Ministry of Transport and Communications of Ukraine

State Administration of Communications
Odessa National Academy of Telecommunications n.a. A.S. Popov

METHODICAL INSTRUCTIONS

for implementation of laboratory work

"Research of Construction Principles and Antenna Characteristics of Mobile Communications Base Stations"

on discipline

«Mobile Communication Systems»

Module 1 — Functional Devices

of Radiochannel of Mobile Communication Systems

for full-time and part-time students of information networks and telecommunication systems departments

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The purpose of the methodical instructions is to assist students in studying of theoretical aspects of module 1 — Functional Devices of Radiochannel of Mobile Communication Systems, themes 1.3 — Antenna device of base and subscriber stations of mobile communication systems, specifically principles of base stations antennas of mobile communications in the form of panel antennas, research of their characteristics within the laboratory exercises to familiarize with the main stages of laboratory work and drafting features of the studying results in the reporting protocol.

Methodological instructions are intended for full-time and part-time students of information networks and telecommunications systems departments.

The English variant was corrected by Stoyanova I.I.

Methodological instructions reviewed and approved at a meeting of technical methodological seminar of the TED and SRC Department
(Protocol № 1 from 28.09.2010)

CONTENTS

1 GENERAL REQUIREMENTS TO THE IMPLEMENTATION OF LABORATORY WORK

Contents of implementing work has to be pre-study on the basis of methodical instructions with the involvement of theoretical material from the lecture course, relevant literature.

Laboratory work is done by groups consisting of 2-3 students, each of whom performs individual assignments.

A report is prepared and defended by each student individually.

Input data for the research assignments are chosen by each student in accordance with the penultimate (m) and last (n) digits of the student's credit book, listed in Annex A.

2 LABORATORY WORK

“Research of Construction Principles and Antenna Characteristics of Mobile Communications Base Stations ”

2.1 Purpose of the work

The aim of the laboratory work is to deepen the theoretical knowledge on the Topic 1.3 — Antenna devices of the base and subscriber stations of mobile communication systems and mastering of computational technique for analyzing of characteristics of the radiation panel antennas of base stations of mobile communications.

2.2 Key Points

Block diagram of antenna-feeder path of mobile communications base station, its constituent elements

In Fig.1 the typical (approximate) schemes of antenna-feeder path of base stations of mobile communications are shown, in particular, in Fig. 1, and an antenna-feeder path from the collinear (omnidirectional) antenna is shown, as in Figure 1,b – with panel (directional) antenna.

By numbers in Fig. 1 the following elements that make up the base station of mobile communications are shown, more precisely, its antenna and feeder path: 1) omnidirectional antenna; 2) directional antenna; 3) cable insert; 4), main feeder; 5) discharge unit; 6) feeders grounding device; 7) two-way adder; 8) transceiver of base station.

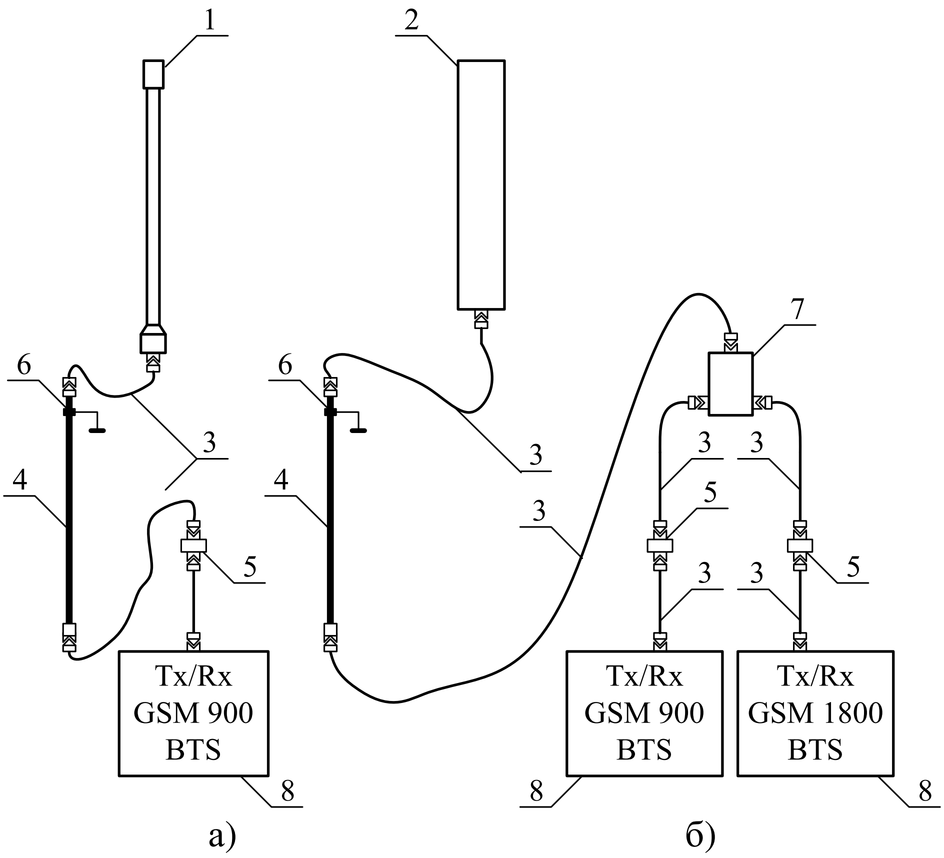
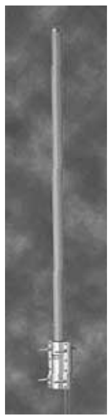


Fig. 1 – Typical schemes of antenna-feeder path
of mobile communications base stations



Antennas of mobile communications base stations are produced in two main modifications: **omnidirectional antennas** and **directional antennas**.

Omnidirectional antenna of base stations for mobile communications, is an antenna array consisting of half-wave dipoles arranged coaxially, so-called collinear antenna. As a rule, half-wave vibrators are excited equally in magnitude and phase, sometimes with a phase delay, which provides a slope of the main beam antenna pattern (AP) in the vertical plane to optimize coverage. Depending on the number of half-wave dipoles range of antenna gain (G) is 2.15 ... 11.0 dBi.

Directional antenna of the base stations for mobile communications in the form of a panel antenna is an antenna array consisting of half-wave dipoles located above a metal screen and combined with rigid coaxial cables. Depending on the type of antenna has one, two, four or six external connectors, which actually indicates the number of independent antennas, placed in a single package. Models differ in the width of the main beam AP in the horizontal plane (60°, 90°, 105° or 120°), G (6,5 ... 18,5 dBi), and the value of the power input (100 ... 500 W). A number of models provides an electrical slope of the beam (fixed or adjustable), ensured by the power scheme.

Among the latest developments, a special place takes a panel antenna with dual slant polarization (XPol, XXPol – antennas). These antennas consist of two, four or six independent dipole systems. On the basis of such antennas multi-band antenna are designed, in particular: dual-band at frequencies 900/1800 MHz and triple-band at frequencies 900/1800/2000 MHz.

Dividers (adders) of power used for power distribution among several antennas (radiating elements) in the complex antenna systems. They can also be used for the formation of branched cable networks. Power dividers are available at all required frequency ranges, the levels of input power from 100 to 500 W. The known power dividers with equal division (splitter) into 2/3/4 channels and with unequal division into 2 channels (tapper) with losses to division of 06/10/1915 dB. Constructions of power dividers and their production technology provide the level of intrinsic losses less than 0.05 dB, and hermetic container enables use in difficult weather conditions with temperatures of –60° ... +55°C.

Discharge units are necessary to protect equipment from lightning. Variants of the dischargers are significantly different both in design and the principle of operation. Thus, in the POLYPHASER discharge unit the diode inserts are installed, shorting the line at certain values of induced voltage. The operating principle of the TERACOM discharger is based on a shunt direct current coaxial line at a quarter wavelength of the working mode. SPINNER dischargers are presented in two versions. The first segment has a shunt line and the second one contains a gas capsule with an inert gas that is ionized by a pulse of high voltage. All of these types of dischargers have several models with different working frequencies, level of transmitted power limits, values of breakdown voltage and discharge current. Dischargers have low intrinsic losses (less than 0.2 dB) and wide operating temperatures range of –40^o...+50^{o}C.

Feeders grounding device (grounding conductor) is used to relieve the induced static potential in the outer conductor cable, as well as for efficient operating of discharge unit, which design does not provide separate grounding conductor. The complex of grounding-discharge unit most effectively protects equipment from electrical discharges and static charge. Grounding conductors are available to all of cable diameters.

Radio frequency coaxial cables used in mobile communication base stations can be divided into two main groups: *general purpose cables* and *extra flexible*.

General purpose cables (labeling RF) provide transmission of radio signals from base station to the antenna and back. Cable diameter: 3/8", 1/2", 5/8 ", 7/8", 11/4 ", 15/8" and 21/4". Cables have low attenuation due to inner use of foamed high density polyethylene (labeling HD) and continuous wave impedance (50 Ω) in a wide range of frequencies. Inner conductor cable is made of copper wire, copper pipe or aluminum wire coated with copper. Outer conductor is a copper corrugated pipe or copper tape, folded in a spiral. Outside inner and inside outer conductors are covered with a thin plastic film and the space between conductors is filled with foamed polyethylene having a degree of extension up to 80%. Such multilayer structure additionally provides increased water resistance. Cables can operate at temperatures of –60° ... +70°C.

Extra flexible cables (labeling RFF) are used in cable inserts that connect the main feeder to the antenna or the equipment. Cable diameter is also standardized: 1/4", 3/8", 1/2", 7/8". Unlike general purpose cables, inside these cables foamed low density polyethylene is used (labeling LD), and the outer conductor is made of corrugated spiral with a smaller step. This technical design solution can significantly reduce the minimum radius of cable repeated bending and increase its flexibility.

Cable inserts are used to connect the main feeder from antenna or base station. In addition, inserts, damp mechanical vibrations that arise under the influence of weather factors, and thereby, relieve mechanical stress on connectors on the antenna, main feeder and base station. Completed cable inserts have a length of 1,2 and 3 meters, are made of highly flexible cable with straight or angled connectors on the ends.

Coaxial connectors are made for all cable diameters of general purpose as well as particularly flexible and are distinguished by the corresponding types (type N; 7/16 DIN, etc.) As well as cable connectors, panel or hardware connectors that are used in various equipment are manufactured, and also coaxial adapters for transition from one type of connector to another. Connectors have a low transitional resistance of contacts (less than 0,001 Ω), low relative level of intermodulation products (–156 dB), high degree of agreement with cable (voltage standing-wave ratio (VSWR) less than 1.03), reusable (up to 10000 screwing). Connectors vary in design, method of building and installing them on cable and method of sealing. Thus, SPINNER sealing connectors are provided by a special silicone compound that is injected into the connector into the space between the outer part of the connector and the outer cable conductor, WISI connectors — by compound or shrink tubing. TERACOM connectors do not require special protection. Moreover, additional rings in the design of these connectors ensure their operability even when damaged cable covering.

Construction Features and Radiation Characteristics of Panel Antennas of Mobile Communications Base Stations

Panel antenna is a flat antenna array with aperiodic reflector (flat metal screen), as antenna elements of which symmetric half-vibrators-curves are frequently used (length of a symmetric vibrator is $2l = \lambda/2$, where λ – length of electromagnetic wave).

Sketch of a panel antenna of mobile communications base station is shown in Fig. 2. It also explains the main geometrical parameters of the antenna, in particular: number of antenna elements and the distance between them in the floor is marked as m and d_m; number of floors and the distance between them is indicated as n and d_n; distance from antenna elements to aperiodic reflector (metal screen) is indicated by variable d_e.

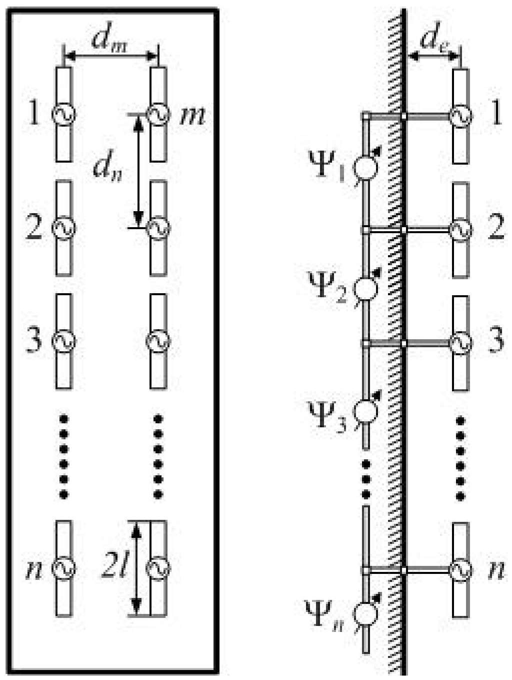


Fig. 2 – Sketch of a panel antenna of mobile communications base station

Antenna elements on the floor of panel antennas are usually excited equally in magnitude and phase, and the floor of panel antenna are excited or equally in magnitude and phase $\Psi_1 = \Psi_2 = \Psi_3 = ... = \Psi_n$, or equally in magnitude and with a linear phase shift $\Delta\Psi$. Linear phase shift $\Delta\Psi = \Psi_1 - \Psi_2 = \Psi_2 - \Psi_3 = ...$ of excitation sources allows to change in minor boundaries direction of maximum radiation θ_{max} of antenna without significant change of the shape of its antenna pattern (AP).

For engineering (approximate) calculation and analysis of directional panel antenna characteristics, in particular, AP in the main orthogonal planes (E- and H-planes) the following formulas can be used:

$$f^E(\theta) = f_{el}^E(\theta) f_s^E(\theta, d_e) f_{arr}^E(\theta, n, d_n, \Delta\Psi) \text{ if } -\pi/2 < \theta < \pi/2, \quad (1)$$

$$f^H(\varphi) = f_{el}^H(\varphi) f_s^H(\varphi, d_e) f_{arr}^H(\varphi, m, d_m) \text{ if } -\pi/2 < \varphi < \pi/2, \quad (2)$$

where $f_{el}^E(\theta)$, $f_{el}^H(\varphi)$ – AP of antenna element (symmetric vibrator) in orthogonal planes; $f_s^E(\theta, d_e)$, $f_s^H(\varphi, d_e)$ – multiplication factors that characterize the influence of an aperiodic reflector (flat metal screen) on AP of antenna system in corresponding orthogonal planes; $f_{arr}^E(\theta, n, d_n, \Delta\Psi)$, $f_{arr}^H(\varphi, m, d_m)$ – multiplication factors in corresponding orthogonal planes, depending on the number of antenna elements, distance between them and the phase shift of excitation sources.

The location of a panel antenna in corresponding planes (E- and H-planes) and counting of angles θ and φ in these planes is illustrated in Fig. 3.

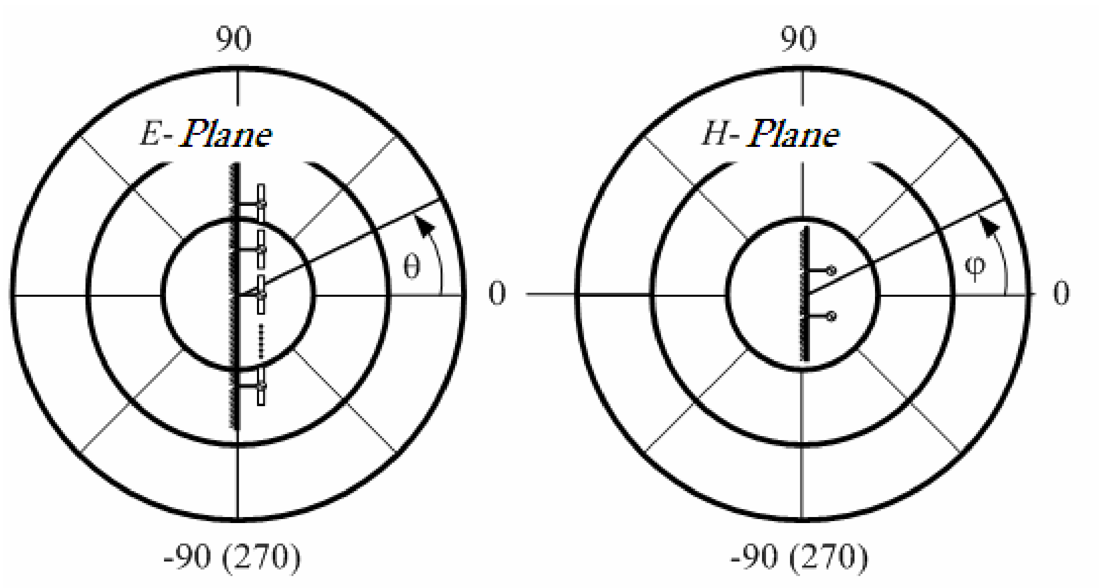


Fig. 3 – Main orthogonal planes and counting angles

AP of symmetric vibrator in *E*-plane can be calculated by the formula:

$$f_{el}^E(\theta) = \left| \frac{\cos(kl \sin\theta) - \cos kl}{\cos\theta} \right|, \quad (3)$$

where $k = 2\pi/\lambda$ – wave number of free space, angle θ is measured from normal to antenna element (see Fig. 3).

While $2l = \lambda/2$ value $kl = \pi/2$ and the equation (3) is transformed into

$$f_{el}^{E}(\theta)=\left|\frac{\cos\left(\frac{\pi}{2}\sin\theta\right)}{\cos\theta}\right|. \tag{4}$$

If $\theta=\pm\pi/2$ the equation (4) is equal to:

$$f_{el}^{E}\left(\pm\frac{\pi}{2}\right)=\left|\frac{0}{0}\right|\equiv 0.$$

AP of symmetric vibrator in *H*-plane can be calculated by the formula:

$$f_{el}^{H}(\varphi)=\left|1-\cos kl\right|. \tag{5}$$

If $2l=\lambda/2$ the equation (5) is transformed into:

$$f_{el}^{H}(\varphi)=1, \tag{6}$$

i.e. AP of symmetric vibrator in H-plane does not depend on angular variable φ.

For calculation of the systems multipliers, characterizing the influence of aperiodic reflector (flat metal screen), we assume that the size of the screen is big enough, and this, in its turn, allows us to use the method of images and to consider the antenna element with the screen as a two-element antenna array with antiphase excitation of elements located at a distance $2d_e$ one from another. Eliminating the intermediate transformations, we obtain expressions for the system multiplier in the corresponding orthogonal planes:

$$f_{s}^{E}(\theta,d_e)=\left|\sin(kd_e\cos\theta)\right|; \tag{7}$$

$$f_{s}^{H}(\varphi,d_e)=\left|\sin(kd_e\cos\varphi)\right|. \tag{8}$$

If $d_e=\lambda/4$ value $kd_e=\pi/2$ and the expressions (7) and (8) are transformed into:

$$f_{s}^{E}\left(\theta,d_e=\frac{\lambda}{4}\right)=\left|\sin\left(\frac{\pi}{2}\cos\theta\right)\right|; \tag{9}$$

$$f_{s}^{H}\left(\varphi,d_e=\frac{\lambda}{4}\right)=\left|\sin\left(\frac{\pi}{2}\cos\varphi\right)\right|. \tag{10}$$

Array multipliers taking into account equally-magnitude with linear phase shift excitation $\Delta\Psi$ in E-plane and equal in phase excitation of antenna elements in H-plane can be calculated by the formulas:

$$f_{arr}^{E}(\theta,n,d_n,\Delta\Psi)=\left|\frac{\sin\left[\frac{n(kd_n\sin\theta-\Delta\Psi)}{2}\right]}{n\sin\left[\frac{kd_n\sin\theta-\Delta\Psi}{2}\right]}\right|; \tag{11}$$

$$f_{arr}^{H}(\varphi,m,d_m)=\left|\frac{\sin\left[\frac{m(kd_m\sin\varphi)}{2}\right]}{m\sin\left[\frac{kd_m\sin\varphi}{2}\right]}\right|. \tag{12}$$

In the case when the distance between floors of a flat antenna array $d_n=\lambda/2$ value $kd_n=\pi$ and the expression (11) can be represented in the following way:

$$f_{arr}^{E}\left(\theta,n,d_n=\frac{\lambda}{2},\Delta\Psi\right)=\left|\frac{\sin\left[\frac{n(\pi\sin\theta-\Delta\Psi)}{2}\right]}{n\sin\left[\frac{\pi\sin\theta-\Delta\Psi}{2}\right]}\right|. \tag{13}$$

Relationship between direction of maximum radiation and a linear phase shift of the exciting sources is given by:

$$\Delta\Psi=kd_n\sin\theta_{\max} \tag{14}$$

or taking into account $d_n=\lambda/2$, $kd_n=\pi$

$$\Delta\Psi=\pi\sin\theta_{\max}. \tag{15}$$

If m = 2 (two antenna elements on a floor) the expression (12) can be transformed into:

$$f_{arr}^{H}(\varphi,m=2,d_m)=\left|\cos\left(\frac{kd_m\sin\varphi}{2}\right)\right|. \tag{16}$$

Thus, taking into account the given formulas (3) – (16) the expressions (1) and (2) can be represented in a form:

$$f^{E}(\theta)=\left|\frac{\cos\left(\frac{\pi}{2}\sin\theta\right)}{\cos\theta}\right|\left|\sin\left(\frac{\pi}{2}\cos\theta\right)\right|\left|\frac{\sin\left[\frac{n(\pi\sin\theta-\Delta\Psi)}{2}\right]}{n\sin\left[\frac{\pi\sin\theta-\Delta\Psi}{2}\right]}\right|, \tag{17}$$

$$f^{H}(\varphi,d_m)=\left|\sin\left(\frac{\pi}{2}\cos\varphi\right)\right|\left|\cos\left(\frac{kd_m\sin\varphi}{2}\right)\right|, \tag{18}$$

if $-\pi/2<\theta<\pi/2$ and $-\pi/2<\varphi<\pi/2$.

In formulas (17) and (18) it is shown that the length of the antenna element (symmetric vibrator) is $2l=\lambda/2$, distance to aperiodic reflector (flat metal screen) is $d_e=\lambda/4$, distance between floors of the plane antenna array is $d_n=\lambda/2$, number of antenna elements on a floor is m =2.

In the analysis of AP often use parameters that define the width of the main beam of AP on half-power level in the corresponding orthogonal planes $2\Delta\theta_{0,707}$ and $2\Delta\varphi_{0,707}$ are often used. Since AP is usually plotted as the angular dependence of the amplitude of electromagnetic field, half-power level corresponds to 0,707 of maximum amplitude of electric field. In the logarithmic scale, half-power level corresponds to –3 dB from the maximum amplitude of the electromagnetic field.

For engineering (approximate) calculation of antenna G (we assume that losses of antenna are missing, that is, antenna efficiency is unity and correspondingly G is equal to the directive gain) we can use the following formula:

$$G=G_{el}G_{s}G_{arr}^{Å}(n,d_n)G_{arr}^{H}(m,d_m), \tag{19}$$

where G_{el} – G of antenna element (symmetric vibrator); G_s – partial G taking into account the effect of aperiodic reflector (flat metal screen); $G_{arr}^{Å}(n,d_n)$, $G_{arr}^{H}(m,d_m)$ – partial G of flat antenna array in the corresponding orthogonal planes.

If $2l=\lambda/2$

$$G_{el}=1{,}64\ \text{(2,15 dBi)}. \tag{20}$$

Assuming that screen sizes are sufficiently big comparing to wavelength λ, screen is flat, highly conductive:

$$G_s=2{,}0\ \text{(3,01 dBi)}. \tag{21}$$

Partial G of plane antenna array in corresponding orthogonal planes can be calculated by the formulae:

$$G_{arr}^{Å}(n,d_n)=\frac{n^2}{n+2\sum_{i=1}^{n-1}(n-i)\frac{\sin i\,kd_n}{i\,kd_n}};\qquad(22)$$

$$G_{arr}^{H}(m,d_m)=\frac{m^2}{m+2\sum_{i=1}^{m-1}(m-i)\frac{\sin i\,kd_m}{i\,kd_m}}.\qquad(23)$$

where $k=2\pi/\lambda$ – wave number of free space.

When $d_n=d_m=\lambda/2$ value of sine argument $kd_n=kd_m=\pi$ and the formula (22), (23) is simplified into:

$$G_{arr}^{Å}\left(n,d_n=\frac{\lambda}{2}\right)=n;\qquad(24)$$

$$G_{arr}^{H}\left(m,d_m=\frac{\lambda}{2}\right)=m.\qquad(25)$$

For a case when number of antenna elements on a floor is m = 2 and elements are placed on random distance d_m one from another, the expression (23) is transformed into:

$$G_{arr}^{H}(m=2,d_m)=\frac{2}{1+\frac{\sin kd_m}{kd_m}}.\qquad(26)$$

Thus, taking into account formulas (20) – (26) the expression (19) can be presented in a form:

$$G(n,d_m)=1{,}64\cdot 2\cdot n\cdot\frac{2}{1+\frac{\sin kd_m}{kd_m}}.\qquad(27)$$

or

$$G(n,d_m)=2{,}15+3{,}01+10\cdot lg\,n+10\cdot lg\frac{2}{1+\frac{\sin kd_m}{kd_m}},\ \text{dBi}.\qquad(28)$$

In formulas (27) and (28) it is also motioned that the length of antenna element (symmetric vibrator) is $2l=\lambda/2$, distance to aperiodic vibrator reflector (plane metallic screen) is $d_e=\lambda/4$, distance between floors of plane antenna pattern is $d_n=\lambda/2$, number of antenna elements on a floor is m =2.

For calculation of G of arbitrary antenna (taking into account that efficiency equals 1) general formula is known:

$$G = \frac{4\pi}{\int_0^{2\pi}\int_0^{\pi} f^2(\theta, \varphi)\,\sin\theta\,d\theta\,d\varphi}, \tag{29}$$

however, while direct using of the formula (29) the definition of special directional antenna characteristics by power has a special mathematical complexity $f^2(\theta, \varphi)$.

Subject to additional simplifications and transformed equations (29) can be transformed into:

$$G = \frac{4\pi}{2\Delta\theta_{0,707}\,2\Delta\varphi_{0,707}} \tag{30}$$

or

$$G = 10\log\frac{4\pi}{2\Delta\theta_{0,707}\,2\Delta\varphi_{0,707}}\ \text{dBi}, \tag{31}$$

where numerical values of width of AP's main beam in main orthogonal planes $2\Delta\theta_{0,707}$ and $2\Delta\varphi_{0,707}$ should be substituted in radians.

2.3 Key Questions

Questions for admittance to the implementation of laboratory work:

1. Explain briefly the scheme of antenna-feeder path of mobile communications base stations, including its constituent elements.
2. Explain structural differences and features of direction characteristics of collinear and panel antennas used in mobile communications base stations.
3. Explain the purpose and features of power dividers (adders).
4. Explain the purpose and features of discharge units and groundings of cable.
5. Explain the purpose and characteristics of radio frequency coaxial cable (general-purpose and extra flexible cables).
6. Explain the purpose and characteristics of cable inserts and coaxial connectors.

Questions to defend a laboratory work:

1. Write the engineering formula to calculate the AP of panel antenna in the vertical plane (E-plane). Explain each of the factors.
2. Write the engineering formula to calculate the AP of panel antenna in the horizontal plane (H-plane). Explain each of the factors.
3. Explain the dependence of the main beam of AP on the finite dimensions of antenna, number of elements and relative distance between them.

4. Explain the dependence of the direction of maximum antenna radiation on a linear phase shift excitation sources of elements and on the relative distance between them.

5. Explain the relationship of panel antenna gain with its relative sizes, width of main beam of AP.

Questions of extra complexity*:

1. Derive the formula (7) or (8).
2. Derive the formula (11) or (12).
3. Derive the formula (16).
4. Derive the formula (22) or (23).
5. Derive the formula (30).

* A reasonable answer to any question of increased complexity is counted as the implementation and defend of a laboratory work with a maximum mark.

2.4 Home task

1. Study theoretical concepts (key points) using the methodical instructions, summary of lectures and recommended literature.
2. Prepare answers to key questions (questions for admittance to the implementation of laboratory work).
3. Prepare a report layout (examples of a title page and contents of the protocol are given in Annex B).
4. Explore the algorithm and the features of the program.
5. Solve the problem (the result of problem solving relates to the input data to perform a laboratory work).
6. Read through the catalog of KATHREIN company (electronic version of the catalog is attached to the electronic version of methodical instructions as well as in printed form in laboratory).

Problem. Determine the desired gain (G) of base station antenna for mobile communication G_{BS} at a given distance D and a given fade margin L_{fad}. Take numerical values D and L_{fad} from Table A1 “Input Data for Home Task” (see Annex A).

Methodical recommendations to solve problems. Signal power at the receiver input of mobile station for mobile communications is defined by the expression:

$$P_{in\,MS} = \frac{P_{out\,BS} G_{BS} G_{MS}}{L_{BS} L_{MS} L_{fs} L_{fad}}, \tag{32}$$

where P_{outBS}, P_{inMS} – powers of signal at the transmitter output of base station and at the receiver input of mobile station, correspondently, W (or mW – miliwatt); G_{BS}, G_{MS} – gains of base and mobile station antennas for mobile communication, correspondently (dimensionless values); $L_{BS} L_{MS}$ – attenuation of signal due to the losses in antenna-feeder paths of base and mobile stations for mobile communications, correspondently (dimensionless values); L_{fs}, L_{fad} – attenuation of signal due to the losses while propagation in free space and fading, correspondently (dimensionless values).

In logarithmic form the formula (32) can be written as

$$P_{in\,MS} = P_{out\,BS} + G_{BS} + G_{MS} - L_{BS} - L_{MS} - L_{fs} - L_{fad}\,, \tag{33}$$

where $P_{out\,BS}$, $P_{in\,MS}$ are defined in dBW (or dBm); G_{BS}, G_{MS} – in dBi (dimension dBi means that G is defined correspondently to isotropic emitter); $L_{BS} L_{MS}$ and L_{fs}, L_{fad} – in dB.

Conversion of measurement units in dB and vice versa is performed by formulas:

$$P, dBW = 10\lg\left(\frac{P, W}{1, W}\right); \quad P, dBm = 10\lg\left(\frac{P, mW}{1, mW}\right);$$

$$P, dBW = P, dBm - 30 \;\; \text{and} \;\; P, dBm = P, dbW + 30$$

$$P, W = 10^{\frac{P, dBW}{10}}; \quad P, mW = 10^{\frac{P, dBm}{10}};$$

$$G, dBp = 10\lg\left(\frac{G}{G_i}\right), \text{ where } G_i = 1 \text{ – gain of isotropic emitter;}$$

$$G = 10^{\frac{G, dBi}{10}}.$$

To calculate the required gain of base station antenna for mobile communications G_{BS} in times by the formula (32) we can use the formula:

$$G_{BS} = \frac{P_{in\,MS} L_{BS} L_{MS} L_{fs} L_{fad}}{P_{out\,BS} G_{MS}}, \tag{34}$$

or to define G_{BS} in dB in accordance with the formulas (33) by expression:

$$G_{BS} = P_{in\,MS} + L_{BS} + L_{MS} + L_{fs} + L_{fad} - P_{outBS} - G_{MS}\,. \tag{35}$$

Numerical values P_{inMS}, P_{outBS}, G_{MS}, L_{BS}, L_{MS} are given for all variants as equal (see additions to Table A1, Annex A). Numerical value L_{fad} is taken from Table A1 “Input Data for Home Task” (see Annex A) with respect to variant.

To calculate L_{fs} the formulas can be used

$$L_{fs} = \left(\frac{4\pi D}{\lambda}\right)^2 \text{ or } L_{fs}, dB = 10 lg\left(\frac{4\pi D}{\lambda}\right)^2 = 20 lg\left(\frac{4\pi D}{\lambda}\right), \tag{36}$$

where D – maximum working range of mobile communications base station; λ – electromagnetic wavelength.

Numerical value D is taken from Table A1 “Input Data for Home Task” (see Annex A) according to variant. Numerical value λ is the same for each variant (see additional to Table A1, Annex A).

While calculating L_{fs} according to (36) values D and λ should be in similar measurement units.

2.5 Laboratory Task

1) Based on the given values of width of main beam of AP on half-power in H-plane $2\Delta\varphi_{0,707}$ (see Table A2 “Input Data for Laboratory Task”, Annex A) define the distance d_m between antenna elements on a floor.

Use the formula (18) and its software realization (see Annex B).

Interim results show the Table 1

Table 1

d_m/λ								
$2\Delta\varphi_{0,707}$, deg								

2) Based on the calculated in the course of home study values of gain of base station antenna G_{BS} determine the number of floors n in a plane of antenna array.

To do this, use the formula (27) or (28) and its software implementation (see Annex B). At fractional values produce rounded to the nearest whole. Write the result into report.

3) Based on the given direction of main beam of AP θ_{max} (see Table A2 “Input data for laboratory task”, annex A) determine the required phase shift $\Delta\Psi$.

To do this, use the formula (15) and its software implementation (see Annex B). Write the result into report.

4) Using the obtained values n – number of floors in a plane of antenna array (Item 2 of laboratory task) $\Delta\Psi$ – required phase shift (Item 3 of laboratory task) define width of AP on a half-power in E-plane $2\Delta\theta_{0,707}$ and adjusted value of θ_{max}.

To do this, use the formula (17) and its software implementation (see Annex B). Write the result into report.

5) Using the obtained values $2\Delta\varphi_{0,707}$ (Item 1 of laboratory task) and $2\Delta\theta_{0,707}$ (Item 4 of laboratory task) define G of panel antenna.

To do this, use the formulas (30) or (31) and its software implementation (see Annex B). Write the result in report and compare with the obtained one during home researches.

6) Qualitatively depict in the report the obtained AP of panel antenna of base station for mobile communications.

7) Draw up detailed conclusions.

2.6 Description of the Algorithm and Features of Program

Layout of the laboratory work "Research of design principles and characteristics of the antenna of base stations for mobile communications" is a program (see Annex B) written in the programming environment MathCAD – mathematically oriented universal system. The program allows you to make calculations and simulation of the radiation characteristics of the panel antenna of base stations for mobile communications in the form of a flat antenna array. Calculation and analysis of the radiation characteristics is produced depending on number, geometric parameters of antenna elements, their location in a planar array antenna and is based on engineering (approximate) formulas.

The main features of the program is determined primarily by features of MathCAD software environment: implementation of calculations using a special system of symbols the closest to the traditional form of recording, performing complex calculations and implementation, in accordance with construction schedules.

The algorithm of program implementation is:

1) Run the MathCAD software environment on a personal computer installed in the workplace (start of a personal computer and run of MathCAD software environment are performed by teacher).

2) Open a file «SMC M1 base stations antennas.xmcd» ("M1 base stations antennas. xmcd" file location gives a teacher).

3) Checking the result of home task solving (in the case of wrong results of gain of base station antenna for mobile communications is recalculated using the program).

4) Input of input data (location of the original data in the program is illustrated in Fig. 4).

5) Input of numerical value of variable that determines the distance between antenna elements on a floor of antenna array in the range $d_m = 0{,}1\ \lambda ... 0{,}5\ \lambda$ (location of variable that determines the distance between antenna elements in the program is illustrated in Fig. 5).

6) Calculation of AP in the H-plane (calculation and plotting of AP in the H-plane in polar coordinates in accordance with the given data is made automatically by the program).

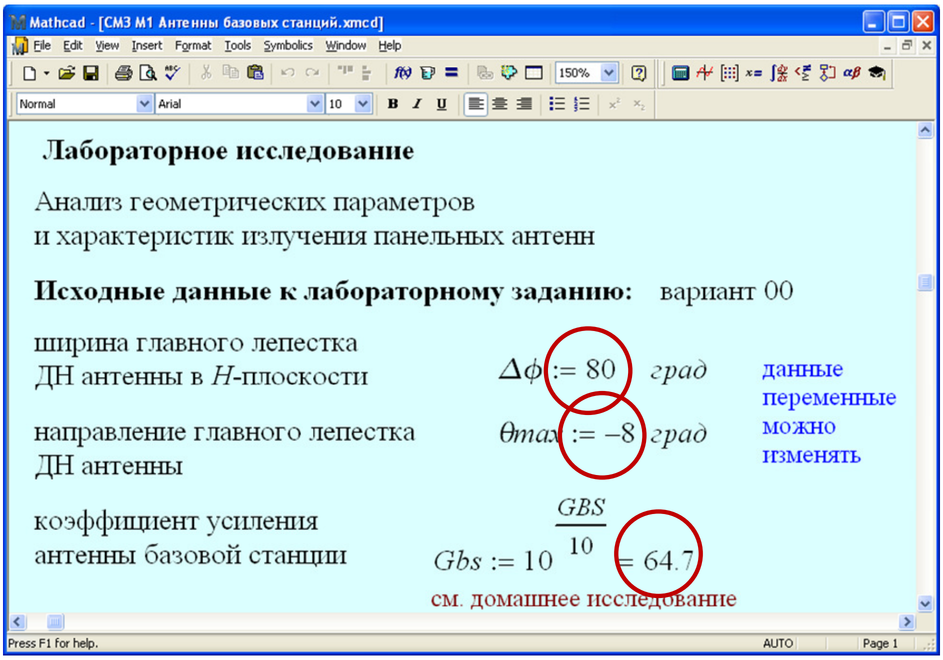


Fig. 4 – Input of input data

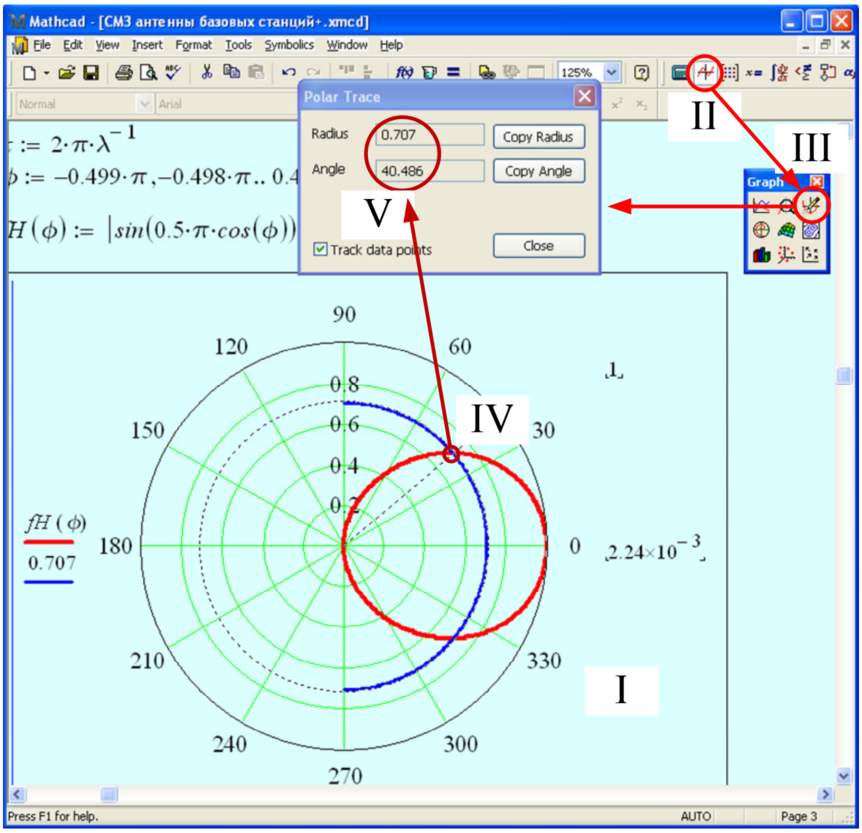


Fig. 5 – Input of numerical value of variable that determines the distance between antenna elements on antenna array floor

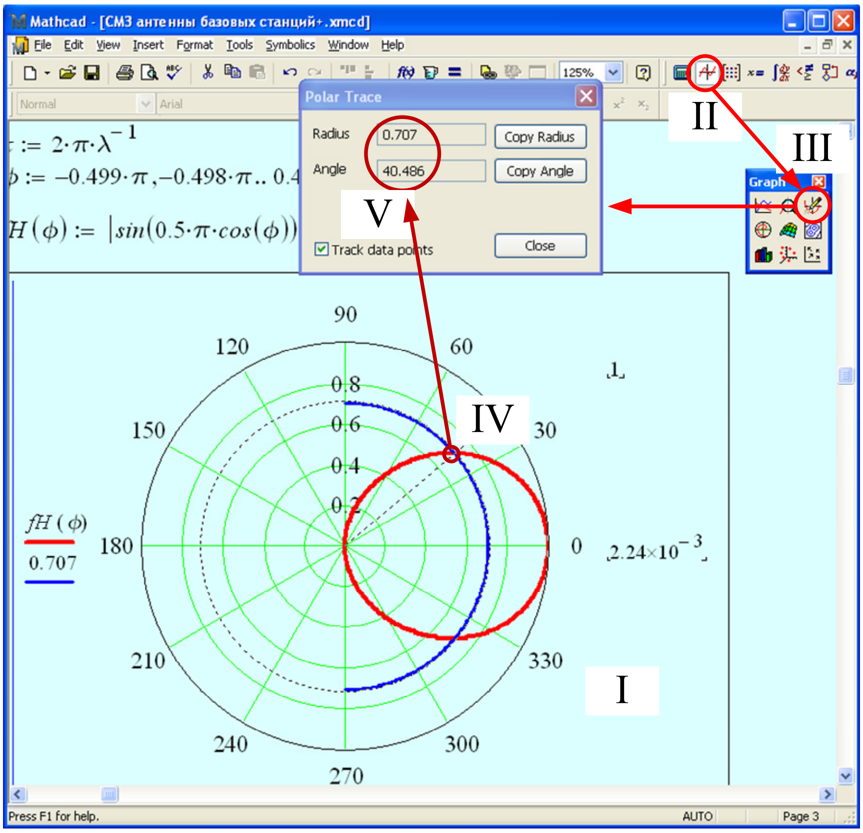


Fig. 6 – Definition of AP width

7) Measure the width of the main beam of AP on the level of half-power in H-plane.

The procedure for measuring the width of the main beam of AP on the half-power level is illustrated in Fig. 6, in particular:

– selecting a picture – I (selection of image is performed by pressing the left button of the mouse when the cursor is in the picture);

– opening a window «Polar Trace» (opening of «Polar Trace» window is performed by consistent implementation of the following actions: activation of «Graph Toolbar» icon – II, resulting in «Graph» window; activation of «Trace» icon in a «Graph» window – III , resulting a «Graph Toolbar» window;

– measurement of the angular coordinates φ_1 of the points of intersection of AP (red curve) and a circle of 0,707 radius (blue curve) (underlining interested point on the graph by pressing left button of mouse when the cursor is at this point that leads to the dotted line running through the center of the coordinate system and the interested point – IV, resulting in a «Polar Trace» window the polar coordinates of the intersection point – V appear);

– measurement of the angular coordinate φ_2 of another intersection points of AP (red curve) and a circle of 0,707 radius (blue curve) (a process similar to the described above);

– determination of the width of AP main beam in terms of half-power of program output (including location of AP in the polar coordinate system and reference angles in this system, width of the main beam of AP on the half-power level is determined by the formula: $2\Delta\varphi_{0,707} = \left|\varphi_1 - (\varphi_2 - 360)\right|$, deg.)

8) Selection of the optimal distance between antenna elements on the floor of antenna array (changing the distance d_m/λ (see Item 5)) and conduct the following measurement of AP width in the H-plane (see Item 7)) need to meet $2\Delta\varphi_{0,707}$ the specified value).

9) Determination of number of floors in antenna array (calculation of number of floors in antenna array at the specified and calculated data, and rounding of result to an integer performed by the program automatically).

10) Definition of linear phase shift of excitation sources (definition of linear phase shift excitation sources data is given by the program automatically).

11) Calculation of AP in E-plane (calculation and plotting of AP in E-plane in polar coordinates data is performed by the program automatically).

12) Measurement of the width of AP main beam on half-power in E-plane and refinement of angle of AP inclination (the procedure for measuring the width of Antenna Pattern on the half-power in E-plane and refinement of the angle of main beam are similar to the above described (see Item 7) using the formula $2\Delta\theta_{0,707} = \left|\theta_1 - \theta_2\right|$, deg.).

13) Determination of approximate values of gain of panel antenna (after input of obtained, namely $2\Delta\varphi_{0,707}$ (see Item 7)) and $2\Delta\theta_{0,707}$ (see Item 12)), the definition of antenna gain on the calculated data is performed by the program automatically). Location of input data into the program is illustrated in Fig. 7.

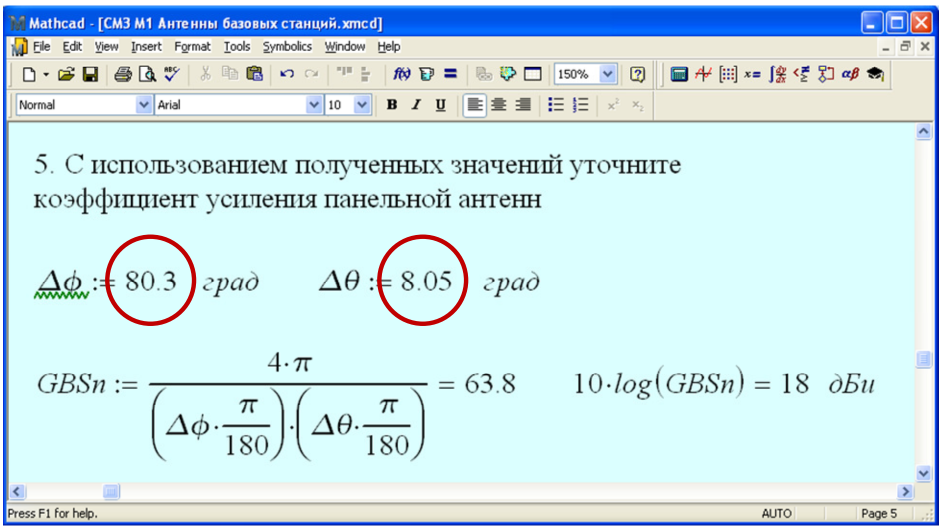


Fig. 7 – Input of numerical values of main beam width of AP in *E*- and *H*-planes

2.7 Contents of the Report

Report on laboratory work (see Annex B) must contain:
1) The title page of the set example.
2) Aim of work.
3) Home task and its results.
4) Task for laboratory tests and their results.
5) Conclusions.

Conclusions of laboratory work should include both general part reflecting the main results and analysis, comparative analysis of theoretical and experimental studies, as well as an explanation of the results.

2.8 Recommended Literature

Basic
1) *Антенно-фидерные устройства и распространение радиоволн: Учебник для вузов* / Г.А. Ерохин, О.В. Чернышев, Н.Д. Козырев, В.Г. Кочержевский; под. ред. Г.А. Ерохина. – 3-е изд. – М.: Горчая линия – Телеком, 2007. – с.58 – 247.
2) *Антенно-фидерные устройства: Учебник для вузов* / В.Г. Кочержевский, Г.А. Ерохин, Н.Д. Козырев. – М.: Радио и связь, 1989. – с.74 – 244.

Additional
3) Base Station Antennas, Filters, Combiners and Ampilifers for Mobile Communications 790…6000 MHz / KATHREIN Antennen Electronic / Catalogue Issue 01.2009. – www.kathrein.de
4) *Алехин Ю.Н.* Антенно-фидерные устройства для базовых станций сотовой и подвижной связи / *Ю.Н. Алехин, Е.В. Лазарева* // Мобильные системы. – 2002.– №3.

Annex A

Table A1 – Input Data for Home Task

n	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
D , km	17,2	17,5	17,9	18,2	18,9	19,4	20,0	20,6	21,2	21,8
M	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
L_{fad} , dB	6,0	6,5	7,0	7,5	8,0	8,5	9,0	9,5	10,0	10,5

Appendix for Table A1

$P_{in\,MS}$ = –77 dBm; $P_{out\,BS}$ = 5 W (or 37 dBm); G_{MS} = 0 dBi; L_{BS} = 2 dB; L_{MS} =1 dB; λ = 0,324 m (f = 925 MHz – average range value 890…960 MHz).

Table A2 – Input Data for Laboratory Task

n	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
$2\Delta\varphi_{0,707}$, deg	120	105	90	60	120	105	90	60	120	105
m	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
θ_{max} , deg	–8	–6	–4	–8	–6	–4	–8	–6	–4	–8

n — last digit of credit book

m — penultimate digit of credit book

Annex B

Laboratory research

Analysis of geometric parameters and characteristics of the radiation of panel antennas

Input data for laboratory tasks: variant 00

width of AP main beam in *H*-plane $\Delta\phi := 70\ deg$

this variables can be changed

direction of AP main beam $\theta max := -7\ deg$

gain of base station antenna $Gbs := 10^{\frac{GBS}{10}} = 64.685$

See home research

Implementation

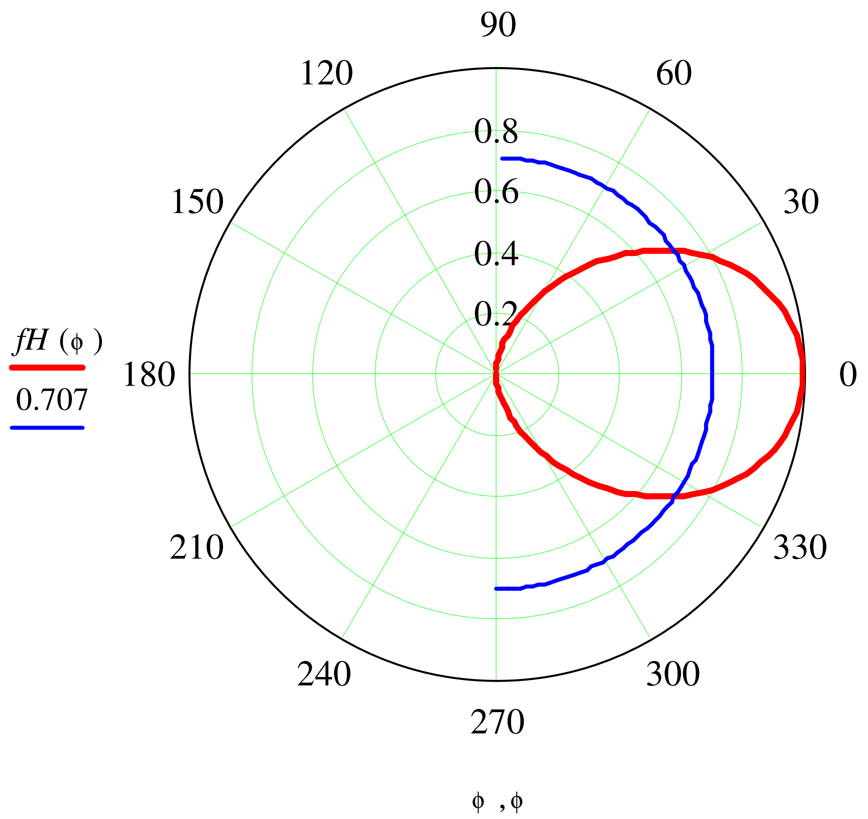
1. On the basis of specified width of the AP main beam on half-power in H-plane, define the distance between antenna elements on the d_m floor

$k := 2 \cdot \pi$

$\phi := -0.499 \cdot \pi, -0.49 \cdot \pi .. 0.499 \cdot \pi$ $dm := 0.415$

This variable must be changed

$$fH(\phi) := \left|sin(0.5 \cdot \pi \cdot cos(\phi))\right| \cdot \left|cos(0.5 \cdot k \cdot dm \cdot sin(\phi))\right|$$



2. On the basis of research of the gain of base station G_{BS} calculated during homework, determine the number of floors n of flat antenna array

$dm \cdot \lambda^{-1} = 0.35$ $\quad dm = 0.114$

m

$Gbs = 64.7$

$$nn := \frac{Gbs}{1.64 \cdot 2 \cdot 2} \cdot \left(1 + \frac{\sin(k \cdot dm)}{k \cdot dm}\right) = 13.5 \qquad n := round(nn) = 13$$

3. On the basis of the predetermined direction of AP main beam of panel antenna, define the desired phase shift of excitation sources.

$$\theta max = -8 \quad deg \qquad \theta max \cdot \frac{\pi}{180} = -0.14 \quad rad$$

$$\Delta\Psi := \pi \cdot \sin\left(\theta max \cdot \frac{\pi}{180}\right) = -0.437 \quad rad \qquad \Delta\Psi \cdot \frac{180}{\pi} = -25.1 \quad deg$$

4. By using of received values: the number of floors of planar array antenna and the required phase shift, determine width of AP main beam at half-power in E-plane

$n = 13$ $\quad \Delta\Psi = -0.437 \quad rad$

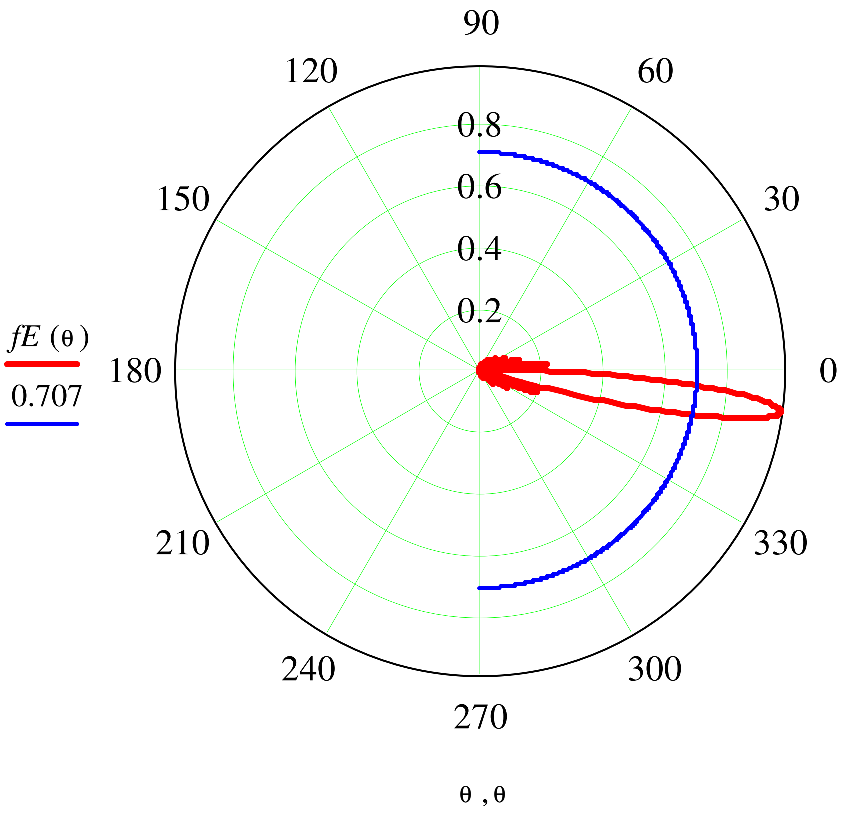
$$\theta := -0.499 \cdot \pi, -0.498 \cdot \pi \,..\, 0.499 \cdot \pi$$

$$f1E(\theta) := \left|\frac{\cos(0.5 \cdot \pi \cdot \sin(\theta))}{\cos(\theta)}\right|$$

$$f2E(\theta) := \left|\sin(0.5 \cdot \pi \cdot \cos(\theta))\right|$$

$$f3E(\theta) := \left|\frac{\sin[0.5 \cdot n \cdot (\pi \cdot \sin(\theta) - \Delta\Psi)]}{n \cdot \sin[0.5 \cdot (\pi \cdot \sin(\theta) - \Delta\Psi)]}\right|$$

$$fE(\theta) := f1E(\theta) \cdot f2E(\theta) \cdot f3E(\theta)$$



5. Using these values, precise gain of panel antenna.

$\Delta\phi := 80.3 \quad deg \qquad \Delta\theta := 8.05 \quad deg$

$$GBSn := \frac{4 \cdot \pi}{\left(\Delta\phi \cdot \frac{\pi}{180}\right) \cdot \left(\Delta\theta \cdot \frac{\pi}{180}\right)} = 63.8 \qquad 10 \cdot log(GBSn) = 18$$

Annex C

Ministry of Transport and Communications of Ukraine
State Administration of Communications
Odessa National Academy of Telecommunications n.a. A.S. Popov

Department of Technical Electrodynamics
and Systems of Radio Communications

REPORT

On laboratory work

“Research of Construction Principles and Antenna Characteristics
of Mobile Communications Base Stations ”

Done by: student of TS 3.401
Petrov Pyotr Petrovich
Credit book number 000000

Checked by: prof. TED & SRC Dep.
Protsenko M.B.

Odessa
2011

The aim of the methodical instructions is to assist students in studying of theoretical aspects of module 1 - Functional Devices of Radiochannel of Mobile Communications Systems, themes 1.3 - Antenna devices of base and subscriber stations of mobile communications systems, specifically principles of base stations antennas of mobile communications in the form of panel antennas.

Task for home research

Problem. *Determine required GC of base station for mobile communications* G_{BS} *according to the given distance D and the given fading reserve* L_{fad}.

Inputl data for home task

L_{fad} = *11 dB; D =18,5 km (variant 00)*

$P_{inMS} = -77$ *dBm;* $P_{outBS} = 37$ *dBm;* $G_{MS} = 0$ *dBi;* $L_{BS} = 3$ *dB;* $L_{MS} = 1$ *dB;*
$\lambda = 0{,}324$ *m (* $f = 925$ *MHz – average range value 890…960 MHz).*

Results of home research

To calculate the required gain of base station antenna for mobile communications G_{BS} *in dB an expression can be used:*

$$G_{BS} = P_{inMS} + L_{BS} + L_{MS} + L_{fs} + L_{fad} - P_{outBS} - G_{MS},$$

where $L_{fs} = 20lg\left(\frac{4\pi D}{\lambda}\right)$, *dB.*

$$L_{fs} = 20lg\left(\frac{4 \cdot 3{,}14 \cdot 18500}{0{,}324}\right) = 117{,}1 \text{ [dB]},$$

$$G_{BS} = -77 + 3 + 1 + 117{,}1 + 11 - 37 - 0 = 18{,}1 \text{ [dBi] or } G_{BS} = 64{,}7$$

Answer: *the required gain of base station antenna for mobile communications is* $G_{BS} = 18{,}1$ *dBi or* $G_{BS} = 64{,}7$.

Task for laboratory research

Input data for laboratory task

G_{BS} =64,7; $\Delta\varphi_{0,707}$ *= 80 deg;* θ_{max} *= –8 deg. (variant 00)*

Results of laboratory research

1. *On the basis of given value of AP width of main beam of panel antenna in H-plane* $2\Delta\varphi_{0,707}$ *=80 deg we can define the distance between antenna elements on d_m floor.*

Table 1

d_m/λ	0,1	0,2	0,3	0,34	0,35	0,36	0,4	0,5
$2\Delta\varphi_{0,707}$, deg	115,9	106,7	90,0	82,5	80,3	78	73,3	61

Most correspondent to the task d_m=0,35λ

2. On the basis of gain of base station antenna value G_{BS} calculated during realization of home research we can define the required number of floors n of plane antenna pattern.

Obtained value n = 13

3. On the basis of given direction of AP main beam, i.e. θ_{max} *= –8 deg, we can define the required phase shift* $\Delta\Psi$ *.*

Obtained value $\Delta\Psi$ *= 21,5 deg.*

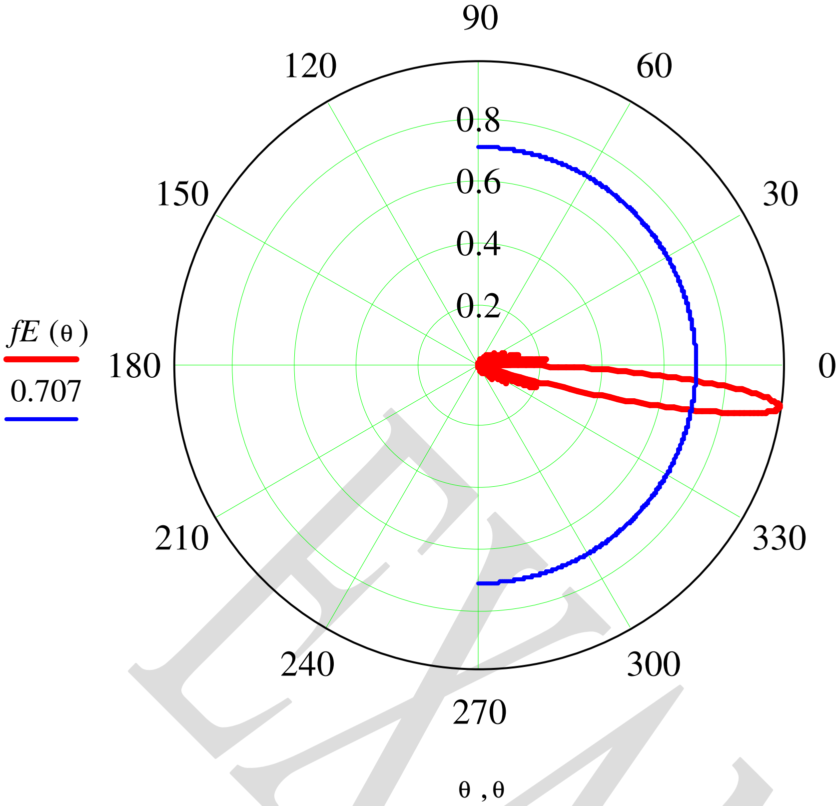
4. Using obtained values n = 13 and $\Delta\Psi$ *= 21,5 deg we can define the width of AP main beam by the level of half-power in E-plane* $2\Delta\theta_{0,707}$ *and precise* θ_{max} *value.*

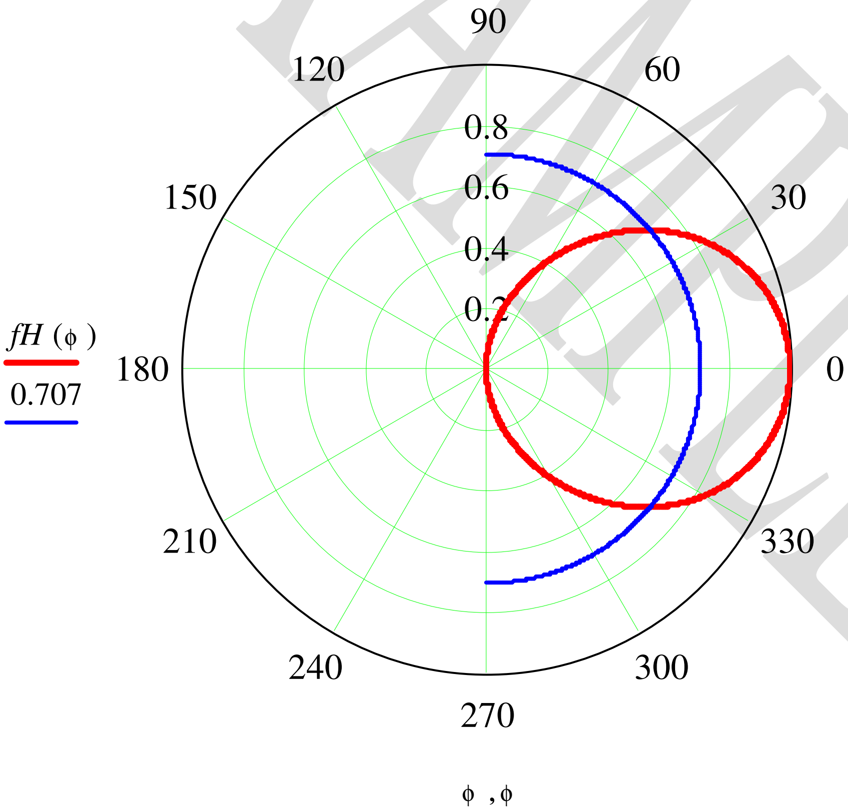
Obtained value $2\Delta\theta_{0,707}$ *= 8,05 deg and* θ_{max} *= –8 deg*

5. Using obtained data $2\Delta\varphi_{0,707}$ *= 80,3 deg and* $2\Delta\theta_{0,707}$ *= 8,05 deg we can define the gain of panel antenna.*

Obtained value G_{BS} = 63,8 or G_{BS} = 18 dBi
Result of home research G_{BS} =64,7 or G_{BS} =18,1 dBi.

6. AP of panel antenna of mobile communication base station





Conclusions. *In a progress of laboratory work realization the following researches have been made… As the result of research it is obtained… In accordance with obtained results… Thus, laboratory work objective has been achieved.*