Electronic data transmission with three times the speed of light and data rates of 2000 bits per second over long distances in buffer amplifier chains

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Abstract

Recently, during the experimental testing of basic assumptions in electrical engineering, it became apparent that ultra-low-frequency (ULF) voltage signals in coaxial cables with a length of only a few hundred meters propagate significantly faster than light. Starting point for this discovery was an experiment in which a two-channel oscilloscope is connected to a signal source via a short coaxial cable and the second input to the same signal source via a long coaxial cable. It was observed that the delay between the two channels can be for short cables and low frequencies so small that the associated phase velocity exceeds the speed of light. In order to test whether the discovered effect can be exploited to transmit information over long distances, a cable was examined in which the signal is refreshed at regular distances by buffer amplifiers. The result was that such an setup is indeed suitable for transmitting wave packets at three times the speed of light and bit rates of about 2 kbit/s over arbitrary distances. The statement that information cannot propagate faster than light is therewith clearly experimentally disproved and can therefore no longer be sustained.

1. Introduction

In today's information technology, hardly any speech or audio signals are transmitted analog and in the baseband, as this is accompanied by numerous disadvantages such as high sensitivities to noise and low information densities. Even the transmission of information by means of electrical voltages is on the decline, since information can be transmitted much better optically over long distances.

In the past, however, the transmission of information in telephone cables played a key role in communications engineering and there even arose a separate discipline dealing with the transmission properties of electrical cables. This sub-discipline of electrical engineering, known as the transmission line theory, is based on the telegrapher's equations [1, p. 307 et seq]. It is primarily concerned with the question of how signals propagate in transmission lines whose length is about the order of the wavelength of the transmitted signals or longer. However, ULF signals have wavelengths of 100 to 1000 kilometers. It is obvious that transmission line theory could possibly provide incorrect results for short cable lengths.

It turns out that the transmission line theory fails indeed for short cables and low frequencies. Nevertheless, it is quite astonishing that there is not a single experiment that measures the phase velocities of ULF signals in cables that are very short compared to the wavelengths. The author can only assume that this omission is related to the apparently lack of technological relevance, the dominance of the special theory of relativity, and the belief that someone else has already performed such measurements.

In fact, the question of how fast slowly oscillating electrical signals propagate is of great theoretical interest. If one permits the idea that the vacuum is a dielectric medium, so the propagation velocity would be a simple material constant. At the same time, however, it would be unclear how fast the actual electrical force propagates. There are some scientists who have studied this question theoretically and experimentally by investigating how fast the electric force propagates in the three dimensional space around moving charges in the near-field [2] [3].

As the authors of the cited articles already suspected, the actual electric force in the near field seems to propagate indeed much faster than light. This article demonstrates experimentally that this also and especially applies to copper cables. Afterwards, it will be shown that this opens up new technological possibilities.

2. Experimental setup

2.1. Hardware

The experiment is simple and can reproduced easily. For the measurements, a *PicoScope 2204A*, BNC connection cables and connectors, a *Debian* Linux PC, several hundred meters of coaxial cable (RG6 PVC, 135 dB, characteristic impedance: 75 Ohm, 0.12 Ω/m, 50 pF/m) and a software are needed, which source code can be downloaded from *Github* [4]. The basic idea is to connect one input of the oscilloscope with a short cable and the other input with a long cable with the same signal source and to measure the delay (Figure 1). Since the *PicoScope 2204A* has an integrated signal generator, the oscilloscope itself can be used as signal source for different frequencies. A further advantage of the *PicoScope 2204A* is that it can sample both inputs in parallel at 1 MHz and transfer the samples to the connected PC via USB. This enables the PC to store the recorded signals and to perform an analysis. Because the *PicoScope*

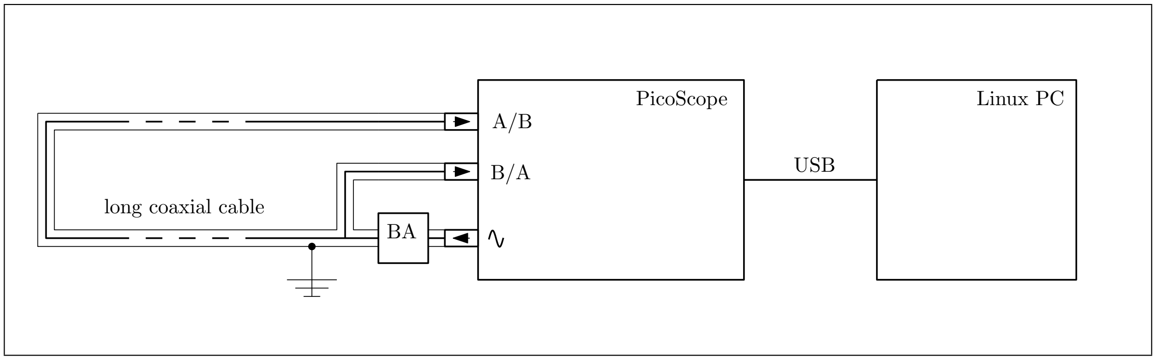

Figure 1: Experimental setup

2204A signal generator output has an internal resistance, it is recommended to use a buffer amplifier (BA) directly behind the output and before the BNC T-adapter for longer cable lengths (Figure 2).

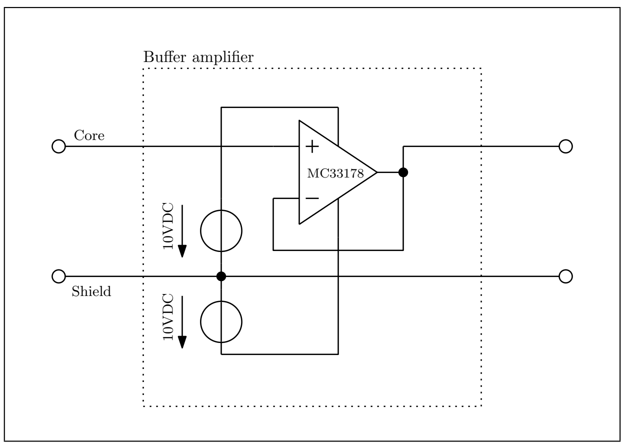

Figure 2: Used buffer amplifier

2.2. Software

For the experiment, a software was developed which configures the PicoScope in such a way that it outputs a sinus signal at the output of the function generator for 65 seconds, simultaneously samples both inputs with 1 MHz and transmits the data to the PC. The PC stores the received sample streams into a stereo WAVE file. This has the advantage that the recorded signals can be easily opened and analyzed with audio tools such as *Audacity*.

To determine the delay, the software calculates the cross correlation between the two channels of the stereo WAVE file in the time domain. The delays are usually below of one microsecond, which means below the time resolution of the sampling. Nevertheless, it is possible to detect even very small delays, since the sampling rate is about twenty times higher than the highest signal frequency and the signal is therefore heavily oversampled.

Due to this oversampling, the calculated correlation function is also a heavily oversampled sequence, which makes it possible to interpolate the calculated correlation function and determine the position of the global maximum of the interpolated correlation function. Cubic splines are used as the interpolation method, although this method is sensitive to noise. In comparison to ideal interpolation using the Shannon theorem, cubic splines have the advantage that the global maximum can be found in an analytic way. The low noise of the measured delays and the good reproducibility of the measurement results show that the use of splines instead of an ideal interpolation does not cause any disadvantages.

The software also provides a method to remove all frequencies beyond a cut-off frequency, for example 100 kHz. An STFT filter is used for this purpose. Using this filter is a way to reduce high-frequency noise, which can have a negative effect on the calculation.

The software is available as source code and can be freely downloaded from *Github*[4].

3. Findings

3.1. Phase velocities

In the first stage of the experiment, phase velocities were determined as a function of frequency and conductor length. For this purpose, sinus signals with frequencies of 1000, 1252, 1568, 1964, 2460, 3080, 3857, 4831, 6050, 7576, 9488, 11882, 14880, 18634, 23336, 29224, 36598, 45833 and 57397 Hz and cable lengths of 500, 300, 200 and 100 meters were examined. For each configuration, several measurements were performed and repeated at different times. Furthermore, the longer cable was sometimes at the first input of the oscilloscope and sometimes at the second input. The measured delays τ are shown in Figure 3. Note, that the error bars for the standard deviations are displayed 20 times amplified.

The following functions for the signal delays were determined by curve fitting of the data:

$$\begin{aligned}\tau_{100m}(f) \; &= 3.31 \cdot 10^{-8}\,\mathrm{s} + 2.80 \cdot 10^{-12}\,\mathrm{s}^2 f - \\ &5.39 \cdot 10^{-17}\,\mathrm{s}^3 f^2 + 3.87 \cdot 10^{-22}\,\mathrm{s}^4 f^3,\end{aligned} \tag{1}$$

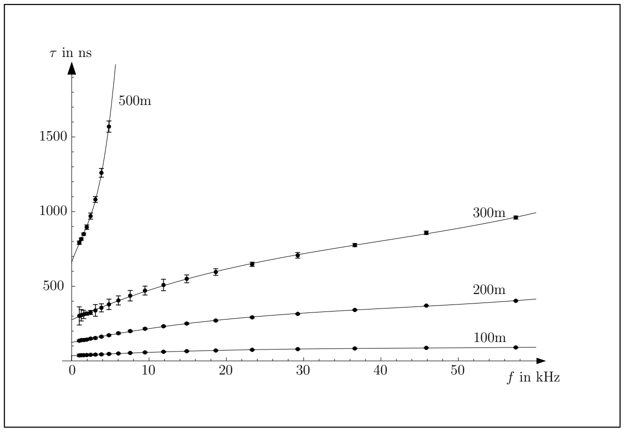

Figure 3: Measured signal delays τ between the two channels as function of cable length and signal frequency f (error bars are 20 times amplified).

$$\tau_{200m}(f) = 1.23 \cdot 10^{-7}\,\mathrm{s} + 1.12 \cdot 10^{-11}\,\mathrm{s}^2 f - 1.99 \cdot 10^{-16}\,\mathrm{s}^3 f^2 + 1.57 \cdot 10^{-21}\,\mathrm{s}^4 f^3 \tag{2}$$

$$\tau_{300m}(f) = 2.76 \cdot 10^{-7}\,\mathrm{s} + 2.35 \cdot 10^{-11}\,\mathrm{s}^2 f - 3.85 \cdot 10^{-16}\,\mathrm{s}^3 f^2 + 3.22 \cdot 10^{-21}\,\mathrm{s}^4 f^3 \tag{3}$$

$$\tau_{500m}(f) = 6.63 \cdot 10^{-7}\,\mathrm{s} + 1.49 \cdot 10^{-10}\,\mathrm{s}^2 f - 2.68 \cdot 10^{-14}\,\mathrm{s}^3 f^2 + 7.39 \cdot 10^{-18}\,\mathrm{s}^4 f^3 \tag{4}$$

Figure 4 shows the phase velocities

$$v_p(f) = \frac{\mathrm{len}}{c \cdot \tau_{\mathrm{len}}(f)} \tag{5}$$

resulting from the measured delays in units of c. As can be seen, these are far beyond the speed of light for frequencies in the audio range ($f = 30 \ldots 15000\,\mathrm{Hz}$).

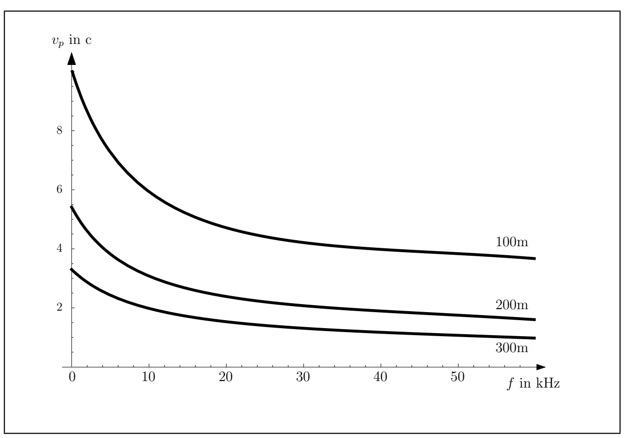

Figure 4: Phase velocities v_p as a function of cable length and signal frequency f

It should be noted that faster-than-light phase velocities with a cable length of 500 meters only occur at frequencies below of about 5 kHz. For frequencies beyond this, the electromagnetic wave effects seem to dominate more and more.

3.2. Signal delay of a music track as a function of the cable length

In order to study whether the very high phase velocities for ULF and VLF signals also lead to very high transmission speeds for general, but band-limited signals, a soundtrack (classical music), namely *An End, Once and For All* from the computer game *Mass Effect 3*, was transmitted over cables with different lengths. For this purpose, instead of the signal generator, the right loudspeaker output of a hifi system was connected with the oscilloscope in two different ways, namely via a long coaxial cable and directly.

The cable lengths were varied and the delays were determined. Furthermore, the input at the oscilloscope was varied again, i.e. the long cable was sometimes at input A and sometimes at input B. The measured delays showed little scattering, were reproducible and symmetrical with respect to the oscilloscope input. The quality of the transmitted music was similar on both channels after the transmission and a difference was not audible. Table 1 summarizes the measurement results.

cable length	needed time	velocity
100 m	39.6 ns	8.4 c
200 m	141.0 ns	4.7 c
300 m	319.2 ns	3.1 c
500 m	944.5 ns	1.8 c

Table 1: Measured propagation velocities of the audio signal

A visual check of the audio data showed that only a 500 meter cable showed a shift of about one sample between the channels. Since this corresponds to a time of 1000 ns at a sampling rate of 1 MHz, this is quite consistent with the results in table 1.

4. Increasing the signal range

4.1. Principle and measurement results

At this point, it was reasonable to assume that it might be possible to transmit ULF signals with velocities beyond the speed of light even over long distances *by refreshing the signal at regular distances*. To test this hypothesis, a 200 meter coax cable was split in the middle. After that, a buffer amplifier (Figure 2) was inserted in between. Then, as before, the signal delay was measured as a function of the frequency. Figure 6 shows the results of the measurement.

By curve fitting the data one obtains the function

$$\hat{\tau}_{200m}(f) = 9.03 \cdot 10^{-8}\,\mathrm{s} + 5.59 \cdot 10^{-12}\,\mathrm{s}^2 f - 1.04 \cdot 10^{-16}\,\mathrm{s}^3 f^2 + 7.90 \cdot 10^{-22}\,\mathrm{s}^4 f^3. \tag{6}$$

As can be seen by calculation of $\hat{\tau}_{200m}(f) - 2 \cdot \tau_{100m}(f)$, the buffer amplifier causes a almost frequency independent delay of $\tau_{BA} = 24.1\,\mathrm{ns}$.

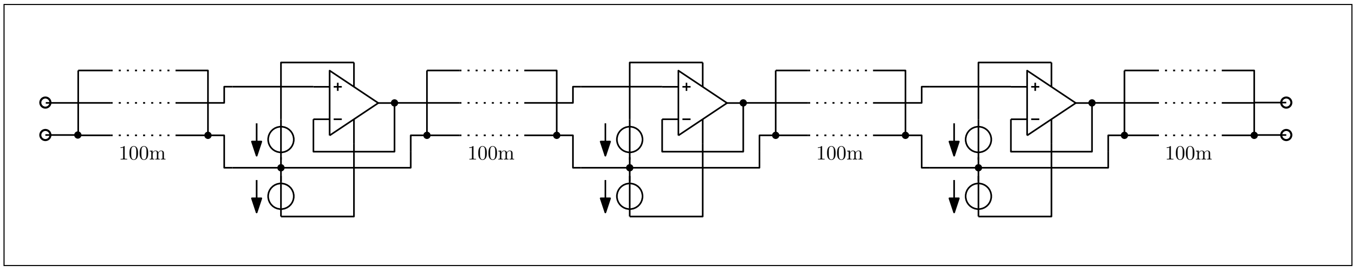

Figure 5: Buffer amplifier chain with 4 coaxial cable segments and 3 buffer amplifiers

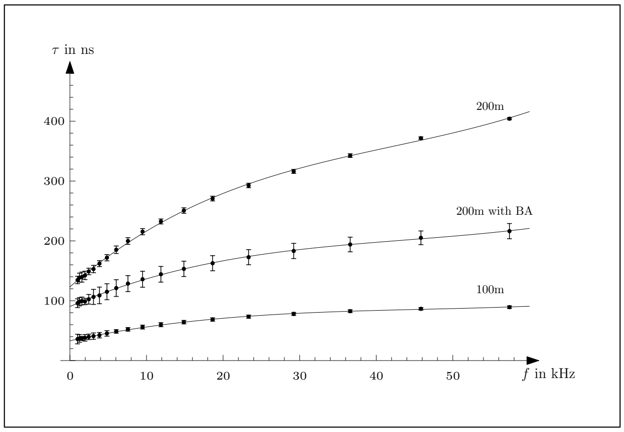

Figure 6: Measured signal delay for the refreshed signal in comparison with non-refreshed transmissions (error bars are 20 times amplified).

It is therefore obvious that in principle it is possible to transmit ULF signals over long distances at extremely high speeds. For example, if a buffer amplifier is used every 100 meters, the signal delay is

$$\hat{\tau}_{100m}(f) \; = \; \tau_{100m}(f) + \tau_{BA} \tag{7}$$

per 100 meters of cable length.

To further confirm this, a buffer amplifier chain consisting of four 100 meter long coaxial cables and three buffer amplifiers was build up and analysed (Figure 5). A curve fitting of the data resulted in

$$\begin{aligned} \hat{\tau}_{400m}(f) \; &= 2.14 \cdot 10^{-7}\,\mathrm{s} + 1.09 \cdot 10^{-11}\,\mathrm{s}^2 f - \\ & 1.92 \cdot 10^{-16}\,\mathrm{s}^3 f^2 + 1.43 \cdot 10^{-21}\,\mathrm{s}^4 f^3 . \end{aligned} \tag{8}$$

As one can notice, is

$$\hat{\tau}_{400m}(f) \approx 4 \cdot \tau_{100m}(f) + 3 \cdot \tau_{BA} . \tag{9}$$

a very good approximation for the measured values.

This shows that it is also possible to establish long transmission lines with very high phase velocities. In the case that a buffer amplifier is used every 100 meters, one obtains the de facto length-independent phase velocity

$$\hat{v}_p(f) = \frac{100\,\mathrm{m}}{\tau_{100m}(f) + \tau_{BA}} . \tag{10}$$

Figure 7 shows this phase velocity as a function of the frequency.

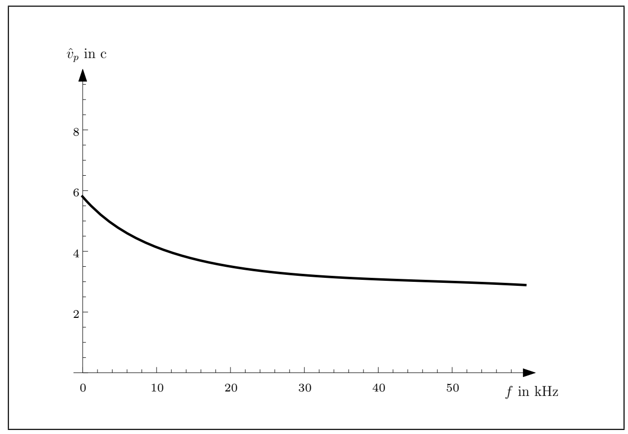

Figure 7: Phase velocity for a cable with signal-refresh every 100 meters

4.2. The transmission properties of a buffer amplifier chain

The section 4 has shown experimentally that it is possible to establish a transmission line in which signals with frequencies below 60 kHz propagate with several times the speed of light. If one connects buffer amplifiers with 100 meter long coaxial or twisted-pair cables, so one obtains a buffer amplifier chain of freely configurable length. The fact that data can be transmitted over such a transmission line at bit rates of 2 kbit/s and a speed of approximately 4 c is discussed below.

The starting point of the considerations is that a temporally localized signal is required for the transmission of a single bit, which ideally does not contain a DC component and only frequencies up to about 50 kHz. Such a signal is for example (wave packet)

$$b(t) = e^{-2\pi^2 f_B^2 t^2} \; \cos(2\pi f_C t) . \tag{11}$$

f_C is hereby the carrier frequency and f_B a frequency which determines the bandwidth of the signal.

The spectrum of this signal can be obtained by calculating the Fourier transform

$$\begin{aligned}\mathcal{F}\{b\}(f) &= \int\limits_{-\infty}^{\infty} b(t)\, e^{i\,2\,\pi\,f\,t}\,\mathrm{d}t \\ &= \frac{1}{2}\left(g\left(f - f_C, f_B\right) + g\left(f + f_C, f_B\right)\right),\end{aligned} \tag{12}$$

with g representing the Gaussian function

$$g(t,\sigma) := \frac{1}{\sqrt{2\,\pi\,\sigma^2}}\, e^{-\frac{t^2}{2\sigma^2}}. \tag{13}$$

The spectrum has the meaning of a distribution function of the frequencies in the signal. For this reason,

$$s(t,x) = \int\limits_{-\infty}^{\infty} \mathcal{F}\{b\}(f)\, e^{-i\,2\,\pi\,f\,\left(t - x/\hat{v}_p(|f|)\right)}\,\mathrm{d}f \tag{14}$$

is the amplitude of the signal at the time t at the location x, because $e^{-i\,2\,\pi\,f\,\left(t-x/\hat{v}_p(|f|)\right)}$ represents a propagating wave. For $x = 0$ one gets, as can be seen easily, the usual inverse Fourier transformation and the signal $s(t, x = 0)$ corresponds to $b(t)$. However, for $x > 0$ the signal is shifted. It is important to note that the calculation of the absolute value in $\hat{v}_p(|f|)$ is necessary because the integration also runs over negative frequencies, but the the phase velocity (10) is only defined for $f \geq 0$.

For the signal (11) the integral (14) can be solved analytically by approximating the function $1/\hat{v}_p(|f|)$ at $f = f_C$ as a Taylor series of first-order, what corresponds to the tangent at this point. For $f_C = 30\,\mathrm{kHz}$ one gets

$$\frac{1}{\hat{v}_p(|f|)} \approx 8.48 \cdot 10^{-10}\,\frac{\mathrm{s}}{\mathrm{m}} + 6.11 \cdot 10^{-15}\,\frac{\mathrm{s}^2}{m}\,|f|, \tag{15}$$

which is a good approximation for a bandwidth parameter of $f_B = 5\,\mathrm{kHz}$.

The solution of the integral (14) is even by using the approximation (15) still too long to be written down here. For this reason it is referred to figure 8. Here on the left side is shown, how the signal $s(t, x)$ for $f_C = 30\,\mathrm{kHz}$ and $f_B = 5\,\mathrm{kHz}$ propagates in an ideal transmission line with frequency independent phase velocity $v_p(f) = c$. On the right side is shown for comparison, which voltage one would measure at a specific position at a certain time, if one would use a buffer amplifier chain as transmission line. As can be seen, in the buffer amplifier chain the wave packet is moving at a significantly higher velocity. At the same time, it can be seen that although dispersion occurs, the wave package remains intact. It is furthermore noted that the higher width of the pulse in the buffer amplifier chain is mainly due to the higher signal velocity and therefore the longer wavelength and not primarily due to dispersion. Figure 9 shows the voltage that one would measure at a distance of a thousand kilometers.

As can be seen in Figure 8, wave packets transmitted at a time interval of about 0.5 ms would not interfere with each other and would be still clearly distinguishable at a distance of 1000 km. This means that with the mentioned parameters for f_C and f_B a bit rate of about 2000 bits per second is possible.

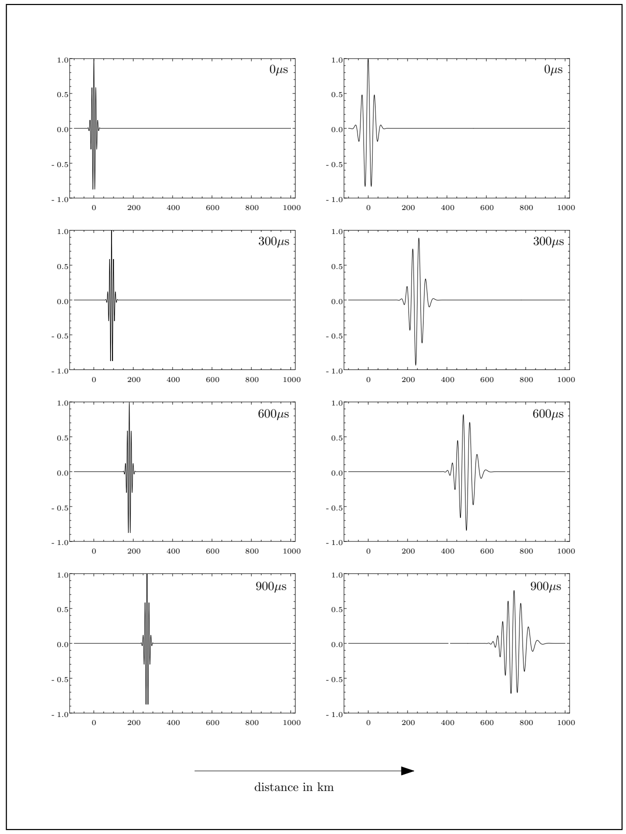

Figure 8: Signal propagation in an ideal ($v_p = c$ for all frequencies) transmission line (left) and in a buffer amplifier chain (right)

Because this bit rate is extremely small compared to today's usual bit rates, the practical use of such a buffer amplifier chain is comparatively limited, especially since the effort for setup and operation would be relatively high. However, the small practical benefit is outweighed by the outstandingly important theoretical insight that the speed of light is by no means the upper limit with which information can propagate.

5. Summary and final remarks

The article has shown that the assumption of some scientists is correct that the electric force in the near field of an electrical charge propagates at a significantly higher velocity than light. Until now, however, it was not clear to experts that this effect also occurs in copper lines and that it can have a range of several hundred meters. In addition, the scientific community was not aware that this effect can be furthermore used technologically to transmit information significantly faster as would it be possible with light.

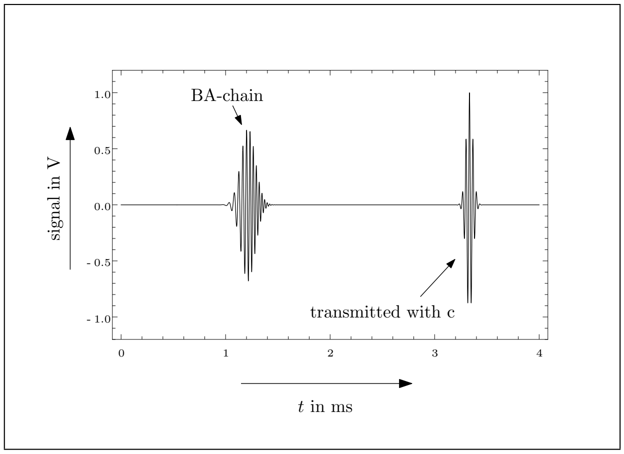

Figure 9: Signal at a distance of 1000 km

How such a transmission line can be constructed was also explained and investigated. The consequences that the discovery will probably have on the theoretical foundations of electrical engineering were, however, not discussed in this article.

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