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OUT-OF-BAND CHARACTERISTICS OF THE MICROSTRIP ANTENNA

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ПОЗАСМУГОВІ ХАРАКТЕРИСТИКИ МІКРОСМУЖКОВОЇ АНТЕНИ

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ВНЕПОЛОСНЫЕ ХАРАКТЕРИСТИКИ МИКРОПОЛОСКОВОЙ АНТЕННЫ

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Abstract. The development of wireless communication systems is accompanied by both the development of new frequency ranges and the simultaneous use of one band of frequencies by several radio services. This fact leads to an increase in the number of noise and the deterioration of the electromagnetic environment. The level of electromagnetic interference at the input of the receiver depends to a large extent on the spatial characteristics of the antennas, such as the directional diagram and the magnitude of the gain in a particular direction. For the efficient operation of wireless communication systems, it is necessary to ensure the electromagnetic compatibility of radio electronic devices. In the case of radio systems operating at different frequencies, or if there are out-of-band and unwanted radiation, the electromagnetic environment assessment process is considerably more complicated. The main characteristics of the antennas, such as the radiation pattern, gain, input impedance, polarization, and others, are often indicated only for the operating frequency range, while the characteristics outside operating range are unknown. Therefore, it is relevant to study the frequency characteristics of antennas outside the operating frequency range.

The main electrodynamic characteristics of a rectangular microstrip antenna outside operating frequency range are considered. The results are obtained by the numerical simulation, based on the method of moments in the frequency domain. The calculated frequency dependencies of the directivity and the gain factor taking into account out-of-band properties of the impedance at the antenna input make it possible to more accurately take into account levels of the electromagnetic interference and thereby ensuring the electromagnetic compatibility of the radio electronic means.

Key words: out-of-characteristics, microstrip antennas, electrodynamic modelling, electromagnetic compatibility.

Анотація. Розвиток бездротових систем зв'язку супроводжується, як освоєнням нових частотних діапазонів, так і одночасним використанням однієї смуги частот декількома радіослужбами. Даний факт веде до збільшення кількості завад та погіршення електромагнітної обстановки. Рівень електромагнітної завади на вході приймача значною мірою залежить від просторових характеристик антен, таких як діаграма спрямованості та величина коефіцієнта підсилення у конкретному напрямку. Для ефективної роботи бездротових систем зв'язку необхідно забезпечити електромагнітну сумісність радіоелектронних засобів. У випадку, коли радіосистеми працюють на різних частотах або мають місце позасмугові та небажані випромінювання, процес оцінки електромагнітної обстановки значно ускладнюється. Основні характеристики антен, такі як діаграма спрямованості, коефіцієнт підсилення, вхідний опір, поляризація та інші найчастіше вказуються тільки для робочого діапазону частот, в той час як характеристики за його межами є невідомими. Тому актуальним є дослідження частотних характеристик антен поза смугою робочого діапазону. У якості досліджуваної моделі був обраний один із розповсюджених типів антен – мікросмужкова антена з випромінювачем прямокутної форми. У статті представлені частотні залежності основних параметрів антен у широкому діапазоні частот (2…10 ГГц), які отримані шляхом розрахунку основних характеристик на основі чисельного моделювання. Принцип розрахункового модуля базується на розв'язанні дифракційної задачі на основі методу моментів у частотній області. Розраховані частотні залежності коефіцієнтів спрямованої дії (КСД) та підсилення (КП) з урахуванням позасмугових властивостей вхідного імпедансу антени дозволяють більш точніше враховувати рівні електромагнітних завад при оцінці електромагнітної обстановки, тим самим забезпечити електромагнітну сумісність радіоелектронних засобів.

Ключові слова: позасмугові характеристики, мікросмужкові антени, електродинамічне моделювання, електромагнітна сумісність.

Аннотация. Развитие беспроводных систем связи сопровождается, как освоением новых частотных диапазонов, так и одновременным использованием одной полосы частот несколькими радиослужбами. Данный факт ведет к увеличению количества помех и ухудшению электромагнитной обстановки. Уровень электромагнитной помехи на входе приемника в значительной степени зависит от пространственных характеристик антенн, таких как диаграмма направленности и величина коэффициента усиления в конкретном направлении. Для эффективной работы беспроводных систем связи необходимо обеспечить электромагнитную совместимость радиоэлектронных средств. В случае, когда радиосистемы работают на разных частотах или имеют место внеполосные и нежелательные излучения процесс оценки электромагнитной обстановки значительно усложняется. Основные характеристики антенн, такие как диаграмма направленности, коэффициент усиления, входное сопротивление, поляризация и другие, чаще всего указываются только для рабочего диапазона частот, в то время как характеристики за его пределами неизвестны. Поэтому актуальным является исследование частотных характеристик антенн вне полосы рабочего диапазона. Рассмотрены основные электродинамические характеристики прямоугольной микрополосковой антенны за пределами рабочего диапазона частот. Результаты получены на основе численного моделирования, основанного на методе моментов в частотной области. Рассчитанные частотные зависимости коэффициента направленного действия (КНД) и коэффициента усиления (КУ) с учетом внеполосных свойств входного импеданса антенны позволяют более точно учитывать уровни электромагнитных помех при оценке электромагнитной обстановки и тем самым обеспечить электромагнитную совместимость радиоэлектронных средств.

Ключевые слова: внеполосные характеристики, микрополосковые антенны, электродинамическое моделирование, электромагнитная совместимость.

The fast development of wireless communication systems is accompanied both by mastering of new frequency ranges and using frequency bands by several radio services. This fact leads to the increasing of number of interference channels and decreasing of signal-to-noise ratio and deterioration of electromagnetic compatibility (EMC) of radio means and their efficiency.

There are two type of electromagnetic interference in wireless communication systems:

- interference caused by electromagnetic coupling between hardware nodes or between two or more elements of which are a short distance from each other;
- interference caused in radio engineering system penetrating through antenna. This type of interference is possible both for near and remote systems.

Level of electromagnetic interference (EMI) at an antenna input can be expressed by follows:

$$P_R(f_i) = P_T(f_i) + G_T(f_i, \theta_{TR}, \varphi_{TR}) + G_R(f_i, \theta_{RT}, \varphi_{RT}) + L(d), \text{ dB}, \qquad (1)$$

f_i is the frequency of interference; $P_T(f_i)$ is the power of transmitter; $G_T(f_i,\ \theta_{TR}, \varphi_{TR})$ is the transmit antenna gain in the direction of the receive antenna; $G_R(f_i,\ \theta_{RT}, \varphi_{RT})$ is the receive antenna gain in the direction of transmit antenna; $L(d)$ is the path loss at the distance d.

From (1) it follows that level of the EMI and, accordingly, EMC greatly depends on spatial parameters of antennas. It is known that from the main parameters which influence at EMC of radio electronic means almost one-third is defined by characteristics of antennas [1].

In the case when the transmit and receive antennas operate at different frequencies or when we have out-of-band and unwanted radiation the process of electromagnetic situation, evaluation is more complicated. Namely, we need to know the directional characteristics of antennas outside the operating frequency band. But usually those characteristics are unknown. Also it should be noted that in EMC problems, it is necessary to know not only level of the maximum antenna gain but also it level in some defined direction.

The main characteristics of antenna such as radiation pattern in two planes, half-power beam width of the major lobe, antenna gain, input impedance, polarization is usually indicated in the technical documentation of antenna. In many cases those parameters are known only for the operating frequency band and parameters outside this range are unknown.

The change in electrodynamics characteristics of antenna outside operating frequency range is due to the following factors:

– frequency dependencies of radiation currents on antenna surfaces;
– changing of parameters of feeding scheme;
– frequency dependencies of impedance at the antenna input.

Therefore, the frequency dependency of antenna gain has an inhomogeneous and complex character of which are relatively small values and its bursts can be observed. The goal of this investigation is to analyze main characteristics of the microstrip antenna outside operating frequency range. The results can help more exactly estimate electromagnetic environment and increase efficiency of wireless systems.

In EMC problems radiation pattern of antenna is usually divided on two regions: major lobe/main beam (region of useful radiation); side and back lobes (region of unwanted radiation).

For the estimation of antenna gain in the region of useful radiation outside the operating frequency range the mathematical models based on statistical data are used. One of them is presented in [2]. In this model, the operating frequency range antenna gain is presented as a random value which has a normal distribution law with a mean G_0, dB and mean deviation $\sigma_G = 2$ dB.

Usually to estimate level of influence out-of-band characteristics of antennas mathematical models are used. These models cause significant difficulties of mathematical nature. Therefore, the use of modern methods of analysis, based on numerical calculation of electrodynamics problems becomes more actual.

In this research a model of the one of the most popular type of antenna was chosen – microstrip (patch) antenna (MSA). Due to its compact size and small weight, those antennas are used in aviation, rocket and space industries. In addition, MSA's are used in mobile communication and broadband wireless systems. In general, this type of antenna consists of microstrip radiator, dielectric substrate and screen (ground).

Due to the simplicity of calculation the most used type of MSA is antenna with rectangular radiator. Figure 1 shows investigation model of antenna in the Cartesian coordinate system with the indicated main geometrical parameters.

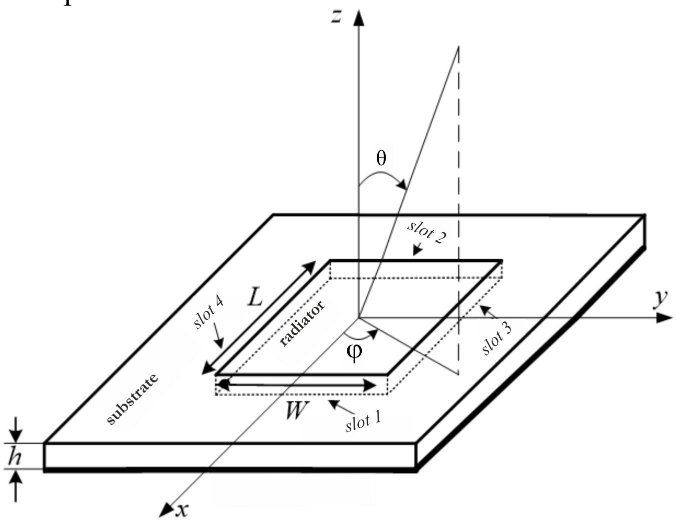

Figure 1 – Geometry of the MSA

The main parameters for calculation MSA usually are: resonant frequency f_r and height of the dielectric substrate h. For estimation of characteristics in wide frequency range, next typical values of the parameters: $f_r = 3$ GHz and $h = 2$ mm were chosen . As a dielectric substrate material with dielectric permittivity $\varepsilon_r = 2{,}3$ was chosen.

The calculation procedure of main geometrical dimensions of MSA is presented in [3].

The width of a rectangular radiator (RR) can be calculated as follows:

$$W = \frac{c}{2f_r}\sqrt{\frac{2}{\varepsilon_r + 1}}, \tag{2}$$

c is the speed of light in a free space.

Effective length of RR for main mode TM_{010} can be found using expression:

$$L = \frac{c}{2f_r\sqrt{\varepsilon_{ef}}} - 2\Delta L, \tag{3}$$

ε_{ef} is effective dielectric permittivity of substrate. If ratio $W/h > 1$ it can be found by the formula:

$$\varepsilon_{ref} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{w}\right]^{-0.5}. \tag{4}$$

ΔL is an extended incremental length of RR. A very popular and approximate relation for the normalized extension of the length is

$$\frac{\Delta L}{h} = 0.412\frac{\left(\varepsilon_{reff} + 0.3\right)\left(\frac{W}{h} + 0.264\right)}{\left(\varepsilon_{reff} - 0.3\right)\left(\frac{W}{h} + 0.8\right)}. \tag{5}$$

For chosen resonant frequency 3 GHz the optimal dimensions are $W = 38{,}9$ mm and $L = 31{,}9$ mm.

The value of the impedance at the antenna input depends on conductivity of the slots G_1 and their mutual influence G_{12}

$$R_{in} = \frac{1}{2\left(G_1 \pm G_{12}\right)}, \tag{6}$$

where sign $\pm$ is depends on resonant voltage distribution beneath the patch and between the slots.

Value of the input impedance at the edge of RR lies in the range 150-300 ohms. For matching MSA with microstrip line, it is necessary to significantly reduce the width of the line. It leads to the increased losses in conductor and complicates the implementation of the antenna.

That's why to match MSA and feed line, different matching techniques are used, e.g. using quarter wavelength transformer. But more spread variant of matching is a displacement of a feed point along x axis relative to the middle of the RR on value x_0:

$$x_0 = \frac{L}{\pi}\arccos\left(\sqrt{\frac{W}{R_{in}}}\right), \tag{7}$$

where W is resistance of the feed line.

In the case of feeding by coaxial line with characteristics impedance 50 ohms, in our case feed point will be at $x_0 = 8$ mm.

The presented results are obtained by the calculating of the main electrodynamic characteristics of the MSA on the basis of numerical simulation. The principle of the calculation module is based on the solution of the diffraction problem based on the method of moments

(Bubnov-Galerkin method). This method is based on the representation of each of the surface of antenna element in the form of triangular segments. This makes it possible to solve the problem of determining the amplitude-phase distribution of currents on the antenna surfaces to solve the system of linear algebraic equations [4].

For investigation of characteristics MSA in wide frequency range, the range from 2 to 10 GHz with discrete step 20 MHz was chosen.

One of the main features of the MSA is a narrow operating frequency range due to rapid changing real and imaginary part of the input impedance. In Fig. 2 shows frequency dependencies of the input impedance of the investigated model.

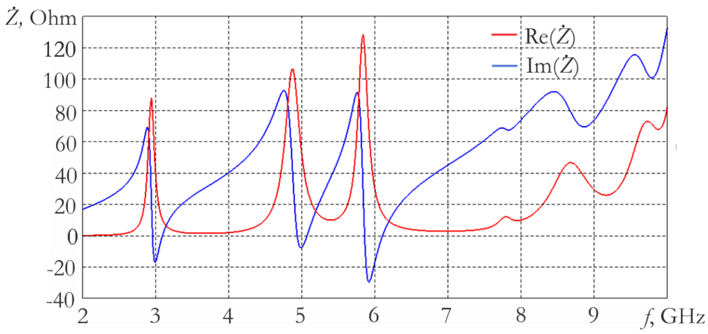

Figure 2 – Dependence of input impedance on frequency

In microstrip lines propagate TM type waves. The resonant frequency for such type can be calculated as follows [5]:

$$f_{mnp} = \frac{c}{2\pi\sqrt{\varepsilon_r}}\sqrt{\left(\frac{m\pi}{h}\right)^2 + \left(\frac{n\pi}{L}\right)^2 + \left(\frac{p\pi}{W}\right)^2}, \tag{8}$$

m, n and *p* represent the number of half-cycle field variation along *z*, *y* and *x* directions, respectively.

The dominant mode of MSA is the TM_{010} whose resonant frequency is given by:

$$f_{010} = \frac{c}{2L\sqrt{\varepsilon_r}}. \tag{9}$$

With increase in frequency appearance of higher modes are possible. In investigated case are observed modes TM_{002} and TM_{012}, for resonances frequency are observed at frequencies $f_{002} \approx 5$ GHz and $f_{012} \approx 6$ GHz, respectively. In further increase in frequency MSA loses resonant properties.

The level of matching antenna and feed line can be estimated by complex reflection coefficient $|\dot{S}_{11}|$ at the antenna input (Fig. 3).

From Fig. 4 it can be seen, that at all resonant frequencies the value of reflection coefficient less than -10 dB. It means good level of matching antenna and microstrip line.

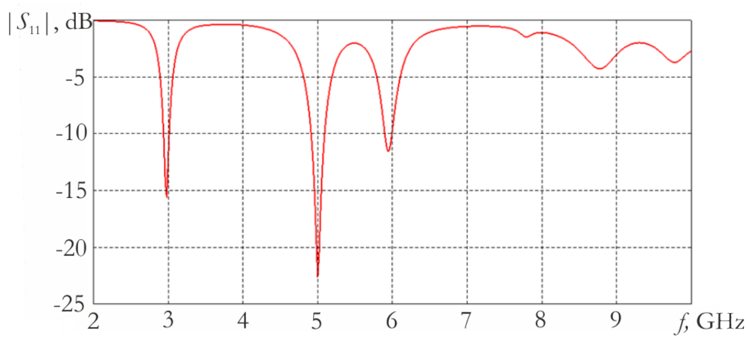

Figure 3 – Reflection coefficient

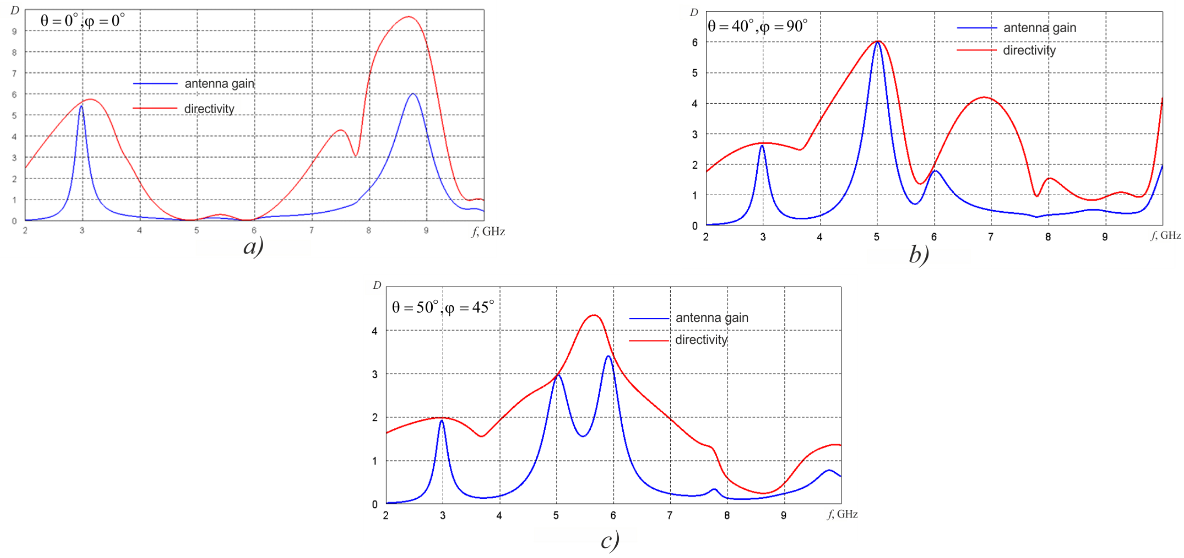

Figure 4 – Dependencies of directivity and antenna gain in different directions

The most urgent (from electromagnetic compatibility point of view) characteristics of antennas are their directional characteristics.

For estimation of directional characteristics of MSA with RR was calculated frequency dependencies of the *directivity* and *antenna gain* in directions: *a*) $\theta = 0^\circ$, $\varphi = 0^\circ$; *b*) $\theta = 40^\circ$, $\varphi = 90^\circ$; *c*) $\theta = 50^\circ$, $\varphi = 45^\circ$.

It can be seen, that in some direction the value of antenna gain can be even more that in the operating frequency band. The appearance of this fact is the result of changing of amplitude-phase distribution of the fields and currents at the antenna surfaces. For clarity, at the Fig. 5 distributions of the surface currents and radiation patterns of the antenna at the operating frequency 3 GHz and frequencies 5, 6 and 8.8 GHz, respectively, are shown.

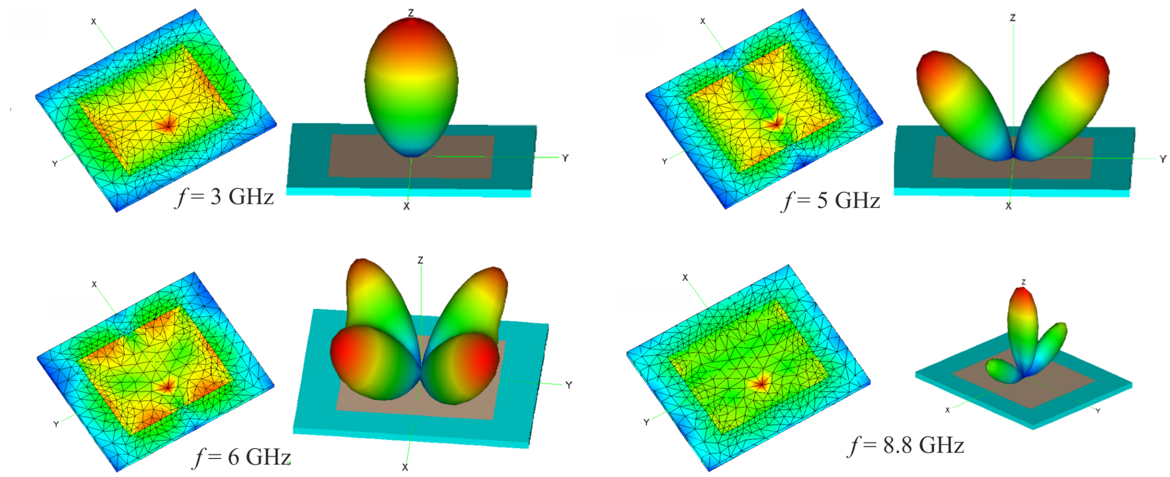

Figure 5 – Distribution of the surface currents and radiation patterns

From Fig. 5 it can be concluded:

– at the operating frequency f_{010} the radiation is formed by in-phase slots 1 and 2 and maximum radiation is observed in the direction of the normal to the MSA screen;

– at the frequencies f_{002} and f_{012} radiation is formed by slots 3 and 4 and by all slots. In this case maximum field intensity take place in directions $\theta = 40^\circ$, $\varphi = \pm 90^\circ$ and $\theta = 50^\circ$, $\varphi = 45^\circ$, respectively;

– due to the change of electromagnetic field in all slots at the frequency 8.8 GHz maximum radiation is observed in the direction of the normal.

As can be seen from these dependencies, the directional characteristics are changed significantly outside operating frequency range. The excitation of the higher modes leads to the change of the directional pattern and appearance of side lobes. Due to the matching of antenna input impedance and wave impedance of the line, the radiation at the higher modes frequencies can lead to significant decrease of the electromagnetic environment and, respectively, to the decreased efficiency of wireless communication systems.

From the obtained results, it follows that the characteristics of the direction of the MSA outside the operating frequency band are subject to significant changes. Due to the excitation of higher types of waves and alignment of the antenna with the line of power at these frequencies, it is possible to receive unwanted signals. Because of this, it should be noted that in the analysis of electromagnetic compatibility of radio-electronic means it is necessary to take into account the conditions of excitation of higher types of waves and the peculiarities of radiation at given frequencies.

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