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Improvement Of Airborne Antennas' Noise Immunity With The Usage Of Periodic Structures

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Abstract: *This article presents a review of different methods of reducing coupling in radio systems. Specifically, we consider the problem of coupling between aperture antennas located on a common impedance surface, and analyze structures which are typically used to solve this form of problem, i.e., periodic structures. We also note that for better design of the structure, there is a need to develop the techniques of synthesis of these structures and, for the future, to develop new electrodynamics and mathematical models, and for research on new electromagnetic bandgap materials.*

Keywords: *Electromagnetic compatibility, electromagnetic bandgap materials, impedance surface, periodic structure, coupling.*

I. Introduction

An analysis of the applications of radio electronic devices shows that, specifically, the number of active radio engineering systems is constantly growing. The total of mobile radio stations doubles every 4~5 years [1]. The number of radar installments is increasing even more rapidly. Many radio engineering systems operate in the immediate proximity of each other. This especially concerns airborne systems located onboard ships, aircraft and satellites. In addition, a growing number of radio electronic systems have a greater radiating power. There are, for example, klystrons with an average power of 1 megawatt (MW) and a pulse power of up to 100 MW; and magnetrons with an average power of 1 kilowatt and a pulse power of up to 10 MW. The imperfection of radio transmitting devices along with generation of the main frequency causes the presence of harmonics and sub harmonics in the spectrum of the generated power, which have a level of 50~90 decibels (dB) and can reach hundreds of watts. The sensitivity of modern receivers is several levels higher and reaches (-130 ~ -160 dB/watt). In this process, the problem of electromagnetic compatibility (EMC) of the receiving and the transmitting radio engineering systems modules becomes acute. This problem is connected with their mutual influence on each other.

The problem of EMC for different radio electronic systems consists in effecting the operation of these systems with no undesirable electromagnetic coupling between antennas, which destroys functioning with the required quality of these and other electronic systems. In other words, the problem of EMC is the problem of interference immunity, i.e., protection from the effects of natural interference of different types, and it has much in common with the problem of protection from interference of the desired signal [2].

The main purpose of this paper is the analysis of the problem of EMC of radio engineering systems and the presentation of the methods of providing EMC by using antenna design techniques. In particular, we review a solution to the problem of reducing coupling between antennas located on the same surface using periodic structures. In addition, we notice the importance of the level of the cross-polarization components on the reduction of coupling between antennas, and present methods to help reduce the influence of aberrations of mirror antennas on EMC parameters. Finally, we suggest some prospects for further research.

The paper is organized as follows: In Section II, we present the main methods of spatial reduction of antenna coupling, and principles of ensuring antenna decoupling using corrugated periodic structures are presented in Section III. The influence of polarization characteristics on decoupling between antennas is presented in section IV. Section V presents the influence of aberration of the mirror antennas on EMC parameters. Finally, Section VI is devoted to the conclusion.

II. Main Methods for Spatial Reduction Of Antennas Coupling

II.1. General Questions

One of the most important problems in radio electronic device development is the provision of EMC of different radio systems, i.e., the provision of their simultaneous and normal functioning under the conditions of real collocation. Accomplishing EMC is most desirable through the use of the strict methods of electrodynamics, without interference into the equipment and without temporal regulation, which destroys normal functioning, i.e., only due to reduction of coupling (increase of decoupling) between antennas. The quantitative estimation of decoupling of antennas is characterized [3], by the coefficient of antenna coupling:

$$K_c = \frac{P_{rec}}{P_{tr}}, \qquad (1)$$

where P_{rec} and P_{tr} are the powers of the signals (the received signal at the exit of the receiving antenna and the transmitted signal at the entrance of the transmitting antenna). The inverse value of K_c, called the decoupling coefficient *K*, is defined as $K = -10\log(K_c)$.

For antennas in the free space, decoupling is defined by directivity diagram levels (in fractions of increasing coefficient) in the direction of the coupling line (taking into account the polarization and spatial spreading). In the case of airborne placement, the electromagnetic field (EMF) of an antenna depends on the configuration of the object. In addition, coupling is provided along spatial and geodesic lines on the object surface. The problem of EMC includes many aspects, from which it is possible to single out the following: the problem of sources of unintended interference, primarily those of radio transmitting devices; reasons and mechanisms giving rise to the interference; ways to control them and to mitigate the interference; the problem of unintended interference receptors, and those of radio receiver devices; mechanism of the interference passage through the receiver; ways to measure interference and reduce it, and methods of EMC calculation and evaluation.

Among the existing methods of providing EMC of radio electronic systems, we can single out technical and organizational methods. Technical methods in their turn can be subdivided into infra-apparatus and extra-apparatus methods. Intra-apparatus methods include the use of frequency selective spatial filters and those methods of EMC provision which are based on reducing interference by means of improved antenna system parameters. At the initial stage of radio engineering development, EMC was provided in one of two ways: frequency distribution or schematic and structural improvements of separate units by each radio engineering systems developer. However, the technical possibilities of both of these methods are practically exhausted. That is why a new direction has appeared in radio electronics which focuses on design, development and exploitation of radio engineering systems subject to the conditions of the existing limitations.

II.2. Methods of reduction of antenna coupling

Investigations into solving EMC problems, conducted at present in many countries of the world, include the development of enhanced interference-protected radio electronic systems, as well as the issues of optimum design from the viewpoint of reduction of the generated interference. Significant attention in these investigations is paid to antennas, because 12 out of almost 30 basic parameters which influence EMC in radio electronic equipment are defined by the antenna system [4]. Spatial and frequency discrimination of interference accomplished by antenna systems allows for significant improvement of EMC. In the process of development and design of new antennas, primary attention is paid not only to their internal parameters, such as amplification, conformity, bandwidth, etc., but also to EMC problems between the antennas [5, 6].

In most cases, when solving the question of EMC of radio engineering complexes, we are working with ready-made radio electronic complexes and antenna systems. Therefore, methods related to the growth of noise immunity of antennas have a great practical application, since the main features of the antennas' construction cannot be changed [4]. If we have the possibility of choosing the point of location of the receiving antennas, then in order to provide decoupling between the receiving and transmitting antennas located in proximity to each other on the same plane, we can use the following methods:

[1] Choice of the point of antennas location

(A) Two transmitting antennas with a phase shift between their currents, along with a receiving antenna [7]. The disadvantages of such a system are complexity of actual construction, immense size and small bandwidth.

(B) The receiving antenna is located in the space where the currents of the transmitting antennas are minimal and are directed in such a way that they do not stimulate the receiving antenna [7]. However, this method also has some disadvantages. In particular, it requires a specific mutual orientation of the antennas, which limits the range of the antennas` spatial directivity diagrams and their polarization characteristics.

[2] Utilization of metallic screen

In this case, metallic longitudinal and transverse diffraction screens which significantly rise above the plane of the antennas are placed between the transmitting and the receiving antennas [7]. From the data of reference [8], with the use of a screen of height λ it is possible to obtain weakening of about 20 dB in the frequency band with an overlapping of 1.5:1. In Ref. [9], the authors propose weakening the electromagnetic coupling between antennas by the use of longitudinal conducting plates placed between the antennas along the line of communication in E-plane. The possibility of weakening the lateral radiation of the aperture antennas in this case is connected with the wave's interference from the edges of the antenna and the borders of the plates. Varying the amplitude-phase correlations, we can obtain in some directions a decrease of radiation of 10~15 dB. The possibility of reducing the mutual coupling of antennas located on the edge of a semi-plane conductor with the help of longitudinal (in the case when the vector E is parallel to the semi-plane) and transverse (the vector H is parallel to the semi-plane) diffraction screens is shown by Yumashev [10]. There are other papers in which the question of reducing coupling between antennas by the use of diffraction screens is considered [8, 11].

[3] Utilization of a radio-frequency absorbing layer and corrugated structures

For this case, on a metallic plane between the antennas there is a radio-frequency absorbing layer (for example, graphite) with a constant thickness, or a corrugated structure [12]. Using an absorbing layer, the field weakening can be calculated by the formula of Shuleikin-Van-der-Paul. According to this formula, if distances are small, the weakening is proportional to the distance; for larger distances, the weakening is proportional to the distance squared. As experiments show, when measuring decoupling between two slot antennas, the best weakening is obtained when the distance between antennas is equal to λ, which gives 30~35 dB of decoupling. This corresponds to additional decoupling in comparison with the case of a metallic plane, which gives 10~15 dB. A disadvantage of radio-frequency absorptive coverings is their large size, which reduces the aerodynamic properties of an object, because it is required that it cover all of the object or its significant parts. Another disadvantage of coverings is the dependence of the reflection coefficient on the frequency and on the incident angle of the electromagnetic waves.

III. Principles of Ensuring Antenna Decoupling Using Corrugated Periodic Structures

The easiest way to study the operation of decoupling devices based on a corrugated structure is by using the impedance approach. For this purpose, the notion of a transverse surface impedance Z is introduced. Z Equals the ratio of mutually perpendicular electric and the magnetic field components which are tangential to the surface:

$$\vec{\mathbf{n}} \times \vec{\mathbf{E}} = -\mathbf{Z}\vec{\mathbf{n}} \times (\vec{\mathbf{n}} \times \vec{\mathbf{H}}), \qquad (2)$$

where $\vec{\mathbf{n}}$ is the unit normal, Z is the surface impedance, $\vec{\mathbf{E}}$ is the $\mathrm{E}-$field, and $\vec{\mathbf{H}}$ is the $\mathrm{H}-$field.
For this case a wave can exist which, for a flat surface with a constant impedance distribution, has the following form [3]:

$$A\exp[-\alpha y - i\gamma z],$$

where z and y are the longitudinal and transverse Cartesian coordinates on the impedance plane, respectively. $\frac{\gamma}{k} = \sqrt{1-(Z/Z_0)^2}$, $\frac{\alpha}{k} = -i\frac{Z}{Z_0}$, ($k = 2\pi/\lambda$ is the wave number, λ is the wavelength), i is the imaginary operator and $Z_0 = \sqrt{\mu_0/\varepsilon_0}$ is the impedance of free space. Here, γ and α are decay constants.

If Z has an inductive imaginary part, with losses in the underlying surface, the amplitude of the field will proportionally diminish with y, as well as along the z direction. If the impedance has a purely reactive (capacitive) character, the amplitude of the field will increase with the distance along the normal to the y direction, i.e., the wave, remaining slow, will be a pseudo-surface wave. The increase in decoupling of near-surface antennas by this process will be accompanied by a decrease in the level of the communication signal. For the inductive case, the signal diminishes by means of ohmic losses, and in the capacitive case, by the reduction of the near-surface field. Real decoupling between the antennas is defined not only by the decoupling structure, but also by the influence of the whole field excited by the transmitting antenna, and this field will contain surface, pseudo-surface, and spatial waves [3].

The main methods of research on periodic structures can be subdivided into two categories: the first category seeks to solve the problem of flat wave scattering by a periodic structure. The results allow the definition of an equivalent impedance, $Z(0)$, of the periodic structure. This impedance conforms with normal incidence of the plane wave on an infinite flat structure and is equal to:

$$Z(0) = Z_0(1-R(0))/(1+R(0)), \qquad (3)$$

where $R(0)$ is the coefficient of reflection for normal incidence. The essense of the impedance method is that for arbitrary angles of incidence, $Z = Z(0)$ is assumed, and the periodicity of the structure is not taken into account. This supposition is certainly true only for periodic structures with high frequency for which the following condition is fulfilled: $0.05 < b/\lambda < 0.3$ (where b is the length of the corrugation). Conclusions obtained on the basis of the impedance approach are limited, since the method and the concept of impedance depend on initial values, which are approximate. As for the second category, more exact results can be obtained only with the use of strict electrodynamic methods, such as the method of integral equations through the results of numerical research.

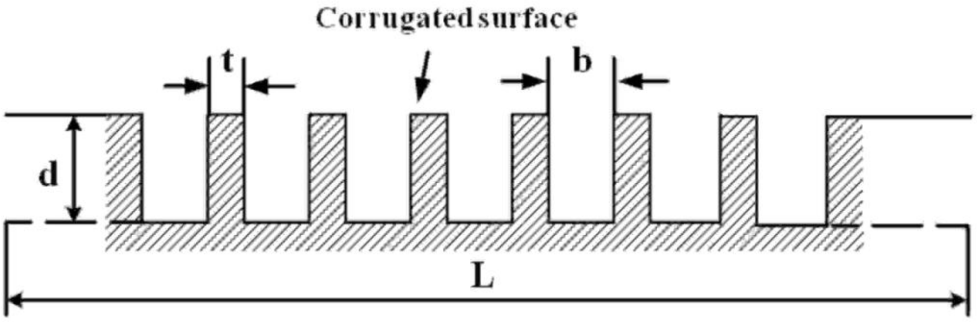

Figure 1. The corrugated metal surface with constant depths of corrugation, where L is the length, d is the depth of the corrugation, b is the width of the corrugation, and t is the thickness of the edges between them

The most common type of periodic structure is a metallic structure with a rectangular cut of corrugations. For example, in Figure 1 we present a sample of a corrugated metal surface usually used to solve the problem of coupling between antennas. The corrugated metal surface shown in Figure 1 is a metal slab into which a series of vertical slots have been cut. The slots are narrow, so that many of them fit within one wavelength across the slab. Each slot can be regarded as a parallel plate transmission line, running down into the slab and shorted at the bottom. If the slots are one quarter-wavelength deep, then the short circuit is at the top end. Thus, the impedance at the top end is very high. In this situation, the surface impedance is capacitive and transverse magnetic (TM) surface waves are forbidden. Furthermore, a plane wave polarized with the electric field perpendicular to the ridges will appear to be reflected with no phase reversal [13]. In fact, such a class of corrugated metal surfaces has been rigorously analyzed and published in numerous papers since the mid-20th century [14]. For instance, the propagation of surface waves along a uniform planar corrugated structure, under TM mode operation, was investigated in the 1950s by Rotman [15], Elliott [16], Hurd [17] and Vainshtein [18]. Additionally, we can also use other corrugation shapes which have been investigated, as shown in Figures 2-6, to solve the problem of reducing coupling between antennas located on different surfaces (see Figures 7 and 8).

Figure 2. Cavity-loaded corrugations Such corrugations have been applied in horn-antenna design, but they are very expensive to machine. The relative bandwidth is about 2.4 [39].

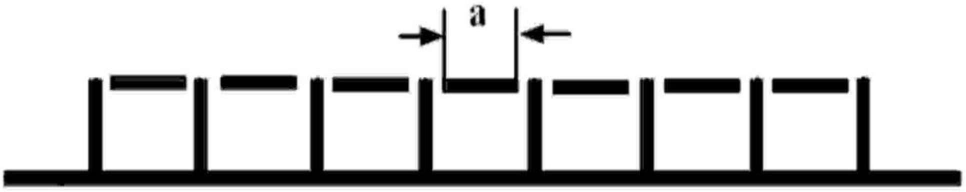

Figure 3. Strip-loaded corrugations This loading is inexpensive to fabricate and is equivalent to the cavity loading even though there is no metal contact between the strips and the corrugations. The relative bandwidth is about 2.1 [39]. a is the strip width.

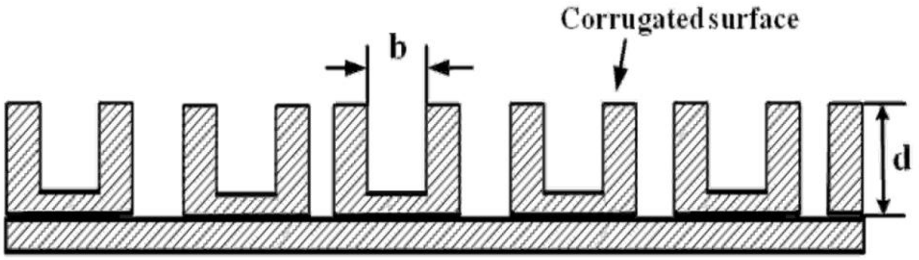

Figure 4. The dual-depth corrugations are used to realize dual-band application. The analysis shows that the soft surface occurs in two narrow bands. In between the two bands there are always surface waves occurring. Also, the two bands must be widely separated; otherwise the performance in the lower band is destroyed by surfaces waves in the shallower corrugations designed for the upper band [39].

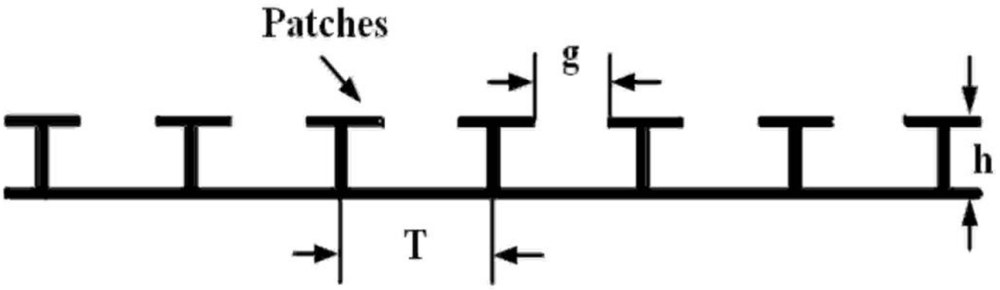

Figure 5. The cross section of a high impedance surface, fabricated as a printed circuit board. The geometrical parameters of the structure are: h the height, **g** the gap between the patches, **T** the periodicity of the high impedance surface. The periodic structure is composed of infinitely many identical cavities, each with an opening to the air half-space. Each cavity may be viewed as a parallel-plate waveguide that is completely short-circuited at one end and partially short-circuited at the other end. Such a structure had been modeled as an impedance surface to explain Wood's anomaly in the scattering of light [14].

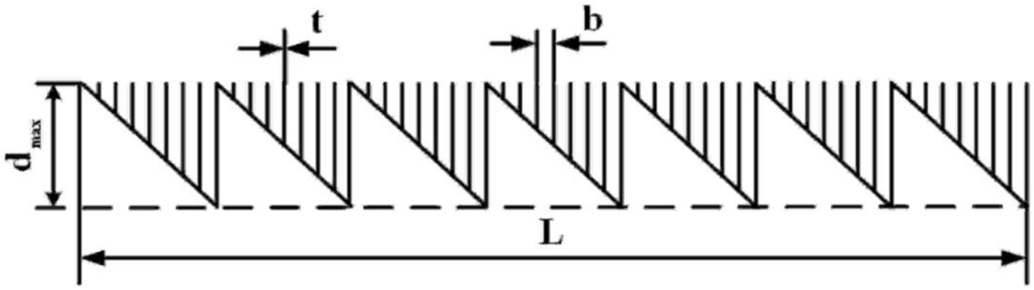

Figure 6. The corrugated metal surface with variable depths of corrugation, where L is the length, $d_{\max}$ is the depth of the corrugation, b is the width of the corrugations and t is the width of the thickness of the edges between them.

It seems that the efficiency of a decoupling structure is 10~15 dB higher when it is located in direct proximity to a source or radiating receiver, as compared with the case when the structure is placed midway between the antennas. This is explained by the fact that the "take-off" and "landing" grounds near the antennas produce a greater influence on the propagation across a plane surface [19]. Often, in quality airborne antenna systems, we use antennas located directly on a surface of complex shape as shown in Figures 7 and 8. Such antennas allow the realization of a considerably wider directional spectrum, in comparison with plane aperture antennas. When a corrugated structure is located on a convex surface, the absolute value of the increase in decoupling with a fixed antenna location is weaker in comparison with the planar case because of shading due to the convex surface. The presence of the corrugated structure therefore has a smaller impact on the form of the directional diagram of the antennas.

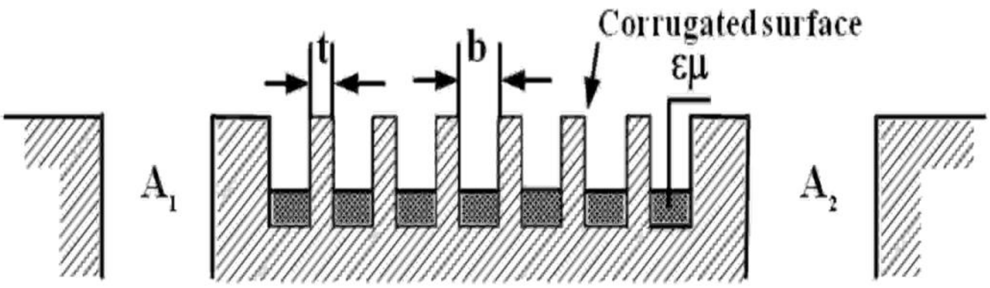

Figure 7. A corrugated metal surface (with a dielectric material of relative permittivity ε and a relative permeability μ) located on the plane with the view of defining the degree of decoupling of the two microwave antennas (transmitting (A_1) and receiving (A_2)).

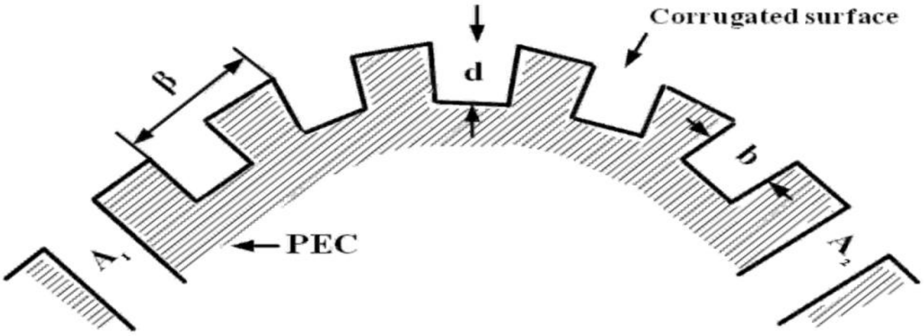

Figure 8. A corrugated metal surface located on a circular cylinder for defining the degree of decoupling between two microwave antennas (transmitting (A_1) and receiving (A_2)). β Is the period.

The broadband properties of the structure can be increased by using trapeze-shaped corrugations and by adding subsidiary resonant elements, for example, a layer of magneto-dielectric. If the equivalent depth of the corrugations is increased, the structure with filled corrugations is excited less effectively, and the dependence of the value of decoupling on geometrical parameters becomes more gradual. With the help of decoupling corrugated structures, it is possible to obtain decoupling of nearly 30 dB in 20% of the frequency band when the length of the structure is on the order of λ. Increasing the bandwidth property of decoupling features can be obtained by the combined use of decoupling structures based on reflection from separate heterostructures by means of radiation losses [11].

The engineering solutions for reducing interference and EMC problems are of increasing importance, particularly for airborne systems located onboard ships, aircraft and satellites. One of the simplest, but most effective ways to reduce the radiating interference is to introduce an electromagnetic bandgap (EBG) by means of periodic structures [7, 12−28, 30−37], such as a corrugated metal surface between the two coupled systems. The EBG materials are periodic structures that exhibit wide band pass and band rejection properties at microwave frequencies [13]. Due to their unique properties, EBG materials find potential applications in antennas, waveguides, amplifiers, filters, power combining, phased arrays, EMC measurements and in many microwave devices. The EBG property emerges by virtue of periodic reactive loading of the guiding structure. Adopting a circuit model, loads can generally be inductive (L), capacitive (C) or resonant (both L and C) [20].

A corrugated structure solution of the EMC problem was first investigated by Tereshin and Chaplin [7]. The application of periodic structures causes the suppression of surface waves. It is well known that a corrugated surface supports surface waves when the depth of the corrugations, *d*, provides an inductive surface impedance, i.e., when $0 < d/\lambda < 1/4$. When the depth of the corrugations is greater than one quarter wavelength, i.e., $1/4 < d/\lambda < 1/2$, the surface wave vanishes, and the surface impedance becomes infinite and provides the soft boundary condition for the field. Consequently, the performance of active and passive microwave components and devices is enhanced. Using a corrugated structure with an inductive impedance of a constant length for the purpose of decoupling, it is impossible to obtain large decoupling, because the surface waves are spread across the impedance surface. However, if a corrugated structure with a capacitive impedance is used, the far-field weakens inversely to the 3/2 power of the distance. The corrugated surfaces have also been classified and named as soft and hard surfaces [21], and different applications have been found, e.g., to control the radiation, scattering, and propagation characteristics of the waves [22−25], to reduce coupling through slots [26], and to improve the performance of element antennas on ground planes [27]. The soft surfaces have been used in corrugated horns to improve their radiation characteristics [28]. The soft and hard surfaces have also been realized by loading a dielectric coating with metal strips [29]. The concept of suppressing surface waves on metals is not new. It has been done before using several geometries, such as a corrugated metal slab [30]. It is well known that the excitation of surface waves may degrade the performance of microwave or millimeter wave circuits and antennas, due to the mutual coupling between antenna elements, resulting in the alteration of the radiation pattern and the reduction of radiation efficiency of antennas. Several methods have been developed for surface-wave suppression, such as the concept of artificial soft and hard surfaces, which has been introduced to generally characterize the interaction between the load surface and surface waves. In particular, various soft surfaces were proposed by Kidal to suppress the lateral lobe in monopole antennas [21, 22, 39].

Recently, a planar periodic structure fabricated by printed-circuit technology had been developed for application as a high impedance surface that suppresses surface waves with a complete stopband [14]. In Ref [8, 12, 31, 32], authors considered two-dimensional problems relating to coupling between waveguide antenna grates with corrugated impedance structures located between them. The results of these studies showed that the value of decoupling generally depends on the electrical and geometrical parameters of the periodic structures. The geometrical sizes of the corrugated surface can be chosen through analysis of infinite periodic structures. However, to solve the problem of the optimum placement of the decoupling devices using such an approach is impossible, since the change in the coupling value is noticeably influenced by surface properties of areas located near the antennas. It has been shown that the weakening of coupling between antennas over a wide band of frequencies can be obtained to a greater extent on convex surfaces than on flat ones [32]. In Ref [8], authors considered obtaining decoupling between antennas located above a corrugated plane with purely reactive surface impedance. It has been shown that the degree of decoupling which can be obtained with the use of a decoupling surface is defined by the practical maximum rate of change of the surface impedance, and by the length of the decoupling structure, i.e., the difference between the impedance at the beginning and at the end of the structure.

Different variations of decoupling structures, namely metal and strip have been examined; as a rule, they are located on the communication line as a plane (a geodesic line) or as a ring covering the reception and transmitting antennas [32]. The main calculation methods used for the study of periodic structures properties (the impedance method and the method of integral equations) are listed. It has been shown that the decoupling properties of the structure are defined only by the structure's length and in fact do not depend on the period of the structure. Moreover, the most effective means of obtaining the required spatial decoupling of antennas, which should be taken into account in their design, is the correct choice of the mutual placement and orientation of the antennas. Besides this, a structure considerably influences the directivity diagram of an antenna which it is located close to (being more dependent on the depth of corrugation in corrugated structures). It has been also noted that the presence of losses in the structure makes the decoupling properties worse. It is shown that application of rapid alternating impedance in a decoupling structure allows a greater decrease of the field with distance [3]. Decoupling cannot be increased without limit by making the decoupling structure bigger or by placing the antennas farther apart. The main reason is because of the fact that on the edges of a finite structure, diffraction effects appear and the field is scattered. Analogous effects are also caused by inaccuracy in the production of the structure. This has a noticeable influence during the use of resonance elements in the structure. It has been shown that to reach the required levels of decoupling between antennas, it is necessary to use structures with a complicated reactive impedance corrugation on the flange of the antennas [36, 37]. For this purpose, it is necessary to set up and solve the problem of synthesis of such structures. Lastly, independent of the conditions of the antenna placement, an increase in decoupling over 130~140 dB is limited as a consequence of the scattering of the radiation field on inhomogeneous elements in the atmosphere.

One of the most important characteristics of a periodic structure is the bandwidth of frequencies over which it can be used. In particular, the frequency band can be limited by the maximum required decoupling which is determined by fixed size of the structure. This limitation is typical for low frequencies. For example, for corrugated structures with period b and rectangular corrugations with width a and depth d, the impedance Z is [3]:

$$Z/Z_0 = i(a/b)tg(k_g d), \tag{4}$$

where $k_g = k\sqrt{\varepsilon\mu/(\varepsilon_0\mu_0)}$ is the propagation coefficient in the corrugations, taking into account their dielectric filling; the impedance is capacitive when $1/4 < d/\lambda < 1/2$. $Z_0 = \sqrt{\mu_0/\varepsilon_0}$, ε and μ are the parameters of the filling of the corrugations. Such structures in principle can be used only in the band of frequencies with an overlap less than 2:1.

There are on the whole, approximate rather than precise methods of investigation of periodic corrugated structures. In general, decoupling structures are placed on the communication line or in the form of a ring enveloping the receiving and transmitting antennas. Specifically, however, there is a selected direction, along which the properties of the decoupling structures are determined. Therefore, it is appropriate to set corresponding boundary problems for cylindrical structures, the form of which are perpendicular to the selected direction. Since in practice the widths of decoupling structures are comparable to the wavelength, the results of optimization calculations of geometrical parameters of the structure (providing maximum decoupling or broadband response of the system) amount to the same thing as for real three dimensional structures.

During the development of the periodic structure, it should be taken into account that radio electronic systems, such as components of radio engineering complexes, function as a rule in different frequencies ranges, i.e., the operating frequency of the transmitter often does not belong to the range of operating frequencies of the antenna of the receiver. For this reason, during EMC analysis one must consider the defining characteristics of the antenna radiation not only over the operating frequency range, but also over its harmonic components. Hence, the level of harmonics in terminal amplifying cascades is not more than -10 ~ -20 dB, but characteristics of antennas at their harmonic frequencies can sufficiently differ from characteristics at their operating frequency. In addition, the level of backscattering can be significant from the viewpoint of EMC. Moreover, for the analysis of antennas, EMC characteristics are required to create the models which adequately describe the operation of the antenna at the main frequency, as well as over the harmonics, which is only possible with the use of strict electrodynamic methods.

IV. Influence of Polarization Characteristics On The Reduction Of Coupling Between Antennas

The level of cross-polarization radiation of an antenna well describes its noise immunity. In a working frequency band, the polarization of radiated antenna fields corresponds to the calculated direction (for example: vertical, horizontal, and circular). In the limit of the main lobe at a level of 3 dB, the cross-polarization component, as a rule, does not exceed -25 ~ -40 dB. For a level of -10 dB, it increases to -25 ~ -15 dB. For an axially symmetric antenna, the lowest values of the cross-polarization components are orientated in the directions of the primary planes of □ and □. Concurrently, in diagonal planes situated at 45^o with respect to the planes of □ and □, a sharp growth of those components are registered. In the lateral and back lobe regions, values of cross components can exceed the level of the main polarization, but averaging the components shows that the main component always prevails with the level around 10 dB [38]. For deep mirror antennas, part of the cross-polarization field increases in the back half-space, and it can exceed 20% of the main polarization.

Improvement of polarization characteristics and growth of the polarization frequency can be obtained with appropriate construction of the antenna itself. Examples of this type are circular horn antennas and feeds with corrugated or smooth walls, but using a dielectric hub. In mirror antennas working in the band 3.4 ~ 7 GHz, with the help of corrugated horn feeds, we can decrease the relative maximum level of cross-polarization components more than 30 dB [38]. To decrease the cross-polarization components, wire netting can be used, covering all of the radiation area or its parts. The conductors of such a netting must be oriented perpendicularly to the main polarization. This allows a decrease in the level of these cross components by 10~13 dB. A technical solution of this sort is applied on the re-transmitter of satellite communication systems, where repeating the use of the working frequency band causes decoupling between the orthogonal polarized components to reach 32 dB in the range of 4~6 GHz. The use of polarization decoupling to solve the problems of EMC is effective only when the antenna is coupled to the main and nearby side lobes; in the distant lobes, it is difficult to manage the polarization.

V. Influence of Aberration of Mirror Antennas on EMC Parameters

When the directivity of the antennas is higher (in the centimeter and decimeter wave range), the violation of EMC conditions can be affected by the presence of different types of aberration. Such violations can arise, for example, in satellite communication systems. In quality, the methods of correcting aberrations include different electronics, mechanical methods, construction, or other measures and methods. For instance, with lattice antennas, such adjustments can be realized with the help of the location or energizing of particular antennas elements. The aberration of mirror antennas can be eliminated with the help of the choice of the necessary forms of the feeds and mirrors themselves. In particular, to accomplish this, the so-called “reactive mirror” can be used to constitute segments of the waveguide, one of the ends of which is shunted. Characteristically, for such artificial reflecting surfaces which satisfy the condition of sinusoidal aberration, the angle of reflection doesn’t equal the angle of incidence. Such a reactive reflector provides inadequate adjustment from the viewpoint of EMC aberration.

VI. Conclusion

We conclude that conducting further research on the design of decoupling structures based on the synthesis of impedance boundary conditions is necessary. In this connection, it is natural to increase the efficiency of existing methods and to develop new ways of reducing coupling of antennas. Beyond this, the prospects of further research are expressed in the following points:

- Development of electrodynamic and mathematical models describing the process of electromagnetic wave distribution in radiating and distributing devices (those found in practice and in prospective ones), and evaluation of the possibility of their experimental realization
- Research and development of anisotropic periodic structures
- Research and development of new EBG periodic structural materials, such as nanomaterials, taking into consideration the fundamental limits of antennas.

Reference

[1] K. G. Klimachev, Fundamentals of Forecasting and Provision of Electromagnetic Compatibility of Radio Engineering Systems and Devices, Moscow: Moscow Aviation Institute, 1994.
[2] D. I. Voskresenskiy, Problems of Antennas Theory and Engineering, Antennas, vol. 1, No. 40, 1998.
[3] L. D. Bakhrakh and E. G. Zelkin, Reference Book on Antenna Engineering, vol.1, Moscow: 1997.
[4] V. G. Yampolskiy and O. P. Frolov, Antennas and Electromagnetic Compatibility, Moscow: Radio and Communication Press, 1983.
[5] V. G. Yampolskiy and O. P. Frolov, Optimization of Antenna Systems on Connection Lines, Moscow: Radio and Communication Press, 1999.
[6] L. D. Bakhrakh, Modern Issues of Antenna Engineering, Moscow: Radio and Communication Press, 1989.
[7] O. N. Tereshin, V. M. Sedov, and A. F. Chaplin, Synthesis of Antennas on Decelerating Structures, Moscow: Communication Press, 1980.
[8] A. G. Kurkchan, “Coupling between Antennas in the presence of Corrugated Structures,” Radiotechnics and Electronics, vol. 22, No. 7, pp. 1362–1373, 1977.
[9] Yu. L. Lomukhin, S. D. Badmayev, and N. B. Chimindorzhiev, “Decoupling of Antennas by the edge of conducting semi-plane”, Radiotechnics, No. 8, pp. 47–50, 1985.
[10] M. M. Yumashev, “Decoupling of the Receiving and Transmitting Waveguide-and-Slot Antenna Grates”, Collection of Scientific Works, Moscow: Moscow Energetic Institute, No. 159, pp. 81–86, 1998.
[11] U. L. Lomukhin and N. B. Chimitdorzhiev, “Increase of Decoupling of Antennas Located on a Convex Object”, Radiotechnics and Electronics, vol. 24, No. 10, pp. 1989–1995, 1979.
[12] O. N. Tereshin, “Decoupling of Two Aperture Antennas by Using a Corrugated Structure Located in the Plane of the Apertures,” Radiotechnics and Electronics, No. 12, vol. 5, pp. 1944–1950, I960.
[13] N. C. Karmakar and M. N. Mollah, “Potential Applications of PBG Engineered Structures in Microwave Engineering: Part I,” Microwave Journal, vol. 47, No. 7, pp. 22–44, 2004.
[14] R. B. Hwang, and S. T. Peng, “Surface-Wave Suppression of Resonance-Type Periodic Structures,” IEEE Transactions on Antennas and Propagation, vol. 51, No. 6, pp. 1221–1229, June 2003.

[15] A. Harvey, "Periodic and Guiding Structures at Microwave Frequencies," IRE Transactions on Microwave Theory and Techniques, vol. 8, pp. 30–61, June 1959.
[16] W. Rotman, "A Study of Single-Surface Corrugated Guides," Proc. IRE, vol. 39, pp. 952–959, Aug. 1951.
[17] R. Elliot, "On the Theory of Corrugated Plane Surfaces," IRE Trans. Antennas Propagation, vol. 2, pp. 71-81, Apr. 1954.
[18] R. A. Hurd, "The propagation of an electromagnetic wave along an infinite corrugated surface," Can. J. Phys., vol. 32, pp. 727–734, 1954.
[19] A. G. Kurkchan, and M. Kh. Zimnov, "Coupling between Antennas on a Cylinder in the Presence of Corrugated Structures," Radiotechnics and Electronics, vol. 12, No. 9, pp. 2308–2316, 1985
[20] G. Goussetis, A. P. Feresidis, and P. Kosmas, "Efficient Analysis, Design, and Filter Applications of EBG Waveguide with Periodic Resonant Loads," IEEE Transactions on Microwave Theory and Techniques, vol. 54, No. 11, pp. 3885–3892, November 2006.
[21] P. S. Kildal, "Artificially Soft and Hard Surfaces in Electromagnetics," IEEE Transactions on Antennas and Propagation, vol. 38, No. 10, pp. 1537–1544, October 1990.
[22] P. S. Kildal, A. A. Kishk, and A. Tengs, "Reduction of Forward Scattering from Cylindrical Objects Using Hard Surfaces," IEEE Transactions on Antennas and Propagation, vol. 44, No. 11, pp. 1509–1520, November 1996.
[23] R. E. Lawrie, "The Control of Echo Area of Ogives by Cutoff Corrugated Surfaces," IEEE Transactions on Antennas and Propagation, vol. 17, No. 3, 1966.
[24] I. Short and K. M. Chen, "Backscattering from an Impedance Loaded Slotted Cylinder," IEEE Transactions on Antennas and Propagation, vol. 14, No. 6, 1969.
[25] D. D. Gabrieliyan, M. Yu Zvezdina, and P. I. Kostenko, "Reduction of side and back radiation antenna level based on the use of impedance structures," Radio electronics, vol. 46, pp. 38–43, 2003.
[26] J. Carlsson and P. S. Kildal, "Transmission through Corrugated Slots," IEEE Transactions on Electromagnetic Compatibility, vol. 37, pp. 114–121, Feb. 1995.
[27] Z. Ying and P. S. Kildal, "Improvements of dipole, helix, spiral, Microstrip patch and aperture antennas with ground planes by using corrugated soft surfaces," IEE Proc. Microwaves, Antennas, Propagation, vol. 143, No. 3, pp. 244–248, June 1996.
[28] A. D. Olivier, P. J. B. Clarriocoats, A. A. Kishk, and L. Shafai, Microwave Horns and Feeds, New-York: IEEE Press, 1994.
[29] A. A. Kishk and P. S. Kildal, "Asymptotic boundary conditions for strip-loaded scatterers applied to circular dielectric cylinders under oblique incidence," IEEE Transactions on Antennas and Propagation, vol. 45, No. 10, pp. 551–557, January 1997.
[30] D. Sievenpiper, L. Zhang, R. F. J. Broas, N. G. Alexopolous, and E. Yablonovitch, "High-Impedance Electromagnetic Surfaces with a Forbidden Frequency Band," IEEE Transactions on Microwave Theory and Techniques, vol. 47, No. 11, pp. 2059–2074, November 1999.
[31] A. G. Kurkchan and M. Kh. Zimnov, "Coupling between Antennas on a Cylinder in the Presence of Corrugated Structures," Radiotechnics and Electronics, vol. 12, No. 9, pp. 2308–2316, 1985
[32] S. Benenson and A. I. Kurkchan, "Decoupling of Antennas by Means of Periodic Structures," Radiotechnics and Electronics, vol. 12, pp. 77–89, 1995
[33] G. I. Markov and D. M. Sazonov, Antennas, Moscow: Publishing House ENERGY, 1975.
[34] A. Freni, C. Mias, and R. L. Ferrari, "Hybrid Finite-Element Analysis of Electromagnetic Plane Wave Scattering from Axially Periodic Cylindrical Structures," IEEE Transactions on Antennas and Propagation, vol. 46, No. 12, pp. 1859–1866, December 1998
[35] V. V. Martsafey and I. G. Shvayko, "Influence of Corrugated Structures on Interaction of Near-Omnidirectional Antennas," Transactions of Higher Education Institutions, Series Radio Electronics, vol. 24, No. 5, pp. 18–22, 1981.
[36] Y. S. Joe, J-F. D. Essiben, and E. M. Cooney, "Radiation characteristics of waveguide antennas located on the same impedance plane", Journal of Physics D.: Applied Physics, vol. 41, No. 12, May 2008.
[37] J-F. D. Essiben, E. R. Hedin, and Y. S. Joe, "Radiation Characteristics of Antennas on the Reactive Impedance Surface of a Circular Cylinder Providing Reduced Coupling," Journal of Electromagnetic Analysis and Applications, vol. 2, No. 4, pp.195-204, April 2010.
[38] Yu. A. Kravsov, Z. I. Feizoulin, and A. G. Vinogradov, Passage of Radio Waves across Atmosphere Earth, Moscow: Radio and Communication, 1983.
[39] Z. Ying, P. S. Kildal, and A. A. Kishk, "Study of Different Realizations and Calculation Models for Soft Surfaces by Using a Vertical Monopole on a Soft Disk as a Test Bed," IEEE Transactions on Antennas and Propagation, vol. 44, No. 11, pp. 1474–1481, 1996.