A Method and Research for Hands-on Measurement of the Propagation Speed of Microwaves through Dielectric Material in Educational Physics Laboratory

Vasileia Nikitaki, Sarantos Oikonomidis & George Kalkanis
University of Athens, Pedagogical Department P.E.,
Science, Technology and Environment Laboratory
13a Navarinou St, Athens GR-106 80
vnikitaki@gmail.com, sarecon@gmail.com, kalkanis@primedul.uoa.gr
http://micro-kosmos.uoa.gr

Abstract. *In this paper we describe a hands on activity in order to calculate the microwave propagation speed though a dielectric material. Through this activity we also calculate the refractive index of the dielectric and the microwaves wavelength.*
This exact experiment was given as a problem, using experimental data without taking measurements, to 193, 17 year-old Greek students, who participate in the Panhellenic Physics Competition (2010) for High school students. We analysed all the answers and in this paper we present all conclusions that we reached. Furthermore, in the last part of this paper we propose educational software, based on the "scientific / educational by inquiry model".

Keywords. Competitions, Interference, Microwaves, Problem solving, Scientific / Educational by inquiry model.

1.Introduction

Microwaves are electromagnetic waves with wavelengths ranging from as long as one meter to as short as one millimeter, or equivalently, with frequencies between 300 MHz (0.3 GHz) and 300 GHz.[3] However, there are no precise boundaries separating the microwaves from the neighbouring regions of the spectrum of electromagnetic radiation in the VHF and infrared radiation. Microwaves are divided into three separate zones:
• Decimetre microwave (Ultra high frequency, abbr. UHF) (0.3-3 GHz),
• Microwaves in centimeters (Super high frequency abbr. SHF) (3-30 GHz),
• Millimetre microwave (Extremely high frequency abbr. EHF) (30-300 GHz).[4]

There are many applications of microwaves in everyday life because of their wide spectrum. Microwaves are used to broadcast terrestrial television signals (UHF), satellite television signals and to satellite communications in general. Also they are applied to mobile phones (Wi-Fi, Bluetooth), to radars and microwave ovens.[2]
Microwaves can provide students with a rich variety of opportunities to explore interference phenomena in waves. They provide an alternative to visible light experiments, reinforcing the relevance of wave optics. Because microwave wavelengths are on the order of centimetres, the length scales of the aperture are easily manipulated and measured by students. Diffraction experiments also allow a quantitative evaluation of the theoretical intensity distribution beyond simply locating intensity minima and maxima.[1]

Dielectrics cannot absorb radiation because they lack of free electrons. So, dielectrics are employed as insulation for wires, cables and electrical equipment. The dielectric and the microwave source that we used in this experiment had zero absorption (the dielectric is considered transparent to microwaves, so the radiation intensity does not increase at all).

2. The experimental problem of 2010 Panhellenic Competition.

In a group of students was given the problem of measuring the speed of propagation of microwaves through a dielectric material. In the case of dielectrics the absorption of radiation is small since the dielectrics do not have free electrons. Especially for the dielectric and the microwave source that were given to students the absorption is almost zero (there is no reduction

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of the intensity of microwave radiation so we can consider the dielectric transparent to microwaves). A microwave receiver and a polymeter are connected. The polymeter's indication (amperage) is proportional to the microwave radiation intensity that reaches the receiver, so when the microwave intensity is high, the polymeter indicates high current. When between the transmitter and receiver is only air, the indication of the polymeter is I. These students thought to place between the microwave transmitter and receiver the dielectric so as to pass through it only half the package of microwaves and the other half arrives at the receiver through the air, as shown in the following figures.

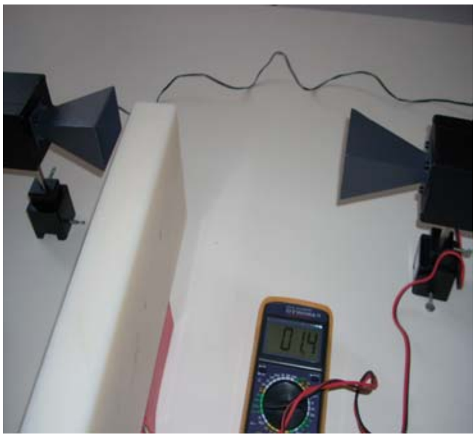

Figure 1. Half microwaves pass through the dielectric.

The students could alter the thickness of the dielectric, by mounting additional bars made from the dielectric. The procedure started from a very small thickness and when the dielectric reached the 25mm, the polymeter's indication was zero for the first time. The questions that were posed to the students of the Panhellenic Competition were the following:

1. Give a full explanation of the phenomenon that was observed when the thickness of the dielectric was 25mm.
2. If the microwave frequency is f=10.7 GHz and the speed of light in air $c_o=3*10^8$m/s, calculate the speed of microwaves in the dielectric.
3. What is the wavelength of microwaves in the air?
4. What is the refractive index of the dielectric for this wavelength?
5. What would the students observe if they had placed the same dielectric in a way that microwaves would pass though the dielectric and then reach the receiver? (See Figure 2.)

Figure 2. Microwaves pass through the dielectric.

Proposed Solution: 1. Half the microwave beam that passes through the material delayed half a period compared with the other half that was traversing the air. The result of this time delay is interference, because when the two beams reach the receiver have phase difference π rad. 2.Microwaves travel through air a distance d=25mm in time t, but when they travel the same distance through the dielectric they spend more time, $t+\frac{T}{2}$. T is microwave period, which is given by this equation: (1) $T=\frac{1}{f}$. The speed of waves in the air is (2) $c_o=\frac{d}{t}$. The speed of waves in the dielectric is (3) $c=\frac{d}{t+\frac{T}{2}}$.

Equation (3) by means of (2) gives: $c=\frac{d}{\frac{d}{c_o}+\frac{T}{2}}$

from which we get finally:

(4) $c=\frac{2dc_o f}{2df+c_o}$ and if we replace with numbers we get:
$c=1.92*10^8$ m/s.

3. (5) $\lambda = \frac{c_o}{f}$ from which we get λ=2.8cm. 4. (6) $n = \frac{c_o}{c}$ which is n=1.56. 5. In this case both halves will have the same delay T/2 so the signal at the receiver will be reset and the polymeter will show again I.

3. Data Analysis

The questions posed to the students was within their capabilities as required knowledge of basic concepts of waves, such as wavelength, propagation velocity, refractive index, which they will need at the entrance examinations for higher education. The students should have read the problem carefully, in order to understand the whole procedure.

We examined 193 students' writings, 102 students were able to answer most of the questions but only 40 answered correct to every one of them. After analysing all the answers, we made the following charts (figures 3-7). Every chart depicts how difficult or not was each question for the students. More specifically the green bar represents the percentage of students who responded correctly, the orange one represents the percentage of students who gave a wrong answer and the white one represents the percentage of students who did not give any answer at all.

1. Question 1: 39% answered correctly, 42% answered incorrectly and 19% did not answer. Most of the students who answered incorrectly gave the same explanation for the phenomenon observed at the receiver. They claimed that the zero indication was due to dielectric's absorption of microwaves.

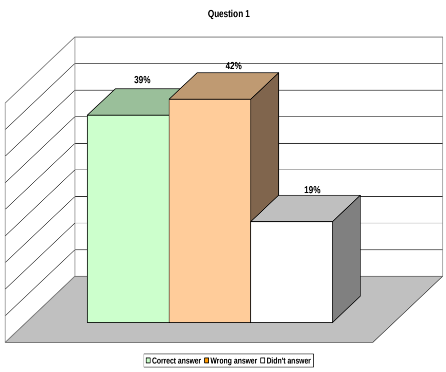

Figure 3. Question 1.

2. Question 2: 19% answered correctly, 21% answered incorrectly, 51% did not answer. We observed that the students were having difficulties in solving equations using only symbols. Additionally, some student's, who had answered correctly the 1st question, didn't succeed in the 2nd one because they did not use the phenomenon that was playing part in their solution.

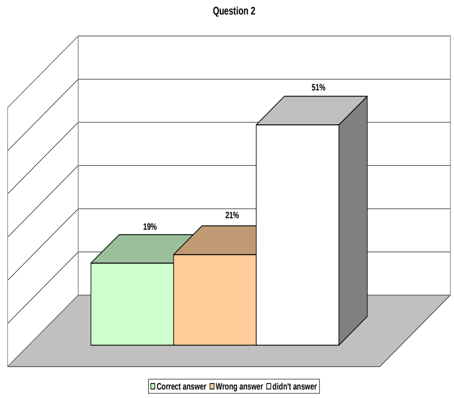

Figure 4. Question 2.

3. Question 3: 51% answered correctly, 39% answered incorrectly, 9% did not answer. Almost every student who answered this question was correct. They were able to use equation (5) and only a few were having problems with conversions to SI units.

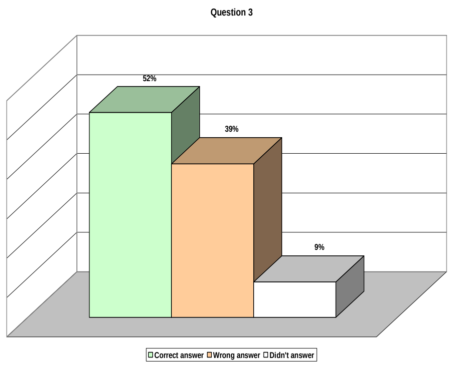

Figure 5. Question 3.

4. Question 4: 19% answered correctly, 42% answered incorrectly, 39% did not answer. Even though 61% of the students were familiar with equation (6), only those who had answered question correctly were able to succeed in this one too.

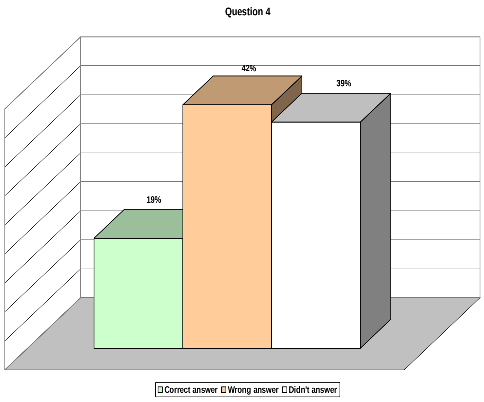

Figure 6. Question 4.

5. Question 5: 31% answered correctly, 22% answered incorrectly, 47% did not answer. Many students were having difficulties speculating about phenomena in physics. Some students justified their answer claiming that the dielectric is absorbent.

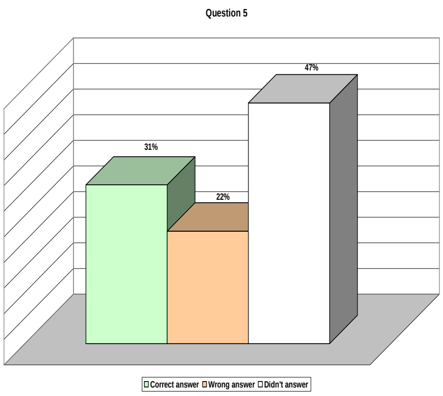

Figure 7. Question 5.

Finally, we gathered in a chart the percentage of correct answer for each question (Figure 8). Question 3 seemed to be the easiest for the students.

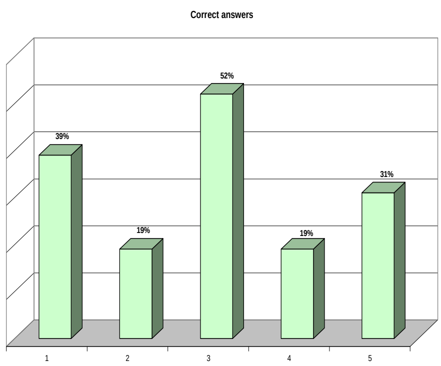

Figure 8. The percentage of correct answer.

4. Conclusions

After analyzing every answer, we came to some interesting conclusions. First, judging from the charts in figures 4, 5 and 6 we conclude that a certain amount of students are familiar with equations that describe phenomena in physics. Unfortunately, based on the chat in figure 3, a lot of students don't pay attention when they read the problem. This means that if they were more careful they would be able to answer question 1. Based on the chart in figure 7 we conclude that the vast majority of the students are having difficulties speculating about phenomena in physics and interpreting experimental results. Perhaps an explanation is that the students are not used to design and perform experiments and the only physics they experience is theoretical physics.
Finally, after taking into consideration all the previous conclusions, we designed educational software, based on the "scientific / educational by inquiry model". The 5-steps which characterise our worksheets are the following:

- Trigger of Interest
- Hypothesizing expression
- Experimenting- testing the hypothesis
- Concluding
- Application

We chose the previous mentioned experiment and other hands on activities in order to study some microwave properties that are used in everyday life. Apart from the experiments that take place in a lab, the software suggests a number of experiments that use interactive simulations.

To sum up, via these experiments students can study some electromagnetic waves' properties using microwaves instead of visible light, which can make it easier for them to follow the continuously advances in Technology, since microwaves are used in communications (antennas, bluetooth etc.), radars and other technological aspects of everyday life.

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