MEASURING THE SPEED OF THE LIGHT

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ABSTRACT

In this workshop I will present a simple method for indirect determination of the speed of the electromagnetic waves. To measure the speed of light in the air we combine an Arduino based device with a handheld emitter-receptor device that is suitable for the direct estimation of the velocity of radio waves. The goal of this project is to estimate the speed of the 433Hz’s frequency radio waves in the air and demonstrate the existing correlation between the air pressure, temperature, humidity and this velocity. This project is suitable for upper secondary school students. The measurements could also be performed in the schoolyard as an outdoor project. It helps the students understand better the scientific measuring method and the fact that the value of speed of the light is independent from reference frame hold.

INTRODUCTION

The speed of light in vacuum is a universal constant. The special relativity postulates that:

- that the laws of physics are invariant (i.e. identical) in all inertial systems (non-accelerating frames of reference).
- that the speed of light in a vacuum is the same for all observers, regardless of the motion of the light source.

Due to the fact that the value of the speed of the light in air is extremely large (c≈3×10^8 m/s), it is not at all easy to measure it directly because the reaction time of electronic devices is very slow in comparison with this value. Therefore, the measuring device needs to be compatible with this condition and it is also very important that students with low budget -in the school lab- can make the device.

The proposed device is a simple walkie-talkie system, which is appropriate for obtaining the speed of electromagnetic waves in air by the “flight time” method. To measure the atmosphere parameters: pressure, temperature, UV index and humidity we connect few sensors with the device. The main parts of this device are an Atmega644P microcontroller and a radio emitter-receiver RFM12BP for 433MHz.
The main part of the measuring device is the Emitter-Receiver (ER) based on transceiver chips. The basic component of the ERs is a cheap ISM integrated circuit. These chips are suitable both for sending and for receiving data, so the same circuit is fitted for ER1 and ER2. ER1 is connected to a computer (we use two laptops) USB port, this will send the measured time-lag data continuously. The RFM circuit element is perfect for being used in simple experiments for direct time measurement. It can work at three different frequencies: 433 MHz, 868 MHz, and 915 MHz. In our measurement, we use the 433 Hz because it is a license-free ISM band in our region.
The emitter-receivers are powered with 12V DC voltage, supplied from an accumulator or storage battery. The ERs send and receive (communicating between each other) a data package of 1 byte. They are able to send and detect a total of 30-40 data packages per second. The ER1 (which is connected to the computer, named host) sends successive packages to the other, like ER2 (named slave). After ER2 detects the first package coming from ER1, it responds with another 1-byte length signal data package. If the first response package returns to ER1, it records, the time elapsed between the original package and the response with 0,125μs accuracy. The received and recorded time is sent than to the laptop, where it is registered. With the settings of the microcontroller we could define the functions of the ERs, which is the host - emitter and which is the slave-receiver.

The ERs run a program written in C++, which command their communication. This is a simple operation protocol: ER1 sends a signal, and starts the clock. If this signal reaches ER2, then ER2 responds with another 1-byte length signal. When the response signal reaches ER1, this stops the clock, records the elapsed time to a file on the attached computer, and sends another signal, starting the clock again. During every 20-minute measurement, for a fixed position of ER2, we can record continuously 35-40000 flight time data. That means for a complete measuring process (for at least 5 different fixed positions of the slave ER), we got more than 200000 flight time values. To improve the speed results it is important to record a lot of flight times at different places and analyze them statistically.

**Student activity**

1. Prepare the measuring device for open-air experiment and calibrate the sensors for pressures, temperature and humidity.
2. Fix the host ER1 on a fixed position, connect the laptop.
3. Put the slave ER2 at least 50m distance, and the check the communication between the two emitter-receivers.
4. Fix the meteorological sensors on a tree or higher location and turn on the transmission unit.
5. Repeat the measurements for a new position of ER2. For every fixed position for ER2 made measurements for 20-25 minutes.
6. Change the position of ER2 at least 5 time, moving toward with 75-100m.
7. Record the sent data date for every position of ER2.
Table 1. Recorded flight times for fixed position of ER1 and different position of ER2.

<table>
<thead>
<tr>
<th>day1</th>
<th></th>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>d (m)</td>
<td>676</td>
<td>726</td>
<td>885</td>
<td>928</td>
</tr>
<tr>
<td>meantime (µs)</td>
<td>7105,847</td>
<td>7118,826</td>
<td>7160,875</td>
<td>7192,725</td>
</tr>
<tr>
<td>a (10^2µs/m-day1)</td>
<td>0,321058</td>
<td>0,31883</td>
<td>0,3508146</td>
<td>average</td>
</tr>
<tr>
<td>c (10^8 m/s)</td>
<td>3,114702</td>
<td>3,13644</td>
<td>2,8505086</td>
<td>3,033882</td>
</tr>
</tbody>
</table>

For every fixed distance (d) between the two ERs, we have 35-40000 flight time data (t). The task is: Plot them (made histograms) and check for some pattern, recurring rule or specific law.

What could observe on the graphs? Why are two peaks on the time histograms plot? How could you explain this?

What is the correlation between the recorded mean flight time values, distance between the two ERs and the speed of light?

Repeat these measurements during every season several times in different weather conditions and compare them. Could you discover correlation between the speed of the light and pressure, temperature, humidity? How could you explain this?

**CONCLUSION**

This project is very useful because the students enjoy these outdoor activities. The speed of electromagnetic waves could be determine with good approximation (2,8·10^8 m/s). During this activities they learn a lot about scientific measurement planning, programming, data processing or building phases of a scientific research, could realize a connection between different school tasks like mechanics, thermodynamics, electromagnetism, computer programming, IT and could introduce basic element linked astronomy or space research.

This measuring device, measuring method and a data processing technique using computer software helps the improvement and development of their knowledge in thermodynamics and electromagnetism on a high school level, in a completely new environ-
ment. The aim of this technique is to improve skills and competences that allow students to solve scientific tasks, to carry out individual research and raise their interest in space sciences research or IT.

REFERENCES

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Direct measurement of the speed of radio waves in air; online from: http://www.phys.ubbcluj.ro/~zneda/rv