

MINISTRY SCIENCES AND HIGHER EDUCATION RUSSIAN FEDERATION FEDERAL
STATE AUTONOMOUS EDUCATIONAL INSTITUTION OF HIGHER EDUCATION
"NORTH CAUCASIAN FEDERAL UNIVERSITY"

METHODOLOGICAL INSTRUCTIONS

By completion of practical exercises

By discipline

Electromagnetic fields And waves /Electromagnetic Fields and Waves"

for students in the field of study

11.03.02 "Infocommunication technologies And systems connections" Profile

"Intellectual processing data V infocommunication systems and
networks"

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INTRODUCTION

1. Goals And tasks mastering the discipline:

Executions laboratory works By discipline « Basics theories "Electromagnetic fields and waves" ensure the development of a set of professional competencies in students (OPK-1, OPK-2), which provide their professional activities in the field of fundamentals of the theory of electromagnetic fields and waves:

1. Ability to independently work on a computer and in computer networks; perform computer modeling of electromagnetic fields and waves, systems and processes using universal software packages.

2. Ability use normative And legal documentation, characteristic of the field of information and communication technologies and communication systems.

3. The ability to conduct research on electromagnetic fields and waves in various environments and guiding systems.

2. Scroll planned results training By discipline (module), correlated with the planned results of mastering the educational program

Code, formulation of competence	Code, formulation indicator	Planned learning outcomes for the discipline (module) characterizing stages of formation competencies, indicators
OPK-1. Capable use provisions, laws And natural methods sciences and to solve engineering activities	ID-1 OPK-1 understands the fundamental laws nature And main physical mathematical laws and methods of accumulation, transmissions And processing	Understands the fundamental laws of nature and the basic physical mathematical laws of theory
	ID-2 OPK-1 applies physical laws and mathematical methods for solving theoretical and applied problems .	Applies physical laws and mathematical methods For solutions tasks theoretical And of an applied nature.
	ID-3 OPK-1 uses knowledge of physics and mathematics at decision practical problems.	Uses knowledge of physics and mathematics to solve practical problems.
OPK-2. Capable on one's own conduct experimental research use basic processing presentation of the received data	ID-1 OPK-2 finds and critically analyzes information, necessary to solve the given problem.	Finds and critically analyzes information, necessary For solutions to the
	ID-2 OPK-2 develops a solution to a specific problem, selecting the optimal option and evaluating its advantages and disadvantages.	Develops a solution to a specific problem, choosing the optimal one option, evaluating his advantages And
	ID-3 OPK-2 understands main methods and means of implementation experimental research, standardization system and	Understands main methods and means of experimental research electromagnetic fields.

Code, formulation of competence	Code, formulation indicator	Planned learning outcomes for the discipline (module) characterizing stages of competence development, indicators
	ID-4 _{OPK-2} chooses methods And measuring instruments and conduct experimental research.	Chooses methods And measuring instruments and conduct experiments research.
	ID-5 _{OPK-2} owns ways processing and presentation of the obtained data and assessment of the error of the measurement results.	Owns ways processing and performances received data And assessments errors in measurement results.

Practical lesson No. 1
Study opportunities programs MathCad And ElectronicsWorkbench for modeling and studying electromagnetic fields

STUDY QUESTIONS:

1. Research of the capabilities of the Mathcad program for modeling and analysis of electromagnetic fields.
2. Research of the capabilities of the Electronics Workbench program for modeling and analyzing electrical circuits.

TARGET SETTING OF PRACTICAL WORK :

Results training, achievable V result execution laboratory work:

Be able to:

– apply the basic laws and mathematical apparatus of electrodynamics to computer modeling and analysis of electromagnetic fields and waves in various media and guiding systems.

Own:

– skills in determining the characteristics of electromagnetic fields required for solving practical problems for calculating radio coverage, radio relay and satellite routes.

TRAINING AND MATERIAL SUPPORT:

- A personal computer with an electronic circuit simulator “Electronics Workbench” and a computer mathematics system “Mathcad”;
- electronic methodological development By laboratory work.

CONTENTS OF PRACTICAL WORK INTRODUCTORY

PART

Mathcad is a unique system for scientific and engineering calculations, allowing you to work with formulas, numbers, text, and graphs. Using Mathcad, you can solve almost any mathematical problem symbolically or numerically. Mathcad allows you to write formulas on your computer screen in their familiar form.

Mathcad has its own reference system. Electronic Books make a variety of useful formulas, reference data, and diagrams available for use in your working document with the click of a button.

Peculiarities Mathcad:

- Full compatibility with Windows: resizing and moving windows, opening multiple windows, mouse support.
- Opportunity combinations text, mathematical calculations And graphs anywhere on the screen.
- Built-in algorithm solutions systems equations and inequalities.
- Actions With derivatives and integrals.
- Calculation sums rows, works And iterations.
- Trigonometric, hyperbolic, exponential and Bessel functions.
- Statistical functions including linear regression, Euler's gamma function, error integral, probability distribution functions.
- Vectors and matrices, including operations of matrix multiplication, inversion, matrix transposition, matrix determinant calculation, scalar and vector multiplication.

- Symbolic integration And differentiation.
- Appeal, transposition and calculation determinant of matrices.
- A variety of graph types: in Cartesian coordinates, graphs in polar coordinates, construction of surfaces in three dimensions, construction of level lines, vector field plots, three-dimensional histograms, scatter plots.
- Animation graphs And any others objects worker document. IN This practical guide covers the Russian version of Mathcad 15. However, for the sake of generality, the English language notations for menu items, windows, etc. are provided.

QUESTIONS, SUBJECTS RESEARCH

1. STUDY OPPORTUNITIES PROGRAMS MATHCAD FOR MODELING AND RESEARCHING ELECTROMAGNETIC FIELDS.

Brief theoretical or reference and information materials

1.1 INTERFACE MATHCAD

The Mathcad interface is similar in structure to the interface of other Windows applications.

Mathcad working window

When you open the Mathcad.exe file, the Mathcad working window appears on the screen with the main menu And five panels: *Standard* (*Standard*), *Formatting* (*Formatting*), *Math* (*Mathematical*).

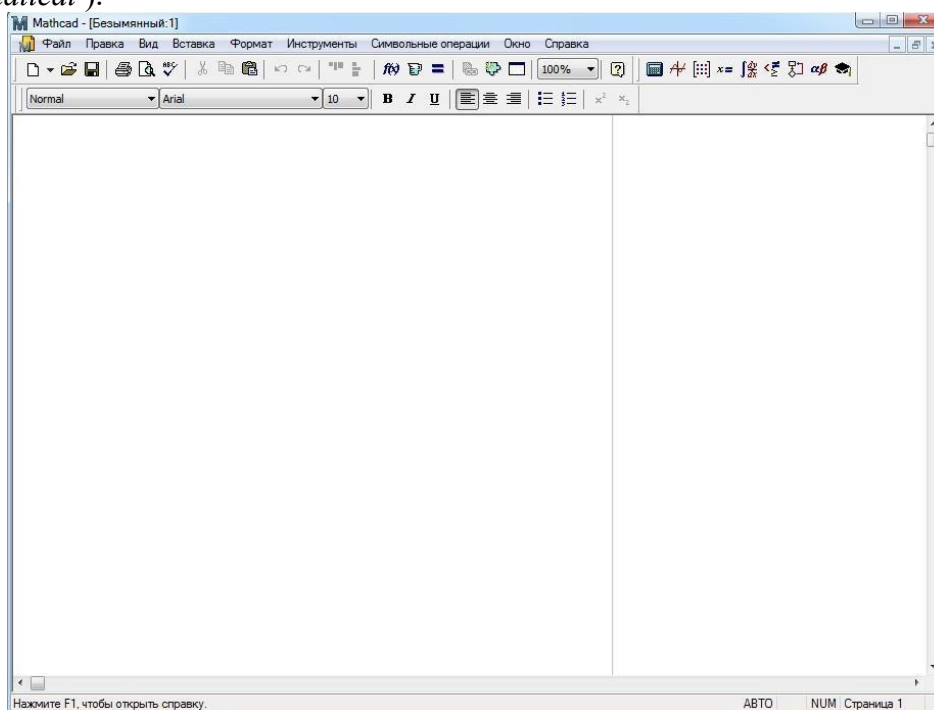


Figure 1.1 - Working Mathcad window

Untitled :1 , which is a *Normal template for a Mathcad worksheet called Worksheet* , is automatically loaded . The *Tip of the day* and *Mathcad windows* are also automatically loaded . *Resource* (*Documentation Mathcad*). Before beginning work their necessary close. IN In the *Tip of the day* window , uncheck the *Show tip at startup* box and click the *Close button* .

Main menu

Mathcad's main menu occupies the top row of the workspace. All necessary actions can be performed by following the menu items and the windows that open sequentially.

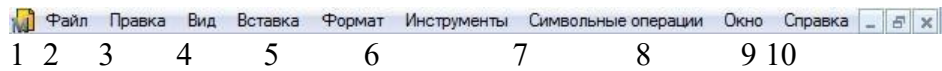


Figure 1.2 - Working Mathcad window

1. Control Mathcad working window .
2. *File (File)* - teams, related With creation, discovery, saving, forwarding via e-mail and printing files with documents cops.
3. *Edit (Edit)* - teams, related To editing text (copying, pasting, deleting fragments, etc.).
4. *View (View)* – commands that control the appearance of the document in the workspace Mathcad window, as well as commands for creating animation files.
5. *Insert (Insert)* - teams inserts various objects V document.
6. *Format (Format)* - teams formatting text, formulas And graphs.
7. *Tools (Tools)* - teams management computing process.
8. *Symbolics (Symbolic calculations)* - teams symbolic computing.
9. *Window* – commands that allow you to manage the arrangement of windows with various documents on the screen.
10. *Help (Help)* - teams call reference information.

Panels tools

Math is used to insert mathematical symbols and operators into documents. Clicking any of the icons inserts the corresponding symbol or mathematical operation template at the cursor's location in the working document .

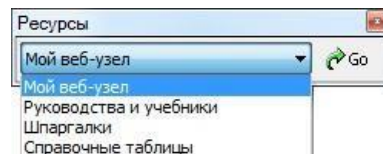


Drawing 1.3 - Mathematical panel And her subordinates panels The

panel consists of:

- ✓ *Calculator (Calculator)* - insert templates main mathematical operations, numbers, signs of arithmetic operations.
- ✓ *Graph (Schedule)* – insert template graphs.
- ✓ *Matrix (Vector and matrix)* - insertion of vector and matrix templates as well matrix operations.

- ✓ *Evaluation (Calculations)* - operators assignments values And conclusion calculation results.
 - ✓ *Calculus (Mathematical analysis)* - insert templates differentiation, integration, summation.
 - ✓ *Boolean (Boolean algebra)* - insert logical (Boolean) operators.
 - ✓ *Programming (Programming)* – operators necessary for creating software modules.
 - ✓ *Greek (Greek symbols)* - insert Greek symbols.
 - ✓ *Symbolic (Symbolic transformations With key in words)* - insertion of symbolic computation operators
 - *Resources (Additional resources)* contains list electronic books included in the Mathcad shell.
 - *Controls (Control)* contains buttons For additional control Mathcad document work .
 - *Debug (Debugging)* appeared V Mathcad 13, serves For program execution tracing.
 - Panel resources
- IN drop-down menu panels Resources (cm. drawing 1.4) contains a list of e-books included in the Mathcad package:



Drawing 1.4 - Mathematical panel And her subordinate panels

1.2 ENTERING, EDITING ,AND FORMATTING MATHEMATICAL EXPRESSIONS

Before you start working, the cursor on the screen looks like a cross. When you enter an expression, the cursor turns blue. The corner surrounding the entered expression. In a working document, you need to enter any literal expressions and assign them numerical values. The expression name can consist of Latin, Russian, Greek, and other letters and numbers, underscores [_], primes ['], and the percent symbol [%], entered from the keyboard.

Variable and function names cannot begin with a number, underscore, dash, symbol percent, Not can include V myself spaces. Symbol infinity Maybe be only first symbol in the name.

Mathcad does not distinguish between variable and function names. If you first define the function $f(x)$ and then the variable f , you will be unable to use $f(x)$ in calculations anywhere after f is defined .

Definition values variables

In order to be able to calculate an expression that depends on some variables, values these variables should be determined. To do this, you need to:

1. Enter variable name .



2. Enter colon [:], What will lead To appearance the assignment sign (:=) and the input field that follows it.



3. Type a number or expression in the input field. Mathcad will calculate it. corresponding meaning And will appropriate his name variable.

$$x := 2$$

To create:

- discrete arguments - enter the initial value, then the period With comma [;] For creation sign range And after the final value of the argument. In this case, the increment step will be equal to 1 by default. If you specify three argument values, the step will be equal to the difference the difference between the second and first values of the argument; $x := 1, 3..20$
- degrees - press key [^]; x°
- indices variable - enter point [.]; y_1
- indices arrays - press key left brackets [[];
- matrices, integrals, etc. – call up the required palette, set the dimensions and enter the corresponding number or expression in the input fields.

Definition functions

Function There is rule, according to which are carried out some You- numeration With her arguments And is being produced her numerical meaning. For Togo, To define a function, you need to:

- Enter Name functions And left bracket [(].
- Enter list arguments, detachable Friend from other commas and end it with a right bracket [)].
- Enter a colon [:], which will result in the character assignment (:=) And next for him fields input.
- Type V field input expression.

$$f()$$

$$f(x, y)$$

$$f(x, y) :=$$

$$f(x, y) := x + y$$

Numerical constants. Input Greek letters

e entered from the keyboard within a mathematical expression denotes the base of the natural logarithm, $e = 2.718$. This value can be discarded and assigned a different value to e using the local assignment sign (:=), for example: $e := 2$.

The infinity sign ∞ can be inserted from the Mathematical *Analysis panel*.

Often used V expressions the number pi Can dial with mathematical

Calculator toolbar, where there is a π button, or press the similar button on the Greek letter bar.

Greek letters	α	β	χ	δ	ε	η	γ	λ	μ	ν	ω	θ	π	ψ	ρ	ζ	η	θ	ξ	ς
Latin analogues	a	b	c	d	e	h	g	l	m	n	w	f	p	y	r	s	t	q	x	z

If any constant or variable does not have any value assigned to it to the left or above its position on the screen, it is colored red, indicating an error.

Discrete variables. Building tables

Expression "discrete variable" - range variable changes :

Instead of a continuous variable, a series of numbers arranged in ascending or descending order is used. A discrete variable specifies a series of values for which is calculated function user. This row values functions Can withdraw in the form of a graph or table.

Definition discrete variable has view $x := 0..5$, What means assigning a series of values $x = 0, 1, 2, 3, 4, 5$.

A discrete variable can specify both integer and fractional values. variable, But Necessarily equidistant Friend from friend, For example:

- $x := 0..5$ – series of integers numbers from 0 to 5;
- $x := 1, 1.1..5$ - row fractional numbers, Where 1 - first number, 1.1 - second number, 5 – the last number. The interval between numbers is $1.1 - 1 = 0.1$;
- $x := \min, \min + \Delta.. \max$ – a series of numbers, where min is the first, Δ is the step (interval), max is the last number (min, Δ and max must be specified in advance). This form of notation is convenient when considering different variants of the same calculation and changing constants allows instantly recount results And rebuild graphics. If the constants included in the right-hand side of the user function are not specified immediately before the function is used, Mathcad takes their values as used V last once before this calculation. Necessary To check these values, type the parameter name and press the (=) key.

1.3 VECTORS AND MATRICES.

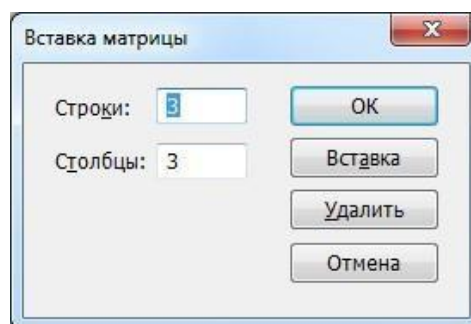
Creation arrays

Eat three method creation array of numbers:

1. Filling template matrices, containing empty places input numbers, What Suitable for entering small arrays (no more than 100 elements).
2. Usage discrete variable. This method fits, When There is explicit formula for calculating array elements.
3. Reading data from files.

Filling matrices according to a template

1. Install cursor V That place, Where necessary create a matrix.
2. Vector and Matrix Toolbar button , and then click the Matrix or Vector button in the toolbar that appears . *Alternatively , you can select Insert → Matrix* from the Mathcad main menu or press [**Ctrl**]+[**m**].
3. IN appeared dialogic window enter number lines (Rows) and the number Columns (Columns), and then click **OK** . A matrix template will appear at the cursor location.



Drawing 1.5 - Dialogue Insert Matrix window

4. Enter a number, letter constant, or function into each entry point. Use the arrow keys to move from one entry point to another. You can also click mouse on necessary place input, But This Not So comfortable, How moving with keys.

Change matrix sizes

Can change size matrices, inserting And deleting lines And columns:

1. Click mouse on extreme element matrices. Blue corner The cursor must be located to the right of the selected element.
2. Select the matrix icon in the math menu or press the key combination [**Ctrl**] + [**m**]. In the window that appears, enter the number of rows and columns, which necessary insert or delete.
3. Click on button *Insert* (*Insert*) or *Delete* (*Delete*), then on **OK** . If necessary insert or delete one line, That necessary enter number of rows – 1, number of columns – 0 and select an item.

To delete all matrix, follows highlight her black color And press Press the [**Delete**] key (to permanently delete the matrix) or select *Cut* from the Mathcad standard toolbar (to cut it to the clipboard). You can also select *Cut* from the context menu that appears when you right-click on the selected matrix.

Built-in ORIGIN variable

The starting point for element numbering in vectors and matrices is determined by the built-in variable **ORIGIN** . By default, **ORIGIN** = 0, meaning the first element of a vector, the first row, and the first column of a matrix have index zero.

To change the index numbering in the first line of a document, type (in capital letters) **ORIGIN** :=1. You can override the built-in **ORIGIN variable** in another way. To do this, select *Tools* → *Worksheet Options* from the main menu, and in the *dialog box* that opens, window go to on tab *Built-in Variables* (*Built-in variables*) And V In the *Array Origin* (*ORIGIN*) field , enter the index of the first element of the array. The **ORIGIN** variable can be assigned different values, including negative ones.

Mathcad has built-in functions whose algorithms include values with a zero index by default, such as **mean** (calculating the mean) or **fft** (Fourier series expansion). If **ORIGIN** :=1 is entered from the keyboard, an error in the calculation is inevitable .

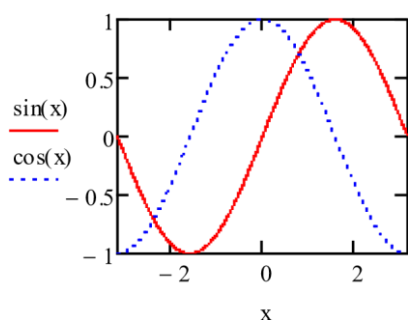
1.4 CONSTRUCTION GRAPHICS FUNCTIONS AND SURFACES

Construction two-dimensional flat graph

For constructions graphics functions necessary:

1. Enter equation of a function
2. Install cruciform cursor there, Where necessary build schedule.
3. On mathematical panels click on *Graph* button *Toolbar* (*Panel graphs*), A on opened panels - on button With image flat graph.
4. IN appeared on place cursor template flat graphics Enter the name of the argument on the x-axis and the name of the function on the y-axis.
5. Click mouse outside template graphics. Schedule built For a given range of argument variation.

If range values argument Not given, By default schedule will be constructed in the range of argument values from -10 to 10.



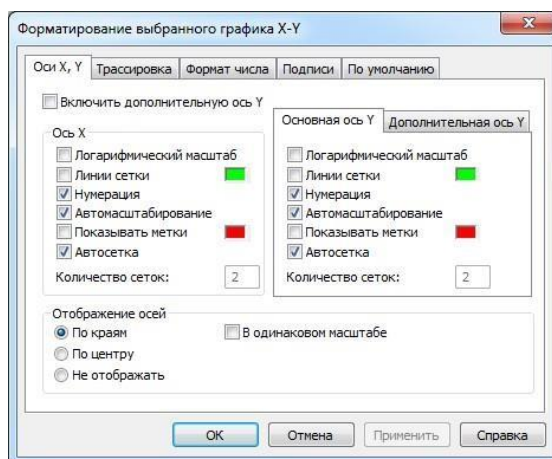
To place multiple graphs in a single template, type the name of the first function on the ordinate axis and press the comma key (the cursor corner must be at the end of the function name). In the input space that appears (the black square), type Name second functions And etc. If two functions have different arguments,

For example, $f_1(x)$ And $f_2(y)$, That on axes ordinate need to enter (separated by commas) names both functions, A on axes abscissa (Also

separated by commas) – the names of both arguments, x and y . Then the first graph will be plotted for the first functions By first argument, A second schedule - For second functions By the second argument. If several functions are entered and there are 2 arguments, then The graph of the first function is constructed using the first argument, and the graphs of the remaining functions are constructed using the second.

Formatting two-dimensional graphs

To format schedule necessary do double click mouse V Chart field – the chart formatting window will open (see Figure 4.4). By selecting various menu items (by clicking on them with the mouse and then on the *Apply* or *OK button*), you can see how the chart's appearance changes.



Drawing 1.6 - Tab Axes X,Y»

IN opened window (cm. drawing 1.6) are located headings five tabs:

1. *XY Axes (XY Axes)* – is used to format the coordinate axes: draw a grid of lines, enter numerical values; draw the abscissa axis through the zero ordinate (*Crossed – Centered*) or along the bottom edge of the graph (*Boxed – Boxed*), and apply marks on the graph. To select the necessary

points necessary click on them mouse (mark their flag).

- *Log Scale (Logarithmic scale)* - introduce numerical values on the axes in a logarithmic scale. By default, numerical values are plotted on a uniform scale;

- *Grid Lines (Lines grids)* - apply grid lines;

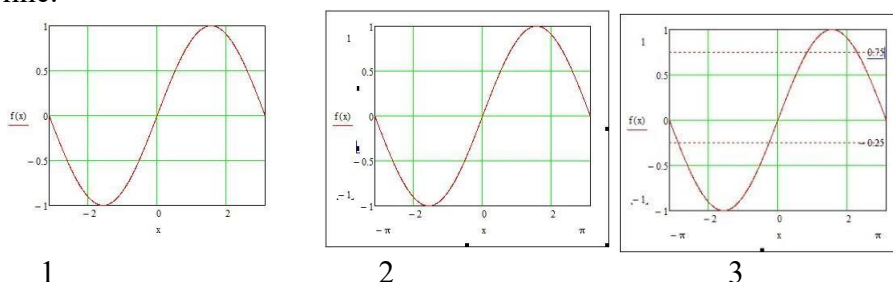
- *Numbered (Numbering)* - apply numerical values For each lines grids;

- *Auto Scale (Autoscaling)* - automatically chooses marginal

Numerical values on the axes that are greater than the maximum calculated values. If this item is not checked, the maximum calculated values will be the limit;

- *Show Markers (Show tags)* - apply tags on graphics. On each two input fields appear on the axis where you can enter numerical values (you can enter nothing or enter a single number or letter designations of constants). On the graph

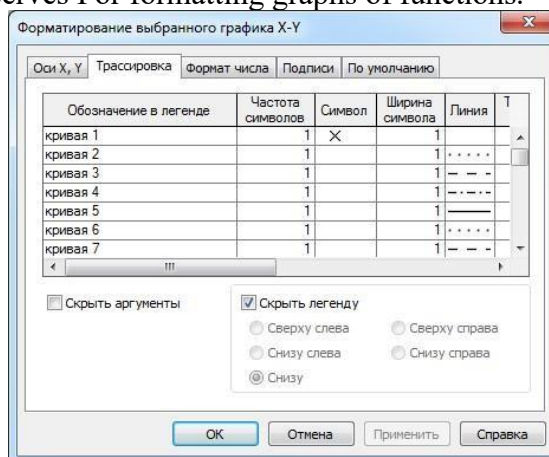
Horizontal or vertical dotted lines will appear corresponding to the specified value on the axis. The number itself appears at the end of this line.



Drawing 1.7 - Addition tags on schedule, Where 1 - original schedule, 2 - adding labels to the Y axis, 3 – data entry and final result

- *Autogrid* – the number of grid lines is selected automatically. If paragraph Not marked, necessary ask quantity lines Number of Grids (Quantity grids). There is opportunity apply numerical values How left, So And on the right from the schedule. If This necessary, follows put flag on point *Enable Secondary Y-axis* (*Turn on additional axis Y*). WITH on the right side of the graph will appear *Placeholder* (*Input location*) where you need to enter the name of the function to be plotted.

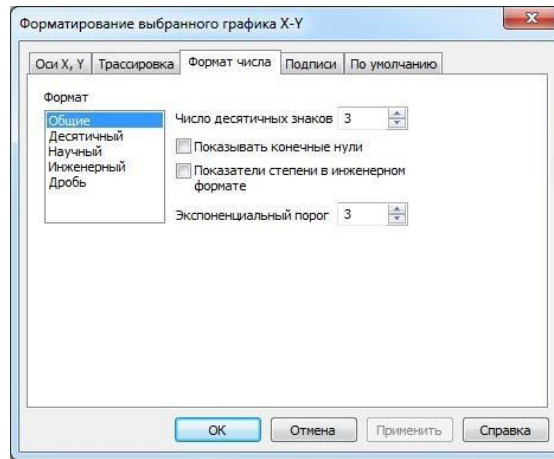
2. *Trace* (*Tracing*) - serves For formatting graphs of functions.



Drawing 1.8 - Tab "Trace" For each graph

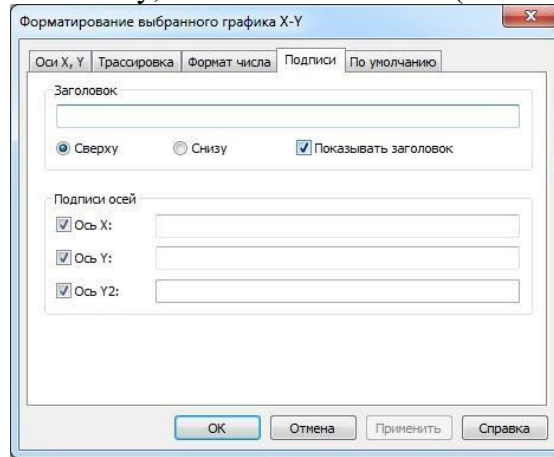
the following are specified separately:

- *Symbol Frequency* (*Frequency characters*) - on graphics Can mark not all calculation points, but every other one, every two, etc.;
 - *Symbol* (*Symbol*) - designation settlement points on graphics (select circle, cross, rectangle, rhombus);
 - *Symbol Weight* (*Width symbol*) - size icon, which the calculation point is designated;
 - *Line* (*Line*) – line type : *Solid* , *Dot* , *Dash* , *Dadot* ;
 - *Line Weight* (*Thickness lines*) - thickness lines;
 - *Color* (*Color*) - color lines;
 - *Ture* (*Type*) - type graphics: *Lines* - *Line* , *Points* - *Points* , *Vag* or *Solid- bar* - *Pillars* , *Step* - *Stepped schedule* And etc.;
 - *Y-Axis* (*Axis Y*) - V this column Mathcad myself puts down *Y* or *Y2* depending on whether the numerical values of the function will be displayed on the left or on the right.
3. *Number Format* (*Format numbers*) – format numbers, indecipherable on schedule.



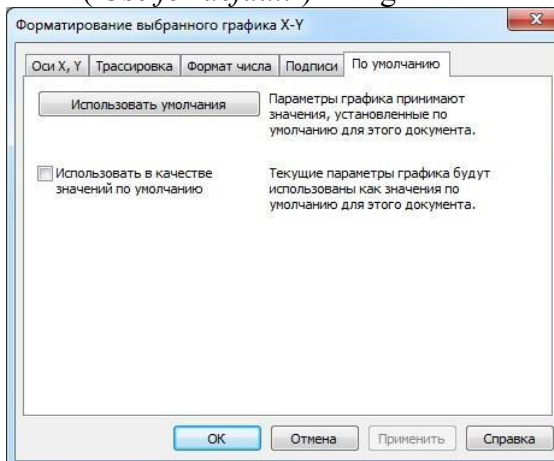
Drawing 1.9 – Tab "Format Numbers"

4. *Labels (Headlines)* - enter V region graphics title. IN window *Title (Heading)* you need to write the heading text, select its position - at the top or at the bottom of the graph. Specify, if necessary, the names of the axes (*Axis Label*).



Drawing 1.10 - Signatures tab

5. *Defaults* – return to the default chart view (*Change to default*), or use By default For everyone graphs This document (*Use for default*) changes made.



Drawing .11 – The Default tab

Scaling graphs

For To change the scale of the graph, it is necessary:

1. Place cursor V field graphics And press right button mice. In the context menu that opens , *select Zoom* .
2. Circle dotted line at pressed left button mice - the area of the graph that needs to be enlarged.
3. IN open window *XY Zoom (Scale By axes XY)* press button *Zoom (Scale)* . Dedicated region will increase to sizes all framework graphics.

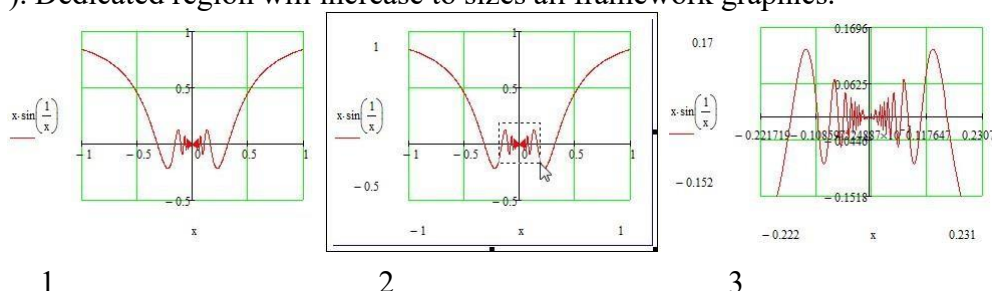


Figure 1.12 – Scaling the graph, where 1 is the original graph, 2 is the selection of the scaling area, 3 is the final result.

To return to the original chart view, click *Unzoom* or *Full View* . To keep the *zoomed* image, click OK.

IN contextual menu, opening at pressing right buttons We-shi, there is a *Trace* option . *Selecting* this option opens the *Trace* window . *XY Trace*. Next need to click left button mice on graphics. On cursor tip will appear crosshairs dotted lines, moving at movement cursor while holding down the left mouse button. Simultaneously, the numbers in the *XY Trace* window indicating the crosshair coordinates change. Once the crosshair is positioned at the desired point on the graph, you can copy its coordinates to the clipboard and then paste them into a document for use. V calculations. If delivered flag *Track Data Points (Follow If you select (data points)* , the crosshair will jump from point to point. If you uncheck this box, the crosshair will move smoothly.

Change sizes and moving graphs

To change dimensions graphics, need to:

1. Click mouse V field graphics.
2. To bring up pointer mice To alone from black squares on edge of the graph.
3. At appearance bidirectional arrows press left button mice and, while holding it, move the edge of the graph to the desired location.

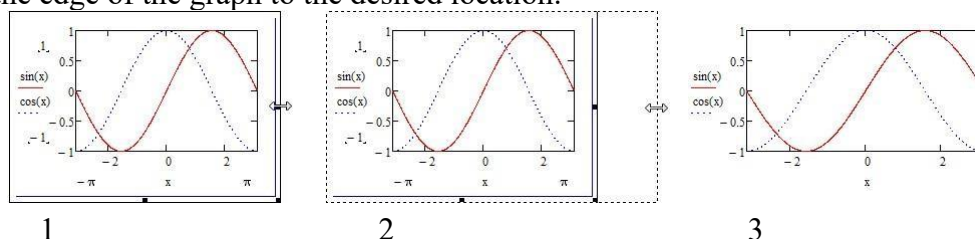
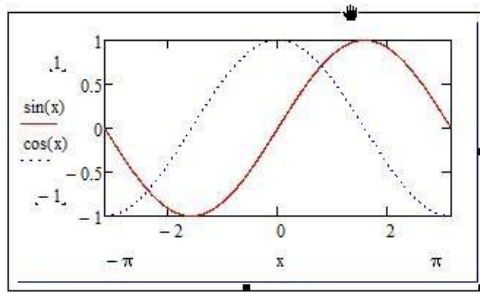


Figure 1.13 – Stages of changing the graph size, where 1 is selecting the graph, 2 is stretching it lengthwise, 3 is the final result.

To move schedule, you need:

1. Click mouse V field graphics;
2. To bring up pointer mice To edge graphics;
3. At appearance black palms press left button mice And, hold-

alive her, move schedule in the right place.



Drawing 1.14 - Moving the graph

If objects (expressions, graphs) overlap each other, the following appears in the context menu: points *Bring to Front* (*Put forward on front plan*) And *Send to Back* (*Put away to the back*). Using these items allows you to save space in your document by deliberately overlaying the edges of objects on top of each other.

To separate overlapping objects, select them by dragging a line through them while holding down the left mouse button. All selected objects will be outlined with a dotted border. From the Mathcad main menu, select *Format* → *Separate Region* . This will separate only the selected regions.

Construction polar graphs

To build schedule functions V polar coordinates necessary:

1. IN panels graphs *Graph Toolbar* click on button, depicting a polar graph.
2. In the input fields, enter the function's angular argument at the bottom and the function name for plotting a regular graph at the left. To plot a parametric graph, enter the function names of the angular argument in both input fields.

Formatting polar graphs similarly formatting plot-skih graphs. Polar graphics, How And flat, Can build V ordinary And in logarithmic coordinates.

To plot a graph in logarithmic coordinates in the formatting window In the graphics, you need to check the box next to *Log Scale* .

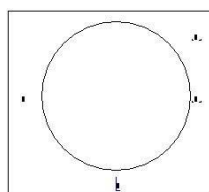
Example :

$f(\alpha) = \cos(2\alpha)$ in polar coordinates with a step of 6 degrees.

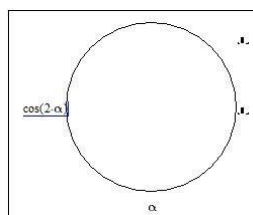
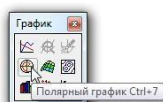
1. Entering a range

$$\alpha := 0, \frac{\pi}{30} .. 2 \cdot \pi$$

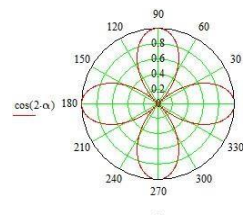
2. Creating a graph of a function



1



2



3

Figure 1.15 – Stages of plotting a graph in polar coordinates, where 1 is selecting a surface graph, 2 is entering a function and an angular argument, 3 is completing the plotting of the graph

Construction three-dimensional graphs

To construct a three-dimensional graph you need:

1. Type the name of the function of two variables, the value assignment sign ($:=$), and the function expression.
2. Install cursor V That place, Where necessary construct a graph.
3. IN mathematical panels click mouse on button *Graph Toolbar* (*Graph panel*) displaying a graph, then on *Surface Plot* . A 3D graph template will appear at the cursor location
4. IN the only one field input template graphics enter function name .
5. Click mouse outside areas template. Schedule built.

Example:

Build schedule functions $f(x, y) = x^2 * y^2$

1. Function input

$$f(x, y) = x^2 * y^2$$

2. Choose button constructions graphics surfaces, then enter function name and click outside the graph template.

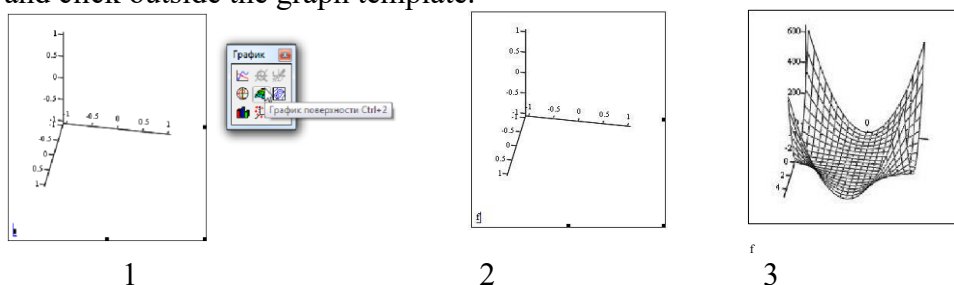


Figure 1.16 – Stages of constructing a surface graph, where 1 – selecting 1 surface graph, 2 – entering the function name, 3 – completing the graph construction

Except described method accelerated constructions graphics superficial-

For functions of two variables, there is another method of creating a graph that is often used surfaces – With using array numerical values functions. To do this, you need:

1. WITH help discrete variables enter values both arguments of the given function.
2. Enter an array whose elements are the values of the function calculated for the given values of the arguments.
3. Repeat p. 3-5 sequences constructions three-dimensional graphics

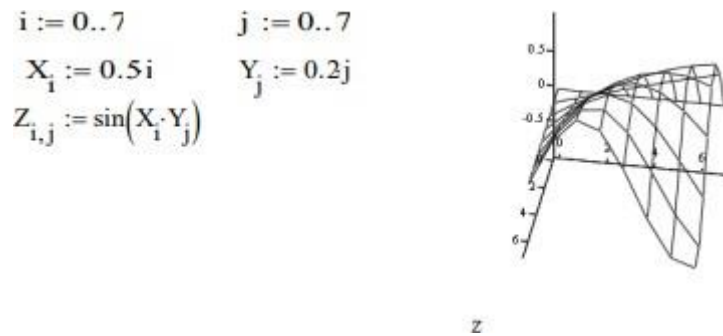


Figure 4.13 – Plotting a surface using an array of numerical values

Formatting three-dimensional graphs

To access the chart formatting window, double-click the chart field. In this window, you can configure:

- By selecting *Appearance* → *Fill surface* → *Colormap* (*Appearance* → *Surface With filling* → *Map flowers*) And clicking mouse on button *Apply* You can make the graph colored.
- To add a lighting effect, you need to select the item in the formatting window *Lighting* → *Enable Lighting* → *On* (*Backlight* → *Necessary backlight* → *Turn on the backlight*). Next need to choose diagram lighting (*Lighting schema*). IN drop-down The menu contains 6 different schemes.

Schedule vector fields

A vector representation of a function is created by constructing short arrows – vectors. The arrow points in the direction of increasing surface height (increasing values) functions). Density shooter depends from speed changes functions, That There is from its gradient. The length of the arrow is proportional to the magnitude of the vector. This type of graph is convenient for calculating various fields: electromagnetic, thermal, gravitational, etc.

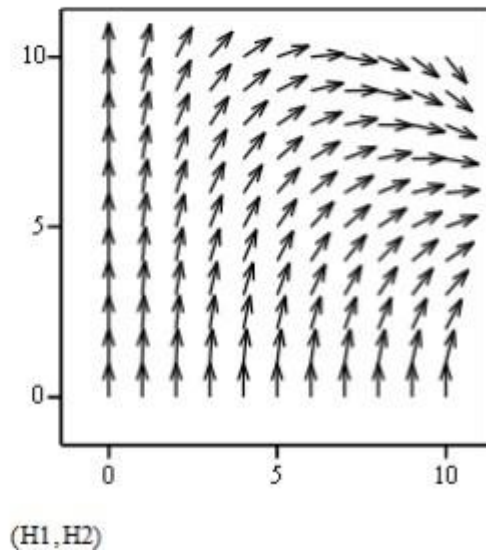
At construction vector fields required ask two-dimensional array

values of the function at given points. Figure 4.22 shows a vector field – a flow functions G , which one X -axis projections and Y is H_1 and H_2 respectively. Sometimes it is convenient to represent a function as a matrix of complex numbers, where one projection of the vector is its real part, and the other projection is its imaginary part.

```

F1(x,y) := sin(x*y)  F2(x,y) := cos(x*y)  n := 10  m := 10
i := 0..n  j := 0..m  x_i :=  $\frac{\pi}{2 \cdot n} \cdot i$   y_j :=  $\frac{\pi}{2 \cdot m} \cdot j$ 
H1_{i,j} := F1(x_i, y_j)  H2_{i,j} := F2(x_i, y_j)  G_{i,j} := H1_{i,j} + i * H2_{i,j}

```



Drawing 1.17 – Construction example vector field graphics

Content practical work, performed students on the first academic question

Tasks for work:

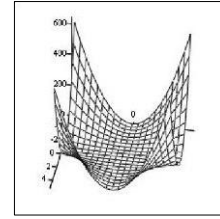
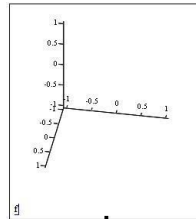
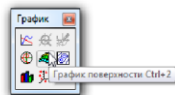
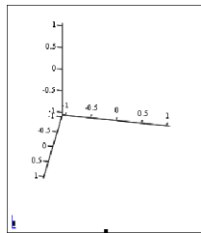
1. Build schedule functions $f(x, y) = x^2 * y^2$

For this execute next actions:

- Enter function:

$$f(x, y) = x^2 * y^2$$

- Choose button constructions graphics surfaces, then enter function name and click outside the graph template.



1

2

3

Drawing 1.16 - Stages constructions graphics surfaces, Where 1 - choice 1 surface graph, 2 – enter the function name, 3 – complete the graph construction

2. Build V polar coordinates With step by step V 6 degrees schedule functions $f(\alpha) = \cos(2\alpha)$

- Enter range:

$$\alpha := 0, \frac{\pi}{30} .. 2 \cdot \pi$$

- Create schedule functions:

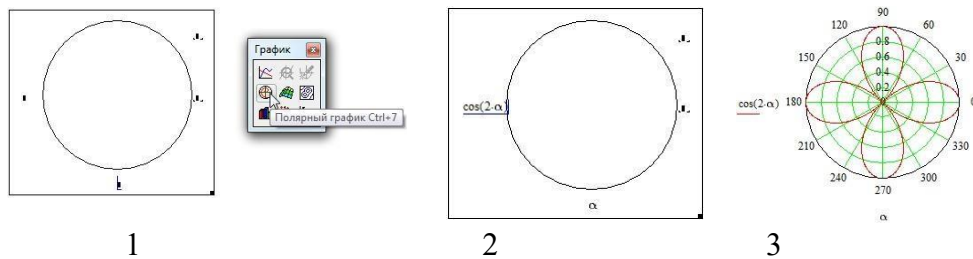


Figure 1.15 – Stages of plotting a graph in polar coordinates, where 1 is selecting a surface graph, 2 is entering a function and an angular argument, 3 is completing the plotting of the graph

3. Build schedule functions $f(X) = \sin(x)$. To do this, follow these steps:
 - Enter function $f(x) := \sin(x)$
 - Choose button constructions flat graphics, then enter axis names and click outside the chart template.

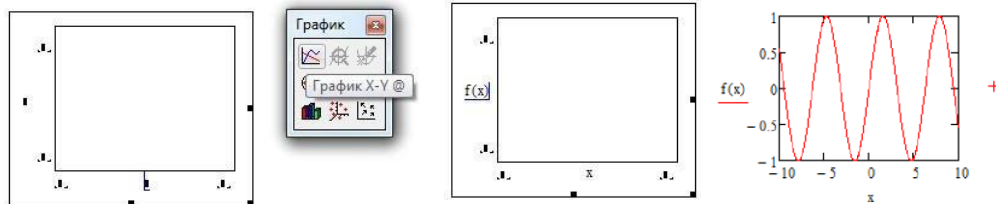


Figure 4.1 - Stages plotting a graph

STUDY CAPABILITIES OF THE ELECTRONICSWORKBENCH PROGRAM FOR SIMULATION AND RESEARCH OF ELECTRICAL CIRCUITS.

Brief theoretical or reference and information materials

1.5 INTERFACE PROGRAMS

After launching the program, a window will appear in front of you, the appearance of which is presented on Fig.2.1. Let's consider V first queue external interface programs Electronics Workbench».

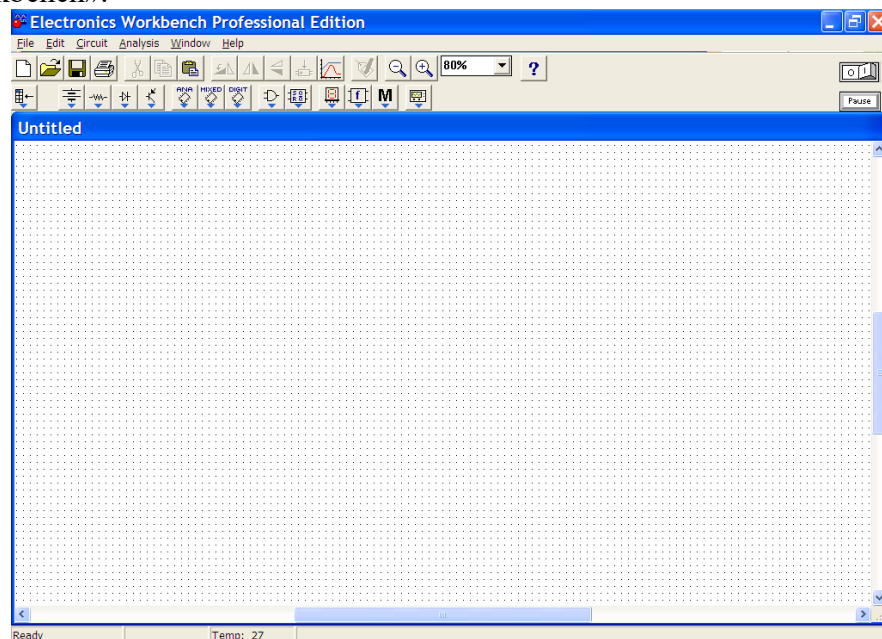


Figure 2.1 – **Electronics** Workbench program window

The first thing you will see when you launch the program is the “editing table” where the video is assembled. model under study schemes. IN itself at the bottom of the window located line states, on which are indicated parameters modeling And readiness programs To performing actions. At launch simulations schemes there will show off imitation time (This is the time the simulated process will take when the real device is running). Simulation time depends on the complexity of the circuit and the number of elements in it.

The program's toolbars and menus are located at the top. The toolbars contain component libraries and buttons that provide access to the necessary actions for assembling circuits and managing the program.

The program interface is designed in such a way that the user works with the program primarily using toolbars, so we will begin our acquaintance with the program with them.

Let's consider briefly appointment buttons panels tools. (New) –



create a new file.



(Open) - open existing file. (Save) – save



the file.



(Print) - print file.



(Display graphs) - outputs on screen window displays results

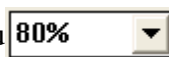
modeling. IN this window Can look testimony everyone devices connected to the diagram, And graphics, received V result analysis schemes (For example, analysis Fourier, transient process graph, voltage at circuit nodes, voltage oscillograms, etc.), voltage at circuit nodes, etc.



(Zoom out) and



(Zoom in), as well as the menu



(Scale factor) –

allows you to select the scale of the created (viewed) diagram.



(Help) – viewing help (if a certain component of the diagram is selected, then help will be displayed specifically for this component).



(Paste) - insert from the clipboard .



(Activate simulation) – button launch circuit simulations .



(Pause simulation) - button temporal stops simulations. Pressing this button

again resumes the simulation from where it stopped.

The buttons below become active only when a specific component (or group of components) of the circuit is selected :



(Cut) – cut to clipboard. (Copy) - copy V



buffer exchange.



(Rotate) - rotate dedicated component.



(Flip horizontal) -reflect dedicated component By Flip vertical – flips the



selected component vertically.



(Create subcircuit) - create subcircuit (this button allows unite selected

components into one block, which is very convenient in some cases).



(Component properties) – parameters component.

It is also worth talking about the contents of the various program menus, since some actions can only be performed using them (Fourier analysis, setting up simulation options, copying a circuit as a drawing, etc.).

Menu **"File"** contains the following points:

- New (create new document): creates new document.
- Open (open document): With help this point Can open existing schematic files.
- Save (save document): this paragraph menu allows save document in the format of program versions 5.0c or 5.1.
- Save as (save document How): allows save document under another name or change the file version.
- Revert to saved: Allows you to undo all changes made to the diagram up until the last save.
- Import (import file): imports file from format SPICE [*.CIR]
- Export (export file): exports file V format SPICE [*.CIR] And EWB Layout [*.PCL]
- Print (seal document): allows print diagram.
- Print setup (parameters seals): installation printing options .
- Exit (exit): exit from programs.
- Install (install): allows install update for the program.

I will not explain the purpose of the last three points, because their purpose is already clear and it is unlikely that they will be used.

- Export to PCB (export V PCB)
- Import from SPICE (import) from SPICE)
- Export to SPICE (export in SPICE) Menu

Edit contains such points How:

- Cut (cut): deletes dedicated component (or group components) V clipboard .
- Copy (copy): copies dedicated component (or group components) to the clipboard.
- Paste (insert): inserts component (or group components) from buffers exchange into the scheme.
- Delete (delete): deletes dedicated component (group components).
- Select all (highlight All): highlight All elements on the diagram.
- Copy as bitmap: This command copies a portion of the circuit as a BMP image to the clipboard.
- Show clipboard (view contents buffers exchange): opens Clipboard folder. Clipboard contents can be saved not only to the clipboard page, but also as a separate clipboard file.

"Circuit" menu allows you to perform operations on components and adjust the circuit's display settings. The menu contains the following sections:

- Rotate: turn allocated component (or groups components) 90⁰ counterclockwise.
- Flip horizontal (reflect By horizontals): mirrored displays selected element of the diagram horizontally.
- Flip vertical: Flips the selected diagram element vertically.
- Component properties (properties component): opens window properties selected component.

- Create subcircuit : Creates a subcircuit from the selected components (combines them into a block).

- Zoom in (increase scale): increase scale of the diagram.

- Zoom out (decrease scale): decrease scale schemes.

- Schematic options (Properties diagrams): outputs window properties schemes,

Where You can set options for displaying the grid, tracing wires, etc.

Analysis menu allows you to perform various types of circuit analysis and change settings. simulations (For example, install time modeling And etc.), V him includes the following items:

- Activate (activate): launches simulation schemes.

- Pause (pause): suspends simulation schemes.

- Stop (stop): stop circuit simulations .

- Analysis options (settings analysis): installation parameters conducting analysis.

- DC operating point (direct voltage at nodes): determines the voltage at the nodes of the circuit.

- AC frequency (frequency analysis): calculates transmission characteristics (amplitude-frequency response).

- Transient (transition process): shows schedule transition process.

- Fourier (Fourier): shows frequency spectrum V certain node of the circuit.

- Monte Carlo (Monte Carlo): analysis Monte Carlo.

- Display graphs (conclusion windows constructions graphs): outputs on screen the window for displaying the analysis results, which was mentioned above.

"Window" menu allows you to manage the program windows and consists of several items, which are listed below:

- Arrange (placement): builds windows on screen (If You displaced or pushed back window, That this team returns his V initial position);

- Circuit (scheme): show mounting table (diagram);

- Description (Description): opens window descriptions schemes. Window descriptions created along with the schema, but is not displayed on the screen by default;

Purpose points menu **Help** consider, Maybe, Not costs, - there And Everything is clear without explanation.

We reviewed buttons panels tools, But to these pores Not touched component libraries. The next section of the book is dedicated to this.

1.6 COMPONENT LIBRARIES

On panels tools are located Also buttons libraries components, which we will consider separately:



(Favorites) – the most frequently used components. This library contains components you'll likely use frequently. How to add a component to the "Favorites" library is discussed below.



(Sources) - sources. IN this library You you will find sources permanent and alternating current (voltage), frequency-modulated and amplitude-modulated voltage sources, pulse sources, controlled current and voltage sources (for example, a voltage-controlled current source), as well as “ground”, programmable sources (linearly varying voltage and nonlinear), etc.

The description of the components included in the "Sources" library is discussed separately in the "Current and Voltage Sources" section of the book.



(Basic) - main elements. Here are located passive radioelements: fixed and variable resistors, capacitors, inductors ;

transformers, etc. This library has one very useful component  (connector) – a mounting point that allows you to connect several conductors at one point, which is very convenient in complex circuits.

 (Diodes) – semiconductor diodes and diode-type devices. Here you can find, For example, rectifier diode (Diode), zener diode (Zener diode), light-emitting diode (LED), dinistor (Shockley diode), thyristor (Silicon-controlled rectifier), diode bridge (Full-wave bridge rectifier) and etc. Unfortunately, the program does not include varicaps and tunnel diodes. 

(Transistors) - transistors. From the name of the library, it is clear that it contains various types transistors - bipolar, field with built-in channel, MDP And others.

 (Analog ICs) – analog integrated circuits. They contain operational amplifiers (of various types and with different numbers of pins), a comparator, a phase-locked loop (PLL), and so on.

 (Mixed ICs) – integrated circuits of mixed types. The library contains digital-to-analog and analog-to-digital integrated circuits, such as ADCs, DACs, 555 timers, and others.

 (Digital ICs) - digital integral microcircuits. Name this The library says that it contains various digital microcircuits (note that these are existing microcircuits).

 (Logic gates) – logical elements. This library contains logical gates, such as OR, NOT, AND, NAND gates, and so on.

 (Digital) - digital devices. Here are located basic devices digital technology - triggers, counters, encoders, decoders, multiplexers And etc. IN Unlike "Digital ICs", these are not microcircuits, but simply blocks.

 (Indicators) – indicator devices – incandescent lamps, seven-segment indicators, logic probe, etc. There are also some measuring devices such as a voltmeter and ammeter, the use of which is described in the section “Working with devices”

 (Controls) - functional blocks And basic elements radio automation (multiplier, adder, integrator, differentiator, etc.).

Description components incoming V compound libraries Controls separately discussed in the section of the book "Functional Blocks"

 (Miscellaneous) – other. The program's creators apparently included in this library what didn't fit in the others.

Here are located quartz resonators, engine permanent current, vacuum tubes, fuses and other useful components.

 (Instruments) – instruments, devices. These contain devices for monitoring processes in a circuit or generating necessary signals (oscilloscope, multimeter, etc.). Working with these components is covered in the corresponding section of this book, where they are described in detail.

Well A Now, after familiarization With panels tools programs and their purpose, you can begin to create the diagram itself.

1.7 METHOD ASSEMBLY CIRCUIT

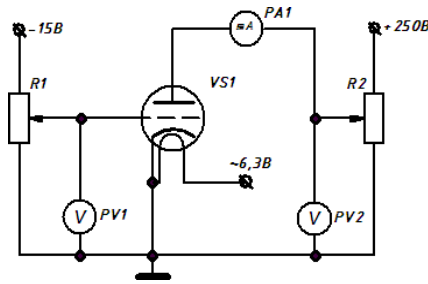


Рисунок 2.2 – Схема,

используемая для снятия статических характеристик компонента триода.

Now that we've gotten a handle on the program's toolbars and menus, we can begin assembling and simulating circuits. Let's try to move forward step by step. Let's look at the methodology for creating a simulated circuit in the Electronics program. Workbench on specific example, for which we will select a circuit for removing the current-voltage characteristics of a vacuum triode (Fig. 3.1).

For creation models schemes us



– electronic vacuum lamp (from libraries "Miscellaneous").



– variables resistors (from libraries "Basic").



– Earth (from libraries "Sources").



– sources permanent current (from libraries "Sources").



– voltmeter (from "Indicators" library).

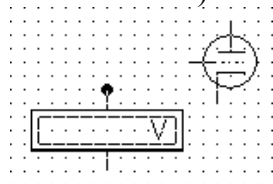


– ammeter (from libraries "Indicators").

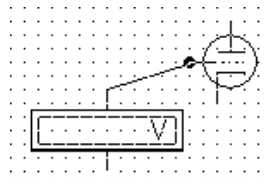
In order to install a component on the assembly table, you need to select the required component library by left-clicking on it, then click on the required one component, A then, Not letting go buttons mice, drag and drop his Place the image on the timeline and release the mouse button. You can move the component on the timeline using the mouse or keyboard, placing it as you like (or as needed).

Components on the timeline can be rotated 90° (counterclockwise), flipped horizontally or vertically using the buttons  (Rotate),  (Flip horizontal) and  (Flip vertical) respectively, or using hot keys (see Appendix).

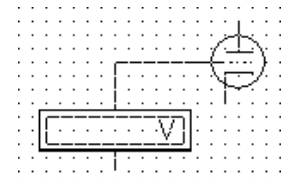
When connecting components, move the mouse pointer over a component's pin. When you move the mouse pointer over a pin, a dot appears on it (Fig. 2.3, a). At this point, press the left mouse button and, without releasing it, drag the resulting wire to the pin of the other component. A dot will also appear on the pin of this component (Fig. 3.2, b), after which the mouse button can be released, and the element terminals will be connected by a conductor, as shown in Fig. 3.2, c (I recommend looking at the description of the “Routing options” item in the fifth section of the book).



A)



b)



With)

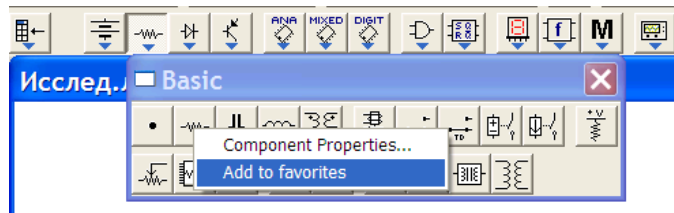
Drawing 2.3 - Compound components between by yourself.

For connections conclusion component With conductor need to to do those same The same actions as when connecting components (when you move the mouse pointer over a conductor and a dot or bend appears on it, you can release the mouse button). If you need to connect several conductors at one point (up to four conductors), you can use

for this, use the mounting point ("connector") from the "Basic" library (we already talked about the mounting point when we looked at the purpose of the toolbar buttons).

When assembling a circuit, it is convenient to use a coordinate grid (see Fig. 2.3). What to display her on screen necessary install pointer mice to free from components field and press right button mice. IN appeared contextual menu should choose paragraph Schematic options». After this V opened window on tab Grid install check the box next to "Show Grid".

The most frequently used elements (or more precisely, components) of the circuits you create can be added to the "Favorites" library. To add a component to the "Favorites" library, open the library containing the desired element and right-click on it (Fig. 2.4). In the context menu that appears, select "Add to favorites» And selected you component Now it will turn out V library "Favorites".



Drawing 2.4 - Addition element V library Favorites

The component won't disappear from its library. If you now save the file as a template that loads by default (default.ewb file), then the next time you launch it programs All components, which You added V library "Favorites", will always be available (otherwise, the next time you launch the program, they will no longer be there).

Content practical work, performed students on the first academic question

1. Task for work:

- 1) Collect simple diagram.

Extract the required components from the libraries and place them on the pasteboard. And connect between by yourself So, How shown on rice. 2.5. Some uncomfortable That, What The diagrams use a foreign standard for designating elements that differs from the standard adopted in our country for electrical circuits, but this is not significant.

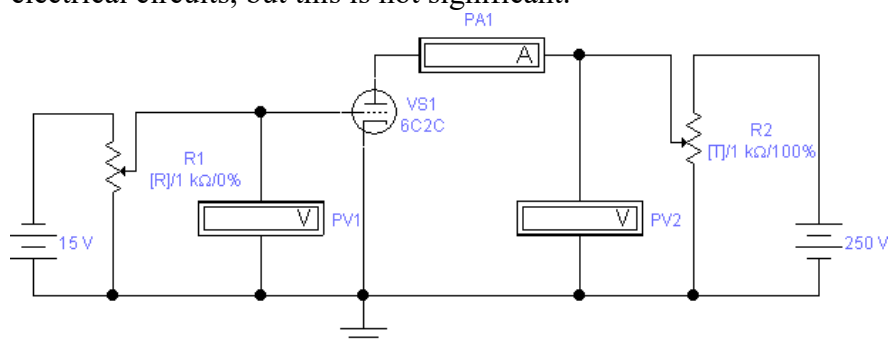


Figure 2.5 – Circuit assembled in Electronics Workbench Required follows

connect To scheme "land" (Ground) from libraries "Sources") before running a circuit simulation. The program refuses to run a simulation (except for circuits with logic elements) if it doesn't have a ground, even when it's not needed.

5. Compose report O done work By first question V in accordance with the requirements set out in the job description .

IN In the report, please provide:

- initial data,

- performed tasks,
 - compiled listings modeling programs ,
 - results of modeling and research – calculated formulas,
- obtained graphs;
- conclusions O done work.

6. Defense of practical work

To defend your lab assignment, submit a fully completed report free of significant errors. As instructed by your instructor, complete the assignment. alone from tasks each educational question, having explained at this All physical phenomena and processes occurring in a simulated physical field.

Practical lesson No. 2
Study operations over vector characteristics physical fields

STUDY QUESTIONS:

1. Study of algebraic, exponential and trigonometric representation of vectors .
2. Research operations additions And multiplication vectors.
3. Research operations integration And differentiation of vector characteristics.

Results training, achievable V result execution laboratory work:

Be able to:

- apply the basic laws and mathematical apparatus of electrodynamics to computer modeling and analysis of electromagnetic fields and waves in various media and guiding systems.

Own:

- skills in determining the characteristics of electromagnetic fields required for solving practical problems for calculating radio coverage, radio relay and satellite routes.

TRAINING AND MATERIAL SUPPORT:

- A personal computer with an electronic circuit simulator “Electronics Workbench” and a computer mathematics system “Mathcad”;
- electronic methodological development By laboratory work.

QUESTIONS, SUBJECTS RESEARCH

1. SCALAR AND VECTOR DESCRIPTION FIELDS

Brief theoretical or reference and information VECTOR MULTIPLICATION materials

From course vector algebra it is known, What exists *three species products of vectors* :

- scalar work, result whom is a scalar quantity,
- vector work, result whom is a new vector,
- a mixed product of vectors that results in a scalar value.

All these results of vector multiplication have different physical meanings, therefore, in the theory of EMF, the application of these operations in practice is appropriate for determining various characteristics of the field.

With the help of vectors in the EMF theory, the force characteristics of the field are displayed, such as the forces $\mathbf{F}$ of Coulomb, Lorentz, Ampere, electric $\mathbf{E}$ and magnetic $\mathbf{H}$ intensity, electric $\mathbf{D}$ and magnetic $\mathbf{B}$ induction, as well as the radius vector $\mathbf{r}$, displacement vector $\mathbf{s}$ or vectors of infinitely small radius and displacement $d\mathbf{r}$ and $d\mathbf{s}$.

Let's consider typical situations (cm. rice. 1) applications various species multiplication vectors at decision various physical tasks theories EMP.

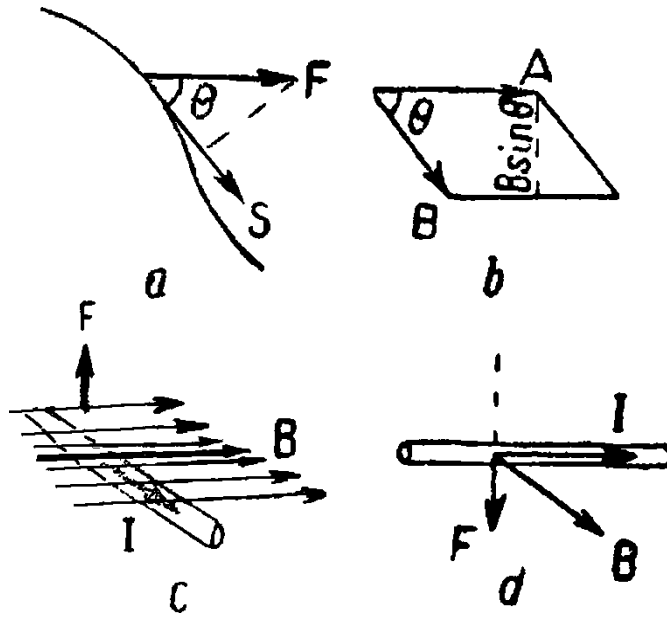


Fig. 3 – Typical situations of application of different types of vector multiplication

Situation 1, given on rice. 1 a), demonstrates happening, When V result actions forces fields $\mathbf{F}$ on some body is happening his movement on distance $\mathbf{s}$. From the course of mechanics it is known that *the product of force and the distance of movement has a physical meaning work A* , committed by force fields. Mathematically This is determined scalar work vectors $\mathbf{F}$ And $\mathbf{s}$ With taking into account angle θ between them directions, those.

$$A = \mathbf{F} \cdot \vec{s} = (\mathbf{F}, \mathbf{s}) = F \cdot s \cdot \cos(\theta) = F_s \cdot s. \quad (1)$$

In this case, as follows from expression (1), the work done by the field force is determined by the scalar product of the force vector and the displacement vector, which geometrically corresponds to multiplying the modulus of the displacement vector s by the projection F_s force vectors $\mathbf{F}$ to the vector $\mathbf{s}$.

Cases when a vector product is used to solve a physical problem vectors, demonstrated on rice. 1 b), 1 c), 1 d). So on rice. 1 b) it is shown that What vector work has geometric meaning, concluded V volume, What

module received vectors $\mathbf{N}$ equal area parallelogram, educated original vectors $\mathbf{A}$ And $\mathbf{B}$, those.

$$\mathbf{C} = \mathbf{A} \times \mathbf{B} = [\mathbf{AB}] = A \cdot B \cdot \sin(\theta). \quad (2)$$

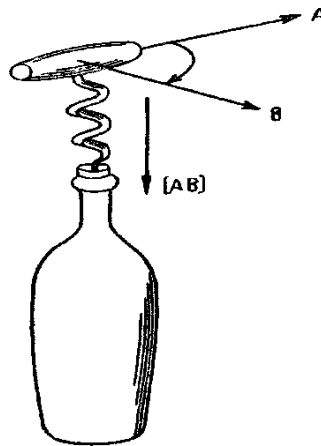
Vector multiplication, for example, *is used* to determine the Ampere force acting on a current-carrying conductor in a magnetic field. If the magnetic field (see Fig. 1 c) is determined in magnitude and direction by the vector $\mathbf{B}$, and the current (which is assumed constant), vector $\mathbf{I}$, That strength, current on conductor long 1 m, will be characterized by a vector $\mathbf{F}$, which is perpendicular to both vector $\mathbf{B}$ and vector $\mathbf{I}$. The magnitude of vector $\mathbf{F}$ is found from the expression

$$\mathbf{F} = I \cdot B \cdot \sin(\theta). \quad (3)$$

IN expression (3) result multiplication represents by yourself vector. However With At first glance, it is unclear why the area in Fig. 1 b) is a vector quantity. It is only clear that the surface must be oriented in space. Therefore, it was agreed to represent the area as a vector whose direction is normal to the surface, A length proportional size area. Like this in this way, square on Fig. 1 c) is depicted by a vector perpendicular to the plane of the drawing.

Naturally arises question O sign resulting vectors, What V equation (3) shows which way the force is directed – up or down? In order to eliminate ambiguity in the mathematical formulation of the problem, it was agreed that in a vector product, the sign of the resulting vector is determined by the order in which the vectors included in the product are written. This method is quite convenient and definite. For establishments directions vector works. However, express in words corresponding ratios some difficult. Usually rule The sign is remembered by placing the fingers of the right hand in a certain way, or by using the rotation of the so-called right-hand screw.

Thus, the product of two vectors $[\mathbf{AB}]$ itself represents a vector of magnitude $AB \sin (\theta)$, having a direction normal to the plane in which both vector $\mathbf{A}$ and vector $\mathbf{B}$ lie, and the sign of the direction is such that if you turn the right screw (drill), as shown in Fig. 2 from $\mathbf{A}$ to $\mathbf{B}$ (by an angle less than 180°), then it will screw in in the direction determined by the direction of the product vector.



Rice. 2 - Rule legal gimlet (screws)

In accordance with this rule, equation (3) gives the direction of the force. Moreover, the vector $[\mathbf{AB}]$, characterizing the area shown in Fig. 1 b), is directed downwards relative to the plane of the parallelogram, while the product $[\mathbf{BA}]$ corresponds to the vector directed upwards relative to the plane of the parallelogram. This represents by yourself only illustration general rules, according to to whom $[\mathbf{VA}] = -[\mathbf{AB}]$. This means that the vector multiplication operation under consideration does not obey the fundamental commutativity law of ordinary algebra, which says that $ab = ba$.

In order to introduce an expression that uniquely and strictly defines the vector product, we use the unit vector $\mathbf{n}$, which is a vector of unit length that is normal to the plane in which the vectors $\mathbf{A}$ and $\mathbf{B}$ are located, and has such direction, What forms right-handed system With these vectors. Thus, the vector product is defined by the expression

$$\mathbf{C} = [\mathbf{AB}] = \mathbf{n} \cdot AB \cdot \sin (\theta), \quad (4)$$

where A and B are scalar values of vectors $\mathbf{A}$ and $\mathbf{B}$, θ - the angle between the vectors, i.e. the result of the vector product is the product of a scalar equal to the area of the parallelogram and a unit vector, which serves to indicate the direction of the normal to the plane of vectors $\mathbf{A}$ and $\mathbf{B}$, and, therefore, precisely determines the direction of the vector product.

So far, vectors in this lecture have been considered abstractly, without reference to spatial coordinates. It is known that the position of any point in space can be determined using Cartesian coordinates based on well-known methods of analytic geometry. Moreover, the length and direction of any vector are expressed using projections vectors on three axes coordinates. Then any vector $\mathbf{A}$ Maybe be

described How having three mutually perpendicular scalar components (projections):

A_x By direction $\mathbf{x}$, *And* A_y By direction $\mathbf{y}$ And A_z By direction $\mathbf{z}$.

For giving this scalar projections direction is introduced system from three orthonormal vectors or unit vectors $\mathbf{i}$, $\mathbf{j}$, $\mathbf{k}$, i.e. vectors of unit length directed along the axis of the Cartesian coordinate system, and therefore orthogonal (perpendicular) to each other.

Content practical work, performed students

1. Description laboratory equipment:

- PC With established system computer algebra Mathcad-14".

2. Initial data for modeling and research Options tasks For research given V table 1. Table 1 – Initial data for tasks 1 – xxx.

Option number	Re(A)	Im(A)	Re(B)	Im(B)	Option number
1	5	4	3	1	8
2	6	-5	-4	-3	9
3	-4	-2	1	4	10
4	3	-1	9	7	11
5	-2	8	-8	1	12
6	-8	5	-5	4	13
7	9	-3	1	-3	14

3. Exercise for work

1. Study algebraic, exponential And trigonometric representation of vectors.
2. Study operations additions And multiplication vectors.
3. Study operations integration And differentiation vector characteristics.

4. Order execution work

Exercise 1. Modeling And study algebraic, exponential and trigonometric representation of vectors.

Mathcad system.

1.1. Algebraic performance complex numbers V system "Mathcad".

1) Enter V working window programs original data:

- complex number A V algebraic form. IN quality first addend enter $\text{Re}(A)$ according to the option, as the second $\text{Im}(A)$ respectively–

$$A := -3 + 5i;$$

- vector representing the real component of the complex number A –

$$A_x := \begin{pmatrix} 0 \\ \text{Re}(A) \end{pmatrix};$$

- vector performances imaginary component complex numbers A –

$$A_y := \begin{pmatrix} 0 \\ \text{Im}(A) \end{pmatrix};$$

2) Build schedule vector performances numbers A V complex plane.:

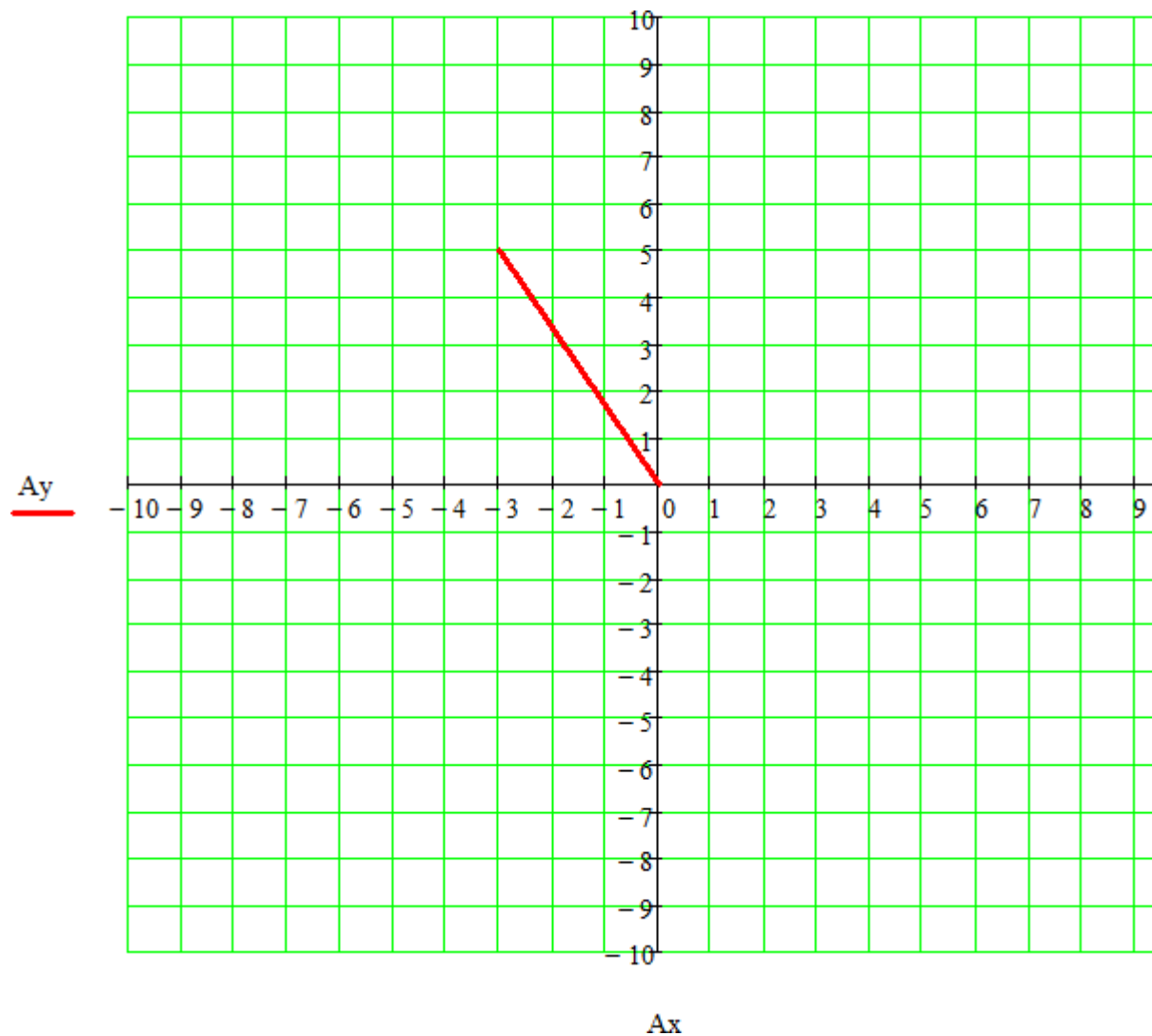


Fig. 1.xx -

- 3) Change signs real And imaginary components complex numbers A on opposite.
Record the changed schedule.
- 4) Do conclusions By results conducted research.

1.2 Exponential And trigonometric performance complex number in the Mathcad system.

- 1) Enter V working window programs original data:

- imaginary unit $j = \sqrt{-1}$;
- module complex numbers A - $A_m := |A|$;
- Argument complex number A - $\varphi_a := \arg(A)$;

- Argument complex numbers A V degrees – $\varphi_{ag} := \arg(A) \cdot \frac{180}{\pi}$;

- 2) Enter formula For performances complex numbers V exponential and trigonometric form:

- Performances complex numbers A V exponential form –

$$A2 := A_m \cdot \exp(j \cdot \varphi_a) = ;$$

- Representations of a complex number A in trigonometric form are $A3 := A_m \cdot \cos(\varphi_a) + j \cdot A_m \cdot \sin(\varphi_a) = ;$

- 3) Compare received results .
- 4) Do conclusions By results conducted research.

Exercise 2. Research operations additions And multiplication vectors in the Mathcad system.

2.1. Addition vectors in the Mathcad system .

1) Enter V working window programs original data:

- complex number **IN** V algebraic form. IN quality first addend enter **Re(B)** according to the option, as the second **Im(B)** respectively–

$$B := 5 - 5i;$$

2) Enter formulas For calculation:

- vector representing the real component of the complex number **B** –

$$B_x := \begin{pmatrix} 0 \\ \text{Re}(B) \end{pmatrix};$$

- vector performances imaginary component of the complex numbers **IN** - :

$$B_y := \begin{pmatrix} 0 \\ \text{Im}(B) \end{pmatrix}$$

3) Enter formulas For calculation amounts complex numbers:

- **WITH** , equal sum of complex numbers **A** And **IN** - **C := A + B =;**

- vector representing the real component of the complex number **C** –

$$C_x := \begin{pmatrix} 0 \\ \text{Re}(C) \end{pmatrix};$$

- vector performances imaginary component complex numbers **C** –

$$C_y := \begin{pmatrix} 0 \\ \text{Im}(C) \end{pmatrix};$$

4) Plot the graph of the sum of vectors **A** and **B** in complex planes. An example is shown in Fig. 1.xx.

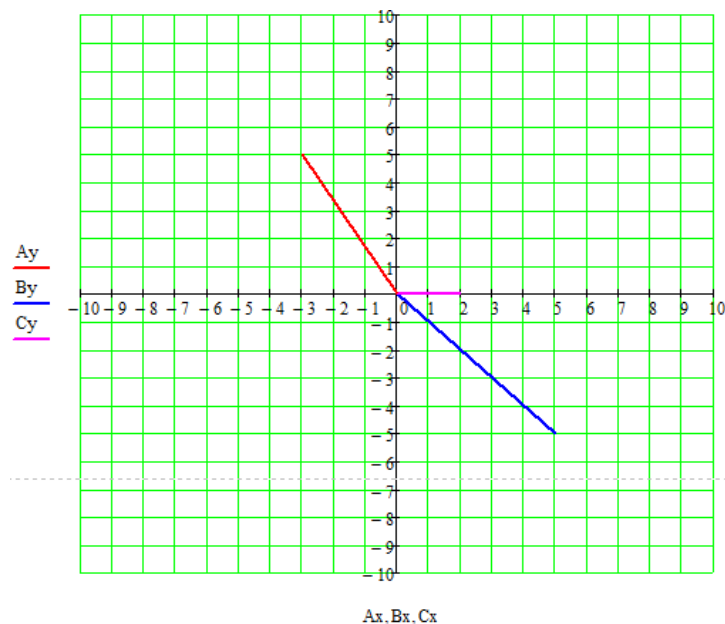


Fig. 1.xx -

2.1. Scalar work vectors V the Mathcad system .

- 1) Enter V working window programs initial data:
 - module complex number **IN** - $B_m := |B|$.
 - Argument complex numbers **IN** - $\varphi_b := \arg(B)$;
 - Argument comprehensive numbers **B** in degrees – $\varphi_{bg} := \arg(B) \cdot \frac{180}{\pi}$;
 - corner between vectors **AND** and **IN** – $\theta := \varphi_{ag} - \varphi_{bg}$.
- 2) Enter formulas For calculation scalar works vectors:
 - cosine angle between vectors, expressed V degrees -

$$\cos\left(\theta \cdot \frac{\pi}{180}\right) = -0.97$$

- Work vectors presented How work modules on cosine angle

$$SP := A_m \cdot B_m \cdot \cos\left(\theta \cdot \frac{\pi}{180}\right) =$$

between them – ;

- Work vectors presented How sum works real And imaginary components of vectors **A** and **B** – $SP2 := \operatorname{Re}(A) \cdot \operatorname{Re}(B) + \operatorname{Im}(A) \cdot \operatorname{Im}(B) =$;

2.2. Vector product of vectors in the Mathcad system.

- 1) Enter formulas For calculation:

- vector performances complex numbers **A** V three-dimensional system coordinates–

$$AA := \begin{pmatrix} \operatorname{Re}(A) \\ \operatorname{Im}(A) \\ 0 \end{pmatrix} ;$$

- vector performances complex numbers **IN** V three-dimensional system coordinates -

$$BB := \begin{pmatrix} \operatorname{Re}(B) \\ \operatorname{Im}(B) \\ 0 \end{pmatrix} ;$$

$$AA \times BB = \begin{pmatrix} 0 \\ 0 \\ -10 \end{pmatrix} ;$$

- vector work vectors V three-dimensional planes–
- Vector work presented How work modules on sinus angle

$$VP := A_m \cdot B_m \cdot \sin\left(\theta \cdot \frac{\pi}{180}\right) ;$$

between them -

- Vector work presented How difference works real and imaginary components of vectors **A** and **B** –

$$VP2 := \operatorname{Re}(A) \cdot \operatorname{Im}(B) - \operatorname{Re}(B) \cdot \operatorname{Im}(A) = -10 ;$$

- 2) Do conclusions By conducted research

Task 3. Study of integration and differentiation operations of vector characteristics.

3.1. Study operations differentiation V system "Mathcad".

1) Enter formulas For:

– Function $F(x)$ –

$$F(x) := \sin(x) ;$$

– The variable q , which Mathcad will use as an initial guess when searching for the root–
 $q := 3$

– Enter the root function from the keyboard, which will find the value of q at which the function $F(q)$ is equal to zero. As arguments to the root function, we write the function $F(q)$ and the variable q , which Mathcad will use as initial approximation at search root. At this For given

approximations located only one root– $\text{root}(F(q), q) = 3.142 ;$

$$z(x) := \frac{d}{dx} F(x) \rightarrow \cos(x)$$

– derivative functions $F(x)$ –

– Variable s , which Mathcad will use How initial approximation

at search root– $s := 3$

– Function root For derivative functions $F(x)$

$$\text{root}(z(s), s) = -14.137$$

$$g(x) := \frac{d^2}{dx^2} F(x) \rightarrow -\sin(x)$$

– derivative functions $F(x)$, erected V square–

– Function root For square derivative functions $F(x)$

$$\text{root}(g(q), q) = 3.142$$

2) Build on one graphics:

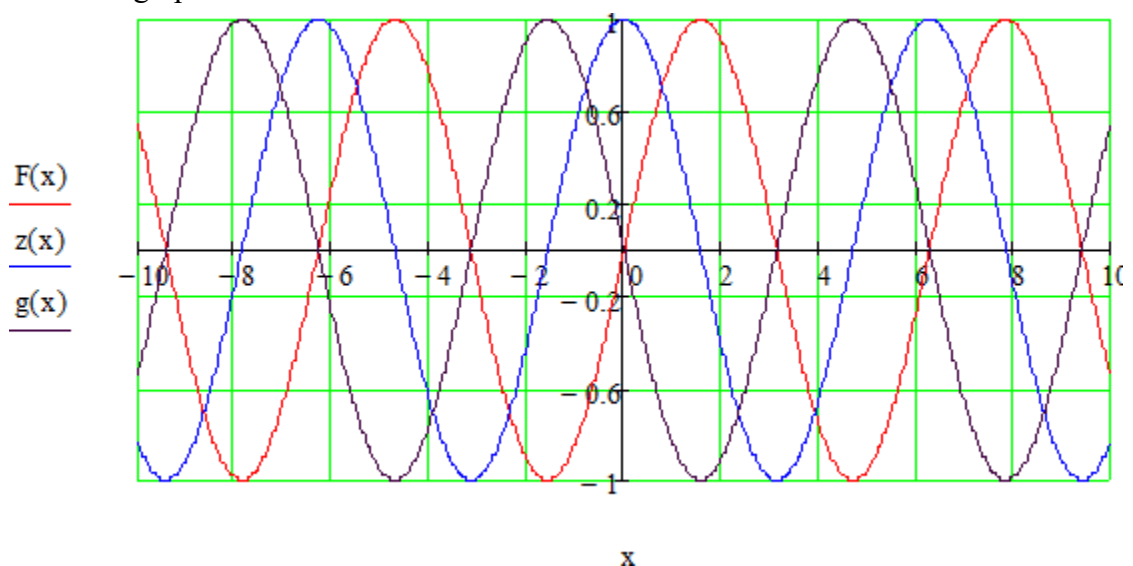


Fig. 1.xx -

3) Build schedule V polar system coordinates:

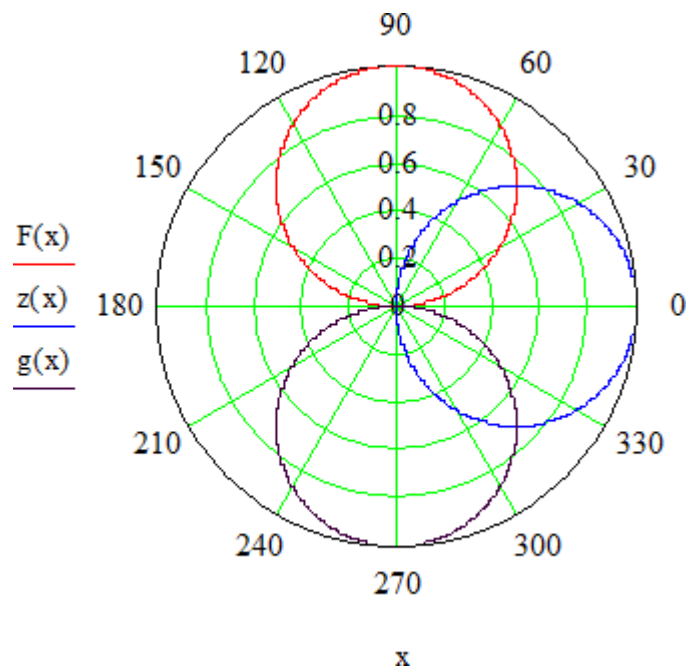


Fig. 1.xx -

4) Do conclusions By conducted research

3.2. *Study operations integration V system "Mathcad".*

1) Enter formulas For:

– Integral from functions F(x) -

$$Z(x) := \int F(x) dx \rightarrow -\cos(x) ;$$

– Integral from already integrated functions–

$$\underline{\underline{G(x)}} := \int Z(x) dx \rightarrow -\sin(x)$$

– Double integral from functions F(x) -

$$\underline{\underline{V(x)}} := \int \int F(x) dx dx \rightarrow -\sin(x) ;$$

2) Build on one graphics:

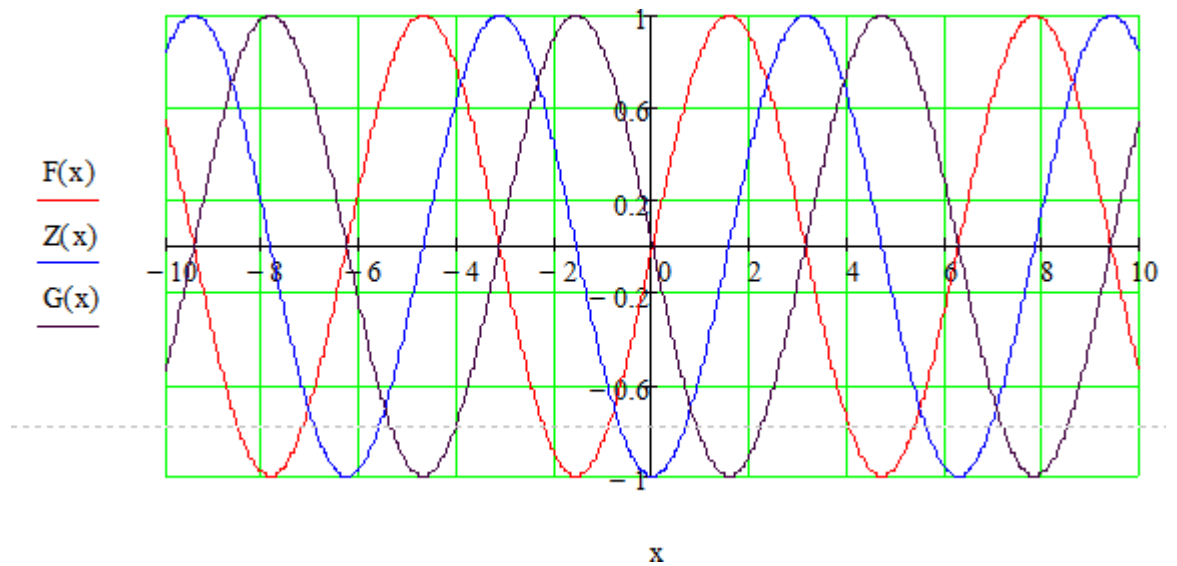


Fig. 1.xx -

3) Build schedule V polar system coordinates:

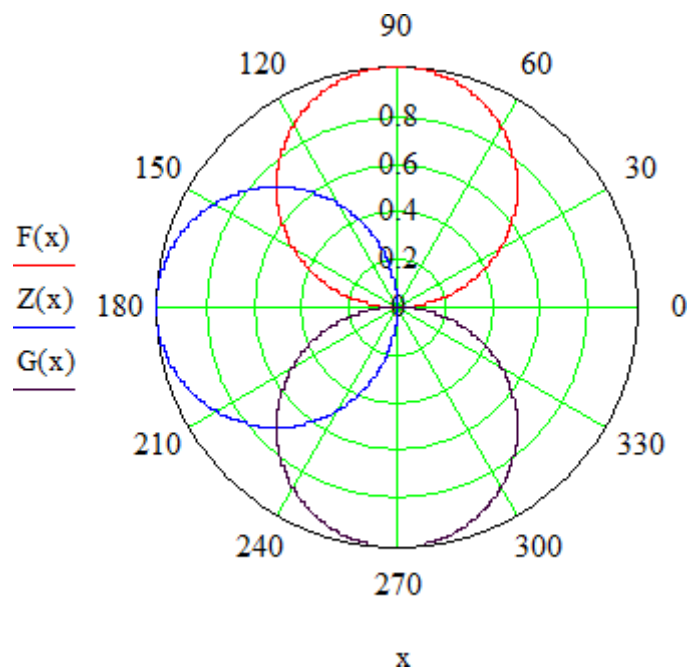


Fig. 1.xx -

4) Do conclusions By conducted research

Defense of practical work

To defend your lab assignment, submit a fully completed report free of significant errors. As instructed by your instructor, complete the assignment. alone from tasks each educational question, having explained at this All physical phenomena and processes occurring in the developed model.

Practical lesson No. 3

Modeling and study of boundary conditions at the interface between media for electric and magnetic field vectors

STUDY QUESTIONS:

1. Modeling and investigation of boundary conditions on the surface section two Wednesday For vectors electric fields V system

TARGET SETTING OF PRACTICAL WORK :

Results training, achievable V result execution laboratory work:

Be able to:

– apply the basic laws and mathematical apparatus of electrodynamics to computer modeling and analysis of electromagnetic fields and waves in various media and guiding systems.

Own:

– skills in determining the characteristics of electromagnetic fields required for solving practical problems for calculating radio coverage, radio relay and satellite routes.

TRAINING AND MATERIAL SUPPORT:

- A personal computer with an electronic circuit simulator “Electronics Workbench” and a computer mathematics system “Mathcad”;
- electronic methodological development By laboratory work.

QUESTIONS, SUBJECTS RESEARCH

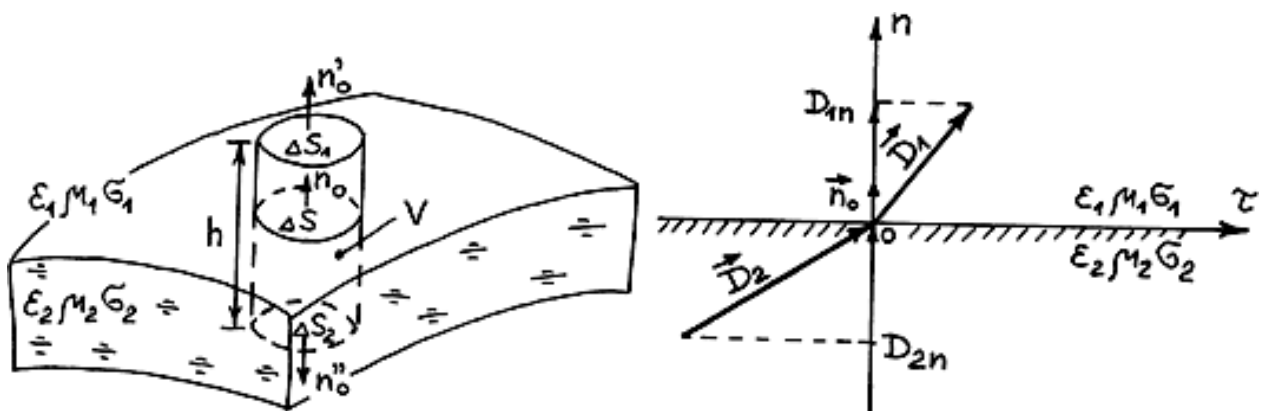
1. SCALAR AND VECTOR DESCRIPTION FIELDS

Brief theoretical or reference and information materials

Let's consider a flat one the interface between two environments with parameters ε_{a1} , μ_{a1} , σ_1

And ε_{a2} ,

μ_{a2} , σ_2 . On the interface between the media, we select a sufficiently small element ΔS , within which V both environments normal components vectors $\mathbf{D}$ evenly distributed. On basis ΔS let's build cylinder With height h So, to his grounds were located V different environments, as shown in Fig. 1.



Rice. 1 - Explanation to the conclusion of the boundary conditions For normal components electric field

We use **Maxwell's 3rd equation in integral form**, according to which the flow vectors electrical induction through any closed surface S equal the sum of charges in the volume V bounded by this surface, i.e.:

$$\oint_S \mathbf{D} d\mathbf{S} = \int_V \rho dV,$$

Where: $d\mathbf{S} = \Delta S \mathbf{n}_0$ - unit vector, normal To small site ΔS ; $\mathbf{n}_0$ - normal To ΔS , ρ - volumetric density electric charge.

Let us split the integral over a closed surface S , which bounds the volume V , into three integrals:

$$\oint_S \mathbf{D} d\mathbf{S} = \int_{\Delta S_1} \mathbf{D}_1 d\mathbf{S} + \int_{\Delta S_2} \mathbf{D}_2 d\mathbf{S} + \int_{S_{\text{бок}}} \mathbf{D}_{\text{бок}} d\mathbf{S} = \int_V \rho dV.$$

Let us tend the height of the cylinder h to zero, then: the bases of the cylinder tend to the area of the circle at the interface between the two media, and the area of the lateral surface of the imaginary cylinder to zero, i.e.

$$\Delta S_1 \text{ And } \Delta S_2 \rightarrow \Delta S; \quad S_{\text{side}} = h \cdot \Delta S \rightarrow 0; \quad \int_{S_{\text{side}}} \mathbf{D}_{\text{side}} d\mathbf{S}_{\text{side}} \rightarrow 0;$$

Then integral By volume V will pursuit To integral By elementary area:

$$\int_V \rho dV = \int_{\Delta S} \rho_S dS,$$

Where: ρ_S - superficial density charge on border section avg.

$$\text{Considering this is what we get:} \quad \int_{\Delta S_1} \mathbf{D}_1 d\mathbf{S} + \int_{\Delta S_2} \mathbf{D}_2 d\mathbf{S} = \int_{\Delta S} \rho_S dS.$$

Let's define Now normal $\rightarrow$ nye components $\rightarrow$ vectors $\mathbf{D}$. From rice. 1 obviously, What:

$$\int_{\Delta S_1} \mathbf{D}_1 \cdot \mathbf{n}'_0 dS + \int_{\Delta S_2} \mathbf{D}_2 \cdot (-\mathbf{n}'_0) dS = \int_{\Delta S} \rho_S dS.$$

Finally, counting site ΔS so small, What on this area vector $\mathbf{D}$ practically Not changes, we get:

$$\mathbf{D}_1 \cdot \mathbf{n}_0 \Delta S - \mathbf{D}_2 \cdot \mathbf{n}_0 \Delta S = \rho_S \Delta S.$$

Finally: $(\mathbf{D}_1 - \mathbf{D}_2) \cdot \mathbf{n}_0 = \rho_S$, or

$$\mathbf{D}_{1n} - \mathbf{D}_{2n} = \rho_S. \quad (1)$$

So, we conclude: **the normal component of the electric induction vector, when passing through the boundary surface, undergoes a jump numerically equal to the surface density of the electric charge.**

Because from material equations $\mathbf{D} = \epsilon_a \mathbf{E}$ That, hence, **border conditions For normal component vectors tension electric fields** will be have view:

$$\epsilon_{a1} \mathbf{E}_{1n} - \epsilon_{a2} \mathbf{E}_{2n} = \rho_S. \quad (2)$$

If the boundary surface is not charged, then **the normal component $\mathbf{D}_n$ of the electric vector induction** on basis (1) **continuous at transition from Wednesday 1 V Wednesday 2**, and **the normal component $\mathbf{E}_n$ of the electric field strength vector suffers a discontinuity**, magnitude whom is determined ratio dielectric permeabilities among:

$$\frac{\boldsymbol{E}_1}{2\boldsymbol{n}} = \frac{\varepsilon\boldsymbol{a}^2}{\varepsilon\boldsymbol{a}^1} \quad (\text{at } \rho_s = 0).$$

Let us now consider the boundary conditions for the normal components of the magnetic field . To do this, by analogy, we enclose both media in a cylinder of volume V and use **Maxwell's fourth equation in integral form** , according to which **the flux of the magnetic induction vector B through any closed surface S is equal to zero :**

$$\oint_S \mathbf{B} d\mathbf{S} = 0.$$

Let's break it down closed integral By surfaces on three integral:

$$\int_{\Delta S_1} \mathbf{B}_1 d\mathbf{S} + \int_{\Delta S_2} \mathbf{B}_2 d\mathbf{S} + \int_{S_{\text{side}}} \mathbf{B}_{\text{side}} d\mathbf{S} = 0.$$

Let's rush height of the cylinder $h \rightarrow 0$ Then:

$$\int_{\Delta S_1} \mathbf{B}_1 d\mathbf{S} + \int_{\Delta S_2} \mathbf{B}_2 d\mathbf{S} = 0.$$

Finally, considering constancy $\mathbf{B}$ on site $\Delta \mathbf{S}$ because of little things the last one, we will receive For normal components:

$$(\mathbf{B}_1 - \mathbf{B}_2) \vec{n}_0 = 0,$$

or

$$\mathbf{B}_{1n} - \mathbf{B}_{2n} = 0. \quad (3)$$

V result we do conclusion O volume, what's

normal component magnetic vector induction at transition through border section two Wednesday remains continuous.

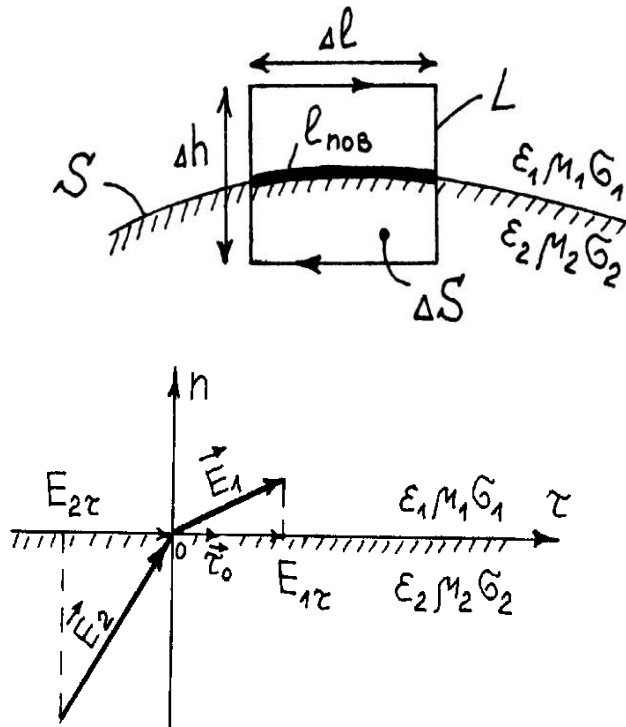
Because from material equations $\mathbf{B} = \mu_a \mathbf{H}$ then, border conditions For normal components vectors tension magnetic fields have view:

$$\mu_{a1} \mathbf{H}_{1n} = \mu_{a2} \mathbf{H}_{2n}. \quad (4)$$

Thus, **the normal component of the vector $\mathbf{H}$ at the boundary of the media suffers a discontinuity** , the magnitude of which is equal to the ratio of the absolute magnetic permeabilities of the media .

$$\frac{\mathbf{H}_1}{n} = \frac{\mu_{a2}}{\mu_{a1}} \mathbf{H}_2.$$

Let us consider a flat interface between two media with parameters $\epsilon_{a1}, \mu_{a1}, \sigma_1$ And $\epsilon_{a2}, \mu_{a2}, \sigma_2$. We will cover both media with an elementary contour L , the plane of which is perpendicular to the interface between the two media (see Fig. 2).



Rice. 2 – Explanation To derivation of boundary conditions For tangents components electric field

We use *the 2nd Maxwell equation in integral form*, according to which *the circulation of the electric field strength vector E (i.e. EMF) along any closed circuit L is equal to the rate of change of the magnetic flux penetrating this circuit with the opposite sign*:

$$\oint_L \vec{E} d\vec{\ell} = - \int_S \frac{d\vec{B}}{dt} \cdot d\vec{S}.$$

Let's break it down circuit L on four plot, two from which are determined vector elementary lengths $d\vec{\ell}$, A two others - vector elementary heights $d\vec{h}$, then the integral over a closed curve can be broken down into four linear integrals:

$$\oint_L \vec{E} d\vec{\ell} = \int_{\Delta\ell} \vec{E}_1 d\vec{\ell} + \int_{\Delta h} \vec{E}_{12} d\vec{h} + \int_{\Delta\ell} \vec{E}_2 d\vec{\ell} + \int_{\Delta h} \vec{E}_{21} d\vec{h} = - \int_{\Delta S} \frac{d\vec{B}}{dt} \cdot d\vec{S}.$$

Let us tend the contour height Δh to zero, then the elementary area bounded by the contour, $\Delta S = \Delta l \cdot \Delta h$ V limit will strives To zero, A sides AB And CD merge on the border, and in this case we get:

$$\int_{\Delta\ell} \vec{E}_1 d\vec{\ell} + \int_{\Delta\ell} \vec{E}_2 d\vec{\ell} = 0.$$

Let's determine the tangential components of the tension vector electric fields:

$$\int_{\Delta\ell} \vec{E}_1 \cdot \vec{\tau}_0 d\ell + \int_{\Delta\ell} \vec{E}_2 \cdot (-\vec{\tau}) d\ell = 0,$$

where $\vec{\tau}$ - unit tangent vector.

$\vec{\tau}$ from

Finally, assuming that the segment Δl is so small that the vector $\vec{E}$ on this the area does not change, we get:

$$\vec{E}_1 \tau_0 \Delta \ell - \vec{E}_2 \tau_0 \Delta \ell = 0.$$

Finally: $(\vec{E}_1 - \vec{E}_2) \tau_0 = 0$, or

$$E_{1\tau} = E_{2\tau}. \quad (5)$$

Thus, **the tangential component of the electric field strength vector is continuous at the interface between the media.**

Using material equation $\vec{D} = \epsilon_a \vec{E}$ we define:

$$\frac{D_1}{\epsilon_a} = \frac{D_2}{\epsilon_a}. \quad (6)$$

As a result, we conclude that **the tangential components of the vector $\vec{D}$ undergo a discontinuity**, the magnitude of which is determined by the ratio of the dielectric constants of both media.

$$\frac{D_1}{\tau D} = \frac{\epsilon_a 1}{\epsilon_a 2}.$$

Let us consider the boundary conditions for the tangential components of the magnetic field strength vector $\vec{H}$. By analogy with the previous case, we will cover the border section Wednesday contour L And we use **1st equation Maxwell**. According to whom **circulation vectors tension magnetic fields N By to anyone closed circuit L is equal to the sum of the conduction current and the displacement current flowing through the surface bounded by this circuit**:

$$\oint_L \vec{H} d\ell = \int_S \vec{J}_{pr} dS + \frac{d}{dt} \int_S \vec{D} dS.$$

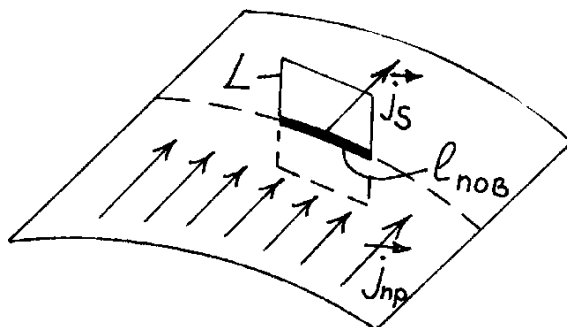
Breaking down integral on closed contour L on 4th integral:

$$\int_{\Delta \ell} H_1 d\ell + \int_{\Delta h} H_{12} dh + \int_{\Delta \ell} H_2 d\ell + \int_{\Delta h} H_{21} dh = \int_S \vec{J}_{pr} dS + \frac{d}{dt} \int_{\Delta} \vec{D} dS.$$

Let us tend the contour height Δh to zero, then the elementary area bounded by the contour, $\Delta S = \Delta \ell \cdot \Delta h$ in the limit will tend to zero, and the integrals:

$$\int_{\Delta S} \frac{dD}{dt} dS \rightarrow 0, \quad \int_{\Delta h} H_{12} \Delta h \rightarrow 0, \quad \int_{\Delta h} H_{21} \Delta h \rightarrow 0, \quad \int_{\Delta S} \vec{J}_{pr} dS \rightarrow \int_{\ell_{pov}} \vec{J}_s d\ell_{pov},$$

Where: $\vec{J}_s$ - vector density superficial current conductivity, intersecting segment lines ℓ_{pov} (cm. rice. 3.).



Rice. 3- Concept vectors density superficial current conductivity Therefore, we obtain:

$$\int_{\Delta \ell} \mathbf{H}_1 d\ell - \int_{\Delta \ell} \mathbf{H}_2 d\ell = \int_{\ell_{pov}} \mathbf{J}_S d\ell_{pov}.$$

Finally, considering constancy $\mathbf{H}$ on site $\Delta \mathbf{S}$, we will receive For tangents components:

$$\begin{aligned} \vec{H}_1 \tau_o - \vec{H}_2 \tau_o &= \mathbf{J}_S, \\ \text{или:} \quad H_{1\tau} - H_{2\tau} &= J_S. \end{aligned} \quad (7)$$

Thus, we conclude that *the tangential component of the magnetic field strength vector at the interface between the media undergoes a jump*, numerically equal superficial density current conductivity, flowing By interface between media.

Using material equation $\mathbf{B} = \mu_a \mathbf{H}$, let's define *border conditions For tangents components vectors magnetic induction*:

$$\frac{B_1}{\mu_{a1}} - \frac{B_2}{\mu_{a2}} = J_S. \quad (8)$$

If By border surfaces current Not is leaking, those. $\mathbf{J}_S = 0$, That *tangent component H_τ vectors tension magnetic fields* on basis (7) *is continuous during the transition from environment 1 to environment 2*, and *the normal component B_τ the magnetic induction vector suffers a discontinuity*, the magnitude of which is determined by the ratio of the magnetic permeabilities of the media:

$$\frac{B_1}{B_2} = \frac{\mu_a}{\mu_{a1}} \quad (\text{at } J_S = 0).$$

2

Content practical work, performed students

1. Description laboratory equipment:

– PC With established system computer algebra "Mathcad- 14".

2. Initial data for modeling and research Options tasks For

research given V table 1. Table 1.1 – Initial data for task 1

O ption number	ε_1	ε_2	Angl e θ , Degrees	surface charge σ , pC	electric field strength E1, B
1	8	4	60	- 5.6	1.25
2	6	3	55	- 4.3	1.1
3	2	1	50	- 2.1	1.05
4	7	5	45	4.5	1.5
5	5	3	60	1.2	1.11
6	4	11	55	-3.4	1.01
7	9	3	50	7.6	1.2
8	3	7	45	-2.1	1.3

9	5	5	60	-4.5	1.25
10	1	9	55	2.6	1.1
11	4	2	50	9.1	1.05
12	5	3	45	2.5	1.5
13	6	1	60	-4.1	1.11
14	3	7	55	2.3	1.015
15	9	2	50	1.5	1.2

3. Exercise for work

4. Order execution work

Task 1. Modeling and study of boundary conditions on the interface of two media for electric field vectors in the Mathcad system.

1.1. Modeling border conditions vectors tension electric fields

5) Enter V working window programs original data:

– dielectric permeability first And second dielectric ϵ_1, ϵ_2 ;

$$\epsilon_0 := \frac{1}{36 \cdot \pi} \cdot 10^{-9} = 8.842 \times 10^{-12} ;$$

– electric constant –

– absolute dielectric permeability first And second dielectric ϵ_1, ϵ_2 –

$$\epsilon_{1a} := \epsilon_0 \cdot \epsilon_1 ; \epsilon_{2a} := \epsilon_0 \cdot \epsilon_2 ;$$

– tension electric fields E1;

– surface charge σ , pC

– corner falls θ (deg) according to the option;

6) Enter formulas For calculation:

– tangential component vectors tension E1–

$$E_{1\tau} := \begin{pmatrix} 0 \\ E_1 \cdot \sin(\theta) \end{pmatrix} ;$$

– normal component of the vector of tension E1 –

$$E_{1n} := \begin{pmatrix} 0 \\ E_1 \cdot \cos(\theta) \end{pmatrix} = \begin{pmatrix} 0 \\ 5 \times 10^6 \end{pmatrix} ;$$

From theoretical course it is known, What $E_{1\tau} = E_{2\tau}$, But, So How We we accept 0 beyond the boundary between the two environments, then

$$E_{2\tau} := -E_{1\tau}$$

– numerical meaning normal component vectors tension E2–

$$E_{1n} := \frac{\epsilon_{1a} \cdot E_1 \cdot \cos(\theta) + \sigma}{\epsilon_{2a}} = 8.473 \times 10^6 ;$$

$$E_{2n} := \begin{pmatrix} 0 \\ -E_{1n} \end{pmatrix} ;$$

– normal component vectors tension E2–

– tangent angle refractions–

$$\text{tg}\theta_2 := \frac{(E1 \cdot \sin(\theta))}{E1n} ;$$

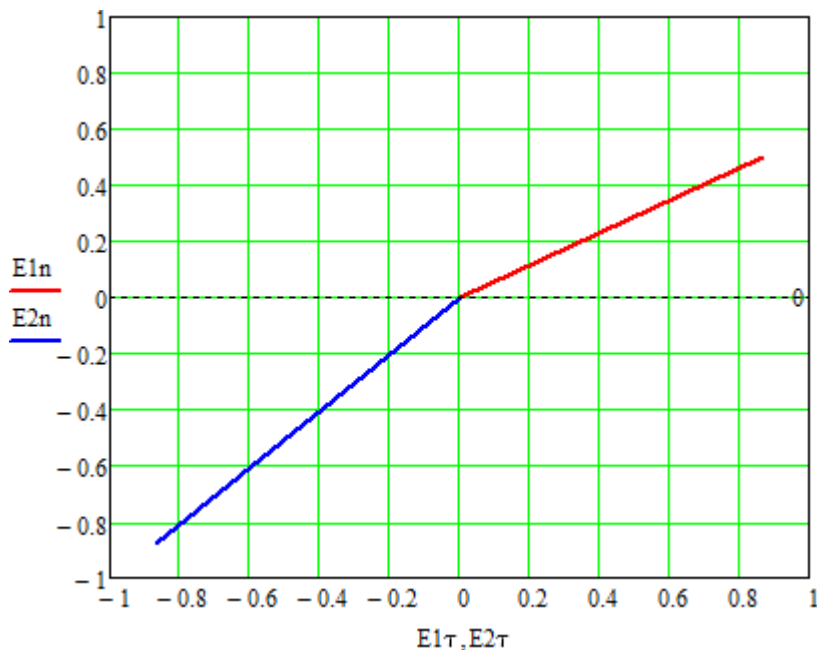
– corner refraction θ radians And degrees –

$$\theta_{2\text{rad}} := \text{atan}(\text{tg}\theta_2) , \quad \theta_2 := \theta_{2\text{rad}} \cdot \frac{180}{\pi} ;$$

– module vectors tension in second Wednesday –

$$E2 := \sqrt{E1n^2 + (E1 \cdot \sin(\theta))^2} = 1.234 ;$$

7) Plot a graph of the field strength vector $E1$ when moving from a medium with a dielectric permeability ϵ_1 V Wednesday With dielectric permeability ϵ_2 , accepting 0 for border section two avg. On drawing For demarcations two environments set the mark on the Y axis with the value 0.



Rice. 1.1 - vector tension $E1$ at transition from Wednesday With permittivity ϵ_1 into a medium with permittivity ϵ_2

1.2 Modeling border conditions vectors displacements electric fields.

1) Enter formulas For calculation:

– numerical meaning normal component vectors displacements $D1$ –

$$D1n := \epsilon_1 \cdot E1 \cdot \cos(\theta) ;$$

– numerical meaning normal component vectors displacements $D2$ after passing the boundary between two media

$$D2n := \sigma + D1n ;$$

– normal component vectors displacements $D1$ –

$$D1n := \begin{pmatrix} 0 \\ D1n \end{pmatrix} ;$$

– normal component vectors displacements $D2$ –

$$D2n := \begin{pmatrix} 0 \\ -D2n \end{pmatrix} ;$$

– numerical meaning tangential component vectors displacements D1–
 $D1_{\tau} := \epsilon_1 a E_1 \cdot \sin(\theta);$

– numerical meaning tangential component vectors displacements D2–
 $D2_{\tau} := E_1 \cdot \sin(\theta) \cdot \epsilon_2 a;$

– tangential component vectors displacements D1–

$$D1_{\tau} := \begin{pmatrix} 0 \\ D1_{\tau} \end{pmatrix};$$

– tangential component vectors displacements D2–

$$D2_{\tau} := \begin{pmatrix} 0 \\ -D2_{\tau} \end{pmatrix};$$

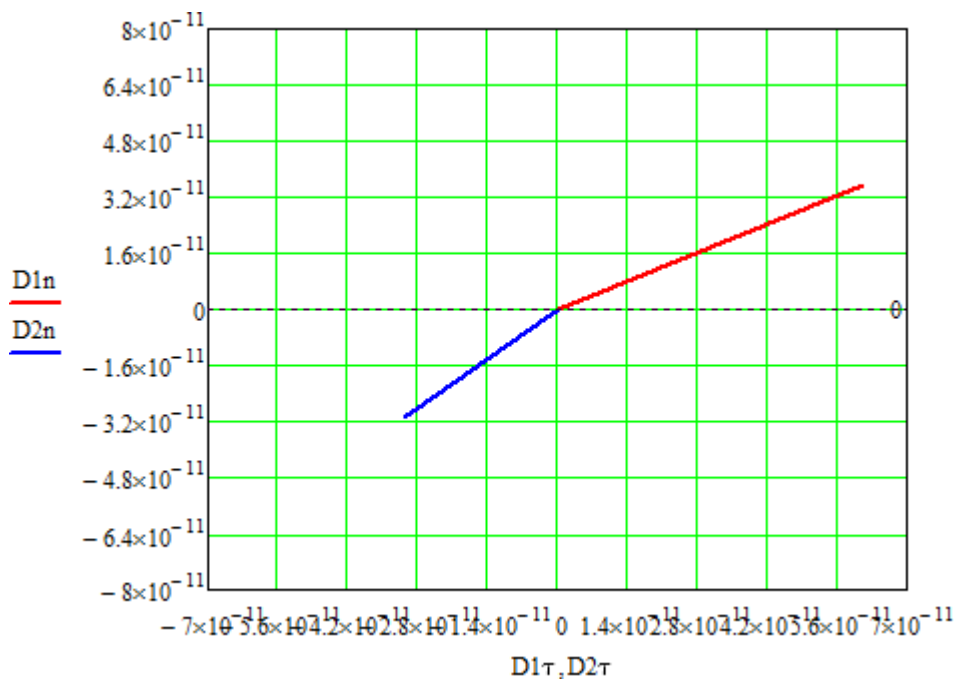
– module vectors displacements V first environment -

$$D1 := \sqrt{D1_{\tau}^2 + D1_n^2};$$

– module vectors displacements in second Wednesday –

$$D2 := \sqrt{D2_{\tau}^2 + D2_n^2};$$

2) Plot the displacement vector graph when moving from a medium with a dielectric constant ϵ_1 to a medium with a dielectric constant ϵ_2 , taking 0 as border section two avg. On drawing For demarcations two Wednesday set the Y-axis label to 0.



Rice. 1.2 - vector displacements at transition from Wednesday With permittivity ϵ_1 into a medium with permittivity ϵ_2

1.3. Study of boundary conditions of the electric field strength vector and displacement.

Fill in the table of dependence of the angle of refraction, the magnitude of the displacement vector and the intensity from angle falls, dielectric permeability And superficial charge. First line tables fill in according to original data, further change parameters according to the following instructions –

1) Conduct study dependencies angle refractions, module vectors bias and voltage on the permittivity. To do this, first double the permittivity ϵ_1 and halve the permittivity ϵ_2 . Then, halve the permittivity ϵ_1 and permeability ϵ_2 increase V two times. Results bring in V Table 1.2

2) Conduct study dependencies angle refractions, module vectors displacement and stress as a function of the angle of incidence. To do this, first increase the angle of incidence by 20 degrees, then decrease it by 20 degrees. Record the results in Table 1.2.

3) Conduct study dependencies angle refractions, module vectors displacement and intensity from the surface charge value. To do this, first double the value of σ , then halve it, and then reverse its sign. Record the results in Table 1.2.

Table 1.2. Dependence of the angle of refraction, the modulus of the displacement vector and the intensity from angle falls, dielectric permeability And superficial charge

	θ_2	E2	D1	D2
according to the initial data				
$\epsilon_1=2\epsilon_1$, $\epsilon_2=0.5\epsilon_2$				
$\epsilon_1=0.5\epsilon_1$, $\epsilon_2=2\epsilon_2$				
$\theta=\theta+20\text{deg}$				
$\theta=\theta-20\text{deg}$				
$\sigma = 2\sigma$				
$\sigma = 0.5\sigma$				
$\sigma = -\sigma$				

4) Do conclusions By results conducted research.

Task 2. Modeling and study of boundary conditions on the interface of two media for magnetic field vectors in the Mathcad system.

Options tasks For research given V table 2. Table 2.1 – Initial data for task 2

Option number	μ_1	μ_2	Angle θ , Degrees	surface charge η , mC	Magnetic field induction B_1, B
1	1	2	60	- 1.6	1.25
2	5	6	55	- 1.3	1.1
3	3	5	50	- 1.1	1.05
4	4	5	45	- 1.5	1.5
5	5	6	60	-1.2	1.11
6	6	7	55	-1.4	1.01
7	2	3	50	-1.6	1.2
8	6	8	45	-1.1	1.3

9	5	6	60	-1.5	1.25
10	1	2	55	-1.6	1.1
11	5	7	50	1.1	1.05
12	3	5	45	-1.5	1.5
13	7	8	60	-1.1	1.11
14	3	6	55	-1.3	1.015
15	1	2	50	-1.5	1.2

2.1. Modeling border conditions vectors induction magnetic fields.

1) Enter V working window programs original data:

– Magnetic permeability first And second dielectric μ_1, μ_2 ;

– magnetic constant – $\mu_0 := 4 \cdot \pi \cdot 10^{-7}$;

– absolute magnetic permeability first And second dielectric–

$$\mu_{1a} := \mu_0 \cdot \mu_1$$

$$\mu_{2a} := \mu_0 \cdot \mu_2;$$

– magnetic field induction B1;

– corner falls θ (deg);

2) Enter formulas For calculation:

– numerical meaning tangential component vectors magnetic induction B1–

$$BI_{\tau} := B1 \cdot \sin(\theta);$$

– numerical meaning normal component vectors magnetic induction B1–

$$BI_n := B1 \cdot \cos(\theta);$$

– numerical meaning tangential component vectors magnetic induction B2–

$$BII_{\tau} := \left(\frac{BI_{\tau}}{\mu_{1a}} + \eta \right) \cdot \mu_{2a};$$

– numerical meaning normal component vectors magnetic induction B2– $BII_n := BI_n$;

– normal component vectors induction B1–

$$B1_n := \begin{pmatrix} 0 \\ BI_n \end{pmatrix};$$

– tangential component vectors induction B1–

$$B1_{\tau} := \begin{pmatrix} 0 \\ BI_{\tau} \end{pmatrix};$$

– normal component vectors induction B2–

$$B_{2n} := \begin{pmatrix} 0 \\ -B_{1n} \end{pmatrix};$$

– tangential component vectors induction B2–

$$B_{2\tau} := \begin{pmatrix} 0 \\ -B_{1\tau} \end{pmatrix};$$

– tangent angle refractions–

$$\text{tg}\theta_2 := \frac{B_{1\tau}}{B_{1n}};$$

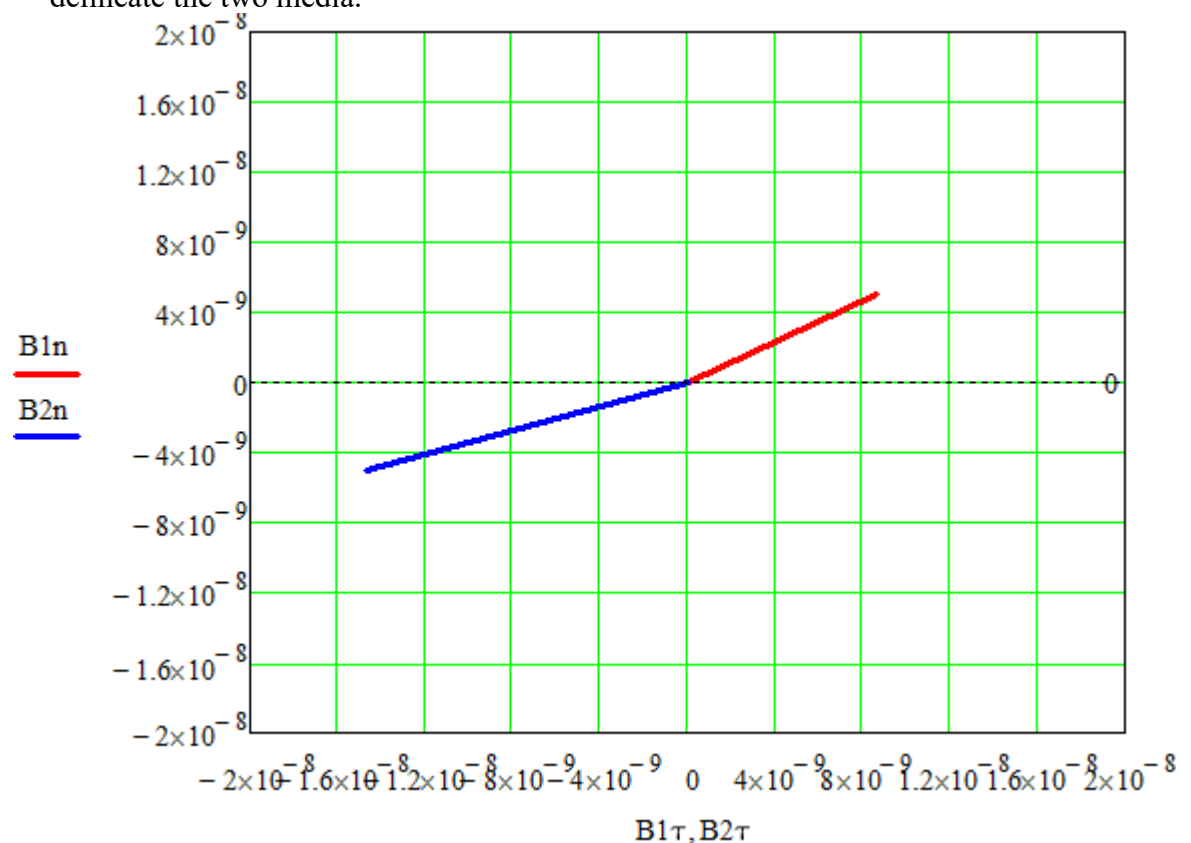
– corner refraction V radians And degrees –

$$\theta_{2\text{rad}} := \text{atan}(\text{tg}\theta_2), \quad \theta_2 := \theta_{2\text{rad}} \cdot \frac{180}{\pi};$$

– module vectors magnetic induction in second Wednesday –

$$B_2 := \sqrt{B_{1n}^2 + B_{1\tau}^2};$$

3) Plot a graph of the magnetic induction vector when moving from a medium with magnetic permeability μ_1 to a medium with magnetic permeability μ_2 , taking 0 as the interface between the two media. In the figure, mark the Y-axis with a value of 0 to delineate the two media.



Rice. 2.1 - vector magnetic induction at transition from Wednesday With magnetic permeability μ_1 into a medium with magnetic permeability μ_2

2.2. Modeling border conditions vectors tension magnetic fields

1) Enter formulas For calculation:

– numerical meaning magnetic tension $H1$ –

$$H1 := \frac{B1}{\mu_1 a};$$

– the numerical value of the tangential component of the magnetic intensity vector $H1$ –

$$H1_\tau := \frac{B1_\tau}{\mu_1 a};$$

– the numerical value of the normal component of the magnetic intensity vector $H1$ –

$$H1_n := H1 \cdot \cos(\theta);$$

– the numerical value of the tangential component of the magnetic intensity vector $H2$ –

$$H2_\tau := H2 + \eta;$$

– the numerical value of the normal component of the magnetic intensity vector $H2$ –

$$H2_n := \frac{H1_n \cdot \mu_1 a}{\mu_2 a};$$

– normal component vectors tension $H1$ –

$$H1_n := \begin{pmatrix} 0 \\ H1_n \end{pmatrix};$$

– tangential component vectors tension $H1$ –

$$H1_\tau := \begin{pmatrix} 0 \\ H1_\tau \end{pmatrix};$$

– normal component vectors tension $H2$ –

$$H2_n := \begin{pmatrix} 0 \\ -H2_n \end{pmatrix};$$

– tangential component vectors tension $H2$ –

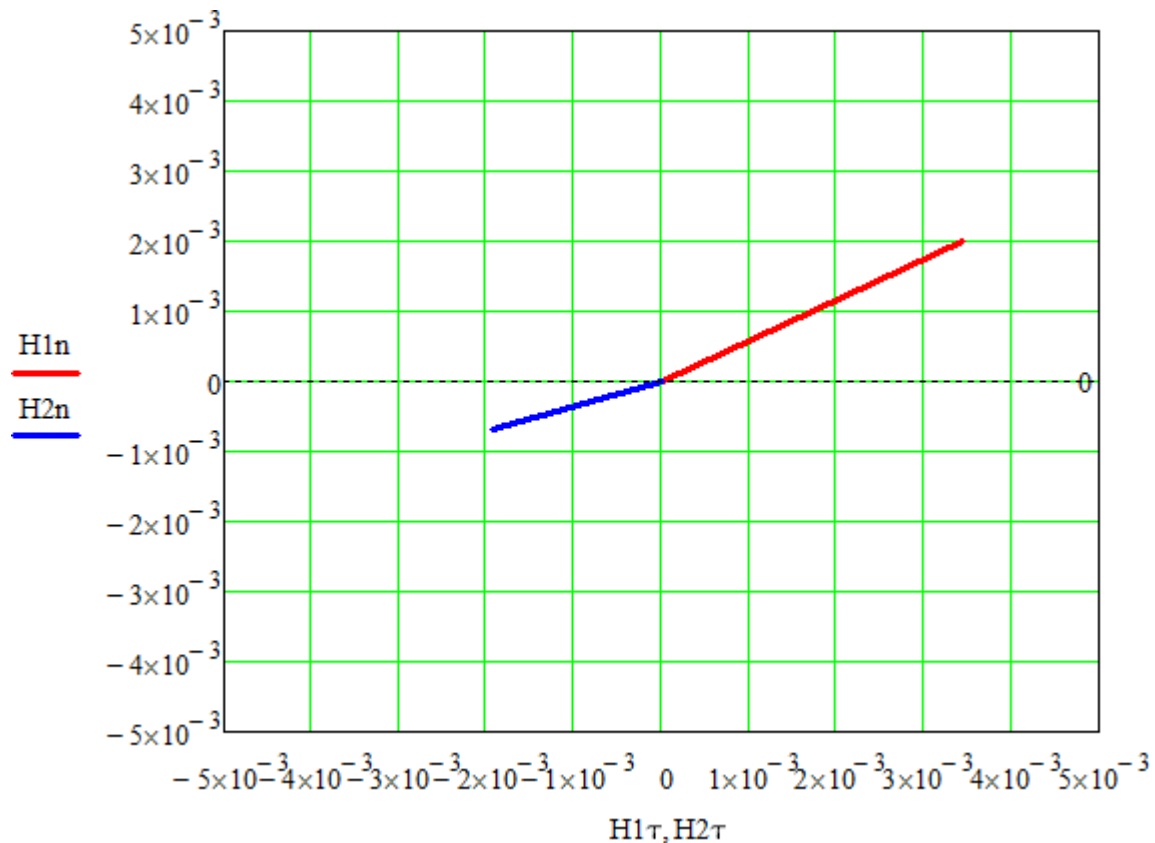
$$H2_\tau := \begin{pmatrix} 0 \\ -H2_\tau \end{pmatrix};$$

– module vectors tension in second Wednesday –

$$H2 := \sqrt{H2_n^2 + H2_\tau^2};$$

2) Build schedule vectors magnetic tension at transition from Wednesday With

magnetic permeability μ_1 into a medium with magnetic permeability μ_2 , taking 0 as the interface between the two media. In the figure, to separate the two media, place a mark on the Y axis with a value of 0.



Rice. 2.3 - vector magnetic tension at transition from Wednesday With magnetic permeability μ_1 into a medium with magnetic permeability μ_2

2.3. Study of boundary conditions of the magnetic field strength and induction vector.

Fill in the table of dependence of the angle of refraction, the magnitude of the displacement vector and the field strength on the angle of incidence, magnetic permeability and surface charge. The first line tables fill in according to original data, further change parameters according to the following instructions –

1) Conduct study dependencies angle refractions, module vectors displacement and voltage from the permittivity. To do this, first increase the magnetic permeability V one and a half times, then decrease V 0.7 once. Results bring in in table 1.2

2) Conduct study dependencies angle refractions, module vectors The displacement and stress depend on the angle of incidence. To do this, first increase the angle of incidence by 10 degrees, then decrease it by 10 degrees. Record the results in Table 1.2.

3) Conduct study dependencies angle refractions, module vectors displacement and stress versus surface charge. To do this, first increase σ by 1.2 times, then decrease it by 0.7 times. Record the results in Table 1.2.

Table 2.2. Dependence of the angle of refraction, the modulus of the displacement vector and the intensity from angle falls, magnet permeability And superficial charge

	θ_2	B2	H1	H2
according to the initial data				

$\mu_1 = 1.5 \mu_1$				
$\mu_1 = 0.7 \mu_1$				
$\theta = \theta + 10^\circ$				
$\theta = \theta - 10^\circ$				
$\eta = 1.2 \eta$				
$\eta = 0.7 \eta$				

4) do conclusions By results conducted research

6. Defense of practical work

To defend your lab assignment, submit a fully completed report free of any significant errors. As directed by your instructor, complete one of the assignments. each educational question, having explained at this all physical phenomena And processes occurring in the developed model.

Practical lesson #4

Study falls flat EMV on border section two Wednesday

Objective of the lesson

Conduct a study of electromagnetic waves at the interface between two media. Acquire skills in using computer technology to conduct research and analyze experimental results.

Exercise

1. Repeat material lecture classes
2. Determine the values of reflection and refraction coefficients for various media and propagation conditions
3. Define projections components electromagnetic waves on axes Cartesian coordinate system
4. Design And protect the report

Instructions By execution tasks

1. Repetition material lecture classes

Review is completed through independent work by each student, who studies the lecture texts independently. As a result of review, students should know the answers to the test questions.

CONTROL QUESTIONS WORKS

1. Parallel And perpendicular polarization electromagnetic waves.
2. Normal components electromagnetic fields on border two avg.
3. Tangents components of the electromagnetic field at the border of two environments.
4. First And second laws Snell.
5. Definition coefficient reflections at parallel polarization.
6. Definition coefficient refraction at parallel polarization.
7. Definition coefficient reflections at perpendicular polarization.
8. Definition coefficient refraction at perpendicular polarization.
9. Corner Brewster And corner complete internal reflection.
10. Those close to you border conditions Leontovich.

2. Definition coefficients reflections and refraction

The laboratory work is carried out using a mathematical model of plane electromagnetic waves at the boundary of two media, compiled in the integrated system of engineering and scientific calculations MathCad 2001. The variants of the tasks are given in Table 1. Data entry is carried out using the keyboard in the usual way in the mode of correction of data highlighted in the program text. yellow color. Characteristics first Wednesday correspond vacuum $\epsilon_1=1$, $\mu_1=1$, $\sigma_1=0$.

Table 1

Option number	Carrier frequency, Hz	E_{po} , V/m	Characteristics second environment for the first experience			Characteristics of the second environment for the second experiment		
			ϵ_2	μ_2	σ_2	ϵ_2	μ_2	σ_2
1	0.1×10^6	100	2.0	1	$3.34 \cdot 10^{-4}$	0.0001	0.937	$6.6 \cdot 10^7$
2	0.2×10^6	110	2.6	1	$14 \cdot 10^{-4}$	0.0001	0.986	$5.9 \cdot 10^7$
3	0.3×10^6	120	2.5	1	$8.34 \cdot 10^{-4}$	0.0001	0.922	$4.4 \cdot 10^7$
4	0.4×10^6	130	2.74	1	$17 \cdot 10^{-4}$	0.0001	0.965	$3.81 \cdot 10^7$
5	0.5×10^6	140	2.35	1	$6.53 \cdot 10^{-4}$	0.001	1,131	$2.43 \cdot 10^7$
6	0.6×10^6	150	3.0	1	$83 \cdot 10^{-4}$	0.001	0.996	$0.21 \cdot 10^7$
7	0.7×10^6	160	6.0	1	$834 \cdot 10^{-4}$	0.001	0.908	$0.9 \cdot 10^7$
8	0.8×10^6	170	9.5	1	$5.28 \cdot 10^{-4}$	0.0001	0.937	$6.6 \cdot 10^7$
9	0.9×10^6	180	9.7	1	$22 \cdot 10^{-4}$	0.0001	0.986	$5.9 \cdot 10^7$
10	1×10^6	190	3.82	1	$2.1 \cdot 10^{-4}$	0.0001	0.922	$4.4 \cdot 10^7$

After conducting research With data first experience And design Based on the research results, swap the characteristics of the first and second environments. Compare the results obtained for the electromagnetic wave passing from the less transparent to the more transparent environment with the previous results. Perform calculations for the data of the second experiment; the characteristics of the first environment must correspond to the characteristics of a vacuum.

3. Carrying out research of plane electromagnetic waves in various environments Restore

conditions conducting first experience. Consistently complete calculations components electromagnetic waves V first And second environments For corners falls ϕ

Experiment number	1	2	3	4
Corner ϕ	0.1π	0.2π	0.3π	0.4π

For each experiment, plot the resulting graphs in your lab report. Reflect V conclusions change lengths waves in second environment. Determine, To what type of environment refers to Wednesday, given characteristics For first And For second Experiments. How does the angle of

incidence affect the total and refracted electric waves?

4. Design And protection report

The report on practical work is prepared in printed view on sheets format A4. The report is considered complete if it reflects the topic and purpose of the laboratory work, presents the research results in the form of numerical values and graphs, and formulates conclusions. The report is defended by submitting a neatly formatted report And answers on control questions work By choice teacher.

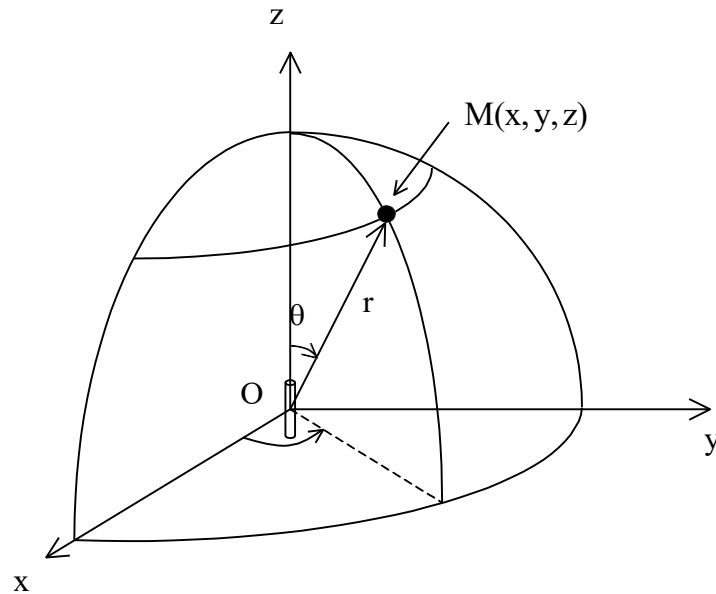
Practical lesson No. 5
Study fields elementary emitters

Preparing for occupation:

1. Which emitters are called elementary?
2. What it's called elementary electrical dipole (EED)?
3. What it's called diagram direction emitter?
4. What such characteristic direction elementary emitter?
5. What it's called resistance radiation elementary emitter?
6. What it's called power radiation elementary emitter?
7. Which one? form has diagram direction EED?
8. What it's called elementary magnetic dipole (EMD)?
9. Which one? form has diagram direction EMD?
10. Write down expression For definitions tension electric fields in the far zone for EED. Explain its components.
11. Write down expression For definitions tension electric fields in the far zone for EMD. Explain its components.
12. Write down expression For definitions tension magnetic fields V far zone for EED. Explain its components.
13. Write down expression For definitions tension magnetic fields V far zone for EMD. Explain its components.
14. Write down expression For resistance radiation EED. Explain incoming V its components.
15. Write down expression For resistance radiation EMD. Explain incoming V its components.
16. Write down expression For power radiation EED. Explain incoming V its components.
17. Write down expression For power radiation EMD. Explain incoming V its components.
18. List famous to you elementary emitters?

Task 1.

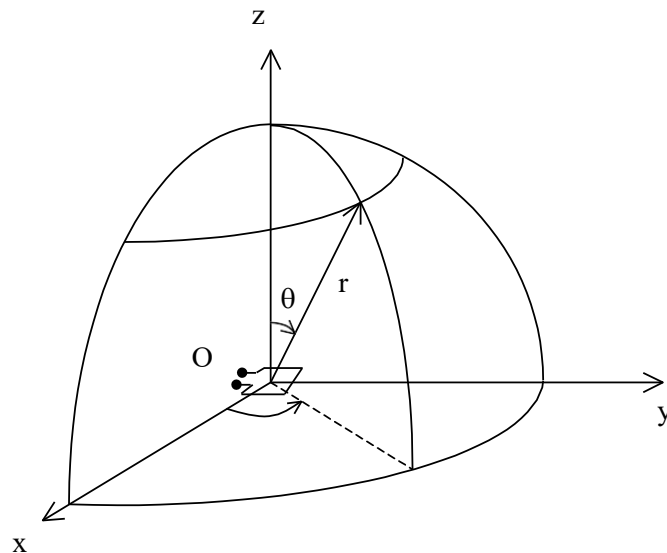
An elementary electric dipole of length ℓ is located at the origin of the Cartesian coordinate system along the z-axis, and current I flows through it frequency f . At some distance from the EED there is an observation point M with coordinates (x, y, z) Fig. 1. Determine the polar coordinates of the observation point, the amplitude values of the electric field strength and the magnetic field strength created by the EED at the observation point, the radiation resistance and the radiation power of the EED. Draw the normalized characteristics direction EED V planes XOY And XOZ. Conduct a study of the emitter's directional characteristics. Data for the study, based on the student's log number, are taken from Table 1.



Rice. 1. Accommodation EED relatively azimuthal And elevation planes.

Task 2.

An elementary magnetic dipole in the form of a square frame with a current and a side length of ℓ is located V beginning Cartesian systems coordinates V planes XOY, By a current I flows through it frequency f . At some distance from the EMD, there is an observation point M with coordinates (x, y, z) in Fig. 2. The conditions are taken from problem number one. Determine the amplitude values of the electric and magnetic field strengths created by the EMD at the observation point, the radiation resistance, and the EMD radiation power. Plot the normalized directivity characteristics of the EMD in the XOY and XOZ planes. Conduct a study of the directivity characteristics of the emitter.



Rice. 2. Accommodation EMD relatively azimuthal And elevation planes

Task 3.

Conduct a comparative analysis of EED and EMD. Based on the resistance and radiation power, and the generated electric and magnetic field strengths, draw a conclusion. about efficiency elementary dipoles. Define at what meaning current

flowing through the EMD, it will create an electric field strength at the receiving point similar to that of the EMD.

Compare characteristics direction EED And EMD.

Table 1.

Initial data

No. by magazine	x, m	y, m	z, m	ℓ , m	A n d , A	f, MHz
1.	1000	2000	1000	2	3.5	5
2.	300	500	200	0.5	0.2	20
3.	7000	10000	6000	10	4	2
4.	2000	2000	2000	4	0.1	6
5.	2200	1300	300	1	2	30
6.	800	2000	200	5	0.3	6
7.	1700	1400	400	10	0.8	3
8.	700	700	700	0.1	5	200
9.	300	400	500	0.2	2	120
10.	500	200	200	0.3	0.3	100
11.	1300	1200	1000	4.5	0.1	6
12.	6000	5000	300	7	5.4	3.7
13.	2300	3500	1500	9	2.6	3.1
14.	100	230	200	0.2	0.3	150
15.	3500	2500	1500	6	3.7	5
16.	950	1050	700	3.5	0.65	7.2
17.	1300	1200	4000	4.2	0.7	6
18.	500	600	300	0.8	1.3	25
19.	700	400	100	0.25	1.4	80
20.	4000	5000	7000	7.5	4.4	3.1
21.	4000	5000	2000	7.8	2.1	2
22.	1600	3600	3100	3.4	0.7	7.2
23.	6500	7000	10000	8.5	6	2.5
24.	100	100	50	0.1	0.25	270
25.	160	160	300	0.15	2	180
26.	420	100	100	0.22	2.4	110
27.	700	350	450	0.36	0.2	65
28.	1700	1100	4500	6.2	0.9	4.3
29.	3300	1000	2500	1	3.5	10
30.	2300	2000	250	5.7	3.1	5
31.	400	3000	2300	4.3	0.3	6.1
32.	8200	8000	1000	20	5	1.5
33.	4100	5200	2000	15	3.2	2
34.	400	500	2000	12	2.1	2.2
35.	500	550	200	0.6	0.3	10

Methodological recommendations:

Elementary emitters are those whose geometric dimensions are significantly smaller than the wavelength.

Studying And study elementary emitters contributes understanding process radiation antennas, So How any how much whatever you like complex antenna Maybe be

presented consisting from some sets elementary emitters With given currents. The field created by these currents is determined as a superposition of the fields of elementary radiators. Determining the field of real antennas using the superposition of fields of elementary radiators is one of the fundamental methods in antenna theory.

The study of the directional properties of elementary emitters consists of experimental measurement of the dependence of the amplitude of the EMF strength or the magnitude vectors Poynting from corner coordinates θ And φ at $r = \text{const}$. Here θ And φ - corner place and azimuth respectively, r – the distance to the observation point. This dependence is called the directivity characteristic (DC) of the emitter. A graphical representation of the DC is called a radiation pattern (RP).

EED they call source electromagnetic fields, presented V view an element of electric current (conduction or displacement), the length of which is much smaller than the wavelength of the source in free space

$$\ell \ll \lambda, \quad (1)$$

Where ℓ - length element current;

λ - wavelength, A current By all length has constant amplitude and phase.

Of greatest interest from a practical point of view are the EED and EMD fields in the far zone, i.e. at points in space for which the inequality is satisfied

$$k \cdot r \gg 1, \quad (2)$$

Where $k = \frac{2 \cdot \pi}{\lambda}$ - wave number;

r - distance to the point observations.

Components electromagnetic fields V further zone For EED are defined by the following expressions

$$E(\theta) = \frac{\text{and} \cdot k \cdot \boxed{I}_m \cdot \ell \cdot Z_c \cdot e^{-i \cdot k \cdot r}}{4 \cdot \pi \cdot r} \cdot \sin(\theta), \quad H(\varphi) = \frac{i \cdot k \cdot \boxed{I}_m \cdot \ell}{4 \cdot \pi \cdot r} \cdot e^{-i \cdot k \cdot r} \cdot \sin(\theta), \quad (3)$$

Where $\boxed{I}_m$ - current leaking By EED;

Z_c - wave resistance environment.

Characteristic direction EED V planes E is determined by the expression

$$f(\theta) = \sin(\theta). \quad (4)$$

Standardized characteristic directions of EED

$$F(\theta) = \frac{f(\theta)}{f\left(\frac{\pi}{2}\right)} = \frac{\sin(\theta)}{1} = \sin(\theta). \quad (5)$$

Characteristic direction EED V planes N

$$f(\varphi) = F(\varphi) = 1. \quad (6)$$

Analysis expressions (4) And (5) shows, What EED creates maximum tension EMP V planes E at $\theta = \frac{\pi}{2}$ And $\theta = \frac{3\pi}{2}$, minimum tension fields 2

at $\theta = 0$ And $\theta = \pi$. IN plane H field radiation EED has non-directional character.

Alone from main characteristics EED is resistance radiation R_Σ , being coefficient proportionality between electric shock, exciting EED and radiation power

$$P_\Sigma = \frac{I^2}{2} \cdot R_\Sigma. \quad (7)$$

The radiation resistance of the EED in free space can be determined from the expression

$$R_\Sigma = 80 \cdot \pi^2 \cdot \left| \frac{\ell}{\lambda} \right|^2. \quad (8)$$

EMD they call source electromagnetic fields, presented V view an element of "magnetic" current, the dimensions of which are much smaller than the wavelength of the source in free space.

Frame small sizes, streamlined electric shock conductivity, Can count EMD. To determine the field created by an EMD, the principle of permutation duality of Maxwell's equations is used.

The components of the electromagnetic field in the far zone for EMD are determined by the following expressions

$$E(\varphi) = \frac{k^2 \cdot I_{\text{in}} \cdot S \cdot Z_c}{4 \cdot \pi \cdot r} \cdot e^{-i \cdot k \cdot r} \cdot \sin(\theta), \quad H(\theta) = -\frac{k^2 \cdot I_{\text{in}} \cdot S}{4 \cdot \pi \cdot r} \cdot e^{-i \cdot k \cdot r} \cdot \cos(\theta), \quad (9)$$

Where S - square framework;

I_{in} - current leaking By coil EMD.

Characteristic direction EMD V planes (N) is determined expression

$$f(\varphi) = \sin(\varphi), \quad (10)$$

A standardized directional characteristic

$$F(\varphi) = \frac{f(\varphi)}{f(0)} = \frac{\sin(\varphi)}{1} = \sin(\varphi). \quad (11)$$

HH V planes (E) is determined by the expression

$$f(\theta) = F(\theta) = 1$$

Resistance radiation EMD is determined from expressions

$$R_{\Sigma} = \frac{2 \pi (k \cdot S)^2}{3 \left(\frac{\lambda}{\lambda} \right)} \cdot Z_B. \quad (13)$$

Polarization studied antenna waves is determined type transmitting antennas and its position in space. Knowledge of antenna polarization characteristics is necessary to ensure reliable radio communications in various wavebands.

LABORATORY JOB No. 6

Calculation fields elementary emitters

Preparing for occupation:

19. Which emitters are called elementary?
20. What it's called elementary elementary slot radiator?
21. What it's called diagram direction emitter?
22. What such characteristic direction elementary emitter?
23. What it's called resistance radiation elementary emitter?
24. What it's called power radiation elementary emitter?
25. What shape does the radiation pattern of an elementary slot radiator have ?
26. What it's called Huygens element ?
27. Which one? form has diagram direction element Huygens?
28. Write an expression for determining the electric field strength in the far zone for an elementary slot radiator. Explain its components.
29. Write an expression for determining the far-field electric field strength for a Huygens element. Explain its components.
30. Write an expression for determining the magnetic field strength in the far zone for an elementary slot radiator. Explain its components.
31. Write an expression for the radiation resistance of an elementary slot radiator. Explain its components.
32. Write an expression for the radiated power of an elementary slot radiator. Explain its components.
33. Write an expression for the radiation power of a Huygens element. Explain its components.
34. List famous to you elementary emitters?

	Contents of the questions	
	Educational questions classes	
	Calculation fields elementary slot radiator.	
	Field calculation element Huygens.	
	Comparative calculation fields elementary emitters.	

Exercise on laboratory lesson.

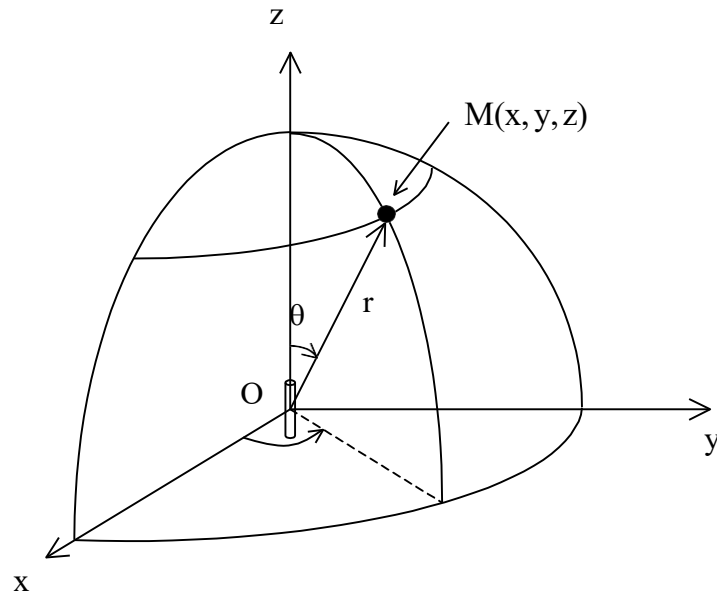
Task 1.

Asked elementary slit emitter length $\ell = \sqrt{N}$ cm And width $a = \frac{\ell}{100}$ s

tension electric fields between edges cracks $E_m = \sqrt{N} \begin{bmatrix} IN \\ |m| \end{bmatrix}$ And frequency fields

$f = N \cdot 10^7$ Hz is located V beginning systems coordinates. Define amplitude values tension electric And magnetic fields created ESHCHI V

direction maximum radiation on distance $r = N \cdot 10^2$ m. Define resistance radiation And power radiation ESHCHI. Draw standardized characteristics of the directional properties of the electrical energy in the XOY and XOZ planes.



Rice. 1. Accommodation ESHCHI relatively azimuthal And elevation planes.

Task 2.

Element Huygens V view square sites with side ℓ , With superficial tension electric fields $E_s = E_m$ And frequency fields f is located V beginning Cartesian coordinate system in the XOY plane. Determine the amplitude values of the electric and magnetic field strengths generated by the Huygens element in the direction of maximum radiation at a distance r . Take the conditions from problem number one. Plot the normalized directional characteristics of the Huygens element in the XOY and XOZ planes.

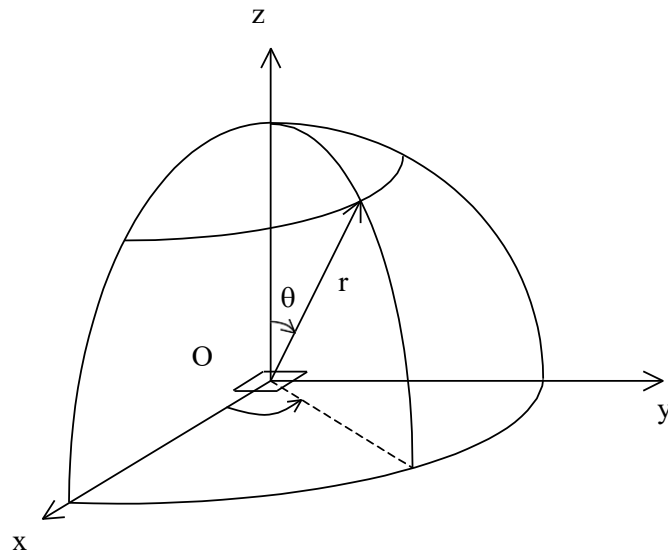


Fig. 2. Placement of the Huygens element relative to the azimuthal and elevation planes

Task 3.

Conduct a comparative analysis of the ESH and the Huygens element in terms of the intensities created electric And magnetic fields V direction maximum radiation. Draw a conclusion about the efficiency of elementary dipoles.

Determine at what electric field strength between the edges of the gap at a distance r the same electric field strength will be created as that of the element Huygens. Compare characteristics direction ESHCHI And element Huygens.

Methodological recommendations:

Elementary slit emitter represents from myself gap, length ℓ And width a , cut through an infinite ideally conducting plane, along which a surface variable flows current and it is carried out condition $a \ll \ell \ll \lambda$, Where λ - current wavelength.

Due to the flow of alternating current along the plane, alternating currents appear at the edges of the gap. in time charges, which induce variable electric field. This field, according to Maxwell's first equation, in turn induces an alternating magnetic field. Thus, an elementary gap emits an alternating electromagnetic field.

Having compared the structure of the field of the elementary gap and the EMD similar to that carried out For elementary framework not difficult make sure V identity structures fields of the listed emitters. Accordingly, the radiation patterns and expressions describing the field of an elementary slot in the far zone have a similar form:

$$E_{\varphi} = \frac{ikU_{III}\ell}{4\pi r} \cdot \text{and}^{-ikr} \cdot \text{are } \theta, \quad (1)$$

$$H_{\theta} = -\frac{ikU_{III}\ell}{4\pi rZ_B} \cdot \text{and}^{-ikr} \cdot \text{two } \theta. \quad (2)$$

Like this in this way, For Togo, to tension fields elementary cracks was equal to the field strength of the EED, the following relationship must be satisfied:

$$U_{III} = 0.5 \cdot I \cdot Z_B. \quad (3)$$

Expressions for the radiation power and radiation resistance of an elementary slit can be obtained on the basis of the corresponding expressions for the EED and the expression:

$$R_{\Sigma} = \frac{2}{3} \cdot \pi \cdot Z_B \left(\frac{\ell}{\lambda} \right)^2, \quad (4)$$

$$P_{\Sigma_{CP}} = \frac{4}{3} \pi \frac{U_{SCH}^2 \left(\frac{\ell}{\lambda} \right)^2}{Z_B}. \quad (5)$$

Element Huygens

For many types of antennas, especially those used in microwave ranges, it is difficult to determine the distribution of currents in the antenna elements, while knowledge of the fields created by the EED, EMD and elementary energy is not suitable for determining the field of such antennas. gap. However, V most cases For such antennas Can determine the distribution fields V planes disclosure antennas. Tension fields specified The far-field performance of antennas can be determined using the Huygens-Kirchhoff principle, which states that each wavefront element is a source of secondary spherical waves. Such a wavefront element is called a Huygens element. Thus, knowledge of the parameters and characteristics of a Huygens element allows us to determine the fields of more complex radiators—antennas—using the superposition principle, as was previously discussed for elementary radiators.

Let's consider rectangular plot front waves With dimensions $\ell_1 \ll \lambda$ And $\ell_2 \ll \lambda$ on which asked tension EMP $E_{\varphi}^{\square}$ And $H_{\theta}^{\square}$ (drawing 3 A). Taking advantage of boundary

conditions For tangents components vectors fields, (SRP No. 1), to write:

$\vec{E}_s$ And $\vec{H}_s$ Can

$$\vec{H}_s = \frac{I_s}{\ell_2} \quad (6)$$

$$\vec{E}_s = \frac{M}{\ell_1} \quad (7)$$

Where V right parts 6, 7 are standing density superficial currents conductivity and magnetic current, respectively.

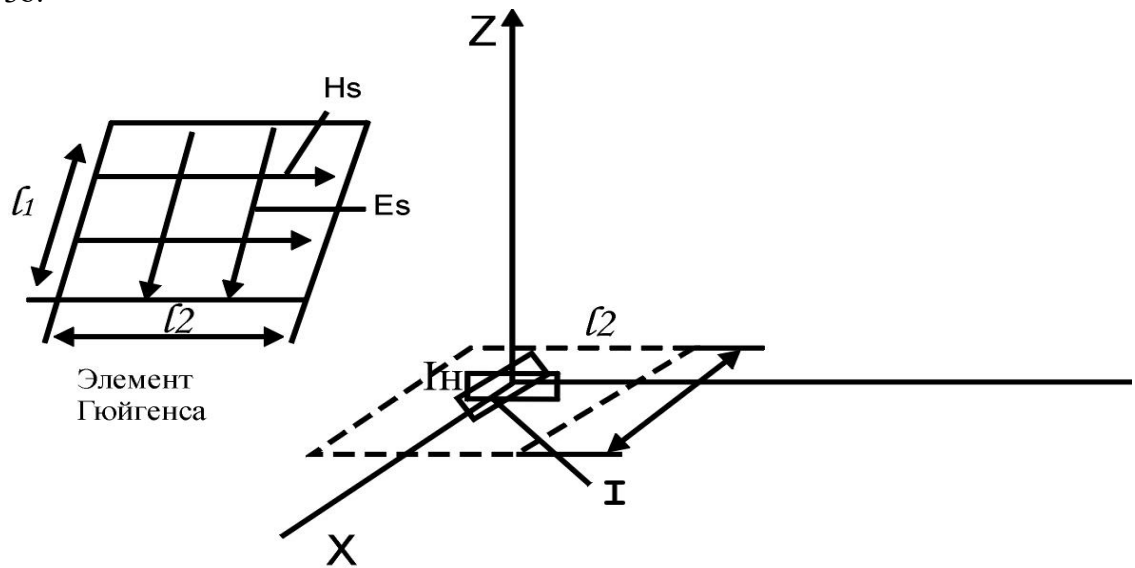
Rewritten 6, 7 in the form of:

$$I_s = \vec{H}_s \cdot \ell_2, \quad (8)$$

$$M = \vec{E}_s \cdot \ell_1. \quad (9)$$

Element Huygens Can consider How two mutually perpendicular elementary emitter EED And EMD length respectively ℓ_1 And ℓ_2 and currents I_s And I_m

Let's arrange specified emitters V beginning systems coordinates, How This shown in Figure 3b.



LABORATORY CLASS No. 8

Study diffraction flat waves on cylinder Research task:

To investigate the dependence of the modulus of the complex amplitude of the secondary voltage electric fields E_m V further zone ($r \gg a, r \gg \lambda$) V dependencies from angle φ for a constant value of the variable r (the ratio of values $E_m(r, \varphi) / E_m(r, 0)$) For various ka .

Table 1 – Initial data for the options:

No. according to the list	ka1	ka2	ka3	ka4
1	0.45	1.5	4.2	8.5
2	0.48	1.52	4.0	8.0
3	0.5	1.54	4.78	9.2
4	0.52	1.56	4.55	9.8
5	0.47	1.58	4.95	8.2
6	0.55	1.6	4.8	9.4
7	0.54	1.62	4.1	10.0
8	0.49	1.64	4.64	8.1
9	0.5	1.66	5.0	8.6
10	0.46	1.68	4.72	9.6
11	0.51	1.7	4.5	8.9
12	0.53	1.72	4.25	9.5
13	0.52	1.74	4.94	8.4
14	0.54	1.76	4.3	9.7
15	0.5	1.78	4.48	8.8
16	0.46	1.8	4.05	8.0
17	0.49	1.82	4.12	9.0
18	0.45	1.84	4.56	9.3
19	0.51	1.86	4.9	8.7
20	0.55	1.8	4.64	9.9
21	0.47	1.84	4.38	9.3
22	0.53	1.88	5.0	8.7
23	0.52	1.92	4.0	8.3
24	0.48	1.96	4.85	9.4
25	0.45	2	4.62	9.8

1. Meaning m install from 1 to 20
2. kr we ask equal to 100
3. according to we choose the option values ka

Methodological recommendations:

Let flat linearly polarized electromagnetic wave falls on perfectly conducting circular cylinder radius A perpendicularly his axes (rice. 11.1). Let's introduce cylindrical system coordinates r, φ, z , axis Z which matches With axis cylinder, A corner φ is being counted down from axes X , opposite direction wave propagation.

When solving the problem, we can limit ourselves to considering two types of polarization of the incident wave relative to the axis of the cylinder:

A) vector $\vec{E}^0$ parallel axes Z ;

b) vector $\vec{H}^0$ parallel to the Z

axis.

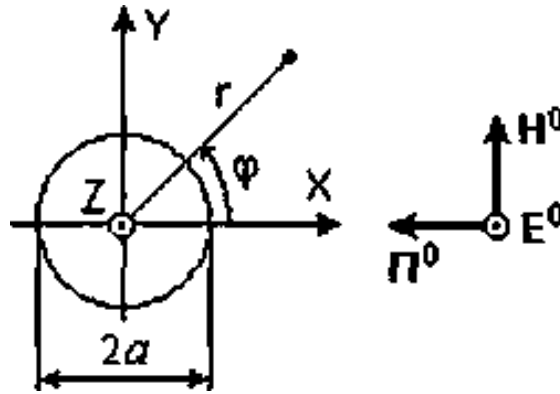


Figure 11.1

I love it another orientation vectors E and H of the primary fields. Can introduce how superposition these cases. Let's stop more details on first task, because second is being decided similarly. Tension electric fields falling waves

has only component by Z-axis ($E = z_0 E(r, \varphi)$)

$$E^{(2)}(r, \varphi) = E_0 \exp(ikx) = E_0 \exp(ikr \cos \varphi). \quad (11.2)$$

The problem under consideration is two-dimensional (there is no dependence on the variable z), That's why equation for tension secondary electric fields,

which also will have only component by Z-axis ($E_m = z_0 E_m(r, \varphi)$), takes the form

$$-\frac{1}{r} \frac{\partial}{\partial r} \left(r \frac{\partial E_m^{(2)}}{\partial r} \right) + \frac{1}{r^2} \frac{\partial^2 E_m^{(2)}}{\partial \varphi^2} + k^2 E_m^{(2)} = 0; \quad r \geq a \quad 0 \leq \varphi \leq 2\pi \quad (11.3)$$

Function E on surfaces S should satisfy border condition (11.1), which in the case under consideration takes the form

$$E_m^{(2)}(a, \varphi) = -E_0 \exp(ika \cos \varphi), \quad (11.4)$$

and V endlessly remote points - condition radiation. This condition, by being, consists of V next. At $r \rightarrow \infty$ in expression for functions $E_m^{(2)}(r, \varphi)$ should enter components with phase multiplier species $\exp(-ikr)$, which correspond wave, outgoing V infinity from axes Z ; components same with phase multiplier $\exp(ikr)$, which correspond wave, spreading from infinity to axes Z , should be absent.

For solutions tasks applicable method Fourier. Let's imagine function sought after

$E_m^{(2)}(r, \varphi)$ view

$$E_m^{(2)}(r, \varphi) = R(r)\Phi(\varphi). \quad (11.5)$$

Let's substitute this one formula V equation (11.3) and let's multiply both his parts on r^2

We will do it differentiation and let's divide then resulting equation member by member on work $R(r)\Phi(\varphi)$

$$\frac{r \frac{d}{dr} \left(r \frac{dR(r)}{dr} \right)}{R(r)} + k^2 \frac{r^2 \frac{d^2 \Phi(\varphi)}{d\varphi^2}}{\Phi(\varphi)} = 0. \quad (11.6)$$

Left part received equations depends only from variable r , a right - only from variable φ . Variables r and φ are independent. Hence,

equation (11.6) represents by yourself equality of two independent functions. This it's only possible at condition, What each from functions equal constant. Designating the last one through m^2 , we are coming To two independent differential equations:

$$\frac{d^2 \Phi(\varphi)}{d\varphi^2} + m^2 \Phi(\varphi) = 0, \quad (11.7)$$

$$\frac{d^2 R(r)}{dr^2} + \frac{1}{r} \frac{dR(r)}{dr} + \left(k^2 - \frac{m^2}{r^2} \right) R(r) = 0. \quad (11.8)$$

Obviously, What at change angle φ on 2π meaning sought after functions $E_m^{(2)}(r, \varphi)$ should remain the same

$$E_m^{(2)}(r, \varphi + 2\pi) = E_m^{(2)}(r, \varphi). \quad (11.9)$$

Condition (11.9) can be rewritten for the function $\Phi(\varphi)$:

$$\Phi(\varphi + 2\pi) = \Phi(\varphi). \quad (11.10)$$

Solution equation (11.7) has the form

$$\Phi(\varphi) = A \sin m\varphi + B \cos m\varphi, \quad (11.11)$$

where A and B - arbitrary constants.

Condition (11.10) is being carried out, if t is an integer number ($m = 0, 1, 2, \dots$).

Tension primary electric fields - even function relative to the angle φ . That's why Can assume What function E , A hence, And function F Also

should be even relatively angle φ . Like this in this way, constant $A = 0$, from here we get

$$\Phi(\varphi) = B \cos m\varphi. \quad (11.12)$$

Equation (11.8) is equation Bessel. His solution Can introduce V view

$$R(r) = C' J_m(kr) + D' N_m(kr), \quad (11.13)$$

Where $J_m(kr)$ And $N_m(kr)$ - functions Bessel m -th order first And second genus respectively (function $N_m(kr)$ often they call Also function Neumann m -go order), and C' And D' - arbitrary constant.

IN under consideration case solution equations (11.8) more convenient express through the Bessel functions of the third kind - the Hankel functions:

$$R(r) = CH_m^{(1)}(kr) + DH_m^{(2)}(kr), \quad (11.14)$$

Where $H_m^{(1)}(kr)$ And $H_m^{(2)}(kr)$ - functions Hankel m -th order first And second genus respectively;

WITH And D - arbitrary constant.

Functions Bessel, Neumann And Hankel often they call Also cylindrical functions first, second And third genus respectively. $H_m^{(1)}(kr)$ And

$H_m^{(2)}(kr)$ are expressed through functions $J_m(kr)$ And $N_m(kr)$ ratios

$$H_m^{(1)}(kr) = J_m(kr) + iN_m(kr);$$

$$H_m^{(2)}(kr) = J_m(kr) - iN_m(kr). \quad (11.15)$$

At $r \rightarrow \infty$ fair next asymptotic representations:

$$\left. \begin{aligned} H_m^{(1)}(kr) \\ H_m^{(2)}(kr) \end{aligned} \right\} \cong \sqrt{\frac{2}{\pi kr}} \exp \left\{ \pm i \left[\pi kr - \left(2m + \frac{1}{2} \right) \frac{\pi}{2} \right] \right\}. \quad (11.16)$$

In other words, the function $H_m^{(1)}(kr)$ corresponds to a cylindrical wave, spreading from infinity to axes Z . A function $H_m^{(2)}(kr)$ - cylindrical wave, spreading from axes Z to infinity along radii r . Hence, For execution conditions radiation necessary count, What constant $C = 0$, at In this case, formula (11.14) takes the form

$$R(r) = D_m H_m^{(2)}(kr), \quad (11.17)$$

Like this in this way, solution equations (11.3), satisfying condition radiation, can serve as a function

$$E_m^{(2)} = D_m H_m^{(2)}(kr) \cos m\varphi. \quad (11.18)$$

Where D_m - some constant.

Left execute boundary condition (11.4). For this - let's imagine sought after solution $E_m^{(2)}(r, \varphi)$ view superpositions everyone possible functions (11.12):

$$E_m^{(2)}(r, \varphi) = \sum_{m=0}^{\infty} D_m H_m^{(2)}(kr) \cos m\varphi. \quad (11.19)$$

Obviously, expression (11.19) is even function, periodic by corner φ with period 2π , which satisfies the radiation condition and equation (11.3). Coefficients D_m - By arbitrary constant. Required define their like this in this way, to was carried out condition (11.4). Let's substitute function (11.13) V (11.4) and we will use the formula known from the theory of Bessel functions:

$$e^{i k a \cos \varphi} = J_0(ka) + 2 \sum_{m=1}^{\infty} (i)^m J_m(ka) \cos m\varphi. \quad (11.20)$$

Ratio (11.20) Can get, For example, decomposing function $e^{i k a \cos \varphi}$ V ordinary row Fourier. Substituting (11.19) And (11.20) V (11.4), we are coming towards equality

$$\sum_{m=0}^{\infty} D_m A_m^{(2)}(ka) \cos m\varphi = \left[J_0(ka) + 2 \sum_{m=1}^{\infty} (i)^m J_m(ka) \cos m\varphi \right]. \quad (11.21)$$

Left And right parts this equality Can consider How decomposition of the same function in a Fourier series. Since such an expansion is unique, the expansion coefficients must be equal and, therefore,

$$\left. \begin{aligned} D_0 &= -E_0 \frac{J_0(ka)}{H_0^{(2)}(ka)} \\ D_m &= -2i^m E_0 \frac{J_m(ka)}{H_m^{(2)}(ka)}, \quad m \geq 1 \end{aligned} \right\} \quad (11.22)$$

Substituting formulas (11.22) into (11.19), we obtain the final expression for the intensity of the secondary electric field arising when a plane wave falls on a perfectly conducting cylinder of radius a :

$$E_m^{(2)} = -E_0 \left[\frac{J_0(ka)}{H_0^{(2)}(ka)} + \sum_{m=1}^{\infty} (i)^m \frac{J_m(ka)}{H_m^{(2)}(ka)} A_m^{(2)}(kr) \cos m\varphi \right]. \quad (11.23)$$

The series in expression (11.23) is absolutely convergent and can be differentiated term by term. Therefore, this expression also allows us to find the secondary magnetic field strength.

$$H_m = \frac{i \cdot \text{rot}(E_m)}{\omega \mu}, \quad (11.24)$$

And distribution currents on surfaces cylinder.

Figure 11.2 shows the dependence of the modulus of the complex amplitude

tension secondary electric fields E_m V further zone ($r \gg a, r \gg \lambda$) V

dependences on the angle φ at a constant value of the variable r (ratio

$E_m(r, \varphi) / E_m(r, 0)$) For various values ka . Dotted curve corresponds data, calculated on basis geometric optics.

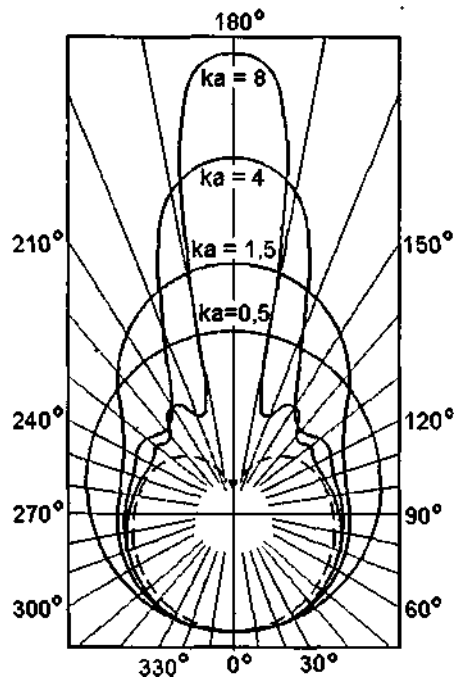


Figure 11.2

As can be seen from the graphs, as a result of diffraction, a secondary field appears with a clearly defined maximum in the direction $\varphi = 180^\circ$.

Solution tasks V form (11.16) V in principle suitable For cylinder any radius. However at large values parameter ka , those. If diameter cylinder great By comparison With length waves ($ka = 2\pi a/\lambda$), row V (11.23) converges slowly And the solution becomes inconvenient For analysis. That's why V case $ka \gg 1$ usually strive get more simple (But enough accurate For practical goals) asymptotic formulas. The rigorous method for solving the diffraction problem described here is called *the Fourier method*.

However, such a solution can only be obtained for bodies of the simplest configuration (e.g., circular and elliptical cylinders, half-planes, wedge-shaped objects, infinitely long, infinitely thin strips of finite width, spheres, circular cones, ellipsoids of revolution, infinitely thin disks, etc.). This is due to the limitations underlying the Fourier method. For its application, it is necessary that the surface of the body under consideration completely coincide with some coordinate surface of the system. coordinates, V which Maybe separation variables V equation Helmholtz. If this condition is not met, other methods must be used to solve the diffraction problem.

LABORATORY JOB No. 8.

Modeling and diffraction study on the phenomenon of Fresnel a circular hole and a half-plane

Preparing for occupation

1. Basic theoretical information:

The diffraction of electromagnetic waves by a circular aperture can be described within the framework of the Huygens-Fresnel principle using Kirchhoff's scalar diffraction theory. The field strength S diffracted by a given aperture can be determined at the receiving point using Kirchhoff's formula.

$$E_2 = \frac{i \cdot k}{2 \cdot \pi} \cdot \sqrt{30 \cdot P_A \cdot G_1} \int_S \frac{f(\theta, \varphi) \cdot \cos \alpha \cdot \exp(-i \cdot k \cdot (r_1 + r_2))}{r_1 \cdot r_2} dS, \quad (1)$$

Where P_A - power supplied To source of electromagnetic waves;

G_1 - coefficient gains transmitting antenna;

$f_1(\theta, \varphi)$ - characteristic direction transmitting antennas;

α - corner I don't want to normal To surfaces S And direction on point observations;

r_1, r_2 - distance from transmitting antennas to screen And from screen to points observations accordingly.

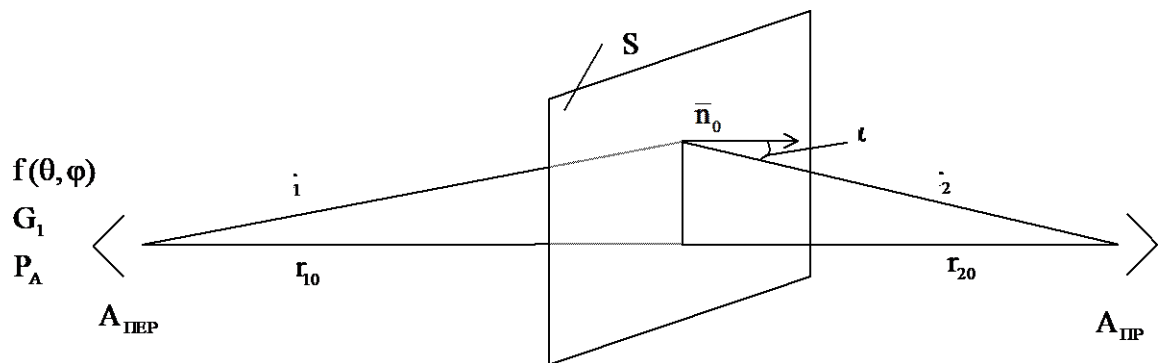


Fig. 1. Explanation of the Huygens-Fresnel principle.

In accordance with the Huygens-Fresnel principle, the surface is divided into Fresnel zones from the condition:

$$(r_{1(n-1)} + r_{2(n-1)}) - (r_{1n} + r_{2n}) \leq \frac{\lambda}{2} \quad (2)$$

Where $r_{1n}, (r_{1(n-1)})$ - distance from transmitting antenna to borders n -th, $(n-1)$ zones;

$r_{2n}, (r_{2(n-1)})$ - distance from borders n -th, $(n-1)$ zones to points, Where located

receiving antenna.

IN in accordance With (2) radius n -th zones:

$$\rho_n = \sqrt{n \cdot \lambda \cdot \frac{r_{10} \cdot r_{20}}{r_{10} + r_{20}}} \quad (3)$$

Radius areas significant For distribution makes up

$$\rho_s = \sqrt{\lambda \cdot \frac{r_{10} \cdot r_{20}}{3 \cdot (r_{10} + r_{20})}} \quad (4)$$

Results calculations $E_2 = f(\pi \cdot \rho^2) = f(S)$ given V standardized view V fifth column of table 2.

Task diffraction flat electromagnetic waves on half-planes was solved Sommerfeld. Standardized tension diffracted on half-plane of the field behind the half-plane is described by the expression

$$F(U) = 1 - \sqrt{2} \cdot \int_0^U \frac{e^{-j \frac{\pi}{4} t^2}}{t^2} dt, \quad (5)$$

where

$$Y_{ou} = \sqrt{\frac{2}{3}} \cdot \frac{H}{\rho_c}, \quad (6)$$

where H is the clearance – the distance from the line connecting the receiving and transmitting antennas to edges opaque half-planes. If half-plane Not crosses line $H > 0$ if it intersects $H < 0$;

ρ_c – is determined relation (4).

Theoretical values Functions $F(U)$ given at 6 column tables 3.

2. DESCRIPTION LABORATORY SETUP:

The laboratory setup is designed to study the laws of diffraction of electromagnetic waves on a circular hole and a half-plane.

The laboratory setup consists of a transmitting and receiving horn antennas With posted between them screen With set round holes or a half-plane screen.

Laboratory installation presented on drawing (1), she includes in yourself:

1. Generator high-frequency G4-111a or G4-111b;
2. Transmitting horn antenna;
3. Screen With set round holes or half-plane screen ;
4. Reception horn antenna;
5. Meter power: voltmeter B7-22A or block wattmeter measuring Ya2M-66.

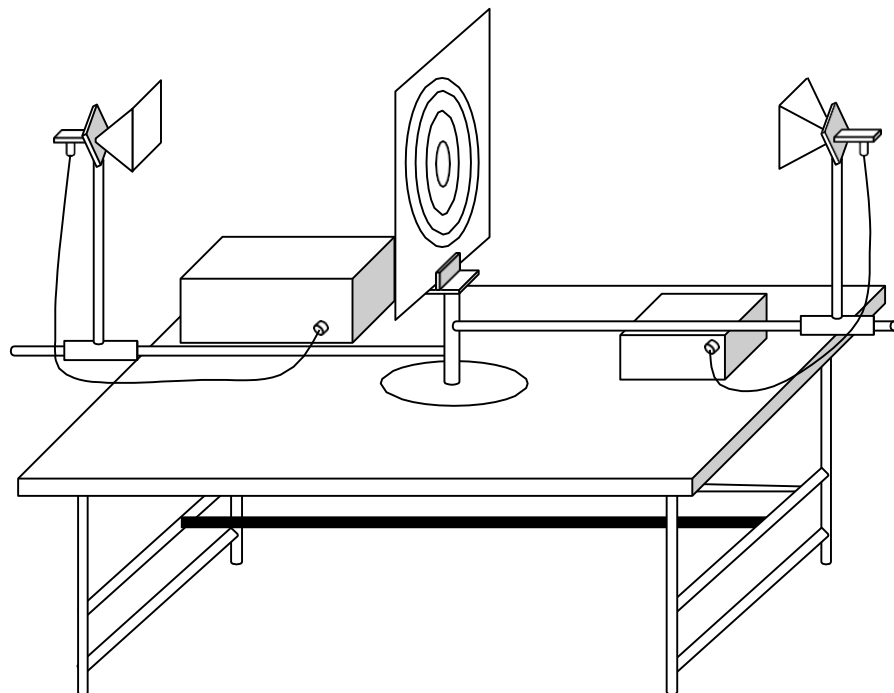


Fig.2. Laboratory installation To paragraph 1 And 2 programs.

The G4-111 generator is designed to generate high-frequency oscillations, which are fed via a coaxial feeder to a transmitting horn antenna. The transmitting antenna generates an electromagnetic field that falls on a screen with a set of circular holes or a half-plane screen. The receiving horn antenna receives diffracted electromagnetic wave And transforms her V

electromagnetic oscillations that enter the waveguide section with the detector, and then on meter power. Reception And transmitting horn antenna installed onto the racks, which are secured to the guide rods with clamping screws. Guides barbells With help couplings installed on axle-post. On end face A holder with fixing screws is attached to the axle-post with a screw, which is used to attach a screen with a set of round holes or a half-plane screen.

3. Instructions By use control and measuring equipment:

Install organs management KIA V indicated below position

4. Rules And measures security at execution works:

1. Electric current passing through the human body poses a danger to health and even life.

2. If someone is electrocuted, remove the victim from contact with live parts of the equipment. To do this, turn off the power source (disconnect the circuit breaker located in the left corner of the room).

3. Immediately call doctor And provide first pre-medical help.

4. Immediately report any excessive heating of the elements or the appearance of a burning smell to the teacher.

PROHIBITED:

1. Include laboratory installations And devices without permissions teacher.

2. Work With ungrounded equipment.

3. Open panels devices And laboratory installations.

4. Serve nourishing voltage without permission of the teacher.

5. Change the order of execution of work provided for by the measurement methodology.

6. Leave working place without permissions teacher.

5. Exercise in preparation for occupation:

1. Study the educational material on the topic "Diffraction of electromagnetic waves on various types of obstacles" and the basic theoretical information of this guide.

2. The day before classes design forms execution laboratory works:

- fill out title sheet With indication team numbers ;

- write down target And program work, measuring instruments;

- draw principled diagram laboratory installations;

- fill out chapter "Brief theoretical information";

- draw tables For results measurements. Get acquainted with the laboratory setup.

4. Get acquainted With rules use KIA. 5. Prepare for the written survey.

Scroll control questions : 1. Formulate Huygens'

theorem.

2. Please explain the significance of Fresnel's complement to Huygens's theorem.

3. Explain the meaning of the quantities included in the Kirchhoff integral.

4. Explain, How understands surface diffraction on zones Fresnel.

5. What are phases fields created neighboring And even (odd) zones?

6. How is distributed power radiation By zones Fresnel and why?

7. What You you know O radius areas significant For reflections?

8. Explain the dependence of the diffracted field strength on the number of open Fresnel zones.

9. Describe and explain the graph of the dependence of the diffracted field strength on the half-plane on the size of the clearance.
10. Describe methodology definitions areas significant For reflection of radio waves.
11. Describe methodology definitions areas significant For refraction of radio waves.

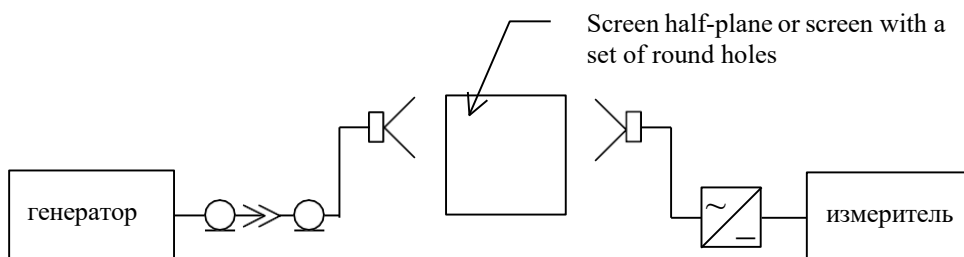


Fig.3. Working diagram to points 1 and 2 programs.

Task :

1. Study diffraction radio waves on round hole.
2. Study of radio wave diffraction on a half-plane.

Methodological explanations And recommendations:

1. By point 1 of the program.

1.1. Measure radius first zones Fresnel V laboratory installation.

- 1.2. Define distance $r_{10} = r_{20}$ from transmitting megaphone to screen And from

screen to reception megaphone, taking advantage of ratio (4) And knowing operating frequency

$$r_{10} = r_{20} = \frac{6 \cdot \rho \cdot c}{\lambda}.$$

- 1.3. Install the receiving and transmitting horns at the distances determined in this way.

- 1.4. Turn on generator and meter power. Calibrate power meter .

- 1.5. Conduct experimental studies on the number of open zones and on the area of the hole.

1.6. To measure the dependence of incoming power on the position of the open zones necessary measure power passing through screen, V which to open only one zone in sequence, starting with the zone of the corresponding area significant For distribution. Results counts power enter in the second column of table 1. in accordance with the number of the open zone, which is placed in column 1 of the table.

Table 1.

Results measurements And calculations By point 1.6.

S	P	$\frac{P}{P_{MAX}}$
$\frac{1}{3} \cdot S_1$		
S_1		
S_2		
S_3		
S_4		

S_5		
S_6		

1.7. Normalize By maximum meaning results power measurements, received data bring in V third column tables. Build

discrete schedule P dependencies $P_{MAX} = f(S)$. Do conclusions O distribution

power radio waves By Fresnel zones .

1.8. For definitions dependencies power EMV passing through the holes V screen from area holes produce measurements passing

power sequentially opening zones Fresnel V screen starting With $S = \frac{1}{3} S_1$.

Results measurements bring in in second column tables 2 V in accordance With quantity open zones. Normalize results measurements power By power received For $S = \frac{1}{3} S_1$, standardized results bring in V third

Column of Table 2. Using the data in the third column, calculate the normalized values of the electromagnetic field strength at the receiving point depending on the number of open Fresnel zones. Enter the data in the fourth column of Table 2. In the fifth column tables 2 entered theoretical data corresponding received in the fourth column. Based on the data in columns 4 and 5, construct theoretical and experimental standardized graphs dependencies tension fields V reception point from the number of open zones. Draw conclusions about the magnitude ρ_c and phases of the EMF in adjacent Fresnel zones.

Table 2.

Result measurements And calculations To point 1.8.

S	P	$\frac{P}{P_{\frac{1}{3}S_1}}$	$\sqrt{\frac{P}{P_{\frac{1}{3}S_1}}}$	$\frac{E}{E_{CB}}$
$\frac{1}{3} \cdot S_1$				
S_1				
S_1, S_2				
$S_1 \div S_3$				
$S_1 \div S_4$				
$S_1 \div S_5$				
$S_1 \div S_6$				

2. By paragraph 2.

2.1. Taking advantage of ratio (4) define radius areas essential for distribution in a laboratory setting.

2.2. Define meaning clearance corresponding values functions U (6) brought in V first column tables 3 by expression

$$H = \sqrt{\frac{3}{2}} \cdot U \cdot \rho_c.$$

Bring in received values in second column tables 3.

Table 3.

Results measurements And calculations To paragraph 2.2.

U	H [cm]	P	$\frac{P}{P_{U0.82}}$	$\sqrt{\frac{P}{P_{U0.82}}}$	F _{THEORETICAL} (In)
4					1
3					1.07
2					1
1					1.13
0.82					1
0					0.5
-1					0.2
-2					0.1
-3					0.04
-4					0.02

2.3. Turn on generator and meter power. Calibrate power meter .

2.4. Move the screen to set the clearance value H in accordance with the second column of Table 3. Measure the power values of the electromagnetic waves diffracted on the half-plane at these screen positions. The measured power values bring in V corresponding graphs third column tables 3.

Calculate standardized relatively $P_{U0.82}$ values passing power And

enter them in the fourth column of Table 3. Calculate the normalized values of the diffracted field strength and enter them in the fifth column of Table 3. The sixth column of Table 3 contains the corresponding theoretical values of the field strength diffracted fields. By data columns 5 And 6 build

graphs of the dependence of the diffracted field strength on f_n And U , draw a conclusion about the dependence of the field strength on the size of the gap.

Reporting per lesson:

1. Fill in report form .
2. Design report.
3. Prepare answers on control questions.
4. Results of calculations and measurements in the form of tables.
5. Theoretical And experimental dependence graphs .
6. Results comparisons theoretical And experimental data.
7. IN reflect in the conclusions :
 - addition distribution power radio waves By Fresnel zones ;
 - meaning quantities ρ_C and EMF phases in adjacent zones Fresnel;
 - addiction tension fields from clearance sizes .

LABORATORY JOB No. 9
Study electromagnetic waves V rectangular waveguide STUDY QUESTIONS:

TARGET SETTING OF PRACTICAL WORK :

Results training, achievable V result execution laboratory work:

Be able to:

– apply the basic laws and mathematical apparatus of electrodynamics to computer modeling and analysis of electromagnetic fields and waves in various media and guiding systems.

Own:

– skills in determining the characteristics of electromagnetic fields required for solving practical problems for calculating radio coverage, radio relay and satellite routes.

TRAINING AND MATERIAL SUPPORT:

- A personal computer with an electronic circuit simulator “Electronics Workbench” and a computer mathematics system “Mathcad”;
- electronic methodological development By laboratory work.

QUESTIONS, SUBJECTS RESEARCH

Brief theoretical or reference and information materials

Let's consider wave magnetic type H_{10} , which V force rows circumstances has become widespread among other types of waves when using a rectangular waveguide as a transmission line. Let's clarify these circumstances, for which we first turn to λ_{kpmm} . As we have found out, λ_{kpmm} Both E and H waves are calculated using the same equation (7.12):

$$\lambda_{\text{kpmm}} = \frac{2\pi}{\sqrt{\left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2}} = \frac{2}{\sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2}}$$

Condition distribution waves How E, So And N - type is inequality $\lambda < \lambda_{\text{kpmm}}$. Let's calculate λ_{kp} some types of magnetic and electric waves:

- wave $H_{10} \Rightarrow \lambda_{\text{kp}} = 2a$;
- wave $H_{01} \Rightarrow \lambda_{\text{kp}} = 2b$;
- wave $H_{20} \Rightarrow \lambda_{\text{kp}} = A$;
- wool $H_{02} \Rightarrow \lambda_{\text{cr}} = b$;

$$\lambda_{\text{cr}} = \frac{2ab}{\sqrt{a^2 + b^2}}$$

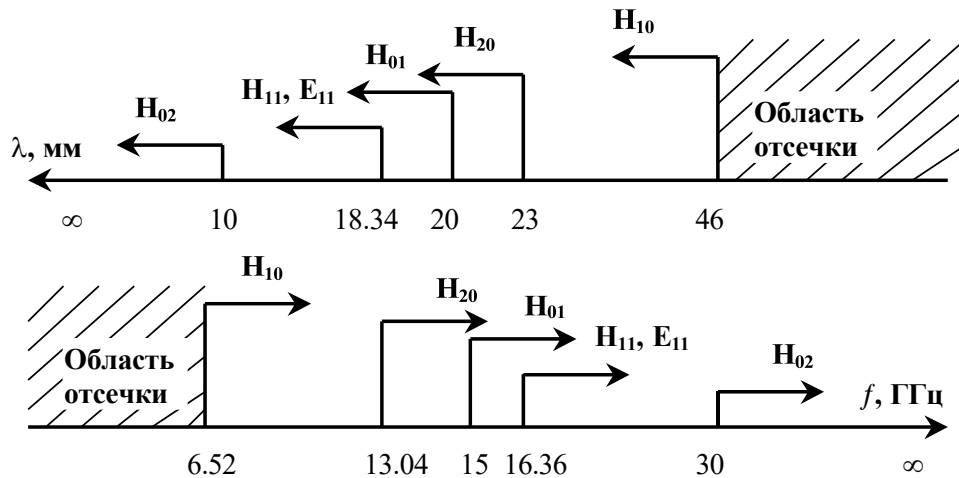
- wool $H_{11} = E_{11} \Rightarrow$; and etc.

If assume What $A > b$ (A - size wide walls, b - narrow walls waveguide), it is clear that:

1. Wave H_{10} possesses the greatest critical length waves;
2. λ_{kp} some types waves match (V particulars E_{11} and H_{11}). Such The waves are called *degenerate*.

Let's depict on Fig. 7.10 scale critical length waves And critical frequencies of a rectangular waveguide (for definiteness, let us set $a = 23 \text{ mm}$, $b = 10 \text{ mm}$):

Shaded region corresponds complete cutoff, By waveguide V this frequency ranges (or length waves) Not can spread none types waves. IN areas from f_{kr10}



Drawing 7.10- Scale $\lambda_{кр}$ And $f_{кр}$ rectangular waveguide $23 \times 10 \text{ mm}$

up to f_{kr20} Only the H_{10} wave can propagate . In the region from f_{kr20} to f_{kr01} – can spread two waves at the same time H_{10} and H_{20} . Thus, the larger f , the more waves can simultaneously propagate in a rectangular waveguide.

IN connections With this distinguish between:

- Single-mode operation is when only one type of wave can propagate through the waveguide.
- Multimode mode, when several types of waves can propagate through the waveguide.

The fundamental difference between these operating modes of a rectangular waveguide is as follows: in single-mode operation, all power from the generator to the load is transferred through the waveguide by a single wave type, H_{10} . In multimode operation , this power is distributed among all wave types capable of propagating in the waveguide. Since the terminal devices used to extract electromagnetic energy from the waveguide can only be designed for a strictly defined wave type, some of the power transferred by other wave types will simply be lost.

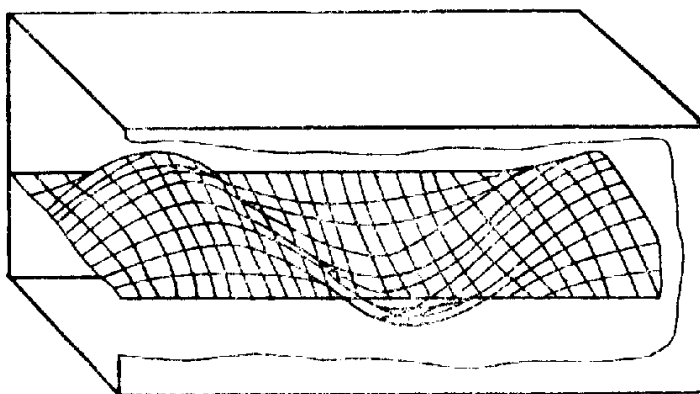
In this regard, in practical implementation of transmission lines, rectangular waveguides are used only in single-mode mode with an H_{10} wave .

Let's consider main characteristics waves H_{10} .

1. Structure fields waves H_{10}

Because indices $m = 1$ And $n = 0$, then from equations (7.21) easily get expressions for the components of the electromagnetic wave H_{10} :

$$\begin{cases}
 E_{\text{and}} = H_{\text{or}} \frac{-j \omega \mu_a \gamma_1}{\gamma^2} \text{without} \left(\frac{\pi}{x} \right) e^{j(\omega t - \beta z)} = E_I \text{without} \left(\frac{\pi}{x} \right) e^{j(\omega t - \beta z)} \\
 H_x = H_{x0} \sin \left(\frac{\pi}{a} x \right) e^{j(\omega t - \beta z)} \\
 H_z = H_{z0} \cos \left(\frac{\pi}{a} x \right) e^{j(\omega t - \beta z)} \\
 E_z = E_x = H_{\text{and}} \\
 x = 0
 \end{cases}
 \quad (7.22)$$



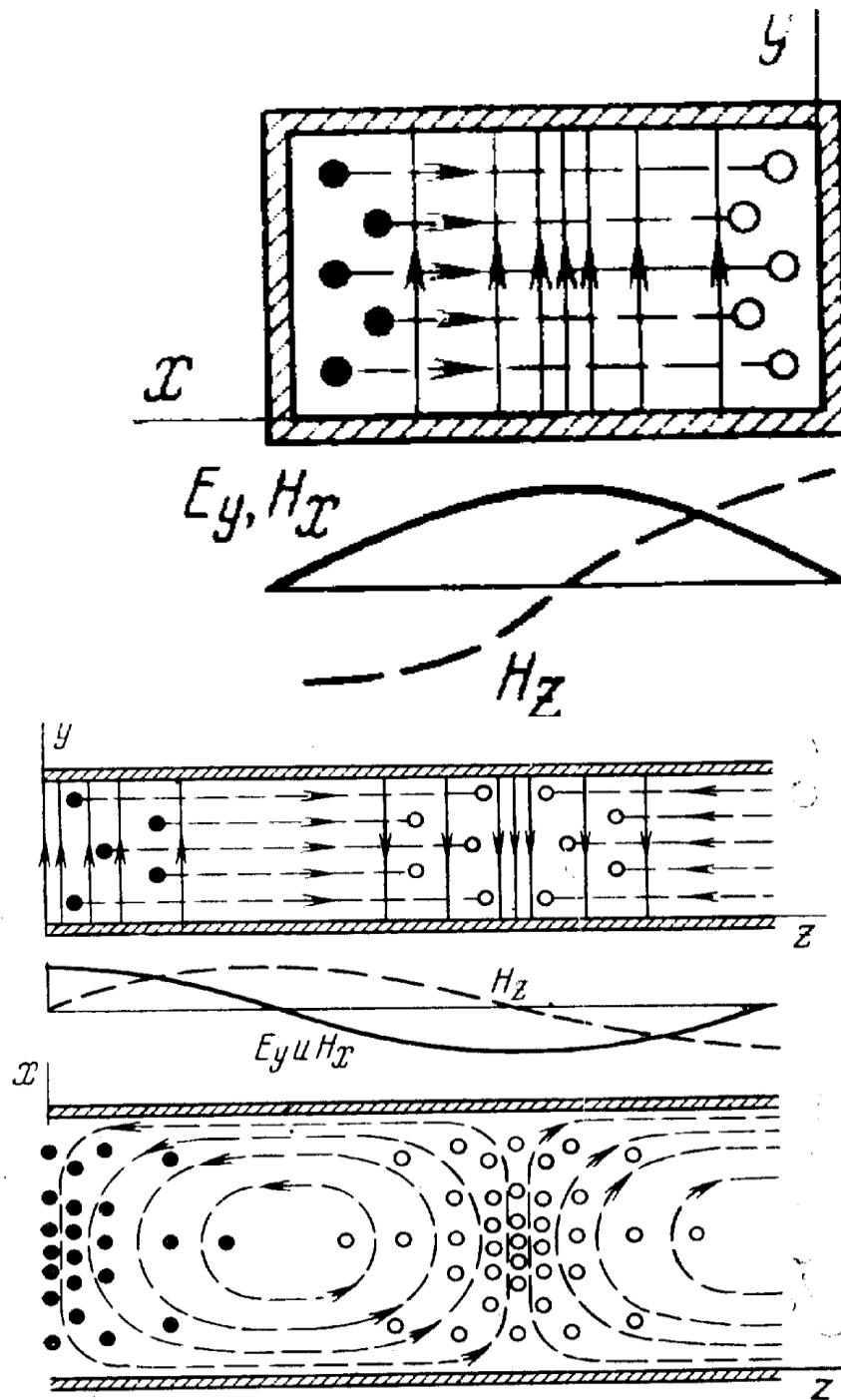


Figure 7.11- Structure of the H_{10} wave field Taking

advantage of these equations, let's depict structure waves H_{10} V directly
 coal waveguide V fixed moment time $t=0$, (see fig. 7.11). At In this we will keep in mind

that:

- tension electric fields waves H_{10} :

$$\vec{E} = x_0 E_x + y_0 E_y + z_0 E_z = y_0 E_{y0} \sin\left(\frac{\pi}{a} x\right) e^{-j\beta z}$$

$$E = \text{Re} \left[\vec{E} e^{j\omega t} \right] = E_{y0} \sin\left(\frac{\pi}{a} x\right) \cos(\beta z)$$

instantaneous value:

- tension magnetic fields:

$$H = x \text{ or } H_x + \text{and } H_y \text{ and } + z \text{ or } H_z = x \text{ or } H_x \text{ without } (x) e^{-j\beta z} + z \text{ or } H_z \cos\left(\frac{\pi}{a} x\right) e^{-j\beta z}$$

$$= H_m \left(\frac{\pi}{a} \sin\left(-\frac{\pi}{a} x\right) + \frac{\pi}{a} \cos\left(-\frac{\pi}{a} x\right) \right) e^{-j\beta z}$$

equation of a circle

Where:

$$H_m = \sqrt{H_{x0}^2 + H_{z0}^2}$$

$$H = \operatorname{Re} \left[e^{j\left(\frac{\pi}{a} x + \frac{\pi}{a} x\right) - j\beta z} \right]$$

$$H = H_m \left(\sin\left(\frac{\pi}{a} x\right) + \cos\left(\frac{\pi}{a} x\right) \right) \cos \beta z$$

instantaneous value:

x)

2. Vector Poynting And power, portable By rectangular waveguide.

From the system of equations (7.22) it follows that the

Poynting vector has two components Π_x and Π_z :

$$\Pi_x = \frac{1}{2} E_y H_z - \frac{1}{2} E_z H_y = \frac{1}{2} E_y H_x \sin\left(\frac{\pi}{a} x\right) \cos\left(\frac{\pi}{a} x\right) = \frac{1}{4} E_{y0} H_{x0} \sin\left(2 \frac{\pi}{a} x\right)$$

Therefore, the average meaning vectors Poynting along the x-axis: $\Pi_x = 0$.

$$\Pi_z = \frac{1}{2} E_y H_x + \frac{1}{2} E_z H_y = \frac{1}{2} E_{y0} H_{x0} \sin\left(\frac{\pi}{a} x\right) \cos\left(\frac{\pi}{a} x\right) + \frac{1}{2} E_{z0} H_{y0} \cos\left(\frac{\pi}{a} x\right) \sin\left(\frac{\pi}{a} x\right)$$

$$= \frac{1}{2} E_{y0} H_{x0} \cos\left(\frac{\pi}{a} x\right) \sin\left(\frac{\pi}{a} x\right) + \frac{1}{2} E_{z0} H_{y0} \sin\left(\frac{\pi}{a} x\right) \cos\left(\frac{\pi}{a} x\right)$$

Hence, average meaning vectors Poynting along axes z: $\Pi_z \neq 0$, A This, V which in turn means that the power is transferred along the waveguide along the z-axis. Let us define this power. Because P - density flow power, portable through unit area, then the total power:

$$P = \int_S \Pi_z dS \quad (7.23)$$

Where: S - square transverse sections waveguide. Considering orthogonality

vectors Π_z And dS , equation (7.23) Can introduce How:

$$P = \int_0^a \int_0^b \Pi_z dx dy = \frac{1}{2} \int_0^a E_{y0} H_{x0} \sin\left(\frac{\pi}{a} x\right) dx \int_0^b dy$$

To calculate this integral, we define the relationship between E_{y0} and H_{x0} . By analogy with free space, the ratio of the transverse components E_y and H_x is called *the wave impedance* of a rectangular waveguide.

$$Z_B = \frac{E_{y0}}{H_{x0}} = \left(\text{iz 7.22} \right) = \frac{\omega \mu_a}{\beta} = \frac{2 \pi f \mu_a}{2 \pi / \lambda_{in}} = \mu_a \frac{f \cdot \lambda}{\sqrt{1 - \left(\frac{\lambda}{\lambda_{cr}} \right)^2}}$$

yes

$$= \mu_a \frac{\text{with}}{\sqrt{1 - \left(\frac{\lambda}{\lambda_{kp}} \right)^2}} = \frac{\mu \cdot}{\sqrt{\epsilon_0 \mu_0} \sqrt{1 - \left(\frac{\lambda}{\lambda_{kp}} \right)^2}} = \frac{Z_0}{\sqrt{1 - \left(\frac{\lambda}{\lambda_{kp}} \right)^2}}$$

$$1 - \left| \frac{\lambda_{\text{кр}}}{\lambda} \right| \quad (7.24)$$

With $= \frac{1}{\sqrt{\epsilon_0 \mu_0}}$ - speed of light,

Where: $Z_0 = \sqrt{\frac{\mu_0}{\epsilon_0}} = 120 \pi$ - characteristic (wave) resistance vacuum.

$$H_{xo} = \frac{E_{yo}}{Z_B}$$

From expressions (7.24) we get:
Then:

$$P = \frac{1}{2} \int_0^a \frac{E_{yo}^2}{Z_B} \sin^2\left(\frac{\pi}{a}x\right) dx \int_0^b dy = \frac{1}{2} \frac{E_{yo}^2}{Z_B} \int_0^a \sin^2\left(\frac{\pi}{a}x\right) dx \int_0^b dy =$$

$$\frac{ab}{4} \frac{E_{yo}^2}{Z_B} = E_{yo}^2 \frac{ab}{4Z_0} \sqrt{1 - \left(\frac{\lambda}{\lambda_{kp}}\right)^2} \quad (7.25)$$

Based on from (7.25), let's build schedule dependencies R from lengths waves (cm. Fig.7.12).

1. Attenuation in a rectangular waveguide. Choice geometric dimensions of the waveguide for single-mode operation.

Calculation attenuation (losses) V rectangular waveguide enough is a labor-intensive task, so we will only give the final expression for the H_{10} wave:

$$\alpha = \frac{R_s \left[1 + \frac{2b}{a} \left(\frac{\lambda}{2a} \right)^2 \right]}{Z_0 b \sqrt{1 - \left(\frac{\lambda}{\lambda_{kp}} \right)^2}} \quad [1/m] \quad (7.26)$$

$$R_s = \sqrt{\frac{\omega \mu_a}{2\sigma}}$$

Where: R_s - superficial resistance walls of the waveguide;
 σ - specific conductivity walls waveguide; b is the size of the narrow wall of the waveguide.

On basis (7.25) let's build graph of the dependence of α on wavelength (see Fig. 7.12). The increase in α with increasing frequency (decreasing λ) is associated with two circumstances:

- R_s increases with increasing frequency;
- The possibility of propagation of higher types of waves appears.

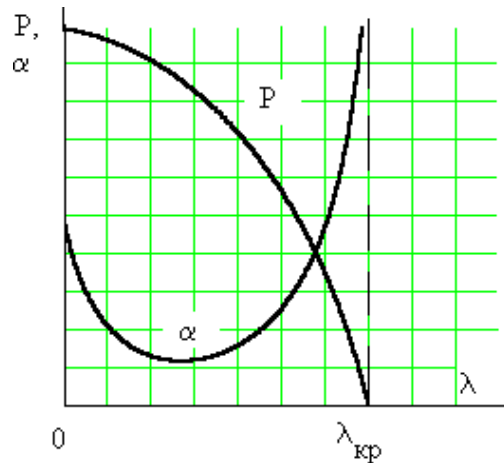
Knowing now the dependence of $P(\lambda)$ and $\alpha(\lambda)$, it is easy to determine the requirements for a rectangular waveguide for practical use as a transmission line:

- Broadcast energy should be carried out only one type of wave.
- Possibility of transmitting high power through a waveguide.
- Losses α should be minimal.
- Geometric sizes and waveguide weight should be minimal.

Let us determine the dimensions of a rectangular waveguide that meet these requirements:

$$\left. \begin{aligned} \lambda_{\text{slave}} < \lambda_{\text{kpH10}} = \frac{2a}{\sqrt{1 - \left(\frac{a}{b}\right)^2}} \\ \lambda_{\text{паб}} > \lambda_{\text{кпH20}} = a \\ \lambda_{\text{паб}} > \lambda_{\text{кпH01}} = 2b \end{aligned} \right\} \Rightarrow \left. \begin{aligned} \frac{2}{\sqrt{1 - \left(\frac{a}{b}\right)^2}} < \frac{\lambda_{\text{паб}}}{a} \\ 0 < b < \frac{\lambda_{\text{паб}}}{2} \end{aligned} \right\}$$

From equations (7.24) and (7.25) it follows that the smaller the size of b , the smaller P and the larger α . That's why size b choose on practice only few less, how $\lambda_{\text{slave}}/2$, i.e. $b \approx (0.35 \div 0.45) \lambda_{\text{slave}}$. Now O size A. At approaching A To $\lambda_{\text{slave}}/2$ sharp increases α and P decreases, and as a approaches λ_{work} α increases monotonically and there is a possibility excitement higher types waves. That's why size A choose V in most cases within the range of $a \approx (0.7 \div 0.8) \lambda_{\text{work}}$.



Drawing 7.12- Addition R And α V rectangular waveguide from the wavelength

1) Definition complex amplitudes transverse components vectors $\vec{H}$, A then from equations Maxwell let's define complex amplitudes components vectors $\vec{E}$, using the ratio

$$\vec{H}_{\perp} = \vec{x}_0 \dot{H}_{xm} + \vec{y}_0 \dot{H}_{ym} = -\frac{j}{\beta_{\perp}^2} \left[\text{grad} H^0(x, y) \right] \exp(-j\beta z) \quad (1)$$

We'll find it complex amplitudes components vectors $\vec{H}$, using the above relationship:

$$\text{grad} H^0(x, y, z) = \frac{\partial H^0}{\partial x} \vec{x} + \frac{\partial H^0}{\partial y} \vec{y} + \frac{\partial H^0}{\partial z} \vec{z} = \frac{\pi H_0 \sin(\frac{\pi x}{a}) \cos(\frac{\pi y}{b})}{a} \vec{x} - \frac{\pi H_0 \cos(\frac{\pi x}{a}) \sin(\frac{\pi y}{b})}{b} \vec{y} \quad (2)$$

Substituting meaning from (2) V (1) let's find the complex vector shape $\vec{H}$:

$$\vec{H} = \frac{j\beta}{2} \left[\vec{x} \frac{\pi H_0 \sin(\frac{\pi x}{a}) \cos(\frac{\pi y}{b})}{a} + \vec{y} \frac{\pi H_0 \cos(\frac{\pi x}{a}) \sin(\frac{\pi y}{b})}{b} \right] \exp(-j\beta z) \quad (3)$$

Let's write it down projections complex amplitudes vectors $\vec{H}$ on coordinate axes:

$$H_{mx} = N \frac{\beta \pi}{\gamma^2 a} \cos\left(\frac{\pi x}{a}\right) \cos\left(\frac{\pi y}{b}\right) \exp\left(j\left(\frac{\pi}{2} - \beta z\right)\right) \quad (4)$$

$$H_{my} = H_0 \frac{\beta \pi}{\gamma^2 b} \cos\left(\frac{\pi x}{a}\right) \sin\left(\frac{\pi y}{b}\right) \exp\left(j\left(\frac{\pi}{2} - \beta z\right)\right) \quad (5)$$

$$H_{zm} = H_0 \cos\left(\frac{\pi x}{a}\right) \cos\left(\frac{\pi y}{b}\right) \exp(-j\beta z) \quad (6)$$

Let us use Maxwell's first equation in complex form to determine the complex amplitude of the vector $\vec{E}$:

$$\text{rot} \vec{H} = j\omega \varepsilon \vec{E}, \quad \text{Where } \varepsilon - \text{absolute dielectric permeability}$$

$\omega = 2\pi f$, f – the frequency of electromagnetic oscillations, then from here $\vec{E}_m = \frac{\text{rot} \vec{H}}{j\omega \varepsilon}$

$$E_{my} = \frac{\text{rot} H_x}{j\omega \varepsilon} = \frac{\partial H_x}{\partial z} = \frac{\pi H_0 \sin(\frac{\pi x}{a}) \cos(\frac{\pi y}{b})}{a} \exp(-j\beta z)$$

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We will find $\vec{rot}\dot{\vec{H}}_m$:

$$\vec{rot}\dot{\vec{H}}_m = \begin{vmatrix} \vec{x}_0 & \vec{y}_0 & \vec{z} \\ \frac{\partial}{\partial x} & \frac{\partial}{\partial y} & \frac{\partial}{\partial z} \\ \dot{H}_{mx} & \dot{H}_{my} & \dot{H}_{mz} \end{vmatrix} = \vec{x}_0 \left(\frac{\partial \dot{H}_{mz}}{\partial y} - \frac{\partial \dot{H}_{my}}{\partial z} \right) - \vec{y}_0 \left(\frac{\partial \dot{H}_{mz}}{\partial x} - \frac{\partial \dot{H}_{mx}}{\partial z} \right) + \vec{z}_0 \left(\frac{\partial \dot{H}_{my}}{\partial x} - \frac{\partial \dot{H}_{mx}}{\partial y} \right)$$

Then components complex amplitudes vectors $\vec{E}$ equal respectively:

$$E_{mx} = \frac{1}{j\omega\epsilon_a} \left(\frac{\partial \dot{H}_{mz}}{\partial y} - \frac{\partial \dot{H}_{my}}{\partial z} \right) \quad (7)$$

$$E_{my} = \frac{-1}{j\omega\mu_a} \left(\frac{\partial \dot{H}_{mz}}{\partial x} - \frac{\partial \dot{H}_{mx}}{\partial z} \right) \quad (8)$$

$$E_{mz} = \frac{1}{j\omega\epsilon_a} \left(\frac{\partial \dot{H}_{my}}{\partial x} - \frac{\partial \dot{H}_{mx}}{\partial y} \right) \quad (9)$$

Let us find expressions for the partial derivatives of the components of the complex vector amplitudes $\vec{E}$ By corresponding coordinates:

$$\frac{\partial \dot{H}_{mz}}{\partial y} = -H_0 \frac{\pi}{b} \cos\left(\frac{\pi x}{a}\right) \sin\left(\frac{\pi y}{b}\right) \exp(-j\beta z)$$

$$\frac{\partial \dot{H}_{mz}}{\partial x} = -H_0 \frac{\pi}{b} \sin\left(\frac{\pi x}{a}\right) \cos\left(\frac{\pi y}{b}\right) \exp(-j\beta z)$$

$$\frac{\partial \dot{H}_{my}}{\partial z} = -H_0 \frac{\pi\beta^2}{\gamma_{\perp}^2 b} \cos\left(\frac{\pi x}{a}\right) \sin\left(\frac{\pi y}{b}\right) \exp(-j\beta z + i\frac{\pi}{2}) \exp(j\frac{\pi}{2})$$

$$\frac{\partial \dot{H}_{my}}{\partial x} = -H_0 \frac{\pi^2\beta}{\gamma_{\perp}^2 ab} \sin\left(\frac{\pi x}{a}\right) \sin\left(\frac{\pi y}{b}\right) \exp(-j\beta z + j\frac{\pi}{2})$$

$$\frac{\partial \dot{H}_{mx}}{\partial y} = -H_0 \frac{\pi^2\beta}{\gamma_{\perp}^2 ab} \sin\left(\frac{\pi x}{a}\right) \cos\left(\frac{\pi y}{b}\right) \exp(-j\beta z + j\frac{\pi}{2})$$

$$\frac{\partial \dot{H}_{mx}}{\partial z} = -H_0 \frac{\pi\beta^2}{\gamma_{\perp}^2} \sin\left(\frac{\pi x}{a}\right) \cos\left(\frac{\pi y}{b}\right) \exp(-j\beta z + i\frac{\pi}{2}) \exp(j\frac{\pi}{2})$$

Substituting found values private derivatives V (7), (8) And (9), we obtain the final expressions for the complex amplitudes of the vector components $\vec{E}$:

$$\begin{aligned}
 (10) \quad E_{mx} &= -H_0 \frac{\pi(\gamma_{\perp}^2 + \epsilon_a)}{\gamma_{\perp}^2 b \omega \epsilon_a} \cos\left(\frac{\pi x}{a}\right) \sin\left(\frac{\pi z}{b}\right) \exp\left[-i\left(\beta z + \frac{\pi}{2}\right)\right] \\
 (11) \quad E_{my} &= -H_0 \frac{\pi(\gamma_{\perp}^2 + \epsilon_a)}{\gamma_{\perp}^2 a \omega \epsilon_a} \sin\left(\frac{\pi x}{a}\right) \cos\left(\frac{\pi z}{b}\right) \exp\left[-i\left(\beta z + \frac{\pi}{2}\right)\right] \\
 (12) \quad E_{mz} &= 0
 \end{aligned}$$

2) Definition range frequencies, V which β - valid number, i.e. the field under consideration is a traveling wave.

By condition tasks $\beta = k \sqrt{1 - (\lambda/\lambda_{kp})^2}$. Means, β will valid V case,

If

$$1 - \left(\frac{\lambda}{\lambda_{kp}}\right)^2 \geq 0, \text{ i.e. at } \lambda \leq \lambda_{kp}$$

$$\lambda_{kr} = \frac{2ab}{\sqrt{a^2 + b^2}} = 0.067\text{m} = 6.7\text{cm}$$

To this range length waves corresponds range frequencies:

$$f \in \left[f_{kp}, \infty \right), \text{ Where } f_{kp} = \frac{c}{\lambda_{kp}} = \frac{c}{\frac{2ab}{\sqrt{a^2 + b^2}}} = 3,005 \text{ GHz},$$

Where $WITH = \frac{1}{\lambda_{kp}}$, $\epsilon_a = \epsilon_0 \epsilon_r$, $\mu_a = \mu_0 \mu_r$

Like this in this way, If frequency waves Not belongs calculated range frequencies, That β is imaginary size. For this case we will produce replacement: $\beta = -j\alpha$, $\alpha = \beta$, while $|\exp(-j\beta z)| = \exp(-\alpha z)$, $\alpha = k \sqrt{(\lambda/\lambda_{kp})^2 - 1}$

3) Definition instant values everyone components vectors $\vec{E}$ And $\vec{H}$ For two cases:

A) When f belongs found V p. 2 range frequencies b) when f does not belong to this range.

For receipt expressions For instant values components vectors fields required multiply their complex amplitudes on expression $\exp(j\omega t)$ And, highlight valid Part, That There is:

$$HAVE BEEN = \text{Re}\left(E_m \cdot have been^{j\omega t}\right); \quad A = \text{Re}\left(H_m \cdot have been^{j\omega t}\right)$$

IN first case expressions For complex amplitudes components remain No changes. In the second case, it is necessary to make the replacement described in paragraph 2.

At $f > f_{kr}$ expressions For complex amplitudes components magnetic and electric fields have the form:

$$H_x = H_0 \frac{\beta \pi}{\gamma^2 a} \cos\left(\frac{\pi x}{a}\right) \sin\left(\frac{\pi y}{b}\right) \cos\left(\omega t - \beta z + \frac{\pi}{2}\right) \quad (13)$$

$$H_y = H_0 \frac{\beta \pi}{\gamma^2 b} \cos\left(\frac{\pi x}{a}\right) \sin\left(\frac{\pi y}{b}\right) \cos\left(\omega t - \beta z + \frac{\pi}{2}\right) \quad (14)$$

$$H_z = H_0 \cos\left(\frac{\pi x}{a}\right) \cos\left(\frac{\pi y}{b}\right) \cos(\omega t - \beta z) \quad (15)$$

$$E_x = -H_0 \frac{\pi(\gamma_{\perp}^2 + \beta^2)}{\gamma^2 b} \frac{1}{\omega \epsilon} \cos\left(\frac{\pi x}{a}\right) \sin\left(\frac{\pi y}{b}\right) \cos\left(\omega t - \beta z + \frac{\pi}{2}\right) \quad (16)$$

$$E_y = -H_0 \frac{\pi(\gamma_{\perp}^2 + \beta^2)}{\gamma^2 b} \frac{1}{\omega \epsilon} \sin\left(\frac{\pi x}{a}\right) \cos\left(\frac{\pi y}{b}\right) \cos\left(\omega t - \beta z + \frac{\pi}{2}\right) \quad (17)$$

$$E_{from} = 0 \quad (18)$$

At $f < f_{kr}$ expressions For complex amplitudes components magnetic and electric fields have the form:

$$H_x = H_0 \frac{\alpha \pi}{\gamma^2 a} \cos\left(\frac{\pi x}{a}\right) \cos\left(\frac{\pi y}{b}\right) e^{-\alpha z} \cos(\omega t) \quad (19)$$

$$H_y = H_0 \frac{\alpha \pi}{\gamma^2 b} \cos\left(\frac{\pi x}{a}\right) \cos\left(\frac{\pi y}{b}\right) e^{-\alpha z} \cos(\omega t) \quad (20)$$

$$H_z = H_0 \cos\left(\frac{\pi x}{a}\right) \cos\left(\frac{\pi y}{b}\right) e^{-\alpha z} \cos(\omega t) \quad (21)$$

$$E_x = H_0 \frac{\pi(\alpha^2 - \gamma_\perp^2)}{\gamma_\perp \omega} \cos \left(\frac{\pi x}{a} \right) \cos \left(\frac{\pi y}{b} \right) e^{-\alpha z} \cos \left(\omega t - \frac{\pi}{2} \right) \quad (22)$$

$$E_y = H_0 \frac{\pi(\alpha^2 - \gamma^2)}{\gamma} e^{-\gamma z} \cos\left(\frac{\pi x}{a}\right) \cos\left(\frac{\pi y}{b}\right) \cos(\omega t - \beta z) \quad (23)$$

$$E_z = 0 \quad (24)$$

Content practical work, performed students

1. Description laboratory equipment:

- PC With established system computer algebra Mathcad-14".

2. Initial data for modeling and research Options tasks For research given V table 1. Table 1 – Initial data for task 1

No. the option	Yes, In/m	a,m	b,m	x	y	z
1	3	0.06	0.04	0.4a	0.2b	0.8z0
2	2	0.05	0.03	0.3a	0.9b	0.5z0
3	4	0.055	0.035	0.6a	0.4b	1.3z0
4	2.5	0.045	0.025	0.8a	0.2b	1,2z0
5	5	0.07	0.05	0.5a	0.75b	0,9z0
6	2.2	0.075	0.055	0.3a	0.4b	1.4z0
7	3.1	0.08	0.06	0.2a	0.25b	1,2z0
8	3.3	0.045	0.025	0.9a	0.6b	0.75z0
9	2.8	0.07	0.05	0,4a	0,15b	0,4z0
10	3.15	0.06	0.04	0,2a	0.6b	1,2z0
11	2.6	0.05	0.03	0,75a	0,4b	0,65z0
12	4.2	0.055	0.035	0,4a	0,2b	0,6z0
13	2	0.06	0.04	0,25a	0.65b	0.8z0
14	4	0.05	0.03	0.6a	0.4b	0.5z0
15	2.5	0.055	0.035	0.15a	0.25b	1.3z0

3. Exercise for work

4. Order execution work

Exercise 1. Modeling And study waves H10 V rectangular waveguide.

1.1. Modeling waves N V rectangular waveguide V system "Mathcad".

Modeling waves N is being conducted For frequencies more critical

8) Enter V working window programs original data:

- dielectric permeability Wednesday ϵ_r according to the option;
- magnetic permeability Wednesday μ_r according to option;
- electric constant -

$$\epsilon_0 := \frac{1}{36 \cdot \pi} \cdot 10^{-9} = 8.842 \times 10^{-12} ;$$

– magnetic constant–

$$\mu_0 := 4 \cdot \pi \cdot 10^{-7} = 1.257 \times 10^{-6} ;$$

– absolute dielectric permeability Wednesday $\epsilon_a := \epsilon_0 \cdot \epsilon_r$;

– absolute magnetic permeability Wednesday $\mu_a := \mu_0 \cdot \mu_r$;

– amplitude magnetic vector fields No according to the option;

– speed Sveta V environment -

$$C := \frac{1}{\sqrt{\epsilon_a \cdot \mu_a}} ;$$

– critical wavelength–

$$\lambda_{kp} := \frac{2a \cdot b}{\sqrt{a^2 + b^2}} ;$$

– critical frequency–

$$f_{kp} := \frac{C}{\lambda_{kp}} ;$$

– frequency -

$$f_1 := f_{kp} + 1 \cdot 10^9 ;$$

– circular frequency–

$$\omega_1 := 2 \cdot \pi \cdot f_1 ;$$

– wavelength in Wednesday–

$$\lambda_1 := \frac{C}{f_1} ;$$

– transverse wave number -

$$\gamma_1 := \frac{2\pi}{\lambda_{kp}} ;$$

– constant wave propagation in unlimited space–

$$k_1 := \frac{2 \cdot \pi}{\lambda_1} ;$$

– constant distribution waves V guide system–

$$\beta := k_1 \cdot \sqrt{1 - \left(\frac{\lambda_1}{\lambda_{kp}} \right)^2} ;$$

$$z_0 := \frac{4 \cdot \pi}{\beta} ;$$

– coefficients H waves $m=1, n=1$;

9) Enter formulas for the complex amplitudes of the components of the magnetic and

of the

electric fields:

$$E_{mx}(x, y, z) := -H_0 \cdot \frac{\pi(\gamma I^2 + \beta^2)}{\gamma I^2 \cdot b \cdot \omega_1 \cdot \epsilon a} \cdot \cos\left(\frac{m \cdot \pi x}{a}\right) \cdot \sin\left(\frac{n \cdot \pi y}{b}\right) \cdot \cos(\beta \cdot z) ;$$

$$E_{my}(x, y, z) := -H_0 \cdot \frac{\pi(\gamma I^2 + \beta^2)}{\gamma I^2 \cdot a \cdot \omega_1 \cdot \epsilon a} \cdot \sin\left(\frac{m \cdot \pi x}{a}\right) \cdot \cos\left(\frac{n \cdot \pi y}{b}\right) \cdot \cos(\beta \cdot z) ;$$

$$H_{mx}(x, y, z) := H_0 \cdot \frac{\beta \cdot \pi}{\gamma I^2 \cdot a} \cdot \sin\left(\frac{m \cdot \pi x}{a}\right) \cdot \cos\left(\frac{n \cdot \pi y}{b}\right) \cdot \cos(\beta \cdot z) ;$$

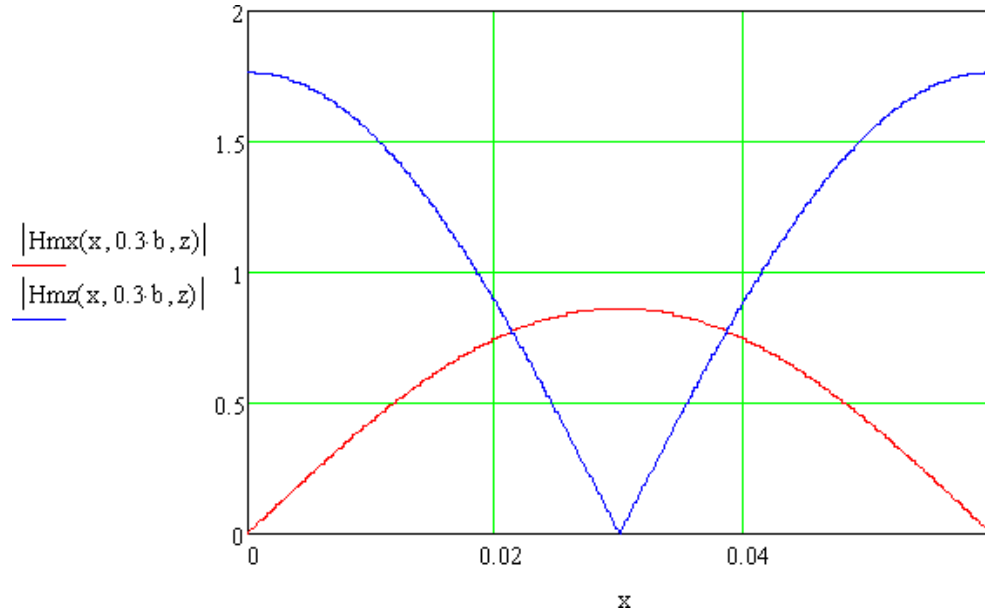
$$H_{my}(x, y, z) := H_0 \cdot \frac{\beta \cdot \pi}{\gamma I^2 \cdot b} \cdot \cos\left(\frac{m \cdot \pi x}{a}\right) \cdot \sin\left(\frac{n \cdot \pi y}{b}\right) \cdot \cos(\beta \cdot z) ;$$

$$H_{mz}(x, y, z) := H_0 \cdot \cos\left(\frac{m \cdot \pi x}{a}\right) \cdot \cos\left(\frac{n \cdot \pi y}{b}\right) \cdot \cos(\beta \cdot z) ;$$

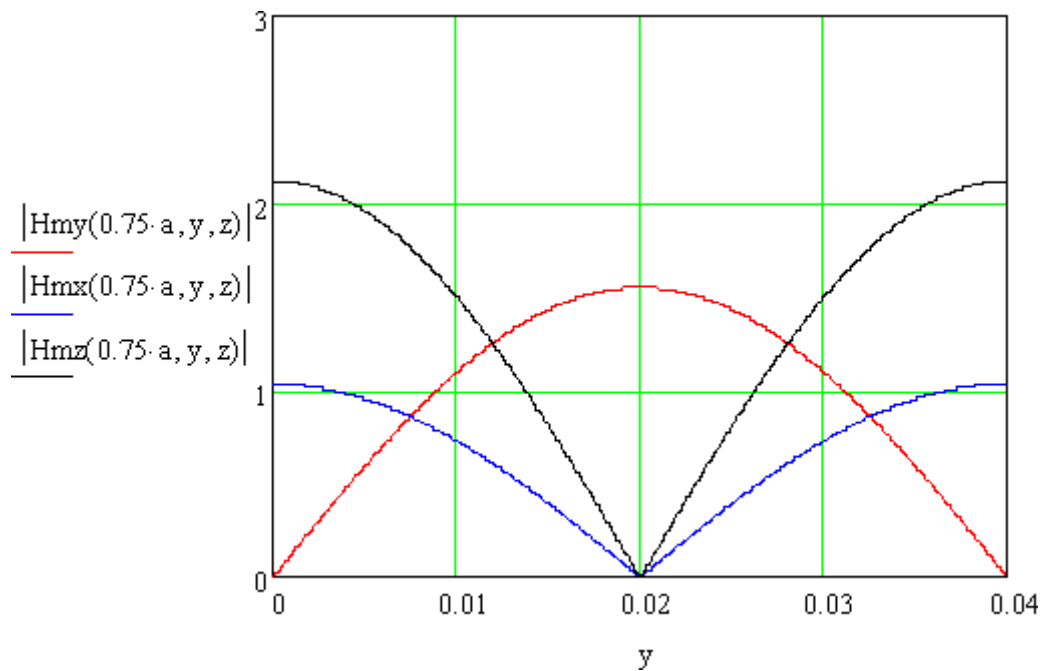
10) For checks results modeling let's build graphs dependencies amplitudes of the field components along the axes x and y:

- Build schedule H_{mx}, H_{my} along axes X. IN quality coordinates take y=0.3*b, z= z₀ ;
- Build schedule H_{mx}, H_{my}, H_{mz} along axes y. IN quality coordinates take x=0.1*a, z= z₀ ;

Examples graphs given on drawings 1.1 And 1.2



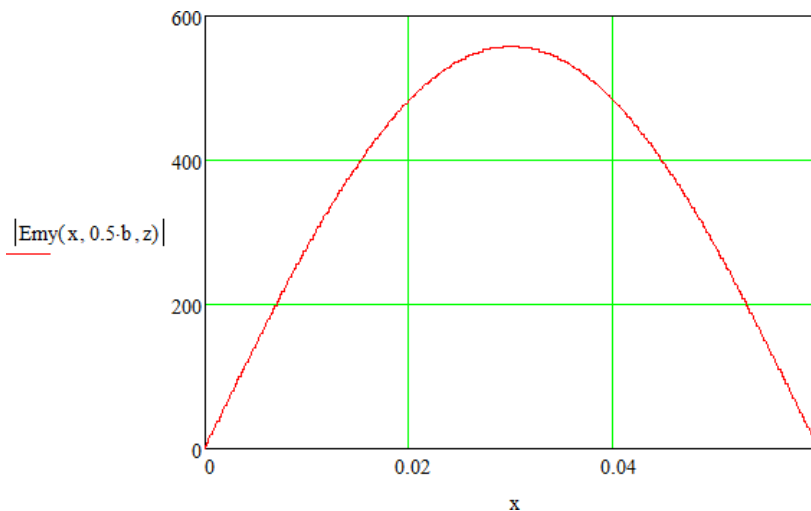
Rice. 1.1 - amplitudes components magnetic fields along axes X



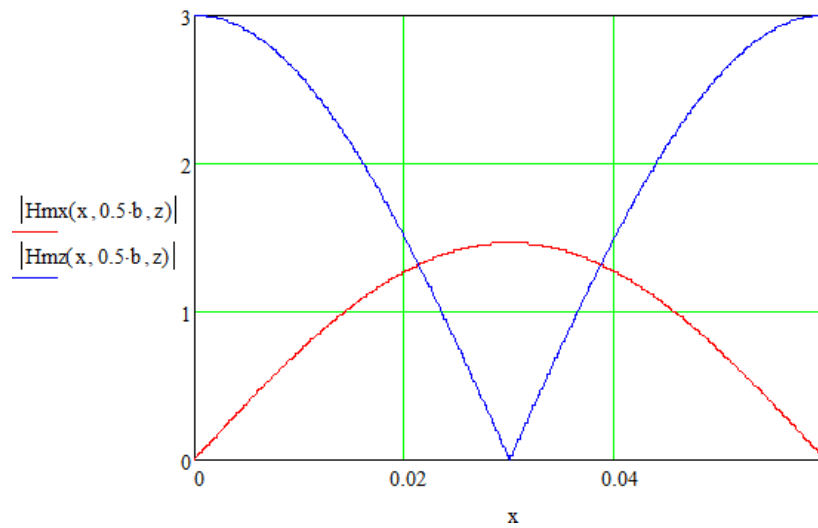
Rice. 1.2 - amplitudes components magnetic fields along axes y

1.2. Display graphically results modeling waves H10 V the Mathcad system.

- 1) Build graphs dependencies amplitudes components fields on frequency f_1
 - For modeling waves H10 install coefficients waves H10 $m=1, n=0$;
 - to plot graphs in the x and y planes, set the current z coordinate according to the option
 - Plot a graph of the amplitudes of the electric and magnetic field components along the x-axis. Set the y-coordinate value according to the option. Examples of graphs are shown in Figures 1.3 and 1.4.

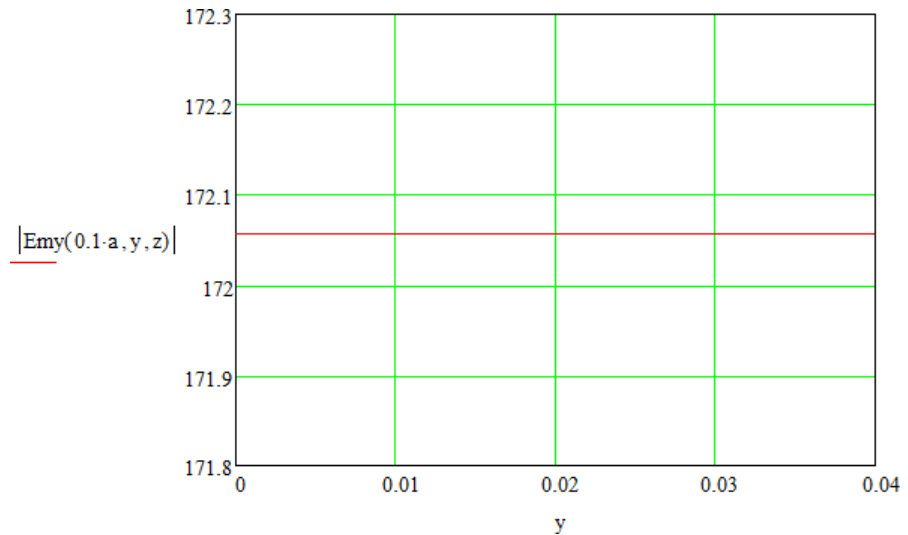


Rice. 1.3 - amplitude transverse component electric fields along axes X

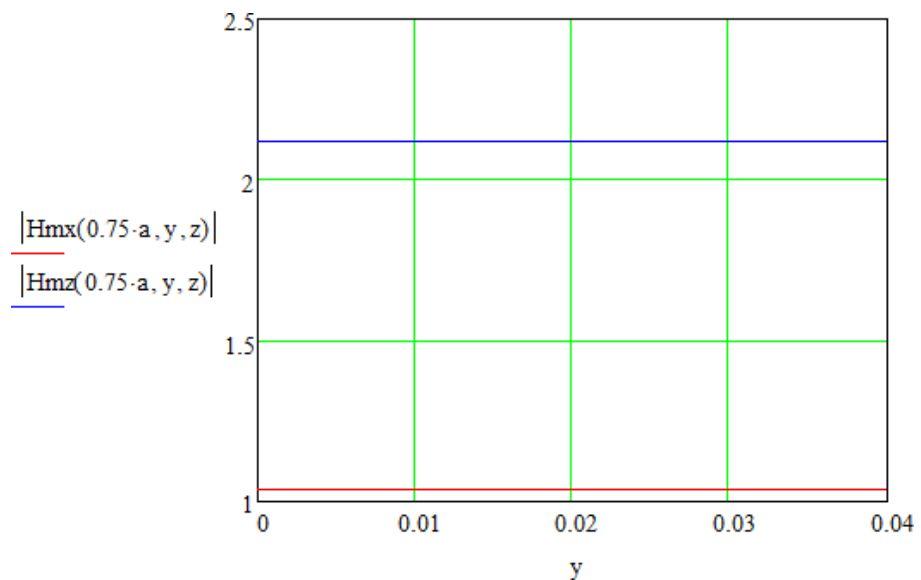


Rice. 1.4 - amplitudes longitudinal And transverse components magnetic fields along axes X

- Plot a graph of the amplitudes of the electric and magnetic field components along the y-axis. Set the x-coordinate value according to the option. Examples of graphs are shown in Figures 1.5 and 1.6.



Rice. 1.5 - amplitude transverse component electric fields along axes y



Rice. 1.6 - amplitudes longitudinal And transverse components magnetic fields along axes y

- 2) Construct vector diagrams of the components of the electric and magnetic field amplitudes in the xy plane at a frequency f
- 1 To do this, enter the formulas:

- Preparatory cycles for assignment of x coordinates And at $i := 0..10$ $j := 0..10$;

- step increments coordinates $dx := \frac{a}{10}$ $dy := \frac{b}{10}$; -
cycles of current coordinates $xx_1 := i \cdot dx$ $yy_j := j \cdot dy$

- vector performance amplitudes Hx -

$$Hhx_{i,j} := Ho \cdot \frac{\beta \cdot \pi}{\gamma I^2 \cdot a} \cdot \sin\left(\frac{m \cdot \pi \cdot xx_1}{a}\right) \cdot \cos\left(\frac{n \cdot \pi \cdot yy_j}{b}\right) ;$$

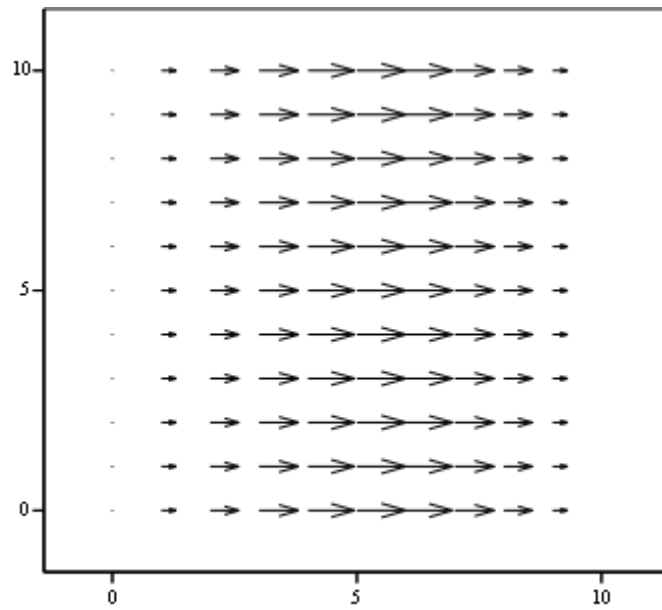
- vector performance amplitudes Hz-

$$Hhz_{i,j} := Ho \cdot \cos\left(\frac{m \cdot \pi \cdot xx_1}{a}\right) \cdot \cos\left(\frac{n \cdot \pi \cdot yy_j}{b}\right) ;$$

- vector performance amplitudes Hey-

$$Eey_{i,j} := \left| -Ho \cdot \frac{\pi(\gamma I^2 + \beta^2)}{\gamma I^2 \cdot a \cdot \omega 1 \cdot \epsilon a} \cdot \sin\left(\frac{m \cdot \pi \cdot xx_1}{a}\right) \cdot \cos\left(\frac{n \cdot \pi \cdot yy_j}{b}\right) \right| ;$$

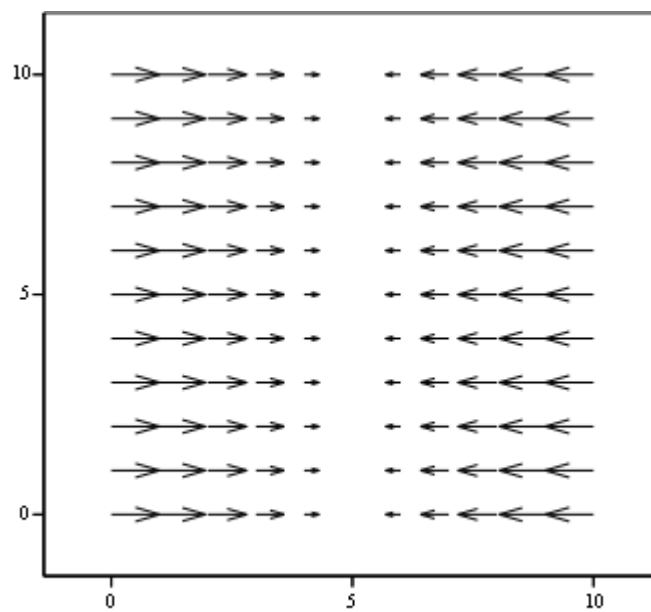
- vector diagram Hx V planes x y. For her constructions necessary Select Insert > Graph > Vector Field. In the function input field, enter Hhx



Hhx

Rice. 1.7 - vector diagram Hx V planes x y X

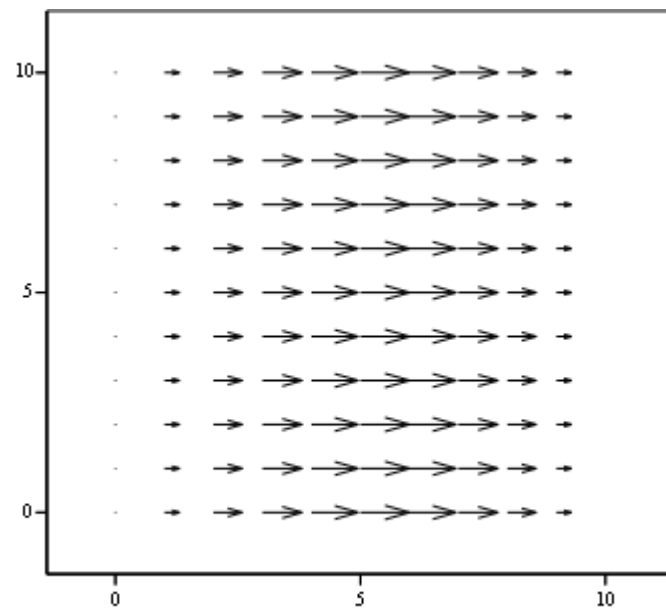
- vector diagram Hz V planes x y.



Hhz

Rice. 1.8 - vector diagram Hz V planes x y

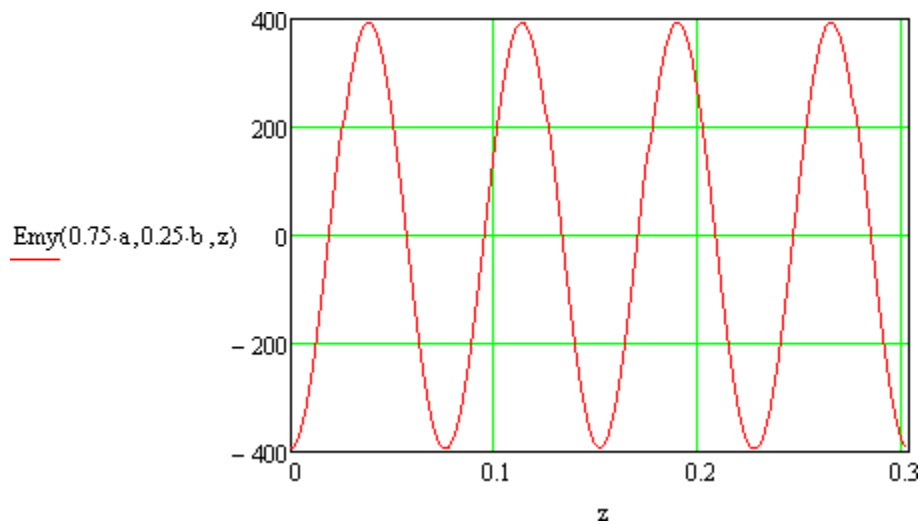
- vector diagram Hey V planes x y.



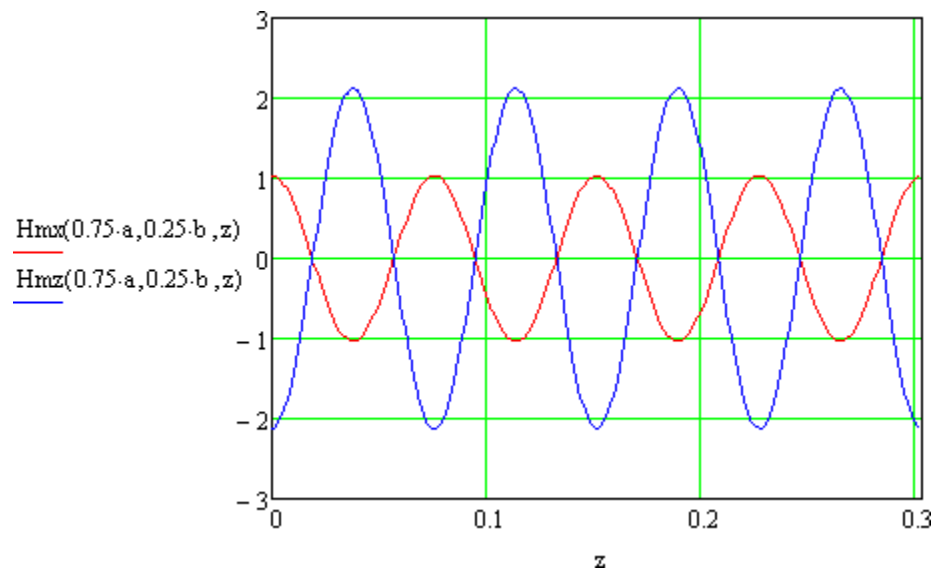
E_{ey}

Rice. 1.9 - vector diagram Hey V planes x y

- 3) Compare vector diagrams V planes x y With graphs components complex amplitudes and draw conclusions based on the comparison results
- 4) Build schedule distribution running waves. For constructions graphs along axes z ask $z := 0, 0.001 \dots 2 \cdot z_0$, coordinates X And at according to option. Examples graphs are shown in the figures



Rice. 1.10 - amplitude transverse component electric fields along axes z

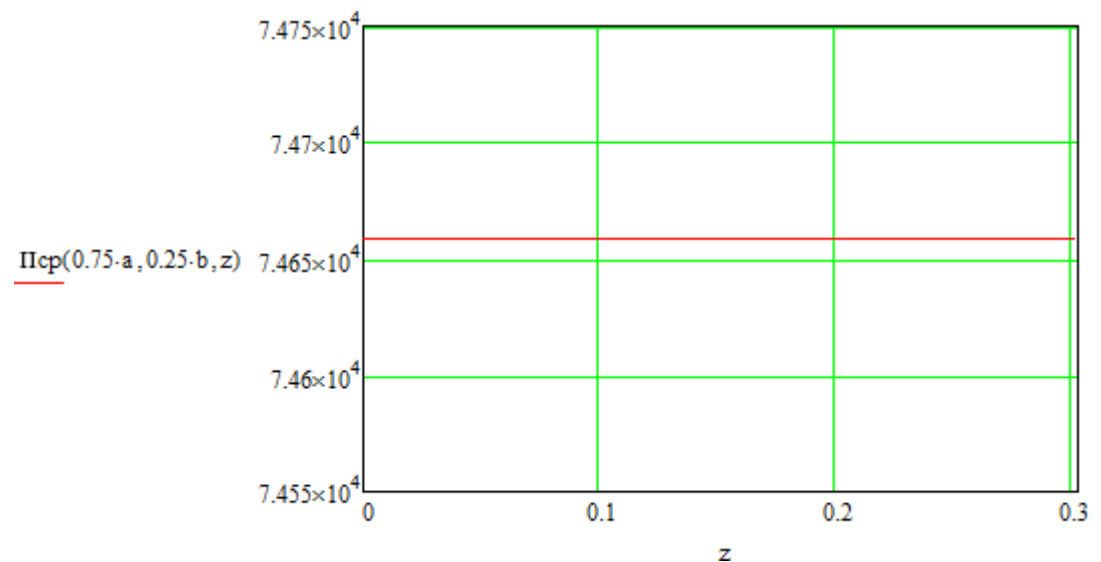


Rice. 1.11 - amplitudes longitudinal And transverse components magnetic fields along axes z

- 5) Plot a graph of the mean value of the Umov-Poynting vector as a function of the z-coordinate. To plot the graph, enter the formula for the longitudinal component of the Umov-Poynting vector and specify the x- and y-coordinates according to option

$$\Pi_{cp}(x, y, z) := \frac{\pi^2 \cdot H_0^2 \cdot \beta \cdot (\beta^2 + \gamma I^2)}{2 \cdot \gamma I^4 \cdot \omega l \cdot \epsilon a} \cdot \left(\frac{1}{b^2} \cdot \cos\left(\frac{\pi \cdot x}{a}\right)^2 \cdot \sin\left(\frac{\pi \cdot y}{b}\right)^2 + \frac{1}{a^2} \cdot \sin\left(\frac{\pi \cdot x}{a}\right)^2 \cdot \cos\left(\frac{\pi \cdot y}{b}\right)^2 \right)^2 ;$$

Example graphics given on drawing 1.12



Rice. 1.12 - schedule dependencies average values vectors Umov-Poynting from coordinates z

1.3 Modeling waves H10 V rectangular waveguide at frequency less than critical in the Mathcad system.

- 1) Enter V working window programs original data:
- frequency f2 -

$$f2 := f_{kp} - 1 \cdot 10^9 ;$$

– circular frequency -

$$\omega2 := 2 \cdot \pi \cdot f2 ;$$

– wavelength in Wednesday–

$$\lambda2 := \frac{C}{f2} ;$$

– constant wave propagation in unlimited space–

$$k2 := \omega2 \cdot \sqrt{\epsilon a \cdot \mu a} = 62.832 ;$$

– constant distribution waves V guide system–

$$\alpha := k2 \cdot \sqrt{\left(\frac{\lambda2}{\lambda_{kp}}\right)^2 - 1} ;$$

$$z01 := \frac{4 \cdot \pi}{\alpha} = 0.178$$

– ;

2) Enter formulas for the complex amplitudes of the components of the magnetic and electric fields for Case 2, f is less than f_{kp} :

$$Emx(x, y, z) := Ho \cdot \frac{\pi(\alpha^2 - \gamma I^2)}{\gamma I^2 \cdot b \cdot \omega2 \cdot \epsilon a} \cdot \cos\left(\frac{m \cdot \pi x}{a}\right) \cdot \sin\left(\frac{n \cdot \pi y}{b}\right) \cdot e^{-\alpha \cdot z} ;$$

$$Emy(x, y, z) := Ho \cdot \frac{\pi(\alpha^2 - \gamma I^2)}{\gamma I^2 \cdot a \cdot \omega2 \cdot \epsilon a} \cdot \sin\left(\frac{m \cdot \pi x}{a}\right) \cdot \cos\left(\frac{n \cdot \pi y}{b}\right) \cdot e^{-\alpha \cdot z} ;$$

$$Hmx(x, y, z) := Ho \cdot \frac{\alpha \cdot \pi}{\gamma I^2 \cdot a} \cdot \sin\left(\frac{m \cdot \pi x}{a}\right) \cdot \cos\left(\frac{n \cdot \pi y}{b}\right) \cdot e^{-\alpha \cdot z} ;$$

$$Hmy(x, y, z) := Ho \cdot \frac{\alpha \cdot \pi}{\gamma I^2 \cdot b} \cdot \cos\left(\frac{m \cdot \pi x}{a}\right) \cdot \sin\left(\frac{n \cdot \pi y}{b}\right) \cdot e^{-\alpha \cdot z} ;$$

$$Hmz(x, y, z) := Ho \cdot \cos\left(\frac{m \cdot \pi x}{a}\right) \cdot \cos\left(\frac{n \cdot \pi y}{b}\right) \cdot e^{-\alpha \cdot z} ;$$

3) Repeat points 1.4 tasks 1.2. Instead of $z0$ use $z01$. For constructions graphs running longitudinal waves (paragraph 4 tasks 1.2), V window input functions

$$|Hmy(0.75 \cdot a, 0.25 \cdot b, z)|$$

$$|Hmx(0.75 \cdot a, 0.25 \cdot b, z)|$$

necessary take function By module

4) Compare received graphs With graphs from tasks 1.2. Do conclusions O their similarities or differences.

Exercise 2. Modeling
propagation of the H10 wave

And study parameters rectangular waveguide during

- 1) Display graphically dependencies phase speed And speed distribution from the frequency. To do this, enter the following formulas:

- phase speed on frequency f1 -

$$V_{\phi} := \frac{\omega_1}{\beta};$$

- speed distribution on frequency f1 -

$$V_{\beta} := \frac{C^2}{V_{\phi}};$$

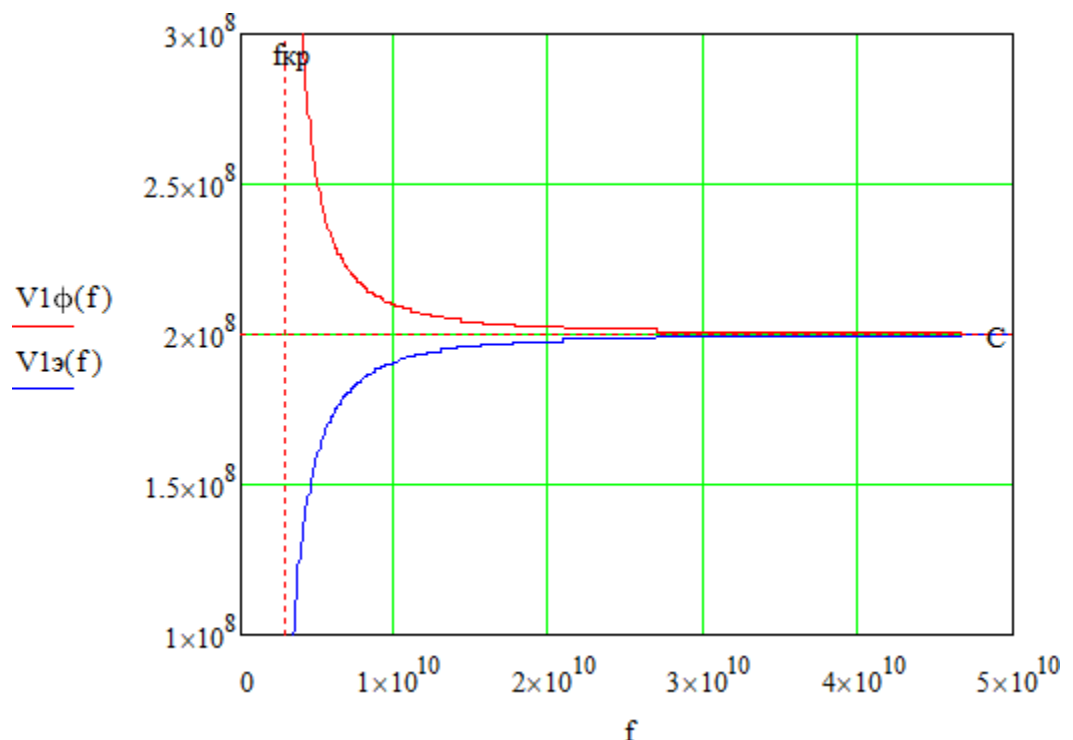
- function dependencies phase speed from frequencies -

$$V_{1\phi}(f) := \frac{1}{\sqrt{\epsilon_a \cdot \mu_a} \cdot \sqrt{1 - \left(\frac{f_{kp}}{f}\right)^2}};$$

- function dependencies speed distribution from frequencies -

$$V_{1\beta}(f) := \frac{C^2}{V_{1\phi}(f)};$$

- build schedule dependencies phase speed And speed distribution from frequencies. On the graph, use marks to indicate the critical frequency and the speed of light.



Rice. 2.1 - schedule dependencies phase speed And speed distribution from frequencies

- 2) Graphically display the dependence of average power and attenuation coefficient on frequency. To do this, enter the following formulas:

- conductivity waveguide (Sim/m)– $\sigma := 3.7 \cdot 10^7$;
- function dependencies active parts superficial resistance waveguide from frequency -

$$R_s(f) := \sqrt{\frac{\pi \cdot f \cdot \mu a}{\sigma}} ;$$

- function dependencies constant distribution from frequencies -

$$\beta(f) := \frac{2 \cdot \pi \cdot f}{C} \cdot \sqrt{1 - \left(\frac{f_{kp}}{f}\right)^2} ;$$

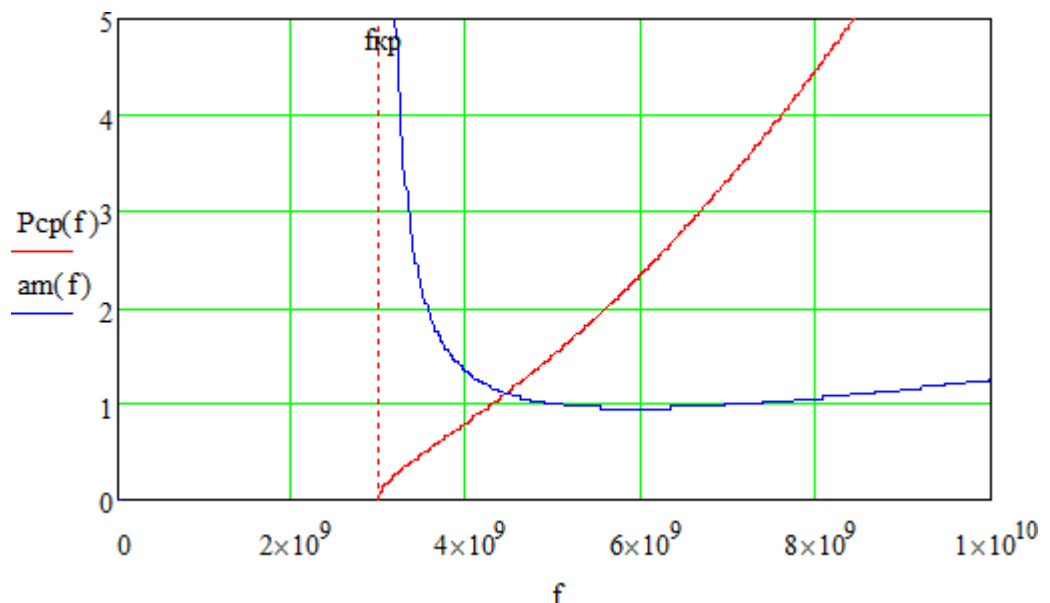
- function dependencies coefficient attenuation from frequencies -

$$am(f) := \frac{1}{2} \cdot R_s(f) \cdot \frac{\frac{32 \cdot \pi^4}{\lambda_{kp}^4} \cdot 2 \cdot \pi \cdot f \cdot \varepsilon a \cdot (a + b) \cdot \left[1 + \frac{\lambda_{kp}^4 \cdot (\beta(f))^2}{16 \cdot \pi^2 \cdot a \cdot b}\right]}{\pi^2 \cdot \left(1 - \frac{f_{kp}}{f}\right) \cdot \left[(\beta(f))^2 + \frac{4 \cdot \pi^2}{\lambda_{kp}^2}\right] \cdot \left(\frac{a}{b} + \frac{b}{a}\right)} ;$$

- function dependencies average power from frequencies -

$$P_{cp}(f) := \frac{\beta(f) \pi^2 \cdot H_0^2 \cdot \left[\beta(f)^2 + \left(\frac{2\pi}{\lambda_{kp}}\right)^2\right]}{8 \cdot \left(\frac{2\pi}{\lambda_{kp}}\right)^4 \cdot 2 \cdot \pi \cdot f \cdot \varepsilon a} \cdot \left(\frac{a}{b} + \frac{b}{a}\right) ;$$

- build schedule dependencies coefficient attenuation And average power from frequency. On the graph, mark the critical frequency.



Rice. 2.2 - schedule dependencies coefficient attenuation And average power from frequencies

3) Do conclusions By results conducted research

6. Defense of practical work

To defend your lab assignment, submit a fully completed report free of significant errors. As instructed by your instructor, complete the assignment. alone from tasks each educational question, having explained at this All physical phenomena and processes occurring in the developed model.

LABORATORY JOB No. 10
Guided electromagnetic waves V round And coaxial waveguides STUDY QUESTIONS:

TARGET SETTING OF PRACTICAL WORK :

Results training, achievable V result execution laboratory work:

Be able to:

– apply the basic laws and mathematical apparatus of electrodynamics to computer modeling and analysis of electromagnetic fields and waves in various media and guiding systems.

Own:

– skills in determining the characteristics of electromagnetic fields required for solving practical problems for calculating radio coverage, radio relay and satellite routes.

TRAINING AND MATERIAL SUPPORT:

- A personal computer with an electronic circuit simulator “Electronics Workbench” and a computer mathematics system “Mathcad”;
- electronic methodological development By laboratory work.

QUESTIONS, SUBJECTS RESEARCH

Brief theoretical or reference and information materials

A hollow metal tube with a circular cross-section is called a circular waveguide.

Let us denote the radius of the circular waveguide by R. We will assume that the waveguide is filled homogeneous isotropic medium without losses ($\sigma \approx 0$). Third parties currents are absent. In this case, the 1st and 2nd Maxwell's equations will take the form:

$$\left\{ \begin{array}{l} \text{rot } \vec{H} = \frac{dD}{dt} = \epsilon_a \frac{dE}{dt} \\ \text{rot } \vec{E} = -\frac{dB}{dt} = -\mu_a \frac{dH}{dt} \end{array} \right.$$

For round waveguide more convenient enter cylindrical system coordinates (r, φ, z) and seek a solution to these equations in this coordinate system. The order of their solution is similar to how we did it in the case of a rectangular waveguide:

1. It's opening up operation rot V cylindrical coordinate system .
2. All transverse components of the field (i.e. $E_r, E_\varphi, H_r, H_\varphi$) are expressed through longitudinal E_z and H_z .
3. A differential equation is drawn up for the longitudinal components and its solution is found.

As in a rectangular waveguide, both E- and H-waves can exist in a circular waveguide. Let's consider E-waves first. By definition, for such waves: $H_z = 0$, all other components are not equal to 0.

Let us compose a differential equation for the amplitude value of the longitudinal component E_{zm} :

$$\nabla^2 E_{zm} + \gamma^2 E_{zm} = 0,$$

Where: $\gamma^2 = k^2 - \beta^2$ – transverse wave number;
 k is the constant of wave propagation in unlimited (free) space;
 β - wave propagation constant in circular waveguide;
 ∇^2 - transverse operator Laplace.

Revealing ∇^2 in cylindrical system coordinates, we get:

$$\frac{1}{r} \frac{\partial}{\partial r} \left(r \frac{\partial E_{zm}}{\partial r} \right) + \frac{1}{r^2} \frac{\partial^2 E_{zm}}{\partial \varphi^2} + \gamma^2 E_{zm} = 0$$

Deciding This differential equation method divisions variables, we get:

$$E_{zm} = E_0 J_n(\gamma r) \cos(n \varphi),$$

Where: E_0 - some constant;

J_n - function Bessel n - go order, $n = 0, 1, 2, \dots$

Now we impose border conditions: tangent component the electric field must be equal to 0 on the walls of the waveguide, i.e. $E_\varphi = 0$ at $r = R$. This means that E_{zm} must be equal to zero when $r = R$, i.e.:

$$E_0 J_n(\gamma R) \cos(n \varphi) = 0$$

For this requirement to be met at any angle φ , the following condition must be met:

$$J_n(\gamma R) = 0. \quad (a)$$

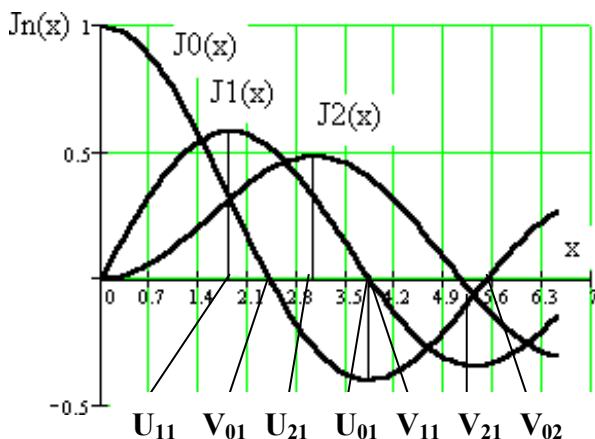
The Bessel function of different orders is shown in the graph in Fig. 1. From the graphs it is visible, What For execution condition (a) is necessary so that:

$$\gamma R = V_{nm}, \quad (1 \text{ point})$$

Where: V_{nm} - m - th root Bessel functions of the n -th order.

From (1 b) we get, What transverse wave number:

$$\gamma = \frac{V_{nm}}{R}$$



Drawing 1.- Bessel functions

Hence, amplitude (meaning) longitudinal component:

$$E_{zm} = E_0 J_n \left(\frac{V_{nm}}{R} r \right) \cos(n \varphi)$$

and the instantaneous value:

$$E_z = E_{zm} e^{j(\omega t - \beta z)} = E_0 J_n \left(\frac{V_{nm}}{R} r \right) \cos(n \varphi) e^{j(\omega t - \beta z)} \quad (2)$$

At famous E_z , further are determined All rest components fields E - waves: E_z , E_φ , H_r , H_φ .

Let's do it analysis received equations 2.

1. A guided E-type wave propagates along a circular waveguide along the z -axis with a propagation constant β . Each pair of numbers m and n corresponds to its own electromagnetic field structure, which is denoted as E_{nm} . From the graphs in Fig. 1, it is clear that the smallest root of the Bessel function is the root V_{01} , therefore, the simplest E-type wave is the E_{01} wave.

2. Let's define constant distribution β For E_{nm} waves. Because:

$$\gamma^2 = k^2 - \frac{V_{nm}^2}{R^2},$$

then from here:

$$\beta = \sqrt{k^2 - \gamma^2} = \sqrt{\left(\frac{2\pi}{\lambda}\right)^2 - \left(\frac{V_{nm}}{R}\right)^2}.$$

Similarly, How And For rectangular waveguide we get:

- if $k^2 > \gamma^2$, That β - real magnitude And, therefore, the electromagnetic wave E_{nm} will propagate in a circular waveguide;
- if $k^2 < \gamma^2$, then β - imaginary quantity, so the electromagnetic process will decay exponentially along a circular waveguide;
- border happening arises When:

$$\frac{2\pi}{\lambda} = \frac{V_{nm}}{R} = \gamma$$

to $^2 = \gamma^2$ or

The wavelength that satisfies this condition is called the critical wavelength in a circular waveguide:

$$\lambda_{kp} = \frac{2\pi R}{V_{nm}}.$$

Let's define length waves V round waveguide. Because $\beta = \sqrt{k^2 - \gamma^2}$, or:

$$\frac{2\pi}{\lambda_{in}} = \sqrt{\left(\frac{2\pi}{\lambda}\right)^2 - \left(\frac{2\pi}{\lambda_{kpnm}}\right)^2},$$

$$\frac{\lambda}{\lambda_{in}} = \frac{1}{\sqrt{1 - \left(\frac{\lambda}{\lambda_{kpnm}}\right)^2}}$$

(3)

Note that (3) has the same form as for a rectangular waveguide. We define phase V_f And group V_{gr} speed E - waves V round waveguide:

$$V_f = \frac{\omega}{\beta} = \frac{2\pi f}{2\pi/\lambda_{in}} = \frac{\text{With}}{\sqrt{1 - \left(\frac{\lambda}{\lambda_{kp}}\right)^2}}.$$

$$V_{gr} = c \sqrt{1 - \left(\frac{\lambda}{\lambda_{kp}}\right)^2}.$$

So How $V_f \cdot V_{gr} = c^2$, That:

Let us now consider H-waves in a circular waveguide. For these waves, by definition, the component $E_z = 0$, all other components are non-zero. Let's compose a differential equation for the amplitude value of the longitudinal component H_{zm} :

$$\nabla^2 H_{zm} + \gamma^2 H_{zm} = 0.$$

Solution this equations has view:

$$H_{zm} = H_0 J_n(\gamma r) \cos(n\varphi).$$

We impose the boundary conditions: $E_\varphi = 0$ at $r = R$. This means that the derivative component H_{zm} when $r = R$ must be equal to zero, i.e.:

$$\frac{dH_{zm}}{dr} = H_0 J'_n(\gamma R) \cos(n\varphi) = 0.$$

To given condition was carried out at any φ , necessary to:

$$J'_n(\gamma R) = 0. \quad (4)$$

First derivative any functions - This There is points maximum or minimum of this function. Therefore (see Fig. 1), in order for condition (4) to be satisfied, it is necessary to require:

$$\gamma R = U_{nm}, \quad (5)$$

where: U_{nm} – the m-th root of the n-th order derivative of the Bessel function.

Therefore, from (5) wave number γ For N - waves V round waveguide:

$$\gamma = \frac{U_{nm}}{R}.$$

Then instant meaning longitudinal component N_z equals:

$$H_{zm} = H_0 J_n(\gamma r) \cos(n\varphi) e^{j(\omega t - \beta z)} = H_0 \frac{J_n(r)}{R} \cos(n\varphi) e^{j(\omega t - \beta z)}.$$

Analysis of the resulting equation shows that each couple numbers m and n corresponds own structure fields N - waves V round waveguide, which is denoted as H_{nm} . From the graphs in Fig. 1 it is clear that the first root is the root U_{11} , therefore the simplest wave of the H-type will be the wave H_{11} .

Critical wavelength H – the type is determined from conditions: $k^2 = \gamma^2$.

$$\text{Or } \frac{\frac{2\pi}{\lambda_{kp}}}{\lambda_{kp}} = \frac{U_{nm}}{R}, \text{ from here: } \frac{\lambda_{kp}}{R} = \frac{U_{nm}}{R}. \text{ Since the root } U_{11} \text{ is}$$

the smallest of all possible roots of the Bessel function, then λ_{kp} H waves 11 will be the largest of all H_{nm} and E_{nm} types of waves. This means that single-mode operation of a circular waveguide is possible only at the H_{11} wave. Derivation of formulas for λ_{in} , V_f , and V_{gr} is similar to how it was done for E-waves and does not seem difficult when studied independently.

IN round waveguide, V difference from rectangular waveguide, V quality the main type of oscillation, one of three types of waves is used: H_{11} , E_{01} or H_{01} . Let us consider the features of these waves that determine their application in practice.

a) Let us turn to the structure of electromagnetic waves of these waves, shown in Fig. 2, And distribution lines superficial current, shown on rice. 3. Let us note, What at

waves H_{01} V difference from waves H_{11} And E_{01} absent longitudinal component
c o n d u c t i o n current (there are only transverse, ring currents).

b) Critical length waves For fluctuations E- And H-type V round waveguide is determined by the expressions:

$$\lambda_{kp}^E = \frac{2\pi R}{V_{mn}} \quad \lambda_{kp}^H = \frac{2\pi R}{U_{mn}}$$

Where: R - radius round waveguide;

V_{nm} - m-th root functions Bessel n-th genus;

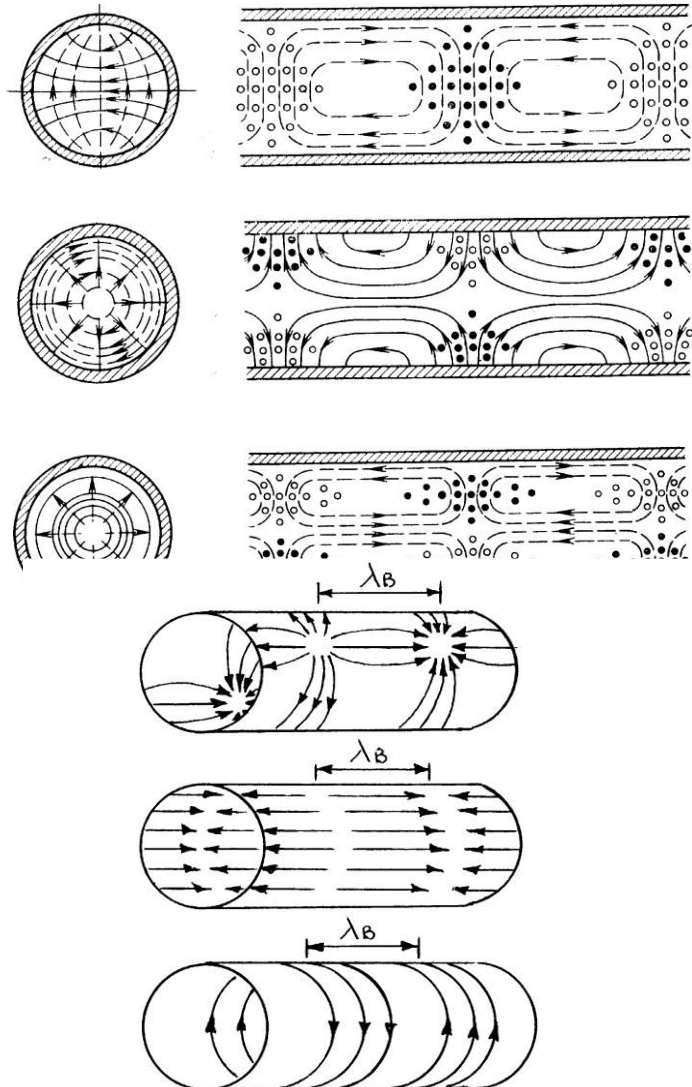
U_{nm} - m-th root derivative functions Bessel n-th genus.

IN Table 7.1 given values λ_{kp} first six types fluctuations V round waveguide.

Table 1

Type waves	11	01	21	11	11	31
λ_{kp}/R	,42	,61	,06	,64	,64	,46

In Fig. 4
the dependences of the coefficient
are given attenuation α
V
circular waveguide from frequency
a)
and acceptable power R from
frequencies for the three types of
waves under consideration. Based
on Fig. 2, 3, 4 And Table 1 it's not
difficult to formulate the following
b)
peculiarities waves H_{11} , E_{01} And
 H_{01} :



Wave H_{11}

1. This type of
c) oscillations has
the greatest λ_{cr}
. Therefore, only on
wave H_{11} single -mode
operation of a circular
waveguide is possible without
the use of any
additional measures;

2. Structure of
electromagnetic the
field of this wave
is asymmetrical
relatively arbitrary transverse
axis (see Fig. 2). As a result,
when movement waves along
a circular waveguide
is happening change polarization waves, How shown on Fig. 5.

Drawing 3 - Distribution lines surface current for H_{11}
waves (a), E_{01} (b) and H_{01} (V).

3. In order to fix the plane of polarization, in practice they resort to changing the
cross-section of a circular waveguide, using an ellipse, and thus moving to elliptical
waveguides (see Fig. 6);

4. Of all three types of waves, wave H_{11} has the highest permissible operating power.

Wave E_{01}

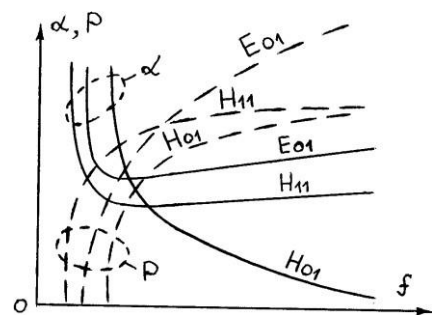
1. Wave is axisymmetric (see Fig. 2), and is therefore extremely convenient as a wave used for transmitting electromagnetic energy in a circular waveguide or for use in functional devices based on a circular waveguide (microwave filters, rotating joints, etc.);

2. The wave exists alongside H_{11} , therefore, to prevent losses of electromagnetic energy required acceptance special measures For suppression waves H_{11} .

Wave H_{01}

1. This wave does not have transverse components of the surface current on the walls of the waveguide (there are only circular currents), see Fig. 3. This leads to the fact that with an increase in the product $R \cdot f$, the attenuation coefficient α of this wave tends to zero (see Fig. 1);

2. Alongside With wave H_{01} exist more By extreme measure four type oscillations (see Table 7.1). In this regard, it is very difficult to ensure the suppression of these parasitic types of oscillations in order to achieve a mode with the lowest attenuation coefficient of electromagnetic energy in a circular waveguide with an H_{01} wave.



Drawing 4- Addition α And R from frequencies

Coaxial waveguide it's called guide system, educated two

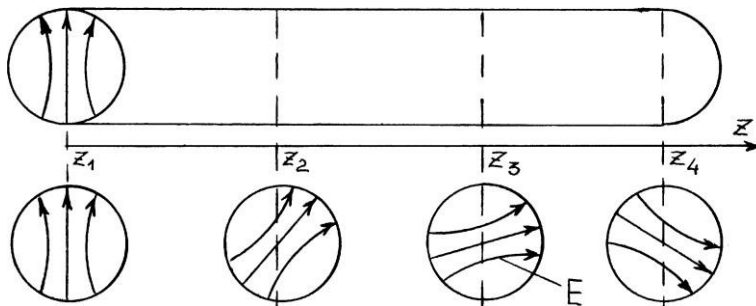


Figure 5 - Change of plane polarization of the H

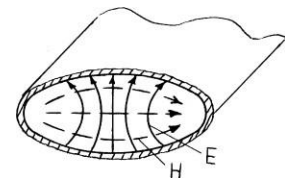


Figure 6 - Elliptical wave waveguide

isolated Friend from friend coaxial, metal round conductors with diameters $2a$ and $2b$ (see Fig. 7).

Let us assume that the waveguide is filled with a homogeneous isotropic medium with parameters ϵ_a , μ_a and without losses ($\sigma=0$). Let there be no external currents, in this case the 1st and 2nd Maxwell equations take the form:

$$\begin{cases} \text{rot } \vec{H} = \frac{d\vec{E}}{dt} = j\omega\epsilon_a \vec{E} \\ \text{rot } \vec{E} = -\frac{d\vec{H}}{dt} = -j\omega\mu_a \vec{H} \end{cases} \rightarrow$$

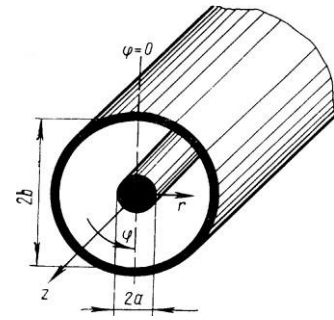


Figure 7 - Coaxial waveguide

From these equations carried out the Helmholtz equations:

$$\nabla^2 \vec{H} + k^2 \vec{H} = 0$$

$$\nabla^2 \vec{E} + k^2 \vec{E} = 0$$

where: $\nabla^2 = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2}$ Laplace operator ;

$$k = \omega \sqrt{\epsilon_a \mu_a}$$

- constant distribution in unlimited environment with parameters

ϵ_a ,
 μ_a .

Let's choose the quality directions distribution waves in a coaxial waveguide z-axis, then:

$$\vec{E} = E_m(x, y)e^{-j\beta z}; \quad \vec{H} = H_m(x, y)e^{-j\beta z}, \quad (6)$$

Where: β - constant distribution in coaxial waveguide.

Substituting (6) into the Helmholtz equation, we obtain the following expressions for the electric field strength:

$$\frac{d^2 E_m}{dx^2} e^{-j\beta z} + \frac{d^2 E_m}{dy^2} e^{-j\beta z} + (-j\beta)(-j\beta) E_m e^{-j\beta z} + k^2 E_m e^{-j\beta z} = 0$$

$$\text{Or: } \nabla_{\perp}^2 E_m + (k^2 - \beta^2) E_m = 0, \quad (7)$$

Where: $\nabla_{\perp}^2 = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2}$ - transverse Laplace operator ;

$(k^2 - \beta^2) = \gamma^2$ - transverse wave number.

A characteristic feature of a coaxial waveguide is that, unlike rectangular and circular waveguides, three types of guided waves can propagate in it:

1. Transverse (TEM - waves)
2. Electric (E - waves)
3. Magnetic (H - waves)

For the existence of TEM waves in a coaxial waveguide (i.e. waves that do not have components E_z and H_z), it follows from equations (7), necessary fulfillment of the condition:

$$\gamma^2 = k^2 - \beta^2 = 0. \quad (8)$$

From these conditions follow two important conclusions:

$$1) \beta^2 = k^2, \text{ or } \frac{2\pi}{\lambda_{in}} = \frac{2\pi}{\lambda}, \text{ or } \lambda_B = \lambda,$$

Where: λ_B - wavelength V coaxial waveguide;

λ - length waves V unlimited environment With parameters ϵ_a And μ_a .

Like this in this way, length waves V coaxial waveguide equal length waves V unlimited space.

$$2) \text{ Because } \frac{\gamma}{\pi} \frac{2}{\lambda_K} = 0, \text{ That } \lambda_{kp} = \infty (f_{cr} = 0),$$

p

where: λ_{kp} , f_{kp} - critical wavelength and critical frequency in a coaxial waveguide.

This means that in a coaxial waveguide, unlike a rectangular or circular waveguide, a signal with any frequency can be carried by a TEM wave.

Therefore, by choosing the geometric dimensions a and b of a coaxial waveguide, in practice, it is always necessary to ensure that the signal power is carried only by the TEM wave. In this regard, let's take a closer look at the propagation of TEM waves in a coaxial waveguide.

From (7) s taking into account (8) we have:

$$\nabla \perp E_m = 0. \quad (9)$$

For a coaxial waveguide, the solution to this equation is most easily found in a cylindrical coordinate system (r, φ , z). In mathematics, an equation of the form (9) is called the Laplace equation, which has the following solution:

$$\text{In } (r, \varphi) = - \text{grad} U = - \left(\frac{du}{dr} + \frac{du}{d\varphi} \right) = - (E_{mr} + E_{m\varphi})$$

And in φ

where: U is some scalar function to be determined. We will define it using famous from mathematicians identity: $\text{div grad } U = 0$. Revealing operation div grad in a cylindrical coordinate system, we obtain:

$$\frac{1}{r} \frac{d}{dr} \left(r \frac{dU}{dr} \right) + \frac{1}{r^2} \frac{d^2 U}{d\varphi^2} = 0$$

We impose border conditions: tangent component electric fields

$$E_\varphi = - \frac{dU}{d\varphi}, \text{ That This means, } \frac{dU}{d\varphi} = 0$$

E_φ should be equal zero at $r = a$ And $r = b$. Since at $r = a$ And $r = b$. Then we have:

$$\frac{1}{r} \frac{d}{dr} \left(r \frac{dU}{dr} \right) = 0, \text{ or } \frac{dU}{dr} = \text{const} = A$$

$$\frac{dU}{dr} = \frac{A}{r}, \text{ respectively } U = A \ln r.$$

From here:

At found U we define complex values components electric field of the TEM wave in a coaxial waveguide:

$$\begin{cases} E_r = E_{rm} e^{j(\omega t - \beta z)} = -\frac{dU}{dr} e^{j(\omega t - \beta z)} = -\frac{d(A \ln r)}{dr} e^{j(\omega t - \beta z)} = 0 \\ E_\phi = E_{\phi m} e^{j(\omega t - \beta z)} = -\frac{dU}{d\phi} e^{j(\omega t - \beta z)} = -\frac{d(A \ln r)}{d\phi} e^{j(\omega t - \beta z)} = 0 \end{cases}$$

Components magnetic fields we define With help second equations Maxwell:

$$\text{rot} \vec{E} = -j \omega \mu_a \vec{H} \quad \text{from} \quad \vec{H} = -\frac{1}{j \omega \mu_a} \text{rot} \vec{E}$$

here :

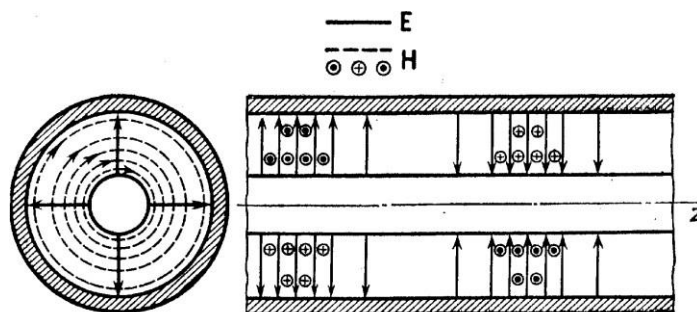
Revealing operation rot V cylindrical system coordinates, we get:

$$\begin{cases} H_r = 0 \\ H_\phi = -\frac{1}{j \omega \mu_a} \frac{A}{r} j \beta e^{j(\omega t - \beta z)} \\ H_z = 0 - \text{by definition} \end{cases}$$

Thus, components electromagnetic field TEM - waves in a coaxial waveguide have the form:

$$\begin{cases} E_r = \frac{A}{r} e^{j(\omega t - \beta z)} \\ H_\phi = -\frac{\beta A}{\omega \mu_a r} e^{j(\omega t - \beta z)} \end{cases} \quad (10)$$

On base equations (10) on Fig. 8 depicted structure fields TEM waves in a coaxial waveguide.



Drawing 8 Structure fields TEM waves in coaxial waveguide

Content practical work, performed students

1. Description laboratory equipment:

- PC With system computer mathematicians Mathcad – 14»;
- electronic methodological development By laboratory work.

2. Initial data for modeling and research Options tasks For research given V table 1. Table 1 – Initial data for task 1

O ption number	Ho mA/m	R,m	r	t	z
1	3	0.008	0.4R	0.2	0.8z0
2	2	0.009	0.3R	0.09	0.5z0
3	4	0.01	0.6R	0.4	1.3z0
4	2.5	0.0085	0.8R	0.2	1.2z0
5	5	0.007	0.5R	0.75	0,9z0
6	2.2	0.0075	0.3R	0.4	1.4z0
7	3.1	0.008	0.2R	0.25	1,2z0
8	3.3	0.0125	0.9R	0.6	0.75z0
9	2.8	0.0079	0.4R	0.15	0.4z0
10	3.15	0.011	0.2R	0.6	1,2z0
11	2.6	0.008	0.75R	0.4	0.65z0
12	4.2	0.009	0.4R	0.2	0.6z0
13	2	0.01	0.25R	0.65	0.8z0
14	4	0.007	0.6R	0.4	0.5z0
15	2.5	0.0075	0.15R	0.25	1.3z0

3. Task for work

1. Modeling And study waves H11 V round waveguide.
2. Modeling and research waves H01 And E01 V round waveguide in the system "Mathcad".
3. Modeling And study TOPICS waves V coaxial waveguide.

4. Order execution work

Exercise 1. Modeling And study waves H11 V round waveguide.

1.1. Modeling waves H11 V round waveguide V the Mathcad system .

11) Enter V working window programs original data:

- coefficients H11 m waves = 1 n = 1 ;
- dielectric permeability Wednesday $\epsilon r=1$;
- magnetic permeability Wednesday $\mu r=1$;
- electric constant -

$$\epsilon_0 := \frac{1}{36 \cdot \pi} \cdot 10^{-9} = 8.842 \times 10^{-12} ;$$
- magnetic constant–

$$\mu_0 := 4 \cdot \pi \cdot 10^{-7} = 1.257 \times 10^{-6} ;$$
- absolute dielectric permeability Wednesday $\epsilon a := \epsilon_0 \cdot \epsilon r$;
- absolute magnetic permeability Wednesday $\mu a := \mu_0 \cdot \mu r$;
- Radius waveguide according to option;
- amplitude magnetic vector H0 fields according to the option;
- speed Sveta V environment -

$$C := \frac{1}{\sqrt{\epsilon_a \cdot \mu_a}};$$

– first root first derivative functions Bessel first order first genus

$$U11 := 1.8412;$$

– critical wavelength-

$$\lambda_{kp} := \frac{2 \cdot \pi \cdot R}{U11} = 0.034;$$

– critical frequency-

$$f_{kp} := \frac{C}{\lambda_{kp}};$$

– frequency -

$$f1 := f_{kp} + 1 \cdot 10^9;$$

– circular frequency–

$$\omega1 := 2 \cdot \pi \cdot f1;$$

– wavelength in Wednesday–

$$\lambda1 := \frac{C}{f1};$$

– transverse wave number -

$$\gamma := \frac{U11}{R};$$

– constant wave propagation in unlimited space–

$$k1 := \frac{2 \cdot \pi}{\lambda1};$$

– constant distribution waves V guide system–

$$\beta1 := \sqrt{k1^2 - \gamma^2};$$

$$r := 0,001 \dots R;$$

$$\varphi := 0, \frac{2 \cdot \pi}{360} \dots 2 \cdot \pi;$$

$$z0 := 0.01;$$

12) Enter formulas amplitudes components magnetic And electric fields:

$$H_{zm}(r, \varphi, z) := H_0 \cdot J_1(\gamma \cdot r) \cdot \cos(m \cdot \varphi) \cdot \cos(-\beta_1 \cdot z)$$

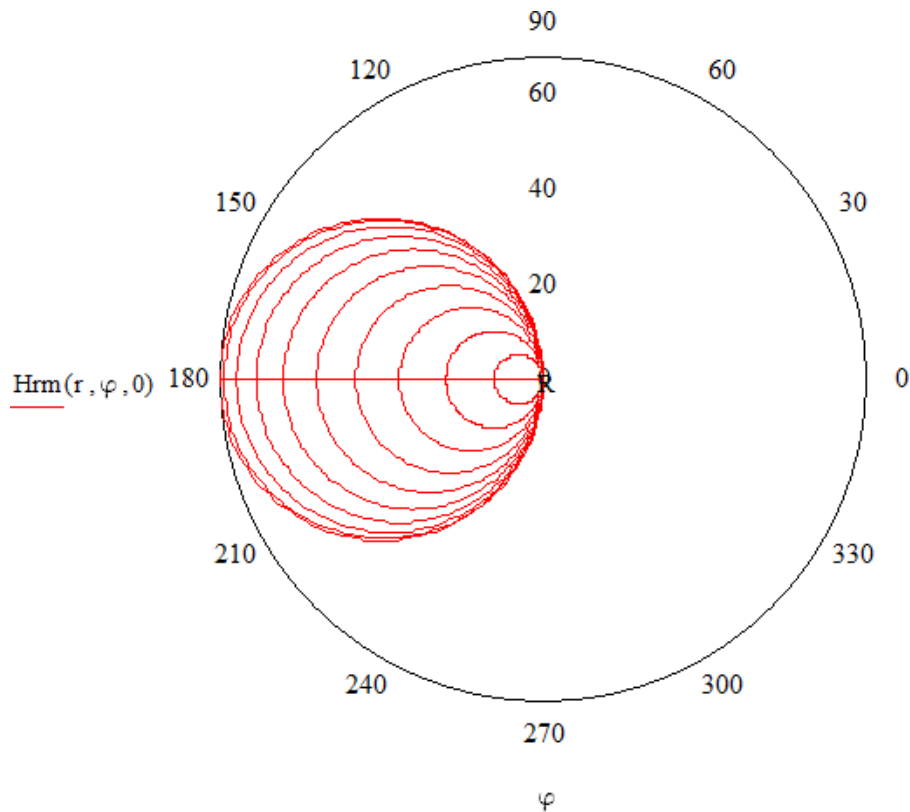
$$E_{rm}(r, \varphi, z) := H_0 \cdot \frac{m}{r} \cdot \frac{\omega l \cdot \mu a}{\gamma^2} \cdot J_1(\gamma \cdot r) \cdot \sin(m \cdot \varphi) \cdot \cos(-\beta_1 \cdot z)$$

$$E_{\varphi m}(r, \varphi, z) := H_0 \cdot \frac{\omega l \cdot \mu a}{\gamma} \cdot \frac{d}{dr}(J_1(\gamma \cdot r)) \cdot \cos(m \cdot \varphi) \cdot \cos(-\beta_1 \cdot z)$$

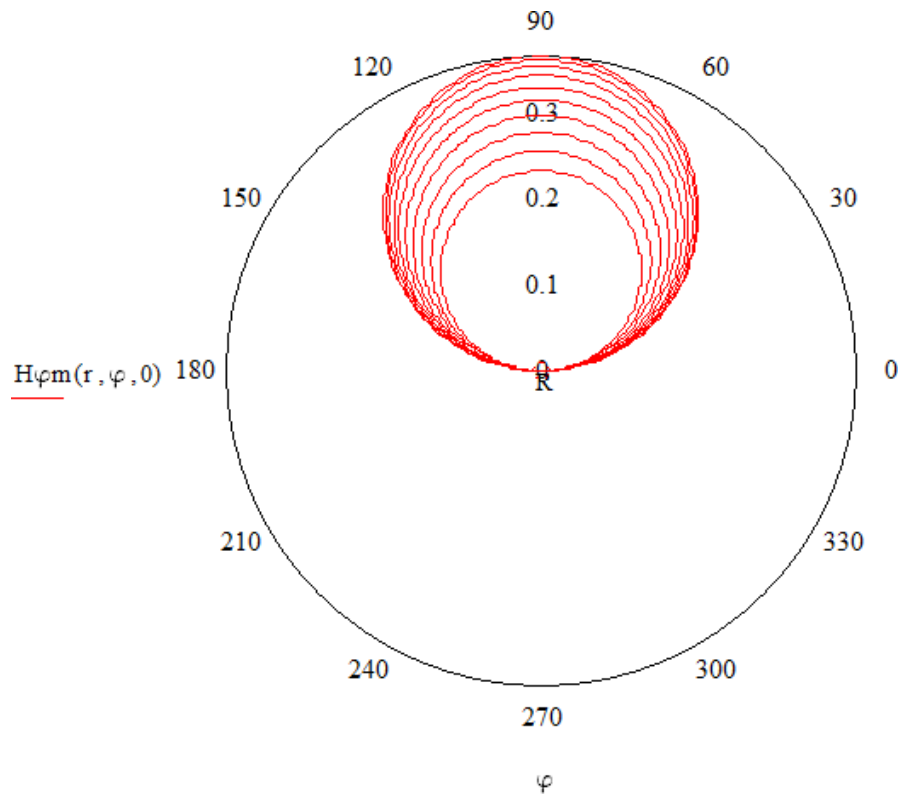
$$H_{rm}(r, \varphi, z) := \frac{-\beta_1}{\omega l \cdot \mu a} \cdot E_{\varphi m}(r, \varphi, z)$$

$$H_{\varphi m}(r, \varphi, z) := \frac{\beta_1}{\omega l \cdot \mu a} \cdot E_{rm}(r, \varphi, z)$$

- 13) To verify the simulation results, we will plot the dependences of the $H_{\varphi m}$, H_{zm} field components in a polar coordinate system. The z coordinate is set equal to zero. Examples of graphs are shown in Figures 1.1 and 1.2.



Rice. 1.1 - schedule distribution radial component magnetic field amplitudes in a polar coordinate system



Rice. 1.2 - schedule distribution angular component amplitudes magnetic field in a polar coordinate system

**1.2. Display graphically results modeling waves H11 V system
"Mathcad".**

- 6) Enter formulas calculation instant values components electric and magnetic fields

$$H_z(r, \varphi, t, z) := H_{zm}(r, \varphi, z) \cdot \cos(\omega_1 \cdot t)$$

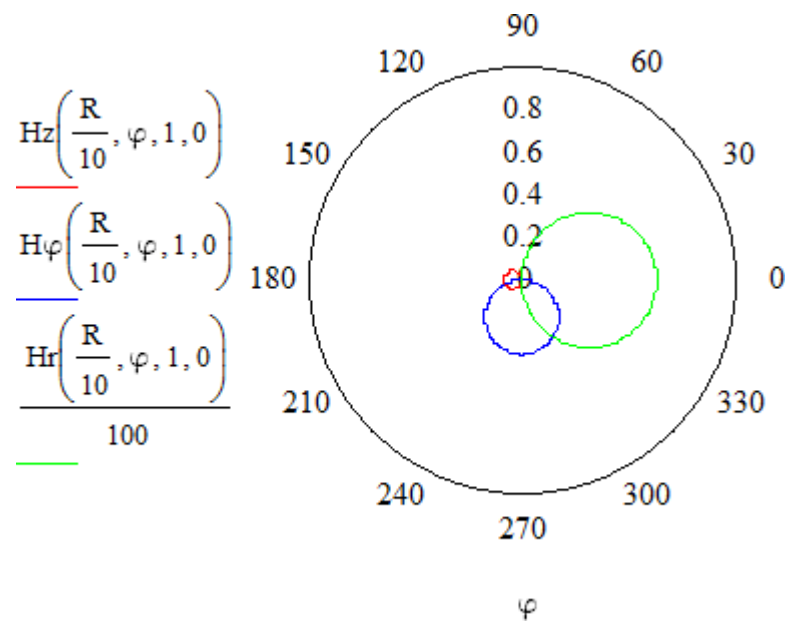
$$H_\varphi(r, \varphi, t, z) := H_{\varphi m}(r, \varphi, z) \cdot \cos(\omega_1 \cdot t)$$

$$H_r(r, \varphi, t, z) := H_{rm}(r, \varphi, z) \cdot \cos(\omega_1 \cdot t)$$

$$E_\varphi(r, \varphi, t, z) := E_{\varphi m}(r, \varphi, z) \cdot \cos(\omega_1 \cdot t)$$

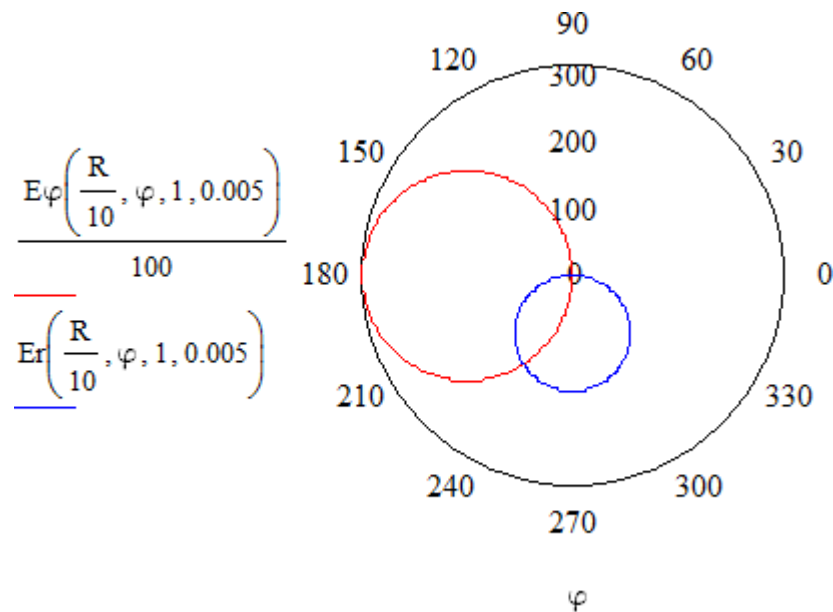
$$E_r(r, \varphi, t, z) := E_{rm}(r, \varphi, z) \cdot \cos(\omega_1 \cdot t)$$

- 3) Display on one graphics longitudinal And transverse components magnetic fields. To plot a graph, use t, z, and r as arguments at the function entry point, as appropriate. An example graph is shown in Figure 1.3. To correctly display all components on a single graph, a 1/100 scale factor has been added to the radial component.



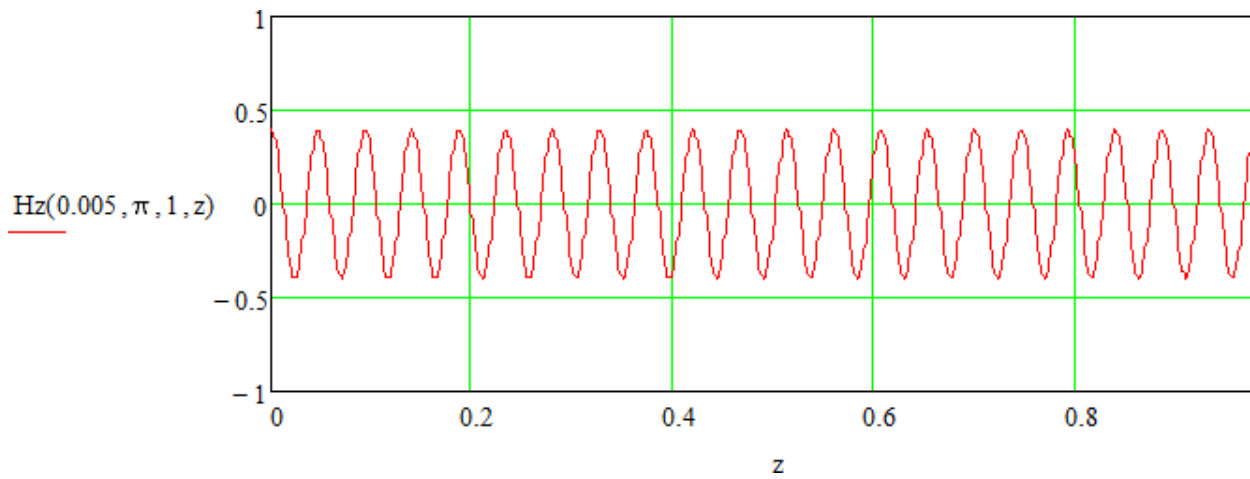
Rice. 1.3 - schedule distribution components magnetic fields in the polar coordinate system

- 4) Display the longitudinal and transverse components of the electric field on a single graph. To plot the graph, use t, z, and r as arguments at the function entry point, as per the variant. An example graph is shown in Figure 1.4. To correctly display all components on a single graph, a 1/100 scale factor has been added to the angular component.



Rice. 1.4 - schedule distribution of electrical components fields in polar coordinate system

- 5) Build V Cartesian system coordinates schedule distribution running waves. For construction graphs along axes z V place input functions V quality arguments ask $\varphi = \pi$, t and r according to the variant.



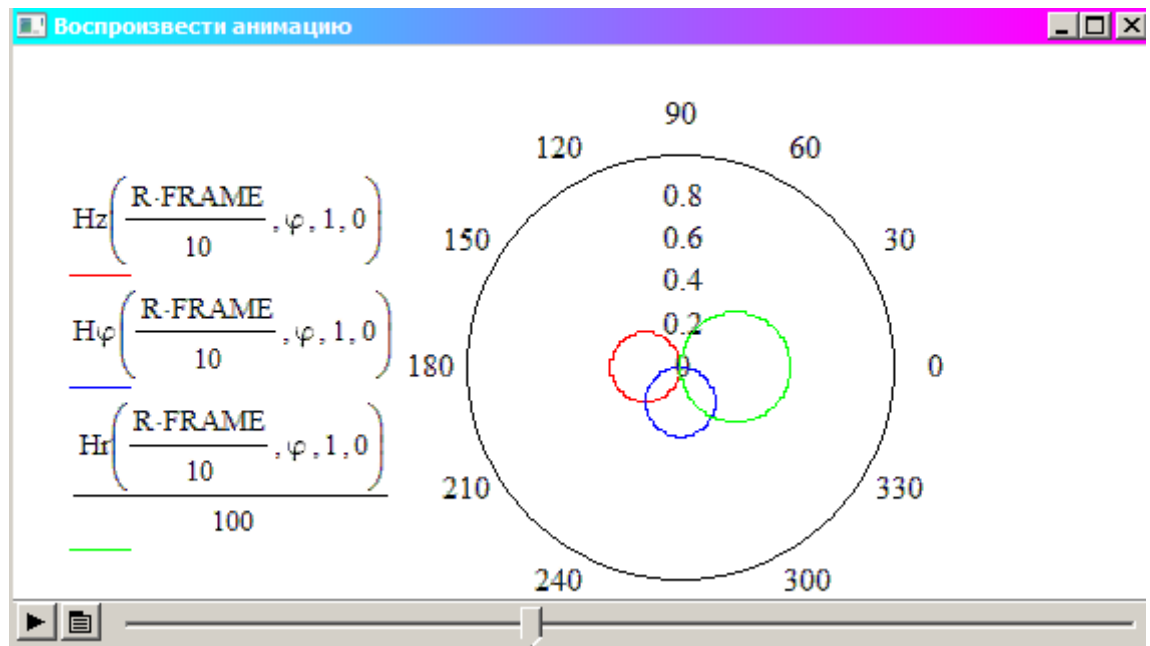
Rice. 1.5 - schedule distribution longitudinal component magnetic fields
along axes z

1.3. Study of the dependence of the components of the H11 wave on time and coordinates in the Mathcad system.

- 1) Animate the graph of the magnetic field component distribution as the radius changes. To do this, add the FRAME variable as an argument to the function entry point, as shown in the figure below. t and z are taken according to the chosen option.

$$\frac{\text{Hz}\left(\frac{\text{R} \cdot \text{FRAME}}{10}, \varphi, 1, 0\right)}{\text{H}\varphi\left(\frac{\text{R} \cdot \text{FRAME}}{10}, \varphi, 1, 0\right)} \cdot \frac{\text{Hr}\left(\frac{\text{R} \cdot \text{FRAME}}{10}, \varphi, 1, 0\right)}{100}$$

Select Tools | Animation| Recording. In the Animate dialog box, specify the first frame number in the C field: 0, the last frame number in the To field: 30 and the animation speed in the Frequency field: 10 in frames per second. Drag the mouse pointer to select the area in the document that will become the animation clip (distribution graph). components magnetic fields). Then click button "Animate." Add several screenshots of the animation to your report. An example is shown in the image below.



Rice. 1.13- animation running waves

- 2) Animate the graph of magnetic field component distribution over time. To do this, add the FRAME variable as an argument to the function entry point, as shown in the figure below. Use r and z as appropriate. Add several screenshots of the animation playback to the report.

$$\begin{array}{l} \text{Hz}\left(\frac{R}{10}, \varphi, 0.01\text{FRAME}, 0.005\right) \\ \text{H}\varphi\left(\frac{R}{10}, \varphi, 0.01\text{FRAME}, 0.005\right) \\ \text{Hr}\left(\frac{R}{10}, \varphi, 0.01\text{FRAME}, 0.005\right) \end{array}$$

100

- 3) Animate the graph of the distribution of magnetic field components as the z coordinate changes. To do this, add the following as an argument to the function input location: variable FRAME, How shown on drawing below. t, r take according to option. Include several screenshots of the animation playback in the report.

$$\begin{array}{l} \text{Hz}\left(\frac{R}{10}, \varphi, 1, 0.001\text{FRAME}\right) \\ \text{H}\varphi\left(\frac{R}{10}, \varphi, 1, 0.001\text{FRAME}\right) \\ \text{Hr}\left(\frac{R}{10}, \varphi, 1, 0.001\text{FRAME}\right) \end{array}$$

100

- 4) Do conclusions By conducted research.

Task 2. Modeling and study of H01 and E01 waves in a circular waveguide in the Mathcad system.

2.1. Modeling And study waves H01 V round waveguide V system "Mathcad".

- 4) For this contribute V Mathcad file the following changes:

- coefficients waves $H_{01} \ m = 0 \ n = 1$;
- the first root of the first derivative of the zero-order Bessel function of the first kind, then in all formulas replace U_{11} with U_{01}
- $U_{01} := 3.83$;
- Enter formulas amplitudes components magnetic And electric fields:

$$H_{zm}(r, \varphi, z) := H_0 \cdot J_0(\gamma \cdot r) \cdot \cos(m \cdot \varphi) \cdot \cos(-\beta_1 \cdot z)$$

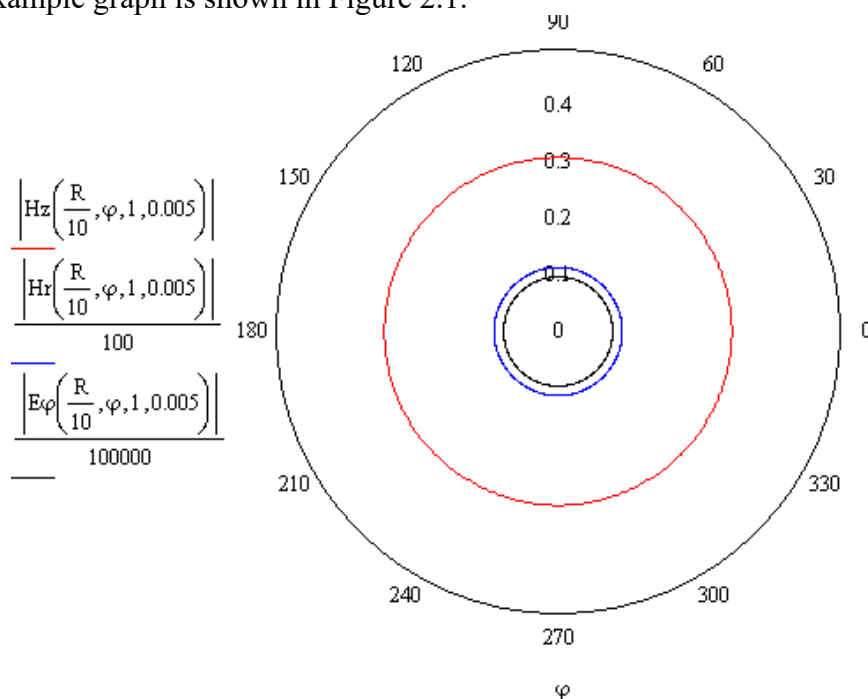
$$E_{rm}(r, \varphi, z) := H_0 \cdot \frac{m}{r} \cdot \frac{\omega_1 \cdot \mu a}{\gamma^2} \cdot J_0(\gamma \cdot r) \cdot \sin(m \cdot \varphi) \cdot \cos(-\beta_1 \cdot z)$$

$$E_{\varphi m}(r, \varphi, z) := H_0 \cdot \frac{\omega_1 \cdot \mu a}{\gamma} \cdot \frac{d}{dr}(J_0(\gamma \cdot r)) \cdot \cos(m \cdot \varphi) \cdot \cos(-\beta_1 \cdot z)$$

$$H_{rm}(r, \varphi, z) := \frac{-\beta_1}{\omega_1 \cdot \mu a} \cdot E_{\varphi m}(r, \varphi, z)$$

$$H_{\varphi m}(r, \varphi, z) := \frac{\beta_1}{\omega_1 \cdot \mu a} \cdot E_{rm}(r, \varphi, z)$$

- 5) Display on one graphics longitudinal And transverse components electric and magnetic fields. For constructions graphics V place input functions V quality For arguments, use t, z, and r according to the variant. To correctly display all components on a single graph, use scaling factors. An example graph is shown in Figure 2.1.



Rice. 2.1 - schedule distribution components magnetic And electric fields in a polar coordinate system

- 6) Investigate the dependence of the H_{01} wave components on time and coordinates. To do this, animate the distribution graph of the magnetic and electric field components, adding the FRAME variable. as an argument, as shown in the image below. Add several screenshots of the animation playback to the report.

$$\begin{array}{ccc}
\frac{\left| \text{Hz} \left(\frac{R \cdot \text{FRAME}}{10}, \varphi, 1, 0.005 \right) \right|}{100} & \frac{\left| \text{Hz} \left(\frac{R}{10}, \varphi, 0.01 \cdot \text{FRAME}, 0.005 \right) \right|}{100} & \frac{\left| \text{Hz} \left(\frac{R}{10}, \varphi, 1, 0.005 \cdot \text{FRAME} \right) \right|}{100} \\
\frac{\left| \text{Hr} \left(\frac{R \cdot \text{FRAME}}{10}, \varphi, 1, 0.005 \right) \right|}{100} & \frac{\left| \text{Hr} \left(\frac{R}{10}, \varphi, 0.01 \cdot \text{FRAME}, 0.005 \right) \right|}{100} & \frac{\left| \text{Hr} \left(\frac{R}{10}, \varphi, 1, 0.005 \cdot \text{FRAME} \right) \right|}{100} \\
\frac{\left| \text{E}\varphi \left(\frac{R \cdot \text{FRAME}}{10}, \varphi, 1, 0.005 \right) \right|}{100000} & \frac{\left| \text{E}\varphi \left(\frac{R}{10}, \varphi, 0.01 \cdot \text{FRAME}, 0.005 \right) \right|}{100000} & \frac{\left| \text{E}\varphi \left(\frac{R}{10}, \varphi, 1, 0.005 \cdot \text{FRAME} \right) \right|}{100000}
\end{array}$$

7) Compare received results With results execution tasks 1 And do it conclusions.

Initial data for modeling and research Options tasks For research
given V table 2. Table 2 – Initial data for task 2

O ption number	Eo Intramu scularly	O ption number	Eo Intramu scularly
1	3	9	2.8
2	2	10	3.15
3	4	11	2.6
4	2.5	12	4.2
5	5	13	2
6	2.2	14	4
7	3.1	15	2.5
8	3.3		

2.2. Modeling And study waves E01 V round waveguide V system "Mathcad".

Modeling waves E01 is being conducted For frequencies more critical V new Mathcad file.

1) Enter V working window programs original data:

- coefficients waves E01 $m = 0$ $n = 1$;
- dielectric permeability Wednesday $\epsilon_r = 1$;
- magnetic permeability Wednesday $\mu_r = 1$;
- electric constant -

$$\epsilon_0 := \frac{1}{36 \cdot \pi} \cdot 10^{-9} = 8.842 \times 10^{-12} ;$$

- magnetic constant–

$$\mu_0 := 4 \cdot \pi \cdot 10^{-7} = 1.257 \times 10^{-6} ;$$

- absolute dielectric permeability Wednesday $\epsilon_a := \epsilon_0 \cdot \epsilon_r$;
- absolute magnetic permeability Wednesday $\mu_a := \mu_0 \cdot \mu_r$;
- amplitude magnetic vector E0 fields according to the option;

- speed Sveta V environment -

$$C := \frac{1}{\sqrt{\epsilon_a \cdot \mu_a}};$$

- first derivative functions Bessel zero order first genus

$$V01 := 2.4048;$$

- critical wavelength-

$$\lambda_{kp} := \frac{2 \cdot \pi \cdot R}{V01};$$

- critical frequency-

$$f_{kp} := \frac{C}{\lambda_{kp}};$$

- frequency -

$$f1 := f_{kp} + 1 \cdot 10^9;$$

- circular frequency–

$$\omega1 := 2 \cdot \pi \cdot f1;$$

- wavelength in Wednesday–

$$\lambda1 := \frac{C}{f1};$$

- transverse wave number -

$$\gamma := \frac{V01}{R};$$

- constant wave propagation in unlimited space–

$$k1 := \frac{2 \cdot \pi}{\lambda1};$$

- constant distribution waves V guide system–

$$\beta1 := \sqrt{k1^2 - \gamma^2};$$

$$z0 := \frac{4 \cdot \pi}{\beta};$$

$$i := \sqrt{-1};$$

$$r := 0,0001 \cdot R;$$

$$\varphi := 0, \frac{2 \cdot \pi}{360} \dots 2 \cdot \pi;$$

$$z0 := 0.01;$$

14) Enter formulas amplitudes components magnetic And electric fields:

$$E_{zm}(r, \varphi, z) := E_0 \cdot J_0(\gamma \cdot r) \cdot \cos(-\beta_1 \cdot z)$$

$$E_{rm}(r, \varphi, z) := \frac{-\beta_1}{\gamma} \cdot E_0 \cdot \left(\frac{d}{dr} J_0(\gamma \cdot r) \right) \cdot \cos(-\beta_1 \cdot z)$$

$$E_{\varphi m}(r, \varphi, z) := E_0 \cdot \frac{m}{r} \cdot \frac{\beta_1}{\gamma} \cdot J_0(\gamma \cdot r) \cdot \cos(-\beta_1 \cdot z)$$

$$H_{rm}(r, \varphi, z) := \frac{-\omega_1 \cdot \varepsilon_a \cdot E_{\varphi m}(r, \varphi, z)}{\beta_1}$$

$$H_{\varphi m}(r, \varphi, z) := \frac{-\omega_1 \cdot \varepsilon_a \cdot E_{rm}(r, \varphi, z)}{\beta_1}$$

- 15) Enter formulas for calculating instantaneous values of the components of electric and magnetic fields

$$H_z(r, \varphi, t, z) := H_{zm}(r, \varphi, z) \cdot \cos(\omega_1 \cdot t)$$

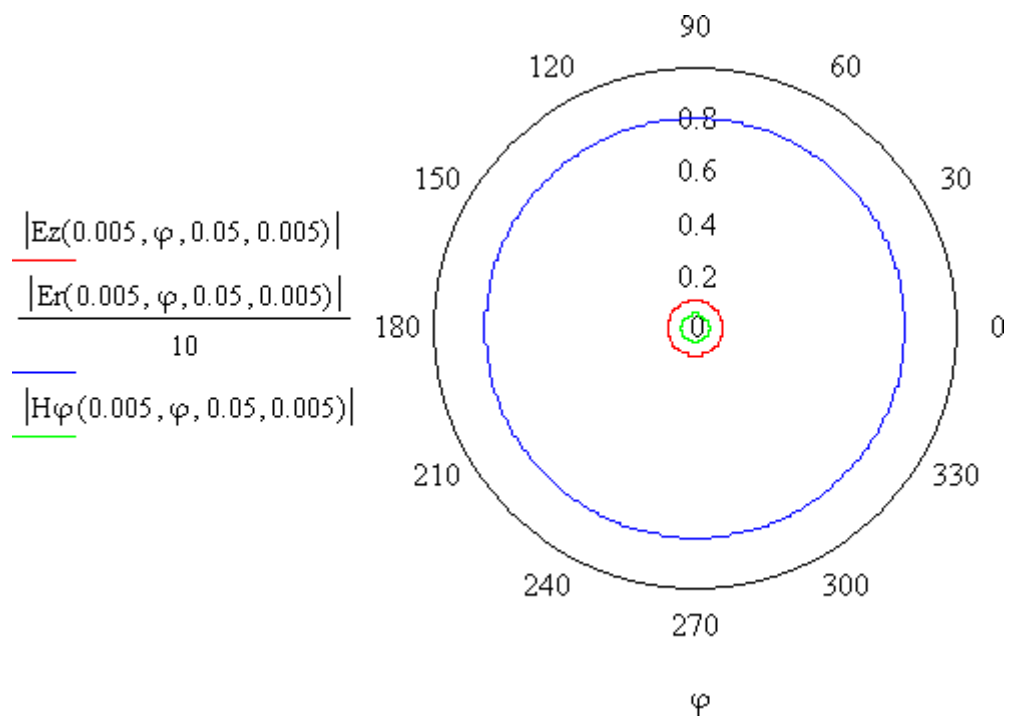
$$H_{\varphi}(r, \varphi, t, z) := H_{\varphi m}(r, \varphi, z) \cdot \cos(\omega_1 \cdot t)$$

$$H_r(r, \varphi, t, z) := H_{rm}(r, \varphi, z) \cdot \cos(\omega_1 \cdot t)$$

$$E_{\varphi}(r, \varphi, t, z) := E_{\varphi m}(r, \varphi, z) \cdot \cos(\omega_1 \cdot t)$$

$$E_r(r, \varphi, t, z) := E_{rm}(r, \varphi, z) \cdot \cos(\omega_1 \cdot t)$$

- 16) Display the longitudinal and transverse components of the electric and magnetic fields on a single graph. To plot the graph, use t, z, and r as arguments at the function entry point, as per the option. To correctly display all components on one graphics, use large-scale multipliers. Example The graphics are shown in Figure 2.2



Rice. 2.2 - schedule distribution components magnetic and electric

fields V polar coordinate system

- 17) Investigate the dependence of the E01 wave components on time and coordinates. To do this, animate the distribution graph of the magnetic and electric field components, adding the FRAME variable. as arguments t, r, z by analogy with the previous task.
- 18) Do conclusions By conducted research

Initial data for modeling and research

Options tasks For research given V table 3. Table 3 – Initial data for task 3

ption number	O A	I0 R1, m	R2	t	z
1	3	0.0026	4R1	0,2	0,8z0
2	2	0.0025	4R1	0,9	0,5z0
3	4	0.005	4R1	0,4	1,3z0
4	2.5	0.0045	4R1	0,2	1,2z0
5	5	0.0027	4R1	0,75	0,9z0
6	2.2	0.00175	4R1	0,4	1,4z0
7	3.1	0.0018	4R1	0,25	1,2z0
8	3.3	0.00245	4R1	0,6	0,75z0
9	2.8	0.0017	4R1	0,15	0,4z0
10	3.15	0.0036	4R1	0.6	1,2z0
11	2.6	0.0025	4R1	0,4	0,65z0
12	4.2	0.00355	4R1	0,2	0,6z0
13	2	0.00245	4R1	0,65	0,8z0
14	4	0.0017	4R1	0,4	0,5z0
15	2.5	0.0036	4R1	0,25	1,3z0

Exercise 3. Modeling And study TOPICS waves V coaxial waveguide.

3.1. Modeling electromagnetic waves V coaxial waveguide in the Mathcad system.

- 1) Enter V working window programs original data:
 - dielectric permeability Wednesday $\epsilon_r = 1$;
 - magnetic permeability Wednesday $\mu_r = 1$;
 - radius central conductor R1 according to the option;
 - interior radius external conductor R2 according to the option;
 - electric constant -

$$\epsilon_0 := \frac{1}{36 \cdot \pi} \cdot 10^{-9} = 8.842 \times 10^{-12} ;$$

- magnetic constant–

$$\mu_0 := 4 \cdot \pi \cdot 10^{-7} = 1.257 \times 10^{-6} ;$$

- absolute dielectric permeability Wednesday $\epsilon_a := \epsilon_0 \cdot \epsilon_r$;

- absolute magnetic permeability Wednesday $\mu_a := \mu_0 \cdot \mu_r$;
- strength current I_0 according to the option;
- speed Sveta V environment -

$$C := \frac{1}{\sqrt{\epsilon_a \cdot \mu_a}};$$

- critical wavelength-
 $\lambda_{kp} := \pi(R1 + R2)$;

- critical frequency-

$$f_{kp} := \frac{C}{\lambda_{kp}};$$

- frequency -

$$f1 := f_{kp} + 1 \cdot 10^9;$$

- circular frequency–

$$\omega1 := 2 \cdot \pi \cdot f1$$

- wavelength in Wednesday–

$$\lambda1 := \frac{C}{f1};$$

- constant wave propagation in unlimited space–

$$k1 := \frac{2 \cdot \pi}{\lambda1};$$

- wave resistance Wednesday, filling space between cylinders–

$$Z_c := 60 \cdot \sqrt{\frac{\epsilon_r}{\mu_r}} = 60$$

- $r := R1, R1 + 0.001 \dots R2$;

- $\varphi := 0, \frac{2 \cdot \pi}{360} \dots 2 \cdot \pi$;

- $z0 := 0.01$;

2) Enter formulas amplitudes components magnetic And electric fields:

$$Em(r, \varphi, z) := \frac{I_0 \cdot Z_c}{2 \cdot \pi \cdot r} \cdot \exp(-k1 \cdot z)$$

$$Hm(r, \varphi, z) := \frac{I_0}{2 \cdot \pi \cdot r} \cdot \exp(-k1 \cdot z)$$

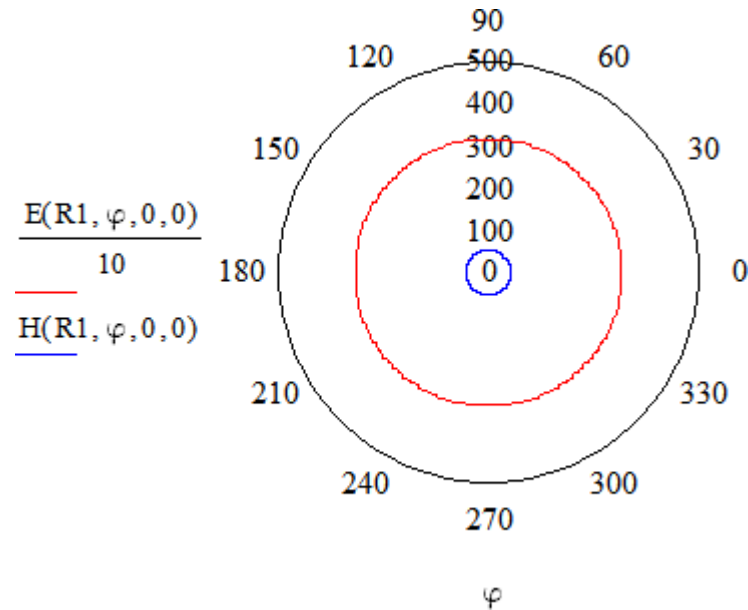
3.2. Study dependencies components TOPICS waves from time and coordinates in the Mathcad system.

1) Enter formulas calculation instant values components electric and magnetic fields

$$E(r, \varphi, z, t) := Em(r, \varphi, z) \cos(\omega1 \cdot t)$$

$$H(r, \varphi, z, t) := Hm(r, \varphi, z) \cdot \cos(\omega1 \cdot t)$$

- 2) Display both components of the electromagnetic field on a single graph. To plot the graph, use t , z , and ω as arguments at the function entry point, as appropriate. An example graph is shown in Figure 3.1. To correctly display all components on a single graph, a $1/10$ scale factor has been added to the electric component.



Rice. 3.1. - schedule distribution components electric And magnetic field in a polar coordinate system

- 3) Animate the distribution graph of the electric and magnetic field components as the radius changes. To do this, add the FRAME variable as an argument to the function entry point, as shown in the figure below. t and z are taken according to the chosen option.

$$\frac{E(R1+0.001\text{-FRAME}, \varphi, 0, 0)}{10}$$

$$H(R1+0.001\text{-FRAME}, \varphi, 0, 0)$$

- 4) Animate the distribution graph of electromagnetic field components as time changes. To do this, add [unclear] as an argument to the function input location. variable FRAME, How shown on drawing below. r , z take according to option. Include several screenshots of the animation playback in the report.

$$\frac{E(R1, \varphi, 0.001\text{FRAME}, 0)}{10}$$

$$H(R1, \varphi, 0.001\text{FRAME}, 0)$$

- 5) Animate the distribution graph of electromagnetic field components as the z -coordinate changes. To do this, add the FRAME variable as an argument to the function entry point, as shown in the figure below. Use t and r as appropriate. Add several screenshots of the animation playback to the report.

$$\frac{E(R1, \varphi, 0, 0.001\text{FRAME})}{10}$$

$$H(R1, \varphi, 0, 0.001\text{FRAME})$$

6) Do conclusions By conducted research

6. Defense of practical work

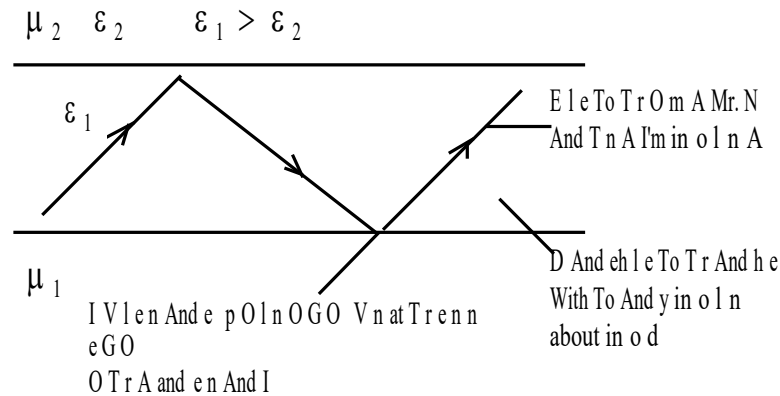
To defend the laboratory, submit a fully completed report that does not contain significant errors. By instructions teacher practically execute By alone from the tasks each educational question, having explained at this All physical phenomena And processes occurring in the developed model.

LABORATORY JOB No. 11

Study dielectric waveguide

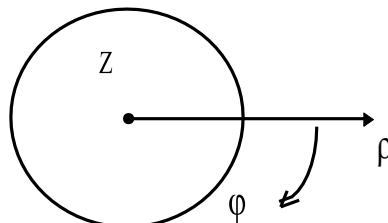
Brief theoretical information

Under certain conditions, electromagnetic waves can propagate without significant loss in dielectric plates or rods not bounded by metal surfaces. In this case, such plates or rods can act as dielectric waveguides. The low loss in dielectric waveguides is explained by the phenomenon of total internal reflection at the boundary. two dielectrics at condition, What electromagnetic waves are spreading in an optically denser medium (see Fig. 18.5)



Drawing 18.5 - Spreading electromagnetic waves V dielectric waveguide.

Most typical dielectric the waveguide is round (see fig. 18.6)



Drawing 18.6 - Transverse section round waveguide V cylindrical system coordinates.

Similarly, the solution to the problem of a hollow circular metal waveguide can be assumed that E and H fields can propagate in a circular dielectric waveguide. Then, for the E field, taking into account $\partial/\partial\varphi = 0$ you can write:

$$E_{\rho} = -\frac{\gamma}{K_c^2} \frac{\partial E_z}{\partial \rho} \quad (18.21)$$

$$H_{\varphi} = -\frac{i\omega\epsilon}{K_c^2} \frac{\partial E_z}{\partial \rho} \quad (18.22)$$

$$\frac{\partial^2 E_z}{\partial \rho^2} + \frac{1}{\rho} \frac{\partial E_z}{\partial \rho} + K_c^2 E_z = 0 \quad (18.23)$$

2. Fields V dielectric waveguide

Solution 18.23 will look similarly $E_z^{(2)}$ For round waveguide:

$$E_z^{(2)} = B_1 J_0(K_{c1} \rho) e^{-\gamma z} \quad (18.24)$$

Where $E_z^{(2)}$ - field inside waveguide;

$$K_{c1}^2 = K_1^2 + \gamma^2 = \omega^2 \epsilon_1 \mu_1 + \gamma^2$$

$$E_z^{(2)} = B_2 H_0^{(2)}(K_{c2} \rho) e^{-\gamma z} \quad (18.25)$$

Where $E_z^{(2)}$ - field outside waveguide;

$$K_{c2}^2 = K_2^2 + \gamma^2 = \omega^2 \epsilon_2 \mu_2 + \gamma^2$$

Using boundary conditions:

$$E_z^{(1)} = E_z^{(2)} \quad \text{at } \rho=0 \quad (18.26)$$

$$H_\phi^{(1)} = H_\phi^{(2)}$$

we get:

$$B_1 J_0(K_{c1} a) = B_2 H_0^{(2)}(K_{c2} a) \quad (18.27)$$

$$\frac{\epsilon_1}{K_{c1}} B_1 J_1(K_{c1} a) = \frac{\epsilon_2}{K_{c2}} B_2 H_1^{(2)}(K_{c2} a) \quad (18.28)$$

From (18.27) and (18.28)

$$\frac{J_0(K_{c1} a)}{J_1(K_{c1} a)} = \frac{\epsilon_2 K_{c2} H_1^{(2)}(K_{c2} a)}{\epsilon_1 K_{c1} H_0^{(2)}(K_{c2} a)} \quad (18.29)$$

The solution of the transcendental equation (18.29) together with the expressions for K_{c1} and K_{c2} allows us to determine the propagation constant for the E field.

Let us define the condition of absence of energy propagation beyond the dielectric waveguide (the condition of total internal reflection).

For this we will use the relation (18.25) for the field outside the waveguide.

Obviously, condition Not distribution V radial direction With taking into account the approximation for the Hankel function

$$H_0^{(2)}(K_{c2} \rho) \approx \sqrt{\frac{2}{\pi}} \cdot e^{-i \left(K_{c2} \rho - \frac{\pi}{4} \right)} \quad (18.30)$$

will look So

$$K_{c2} = -i |K_{c2}| \quad (18.31)$$

those. To K_{c2} must be purely imaginary, V this case field for beyond waveguide

$$\frac{1}{\sqrt{\rho}} \cdot e^{K_{c2} \rho}$$

will fade out proportionally

Can show, What condition (18.31) is being carried out V case, If the frequency of electromagnetic waves in the waveguide is greater than the critical frequency, determined by the expression:

$$f_{\text{tor}} = \frac{1}{2\pi a} \sqrt{\epsilon_1 \mu_1 - \epsilon_2 \mu_2} \quad (18.32)$$

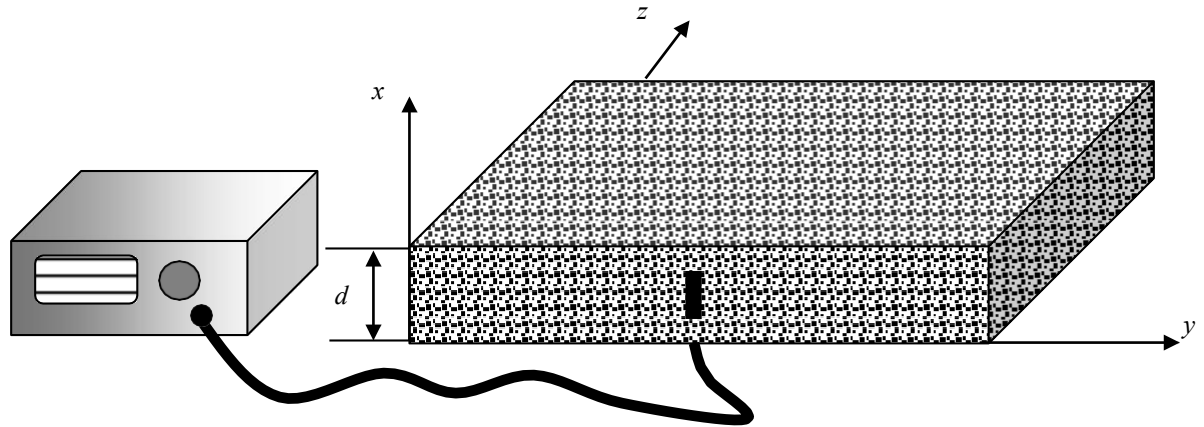
Where χ_{on} - roots equations $J_0(\chi) = 0$

From (18.32) follows, What V waveguide Maybe spread infinite number of waves, which corresponds to the conclusions obtained for the previously considered waveguides.

Dielectric waveguides are used to transmit millimeter and submillimeter waves, as they have the lowest losses in these ranges.

Initial data

In free space ($\mu=\mu_0$ And $\varepsilon=\varepsilon_0$) a dielectric plate of thickness is located d And electromagnetic constant $\mu=\mu_0$ And $\varepsilon=\varepsilon_a$. Generator microwave oscillations with frequency f_g an electromagnetic field is excited in it.



EXERCISE ON STUDY

1. Define types fluctuations, excited generator V plate.
2. For each type of vibration, determine: transverse coefficients phases g And p ; phase velocity v_f ; critical frequency f_{cr} .
3. Research structure electromagnetic fields V plate.
4. Research influence parameters plates on phase speed of electromagnetic waves.

ORIGINAL DATA FOR RESEARCH

N (No. options)	1	2		15
Thickness plates d , cm	$(2+0.2 N)^{0.5}$			
Relative permittivity permeability ε_r	$2 + 0.2 N$			
Frequency f_g , GHz	$10 N^{0.1}$			

For waves EVEN type E10, E30 And etc. decide graphic by the method of transcendental equation with respect to transverse phase coefficients in the dielectric g and in free space p

$$\left\{ \begin{array}{l} \epsilon_r dg \operatorname{tg}(gd) = dd \\ (gd)^2 + pd^2 = \omega^2 d^2 \epsilon_0 (\epsilon_r - 1) \mu \end{array} \right.$$

For waves ODD type E20, E40 And etc. decide graphic by the method of transcendental equation with respect to transverse phase coefficients in the dielectric g and in free space p

$$\left\{ \begin{array}{l} \epsilon_r dg \operatorname{ctg}(gd) = -dp \\ (gd)^2 + pd^2 = \omega^2 d^2 \epsilon_0 (\epsilon_r - 1) \mu \end{array} \right.$$