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An Indirect Measurement of the Speed of Light Using EMF Meter

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ABSTRACT

This research aims to measure indirectly the speed of light using EMF meter. An EMF meter is a device to measure separately magnetic and electromagnetic field sources. In this research we use 44 different smartphones as the sources and calculate the speed of light using ratio of magnetic field to electromagnetic field (c=E/B). Standard deviation or relative error is also calculated to make sure the speed of light measured is within the range speed of light in vacuum which is 3 x 10^8 m/s. This method provides relatively straightforward method way to determine speed of light. In this measurement, we find the speed of light is 3.21 x 10^8 m/s. However, there is an anomaly with the data due to standard deviation higher than the speed of light. This anomaly caused by high variability of data, strong outlier and right skew distribution which has relation to uncalibarated device. By reducing the accepted speed of light data measurement between 2 x 10^8 m/s - 5 x 10^8 m/s we then obtain the speed of light 3.22 x10^8 m/s and the standard deviation is 0.85 x 10^8 m/s.

1. INTRODUCTION

The entire spectrum of electromagnetic waves obeys Maxwell's equations. Maxwell's equations are among of the most elegant and concise ways to express the fundamentals of electricity and magnetism. The most important prediction arising from Maxwell's equations is the existence of electromagnetic waves, which are time-varying (coupled) electric and magnetic fields propagating through space. The wave speed, according to these equations, turns out to be very close to the speed of light (3×10^8 m/s), obtained from optical measurements. This led to the remarkable conclusion that light is an electromagnetic wave. Maxwell's work thus unified the domains of electricity, magnetism, and light. Hertz, in 1885, experimentally demonstrated the existence of electromagnetic waves. The use of his technology by Marconi and others eventually led to the communications revolution we witness today (Cao, 2023).

The speed of light is a fundamental constant in physics, playing a crucial role in our understanding of the universe. In a vacuum, light travels at approximately 3x10^8 m/s denoted by the symbol 'c'. This universal speed limit governs the behavior of light and all electromagnetic radiation, influencing theories such as Einstein's special relativity, which states that in a vacuum nothing can exceed the speed of light. The precise measurement of c has evolved over centuries, from early experiments by Ole Rømer in the 17th century to modern laser-based techniques. According to the National Institute of Standards and Technology (NIST), the speed of light is now defined as exactly 299,792,458 meters per second, forming the basis for the International System of Units (SI) (Jennings et al., 1987). Beyond its theoretical importance, the speed of light underpins cutting-edge technologies, from fiber-optic communications to deep-space navigation. According to the European Space Agency, even minor deviations in c would disrupt satellite-based systems like GPS, highlighting its real-world significance (NASA, 2017).

Aristotele and Descartes believed that its speed was infinite until in the second half of the 17th century, the first measurements began to be made (Marhuensda, 2018 as cited in Arribas et al., 2020). In 1690, Huygens observed that light takes 11 minutes to travel the distance which extends from the Sun to the Earth, which he estimated at 160x 10^6 km (Huygens, 1920 as cited in Arribas et al., 2020). With this data, Huygens obtained c = 2.42 10^8 m/s. Now we know that light takes 8 minutes and 19 seconds to arrive from the Sun to the Earth. In 1887, Michelson and Morley designed a meticulous experiment to measure the relative speed of light in relation to the ether. At the end of the experiment, they concluded that the speed of light was constant, hence, the ether does not exist. The experiment was a failure but at the same time, it was a successful experiment. A few years later among other evidence, this led to the appearance of Einstein's Special Theory of Relativity (Griffiths, 2023). In 2018, Voudoukis measured the wavelength and frequency of light and then determined the speed of light using the fundamental equation of wave. The measuring of wavelength based on the phenomenon of light interference or the phenomenon of light diffraction. The measuring of frequency based on the fact that the energy of a photon is proportional to the voltage needed to cause electrons to flow ((Voudoukis, 2018). Enrique Arribas et al., in 2020 used an indirect method to measure the speed of light by using the equation $c = \frac{1}{\sqrt{\varepsilon_0 \mu_0}}$. First, the electrical permittivity of air (ε_0) is obtained by using a capacitance meter. To measure the capacitance of a parallel-plate capacitor, by varying the separation between its plates. The magnetic permittivity of air μ_0 is obtained by using a solenoid through which different currents are circulated and the magnetic field is measured in its center using the Hall sensor of a smartphone. This method obtained the speed of light in the air is c = 3.00 ±0,06 x 10^8 m/s (Arribas et al., 2020).

Even with modern technology, several factors complicate the measurement process including:

1. Short time scales: Light travels ~30 cm in one nanosecond. Standard electronics often struggle to resolve such small intervals without expensive high-speed circuitry (Mehdi & Kolwankar, 2021; Ortiz & Montecinos, 2015)
2. Environmental noise vibrations from footsteps or traffic can disrupt laser alignments. Researchers often use "low-budget" solutions like bicycle inner tubes for vibration isolation (Ortiz & Montecinos, 2015).
3. Medium effects measuring in air requires corrections for refractive index. For absolute precision, measurements must be performed in a vacuum (Gülmez, 1997; Szostek & Szostek, 2023)
4. Calibration time traditional methods, such as rotating mirrors (Michelson/Foucault), are often overshadowed by the excessive time required for calibration and alignment (Carlson, 1996; Heiszler, 2017)

Traditionally, measurements of the speed of light (like those by Fizeau or Michelson) are two-way measurements. They involve reflecting light off a mirror, measuring the time it takes to go out and come back, and dividing the total distance by the total time (Greaves et al., 2009). However, using an EMF meter to find the E/B ratio is a steady-state measurement. We do not need to pulse the light, use a high-speed oscilloscope, or set up mirrors kilometers away. You simply measure the field strengths at a single point in space. You can use an EMF meter to measure the fields of radio waves or microwaves. Because these waves have much longer wavelengths than visible light, it is significantly easier to position sensors to capture accurate E and B readings without the interference patterns that plague optical measurements (Froome, 1958).

2. METHODS

An EMF (Electromagnetic Field) meter is a device used to measure the strength of electromagnetic and magnetic field independently in the surrounding environment. These fields are generated by both natural sources (e.g., Earth's magnetic field) and man-made sources (e.g., power lines, Wi-Fi, cell phones, and appliances) (Bates, 1983). Unlike "Time-of-Flight" methods (which treat light like a particle or bullet), this method treats light as a field. It allows researchers to confirm that the ratio of these fields remains constant and equal to c regardless of the frequency of the wave (Rosa & Dorsey, 1907).

The entire spectrum of electromagnetic waves obeys Maxwell's equations. Maxwell's equations are one of the most elegant and concise ways to express the fundamentals of electricity and magnetism. The most important prediction arising from Maxwell's equations is the existence of electromagnetic waves, which are time-varying (coupled) electric and magnetic fields propagating through space. Maxwell's equations also show that the magnitudes of the electric and magnetic fields in an electromagnetic wave are related as follows: (Griffiths, 2023).

$$B_0 = E_0/c \qquad (1)$$

From equation 1, we can measure the speed of light from electric and magnetic fields using an EMF meter. This measurements were carried out once on every 44 smartphone from various brands of smartphone students. Since in all cases, the magnetic field strength decreased sharply as distance from the source increased (Ponnle, 2022), the EMF meter in direct contact to smartphone screen.. The EMF meter used in this measurement is categorized as consumer or hobbyist retailers product which is for basic demonstrations of electromagnetic fields. The average magnetic and electric fields were then calculated using the following equation:

$$E_{mean} = \Sigma\ Ei\ /\ N \qquad (2)$$

$$B_{mean} = \Sigma\ Bi\ /\ N \qquad (3)$$

E_{mean} = Average Electric Field
B_{mean} = Average Magnetic Field
N = Number of smartphones measured
and standard deviation given by

$$\sigma = \sqrt{\frac{\sum(x_i - \mu)^2}{N}} \qquad (4)$$

σ = Standard deviation of the speed of light
x_i = Value of i-th measurement result of the speed of light
μ = Average measurement
N = Number of measurement data samples

Picture 1: EMF Meter to measure electric field and magnetic field

3. RESULT AND DISCUSSION

Table 1. Measurent of Electric and Magnetic Field of smartphones

E (N/m)	**B** (uT)	**c** (10^8 m/s)
58	0,16	3,62
1	0,26	0,038
280	0,25	11,200
8	0,26	0,308
9	0,25	0,360
105	0,25	4,200
37	0,28	1,321
100	0,26	3,846
4	0,35	0,114
6	0,17	0,353
42	0,28	1,500
24	0,64	0,375
190	0,32	5,938
24	0,28	0,857
24	0,39	0,615
470	0,66	7,121
910	0,75	12,133
380	0,35	10,857
30	0,59	0,508
22	0,33	0,667
170	0,28	6,071
29	0,3	0,967
96	0,32	3,000
123	0,39	3,154

230	0,23	10,000
24	0,25	0,960
24	0,44	0,545
29	0,39	0,744
113	0,21	5,381
21	0,38	0,553
2,44	0,37	0,066
656	0,66	9,939
13	0,19	0,684
34	0,19	1,789
16	0,25	0,640
6	0,19	0,316
123	0,28	4,393
11	0,21	0,524
42	0,25	1,680
35	0,3	1,167
330	0,19	17,368
40	0,3	1,333
99	0,41	2,415
60	0,3	2,000

Electric and magnetic field data were collected from 44 different smartphones using an EMF meter yielding the average speed of light of 3.21 x 10^8 m/s. This speed of light was obtained directly by dividing the electric field and the magnetic field measurements. The calculated speed of light is on the order of 10^8 m/s, but the standard deviation of the speed of light is 4.03 x 10^8 m/s, which exceeds the mean. This appears to be an anomaly in the measurement of the speed of light. In statistical analysis, the mean and standard deviation are two fundamental descriptive measures. The mean is used to determine the center of the data, while the standard deviation measures the degree of dispersion of the data relative to the mean. It is often assumed that the standard deviation cannot be greater than the mean. However, this assumption is not always true. Under certain conditions, the standard deviation can be greater than the mean, and this is a statistically valid condition (Altman & Bland, 2005; Richards, 2008). For example when someone measures average of monthly income of 5 people; 4 people have income $1.000 monthly and one person has income $1.000.00 monthly, this example will give standard deviation larger than average value. To understand why the standard deviation can be greater than the mean, we need to look at the distribution of the data which can be caused by the following (Tabachnick & Fidell, 2019.)

1. Highly Distributed Data (High Variability): Your data set has very high heterogeneity. The members of the group are very different from each other.
2. Strong Outliers: It is very likely that one or more values differ drastically from the group. These values inflate the standard deviation.
3. Skewed Data Distribution: Data tends not to be normally distributed. The pattern will be skewed, usually to the right (right-skewed) due to the presence of large extreme values. This indicates an anomaly in the measurement.

The data distribution in table 1 and figure 2 shows that all three factors mentioned above contribute to the standard deviation being greater than the mean. The 44 data points for measuring the speed of light are spread out from 0.038 x 10^8 m/s to 17.6 x 10^8 m/s which means it has highly dispersed data. Then, some of the light speed measurements are 3 to almost 6 times greater than the average speed, while the majority (around 30 data) fall below 2.5 x 10^8 m/s, demonstrating the presence of strong outliers. Finally, from figure 2 shows that the data distribution is skewed to the right, caused by several very large measurements in the right-hand graph, which appear to be non-normally distributed. Unlike people's monthly income, a standard deviation exceeding the mean in light speed measurements is an anomaly, as the speed of light should not vary based on smartphone models. To eliminate this anomaly, data reduction was performed so that the average light speed measurement are more proportional to the standard deviation (Osborne & Overbay, 2004). After taking a threshold as accepted value for the speed of light from 2 x 10^8 to 5 x 10^8 m/s, the dataset filtered to 9 valid points which gives lowest standard deviation with minimum accepted data points. With this threshold, we find the average speed of light becomes 3.22 x 10^8 m/s and the standard deviation is 0.85 x 10^8 m/s.

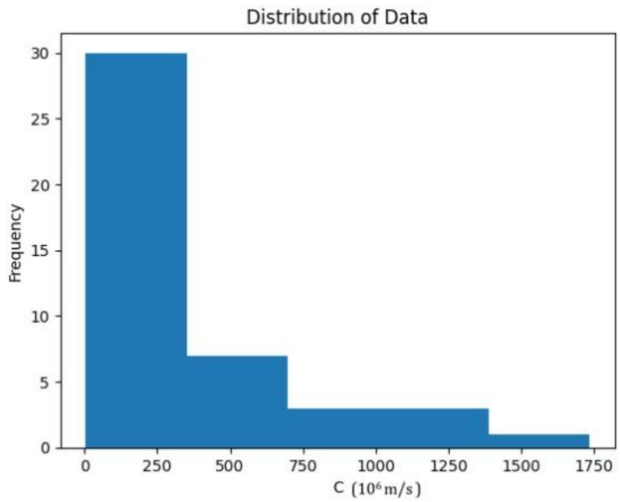

Figure 2 Data Distribution of measurement light speed

4. CONCLUSION

The measurements for the speed of light using an EMF meter from 44 smartphones as electromagnetic sources gives c= 3.22 x 10^8 m/s. The method is conceptually simple but requires careful calibration and standardization. There is an anomaly appears on this measurement due to high variability of data, strong outlier and right skew distribution yielding standard deviation is larger than the mean of the speed of light. Since the EMF meter used in this measurement is the lowest grade we recommend to upgrade with higher precision device.

REFERENCES

Altman, D. G., & Bland, J. M. (2005). Standard deviations and standard errors. *BMJ*, *331*(7521), 903. https://doi.org/10.1136/bmj.331.7521.903

Arribas, E., Escobar, I., Ramirez-vazquez, R., Franco, T., & Belendez, A. (2020). *Journal of King Saud University – Science An indirect measurement of the speed of light in a General Physics*. *32*, 2797–2802. https://doi.org/10.1016/j.jksus.2020.06.017

Bates, H. E. (1983). Measuring the speed of light by independent frequency and wavelength determination. *American Journal of Physics*, *51*(11), 1003–1008. https://doi.org/10.1119/1.13358

Cao, X. (2023). New insights into Maxwell's equations based on new experimental discoveries. *Composites Communications*, *39*, 101552. https://doi.org/10.1016/j.coco.2023.101552

Carlson, J. E. (1996). Speed of light measurement with the laser pointer. *The Physics Teacher*, *34*(3), 176–177. https://doi.org/10.1119/1.2344390

Froome, K. D. (1958). A new determination of the free-space velocity of electromagnetic waves. *Proceedings of the Royal Society of London. Series A. Mathematical and Physical Sciences*, *247*(1248), 109–122. https://doi.org/10.1098/rspa.1958.0172

Greaves, E. D., Rodríguez, A. M., & Ruiz-Camacho, J. (2009). A one-way speed of light experiment. *American Journal of Physics*, *77*(10), 894–896. https://doi.org/10.1119/1.3160665

Griffiths, D. J. (2023). *Introduction to Electrodynamics*. Cambridge University Press. https://doi.org/10.1017/9781009397735

Gülmez, E. (1997). Measuring the speed of light with a fiber optic kit: An undergraduate experiment. *American Journal of Physics*, *65*(7), 614–618. https://doi.org/10.1119/1.18617

Heiszler, F.-J. (2017). Measuring the speed of light in classroom. *Physics Education*, *52*(1), 013009. https://doi.org/10.1088/1361-6552/52/1/013009

Jennings, D. A., Drullinger, R. E., Evenson, K. M., Pollock, C. R., & Wells, J. S. (1987). The continuity of the meter - the redefinition of the meter and the speed of visible-light. *Journal of Research of the National Bureau of Standards*, *92*(1), 11. https://doi.org/10.6028/jres.092.001

Mehdi, F., & Kolwankar, K. M. (2021). *Low-cost experiment to measure the speed of light*. 1–4. http://arxiv.org/abs/2108.06773

NASA. (2017). *Introduction to GPS and other Global Navigation Satellite Systems. NASA Technical Reports Server*. Https://Ntrs.Nasa.Gov/Api/Citations/20170004590/Downloads/20170004590.Pdf.

Ortiz, M., & Montecinos, A. M. (2015). How to measure the speed of light at your university with a dinner budget. *Revista Brasileira de Ensino de Física*, *37*(1), 1502. https://doi.org/10.1590/S1806-11173711649

Osborne, J. W., & Overbay, A. (2004). *The power of outliers (and why researchers should ALWAYS check for them) - Practical Assessment, Research & Evaluation* (Vol. 9, Issue 6). https://doi.org/10.7275/qf69-7k43

Ponnle, A. A. (2022). Measurement and Assessment of Exposure to 50 Hz Magnetic Fields from Common Home Electrical Appliances. *European Journal of Engineering and Technology Research*, *7*(3), 119–127. https://doi.org/10.24018/ejeng.2022.7.3.2832

Richards, S. A. (2008). Dealing with overdispersed count data in applied ecology. *Journal of Applied Ecology*, *45*(1), 218–227. https://doi.org/10.1111/j.1365-2664.2007.01377.x

Rosa, E. B., & Dorsey, N. E. (1907). A new determination of the ratio of the electromagnetic to the electrostatic unit of electricity. *Bulletin of the Bureau of Standards*, *3*(3), 433. https://doi.org/10.6028/bulletin.070

Szostek, K., & Szostek, R. (2023). The concept of a mechanical system for measuring the one-way speed of light. *Technical Transactions*, *2023*(1), 1–9. https://doi.org/10.37705/TechTrans/e2023003

Tabachnick, B. G., & Fidell, L. S. (n.d.). *Using Multivariate Statistics*. 1–14.

Voudoukis, N. F. (2018). Speed of Light Measurement with a Simple Way. *European Journal of Engineering Research and Science*, *3*(4), 69. https://doi.org/10.24018/ejers.2018.3.4.714