UDC 621.396.96 DOI: 10.30748/nitps.2017.28.05

S. Nechitaylo, O. Sukharevsky, V. Vasilets

Ivan Kozhedub Kharkiv National Air Force University, Kharkiv

RADIATION CHARACTERISTICS OF THE APERTURE ANTENNA WITH TWO-LAYER CONIC RADOME

The calculation method of the radiation characteristics obtaining has been proposed for octagonal aperture antenna with two-layer conic dielectric radome. For all that the method for radiation field calculation created early by authors is used. This method allows to calculate the radiation field for aperture cut in perfectly absorbing screen at the presence of arbitrary scatterer system (particularly, radome). Numerical results for radiation patterns of the aperture antenna with two-layer radome have been brought out for different parameters of layers. For that calculation the solving model problem about scattering plane electromagnetic wave by two-layer plane-parallel plate have been used.

Keywords: *radome, aperture antenna, radiation characteristics, electromagnetic wave scattering.*

Introduction

The development on on-board systems of radar intelligence [1], the improvement of anti-aircraft missiles [2] need the creation of new calculation methods for radiation characteristics of onboard antenna systems with radomes.

The influence of nose radomes on the antenna radiation characteristics has been devoted to a large number of works [3–8].

The series of aerial objects, such as aircrafts, missiles with radar homing head, have nose dielectric radomes which cover antenna system. For all that the radome walls can be multilayer (particularly, two-layer) for improvement of electromagnetic wave passing through, and also for decreasing influence of high temperature on antenna equipment of aerial objects. In this connection the necessity appears in calculations of radiation characteristics for antenna system with such ramomes. As a model of such antenna system in article we consider octagonal aperture cut in in perfectly absorbing screen at the presence of two-layer conic dielectric radome.

The outer layer with thickness 11…12 mm has relative permeability $\varepsilon' = 3,5 + j0,0175$, the inner layer with thickness 0…12 mm has relative permeability $\varepsilon' = 2,08 + j0,0004$. At the radome nose part there is the metal cap with spherical shape smoothly connected with the cone surface. The calculation of electromagnetic wave passing through radome has been brought out by geometrical optics approach taking into account that metal cap.

For radiation field calculation of antenna system with radome the expression obtained in [9] with the help of Lorentz reciprocity theorem is used. At that the key problem for these calculations is the passing of electromagnetic wave through two-layer plane-parallel plate.

Main part

We consider the antenna in view of octagonal aperture cut in perfectly absorbing plane. The antenna is covered by radome described above (fig. 1).

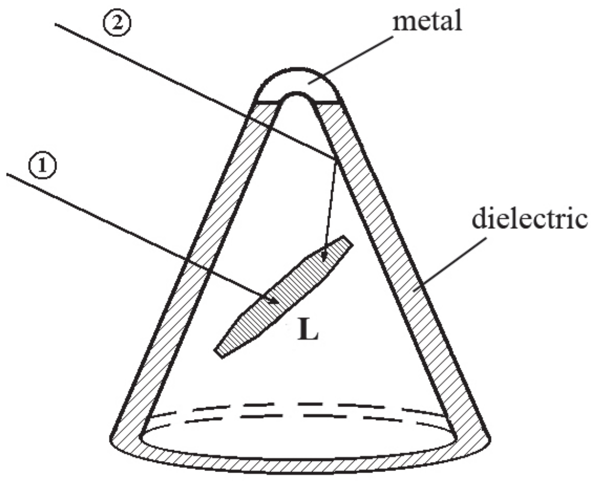

Fig. 1. Propagation paths of incident wave

As it is shown in [9], the radiation pattern for such antenna system in projection to unit vector $\vec{p}$ can be represented by formula

$$\vec{p}\cdot\vec{E}\left(\vec{R}^0\right)=\int\limits_{S_0}\left(\left(\vec{E}^T(x)\times\vec{\mathcal{H}}_0\left(x,\vec{R}^0,\vec{p}\right)\right)-\right.$$
$$\left.-\left(\vec{H}^T(x)\times\vec{\mathcal{E}}_0\left(x,\vec{R}^0,\vec{p}\right)\right)\right)\cdot d\vec{S}. \quad (1)$$

Here $\vec{\mathcal{E}}_0\left(x,\vec{R}^0,\vec{p}\right)$, $\vec{\mathcal{H}}_0\left(x,\vec{R}^0,\vec{p}\right)$ is the field scattered by "symmetrized" radome (fig. 2), in points x of aperture at the absence of perfectly absorbing screen with cut aperture for falling plane wave with direction unit vector $\left(-\vec{R}^0\right)$:

$$\vec{E}_0=\left(\vec{R}^0\times\left(\vec{p}\times\vec{R}^0\right)\right)\exp\left(-jk_0\left(\vec{R}^0\cdot\vec{x}\right)\right), \quad (2)$$

$$\vec{H}_0=\left(\vec{p}\times\vec{R}^0\right)\sqrt{\varepsilon_0/\mu_0}\exp\left(-jk_0\left(\vec{R}^0\cdot\vec{x}\right)\right). \quad (3)$$

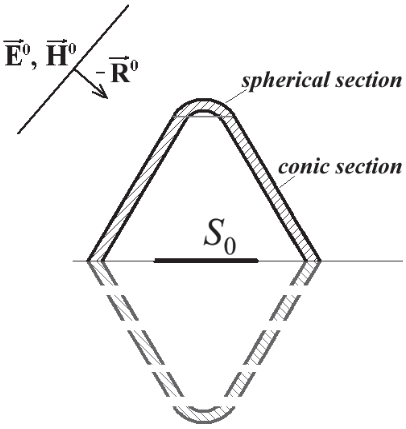

Fig. 2. "Symmetrized" radome

The functions $\vec{E}^T, \vec{H}^T$ are aperture distributions of tangential field components in Kirchhoff approach.

Taking into account the cone shape of radome it can be make conclusion that the radiation filed level for radome "mirror reflection" is lower essentially than field passed directly through real radome. Thus, in first approach, it could consider that $\vec{\mathcal{E}}_0\left(x,\vec{R}^0,\vec{p}\right)$, $\vec{\mathcal{H}}_0\left(x,\vec{R}^0,\vec{p}\right)$ is the field in aperture points x created by two propagation paths (fig. 1): direct passing (path 1) and re-reflection from inner radome surface (path 2). The integrals in (1) are calculated by average rectangles method.

The antenna polarization, i.e. vector $\vec{E}^T(x)$ is oriented along aperture symmetry axis in direction where the aperture linear size is maximum.

We note also, that in case of antenna turning on the some angle the surface of perfectly absorbing screen with cut aperture is turned on the same angle also in case of antenna small turning angles ($\le 25°$) all made assumptions about field $\vec{\mathcal{E}}_0\left(x,\vec{R}^0,\vec{p}\right)$, $\vec{\mathcal{H}}_0\left(x,\vec{R}^0,\vec{p}\right)$ structure still hold.

The computation of field $\left(\vec{\mathcal{E}}_0,\vec{\mathcal{H}}_0\right)$ is carried out with accounting locality principle. I.e the field passed through radome in some point in direction $-\vec{R}^0$ is calcu the passing of electromagnetic wave through two-layer plane-parallel plate for radome materials. This plate is tangent to radome surface in corresponding point. The calculation for re-reflection from radome inner surface is carried out by the same way, but we calculate the reflection filed in model problem about the passing of electromagnetic wave through two-layer plane-parallel plate [9]. In this case the electromagnetic wave falling to two-layer plate is passed through radome wall previously (path 2, fig.1).

The solving model problem is carried out with help of solving two-dimensional boundary problem for Maxwell's equations [10–12]. As result we obtain complex reflection and transmission factors for considered structure and electromagnetic field values inside of each layer.

For example, the field in point $\vec{x}$, passed through radome (corresponds to path 1, fig. 1) can be represented in view

$$\vec{E}_1(\vec{x})=\left[\tau_\perp p_\perp\vec{e}_\perp+\tau_{||}p_{||}\vec{e}_{||}\right]\exp\left(-jk_0\left(\vec{R}^0\cdot\vec{x}\right)\right), \quad (4)$$

$$\vec{H}_1(\vec{x})=\sqrt{\frac{\varepsilon_0}{\mu_0}}\left[\tau_\perp p_\perp\vec{e}_{||}-\tau_{||}p_{||}\vec{e}_\perp\right]\exp\left(-jk_0\left(\vec{R}^0\cdot\vec{x}\right)\right), \quad (5)$$

where $\vec{e}_\perp=\dfrac{\vec{n}\times\vec{R}^0}{\left|\vec{n}\times\vec{R}^0\right|}$, $\vec{e}_{||}=\left(\vec{e}_\perp\times\vec{R}^0\right)$, $p_\perp=\left(\vec{p}\cdot\vec{e}_\perp\right)$, $p_{||}=\left(\vec{p}\cdot\vec{e}_{||}\right)$, $\vec{n}$ is the normal unit vector in corresponding radome point $\vec{x}$.

For that $\tau_\perp$ and $\tau_{||}$ are complex transmission factors through plane-parallel plate for perpendicular and parallel polarizations of incident plane wave, respectively. Using the method described above the calculations have been carried out for octagonal aperture antenna (maximum length is 188 mm, maximum width is 152 mm), placed under two-layer conic radome. First (external) layer is the composite material "niasit" (quartz ceramics) with thickness 11…12 mm and relative permeability $\varepsilon'=3,5+j0,0175$, second (internal) layer is teflon with thickness 0…12 mm and relative permeability $\varepsilon'=2,08+j0,0004$.

In fig. 3–4 there are the power losses due to radome in antenna radiation pattern maximums for different layer thicknesses in two turning angles of the radiation aperture.

The calculations showed that for aperture turning angle 5° (fig. 3) there are essential dips in losses plots. At the same time for aperture turning angle 15° (fig. 4) the power losses depend lightly from internal layer thickness. This is because the main (in power) antenna radiation for turning angle 15° are to radome surface with relatively small curvatures.

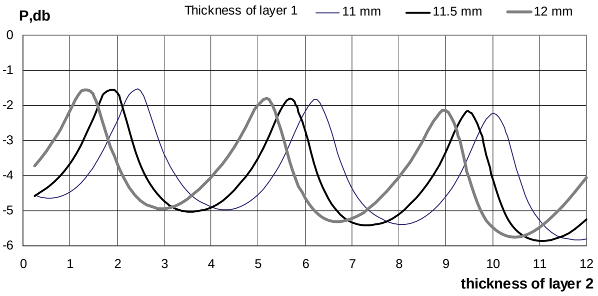

Fig. 3. The power losses due to radome in radiation pattern maximum for aperture turning angle 5°

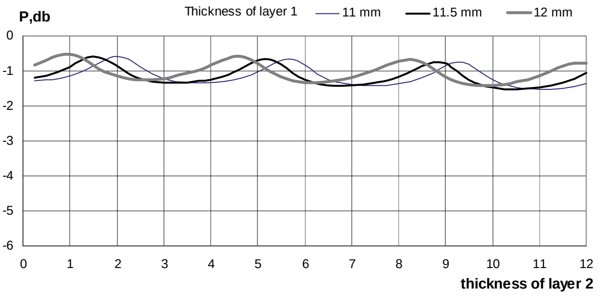

Fig. 4. The power losses due to radome in radiation pattern maximum for aperture turning angle 15°

For turning angle 5° the main antenna radiation is directed on radome region with big curvatures and for all that the perfectly conducting radome cap makes marked contribution to whole antenna radiation.

In fig. 5–6 there are the antenna system radiation patterns for aperture turning angles 5° and 15°, respectively. External layer thickness is 12 mm and teflon layer thickness is 9 mm, that corresponds to power local maximum for turning angle 5° (fig. 3).

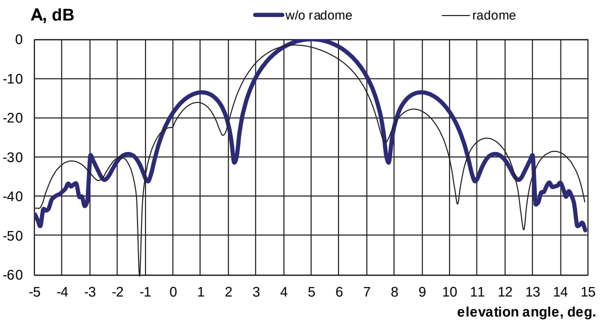

Fig. 5. Radiation patterns for antenna with two-layer radome and aperture turning angle 5°

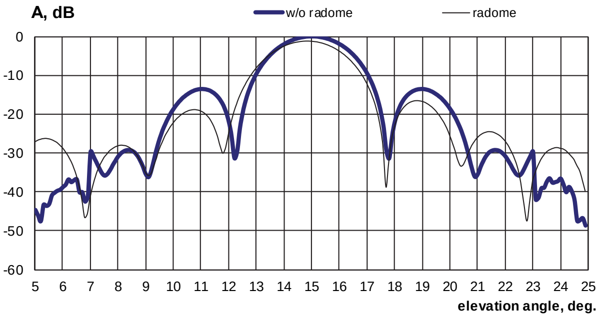

Fig. 6. Radiation patterns for antenna with two-layer radome and aperture turning angle 15°

In this case the power loss in radiation pattern maximum is equal more than 2 dB. For aperture turning angle 15° the power loss is near 1 dB regardless of the internal layer thickness.

It should be noted that the radome presence are to displacement of radiation pattern maximum point in aperture turning. In fig. 7 there is dependency of displacement error of radiation pattern maximum versus aperture turning angle. Here the maximum displacement error is 0,6° for antenna turning angle 5°.

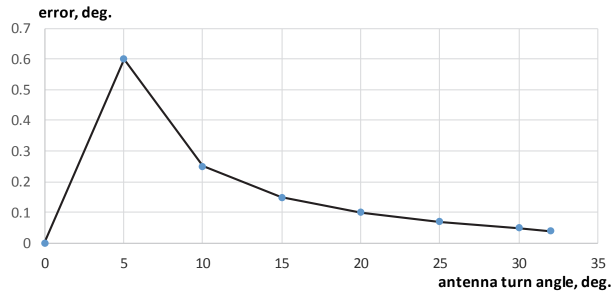

Fig. 7. Displacement error of radiation pattern maximum versus aperture turning angle

Conclusion

Thus in paper the calculation method is developed for radiation of aperture antenna with two-layer dielectric radome. The calculation results have been brought out and analyzed. Radome have external layer from quartz ceramics and internal layer from teflon. Obtained results allow to choose optimal (in respect to radioparency) layer thicknesses and to estimate displacement error due to radome.

References

1. Stepanenkov, M.M., Kobzev, A.V. and Romanenko, V.V. (2017), "Shljakhy vdoskonalennja metodiv otrymannja i obrobky informaciji u zasobakh povitrjanoji radiotekhnichnoji rozvidky" [Methods of information obtaining and processing, in airborne electronic intelligence collection means, ways to improve], *Science and Technology of the Air Force of Ukraine*, No. 2(27), pp. 121-123.

2. Karpenko, D. (2017), "Stan ta perspektyvy rozvytku zenitnoho raketnoho ozbroiennia Povitrianykh Syl Zbroinykh Syl Ukrainy" [The state and perspectives of the development of anti-aircraft missile armaments in the air force of Ukraine], *Science and Technology of the Air Force of Ukraine*, No. 2(27), pp. 75-78.

3. Kozakoff, D.J. (2010), *Analysis of Radome-Enclosed Antennas*, 2nd ed., Artech House, Inc., 294 p.

4. Lansink Rotgerink, J., H. van der Ven, Voigt, T., Jehamy, E., Schick, M. and Schippers, H. (2016), Modelling of effects of nose radomes on radar antenna performance, *10th European Conference on Antennas and Propagation (EuCAP)*, pp. 1-5.

5. Liu Shangji, Zhou Huiyuan, Ding Chang, Song Lizhong (2016), Electrical properties analysis of conical radome, *2016 IEEE International Conference on Ubiquitous Wireless Broadband (ICUWB)*, pp. 1-4.

6. Branko Lj. Mrdakovic, Branko M. Kolundzija (2016), A method for full wave analysis of electrically large transparent radomes. *2016 IEEE International Symposium on Antennas and Propagation (APSURSI)*, pp. 1331-1332.

7. Jae-Won Rim, Il-Suek Koh, Kwang Sik Choi (2016), IPO analysis of performance of arbitrary shaped radome (2016), *10th European Conference on Antennas and Propagation (EuCAP)*, pp. 1-5.

8. Ji Hyung Kim, Yong Bae Park, Sung-Chan Song (2016), Electromagnetic analysis of a tangent-ogive dielectric radome with a metallic cap, *2016 International Workshop on Antenna Technology (iWAT)*, pp. 367-368.

9. Sukharevsky, O., Vasylets, V. and Nechitaylo, S. (2017), Scattering and Radiation Characteristics of Antenna Systems under Nose Dielectric Radomes, *Progress In Electromagnetics Research B*, Vol. 76, pp. 141-157.

10. Taylor, James D. (ed.), (2012), *Ultrawideband radar applications and design*, CRC Press, 520 p.

11. Ryapolov, I.E., Vasylets, V.A. and Sukharevsky, O.I., (2014), "Vyisokochastotnyiy metod rascheta rasseyaniya vtorichnogo izlucheniya dielektricheskih chastey modeli bespilotnogo letatelnogo apparata" [High-frequency method for calculating the scattering of secondary radiation from the dielectric parts of the unmanned aerial vehicle model], *Information Processing Systems*, No. 2(118), pp. 58-62.

12. Ryapolov, I.E. (2016), "Vysokochastotnyi asymptotychnyi metod rozrakhunku vtorynnoho vyprominiuvannia modeli bezpilotnoho litalnoho aparatu" [High-frequency asymptotic method of calculation of the secondary radiation model unmanned aerial vehicle], *Science and Technology of the Air Force of Ukraine*, No. 3(24), pp. 86-89.

Надійшла до редколегії 23.06.2017
Схвалена до друку 7.09.2017

Відомості про авторів:

Нечитайло Сергій Вячеславович
кандидат технічних наук старший науковий співробітник
провідний науковий співробітник Харківського
національного університету Повітряних Сил
ім. І. Кожедуба,
Харків, Україна
orcid.org/0000-0002-5341-8684
e-mail: nechitaylo_s@ukr.net

Сухаревський Олег Ілліч
доктор технічних наук професор
провідний науковий співробітник Харківського
національного університету Повітряних Сил
ім. І. Кожедуба,
Харків, Україна
orcid.org/0000-0002-4607-5361
e-mail: sukharevsky@euro.dinos.net

Василець Віталій Олексійович
доктор технічних наук старший науковий співробітник
провідний науковий співробітник Харківського
національного університету Повітряних Сил
ім. І. Кожедуба,
Харків, Україна
orcid.org/0000-0002-3614-559X
e-mail: rainbow.dome@gmail.com

Information about the authors:

Nechitaylo Sergey
Candidate of Technical Sciences Senior Research Associate,
Lead Researcher of Ivan Kozhedub Kharkiv National Air
Force University,
Kharkiv, Ukraine
orcid.org/0000-0002-5341-8684
e-mail: nechitaylo_s@ukr.net

Sukharevsky Oleg
Doctor of Technical Sciences Professor,
Lead Researcher of Ivan Kozhedub Kharkiv National Air
Force University,
Kharkiv, Ukraine
orcid.org/0000-0002-4607-5361
e-mail: sukharevsky@euro.dinos.net

Vasilets Vitaly
Doctor of Technical Sciences Senior Research Associate,
Lead Researcher of Research Centre of Ivan Kozhedub
Kharkiv National Air Force University,
Kharkiv, Ukraine
orcid.org/0000-0002-3614-559X
e-mail: rainbow.dome@gmail.com

ХАРАКТЕРИСТИКИ ВИПРОМІНЮВАННЯ АПЕРТУРНОЇ АНТЕНИ, ЩО РОЗТАШОВАНА ПІД КОНІЧНИМ ДВОШАРОВИМ РАДІОПРОЗОРИМ ОБТІКАЧЕМ

С.В. Нечитайло, О.І. Сухаревський, В.О. Василець

Запропонований розрахунковий метод для отримання характеристик випромінювання восьмикутової апертурної антени, що розташована під двошаровим конічним діелектричним обтікачем. При цьому використовується розроблений авторами раніше метод для розрахунку поля випромінювання апертурної антени, що вирізана у ідеально поглинаючому екрані, у присутності довільної системи розсіювачів (а саме, обтікача). Наводяться результати розрахунків діаграм спрямованості апертурної антени під двошаровим обтікачем для різних параметрів шарів. При розрахунках було використане рішення модельної задачі про розсіяння плоскої електромагнітної хвилі на двошаровій плоскопаралельній структурі.

Ключові слова: *радіопрозорий обтікач, апертурна антена, характеристики випромінювання, розсіяння електромагнітної хвилі.*

ХАРАКТЕРИСТИКИ ИЗЛУЧЕНИЯ АПЕРТУРНОЙ АНТЕННЫ, НАХОДЯЩЕЙСЯ ПОД КОНИЧЕСКИМ ДВУХСЛОЙНЫМ РАДИОПРОЗРАЧНЫМ ОБТЕКАТЕЛЕМ

С.В. Нечитайло, О.И. Сухаревский, В.А. Василец

Предложен расчетный метод для получения характеристик излучения восьмиугольной апертурной антенны, находящейся под двухслойным коническим диэлектрическим обтекателем. При этом используется разработанный авторами ранее метод для расчета поля излучения апертурной антенны, вырезанной в идеально поглощающем экране, в присутствии произвольной системы рассеивателей (в частности, обтекателя). Приводятся результаты расчетов диаграмм направленности (ДН) апертурной антенны под двухслойным обтекателем для различных параметров слоев. При расчетах использовалось решение модельной задачи о рассеянии плоской электромагнитной волны на двухслойной плоскопараллельной структуре.

Ключевые слова: *радиопрозрачный обтекатель, апертурная антенна, характеристики излучения, рассеяние электромагнитной волны.*