РАДІОТЕХНІКА, ТЕЛЕКОМУНІКАЦІЯ ТА ЕЛЕКТРОНІКА

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WIDEBAND PLANAR SPIRAL ANTENNA WITH PERIPHERAL FEEDING

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ШИРОКОСМУГОВА ПЛАНАРНА СПІРАЛЬНА АНТЕНА З ПЕРИФЕРІЙНИМ ЗБУДЖЕННЯМ

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Abstract. The topology of a planar Archimedes spiral antenna with a small number of turns is presented. Its main feature is the peripheral feeding of the spiral, which does not violate the planarity of the structure. On the basis of numerical simulation, the main electrodynamic characteristics for several antenna designs, differing in the number of turns, including the constant and variable width of the tape of the spiral element, are obtained, compared and discussed. The results of the numerical analysis showed that the relative bandwidth defined by the VSWR at the antenna input and by the directivity, reach from 75 to 120 percent.

Key words. Planar antennas, spiral of Archimedes, peripheral feeding, wideband, computer design.

Анотація. Розвиток бездротових технологій призводить до необхідності розробки нових типів антен, які мають широкосмугові характеристики, як по вхідному опору, так і по характеристиках спрямованості (коефіцієнта спрямованої дії). Одним із розповсюджених типів широкосмугових антен є спіральні антени. Основним недоліком даних антен можуть бути методи реалізації їх збудження (коаксіальною або двопровідною лінією), за яких зменшуються широкосмугові характеристики антени та втрачається планарність усієї конструкції. Тому є необхідність у створенні конструкції антен без даних недоліків. У статті надана топологія планарної спіральної антени Архімеда з малою кількістю витків. Головною її особливістю є периферійне живлення витків спіралі, що не порушує планарність конструкції. Результати отримані на основі чисельного аналізу, що базується на методі моментів, який реалізований у частотній області. В результаті моделювання були отримані амплітудно-фазові розподіли густини струму на поверхні антенних елементів, що дозволили розрахувати частотні залежності основних електродинамічних характеристик, таких як вхідний імпеданс, коефіцієнт відбиття на вході антени, а також кутові залежності всіх компонентів випромінюваного поля та діаграми спрямованості. На основі отриманих результатів порівнюються й обговорюються основні електродинамічні характеристики для декількох конструктивних варіантів антени, числом витків, що відрізняються, у тому числі з постійною і змінною шириною стрічки спірального елемента. Результати наданого чисельного аналізу показали, що відносна ширина смуги частот, визначувана як за КСХ на вході антени, так і за КСД, досягає від 75 до 120 відсотків.

Завдяки планарній конструкції, периферійному збудженню витків та вхідному опорі на рівні 200 Ом, даний елемент може бути використаний як випромінюючий елемент у широкосмугових антенних решітках. Крім того, даний елемент може використовуватися як опромінювач дзеркальних антен.

Ключові слова: планарні антени, спіраль Архімеда, периферійне живлення, широкосмуговість, комп'ютерне моделювання.

Аннотация. Представлена топология планарной архимедовой спиральной антенны с малым количеством витков. Главной ее особенностью является периферийное питание спирали, не нарушающее планарность конструкции. На основе численного моделирования получены, сравниваются и обсуждаются основные электродинамические характеристики для нескольких конструктивных вариантов антенны, отличающихся числом витков, в том числе с постоянной и переменной шириной ленты спирального элемента. Результаты приведенного численного анализа показали, что относительная ширина полосы частот, определяемая как по КСВ на входе антенны, так и по КНД, достигает от 75 до 120 процентов.

Ключевые слова: планарные антенны, спираль Архимеда, периферийное питание, широкополосность, компьютерное моделирование.

The creation and application on practice of modern wireless technologies in the civil and military sphere [1] leads to the need for the investigation the antennas of new design with good wideband properties. Such antennas should satisfy the required characteristics (e.g. input impedance, radiation pattern) in a wide frequency range. In addition, such antennas should have acceptable weight and dimensional characteristics.

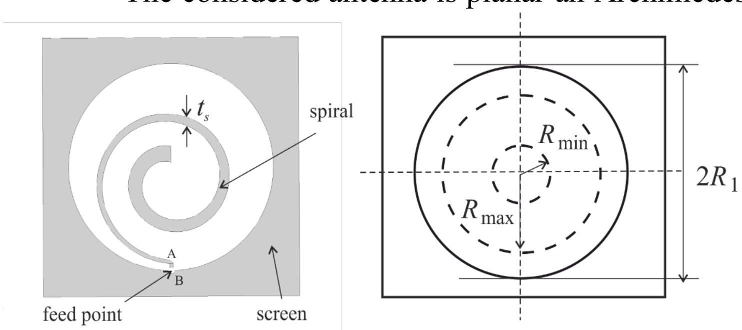
As is well known [2, 3], spiral antennas, in which the radiation (reception) of the electromagnetic field of circular (or elliptical) polarization, are largely satisfied by such requirements. These include quite simple technology in the manufacture one or two arm spirals and low-profile planar spiral antennas, such as Archimedes spirals, which occupy comparatively small volume.

The features of the antennas with the planar spiral are they a method of connection with the feed line. There are few main methods of excitation of planar spiral antennas, features of it are described in [4].

We note that with similar methods of excitation using symmetrical and matching devices are needed, which are usually located in orthogonal plane and violates the planarity of the antenna constructions and increases its occupying volume. Also use of matching and balancing devices (which are usually narrow-band) lead to the losses of wideband parameters of these antennas.

In this work the main electrodynamic characteristics of planar spiral antenna with a small number of turns based on computer modelling is presented and discussed. The features of this type of antenna is that the spiral is located in the circular hole in the flat conductive screen and with peripheral feeding which does not violate planarity of all construction.

The considered antenna is planar an Archimedes spiral in the form of plane tape, its arm can be of constant or variable width. The features of this design are an antenna element which is placed in a circular hole of radius (and displaced with respect to its center) in a flat conducting screen, which (in this study it has no special significance) has a square shape (Fig. 1, *a*).



a) *b*)

Figure 1 – The topology of the model

The antenna is excited in the peripheral region of the spiral by means of a coaxial or coplanar line (which is located in the plane of the screen). The spiral element is displaced so that the distance between the feeding points (from the edge of the peripheral turn to the edge of the hole) is approximately equal to the width of the spiral element. At the same time, the geometry of the antenna is such that all its elements (screen, spiral element, and feed line) are located in the same plane. This is a characteristic feature of such a design.

This model differs from the antenna presented in [4] by the presence of the flat conductive screen what simplifies the creation of planar antenna arrays based on them.

For the electrodynamic analysis of the main characteristics of this spiral antenna, the calculation of the characteristics was carried out at discrete frequencies in the range 1-6 GHz in 20 MHz steps.

To carry out the research, a computer model of a spiral with small number of turns and peripheral feeding with such geometric parameters was realized (Fig. 1, *b*):

- radius of the hole in the screen $R_1 = \lambda_0 / 4$;
- maximum radius of the spiral R_{max} (Fig. 2, *b*) which is related to radius R_1 with relation $R_{max} = \tau R_1$;
- minimum radius of the spiral $R_{min} = 10$ mm;
- scale factor τ – 0,6; 0,7; 0,8;
- number of turns n – 1,25; 1,5; 1,75;
- dimensions of the conductive screen – $2{,}5R_1$.

In this case, the basic geometric parameters of the antennas are assigned to the calculated wave length in free space λ_0 corresponding to the frequency $f_0 = 2{,}5$ GHz.

With the above values of the scale factor and the number of turns, three variants of the design of the spiral element of the antenna under consideration are considered:

- width of the spiral tape t_s is constant and equal 1 mm;
- the value of t_s varies smoothly from 1 mm at the feed point and up to 3 mm at the center of the spiral;
- the value of t_s varies smoothly from 1 mm at the feed point and up to 1 mm at the center of the spiral;

The numerical solution of the problem is based on the method of moments for the integral equation with respect to the density of the surface currents on the antenna elements realized in the frequency domain [5]. As a result of the numerical experiment, the amplitude-phase distribution of the current density on the surface of the antenna elements was determined. This further allowed the calculation of the frequency dependences of the main characteristics, such as impedance and standing wave ratio (SWR) at the antenna input, as well as the angular dependences of all components of the radiation field, directivity and thus build a radiation pattern.

Results of modeling. Fig. 2 shows frequency dependencies of real $\mathrm{Re}\,\dot{Z}_{in}$ and imaginary $\mathrm{Im}\,\dot{Z}_{in}$ parts of input impedance for investigated modification of antenna at τ = 0,6.

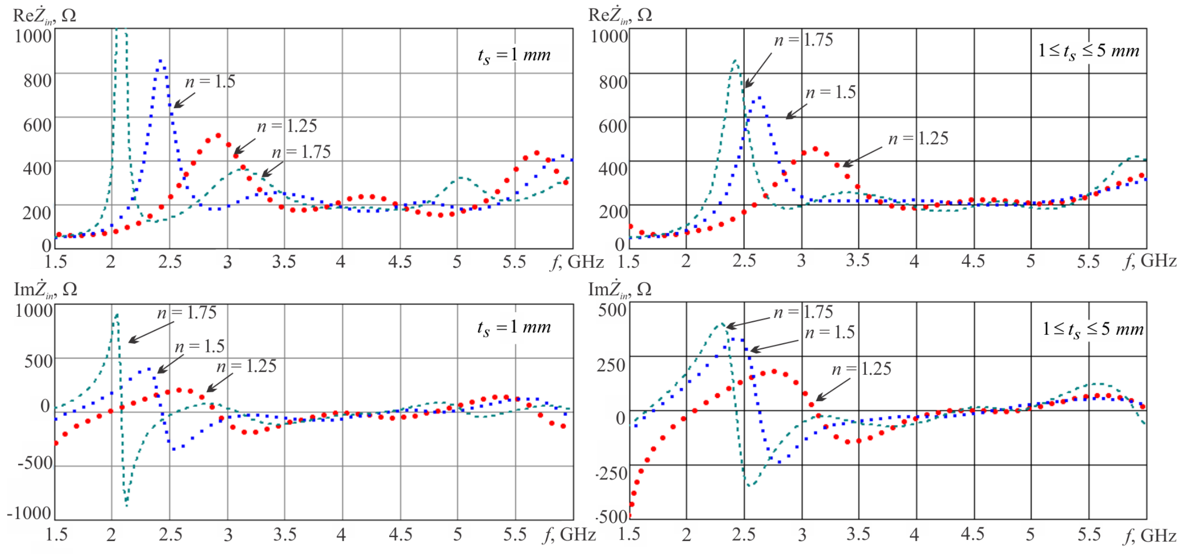


Figure 2 – Frequency dependencies of impedance at the antenna input

Analyzing the curves shown in Fig. 2, we can note the following:

– in the region near the calculated frequency, resonant phenomena are observed in which the real part of the input impedance increases sharply, and its imaginary part vanishes;

– with an increase in the number of turns, that is, with an increase in the total length of the spiral element, the resonance points are shifted to the low-frequency region.

The noted resonance effects are manifested due to the fact that at low frequencies the transformation of the energy of surface currents in the spiral element into the energy of the radiation field is insignificant.

Standing wave ratio. The degree of matching of the antenna with the feeder is usually evaluated by the voltage standing wave ratio (VSWR) at the antenna input. The wideband properties of antenna are illustrated on the frequency dependences of the VSWR at the antenna input, shown in Fig. 3 (at τ = 0,6 and the active load resistance R_{in}).

In most practical cases, the degree of matching of the antenna to the feeder is considered acceptable if at the antenna input the $\text{VSWR} \le 2$.

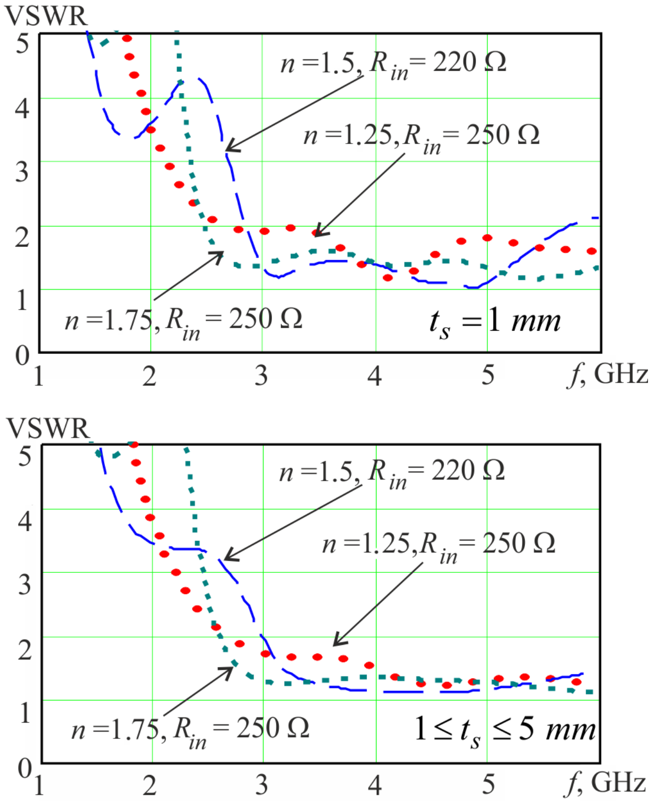


Figure 3 – Frequency dependencies of VSWR

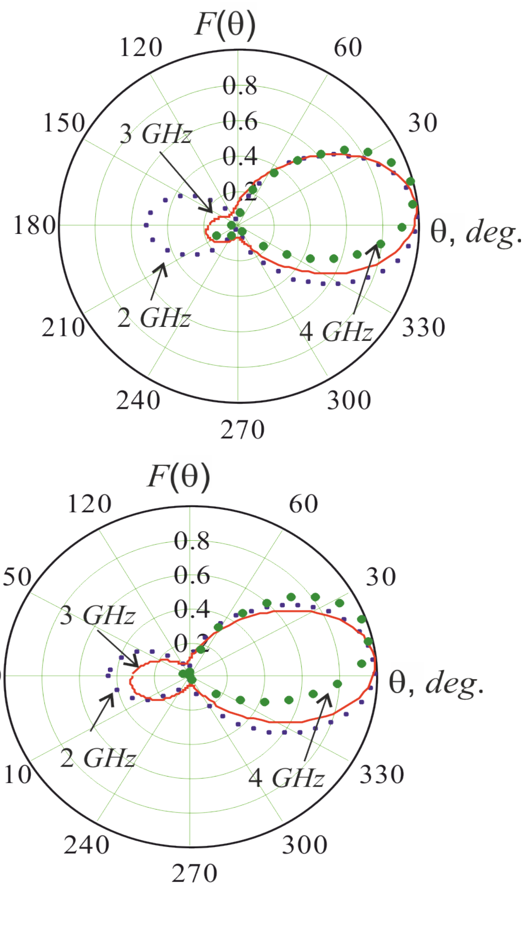
Based on this criterion, it is possible, for the previously mentioned constructive variants of the antenna in question, to compare antennas properties, using the data of the relative width of the operating range $\Delta f / f_0$ given in Table 1.

The change (increase) in the scale factor in all the considered design variants of the antenna leads to a certain increase in the relative width of the working range, measured on the VSWR level = 2. The width of the working range varies from 66 to 100%, which indicates broadband properties of the antenna as agreed with the load) made according to the topology described above.

Table 1 – Relative frequency bandwidth by VSWR

Width of the spiral tape, mm	*Scale factor* τ	*Number of turns* $n=1{,}25$	$n=1{,}5$	$n=1{,}75$
		$\Delta f / f_0$,%		
$t_s=1$	*0,6*	**75**	**72**	**85**
	0,7	**92**	**82**	**92**
	0,8	**96**	**87**	**100**
$1 \le t_s \le 3$	*0,6*	**79**	**69.6**	**82**
	0,7	**91**	**82**	**91**
	0,8	**98**	**89**	**98**
$1 \le t_s \le 5$	*0,6*	**77**	**66.6**	**79**
	0,7	**91**	**79**	**91**
	0,8	**96**	**87**	**96**

Directional characteristics. For the analysis of the directional properties, radiation patterns for the left circular polarization of the radiated field are presented (Fig. 4), constructed with a scale factor. $\tau = 0{,}8$.



a) *b)*

Figure 4 – Radiation pattern at $\tau = 0{,}8$: *a)* $t_s=1$ *mm; b)* $1 \le t_s \le 5$ mm

Note that in all considered cases this antenna in the direction of the normal the field radiates of the left circular polarization (and in the opposite direction – the right one). Considering these diagrams, it can be noted that as the frequency increases, the main lobe deviates relative to the normal of the plane of the spiral.

It is with this effect of decreasing the value of the directivity *D* observed on the right half of the graphs (Fig. 5) in the direction of the normal to the screen plane, (given for different values of *n*, at $t_s = 1$ mm) is associated with this effect. However, calculations show that the maximum value of the directivity is not only not decreasing, but even slightly increasing.

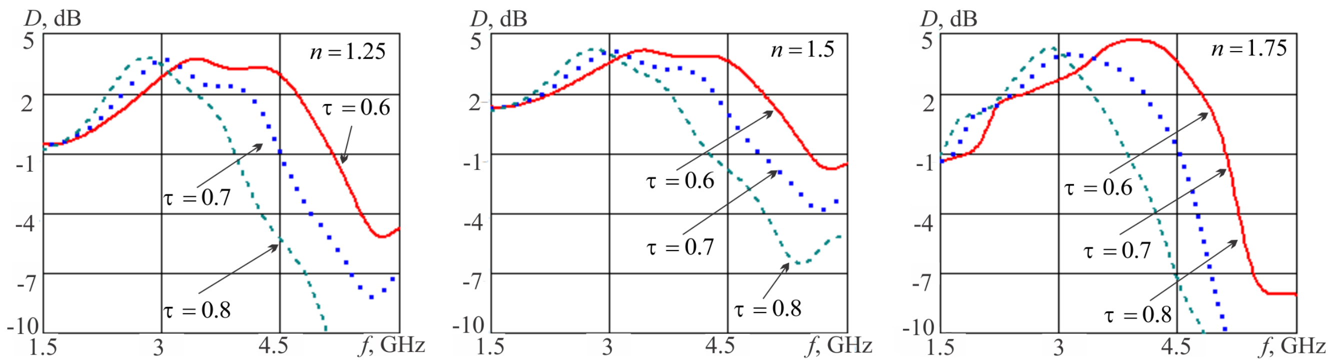


Figure 5 – Dependencies of directivity on frequency

The values of the relative width of the working band, determined from the –3 dB level relative to the maximum of the directivity at different values of the geometric parameters of the antenna, calculated on the basis of these and similar dependencies, are given in Table. 2.

Table 2 – Relative frequency bandwidth by directivity

Width of the spiral tape, mm	*Scale factor* τ	*Number of turns*								
		$n = 1{,}25$			$n = 1{,}5$			$n = 1{,}75$		
		$f_{\min}$	$f_{\max}$	$\Delta f/f_0$,%	$f_{\min}$	$f_{\max}$	$\Delta f/f_0$,%	$f_{\min}$	$f_{\max}$	$\Delta f/f_0$,%
$t_s = 1$	0,6	*1,25*	*5,12*	**121,5**	*2,15*	*5,06*	**80,7**	*2,08*	*5,02*	**82,8**
	0,7	*1,47*	*4,47*	**101**	*1,65*	*4,53*	**93**	*1,75*	*4,44*	**80**
	0,8	*1,55*	*3,9*	**86**	*1,62*	*3,78*	**80**	*1,61*	*3,77*	**80,3**
$1 \le t_s \le 3$	0,6	*1,32*	*5,3*	**120**	*2,13*	*5,27*	**84,8**	*2,12*	*5,17*	**83**
	0,7	*1,27*	*4,67*	**114**	*1,66*	*4,73*	**96**	*1,75*	*4,62*	**90**
	0,8	*1,67*	*4,07*	**83**	*1,62*	*4,15*	**87,8**	*1,62*	*3,88*	**82**
$1 \le t_s \le 5$	0,6	*1,31*	*5,45*	**122**	*2,03*	*5,45*	**91,5**	*2,14*	*5,31*	**85**
	0,7	*1,27*	*4,86*	**117**	*1,75*	*4,87*	**94**	*1,75*	*4,73*	**92**
	0,8	*1,62*	*4,22*	**89**	*1,62*	*4,2*	**88,6**	*1,62*	*4*	**84,7**

Analyzing the results presented in Table 1 and Table 2, we can draw the following conclusions:

– the best values of the relative width of the operating frequency band $\Delta f/f_0$ take place at a number of turns $n = 1{,}25$, reaching 120% in some cases. With this value of n, increasing the scale factor τ by more than 0,6 leads to a narrowing of the frequency operating band. In all other cases, this effect is hardly noticeable;

– for number of turns $n = 1{,}5$ and $n = 1{,}75$, the relative width of the operating band is weakly dependent on the scale factor τ. In these cases, the value of $\Delta f / f_0$ is lies between 80 ... 95%.

Conclusions. The topology of a planar helical antenna with a small number of turns and peripheral feeding of a spiral element is considered. This topological feature, ensuring the planarity of the entire structure as a whole, retains a good wide-banding of the antenna, both on load matching and on the directivity.

The basic electrodynamic characteristics for several constructive variants of antennas differing in the number of turns are discussed and compared, including with the constant and variable width of the ribbon of the spiral element. As shown by the results of numerical analysis, the relative bandwidth of the operating frequencies is in the range of 75 ... 120%.

Therefore, the represented topology for circular polarization antennas allows the creation of planar (low profile) structures intended for use over a sufficiently wide frequency range. At the same time, we note that peripheral excitation of the spiral element gives an advantage to such an antenna for use at higher frequencies, for example, in the frequency bands of advanced radio systems.

The possible further research directions of the described type antennas include the creation and analysis of the properties of spiral antenna elements in the peripheral feeding by their microstrip line, and also the study of the characteristics of antenna arrays formed from such elements.

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