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 радиосистеми 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 прямоугольної форми.
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that in EMC problems, it is necessary to know not only level of the maximum antenna gain but also its 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: \( f_r = 3 \text{ GHz} \) and \( h = 2 \text{ mm} \) 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:

\[
W = \frac{c}{2f_r \sqrt{\varepsilon_r + 1}},
\]

\( c \) is the speed of light in a free space.

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

\[
L = \frac{c}{2f_r \sqrt{\varepsilon_r}} - 2\Delta L,
\]

\( \varepsilon_{ref} \) is effective dielectric permittivity of substrate. If ratio \( W/h > 1 \) it can be found by the formula:

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

\( \Delta L \) is an extended incremental length of RR. A very popular and approximate relation for the normalized extension of the length is

\[
\frac{\Delta L}{h} = 0.412 \left( \frac{\varepsilon_{ref} + 0.3}{h} \frac{w + 0.264}{h} \right) - \left( \frac{\varepsilon_{ref} - 0.3}{h} \frac{w + 0.8}{h} \right).
\]

For chosen resonant frequency 3 GHz the optimal dimensions are \( W = 38.9 \text{ mm} \) and \( L = 31.9 \text{ mm} \).

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

\[
R_{in} = \frac{1}{2(G_i \pm G_{12})},
\]

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 \( x_0 \):

\[
x_0 = \frac{L}{\pi} \arccos \left( \frac{W}{\sqrt{R_{in}}} \right),
\]

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 \( x_0 = 8 \text{ mm} \).

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

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(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.

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

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]:

$$f_{\text{res}} = \frac{c}{2\pi \sqrt{\varepsilon_r}} \left( \left( \frac{m\pi}{h} \right)^2 + \left( \frac{n\pi}{L} \right)^2 + \left( \frac{p\pi}{W} \right)^2 \right),$$  \hspace{1cm} (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:

$$f_{010} = \frac{c}{2L\sqrt{\varepsilon_r}}.$$ \hspace{1cm} (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 $|S_{11}|$ 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

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Out-of-band characteristics of the microstrip antenna
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.

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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ЛІТЕРАТУРА: