

## Optimization of Surface Impedance for Reducing Surface Waves between Antennas

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**ABSTRACT:** Electromagnetic coupling between two aperture antennas in the shape of the open ends of parallel-plate waveguides located on the same metal surface has been analyzed. The design optimization of the surface impedance model is used to solve this problem. The required level of antenna decoupling is obtained taking into account the initial metal surface, which is a natural decoupling structure. The search method is applied to determine a minimum value of the antenna-coupling coefficient. The method of moments (MoM) technique has been used to solve the integral equations. Numerical solutions for optimized surface impedance distributions and antenna decouplings are presented.

**Keywords:** Aperture Antennas, Coupling, Method of Moments, Surface Impedance.

### I. INTRODUCTION

Nonplanar antennas with radiating apertures find frequent use in radio electronics. These antennas have several advantages compared to traditional antennas with plane apertures. One of these advantages is the possibility of placing such antennas directly on surfaces with a complex shape. Another important advantage is the fact that antennas with nonplanar apertures allow the realization of a wider class of geometries than antennas with planar apertures.

High saturation of modern systems of radio electronics necessitates creating the placement of antennas of different usage in direct proximity relative to other antennas. As a result, these antennas can produce interference with each other. With the aim of reducing this harmful form of mutual influence, various measures are used to increase the decoupling between the antennas. One of the most effective measures, as shown in Refs. [1-3] for the case of surface plane location of antennas, is the use of corrugated structures. The corresponding electrodynamic model has been considered [1, 2, 4], where the problem of coupling of two antennas located on a plane in the presence of an intervening corrugated structure is solved explicitly. The results obtained from this model can be used as an initial proposition or approximation [4].

The main purpose of this paper is the optimization problem of surface impedance for decreasing antenna-coupling coefficients, in the case where the antennas have a common location. The history of this problem is addressed in Refs. [5-7], where the antenna coupling coefficients are defined for different dispositions of antennas on a mobile board. Although the problem of the definition of a minimum value of the antenna-coupling coefficient is not mentioned in these papers, the problem of minimization of the antenna-coupling coefficients for the radio board and electronic systems has been solved using the search method [8]. The minimum value of the antenna-coupling coefficient is defined with the help of the Gauss-Zeidel optimization method [9, 10].

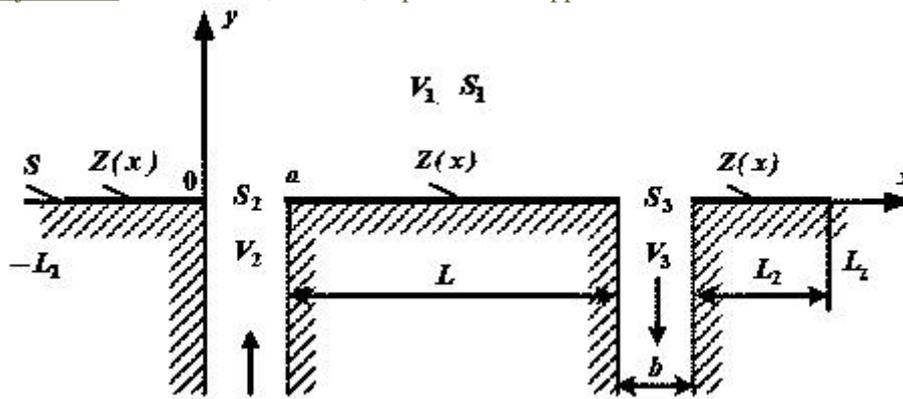
In Section II of this paper, a solution to the problem of the reduction in coupling between two waveguide antennas located on a surface impedance is given. A solution to the design optimization problem of the surface impedance for reducing coupling between antennas is obtained in section III. In section IV, the numerical simulation results are presented. Finally, conclusions are drawn in Section IV.

### II. ANALYTICAL FORMULATION

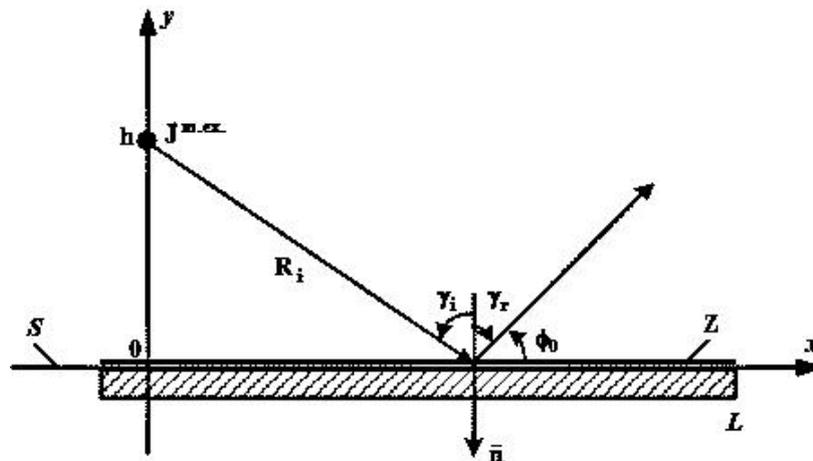
We consider the problem of coupling between two waveguide antennas as shown in Figure 1a. The two aperture antennas in the shape of the open ends of parallel-plate waveguides (transmitting and receiving) with opening sizes of  $a$  and  $b$  are located on the  $y=0$  plane, separated by a distance  $L$ . On the surface  $S$ , the impedance boundary conditions of Shukin-Leontovich are fulfilled:

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

where  $\vec{n}$  is the normal unit to the  $y=0$  plane,  $Z$  is the surface impedance, and  $\vec{E}$  and  $\vec{H}$  are the electric and magnetic fields, respectively.



(a)



(b)

**Figure 1.** (a) Geometry of the problem. (b) Geometry of the design problem. The magnetic current  $\vec{J}^{m.ex}$  is located at the height  $h$ .

It is necessary to determine the electromagnetic field (EMF) in the following regions: the upper half-space ( $y \geq 0$ , region  $V_1$ ), the radiating waveguide ( $y=0$  and  $0 \leq x \leq a$ , region  $V_2$ ), and the receiving waveguide ( $y=0$  and  $a+L \leq x \leq a+L+b$ , region  $V_3$ ). The minimum level of coupling between the two antennas can then be determined using the surface impedance plane synthesized below. Notice that the required EMF should satisfy boundary conditions on the flange, namely the requirement of infinite tangential components in the openings, and the standard conditions of Maxwell's equations for radiation.

For the solution of the general structure studied in our calculations and sketched schematically in Figure 1a, we use the Lorentz lemma in the integral form and obtain integral correlations for each of the regions,  $V_1$ ,  $V_2$  and  $V_3$ , respectively [1, 2]. We consider the boundary conditions on the surfaces of the impedance flanges, and the equality of the tangential field components in the openings of the waveguides ( $H_{z1} = H_{z2}$ ,  $E_{x1} = E_{x2}$  in  $x \in [0, a]$ ;  $H_{z1} = H_{z3}$ ,  $E_{x1} = E_{x3}$  in  $x \in [a+L, a+L+b]$ ), where the subscript numbers refer to the regions  $V_1$ ,  $V_2$  and  $V_3$ . With regards to the specifics of the electric field at the edges,  $x=0, a, a+L, a+L+b$ , the solution will consist in solving the system of integral equations, subject to the boundary conditions, for the unknown tangential component of the electric field on the surface  $S$  ( $x \in [-L_1, a+L+b+L_2]$  and  $y=0$ ) as shown in detail in Refs. [1, 2]. The solution of this equation is conveniently solved with the use of the Krylov-Bogolyubov method [11], which gives an iterative approximation for the required value. After obtaining the system of integral equations relative to the electric field  $E_x(x)$  on the  $y=0$  plane, we propose the use of the periodic structure designed below in order to solve the given problem of coupling between the antennas.

### III. DESIGN OPTIMIZATION OF THE SURFACE IMPEDANCE PLANE

In this section, we consider a solution to the two-dimensional design problem for the arrangement shown in Figure 1b. Above the plane  $S$  ( $y=0$ ), there is an infinite thread of in-phase magnetic current  $\vec{J}^{m.ex}$  located at height  $h$ . On the surface  $S$ , the boundary impedance conditions of Shukin-Leontovich are fulfilled by Eq. (1). It is necessary to determine the dependence of the passive impedance  $Z(x)$  ( $\text{Re}(Z) \geq 0$ ) on the surface  $S$ . Once  $Z(x)$  is obtained, the complete field in the upper space is found, and then the degree of decoupling between antennas can be obtained.

It is well known that surface impedance, comprising a mathematical model of a corrugated structure, can be used systematically to control the radiation, scattering and propagation characteristics of the waves and, thereby, can be used to design better antennas. Furthermore, the effective solution to the problem of reducing the coupling of airborne antennas requires the solution of the structural design problem. The design of such a two-dimensional structure is obtained in Ref. [12], which investigates the design problem of the impedance surface when an infinite thread of in-phase magnetic current is located above the plane at a certain height. The designed impedance structure has the following form:

$$Z = -iW \cos \gamma_r \tan \frac{\chi}{2}, \quad (2)$$

where  $i$  is the imaginary unit,  $W = 120\pi$  (ohms) is the characteristic resistance of a free space and  $\gamma_r$  is the angle of reflection.  $\chi = k(R_i - x \cos \phi_0)$  is a dimensionless quantity,  $k = 2\pi/\lambda$  is the wave number,  $R_i = \sqrt{h^2 + x^2}$ ,  $h$  is the height, and the coordinate  $x$  gives the position of the subsidiary source. The derived impedance variation can be used as an independent solution of the problem of providing electromagnetic compatibility, as well as the first step in further optimization of the structure with the help of non-linear programming methods.

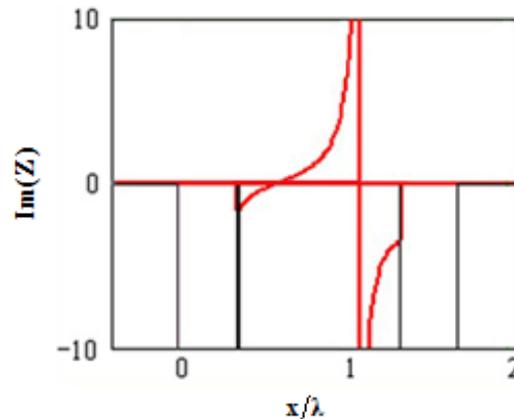
#### IV. NUMERICAL RESULTS

The solution for the designed impedance distribution is given as

$$Z(x) = -i \tan \left( k \left( \sqrt{h^2 + x^2} - x \cos \phi_0 \right) \right), \quad (3)$$

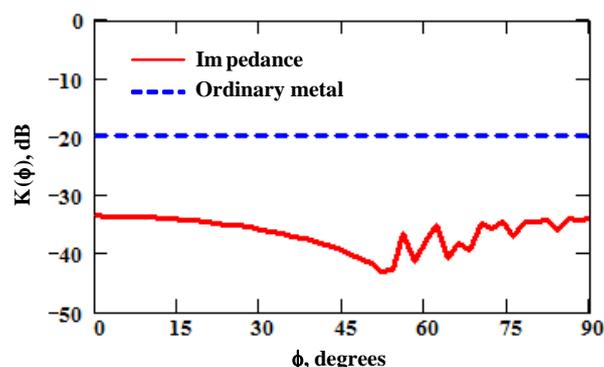
in which the two free parameters  $h$  and  $\phi_0$  are included [12]. These parameters can be used for an optimization of the impedance,  $Z(x)$ , yielding a minimal coefficient of coupling (maximum decoupling) between the antennas.

In Figure 2, we show a graph of the variation of the impedance distribution, which provides the best decoupling for the parameters,  $h = 0.5\lambda$  and  $\phi_0 = 54^\circ$ . The optimized impedance also gives a nearly hyperbolic reactance. The vertical solid lines represent the geometry of the problem.



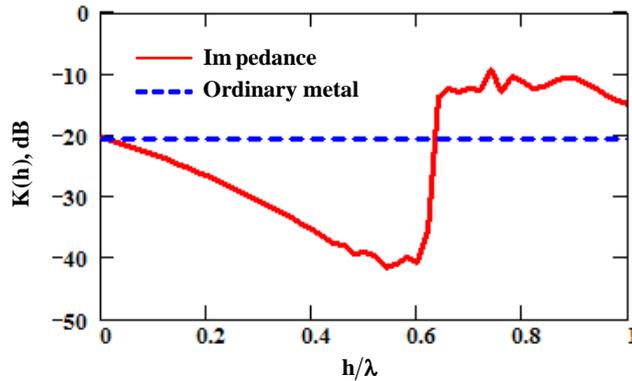
**Figure 2.** Variation of the optimized surface impedance for the parameters:  $h = 0.5\lambda$  and  $\phi_0 = 54^\circ$ . The vertical solid lines represent the geometry of the problem.

Figure 3 shows the dependence (red solid curve) of the decoupling coefficient  $K$  on the parameter  $\phi_0$  for the fixed value  $h = 0.5\lambda$ , for a structure with length  $L = \lambda$  and  $a = b = 0.34\lambda$ . The blue dashed curve corresponds to the ideal conducting structure. As seen, the optimum in this case occurs for the angle of  $54^\circ$ . It can be stated that decoupling of antennas does not depend sensitively on the angle  $\phi_0$ . This parameter alters  $K$  by not more than 10 dB.



**Figure 3.** Dependence of the decoupling coefficient  $K$  on the parameter  $\phi_0$  for the fixed value  $h = 0.5\lambda$ . The optimal decoupling in this case is when the angle equal to  $54^\circ$ .  $L = \lambda$  and  $a = b = 0.34\lambda$ .

In Figure 4, the dependence of the decoupling coefficient  $K$  on the parameter  $h$  for the fixed angle  $\phi_0 = 54^\circ$  is shown for the same structure (red solid curve). As in the previous graph, the blue dashed curve corresponds to the ideal conducting structure. As shown here, the best decoupling of  $K \approx -40$  dB is obtained for the parameter  $h = 0.5\lambda \sim 0.6\lambda$ . Further numerical research shows that alteration of the height  $h$  leads to a shift of the maximum reactance from the opening of one antenna to the other. This, in turn, leads to periodic alteration of the decoupling coefficient between antennas. Increasing the length of the structure leads to the appearance of an additional maximum in the variation of the impedance distribution.

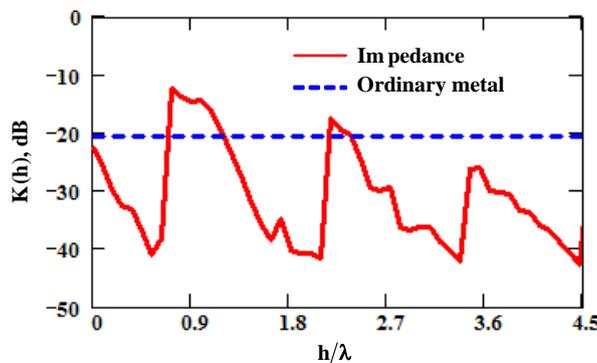


**Figure 4.** Dependence of the decoupling coefficient  $K$  on the parameter  $h$  for the fixed angle  $\phi_0 = 54^\circ$ . The best decoupling is obtained for the parameter  $h = 0.5\lambda \sim 0.6\lambda$ . The parameters for our calculation are the same as in the previous case.

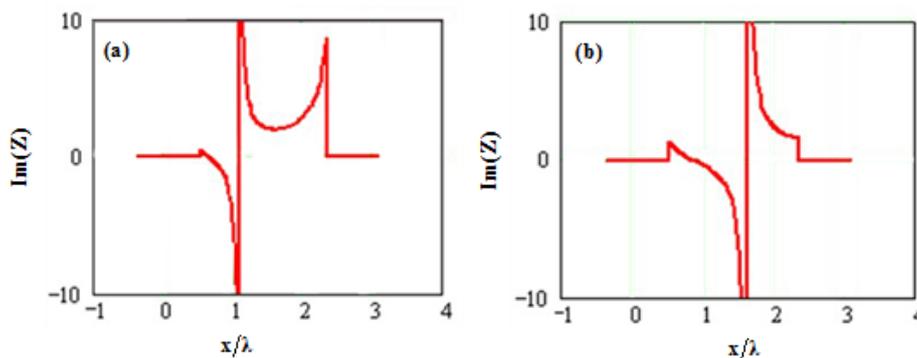
Figure 5 shows the dependence (red solid curve) of the decoupling coefficient  $K$  for the fixed angle  $\phi_0 = 45^\circ$ , for a structure with the parameters,  $L = 2\lambda$  and  $a = b = 0.34\lambda$ . The impedance distributions for  $h = 0.5\lambda$  and  $h = 1.8\lambda$ , which give the maximum values of decoupling, are also presented in Figures 6 (a) and 6 (b), respectively. Here, it is also possible (with  $L = 2\lambda$ ) to consider the parameter  $h = 0.5\lambda$  as optimum. Compared to the reactance of Figure 6 (a), the reactance of Figure 6 (b) shows a shift of  $x = 0.5\lambda$  in the values of the sharp transitions. Additionally, the reactance of the Figure 6 (a) shows a half parabola between the points  $x = \lambda$  and  $x = 2.3\lambda$ .

The impedance distributions considered above have a reactance following the functional form of tangent or cotangent over the region  $x = 0 \sim \lambda$ :

$$Z(x) = iZ_0 \tan(qkx) \text{ or } Z(x) = -iZ_0 \cot(qkx). \tag{4}$$

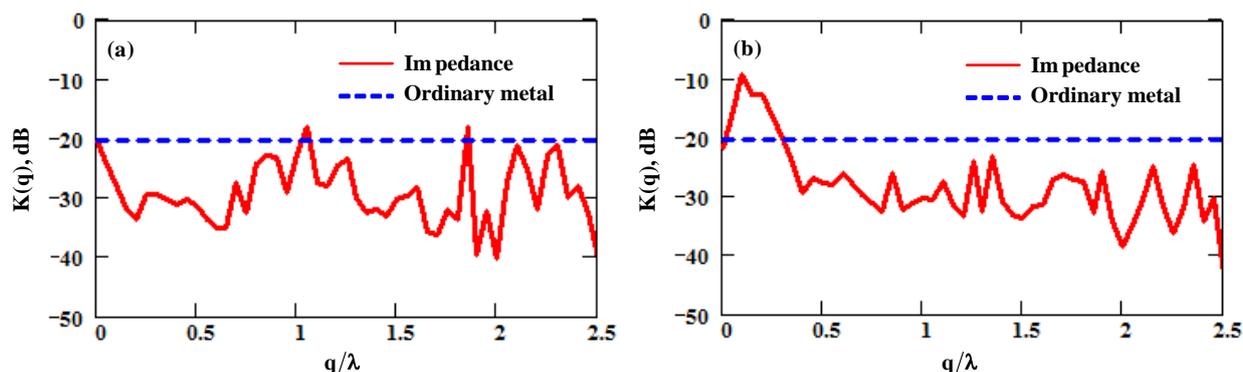


**Figure 5.** Dependence of the decoupling coefficient  $K$  on the parameter  $h$  over a wide range for a fixed angle  $\phi_0 = 45^\circ$ . Parameters used are  $a = b = 0.34\lambda$  and  $L = 2\lambda$ .



**Figure 6.** Variations of impedance distribution for (a)  $h = 0.5\lambda$  and (b)  $h = 1.8\lambda$ . In both cases, the parameters used are  $a = b = 0.34\lambda$ ,  $\phi_0 = 45^\circ$ , and  $L = 2\lambda$ .

Figure 7 (a) shows (red solid curve) the dependence of the decoupling coefficient of the two antennas  $a = b = 0.34\lambda$ , separated by the impedance structure with length  $L = \lambda$ , using the form of the impedance  $Z = i \tan(qkx)$  with the dimensionless parameter  $q$ . Analogous results (red solid curve) are shown in Figure 7(b) for the structure with the impedance  $Z = -i \cot(qkx)$ . The reactance with the functional form of the tangent gives larger local minima, reaching  $-43$  dB. The reactance with the functional form of the cotangent gives smaller local minima but has a smoother dependence on the parameter  $q$ . As shown, the decoupling coefficient for the cotangent case becomes  $K = -30 \sim -40$  dB, reached when  $q = 0.4 \sim 2$ . This means that if such a structure is calculated with a coefficient  $q = 0.4$  on the lower frequency of the range, it will give a decoupling of  $K = -30 \sim -40$  dB over the frequency range of interest. From the viewpoint of frequency properties, such a structure is preferable. We observe that in Figures 5, 7(a) and 7(b), the blue dashed curve also corresponds to the decoupling level for the case of an ideal conducting structure.



**Figure 7.** Dependence of the decoupling coefficient  $K$  on the parameter  $q$  for the impedances (a)  $Z = i \tan(qkx)$  and (b)  $Z = -i \cot(qkx)$ . Parameters used are  $a = b = 0.34\lambda$  and  $L = \lambda$ .

#### IV. CONCLUSION

We have solved the optimization problem of the surface impedance for reducing surface waves between antennas located on a common plane surface. The optimized surface impedance is an inhomogeneous impedance plane designed by a fixed reflected field. In the optimization results, we have obtained a reactance close to the functional form of tangent or cotangent, which can provide significant decoupling over a large range of frequencies.

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