Design and simulation of multi-sector switchable antenna array for the frequency range of 2.4 GHz Wi-Fi networks

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ABSTRACT*: The paper describes the calculation and simulation of microstrip antenna array. The basic formulas, graphs, directional pattern.*

Keywords - *simulation, microstrip antennas, calculation of microstrip antenna array.*

I.   INTRODUCTION

Currently there is an intensive use of wireless telecommunications networks to transmit information, among which the Wi-Fi network is particularly popular. It is not always possible to achieve a high data transfer speed even in the city due to the low signal strength and a large number of noise sources. It is known that the attenuation of the signals is caused by a lot of obstacles (reinforced concrete structures, trees, etc.) in the path of propagation of electromagnetic radiation, as well as the significant distance between the access point and subscribers.

To overcome this problem, there is intense enhancement of microstrip antennas, featuring a large variety of designs and are suitable for applications as both independent antennas and antenna arrays elements. The working frequency range of microstrip antennas extends from 300 MHz to 20 GHz.

Stripline and microstrip antenna are able to radiate with linear, circular and elliptical polarization, allowing for suitable design solutions to provide two or multi-frequency modes, make it easy to combine many elementary emitters in a phased antenna arrays and place them on the complex shape surface. The big advantage of such antennas are low weight and size, simple structure, high fabrication precision [1].

II.   BLOCK DIAGRAM OF THE DEVICE

The useful information signal gain and the interference suppression are necessary to develop an antenna array with the coverage of 360°. Each sector should have a maximum gain in a given frequency band (2.4-2.5 GHz). In addition, it is necessary to suppress reception of all signals incident from other directions. Based on the above considerations the configuration of the six switchable spatial sectors is selected.

The most important parameter is the lattice spacing (the distance between the phase centers of emitters) along the respective axes. The array spacing is chosen based on the following factors:

1) Excluding the possibility of emergence of secondary principal maxima of the directional characteristic. That is $d < 0{,}9\lambda_0$;

2) Elimination of the influence of microstrip antennas at each other in the array, because this leads to changes in the parameters of the emitters, such as, input impedance, resonant frequency, and also worsens the agreement in the working frequency band and the efficiency of the antenna. To eliminate this phenomenon, the distance between the emitters should be selected based on the conditions $d > 0{,}5\lambda_0$ [2].

Based on these recommendations, the array spacing must lie within $0{,}5 \cdot \lambda_0 < d < 0{,}9 \cdot \lambda_0$.

Express this inequality using the unit of length:

$60{,}25 < d < 108{,}45$ mm.

We will take the interelement spacing: $d = 0{,}7 \cdot \lambda_0 = 85$ mm.

In accordance with the calculations six antennas were embedded into a unified system in the form of a regular hexagon with the aim of improving the quality of a radio transmission at all viewing angles (fig. 1).
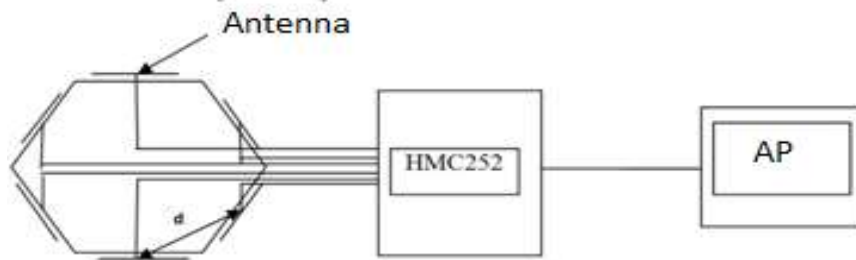
Figure 1. Block diagram with switchable antenna

The each emitter (Antenna) is connected to the RF switch (such as HMC252QS24E), which in turn is connected to an input of the access point (AP). The channel is manually selected with the highest output power.

III. CALCULATION OF THE MICROSTRIP ANTENNA PARAMETERS FOR FREQUENCY 2.4 GHZ

Calculation of parameters of microstrip antenna is as follows [3]:

The optimum width of a rectangular emitter:

$$W = \frac{c}{2f_0}\left(\frac{\varepsilon_\gamma + 1}{2}\right)^{-0.5} = \frac{3 * 10^8}{2 * 2.4 * 10^9}\left(\frac{1+1}{2}\right)^{-0.5} = 0.0625 \ (m), \qquad (1)$$

where f_0 - the resonant frequency of the antenna; ε_γ - dielectric permittivity; c - speed of light.

The environment around the emitter is not homogeneous, as one side of the radiator is a dielectric, and the other is air. Therefore, the effective dielectric constant of the emitter is estimated by the formula:

$$\varepsilon_e = \frac{\varepsilon_\gamma + 1}{2} + \frac{\varepsilon_\gamma - 1}{2}\left(\frac{1 + 12h}{W}\right)^{-0.5} = \frac{1+1}{2} + \frac{1-1}{2}\left(\frac{1 + 12 * 0,003}{0.0625}\right)^{-0.5} = 1, \qquad (2)$$

The length of the emitter is equal to:

$$L = \frac{c}{2f_0\sqrt{\varepsilon_e}} - 2\varDelta l = \frac{3 * 10^8}{2 * 2,4 * 10^9\sqrt{1}} - 2 * 0,0021 = 0.0584 \ (m), \qquad (3)$$

where Δl – changing the length of the boundary fields at the ends of the radiator, ε_e — effective dielectric permittivity. The value of Δl can be estimated using the expression:

$$\varDelta l = 0.412h\frac{(\varepsilon_e + 0.3)\left(\frac{W}{h} + 0.264\right)}{(\varepsilon_e - 0.258)\left(\frac{W}{h} + 0.8\right)} = 0.412 * 0,003\frac{(1 + 0.3)\left(\frac{0.0625}{0,003} + 0.264\right)}{(1 - 0.258)\left(\frac{0.0625}{0,003} + 0.8\right)} = 0.0021 \ (m), \qquad (4)$$

At the resonant frequency, the input impedance of the radiating antenna screen is defined by the equations:

$$Z_{in} = \frac{1}{2G_1} = \frac{1}{2 * 0,002989} = 167,2733 \ (Ohm), \qquad (5)$$

where

$$G_1 = \frac{1}{90}\left(\frac{W}{\lambda_0}\right)^2 = \frac{1}{90}\left(\frac{0,0625}{0,1205}\right)^2 = 0,002989, \qquad (6)$$

where λ_0 - wavelength, $\lambda_0 = 0,1205 \ m$.

At the resonance the input impedance is purely resistive. A place of power is calculated using the input resistance of the screen. The input impedance varies depending on the location of the feed point y_0:

$$R_{in} = Z_{in} * cos^2\left(\frac{\pi}{L}y_0\right), \qquad (7)$$

Y_0 is expressed from this formula:

$$y_0 = arccos\left(\sqrt{\frac{R_{in}}{Z_{in}}}\right) * \frac{L}{\pi} = arccos\left(\sqrt{\frac{50}{167,2733}}\right) * \frac{0.0584}{\pi} = 0,01884 \ (m), \qquad (8)$$

Given the calculations the values for the designed microstrip antenna were obtained:

Table 1. Values of the size of the microstrip antenna

Name	Value (m)
W	0,0625
L	0,0584
y_0	0,01884
Δl	0,0021
h	0,003
ε_y	1

Now we know the dimensions of the radiating screen. The length and width of the grounding screen are calculated by the following formulas:

$$Lg = 6h + L = 6*0,003+0,0584= 0,077 \text{ (m)} \qquad (9)$$
$$Wg = 6h + W = 6*0,003+0,0625 = 0,0805 \text{ (m)} \qquad (10)$$

IV.   SIMULATION OF MICROSTRIP ANTENNA

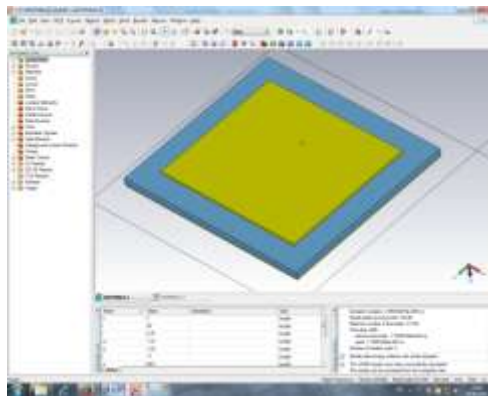The creation of a model of the analyzed object is shown in fig. 2.

Figure.2. View from above

So as to improve the antenna settings in the program there is a function optimization (fig. 3). It automatically selects the size of the antenna to improve the specified characteristics [4].
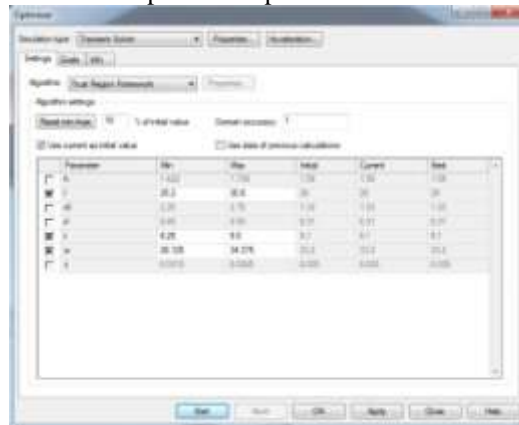

Figure 3. Optimization setup

After optimization, we obtain the following characteristics shown in table 2.

Table 2. Data of calculations for the antenna after optimization

Name	Value	Value after optimization
W, (м)	0,0625	0,0605
L, (м)	0,058	0,055
Wg, (м)	0,0805	0,0785
Lg, (м)	0,077	0,073
y_0, (м)	0,01884	0,017
Δl, (м)	0,0021	-
h, (м)	0,003	-
ε_y	1	-

Here are the results of calculation of parameters in the frequency range previously selected (fig. 4-6).
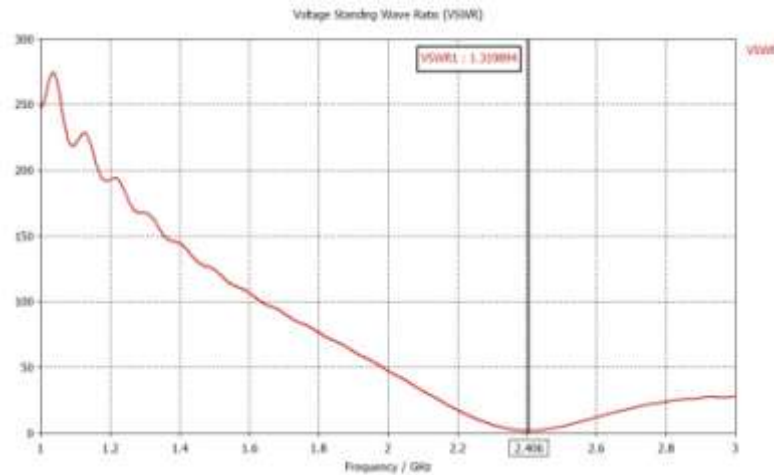

Figure 4. Voltage standing wave ratio

Standing wave ratio (VSWR) characterizes matching of the antenna and feeder. The VSWR is numerically equal to the ratio of the maximum value of the amplitude of the electric or magnetic field of the standing wave in the transmission line to the smallest one. Ideally, the VSWR = 1 [5].
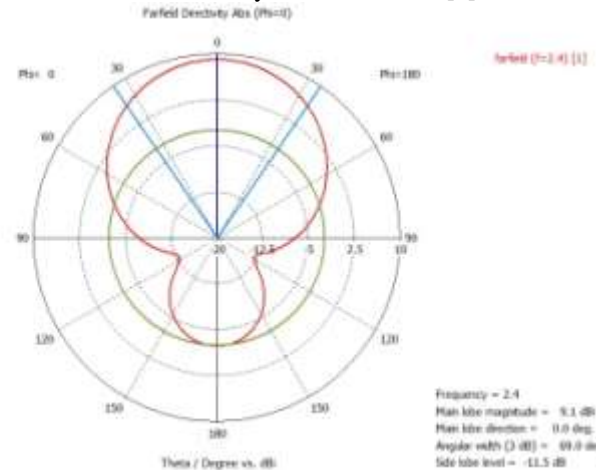

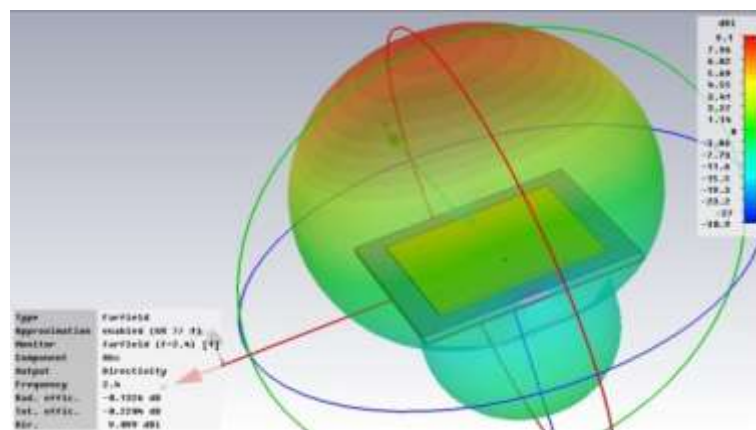**Figure 5.** The radiation pattern in the polar coordinate system

Figure 6. The antenna pattern in 3D

The radiation pattern of the antenna characterizes the dependence of the amplitude, phase and polarization on the electromagnetic field in the far field of the antenna from the point of view. The directivity pattern of an antenna usually has several "petals". Petal focusing the radiation maximum is called *the main beam*; petal directed in the opposite direction (at 180°) – *rear*; all other petals – *sides* (these petals are usually parasitic) [5]. Fig. 6 shows that the maximum of the radiation pattern has a gain of more than 9 dBi.

V. MAKING THE SINGLE ANTENNA

In accordance with the calculations the antenna from a sheet of brass (radiant screen) and galvanized iron (ground screen) (fig. 7) was made. The dielectric between the two screens is the air. The antenna is connected to the Wi-Fi router by using the SMA connector.
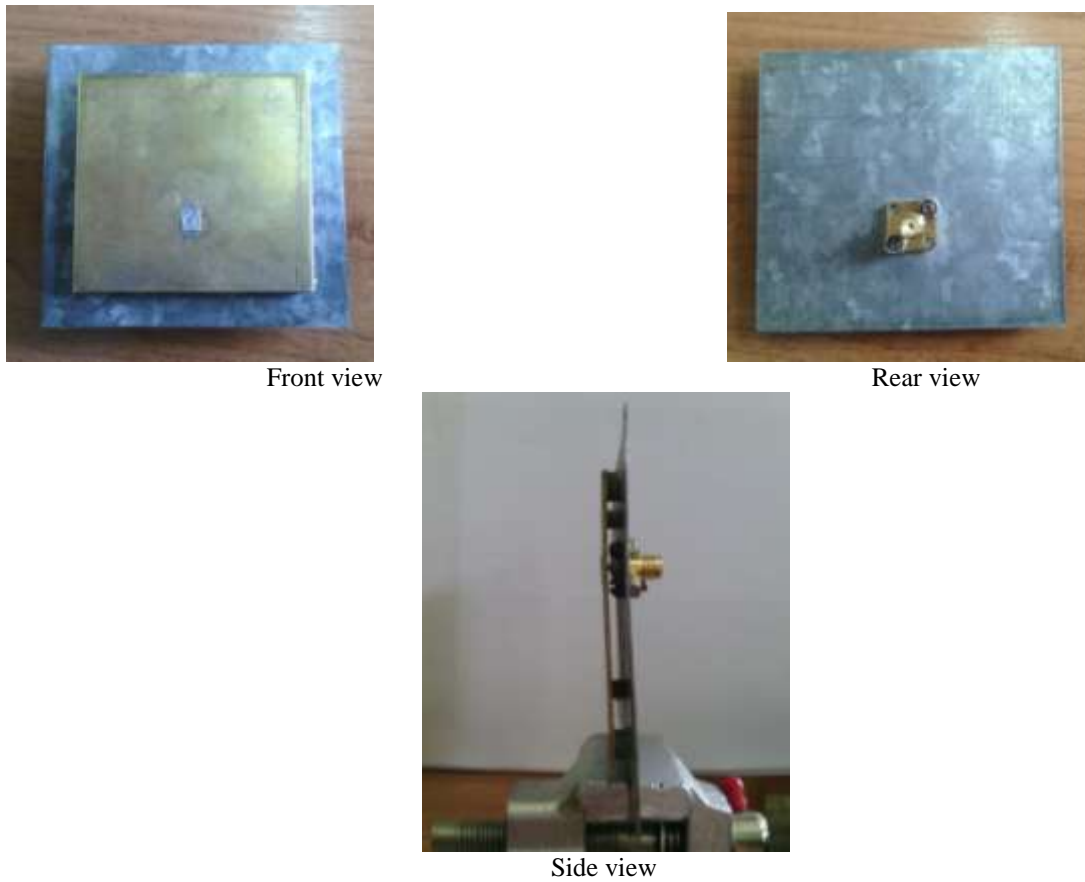

Front view

Rear view

Side view

Figure 7. Microstrip antenna, made from sheet brass and galvanized iron

VI. THE SWITCHING UNIT

Chip HMC252QS24 is a high-frequency switch operating in the range from 0 to 3 GHz. The control switching is carried out by submitting the codeword TTL levels on the addresses inputs [6]. By that way, switching between one input and all the six outputs is carried out of the chip (fig. 8).
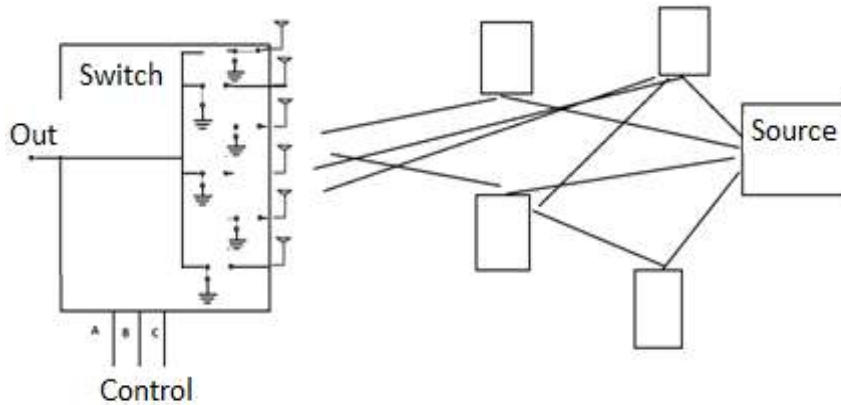

Figure 8. Block diagram of the chip HMC252QS24 work.

PCB in the DipTrace program was designed for connecting the antennas with the chip (fig. 9-10) that includes a chip, a connector for power supply and three switches.
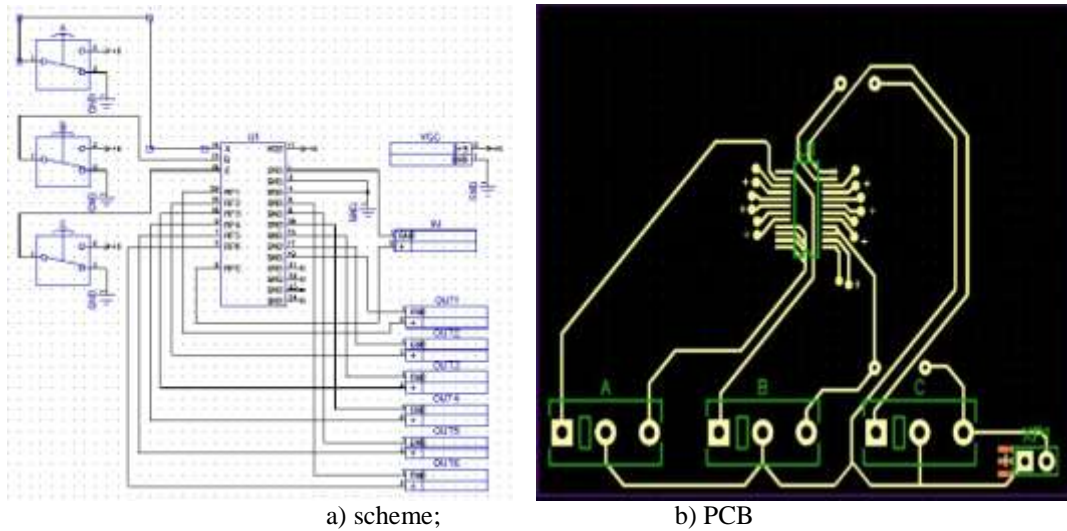
a) scheme;   b) PCB
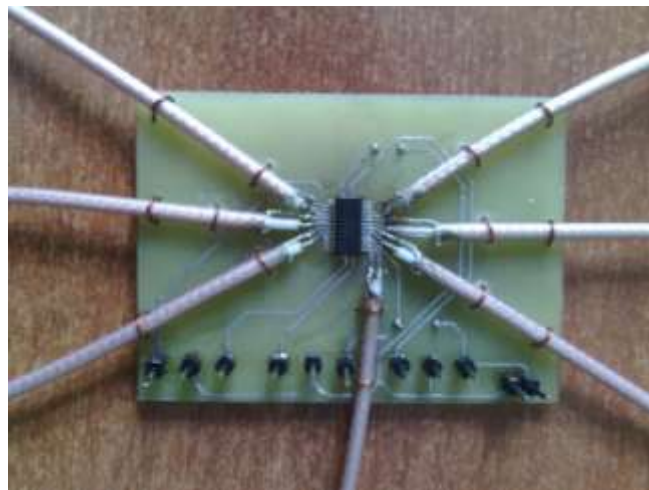
Figure 9. Type of PCB

Figure 10. The appearance switch designed for microstrip antenna array

When applied to three inputs of different combinations of high and low TTL levels, the chip turns on one of the outputs and transmits the RF signal to the corresponding antennas.

Table 3. The truth table chip HMC252QS24

Control input			Signal path state
A	B	C	RFCOM to:
LOW	LOW	LOW	RF1
HIGH	LOW	LOW	RF2
LOW	HIGH	LOW	RF3
HIGH	HIGH	LOW	RF4
LOW	LOW	HIGH	RF5
HIGH	LOW	HIGH	RF6
LOW	HIGH	HIGH	All off
HIGH	HIGH	HIGH	All on

Figure 11. External view of the developed antenna array

VII. EXPERIMENTAL VERIFICATION OF DEVICE

A Wi-Fi access point was used for testing the antenna array.

Testing of microstrip antennas was carried out by comparing it with a conventional omnidirectional antenna in conditions close to ideal (the lack of obstacles on the signal propagation). Using a special device the values of the signal strength (dBm) at various points were obtained and the measurement results are drawn in the polar coordinate system (fig. 12).
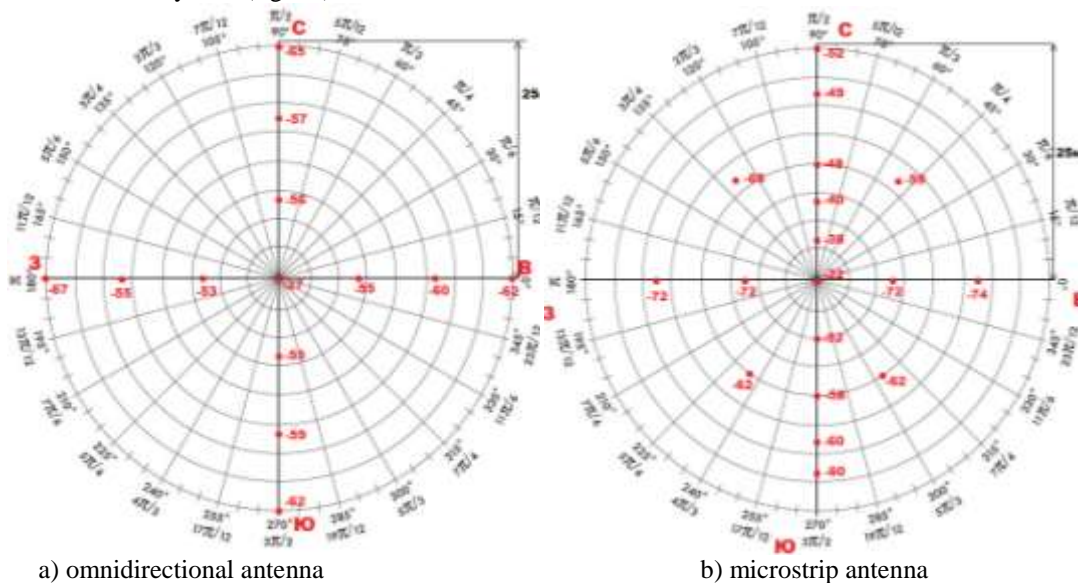

a) omnidirectional antenna   b) microstrip antenna
Figure 12. Directional pattern (radiation on North)

From this radiation pattern it is seen that the whip antenna is the isotropic radiator (radiation occurs in all directions with the same signal strength).

The following measurements were performed for microstrip directional antenna, which has the best characteristics of the radiation that can be seen from fig. 12 (b).

From fig. 12 a), b) it is seen that the designed antenna in the direction of the main lobe has gain up to 15 dBm higher than the standard omnidirectional. In this case, there is a significant increase in throughput of the wireless communication channel. Since the designed microstrip antenna has a higher directivity factor, the signal strength of the received signal is reduced in directions different from the main.

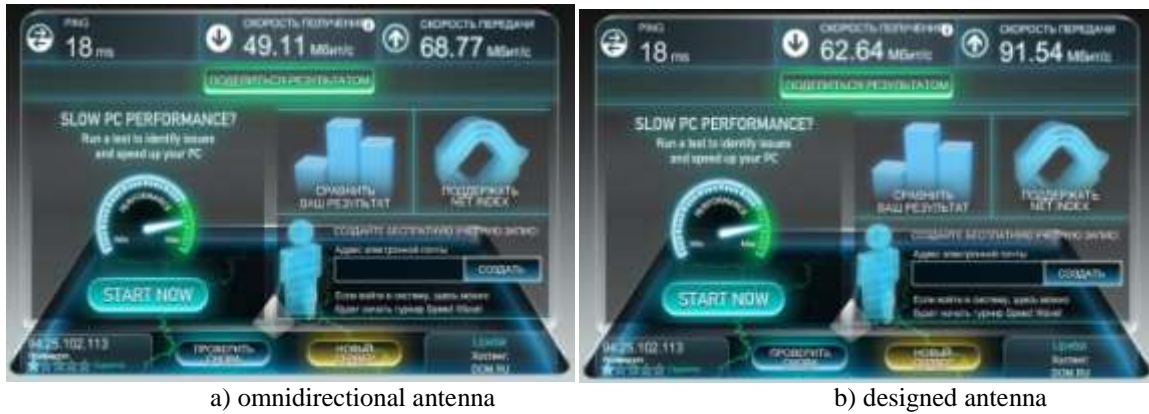Also the data transfer rate for two antennas was measured (fig. 13).

| a) omnidirectional antenna | b) designed antenna |

Figure 13. Data transfer rate

As can be seen from the measurements, the speed of acquiring data using the microstrip antenna exceeds the receive rate using the whip antenna up 13 Mbps, and the transmission speed of 22 Mbps.

To check the antenna PCB with RF-key was connected to Wi-Fi router. The signal is switched to the appropriate output when applying the various code combinations of TTL levels on the address inputs

In the first case, in accordance with the code 110 the signal switched to the output RF4.

Figure 14. Measuring signal strength on the antenna No. 4.

As can be seen from fig. 14, now the radiation is incident on the antenna No. 4. The measured signal power within its radiation pattern is -25 dBm. The signal power on the antennas, which do not correspond to the codeword 110, is substantially below of the power from the No.4 antenna.

VIII. CONCLUSION

In this paper, we have considered the basic principles of modeling and design of antennas and antenna arrays.

At each stage of development different information technology were used. For example, for calculation and modeling of a prototype of the microstrip antenna we used CST Microwave Studio. It allows in real time to

change the antenna parameters and watch the changes in its characteristics (size optimization, VSWR, directivity, traveling-wave ratio, etc.).

Basic calculations were made in the software environment GNU Octave, which allows without rounding and with a small error to make all the necessary calculations.

The structural scheme was developed in the environment of Schematics of a multifunctional development environment electronic devices DipTrace, printed circuit boards – PCB Layout in the same software environment.

The data obtained were prototypes, which, subsequently, were compared to serial samples of antennas, built the radiation pattern and the reading capacity of the investigated antennas.

Based on shot parameters, it was concluded that this type of antennas in many respects superior to the standard antennas used in modern Wi-Fi routers:

- signal strength of microstrip antennas is 20% more than signal strength whip antenna;
- data transfer rate increased by 17%;
- increased the range of radiation.

Summing up the paper we can say that this model can go into production as the standard antenna for Wi-Fi routers High-End [7].

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