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ELECTROMAGNETIC SIMULATION OF SPLIT RING RESONATORS IN KA-BAND

We consider artificial materials where possible to achieve the negative values of effective magnetic permitivity in the Ka-band wavelengths of electromagnetic radiation ((26.5–40) GHz). Using electromagnetic modeling the parameters of the double ring resonators are defined.

Key words: split ring resonators, metamaterials, Ka-band.

Introduction. In some artificial structures possible to achieve negative values of effective permeability or permittivity (or both) in finite frequency band. These materials are called metamaterials [2; 5; 8]. The best-known examples of media with negative permittivity are low-loss plasmas, and metals and semiconductors at optical and infrared frequencies; media with negative permeability are ferrimagnetic materials near the ferrimagnetic resonance. But the subject of our investigation is the split ring resonators (SRR). These artificial structures represent the metallic strips, coated on the dielectric substrate. In the 19th century W. Weber formulated the first theory of diamagnetism, discovered by Faraday. He assumed the existance of closed circuits at the molecular scale, and invoked Faraday's law to prove that currents would be induced in these circuits when they were under the effect of an external time-varying magnetic field. As the secondary magnetic flux created by such currents would be opposite to that created by the external field. However, the diamagnetic effect associated with a closed metallic ring is not strong enough to produce negative values for μ. But, when add capacitance C to the inductance of the ring L, we will see that polarizability becomes negative above the frequency of resonance $\omega_0 = 1/\sqrt{LC}$. Some types of the SRR are represented in Fig. 1.

SRR has many design solutions [2; 8]. Each has its own special features and it defines their area of practical use. Very important characteristics are resonant frequency, width of the resonance band, magnitude of losses in the band and beyond and, of course, ease of fabrication. SRR are used to hide the object from external radiation, as filters, in the media with negative refractive index. We decided conduct research in Ka-band, because in this band work many radars.

The aim of this work is to find the parameters of SRR using electromagnetic simulation.

Simulation method. To calculate the geometric dimensions can use the following methods: equivalent circuit model [1; 7] and electromagnetic simulation.

The first method is that the resonator substitutes an equivalent electric circuit. Parameters such as inductance, capacitance and resistances are calculated. After, they determine a resonant frequency. This method is relatively simple. But this method has the error of determination of the resonance frequency, which is 10 percent or more. In Ka-band these error may be crucial.

We decided to use electromagnetic simulation. Electromagnetic simulation uses Maxwell's equations to determine the characteristics of a given device to his physical geometry. Using electromagnetic simulation to analyze arbitrary structure and provide very accurate results. In addition, electromagnetic simulation free from the restrictions that exist in models of electric circuits as well as using the fundamental equation for calculating characteristics. The disadvantage of this simulation is that depending on the complexity of the structure increases the required amount of memory and simulation time increases exponentially. Therefore it is important to minimize the complexity of the structure to the simulation was acceptable.

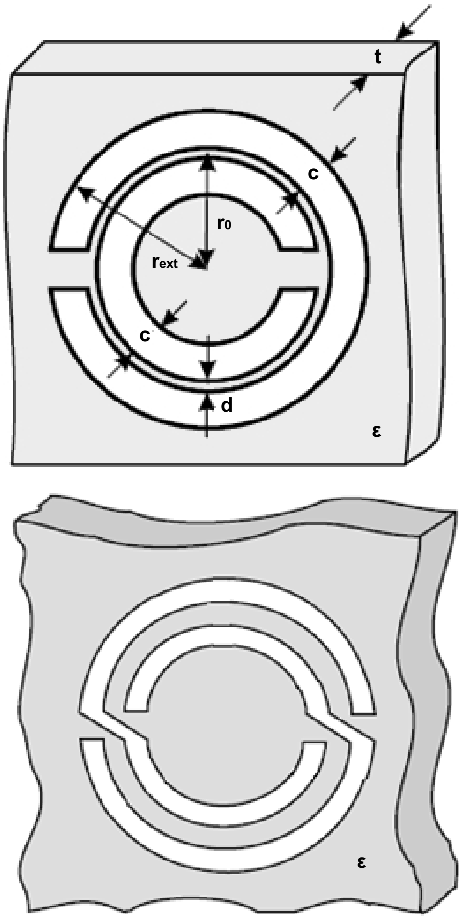

Fig. 1. Schematics of SRR elements: upper structure – edge coupled (EC-SRR), lower structure – nonbianisotropic (NB-SRR). For EC-SRR: r_{ext} – large ring resonator radius, r_0 – inner ring resonator radius, c– resonators metal strip width, d – distance between the rings, t – thickness of the structure, ε – permittivity of the substrate. Metallization are in white and dielectric substrate in gray

Electromagnetic simulation uses the Galerkin method of moments in the spectral region, which is very accurate for the analysis of strip, microstrip, coplanar, and many other random structures. This technique provides accurate simulation results up to 100 GHz or higher.

Results and discussion. The first structure that was simulated was EC-SRR (see Fig. 1, upper structure). As the dielectric substrate used duroid 5880 with ε = 2.2, losses tg δ = 0.0009, thickness t = 0.125 mm, rings are copper with thickness h = 17 μm. As a result of simulation were obtained the following parameters for the EC-SRR: external radius r_{ext} = 0.6 mm, outer radius r_0 = 0.4 mm, width of the rings c = 0.1 mm, distance between the rings d = 0.2 mm. The resonance curve is shown in Fig. 2.

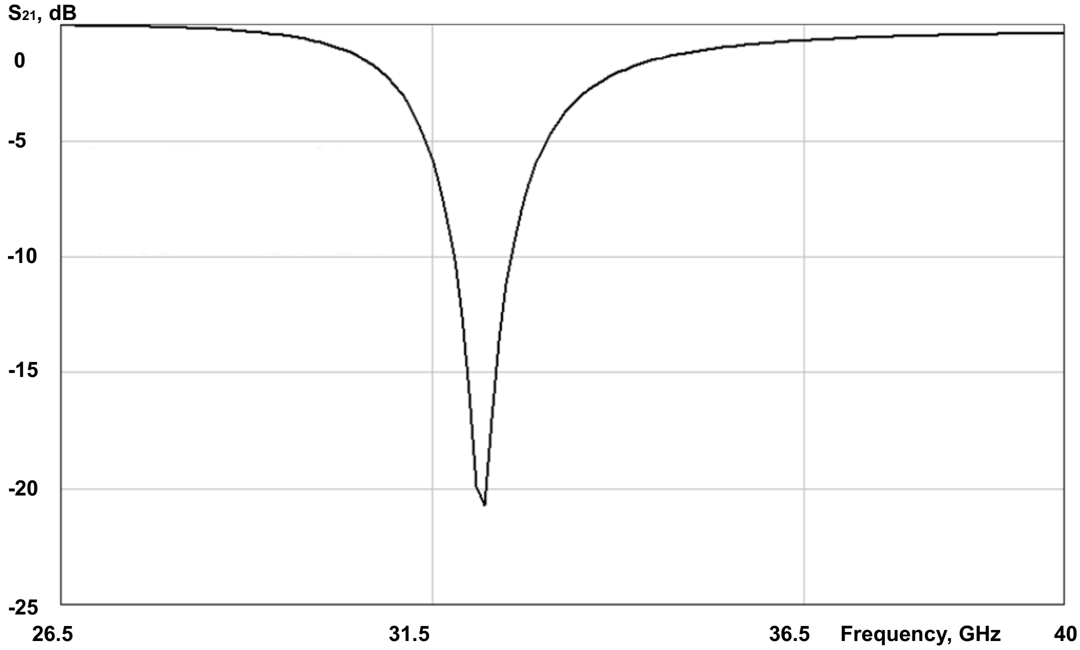

Fig. 2. Resonance curve for EC-SRR

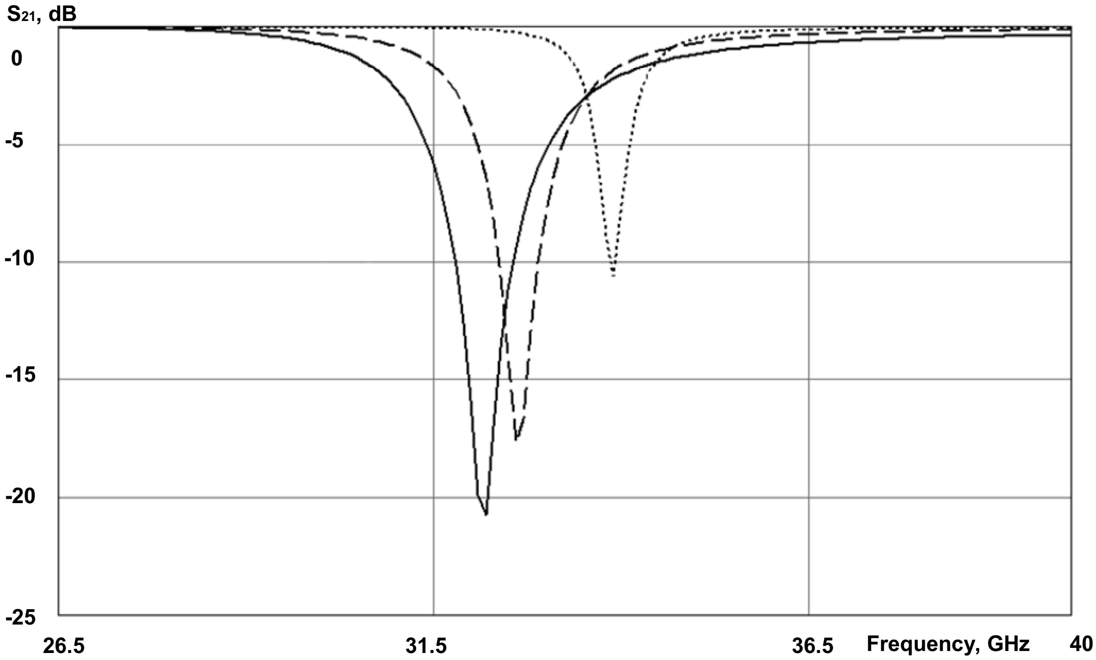

Fig. 3. Demonstration of cross-polarization effects in EC-SRR. Solid line corresponds to the electric and magnetic excitation, small dashed – magnetic, dashed – intermediate variant

From this graph we can determine the resonant frequency f_0 = 32.2 GHz, the width of the resonance curve (at the -3 dB level) Δf = 2.43 GHz, loss at the resonant frequency L_0 = -20.73 dB. EC-SRR has cross-polarization properties. This means that when you change the orientation of the structure will change the resonance curve. This is because not diagonal cross polarization tensor components are not zero. In other words, this type of resonators can excite not only the alternating magnetic field perpendicular to the plane of the rings, but the electric field that is parallel to the gap in the rings. This effect is shown in Fig. 3.

This effect is also observed experimentally, but in the range of 2 to 4 GHz. Results are shown in Fig. 4. Experimental investigations were performed by using analyzer of standing wave ratio and attenuation, open strip-line waveguide and generator with microwave block. In experiment used metastructures with different number of SRR and different size parameters.

Next type SRR was broadside-coupled SRR (BC-SRR) (see Fig. 5).

BC-SRR represents the two rings, coated on both sides of the dielectric substrate. This type of resonator is free of cross polarization effects. This is because the BC-SRR has mirror symmetry [2; 3]. As a result of simulation were obtained the following parameters for the BC-SRR: external radius r_{ext} = 0.5 mm, width of the rings c = 0.25 mm. The resonance curve is shown in Fig. 6.

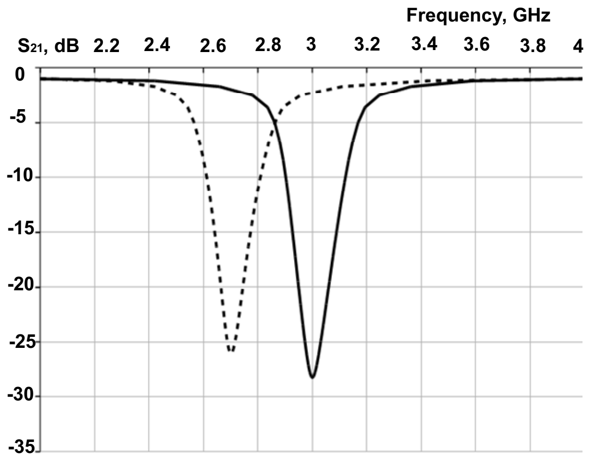

Fig. 4. Frequency response for metastructure that consists of eight EC-SRR for different orientation on strip-line waveguide. Dashed line – structure turned on 180^0

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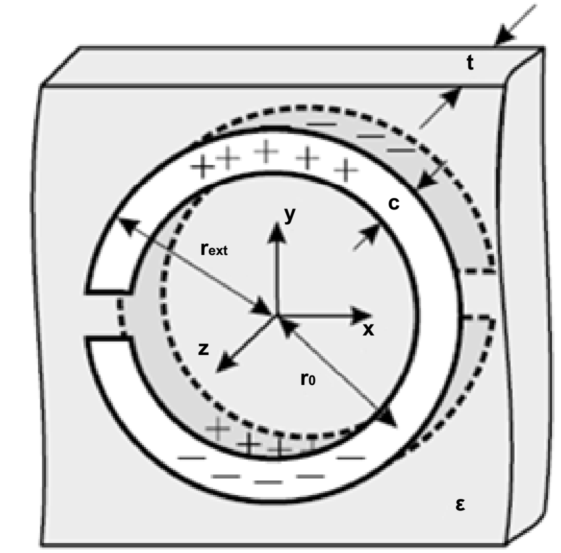

Fig. 5. Broadside-coupled SRR. r_{ext} – external radius of the ring, r_0 – inner ring resonator radius, c– resonators metal strip width, t – thickness of the structure, ε – permittivity of the substrate. Metallization are in white and dielectric substrate in gray

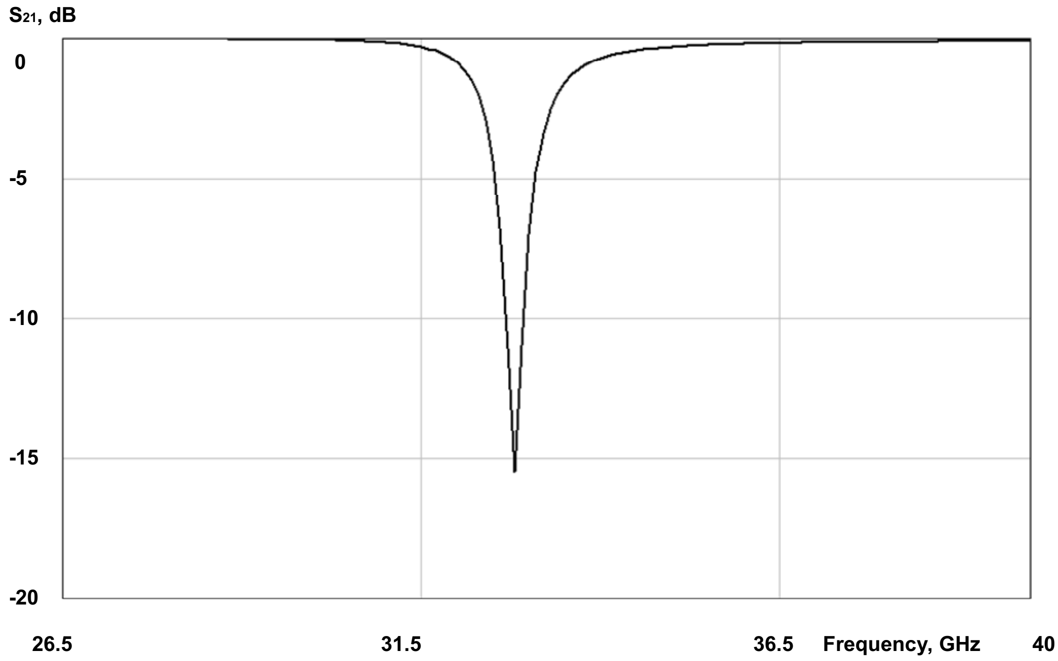

Fig. 6. Resonance curve for BC-SRR

From this graph we can determine the resonant frequency f_0 = 32.8 GHz, the width of the resonance curve (at the -3 dB level) Δf = 0.83 GHz, loss at the resonant frequency L_0 = -15.48 dB. As the band radars are operating frequencies up to several GHz, the main disadvantage of this type of SRR can be considered narrow band resonance curve.

Was drawn attention to the SRR with rectangular geometry (see Fig. 7), are well established in the manufacture of structures for hiding objects from the probing radiation [6]. Such resonators are relatively simple to manufacture. And by slight variations of length s and radius r can be obtained gradient changes the effective value of the relative permeability, if you create an environment that consist of layers which in turn consist of cells with this resonators.

As a result of simulation were obtained the following parameters for the rectangular SRR: length l = 1 mm, width of the rings w = 0.15 mm, length s = 0.25 mm. The resonance curve is shown in Fig. 8.

From this graph we can determine the resonant frequency f_0 = 30.9 GHz, the width of the resonance curve (at the -3 dB level) Δf = 1.45 GHz, loss at the resonant frequency L_0 = -18.79 dB. This type SRR has a good resonance width, but it also contains cross polarization effects. But the main advantage of such structures is the relative ease of fabrication.

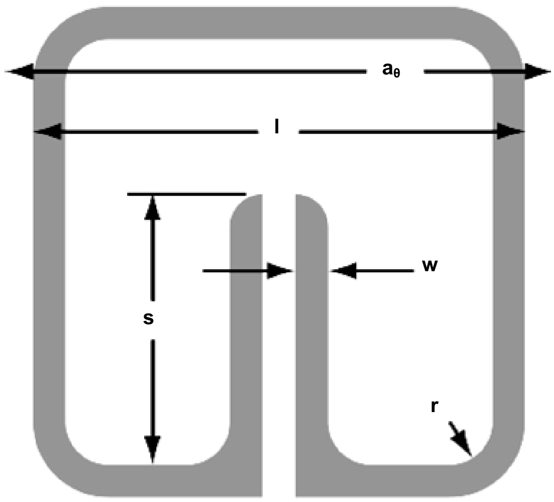

Fig. 7. SRR with rectangular geometry. Metallization are in gray and dielectric substrate in white: a_0 – cell size, r – radius, l – length of the resonator, w – resonators metal strip width, s – length

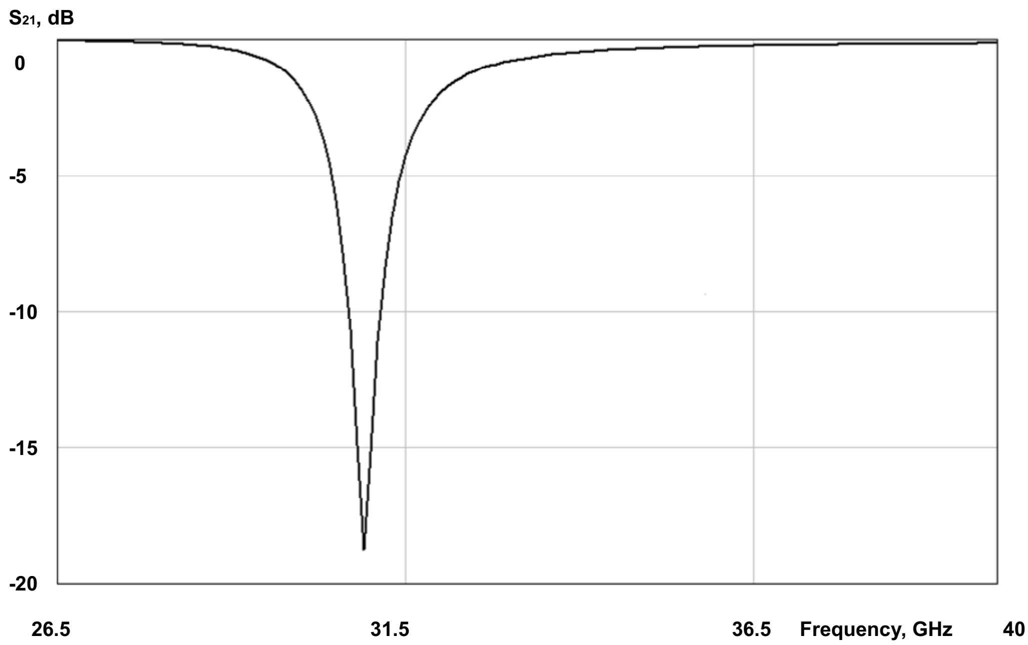

Fig. 8. Resonance curve for rectangular SRR

Conclusion. Were considered and modeled different types of structures, which may receive negative effective permeability. It was found that different types of split ring resonators have as advantages and disadvantages. This is due to the geometry of the structure. These calculated parameters are fit to make based on these resonators. The most promising are rectangular SRR. Their geometry is relatively easier in the long run the transition to optical range is a very important argument in their favor. Also, they have a rather broad resonance band. Varying length s and radius r can change the value of the effective magnetic susceptibility in sufficient range to create a gradient refractive index that probe radiation will bend around the object you want to hide.

Reference

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ЕЛЕКТРОМАГНІТНЕ МОДЕЛЮВАННЯ ПАРАМЕТРІВ ПОДВІЙНИХ КІЛЬЦЕВИХ РЕЗОНАТОРІВ В КА-ДІАПАЗОНІ

В роботі розглянуто штучні матеріали, в яких можливе досягнення негативного значення ефективної магнітної сприйнятливості в Ка-діапазоні довжин хвиль електромагнітного випромінювання ((26.5–40) ГГц). За допомогою електромагнітного моделювання визначено параметри подвійних кільцевих резонаторів.

Ключові слова: подвійні кільцеві резонатори, метаматеріали, Ка-діапазон.

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ЭЛЕКТРОМАГНИТНОЕ МОДЕЛИРОВАНИЕ ДВОЙНЫХ КОЛЬЦЕВЫХ РЕЗОНАТОРОВ В КА-ДИАПАЗОНЕ

В работе рассмотрены искусственные материалы, в которых возможно достижение негативного значения эффективной магнитной восприимчивости в Ка-диапазоне длин волн электромагнитного излучения ((26.5–40) ГГц). При помощи электромагнитного моделирования определены параметры двойных кольцевых резонаторов.

Ключевые слова: двойные кольцевые резонаторы, метаматериалы, Ка-диапазон.

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DEPENDENCE OF SYNCHRONIZATION COEFFICIENT CHANGING FROM IZIKEVICH MODEL RECOVERY PARAMETERS IN CORTICAL COLUMN NEURONS FOR ASCENDING INFORMATION FLOW

The paper considers the synchronization of neurons in cortical column with complex dynamics for ascending information flow. Graphics of the synchronization coefficient dependence from different variations of Izhikevich model recovery parameters were constructed. For visual study of synchronization the raster plots were constructed and corresponding diagrams were plotted for the opportunity to compare the synchronization coefficient on different layers of cortical column.

Keywords: synchronization coefficient in cortical column, ascending information flow, raster plot.

Problem statement. Converting signals and transmission of information in the nervous system are of interest to researchers applied various specialties, such as biophysics, neurophysiology, medical informatics. Launched more than half a century ago a description of oscillatory processes in neural networks evolved from logical calculations and evaluation of information capacity to the theory of information flow concepts and synchronization of neural activity of the cerebral cortex. [8]. Highly relevant research directions of modern science is to discover the principles of representation and transformation of information in the human brain, depending on the architecture of its neural networks. Due to the complexity of setting real experiments, significant role in this process is played by model studies by building computer models of neural networks. [3]

Analysis of recent researches and publications. The study of cognitive functions of the human brain is one of the leading trends in modern neurobiology, neurophysiology and neuropsychology. One of the approaches to the study of the processes occurring in such a system is the use of dynamic models of neural networks of the brain [7].The basic structural and functional unit of the cerebral cortex is a cortical column. This term was first used by Economo [6] to describe the vertically arranged rows of neurons that are linked predominantly with vertical connections.

Various experimental studies showed that the count of neurons in the vertical chain of neural cells is 110. [4] This chain has a diameter of about 30 microns. The cortex of the human brain consists of six different layers, each of which can be identified by the type of neurons that are in it.

Synchronous neuronal discharges are recorded in various brain structures (thalamus, sensory systems, central olfactory cortex and neocortex), they play a key role in the perception, selective attention and working memory. Synchronous neuronal activity supports the coordination of the locomotors system. Synchronization – is a mechanism that provides life rhythms like breathing. But also the presence of synchronization can be a sign of pathological abnormalities. [5] For example, one of the symptoms in patients with schizophrenia is disordering of the mechanism of generation synchronous oscillations. [9]

The purpose of article. In this work it is investigated the synchronization of neural networks with the architecture of communications for ascending information flow in which the neuron is described by the Izhykevych model. The change of the coefficient of synchronization based on changes in neural activity from recovery model parameters in cortical column is investigated.

Results and discussions. It was investigated the homogeneous neural structure, i.e. a network in which all elements are identical and have the same neural connections. All the studied neural systems are fully connected, i.e. those in which each element of the next layer take synaptic current from all the neural elements of the previous layer structure and connected to all neurons in a layer. The highest, the first layer contains few cells and consists mainly of a set of axons. In our work on the first layer of cortical column there are 9 neurons. The second and third layers look almost the same, and are have both 11 neurons. The fourth layer consist of 15 neurons, and the fifth consist of 17. The sixth layer is the deepest, and is different from all others, it has the largest number of neurons in this study – 47 neural elements (Fig. 1).

To describe the neural element for such morphology network the mathematic neural model of Izhykevych was used. It is two-compartment model that contains an additional requirement for cell membrane discharge:

$$\frac{dv}{dt} = 0.04v^2 + 5v + 140 - u + I\,, \quad \frac{du}{dt} = a(bv - u),$$

$$v \leftarrow c, u \leftarrow u + d\,, \text{ if } v>=30 \text{ mV},$$

where *v* and *u* are the dimensionless membrane potential and membrane potential recovery variables respectively; *a, b, c and d* – dimensionless parameters. The variable *u* simulates the activation of ionic K^+ currents and the