Electronic data transmission at 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 has become 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. The starting point for this discovery was an experiment in which a two-channel oscilloscope was connected to a signal source via both a short and a long coaxial cable. It was observed that the delay between the two channels for short cables and low frequencies can be so small that the associated phase velocity exceeds the speed of light. To test whether the discovered effect can be exploited to transmit information over long distances, a cable was examined in which the signal was refreshed at regular distances by buffer amplifiers. The results show that such a setup is indeed suitable for transmitting wave packets at three times the speed of light and bit rates of approximately 2 kbit/s over arbitrary distances. The statement that information cannot propagate faster than light is clearly experimentally disproven and can therefore no longer be sustained.

1. Introduction

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

In the past, however, the transmission of information via 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 roughly the order of the wavelength of the transmitted signals or longer. However, ULF signals have wavelengths of 100 - 1000 kilometers, and it is obvious that transmission line theory may provide incorrect results for cables of short lengths.

It transpires that the transmission line theory does indeed fail for short cables and low frequencies. Nevertheless, it is rather astonishing that there is not a single experiment that measures the phase velocities of ULF signals in cables that are very short as compared with the transmitted wavelength. The author can only assume that this omission is related to the apparent 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, 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. Some scientists 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 appears to propagate much faster than light. The present article demonstrates experimentally that this particularly applies to copper cables and opens up new technological possibilities.

2. Experimental setup

2.1. Hardware

The experiment is simple and can be easily reproduced. 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 software are needed, the source codes for which 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 to the same signal source and measure the delay (Figure 1). Since the *PicoScope 2204A* has an integrated signal generator, the oscilloscope itself can be used as a 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 perform an analysis. Since the *PicoScope 2204A* signal generator output has an internal resistance, it is rec-

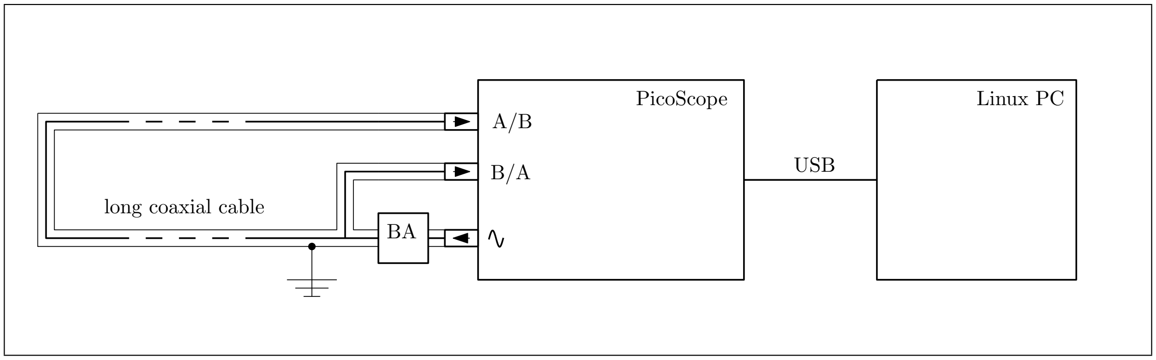

Figure 1: Experimental setup

ommended that a buffer amplifier (BA) be used directly behind the output and before the BNC T-adapter for longer cable lengths (Figure 2).

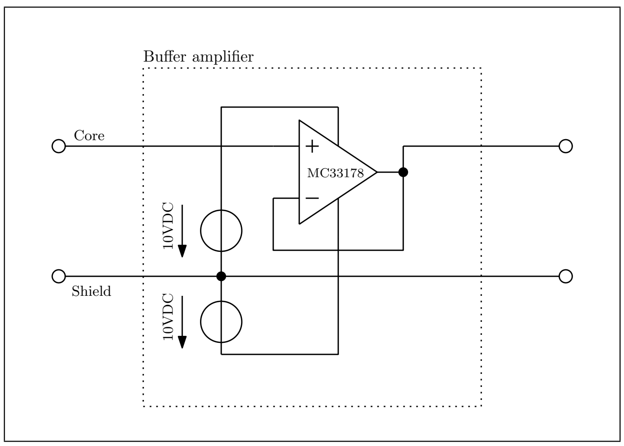

Figure 2: Used buffer amplifier

2.2. Software

For the experiment, software was developed that configures the PicoScope in such a way that it outputs a sine wave 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 in a stereo WAVE file, which has the advantage that the recorded signals can be easily opened and analyzed using 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 one microsecond, and therefore below the time resolution of the sampling. Nevertheless, it is possible to detect even extremely small signal shifts, since the buffers have a length of 60 s and the sampling rate is approximately 20-times higher than the highest signal frequency; thus, the signal is 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 with ideal interpolation using the Shannon theorem, cubic splines have the advantage that the global maximum can be found in an analytical manner. 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, since high-frequency noise can have a negative effect on the calculation. An STFT filter is used for this purpose.

The software is available as a 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, sine wave 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 connected with the first input of the oscilloscope and sometimes with the second. The measured delays τ are shown in Figure 3. Note that the error bars for the standard deviations are 20-times amplified.

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

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

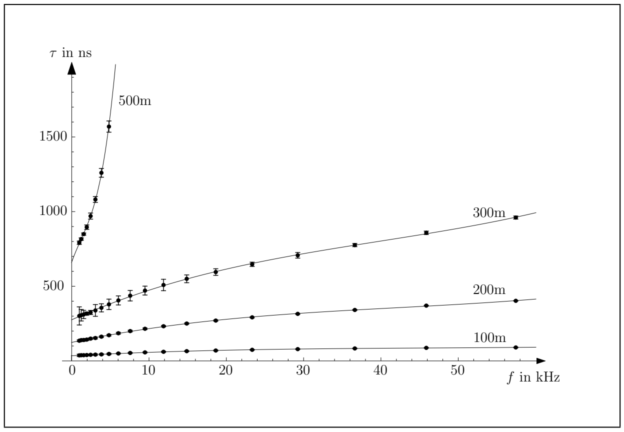

Figure 3: Measured signal delays τ between the two channels as a function of cable length and signal frequency f (error bars are 20-times amplified).

$$\begin{aligned}\tau_{200m}(f) &= 1.23\cdot10^{-7}\,\mathrm{s} + 1.12\cdot10^{-11}\,\mathrm{s}^2 f - \\ &\quad 1.99\cdot10^{-16}\,\mathrm{s}^3 f^2 + 1.57\cdot10^{-21}\,\mathrm{s}^4 f^3\end{aligned} \tag{2}$$

$$\begin{aligned}\tau_{300m}(f) &= 2.76\cdot10^{-7}\,\mathrm{s} + 2.35\cdot10^{-11}\,\mathrm{s}^2 f - \\ &\quad 3.85\cdot10^{-16}\,\mathrm{s}^3 f^2 + 3.22\cdot10^{-21}\,\mathrm{s}^4 f^3\end{aligned} \tag{3}$$

$$\begin{aligned}\tau_{500m}(f) &= 6.63\cdot10^{-7}\,\mathrm{s} + 1.49\cdot10^{-10}\,\mathrm{s}^2 f - \\ &\quad 2.68\cdot10^{-14}\,\mathrm{s}^3 f^2 + 7.39\cdot10^{-18}\,\mathrm{s}^4 f^3\end{aligned} \tag{4}$$

Figure 4 shows the phase velocities

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

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 ($f = 30\ldots15000\,\mathrm{Hz}$).

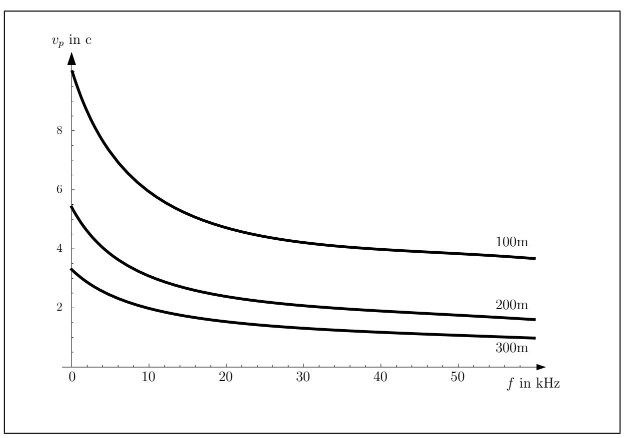

Figure 4: Phase velocities v_p as a function of cable length and signal frequency f

It should be noted that faster-than-light phase velocities with a cable length of 500 meters occur only at frequencies below approximately 5 kHz. For higher frequencies, the electromagnetic wave effects appear to increasingly dominate.

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

To study whether extremely high phase velocities of ULF and VLF signals also lead to extremely 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 via cables of different lengths. For this purpose, instead of the signal generator, the right loudspeaker output of a HiFi system was connected to the oscilloscope in two different ways: via a long coaxial cable and directly.

The cable lengths were varied, and the delays were determined. Furthermore, the input positions of the oscilloscope were differed again, i.e., the long cable was sometimes connected with input A and sometimes with input B. The measured delays showed little scattering and were reproducible and symmetrical with respect to the oscilloscope input. The quality of the music was similar on both channels after transmission, with no audible difference. Table 1 summarizes the measurement results.

cable length	required 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 the 500-meter cable showed a shift of approximately one sample between the channels. Since this corresponds to a time of 1000 ns at a sampling rate of 1 MHz, this is consistent with the results shown in table 1.

4. Increasing the signal range

4.1. Principle and measurement results

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

By curve fitting the data, one obtains the function:

$$\begin{aligned}\hat{\tau}_{200m}(f) &= 9.03\cdot10^{-8}\,\mathrm{s} + 5.59\cdot10^{-12}\,\mathrm{s}^2 f - \\ &\quad 1.04\cdot10^{-16}\,\mathrm{s}^3 f^2 + 7.90\cdot10^{-22}\,\mathrm{s}^4 f^3.\end{aligned} \tag{6}$$

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

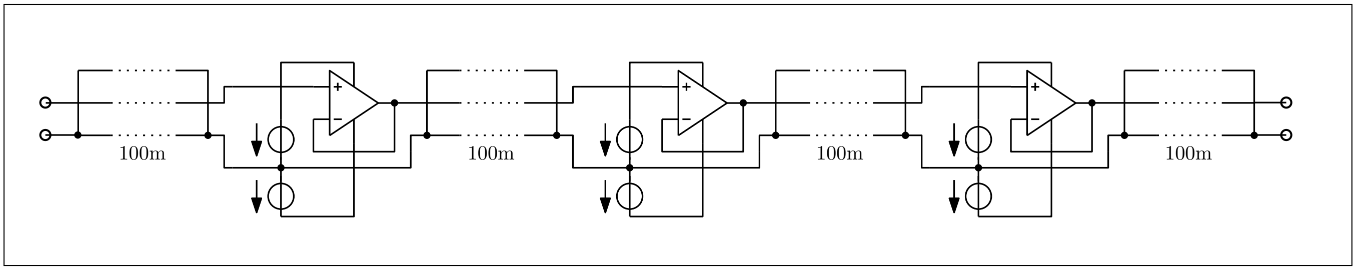

Figure 5: Buffer amplifier chain with 4 coaxial cable segments and 3 buffer amplifiers

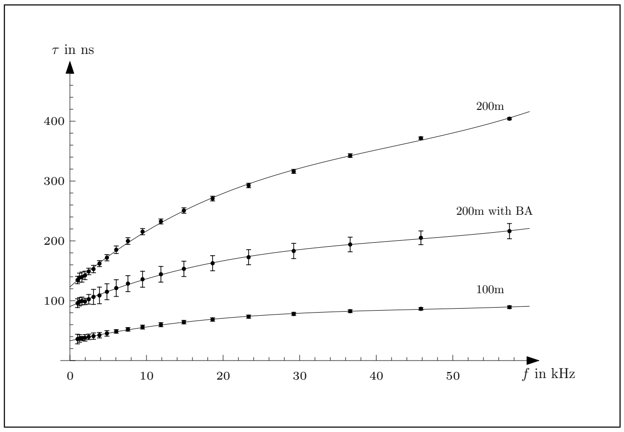

Figure 6: Measured signal delay for the refreshed signal in comparison with non-refreshed transmissions (error bars are 20-times amplified).

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.

To further confirm this, a buffer amplifier chain consisting of four 100-meter coaxial cables and three buffer amplifiers was built and analyzed (Figure 5). Curve fitting of the data resulted in:

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

As one can see,

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

is a very good approximation of the measured values.

This shows that it is also possible to establish long transmission lines with extremely 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 frequency.

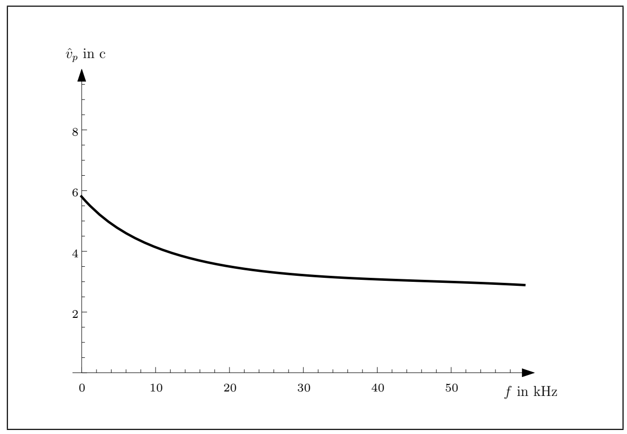

Figure 7: Phase velocity for a cable with signal-refresh every 100 meters

4.2. The transmission properties of a buffer amplifier chain

Section 4 has shown experimentally that it is possible to establish a transmission line in which signals with frequencies under 60 kHz propagate at several times the speed of light. If one connects 100-meter coaxial or twisted-pair cables with buffer amplifiers, one obtains a buffer amplifier chain of a 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 $3\,c$ is discussed below.

The starting point 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 approximately 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 that 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:

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

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 and the location x, since $e^{-i\,2\,\pi\,f\,\left(t-x/\hat{v}_p(|f|)\right)}$ represents a propagating wave. For $x = 0$, as can be seen easily, one obtains the usual inverse Fourier transform, 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 calculation of the absolute value in $\hat{v}_p(|f|)$ is necessary, since the integration also runs over negative frequencies, but 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, which corresponds to the tangent at this point. For $f_C = 30\,\mathrm{kHz}$, one obtains:

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

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, refer to figure 8: shown on the left side is 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 $v_p(f) = c$; and shown on the right side for comparison is the voltage one would measure at a specific position at a certain time, if one were to use a buffer amplifier chain as a transmission line. As can be seen, in the buffer amplifier chain, the wave packet moves at a significantly higher velocity. At the same time, although dispersion occurs, the wave package remains intact. Moreover, it is noted that the higher width of the wave packet in the buffer amplifier chain is not primarily due to dispersion but the higher signal velocity and, therefore, the longer wavelength. Figure 9 shows the voltage that one would measure at a distance of 1000 km.

As can be seen in Figure 8, wave packets transmitted at a time interval of approximately 0.5 ms would not interfere with each other and remain 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 roughly 2000 bits per second is possible.

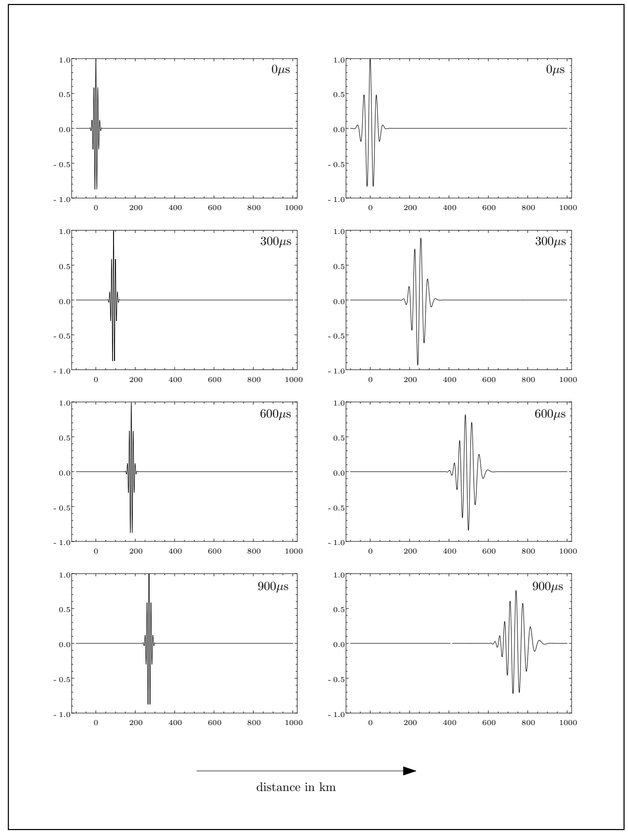

Figure 8: Signal propagation in an ideal ($v_p = c$ for all frequencies) transmission line (left) and in a buffer amplifier chain (right)

Since this bit rate is extremely small in comparison with current 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 important theoretical insight that the speed of light is by no means the upper limit at which information can propagate.

5. Summary and final remarks

The article shows 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. To date, 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 used technologically to transmit information significantly faster than would be possible with light. How such a transmission line can be constructed was also explained and investigated; however, the consequences that the discovery will have on

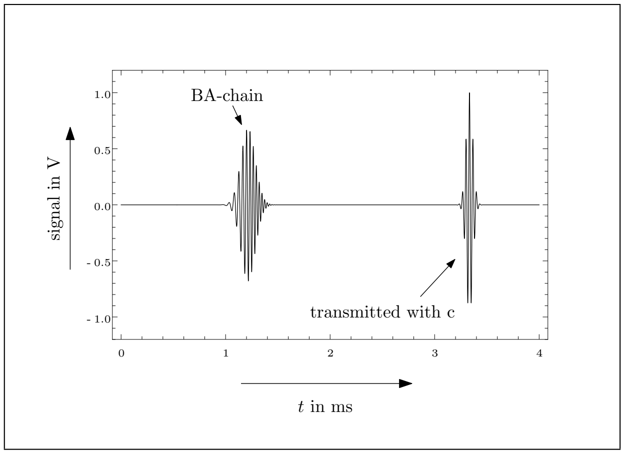

Figure 9: Signal at a distance of 1000 km

the theoretical foundations of electrical engineering were not discussed in this article.

References

[1] O. Heaviside, *Electrical papers, Volume II*. Macmillan and co., New York and London, 1894. [Online]. Available: https://archive.org/details/electricalpapers02heavrich

[2] R. de Sangro, G. Finocchiaro, P. Patteri, M. Piccolo, and G. Pizzella, “Measuring propagation speed of coulomb fields,” 2012. [Online]. Available: https://arxiv.org/abs/1211.2913

[3] W. D. Walker, “Experimental evidence of near-field superluminally propagating electromagnetic fields,” 2000. [Online]. Available: https://arxiv.org/abs/physics/0009023

[4] S. Kühn, “Evaluation and measurement software,” 2019. [Online]. Available: https://github.com/stnkuehn/phaseshift.git