E-Learning in the Courses on “Electromagnetics”, “Radio Wave Propagation” and “Electromagnetic Fields and Waves”

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Abstract. The features of the educational and methodological software of E-Learning in the courses on “Electromagnetics”, “Radio Wave Propagation”, “Electromagnetic Fields and Waves” at the Southern Federal University (Russia), are considered. The electronic content MWLab EMPW of the type of online learning laboratory was developed, which allows you to organize online lectures, practical and laboratory classes, as well as self-monitoring and online knowledge control. A distinctive feature of the content is the use of video-clips of electromagnetic processes and virtual models of laboratory setups developed using Ansys HFSS. They clearly explain the formation in space and the change in time of the field lines and the values of the field vectors. This compensates for students’ difficulties in understanding the complex mathematical apparatus and the spatial-time nature of the processes of radiation and wave propagation, and increases interest in learning. E-Learning can be carried out on the MS Teams platform using the functionality of meetings and other interaction tools between the teacher and students.

1. Introduction

In modern higher education, various information technologies of distance, blended and online education are intensively applied. First of all, these are multimedia technologies in learning laboratories such as the information environment [1-4], online learning technologies using Learning Management Systems (LMS) based on various platforms, for example, Microsoft Teams [5, 6], Moodle [7] etc. These technologies provide accessibility, visualization, effectiveness of training, as well as the development of creative research skills in the online conditions of interaction "teacher-electronic content-students" [8].

One of the fundamental courses in radio engineering of university education is the “Electromagnetics” or “Electromagnetic fields and waves” [9]. When studying these courses, students usually experience difficulties associated with a lack of practical knowledge in higher mathematics and physics, the bulkiness, complexity, and the variety of mathematical apparatus used (vector analysis, field theory, equations of mathematical physics), difficulties in representing and understanding three-dimensional vector electromagnetic (EM) processes and their dynamic nature [4, 10]. The papers [3, 5, 11, 12] discuss the effective use of multimedia web technologies in the learning of electromagnetism. In there, the use of interactive components such as virtual laboratories, multimedia modules, EM modeling, animation, and virtual participation in practical applications is described.

It is noted that E-Learning of electromagnetic theory is complicated if there is no in-class interaction between students [13] and is simplified by using computer modeling, visualization, and field animation, especially in sections such as transmission lines, Smith diagram, and wave propagation [3, 14, 15].
This paper briefly describes the features of educational and methodological support for E-Learning in the courses “Electromagnetics”, “Radio Wave Propagation” and “Electromagnetic fields and waves” at the Department of Antennas & Radio Transmission Devices of the Institute of Radio Engineering Systems and Control of the Southern Federal University (Russia). The learning is carried out on the Microsoft Teams platform and uses the developed electronic content of MWLab EMPW, such as a learning online laboratory. The functionality of online meetings and other tools of interaction between the teacher and students integrated into MS Teams are used. The electronic content of the laboratory allows you to organize online lectures, practical and laboratory classes with the implementation of virtual laboratory work, as well as self-monitoring and online knowledge control. At the same time, MWLab EMPW content becomes an accessible online medium, a simple tool for studying theoretical material with visualization and animation of complex spatial-time electromagnetic phenomena, which increases interest in learning.

2. MWLab EMPW Electronic Content Modules

MWLab EMPW electronic content contains 11 modules. The first three modules consider EM field vectors, Maxwell equations, field sources, and vector potentials. In the fourth and fifth modules, the basic theorems and principles of the theory of EM waves, the radiation of waves by dipole sources and linear radiators are studied. The next four modules study wave diffraction and reflection, wave interference and refraction on ground radio links, plane waves in various media, including gyrotropic ones. In the tenth and eleventh modules, waves in guiding systems and fields in resonators are considered.

A distinctive feature of the content is the demonstration in online occupation (in lectures, practical, and laboratory works) of numerous original video clips of EM processes and phenomena developed using the Ansys HFSS package [16] (see examples in figures 1-4).

![Figure 1](image1.png)

**Figure 1.** The field lines of the electric (a) and magnetic (b) fields and the lines of the Poynting’s vector (c) in the volume with an electric circuit with a quasi-stationary current source in the centre of one conductor, with a capacitor (a, b) or resistor (c) in centre of the opposite conductor.

The MS Teams platform allows real-time broadcast to students of the contents of the teacher’s computer desktop with pre-loaded necessary applications, for example, electronic module files, video files with the behavior of field lines and field values, lines of Poynting’s vector, HFSS-projects with models of virtual laboratory works.

Note that for the formation of professional competencies among students, the content of MWLab EMPW is not only fundamental, but also an applied one. It is aimed at the application of theoretical materials for calculating the characteristics of EM waves excited in various media and radio engineering devices, traditionally studied in university courses. Students independently solve the applied express problems; a teacher at MS Teams supervises the answers.

![Figure 2](image2.png)

**Figure 2.** Field lines (a), an intensity (b) of the electric field and lines of the Poynting’s vector (c) of the Hertz dipole in the observation zone $0.5\lambda < R < 1.5\lambda$, where $\lambda$ is the wavelength.
3. Modules of Self-control and Online Knowledge Control

The student can carry out electronic self-testing of knowledge on the studied module in the Knowledge testing menu in the electronic shell of MWLab EMPW. The dialogue is based on the so-called constructed student responses. The question is displayed on the screen and key phrases of the answer are offered. From them, you need to make a correct and complete answer. For this, three areas are formed on the screen. The above part is the area of the Question; in the middle is the area of Key phrases with three directives Add, Delete, and Ready!; below is the Answer window (at first it is empty). Key phrases can be added alternately to the answer window or deleted from the window. By moving all the correct phrases to the bottom window, the final answer can be read in it. Therefore, the correct and complete answer should be the corresponding sentence or formula. The answer must not contain incorrect key phrases and all correct phrases must be present. Practice has confirmed the high efficiency and simplicity of such a dialogue with a minimum of keyboard operations.

Self-control of the assimilation of educational material for each studied electronic module, consisting of \( L \) topics, is organized along personal trajectories. At first, the electronic shell asks the student only simple questions. The complexity of the next question depends on the correctness of the previous answers. The complexity can increase (with the correct answer in a row to two questions of fixed complexity) and decrease (with the wrong answer). Each new question is fall from the next topic of this module. The computer asks the student \( M \) questions from databases with a capacity of 60 ... 100 questions allots \( T = 10 \) minutes for answers, indicates the remaining time, the serial number of the question, its complexity, and the total number of correct and incomplete answers on the screen. Each time the question is called up, the key phrases of the answer on the screen are rearranged according to a random law.

The final score \( Q \) in points is determined based on the norm \( N = 10 \) points, and takes into account the number of correct answers to \( M \) questions, the complexity of the questions, and the time \( t \) spent on the answers:

\[
Q = N K_c K_t \sum_{i=1}^{M} w_i r_i \sqrt{\sum_{i=1}^{M} w_i},
\]

where \( r_i = 1 \), if the student answered to \( i \)-th question or \( r_i = 0 \), if the student didn’t answer; \( w_i \) is the complexity of the question (for simple \( w_i = 0.1, \ldots, 0.5 \); for medium \( w_i = 0.6, \ldots, 1 \); for high complexity \( w_i = 1.1, \ldots, 2 \)); \( K_c \) is a complexity factor (\( K_c = 0.8 \), if only simple questions were presented; \( K_c = 1 \), if at least one question of medium complexity was earned, and \( K_c = 1.2 \), if the question was earned with \( w_i > 1 \)); \( K_t = 1.1 - 0.4 \left( t/T \right)^2 \).

The online control of knowledge is carried out by the teacher by issuing a task in MS Teams for each studied module in the form of 10 tasks and questions (from a bank containing 450 tasks for the entire course). Problem solving is assessed by a teacher at MS Teams.

4. Modules of Virtual Laboratory Works

Virtual interactive laboratory works can be performed by the student in the menu Laboratory work of the electronic shell. Models of laboratory setups were created in the HFSS program (for example, see...
figures 4-7). Some works use LabVIEW NI programs [17]. Let us briefly consider the features of modeling and execution of work.

When modeling EM processes, the computer visually displays the studied spatial-time distributions and properties of EM fields, implements a number of screen “measurements” that are difficult to perform in a physical experiment, and calculates the necessary characteristics (for example, field distributions, field lines of current and field patterns, ray reflection schemes, characteristics of waves during interference).

The model of the laboratory setup of “Properties of electromagnetic waves” with a horn radiator and a reflective screen allows us to study the properties of locally plane traveling and standing waves (figure 4). The student studies the polarization of the waves, the distribution and patterns of the field lines of the electric and magnetic fields in various observation planes, the interference of waves; has the ability to measure the wavelength.

![Figure 4](image)

**Figure 4.** The model of the laboratory setup of “Properties of electromagnetic waves” (a) and the distribution of the electric field of a standing wave in front of the screen (b).

Figure 5 shows a model of the “Surface waves” setup with a horn radiator, a slowing dielectric plate, and a reflective screen. The student can see the distributions and patterns of field lines of the traveling and standing (in front of the screen) surface E-waves, measure the surface wavelength, slowing coefficient, compare the results of on-screen “measurements” and his calculations in homework for work.

The model of the “A rectangular waveguide” laboratory setup (a) allows investigating the frequency characteristics of the copper waveguide section, the properties of the fundamental H_{10}-mode, the behavior of fields, and current lines in the cut-off region and in the propagation region (figure 6).

![Figure 5](image)

**Figure 5.** The model of the “Surface waves” laboratory setup (a); the electric field distribution (b); and the magnetic field lines (c) of the surface E-wave in front of the screen.

The laboratory work “A reflection of electromagnetic waves” demonstrates the formation of rays when plane waves are reflected from the interface between two media, including at the boundary with a metamaterial (figure 8). It allows you to study the angular dependence of the modules and phases of the reflection and transmission coefficients, the main phenomena in the reflection of waves.
In interactive windows, the parameters of the experiment such as the angle of incidence, the polarization of the waves, the relative permeability, and permittivity of the two media can be changed. A student can realize the phenomena of total refraction, total reflection, and matching (at an interface), write down the conditions for their implementation.

In the work “Wave propagation on the ground radio link”, the basic patterns of radio wave propagation on a flat model of a radio link are studied (figure 9, a). The fields of the antenna are modeled in the form of a lattice of three vibrators located on a metal mast in free space and on the flat surface with a given height of irregularities. The student can see the distribution of current and charge along the vibrators and along the mast, study the radiation patterns and “measure” the maximum directivity of the antenna, both in free space and taking into account the influence of the flat surface. An analysis of the angular diagrams of the flat earth factor allows one to “measure” the observation angle of the 1st interference maximum of the field above the surface and compare it with the results of its calculations in the homework.

Figure 8. Laboratory models of the waves' reflection from the interface between two media; interactive windows of rays' circuit (a) and modules and phases of the reflection coefficients (b).

Figure 9. Laboratory model of the transmitting antenna on the mast (a) and a 3D antenna pattern (b) taking into account the influence of the flat surface.

5. Conclusion
The developed electronic content can be useful in organizing lectures, practical and laboratory online classes at universities (with the implementation of virtual laboratory works, self-monitoring, and online knowledge control) in the courses on “Electromagnetics”, “Radio Wave Propagation”, and “Electromagnetic Fields and Waves”. E-Learning can be carried out on the MS Teams platform using the functional of online meetings and other tools of interaction between the teacher and students. A distinctive feature of the content is the use of original video clips of electromagnetic processes and phenomena, and virtual models of laboratory setups developed using HFSS. They clearly explain the formation and change in time of the field lines and the values of field vectors. This compensates to some extent for students' difficulties in understanding the complex mathematical apparatus and the spatial-time nature of the processes of radiation and propagation of EM waves, which increases interest in learning.
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