Surface-Wave Suppression Using Periodic Structures

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ABSTRACT

The objective of this paper is to design impedance surfaces for the solution of the problem of electromagnetic compatibility of antennas. In a recent paper, corresponding surfaces were used to reduce coupling between antennas located on a plane. These surfaces were made artificially, e.g., by loading a conducting surface with corrugations. The design of the impedance structure is done for a given electromagnetic field distribution. The behavior of the electromagnetic field along the impedance structure and in the openings of the antennas is studied for various designs of impedance surfaces. The method of integral equations is used for the solution of this problem, and numerical results are presented and analyzed.

Keywords - Electromagnetic compatibility, coupling, surface-wave, impedance surface

I. INTRODUCTION

Contemporary models of mobile technology have facilities consisting of one to a hundred antennas, depending on their specific function. Practice shows that airborne antenna facilities have strong sources of high effective scattering area over a wide sector of angles and frequency bands. In this way, the largest effective scattering area occurs for antennas with large apertures, and also for multiple-unit plane phase antennas with a grating or lattice. Apart from this, antenna facilities considerably influence the electromagnetic compatibility of radio systems due to lateral back-scattering radiation and other properties.

It is well-known that for airborne antennas, one of the major problems is the presence of the surface waves. As is known, the excitation of surface waves may degrade the performance of microwave circuits and antennas, by affecting the mutual coupling between antenna elements, resulting in an alteration of the radiation pattern and a reduction of the radiation efficiency of the antennas. Several methods had been developed in the literature 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 Kildal to suppress the lateral lobe in monopole antennas [1].

To solve the problem of reduction of radar perceptibility and questions of electromagnetic compatibility, it is necessary to use high-performance methods of analysis and synthesis of the scattering characteristics of antenna facilities. One of the most common ways of reducing coupling between antennas is the use of periodic structures [1-4]. The capability of periodic structures to provide the required electrodynamic properties of a surface of practically any form [5], allows their use as the basis for development of conformal antenna devices and reflectors with specific characteristics of radiation and scattering. The easiest method of studying the operation of decoupling devices on the basis of periodic structures is by means of the impedance approach. Presently, a great number of works are devoted to the research and development of such structures (see, for example, Refs. [2, 6-8]).

The main purpose of this paper is to introduce different designs of impedance surfaces in order to reduce the coupling between antennas located on the plane. In particular, we investigate the behavior of the complete field along the impedance surface and in the openings of the antennas. We calculate some key parameters of the antennas, such as the coefficient of standing waves and the decoupling level between antennas.

The paper is organized as follows: in Section II, we develop a solution to the problem of coupling of antennas on an impedance plane. Numerical results are analyzed in Section III. Finally, Section IV is devoted to conclusions.

II. ANALYTICAL FORMULATION

A solution to the problem of analysis of the electromagnetic field of two waveguide antennas located on the same impedance plane was obtained in Ref. [4]. It is also studied for the problem of synthesis of impedance structures [2], which provides the required attenuation of the field along the impedance structure, with the purpose of thereby creating decoupling structures. However, in the solution to the problem of synthesis, the interaction between the antennas was not taken into account. It is expected that the presence of a receiving aperture antenna will also lead to undesirable reduction in the antenna decoupling by means of an inhomogeneity created by the aperture of the receiving antenna.

This section considers the problem of coupling between two waveguide antennas located on the same impedance plane, as shown in Figure 1. The problem can be broken into three regions. Region one is defined as the upper half-space containing the incident plane wave and bounded by the conducting plane and the opening of the aperture antennas. The two others regions consist of the internal surfaces of the waveguides. These waveguides are aperture antennas with opening sizes of a and b, located on the $y=0$ plane with a separation L from each other. On the $y=0$ plane, the vector boundary conditions of Shukin–Leontovich are fulfilled:

$$\vec{n}\times\vec{E} = -Z\vec{n}\times(\vec{n}\times\vec{H}), \tag{1}$$

where $\vec{n} = -\vec{i}_y$ is the unit normal to the $y=0$ plane, Z is the surface impedance, $\vec{E}$ is the $E-$field, and $\vec{H}$ is the $\mathrm{H}-$field.

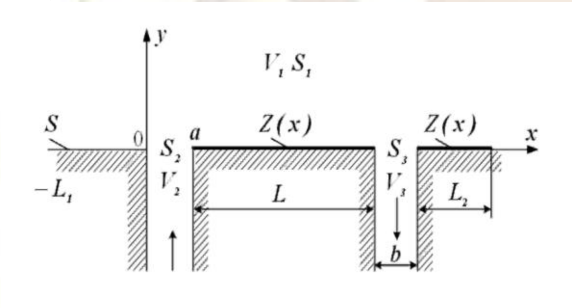

Figure 1. Geometry of the problem. The problem is divided into three regions : V_1, V_2 and V_3. Region one is defined as the upper half-space and the other two regions consist of the internal surfaces of the waveguide aperture antennas with opening sizes of a and b, located on the $y=0$ plane at a separation L from each other.

For the solution to the coupling problem, we use the Lorentz lemma in the integral form as in Ref. [4], for each of the three areas: V_1, V_2 and V_3, respectively. Taking into account the boundary condition on the surface of the impedance flanges, and the equality of the tangential field components in the opening of the waveguides, the solution will consist of solving a system of integral equations relative to the unknown tangential component of the electric field on the surface ($x\in[-L_1, a+L+b+L_2]$ and $y=0$).

III. RESULTS AND DISCUSSION

This section considers the problem of reducing the coupling by using the impedance surfaces designed in Ref. [2], while also considering the receiving antenna. Figure 2 ($\mathrm{Re}(Z)$, solid line and $\mathrm{Im}(Z)$, dashed line) presents the variation of the designed impedance along the plane for a coefficient of attenuation $\alpha=0.5k$. It is seen that the impedance monotonically increases between the two antennas and then decreases just to the left of the receiving antenna. Zero impedance corresponds with the placement of the transmitting and receiving antennas. In Figure 3, we present the behavior of the complete magnetic field, normalized to the decaying field in the opening of transmitting antenna on the $y=0$ plane, for the synthesized impedance with $Z=0$ (dashed line) and $\alpha=0.5k$ (solid line). As we can see, the field in the aperture of the receiving antenna (centered on $x/\lambda=1.5$) significantly surpasses the level of the complete field outside the aperture (compare also to Figure 4(a) in Ref. [2]). The parameters for the system are: $a=b=0.34\lambda$ and $L=\lambda$.

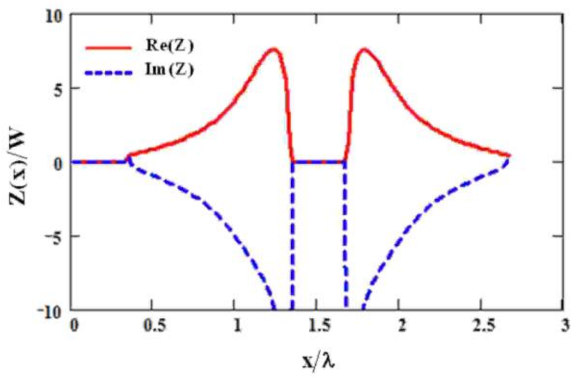

Figure 2. Impedance variation: $\mathrm{Re}(Z)$ (solid line) and $\mathrm{Im}(Z)$ (dashed line) for the decay coefficient $\alpha=0.5k$. Zero impedance corresponds with the placement of the transmitting and receiving antennas.

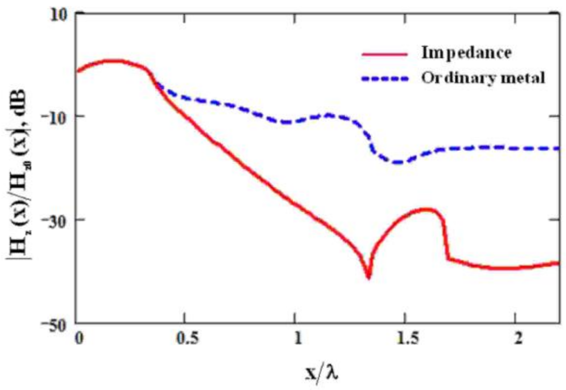

Figure 3. Behavior of the complete magnetic field along the impedance structure and in the openings of antennas, for the decay coefficient $\alpha=0.5k$ (solid line). The case for an ideally conducting surface is represented as $Z=0$ (dashed line). The parameters for the system are: $a=b=0.34\lambda$ and $L=\lambda$.

Next, we present the variation of the designed impedance along the plane over two periods of the impedance as shown in Figure 4, calculated for $\alpha = 0.5k$, where zero impedance, as in Figure 2, corresponds with the placement of the transmitting and receiving antennas. Figure 5 shows the distribution of the complete magnetic field along the impedance structure and in the openings of the antennas. As is shown, the level of decoupling grows non-monotonically. The dashed line corresponds to the ideal conducting surface, i.e., the original metal. The level of decoupling, K, in this case for both of the antennas separated on the impedance surface is –34 dB. Here, the coefficient of standing waves (CSW) of the transmitting antenna is 1.9 and the CSW of the receiving antenna is 2.45. For the ideal conducting structure, the level of decoupling is equal to –20.4 dB and the CSW is 1.9.

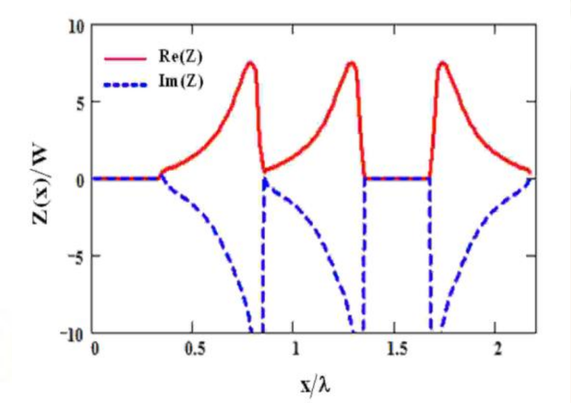

Figure 4. Two periods of impedance variation: $\mathrm{Re}(Z)$ (solid line) and $\mathrm{Im}(Z)$ (dashed line) for the decay coefficient $\alpha = 0.5k$. As in Figure 2, zero impedance corresponds with the placement of the transmitting and receiving antennas.

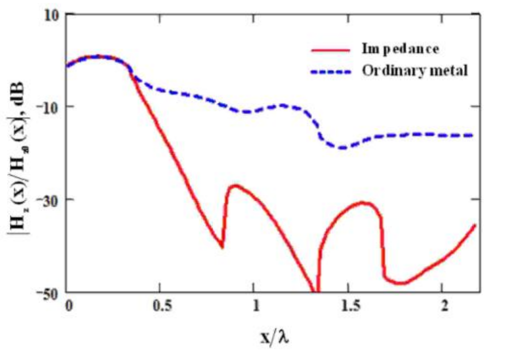

Figure 5. Distribution of the field along the impedance structure and in the openings of antennas for $\alpha = 0.5k$ (solid line). $Z = 0$, dashed line. The parameters for this calculation are the same as in Figure 3.

If the receiving antenna is to operate in the transmission mode, then its CSW should be low (or at least not higher than that of the transmitting antenna). Consequently, the value of impedance near its opening should also be small or equal to zero. The best results for a waveguide antenna, in accordance with the results of Ref. [4], are obtained with an inductive impedance, $Z = -i$. In order to solve this problem, it is possible to use the principle of commutative duality, changing the impedance behavior from an increasing function to its inverse. To demonstrate that the results obtained are in accordance with this basic electrodynamic principle, Figures 6 (a) and (b), show the impedance distributions, and corresponding to them, the field distributions of the impedance structures and the openings of antennas are shown in Figures 7 (a) and (b). In both cases, the level of decoupling reaches -34 dB in the aperture of the receiving antenna. In the first case, the CSW was 1.9, and in the second it was 2.45 for both the antennas. Numerical research also shows that simple rejection of the active part of the impedance in the structure shown in Figure 6 (a), i.e., the distribution of the field for a purely reactive structure, leads to a small increase in the decoupling by 0.4 dB ($K = -34.4$ dB) and a reduction of the CSW to 1.8.

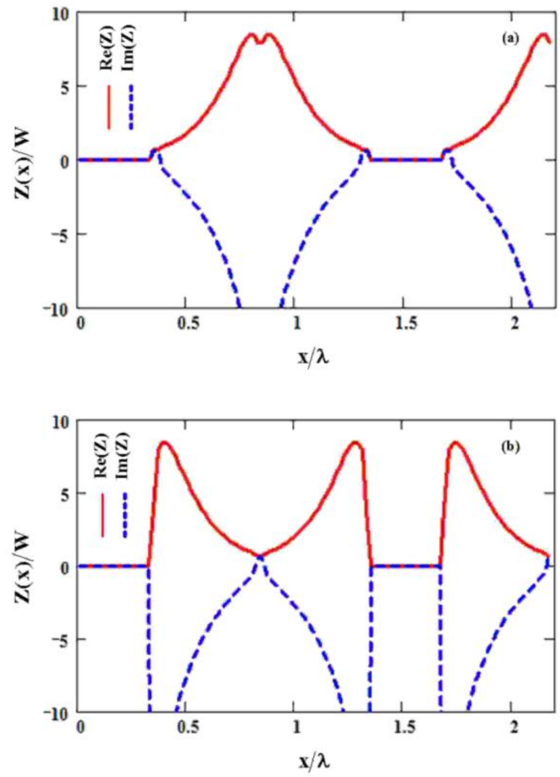

Figure 6 (a) and (b). Two periods of the impedance variation: $\mathrm{Re}(Z)$ (solid line) and $\mathrm{Im}(Z)$ (dashed line) for the decay coefficient $\alpha = 0.5k$ using the principle of commutative duality.

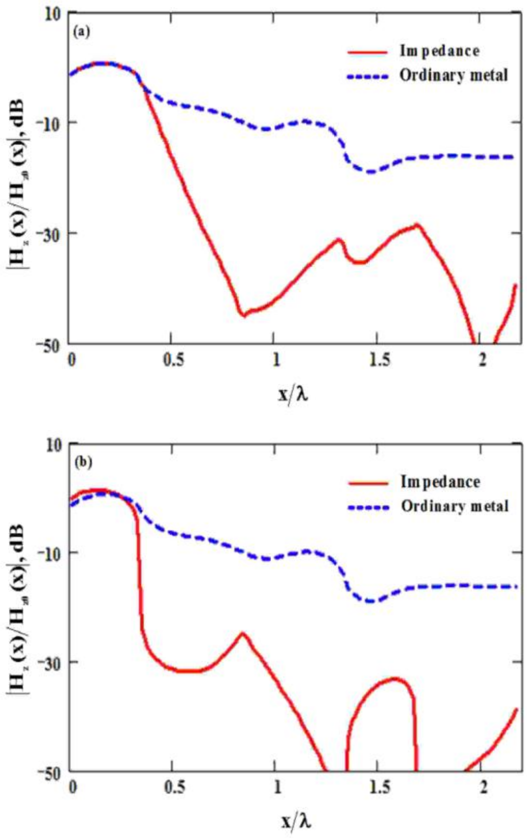

Figure 7 (a) and (b). Distributions of the field relative to Figure 6 (a) and (b), respectively. The parameters for this calculation are the same as in Figure 3.

Thus, through an alteration of the synthesized impedance distribution, it is possible to realize a structure which provides the same level of decoupling but with a significantly lower CSW, which is very important for antennas operating in the radiation mode.

Figures 8 and 9 show the results of analysis of the decoupling structure constructed on the basis of the impedance synthesized in Ref. [2], (see Figure 8) for a fixed Ω -factor which weakens H_z :

$$H_z(x) = 2H_z^i(x)\left|H_0^{(2)}(k|x|)\right|^2 \Omega . \qquad (2)$$

In this example, $\Omega = 0{,}0001$, for which the decoupling level (see Figure 9, solid line) reaches $K = -37.54$ dB. The dotted line corresponds with the ideal conducting structure. The CSW is 2.36 because of the large capacitive reactance near the open end of the antennas. Such a structure for near-omnidirectional transmitting antennas is of little use. In order to reduce the CSW, it is necessary to move the impedance structure away from the opening of the antenna, so that near the opening the inductive reactance is small or vanishes.

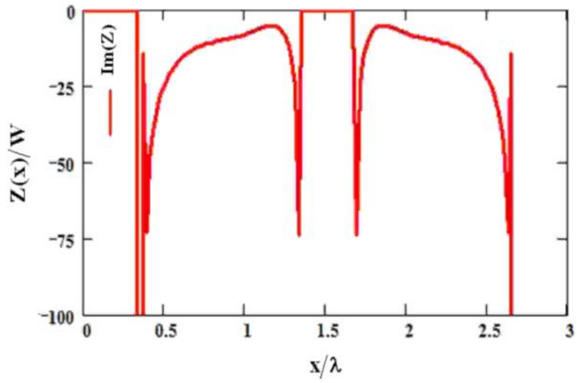

Figure 8. Distribution of the impedance synthesized in article [2] for a fixed Ω - factor to weaken H_z .

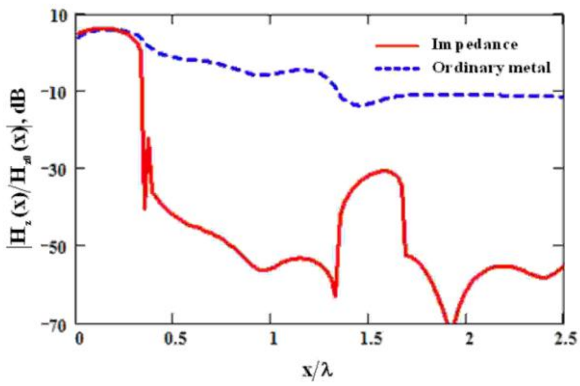

Figure 9. Distribution of the complete field relative to Figure 8. The parameters for our calculation are $a = b = 0.34\lambda$, $\Omega = 0{,}0001$ and $L = \lambda$. The dashed line corresponds with the ideal conducting surface.

Therefore, during the synthesis of decoupling structures with a given weakening factor, Ω , of the complete field (see Eq. 2), it is pointless to set the level of Ω lower than 0.001, otherwise the CSW is too large. The reactance obtained for small Ω is more easily realized with the use of a corrugated structure (a lower value of reactance requires less precision in the manufacture of the structure).

Figure 10 shows the impedance distribution obtained by the method of pointwise synthesis (the exchange method of Stiefel) corresponding to the structure shown in Figure 7 (with the same geometry). As the results of the calculations show (Figure 11, solid line), making the impedance distribution more complicated does not lead to a significant growth in the decoupling. In this case, the decoupling $K = -38$ dB, and the $CSW = 2.37$. However, this applies only to the calculated frequency. It can be concluded that due to the discontinuous character of the impedance, the structure will have a greater bandwidth (see Figure 10).

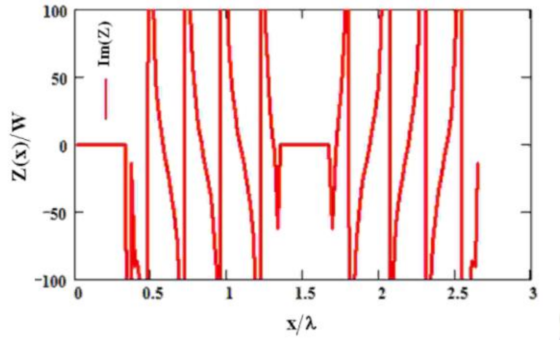

Figure 10. Distribution of the impedance synthesized in article [2], by the method of pointwise synthesis.

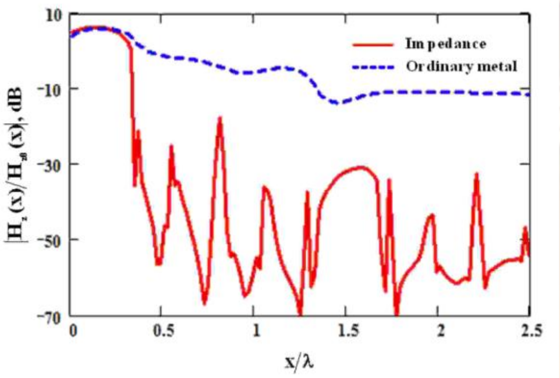

Figure 11. Distribution of the complete field relative to Figure 10.

IV. Conclusion

On the basis of the theoretical and numerical research in this paper, we have obtained several important results. First, we studied a means of reducing the coupling between two antennas, separated by an inhomogeneous impedance structure. The structure is synthesized for a given decay coefficient, α, of the complete field, and for the case when the synthesized impedance is compressed by a factor of two, i.e., with a rate of impedance variation which is twice as large. We have shown that the use of several periods of impedance variation brings an additional gain in the antenna decoupling, but then the CSW of the transmitting antenna equals 1.9 and coincides with the CSW for an ideally conducting surface. We have also studied a means of reducing the coupling between two antennas for the impedance synthesized by a prescribed weakening factor, Ω, of the complete field H_z along the structure. In this case, the decoupling level is better than before, but the CSW is too large. It is proposed to move the impedance structure away from the antenna opening in order to decrease the CSW. Finally, we have considered the case of an impedance distribution calculated by the method of pointwise synthesis. As in the previous case, the level of decoupling and the CSW are both large.

In conclusion, we can say that the most effective way of solving the problem of electromagnetic compatibility of antennas located on the same surface is to use high-performance methods of analysis and the synthesis of periodic structures.

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