Numerical Investigation of Linear Waveguide Paa with Dielectrically Filled Matching Periodical Strucure

Marchenko Sergei, Morozov Valentin, Syanov Alexander

Abstract – ***Numerical investigation of plane-waveguide PAA with dielectrically filled matching periodical structure (MPS) is presented. MPS is investigated both with dielectrical filling and without filling. Obtained results are demonstrated that application of MPS improves matching with free space.***

Keywords: ***integral equation, Green's function,***

I. INTRODUCTION

Matching of phased array with freee space is an important task. There are various methods to improve coordination: the use of magnetodielectric inserts and segments [1], inductive irises, flanges impedance [2], etc. This paper investiges the application of the matching structure (MS) in the form of MPS with dielectric layers and inserts, as well as the result of the influence of the dielectric filling on the reflection coefficient.

II. STATEMENT OF PROBLEM

Let's consider the scalar problem of electromagnetic wave radiation from a linear waveguide infinite phased array with MPS. MPS consists of the main array and the subarray with the same geometrical dimensions of the cross-section, located at some distance from it with an internal (ε1-ε4) and external (ε5-ε7) dielectric filling. Figure 1 shows the geometry of the problem. One can decomposite the defined field domain of chosen central unit cell by three areas:

I (penetrating) area - "waveguide channel" with the dielectric filling (ε1-ε7):

$$-\frac{W}{2} \le x \le \frac{W}{2}; \quad -\infty < z < +\infty$$

II (partial) domain - "Floquet channel" of finite length, filled with a dielectric (ε3):

$$-\frac{F}{2} \le x \le \frac{F}{2}; \; -z2 \le z \le -z1$$

III (partial) domain-external space radiation (semi-infinite "channel Floquet"), filled with a dielectric (ε5, ε6), ε7 = 1:

$$-\frac{F}{2} \le x \le \frac{F}{2}; \quad 0 \le z < +\infty$$

III. NUMERICAL ANALYSIS

Applying the approach in [3] we obtain an integral representation for the determination of the total penetrating field of PAA with MPS and account for the dielectric filling (defining of the Green's function and an exciting field source) [4].

Marchenko Sergei, Syanov Alexander, Dneprodzerzhinsk State Technical University, Dneprodzerzhinsk, Dniprobudivska Str. 2a 51923,Ukraine , E-mail: smars@inbox.ru, Morozov Valentin, Dnepropetrovsk National University, Dnepropetrovsk, Ukraine

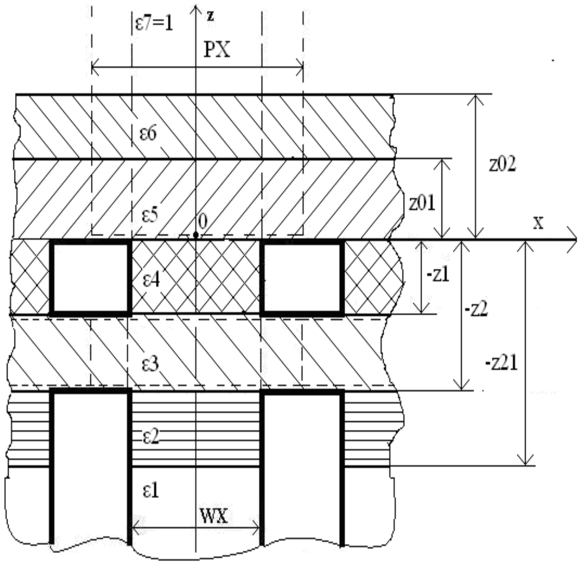


Fig.1 Linear waveguide PAA with dielectrically filled MPS

Taking account of the fields equality in the general area of the intersection, we equate the integrands in the tangential component of the electric field vector of penetrating area the field $E_y^{I(n)}(x',z')$ with the tangential components of the electric field vector of partial regions $E_y^{I(3)}(x',z'), E_y^{I(5)}(x',z'), E_y^{I(6)}(x',z'), E_y^{I(7)}(x',z')$ and we can obtain an integral representation relative of the fields components of II and III areas.

$$E_y^{I(n)}(x,z)=E_{y_{exc}}^{I(n)}(x,z)+$$

$$+\int_{-z2}^{-z1}\left\{E_y^{II(3)}(x',z')\frac{\partial G_3^I(x,z;x',z')}{\partial x'}\bigg|_{x'=-\frac{W}{2}}\ \bigg| -E_y^{II(3)}(x',z')\frac{\partial G_3^I(x,z;x',z')}{\partial x'}\bigg|_{x'=\frac{W}{2}}\right\}dz'+$$

$$+\int_{0}^{z01}\left\{E_y^{III(5)}(x',z')\frac{\partial G_5^I(x,z;x',z')}{\partial x'}\bigg|_{x'=-\frac{W}{2}}\ \bigg| -E_y^{III(5)}(x',z')\frac{\partial G_5^I(x,z;x',z')}{\partial x'}\bigg|_{x'=\frac{W}{2}}\right\}dz'$$

$$+\int_{z01}^{z02}\left\{E_y^{III(6)}(x',z')\frac{\partial G_6^I(x,z;x',z')}{\partial x'}\bigg|_{x'=-\frac{W}{2}}\ \bigg| -E_y^{III(6)}(x',z')\frac{\partial G_6^I(x,z;x',z')}{\partial x'}\bigg|_{x'=\frac{W}{2}}\right\}dz'+$$

$$+\int_{z02}^{+\infty}\left\{E_y^{III(7)}(x',z')\frac{\partial G_7^I(x,z;x',z')}{\partial x'}\bigg|_{x'=-\frac{W}{2}}\ \bigg| -E_y^{III(7)}(x',z')\frac{\partial G_7^I(x,z;x',z')}{\partial x'}\bigg|_{x'=\frac{W}{2}}\right\}dz'$$

where, $E_y^{I(n)}(x,z)$ the tangential component of the electric field vector of penetrating area (n = 1 ÷ 7); $E_{y_{exc}}^{1(n)}(x,z)$ - the same for exciting source; $E_y^{II(3)}(x,z)$ − tangential component of the electric field vector of II area (n=3); $E_y^{III(5)}(x,z), E_y^{III(6)}(x,z), E_y^{III(7)}(x,z)$ -tangential component of the electric field vector of III area (n=5÷7); $G_n^I(x,z;x',z')$ - Green function of infinite waveguide with stratified dialectical filling (n=1÷7).

According to the method presented in [5], we define the sourcewise Green's function taking into account the stratified dielectric filling with consider locatingg a point source at a fixed point of observation z=-z2; -z1; 0. The longitudinal component of the Green's function taking into account the stratified dieletrical filling has the following view:

$$f_{MWG}^{[n]}(z,z')=\begin{cases} kIr\cdot e^{CJ\cdot CWL_{MWG}^{[n]}(z+z21)}, & n=1 \\ kIIt\cdot e^{-CJ\cdot CWL_{MWG}^{[n]}(z+z2)}+kIIr\cdot e^{CJ\cdot CWL_{MWG}^{[n]}(z+z2)}+ \\ +\begin{cases} 0, & z'\notin[-z21;-z2] \\ \dfrac{e^{CJ\cdot CWL_{MWG}^{[n]}(z+z21)}}{CJ\cdot CWL_{MWG}^{[n]}}, & z'\in[-z21;-z2] \end{cases} \\ kIIIt\cdot e^{-CJ\cdot CWL_{MWG}^{[n]}(z+z1)}+kIIIr\cdot e^{CJ\cdot CWL_{MWG}^{[n]}(z+z1)}+ \\ +\begin{cases} 0, & z'\notin[-z2;-z1] \\ \dfrac{e^{CJ\cdot CWL_{MWG}^{[n]}(z+z21)}}{CJ\cdot CWL_{MWG}^{[n]}}, & z'\in[-z2;-z1] \end{cases} \\ kIVt\cdot e^{-CJ\cdot CWL_{MWG}^{[n]}z}+kIVr\cdot e^{CJ\cdot CWL_{MWG}^{[n]}z}+ \\ +\begin{cases} 0, & z'\notin[-z1;0] \\ \dfrac{e^{CJ\cdot CWL_{MWG}^{[n]}(z+z21)}}{CJ\cdot CWL_{MWG}^{[n]}}, & z'\in[-z1;0] \end{cases} \\ kVt\cdot e^{-CJ\cdot CWL_{MWG}^{[n]}(z+z01)}+kVr\cdot e^{CJ\cdot CWL_{MWG}^{[n]}(z+z01)} \\ kVIt\cdot e^{-CJ\cdot CWL_{MWG}^{[n]}(z+z02)}+kVIr\cdot e^{CJ\cdot CWL_{MWG}^{[n]}(z+z02)} \\ kVIIt\cdot e^{-CJ\cdot CWL_{MWG}^{[n]}(z+z02)} \end{cases}$$

The tangential electric field components II and III areas:

$$E_y^{II(3)}(x,z)=\sum_{mf=-\infty}^{\infty}\left(T3_{mf}e^{-CJ\cdot g3_{mf}\cdot(z-z1)}+R3_{mf}e^{CJ\cdot g3_{mf}\cdot(z-z1)}\right)\cdot FD_{mf}(x)\quad,$$

$$E_y^{III(5)}(x,z)=\sum_{mf=-\infty}^{\infty}\left(T5_{mf}e^{-CJ\cdot g5_{mf}\cdot(z-z01)}+R5_{mf}e^{CJ\cdot g5_{mf}\cdot(z-z01)}\right)\cdot FD_{mf}(x)\quad,$$

$$E_y^{III(6)}(x,z)=\sum_{mf=-\infty}^{\infty}\left(T6_{mf}e^{-CJ\cdot g6_{mf}\cdot(z-z02)}+R6_{mf}e^{CJ\cdot g6_{mf}\cdot(z-z02)}\right)\cdot FD_{mf}(x)\quad,$$

$$E_y^{III(7)}(x,z)=\sum_{mf=-\infty}^{\infty}T7_{mf}e^{-CJ\cdot g7_{mf}\cdot(z-z02)}\cdot FD_{mf}(x)\quad,$$

where, $T3_{mf}$ and $R3_{mf}$- unknown complex amplitude coefficients of the transmitted and reflected fields in the "Floquet channel" of finite length; $T5_{mf}, T6_{mf}$ и $R5_{mf}, R6_{mf}$ − unknown complex amplitude coefficients of transmitted and reflected field in dialectrical layers of"Floquet channel"; $T7_{mf}$- unknown complex amplitude coefficients of free space, $g3_{mf}$ -the longitudinal coefficient propagation in the "Floquet channel" of finite length, $g5_{mf}, g6_{mf}$ и $g7_{mf}$ −in dialectrical layers “Floquet chanel” and free space .

Fixing the observation point and equating the tangential components at the boundary between the media z=-z2, -z1 $E_y^{I(3)}(x,z)=E_y^{II(3)}(x,z)$, and z=0 $E_y^{I(5)}(x,z)=E_y^{III(5)}(x,z)$ and one can get to the integral equation. By reducing the number of unknown coefficients of the amplitude of integrated, we express $E_y^{III(5)}(x,z), E_y^{III(6)}(x,z)$ by $E_y^{III(7)}(x,z)$ and applying Galerkin’s procedure, we can obtain system linear algebric equation (SLAE) relative to 3 unknown coefficients.

Having computing $T3_{mf}, R3_{mf}$, and defining exciting field source at z=-z2, we equate field components I area and II area at z=-z2, and finally calculate reflection coefficient H_{10}.

IV. OBTAINED RESULTS

Figures 2-4 shows the modulus of the reflection coefficient for different values of the thickness of the waveguide walls (curve 1 - z1 = z2 = 0, curve 2 - MPS without the dielectric, the size of z1 and z2 are indicated below the figure, curve 3 - MPS with dielectric parameters are in the text below.) The graph shows the results for PAA both MPS without filling and for the MPS with the filling at which the minimum reflection coefficient.

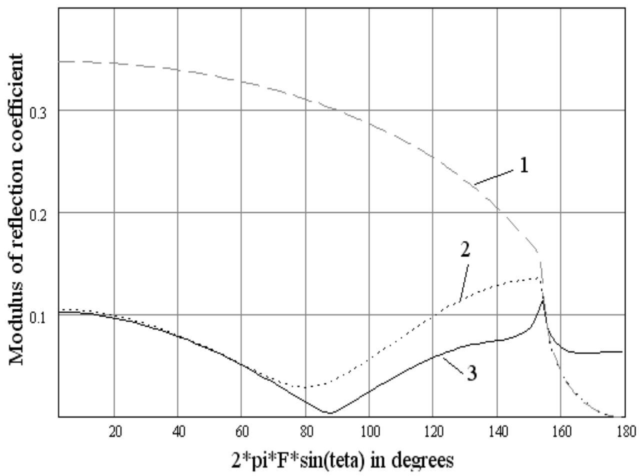
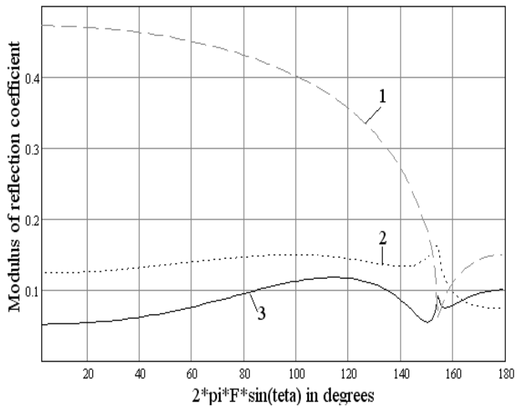
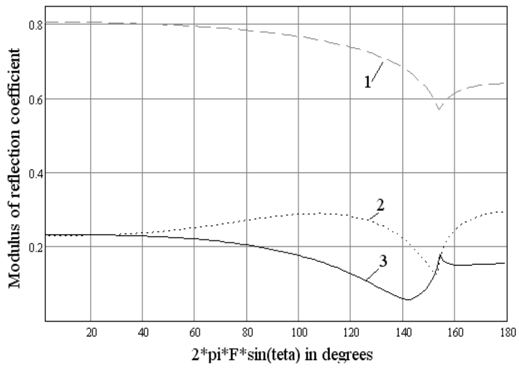


Fig.2 Infinitely thin walls: W=F=0.5714

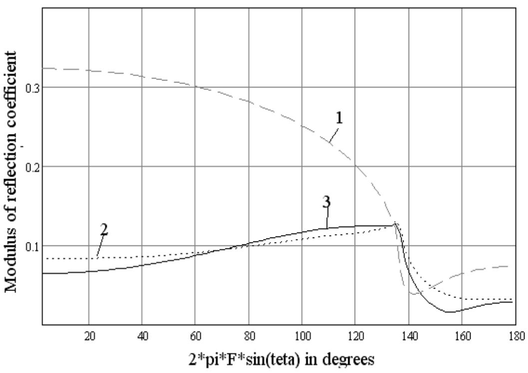


a.

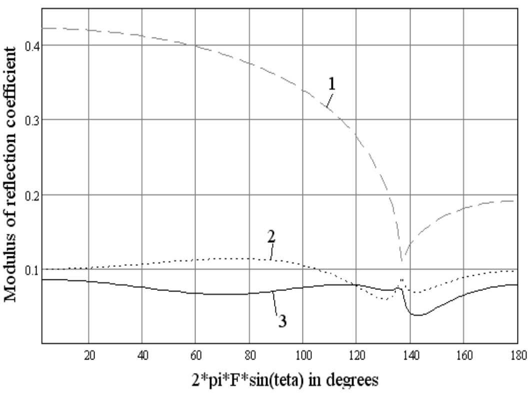


b.

Fig.3 Thin walls: a. F=0.5714λ, W=0.937F
b. F=0.6205λ, W=0.937F



a.



b.

Fig5. Thick walls: a. F=0.5714λ, W=0.88F
b. F=0.6205λ, W=0.88F

For the PAA with infinitely thin-walled waveguides: W = F = 0.5714. The best option: the presence of a dielectric $\varepsilon 4 = 1.5$ ($z1 = 0.6\lambda$, $z2 = 0.75\lambda$). Comparing MPS with dielectric filling and without the ratio of the reflection modulus of) 0.12/0.14, MPS with dielectric filling gives a slight improvement matching.

In the phased array with thin walls W = 0.937F: F = 0.5714λ the best option for $\varepsilon 2 = 2.5$ ($z1 = 0.15\lambda$, $z2 = 0.25\lambda$, $z21 = 0.65\lambda$). For this case the MPS with dielectric filling does not reduce the reflection coefficient. When F = 0.6205λ and W = 0.937F best option for $\varepsilon 2 = 2.5$ ($z1 = 0.15\lambda$, $z2 = 0.25\lambda$, $z21 = 0.65\lambda$). from the curves of the modulus of the reflection coefficient for the MPS with / without dielectric filling the difference between them is small.

For the case of PAA with thick walls W = 0.88F: F = 0.5714λ and the best option $\varepsilon 3 = 1.2$ ($z1 = 0.45\lambda$, $z2 = 0.55\lambda$)-R0 = 0.235. In this case, the MPS with dielectric filling and without them the ratio of the reflection coefficients modulus (with dielectric / without dielectric) 0.235/0.31, PCA with dielectric filling has improved matching by 32%. For F = 0.6205λ best - $\varepsilon 4 = 1.6$ ($z1 = 0.6\lambda$, $z2 = 0.85$) R0 = 0.082. In this case, the MPS with dielectric invaded by without it by the ratio of moduli of the reflection coefficients (c dielectric / without dielectric) 0.085/0.115, PCA with dielectric filling gives better agreement at 35%..

CONCLUSIONS

Numerical study of matching of phased array with free space space by means of MPS showed that using of PMS with increasing thickness of the waveguide becomes more noticeable. The use of dielectric inclusions in the PMs are useful within the structure, because covers do not contribute to the reduction of reflectance due to the appearance of a surface wave propagating in the dielectric layer. The average decrease in the modulus of the reflection coefficient using PMS with dielectric inclusions in comparison without the filling is 25-35%..

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