagating in x-direction. At $r$ it meets a transversal plasma antenna B.

based Hall-effect sensor, with the magnetic component being negligible in this case.

Transverse plasma antennas have a property that ordinary antennas do not possess. This property becomes clear when one analyzes the situation schematically, as shown in Figure 2. Here, a radio tower (A) at location $x = 0$ emits a z-polarized electromagnetic wave in the x-direction. This wave then meets a transverse plasma antenna (B) at location $x = r$, which is aligned parallel to the x-axis, corresponding to the direction of wave propagation.

In the transverse plasma antenna, electrons rapidly move along or against the direction of the x-axis depending on the sign of the applied DC voltage. According to the principle of relativity, an approximately uniformly moving electron in the antenna may consider itself to be at rest and instead assume that the radio tower is moving.

Let us now assume that an electron is moving toward the right at velocity $\boldsymbol{e}_x\, v$. Thus, the velocity of the radio tower is

$$\boldsymbol{v} = -\boldsymbol{e}_x\, v \tag{6}$$

from the electron's point of view. Furthermore, we can see from the sketch in Figure 2 that the electron's location is approximately

$$\boldsymbol{r} = \boldsymbol{e}_x\, r \tag{7}$$

and that the elementary antennas in the radio tower oscillate in the z-direction. For this reason, we have

$$\boldsymbol{s}(t) = \boldsymbol{e}_z\, s(t). \tag{8}$$

For a transverse plasma antenna that is far from the transmitter, the entire radio tower can be considered as a single point-like transmitter – i.e., a Hertzian dipole – to a good approximation. For this reason, we can substitute Equations (6), (7), and (8) into the solution of Maxwell's equations (2).

First, because $\boldsymbol{r}_s = 0$, we obtain the relation $\boldsymbol{r}_h = \boldsymbol{r} - \boldsymbol{r}_s = \boldsymbol{e}_x\, r$. Here, we must consider that although the radio tower has a relative velocity from the point of view of the electrons, the distance between the radio tower and the transverse plasma antenna does not change. We can apply this in Equation (2). After summing all of the terms, we obtain the force[5]

$$\boldsymbol{F} = -\frac{q_d\, q\left(1 - \frac{v}{c}\right)}{2\,\pi\,\varepsilon_0\, c^2\, r}\, \ddot{s}\,(t-\tau)\; \boldsymbol{e}_z \tag{9}$$

with

$$\tau = \frac{r}{c} - \frac{r\,v}{c^2}. \tag{10}$$

The time constant $\tau$ depends on the velocity $v$. Without the approximation, we would have obtained

$$\tau = \frac{r}{c+v}, \tag{11}$$

which corresponds in first order to Equation (10) for $v \ll c$.

This means that if the electron moves in the direction of the x-axis, the signal $\ddot{s}(t)$ emitted by the radio tower moves at speed $c + v$. This result is indeed required because Einstein's second postulate states that the wave must move with respect to the receiver at exactly the speed of light $c$. However, because the electron itself has a velocity $v$, the wave must propagate correspondingly faster.

The force $\boldsymbol{F}$ exerted on the electron causes it to move in a vertical direction. Because the distance to the electrode is very small, a reaction is triggered almost instantaneously. Thus, it can be concluded that one should be able to receive the transmitted signal earlier with a transverse plasma antenna than with an ordinary antenna.

It is apparent that this result is in gross contradiction to our expectations based on special relativity, because both the transmitter and the transverse plasma antenna are at rest. Superluminal signal transmission – especially between antennas at rest with respect to each other – should not be possible. Nevertheless, this result is achieved by solving Maxwell's equations without additional ad hoc assumptions in the receiver's rest frame. In other words, when applied in their pure form, Maxwell's equations lead exactly to this result.

Because this theoretical prediction of Maxwell's equations is diametrically inconsistent with Lorentz-Einstein electrodynamics, an experimental investigation was urgently needed. In the following section, a corresponding experiment is described.

## III. Experimental setup

### A. Hardware

This experiment utilized an antenna module with two transverse plasma antennas operating in opposite directions. Figure 3 shows the module used in the experiment.

Figure 4 shows the corresponding PCB layout, where the electrodes of the two transverse plasma antennas are immediately apparent. Notably, the board was designed so that the currents in the two tubes flow in opposite directions. If a positive DC voltage is connected to the high-voltage input, the electrons move from left to right in the lower transverse plasma antenna and from right to left in the upper antenna.

[5]The term $v/c$ in $(1 - v/c)$ is the magnetic part of the net force. The sign of $v$ indicates whether this magnetic component strengthens or weakens the effect of the electric component. It is obvious that a transverse plasma antenna is only secondarily a Hall sensor .

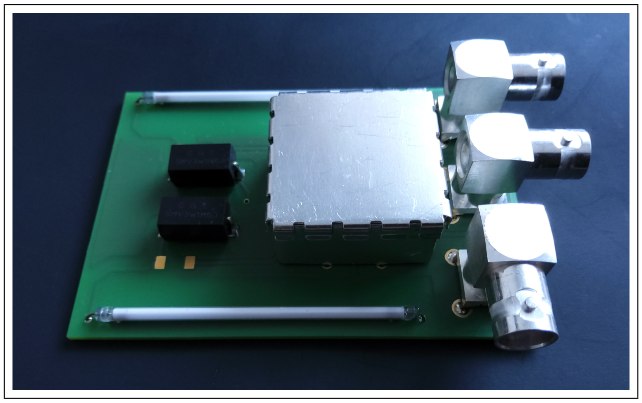

Figure 3. Antenna module with two transverse plasma antennas operating in opposite directions and a passive bandpass filter in a shielded housing.

We note that the circuit for operating the tubes and the measuring outputs connected to the electrodes are galvanically isolated. The electrode of the lower transverse plasma antenna is connected to measurement output 2 (Out 2), and the electrode of the upper transverse plasma antenna is connected to measurement output 1 (Out 1).

Since the board was designed for experimentation, many component locations were provided but ultimately not mounted. The component locations actually used are marked with resistance and capacitance values in Figure 4.

A transverse plasma antenna is basically a broadband antenna. Because of the tube length of 6 cm, the assembled antenna module is suitable for wavelengths up to approximately 1 m, corresponding to a frequency of 5 GHz. However, a simple passive RC bandpass was assembled under the shield case with a center frequency of approximately 100 MHz. This frequency is within the frequency range used for analog frequency modulation (FM) broadcasting in Germany and in most other countries around the world[6].

In this experiment, using broadcast signals from ordinary radio stations has numerous advantages:

- There are different radio masts at different known locations.
- The effective radiated power is high, and the signals have a long range.
- The signals can be demodulated by means of conventional FM radio receivers.
- The quality of the demodulated signal can be easily verified by listening.
- FM radio signals contain a hidden 19 kHz pilot tone for stereo decoding when received in mono[7].

In particular, the presence of the pilot tone is very useful, as discussed below.

In addition to the antenna module, the experimental setup includes two FM radio receivers in mono operation mode (PEMENOL Mini-FM-Radio) installed in metal housings and thus fully shielded and a 3000 series Picoscope (digital oscilloscope for connection to a PC via USB 3.0). Figure 5 shows the entire setup without the PC.

[6] In Germany, the frequency range is 87.5 . . . 108.0 MHz.

[7] According to BS.450 transmission standards for FM sound broadcasting at VHF.

The basic idea of the experiment is to select a station, align the antenna module in a certain cardinal direction, and measure the time shift between the two demodulated audio signals. If special relativity is correct, there should be no significant measurable time shift between the signals as a function of the cardinal direction. However, if Weber-Maxwell electrodynamics is correct, it should be possible to determine the direction of the radio tower site by rotating the antenna module. During the experiment, it quickly became clear that the latter is true.

### B. Software

The software used in this experiment consists of two separate parts, both implemented as simple command line tools in *C++* for *Linux Ubuntu* or *Debian*.

The purpose of the first program – *pico2wav* – is to stream the mono audio signals output from the two radio receivers to the PC in a digitized form and to store these signals into a stereo wav file. The basic goal is to guarantee that the temporal shift of the two demodulated signals under investigation is preserved by saving the signals in a single file. It is worth mentioning here that the wav format, which is actually intended for audio data, is well suited for any form of oscilloscope data, as freely available open-source audio processing tools such as *Audacity* can be used to quickly and conveniently plot spectrograms or apply filters, regardless of whether the data are audio signals. For example, in preparation for the experiment, the entire broadband signal delivered by the plasma antennas was studied spectrographically, which led to the decision to focus on signals transmitted by radio broadcasting stations.

The program *pico2wav* initializes the oscilloscope with a sampling rate of 5 MHz in DC mode. The audio signals are then streamed to the Linux PC via a USB connection. During streaming, the program removes the DC component by means of a digital high-pass filter. Next, a digital filter is used to reduce frequencies above 10 kHz, which corresponds to soft anti-aliasing filtering. Then, downsampling to 50 kHz is performed in the software, and the result is written to a wav file. Notably, the anti-aliasing filtering does not remove the pilot tone at 19 kHz.

The recorded wav files are evaluated in a separate step with the program *calcshift*. The basic purpose of *calcshift* is to calculate the cross correlation

$$r_{12}(n) = \sum_{k=-m}^{m} s_1(k)\, s_2(n+k) \tag{12}$$

of the two channels $s_1(n)$ and $s_2(n)$ and to determine the $n$ value at which $r_{12}(n)$ is at a maximum.

However, because it is clear from the outset that the shift of the two channels with respect to each other is smaller than a single sampling interval, some additional actions are required. First, it is not necessary to calculate the complete cross correlation. For this reason, the value for $m$ can be comparatively small. However, it is very important to convert

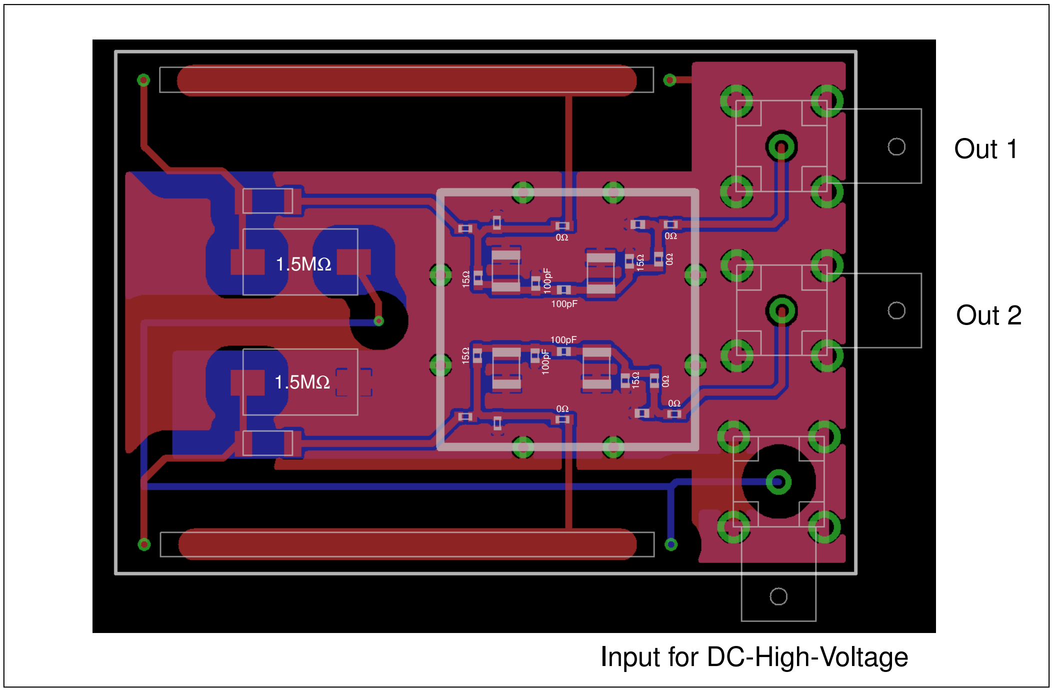


Figure 4. PCB layout of the antenna module. The top layer is shown in red, and the bottom layer is shown in blue.

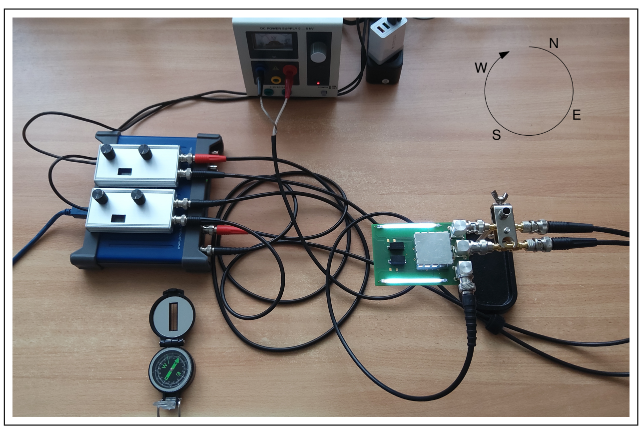


Figure 5. Complete setup of the experiment: Two FM radio receivers were tuned to a specific station. Then, the antenna module was aligned in different cardinal directions, and the time shift of the pilot tone between the demodulated signals was measured for each case.

the discrete-time signal $r_{12}(n)$ back to a quasi-continuous-time signal $r_{12}(t)$ using Whittaker-Shannon interpolation. In principle, this step can be performed *perfectly* due to the satisfied Nyquist-Shannon criterion. Consequently, for sufficiently long input signals $s_1$ and $s_2$, one can detect shifts significantly smaller than the sampling interval of 20 µs.

In principle, it is possible to include the audible audio signal of the transmitted broadcast program when calculating the temporal shift of the two channels relative to each other. The fact that the content is random is less important the longer the recording time becomes. However, *calcshift* uses only the 19 kHz pilot tone transmitted by the radio station by removing the audio component with a digital bandpass.

The period of a 19 kHz signal is 52.6 µs. Consequently, there is no risk that there could be a shift due to the expected effect that would cover more than one period. In contrast, if an FM signal of, for example, 93.1 MHz were directly used in an unmodulated form to calculate the correlation, this would no longer be the case, because the period here is only 10.7 ns. Depending on the distance between the transverse plasma antenna and the radio tower, the expected time shifts could exceed 1µs, which makes the necessity of demodulation evident. The pilot tone contained in the audio signals is a useful feature that can be exploited for the experiment.

## IV. Tests and measurement results

Several experiments were performed in this work. In the first experiment, the radio station *RBB infoRADIO* with a carrier frequency of 93.1 MHz was selected because its FM signal could be easily recognized in the broadband spectrogram of the antenna signal. According to official lists, the radio mast used for broadcasting *RBB infoRADIO* at this frequency is located at *Berlin-Scholzplatz* and has geocoordinates of 52.506033, 13.219514. The measurements were carried out at geocoordinates 52.394803, 12.923331.

The radio mast *Berlin-Scholzplatz* is 23.6 km away from the measuring site, located in the east-northeast direction (58.36°). Under normal conditions, a duration of 78.67 µs is needed for an electromagnetic wave to travel this distance. The drift velocity of the electrons in the tubes of the plasma antennas is not exactly known and has also no specific value. However, it can be roughly estimated [17] as $\upsilon \approx 0.0076\,c$.

Provided that Equation (11) is correct, an electromagnetic wave would need a duration of

$$\tau = \frac{r}{c + 0.0076\,c} = 0.992457\,\frac{r}{c} = 78.08\,\mu\text{s} \qquad (13)$$

if the electrons in the tube of the transverse plasma antenna are moving away from the transmitter at velocity $v$. This means that the signal requires 590 ns less. When the direction of electron motion is reversed, we have

$$\tau = \frac{r}{c - 0.0076\,c} = 1.007658\,\frac{r}{c} = 79.27\,\mu\text{s}, \tag{14}$$

i.e., the signal needs 600 ns more.

From this result, one might conclude that the antenna module used in the experiment should produce a time shift between the two channels of approximately 1.2 µs if optimally aligned with the transmitter. However, the measured time delay between the two channels may be much smaller because a transverse plasma antenna is not only sensitive to signal $\ddot{s}\,(t - r/(c \pm v))$, but also to signal $\ddot{s}\,(t - r/c)$, since a plasma antenna contains components that are not moving relative to the transmitter. For example, the electrode is a regular rod antenna, which becomes obvious when the tube voltage is turned off, because a signal is still received, even though the signal strength is reduced. The current component in the plasma caused by the ions is also sensitive only to a signal moving at $c$, since the drift velocity of the ions is very small and can be ignored.

Consequently, the received signals $s_1$ and $s_2$ are a mixture of the form

$$s_1(t) = a_{11}\,\ddot{s}\left(t - \frac{r}{c}\right) + a_{12}\,\ddot{s}\left(t - \frac{r}{c + v}\right) \tag{15}$$

and

$$s_2(t) = a_{21}\,\ddot{s}\left(t - \frac{r}{c}\right) + a_{22}\,\ddot{s}\left(t - \frac{r}{c - v}\right) \tag{16}$$

with the unknown parameters $a_{11}$, $a_{12}$, $a_{21}$, and $a_{22}$[8]. Because the pilot tone of the FM signal is used, the $\ddot{s}(t)$ signals are sinusoidal. However, the sum of two sinusoidal signals of the same frequency shifted with respect to each other is again a sinusoidal signal with the same frequency. Therefore, when calculating the cross correlation, only the shift of these two sinusoidal signals is calculated, which can be significantly smaller than the theoretical maximum value obtained for $a_{11} = a_{21} = 0$.

In the first experiment, the time shift of the two pilot tones was determined as a function of the cardinal direction in 30° increments. The measurement results are shown in Figure 6. Each spatial direction was measured 20 times for 30 s. After each measurement, the orientation of the antenna was changed to avoid systematic errors, which occur because the two radio receivers drift slightly with respect to each other and the positions of the measurement cables change with each adjustment of the direction.

Figure 6 clearly shows a directional dependency. The maximal time shift corresponds to the theoretical expectations of Equation (2), as the maximum of the fitted sine curve is approximately located near the direction of the radio tower. The amplitude of the fitted sine curve was 165 ns, corresponding to a peak-to-peak value of 330 ns. This result fits well with the previously estimated value.

It should be mentioned that the radio receivers had a time shift with respect to each other, which reached up to 200 ns and changed when the receivers were switched off and on or when a radio station was selected. This time shift could be determined by connecting two ordinary rod antennas instead of the transverse plasma antenna module, measuring the shift, and then swapping the channels at the oscilloscope. The curve in Figure 6 includes a corresponding error correction obtained by adjusting the offset.

In a second experiment, the tube voltage was switched off to determine whether the effect still occurred. The result for this test is shown in Figure 7. As can be seen, the results are essentially random in this case. The small remaining directional dependency can be explained by direction-dependent noise because, depending on the orientation, sometimes the first or second channel was more strongly affected by noise. In this context, it should be mentioned that when the tube voltage was turned off, the quality of the demodulated audio signal was significantly reduced. When the tube voltage was on, however, the audio signals were of good quality and nearly free of noise, except for occasional glitches. Incidentally, this result shows that transverse plasma antennas also have advantages as ordinary antennas, as they are relatively compact and have good broadband characteristics.

In another experiment, a different radio station was selected, namely *Antenne Brandenburg Potsdam* at 99.7 MHz, broadcasted from the Berlin TV tower. The TV tower is located at geocoordinates 52.520833, 13.409444 and is located 35.8 km from the measurement site at an angle of 66.95°. Because of the greater distance, the signal strength was much lower, and HF preamplifiers (NooElec Lana - LNA module, 20-4000 MHz) had to be added for this experiment. Furthermore, in this case, only the second transverse plasma antenna was connected to the second channel of the oscilloscope via the amplifier and the radio receiver. For the first radio, an ordinary rod antenna was attached instead. The experimental setup is shown in Figure 8.

The objective of this experiment was to determine whether a 180° rotation of the antenna is equivalent to a reversal of the current direction in the tube. For this purpose, the transverse plasma antenna was aligned in two directions, namely, in the direction of 70°, i.e., pointing towards the Berlin TV tower, and in the opposite direction, i.e., in the direction of 250°. After each measurement, the antenna was rotated by 180°. Again, audio signals with a duration of 30 s were recorded each time. A total of 30 measurements were performed in each direction. The results are shown by probability distributions in Figure 9 on the left.

As can be seen, the transverse plasma antenna received the signal approximately 40 ns earlier when the electrons in the tube were moving away from the transmitter (70°) and approximately 40 ns later when the antenna was rotated (250°). Moreover, in this case, the temporal shift is smaller, even though the distance to the transmitter is greater. This effect is most likely due to the fact that the contribution of the direct wave to the total signal is smaller for a distant transmitter than for a transmitter that is closer to the measurement site.

Importantly, this effect also occurs when the direction of motion of the electrons in the tube is inverted. Because this effect must be compensated by an opposite orientation of the

[8] In fact, there should be even more terms.

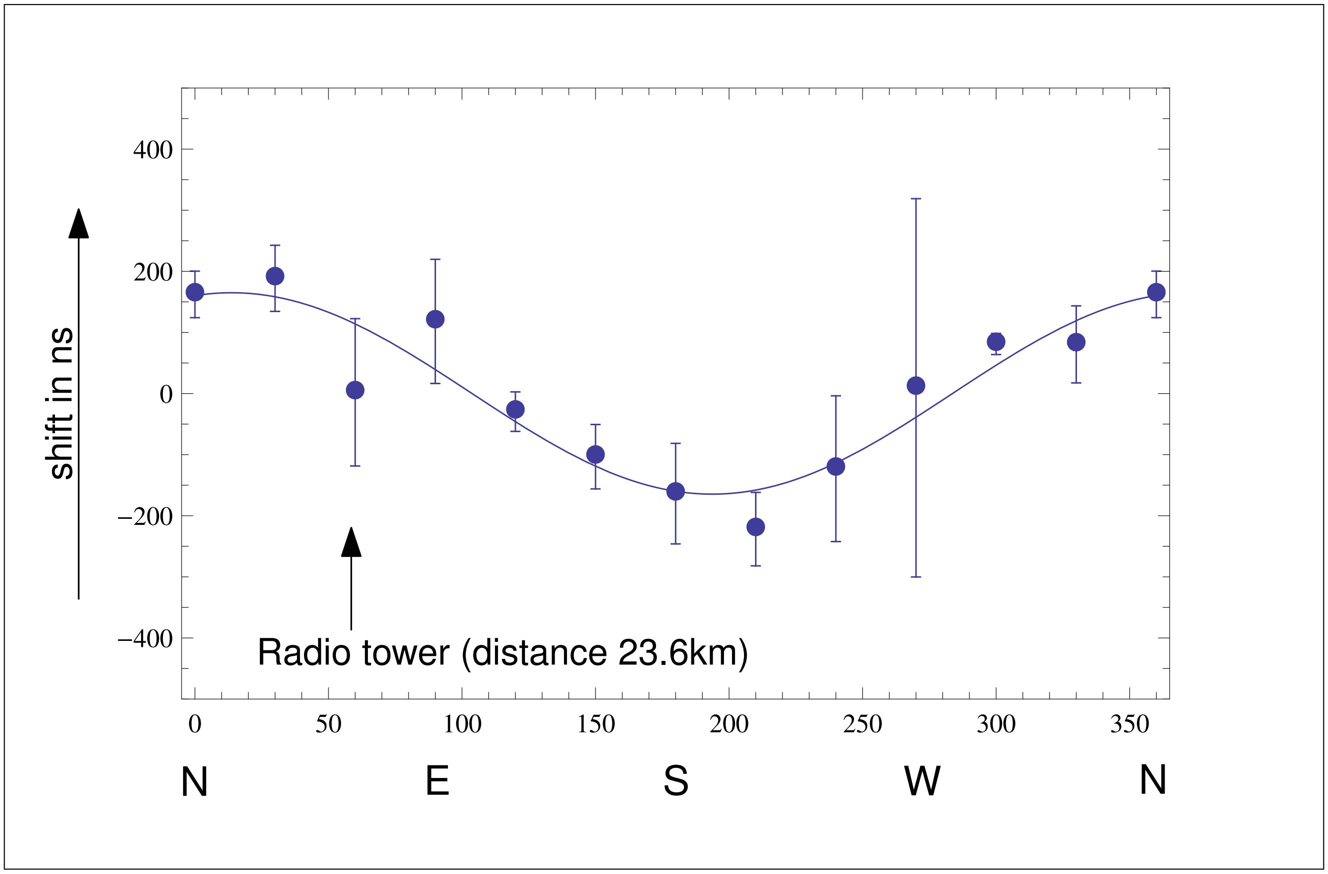


Figure 6. Measured time shift of channel 2 with respect to channel 1 when the tube voltage is switched on. The radio tower was located 23.6 km away in the northeast direction (transmitter Berlin-Scholzplatz, infoRADIO (RBB), 93.1 MHz). In each direction, 20 measurements with a duration of 30 s were performed. The error bars show the standard deviation. After each measurement, the orientation of the antenna was altered.

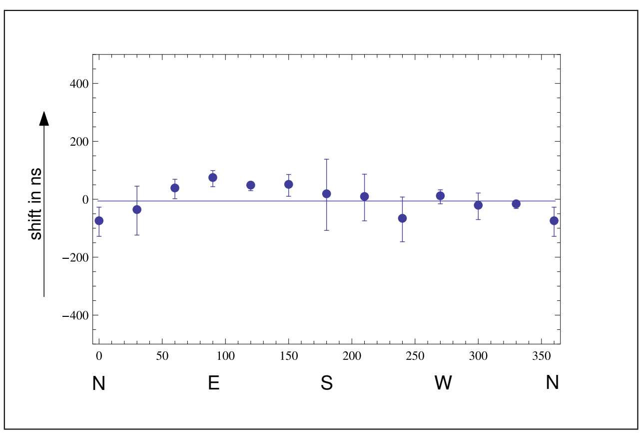


Figure 7. Measured time shift of channel 2 with respect to channel 1 when the tube voltage is turned off. Here, 10 measurements were taken in each direction. All other parameters correspond to those in Figure 6. With the tube voltage turned off, the signal quality was significantly reduced (noise).

antenna module, the two Gaussian functions on the right side of Figure 9 change position. This result proves that the effect is indeed related to the direction of motion of the electrons in the tube.

The greater distance of the Gaussian functions on the right side of Figure 9 can be explained by a higher current strength for the reverse current direction. A different current strength results in different $a$ parameters in Equations (15) and (16). The higher current can be explained by the fact that the tube was always operated with the same voltage direction in the previous experiments. A cold cathode fluorescent lamp, however, deteriorates under DC operation, because the fluorescent substance accumulates on one side of the tube. After the voltage direction was reversed, the brightness visibly increased, as well as the measured temporal shift.

It is further pointed out that no Doppler effect was observed in the broadband signal when the tube voltages were turned on. All radio stations maintained their carrier frequency, and no additional lines were observed in the spectrogram. Only the signal strength of the undemodulated FM signals increased. This result indicates that for the moving electrons in the tube, the wavelength and wave velocity are different from those for the stationary parts of the antenna. However, a Doppler effect would occur if there were not only a relative velocity, but also an actual change in the distance between transmitter and receiver. This can be explained with help of Equation (2)[9].

In summary, the experiments show an effect of directionality, and the solution of Maxwell's equations (2) seems to

[9]For example, if the transmitter and receiver are moving away from each other in a straight line, $\ddot{s}(t-\tau) = \ddot{s}(t-(r+v\,t)/(c+v)) = \ddot{s}(c/(c+v)(t-r/c))$. $c/(c+v)$ is the Doppler factor. The Doppler factor does not depend on the velocity in a medium. Formula (2) also contains a transverse Doppler effect, provided that one does not use the approximation (4), but the exact value [2].

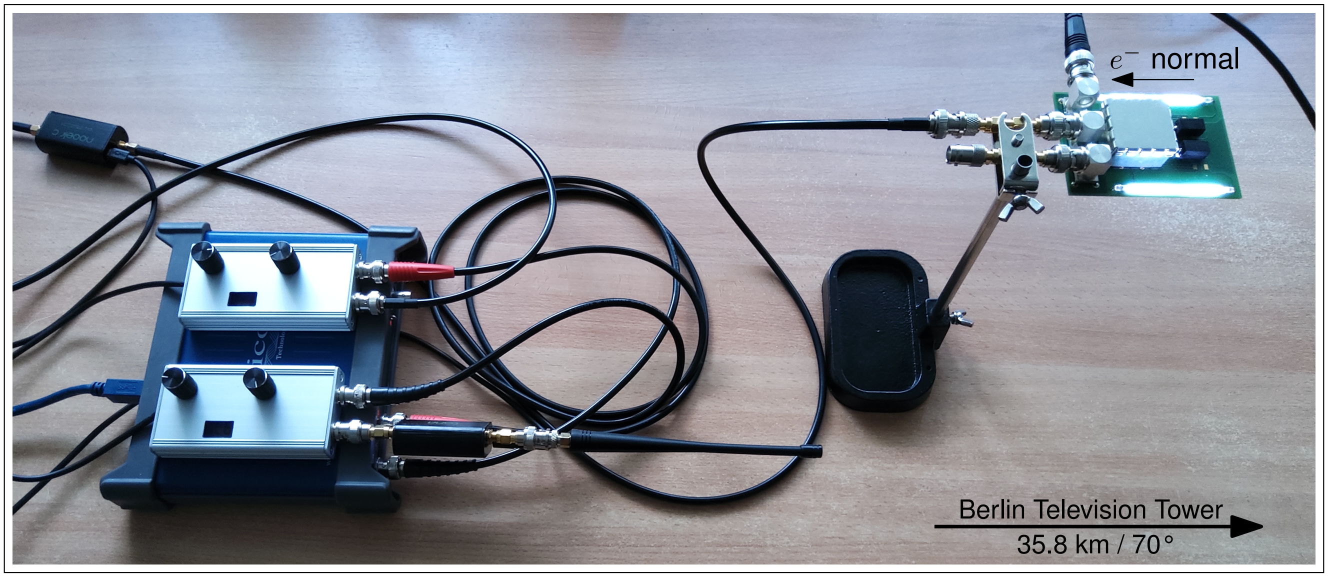


Figure 8. Here, one of the plasma antennas was replaced by a rod antenna (channel 1). Subsequently, measurements were performed alternately in the direction of the Berlin TV tower (70°) and exactly opposite (250°) (Antenne Brandenburg Potsdam, 99.7 MHz). After 30 measurements in each direction, the high voltage was inverted, and the measurements were repeated.

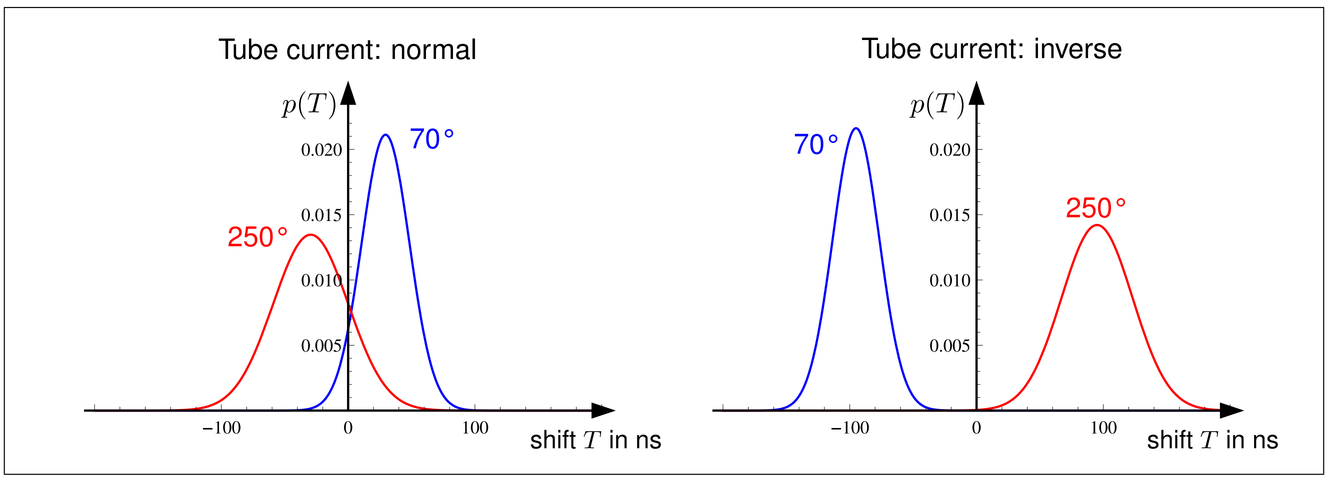


Figure 9. Time shift between the radio signal at channel 1 (rod antenna) and the radio signal received with the transverse plasma antenna (see Figure 8). The signal arrives earlier when the electrons are moving away from the transmitter and arrives later when the electrons are moving toward the transmitter. The effects of rotating the antenna or reversing the polarity of the current direction are principally equivalent. The different distances of the Gaussian functions from each other in the two plots can be explained by different current strengths (explanation in the text).

be in fairly good agreement with the experiment. In the next section, an alternative to special relativity is explained, which is compatible with Maxwell's equations and Einstein's postulates and which can explain the experimental results of this article in a logical way.

## V. Physical interpretation

Although the main purpose of this article is to describe an experiment and its results, it seems necessary and reasonable to briefly discuss the basic idea that led to this experiment.

Similar to the special theory of relativity, the basic idea is based on Einstein's two postulates listed at the beginning of the article. These postulates state that an electromagnetic impulse moves at the same constant velocity in the rest frame of *all* uniformly moving receivers. Figure 10 illustrates this problem in the form of a sketch.

The force in Equation (2) shows exactly that behavior. From the perspective of the measurement system, the transmission tower in Figure 10 has velocity $\boldsymbol{v} = -u\,\boldsymbol{e}_x$. Furthermore, the measuring point A is located at the place $\boldsymbol{r} = A\,\boldsymbol{e}_x$. Substituting $\boldsymbol{v}$ and $\boldsymbol{r}$ into the equations (1), (3), and (4), gives[10]

$$\tau = \frac{c-u}{c^2}\,(A + u\,t) \approx \frac{A + u\,t}{c+u}. \tag{17}$$

When the argument of the signal $\ddot{s}(t-\tau)$ in equation (2) becomes zero, the signal reaches point A, i.e. we have to solve equation

$$t - \tau = t - \frac{A + u\,t}{c+u} = 0. \tag{18}$$

[10]The approximation on the right side is actually the correct value and the left side is the approximation. [2]

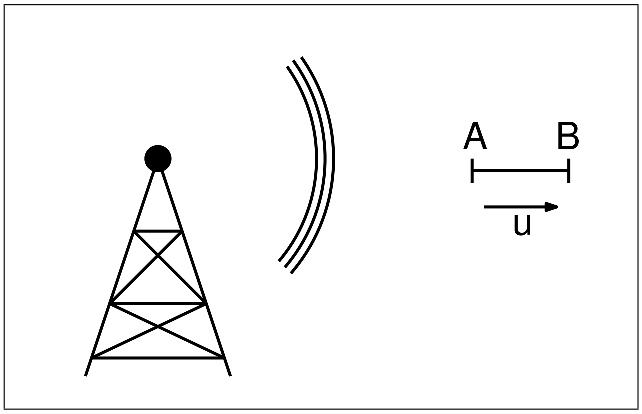


Figure 10. The time needed for an electromagnetic impulse to travel from the beginning of a measuring system $A$ to the end of the measuring system $B$ is always equal to $(A-B)/c$. The speed $u$ does not influence this result, as long as it is constant over time.

The solution of this equation is $t_A = A/c$. For $B$, $t_B = B/c$ applies accordingly. The time period during which the electromagnetic impulse is inside the measuring system is the difference between these two times, i.e.,

$$t_B - t_A = \frac{B}{c} - \frac{A}{c} = \frac{B-A}{c}. \tag{19}$$

As we can see, this time difference does not depend on the velocity $u$ or the choice of the origin of the coordinate system in space or time. Hence, it does not matter how fast the measuring system is moving relative to the electromagnetic impulse or the transmitter because Equation (19) is valid for *every* measuring system moving on a direct line toward or from the transmitter.

When considered logically, it seems impossible that an entity such as an electromagnetic impulse would always needs the same time to travel from $A$ to $B$ independent of the velocity $\boldsymbol{v}$. The basic idea of special relativity is addressed in countless textbooks and articles and therefore does not need to be discussed here. However, it is important to point out that this phenomenon can also be explained by the hypothesis that the electromagnetic impulse exists with different velocities at the same time and that each receiver perceives only exactly that part of the electromagnetic impulse that has the suitable velocity $c$ in its own frame of reference.

At first glance, this concept seems to be as strange as spacetime. Upon closer consideration, however, it becomes clear that this effect can be logically explained if one assumes that an electromagnetic impulse does actually not propagate at $c$, but instead possesses a continuum of velocities. If one further assumes that matter cannot perceive – for whatever reason – any components that are faster than $c$ in its own rest frame, the maximal propagation velocity would be limited to $c$, independent of $\boldsymbol{v}$.

With this interpretation, Einstein's postulates are almost fulfilled. The only remaining questions are why the receiver perceives the electromagnetic impulse as a short event and why he does not also receive all other parts with velocities slower than $c$ in his reference frame. The answer can be found in the wave aspect of the signal: if one integrates over all wave velocities, only the part moving exactly at $c$ remains (under certain conditions). All other parts interfere destructively. Detailed and elaborate analyses, experiments, and investigations on this topic can be found in other articles by the author.

At this point, it is important to mention that it has recently been shown that (i) the universal constancy of the speed of the electromagnetic force for *any* receiver and (ii) the assumption that the electromagnetic force between two charges at rest with respect to each other can be described by the Coulomb law are sufficient to derive the *complete* set of Maxwell's equations [22]. If electric charges move sufficiently slowly and uniformly, one can derive the Weber force [2]. More general cases, however, must be analyzed by means of Maxwell's equations. Yet, one must apply these equations correctly by performing calculations in the rest frame of the receiver. For very small relative velocities, however, one can solve Maxwell's equations in the typical manner in the frame of reference of the transmitter along with the Lorentz force, as the slight violation of the principle of relativity can be neglected in this case. For electrical engineering applications, this is almost always sufficient.

For high relative velocities, however, it is *not possible* to obtain Equation (2) if one performs calculations in the rest frame of the transmitter by using the mathematical framework of Lorentz-Einstein electrodynamics. If this were the case, then special relativity would also predict the results of this experiment. However, these are undoubtedly in contradiction to the special theory of relativity.

## VI. Summary and conclusions

This article has demonstrated, both experimentally and by interpretation of the solution of Maxwell's equations for a moving Hertzian dipole, that it is possible to construct receiving antennas in such a way that electromagnetic waves in the far field are received earlier than should be possible due to the upper speed limit of $c$. Moreover, it was made clear that these antennas and the experimental results do *not* contradict Maxwell's equations and Einstein's postulates.

However, the results are in contradiction to special relativity (Tolman's paradox, see, e.g., [23]) as well as ether theories, which are often brought into the discussion by critics of special relativity. Fortunately, a satisfyingly logical and physically clear mechanism can be found, which is compatible with Maxwell's equations, fits the test experiments of Einstein's postulates, and predicts the experimental results documented here.

As explained in this article, the basic hypothesis of this mechanism is based on the assumption that matter can perceive only that part of the electromagnetic field that is sufficiently slow in the corresponding rest frame. In turn, this assumption implies that the Earth is continuously penetrated by electromagnetic waves moving faster than $c$ with respect to our planet. This may sound implausible, but it is the only logical explanation. By using the plasma antenna introduced in this article, it has been shown that a completely undiscovered field of research may exist. This possibility should not be lightly dismissed with the argument that special relativity is old and therefore necessarily correct.

Should this hypothesis be confirmed in further experiments, numerous new technologies would become available. For example, in principle, it would be possible to transmit signals between distant space vehicles at superluminal speeds. As a first test, one could attempt to receive the signal of the space probe Voyager 1 some minutes earlier than is currently possible. However, the development of special amplifiers would be needed to amplify the superluminal component of that very weak radio signal.

## VII. Data availability

Source code, schematic, layout and measurement data of this study are available from the author upon reasonable request.

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