Radar Signal Attenuation due to Finite Radome Thickness

Slabljenje radarskog signala zbog ograničene debljine kućišta

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Summary

Radar antennas deployed in real use usually include a protective dome, which shields them from potentially harmful weather conditions. The protective dome is typically constructed from a plastic material, which can affect the radar signal. The presented paper deals with signal attenuation caused by radar's dome. It provides results of a computer simulation concerning this attenuation based on different thickness of the material used for radome construction. The presented results give insight on the impact of different radome material thickness on overall radar aperture gain.

KEY WORDS
radar
radome
material thickness
gain

Sažetak

Radarske antene koje se koriste u stvarnosti obično imaju zaštitnu kupolu koja ih štiti od potencijalno štetnih vremenskih uvjeta. Zaštitna kupola obično je napravljena od plastike, koja može utjecati na radarski signal. U ovom radu govori se o slabljenju signala uzrokovanom kupolom radara. Izloženi su rezultati kompjuterske simulacije slabljenja na temelju različitih debljina materijala koji se koriste u izradi kućišta. Rezultati daju uvid u utjecaj različitih debljina materijala od kojih se prave kućišta na ukupni dobitak otvaranja radara.

KLJUČNE RIJEČI
radar
kućište
debljina materijala
dobitak

INTRODUCTION

Modern radar antennas often incorporate advanced technologies, which makes them not only high-performance devices, but also fine devices construction-wise, therefore susceptible to conditions of the environment in which they are used. Radar antennas used in real-world have to be protected from these conditions, which include high wind, rain, snow and icing. Such protection is achieved by covering the radar by a protective dome, shortly called radome. The radome should be transparent to radio frequency so that it does not degrade the electrical performance of the enclosed antenna [1]. Radomes are used for wide variety of applications, for example in maritime, ground and aircraft radar systems. Anywhere the environment protection is needed.

Good transparency of a radome to the desired radio frequency can be achieved by constructing the dome out of a material of a low relative permittivity (dielectric constant). A material of low relative permittivity reduces reflections, which rise from the different impedance of the free space and the dielectric material. Reduced reflections minimize their impact on the radiation pattern and insertion loss [2]. Impedance of a material can be calculated as:

$$Z = \sqrt{\frac{\mu}{\varepsilon}} = \sqrt{\frac{\mu_0 * \mu_r}{\varepsilon_0 * \varepsilon_r}} \tag{1}$$

where:
Z – impedance [Ω],
μ – permeability [H/m],
μ_0 – permeability of free space, $\mu_0 \approx 1{,}256 * 10\text{-}6$ [H/m],
μr – material relative permeability,
ε – permittivity [F/m],
ε_0 – permittivity of free space, $\varepsilon_0 \approx 8{,}854 * 10\text{-}12$ [F/m],
ε_r – material relative permittivity.

Impedance of free space is roughly equal to 377Ω. Many plastic materials have the desired low relative permittivity, typically of values ranging from 2 to 5, and are also strong enough to support the radome construction. There are several ways of constructing the radome wall, defined as radome styles [1]:

Style A: half-wave wall monolithic radome
Style B: thin wall monolithic radome, with thickness of maximum 0,1λ at the highest operating frequency
Style C: three-layered wall of two high-density shells and one low-density core, also called A-sandwich
Style D: multi-layered wall of five and more layers, with odd number of high-density layers and an even number of low-density core layers
Style E: other radome constructions, not fitting into any of the A to D style definition

This paper analyses the radio signal attenuation of a monolithic wall construction of thickness ranging from 0,1λ to 1,5λ, which falls into style categories of A, B and E, with emphasis on the half-wave wall monolithic radome. The principle of the half-wave radome is that the electromagnetic wave radiated by the radar antenna travels 180° through the radome wall, is reflected with a phase shift of -180°, and travels another 180° on the return trip to achieve the net 180° phase shift required for cancellation, which minimises the signal losses [2]. The thickness of the half-wave radome wall has to consider the lower speed of electromagnetic wave propagation caused by the electric properties of the wall material. The half-wave thickness is therefore calculated as:

$$t = \frac{1}{2} * \frac{v}{f} = \frac{1}{2} * \frac{c_0}{f * \sqrt{\mu_r * \varepsilon_r}} \approx \frac{1}{2} * \frac{\lambda_0}{\sqrt{\varepsilon_r}}, \qquad (2)$$

where:

t – desired wall thickness [m],

v – speed of wave propagation inside the wall [m/s],

f – operating frequency [Hz],

c_0 – speed of wave propagation in free space, c_0 = 299 792 458 [m/s],

λ_0 – wavelength in free space [m],

μ_r – wall material relative permeability, usually neglected due to valuebeing close to 1,

ε_r – wall material relative permittivity.

The optimal distance between the radar antenna and the radome is 0,5λ_0 considering free space between these two components, which minimises the effects of reflections caused by the radome [3]. The original research presented in this paper is based on this current knowledge and specialises onthe effect that monolithic wall thickness has on the signal strength perceived outside the radome construction.

DESCRIPTION OF RESEARCH METHODS

The effect of different thickness of a radome on the signal strength was analysed with a computational tool FEKO, which implements suitable numerical method for solving this issue. A computer model of a radiating element in the X-band was created, the element being chosen to be a resonant dipole at the operating frequency of 9,4 GHz. This frequency corresponds to λ_0 ≈ 3,189 cm.The radiating element was then put into a hollow spherical shell of dielectric material, while thickness of this shell was the base variable in this research. Created spherical shell all around the dipole ensures no unwanted deformation of the dipole's radiation pattern. Centre of the dipole was placed at Cartesian coordinates [0,0,0]. Distance between the centre of the dipole and the inner wall of the shell remained always constant and was set to 0,5λ_0. Vertical cut of such model is illustrated in Fig. 1.

The construction material of the shell wall was chosen to be polyvinyl chloride (PVC) with relative permittivity ε_r= 3,19 and dielectric loss tangent tanδ = 0,0096 [4]. The wavelength in this dielectric material is, as can be seen from equation (2), roughly equal to λ_d ≈ 1,786cm. Thickness of the wall was varied from 0,1λ_d to 1,5λ_d with step of 0,1λ_d. The $\lambda_d$is in the result chapter of this paper referred to as the λ, without index, as it is the actual wavelength of interest.

Regarding the computer simulation itself, it was

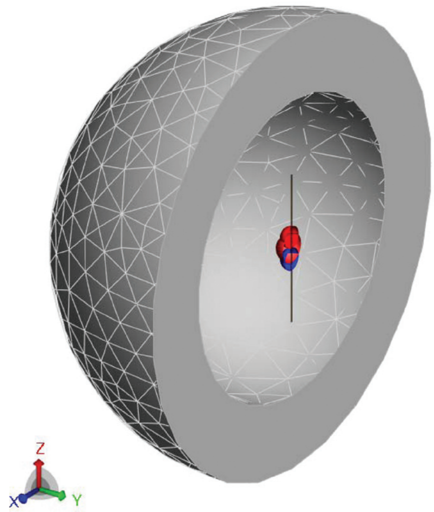

Figure 1 Vertical cut of the simulation model

performed in the FEKO Suite 6.1. The numerical method for the computation was set to the method of moments. Meshing rules were set to triangle edge length and wire segment length of approximately 0,399 cm and the wire segment radius was set to be 0,010cm. Outlines of the created mesh grid can be seen in the Fig. 1.

Evaluated parameter of this research was the achieved overall antenna gain, perceived outside the dielectric dome, in the horizontal XY plane (θ=90°). In this plane the distance between the dipole and the inner wall of the dome is the desired 0,5λ_0 and the peak of radiation is located in this plane due to the dipole placement. The effect of the shell dome is evaluated as the difference between the gain of the dipole inside the dome and the gain of the dipole without any dome. It is referred to this difference in the presented figures as the signal pass.

Due to the fundamental principle of numerical solution and the necessary triangular mesh, the resulting gain can slightly differ based on angular position of the gain calculation in the analysed horizontal plane. Therefore gain in all angular positions (φ = 0° … 360°) was recorded, with step change of 1°, and the average value was calculated. This ensures that comparison of different dome thicknesses, every which has a different mesh, can be done objectively.

RESULTS

The described simulations were performed and the resulting graph is displayed in Fig. 2.

The obtained trace has clear descending character, which is caused by the increased absorption of the wave energy due to the increased dielectric material thickness [5]. The trace also has local maximums and minimums. These peaks are caused by reflections of the electromagnetic wave on the dielectric / free space boundary [5].

The results from Fig. 2 show peak of signal strength at thickness just a bit less than 0,5λ. Therefore more simulations were performed and the more precise value of the ideal radomethickness was found. Detail on this area is displayed in Fig. 3.

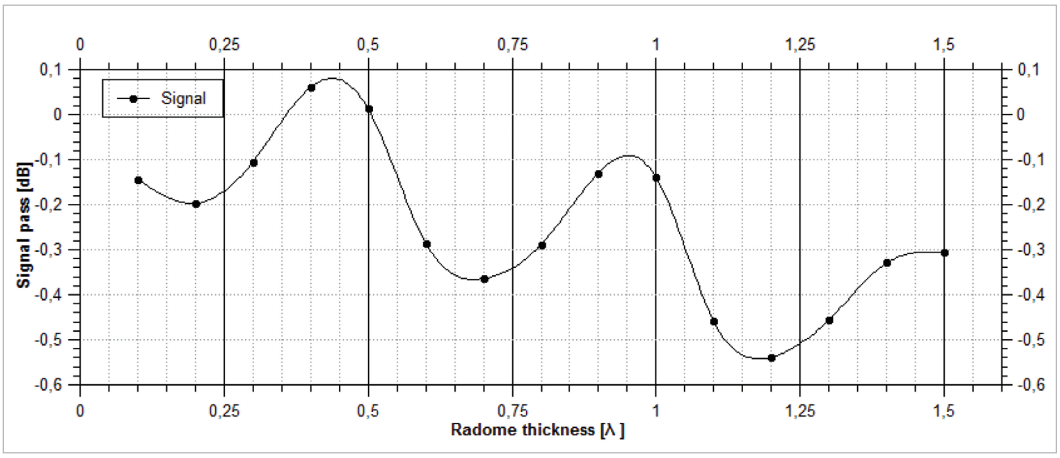

Figure 2 Signal pass dependence on the radome thickness

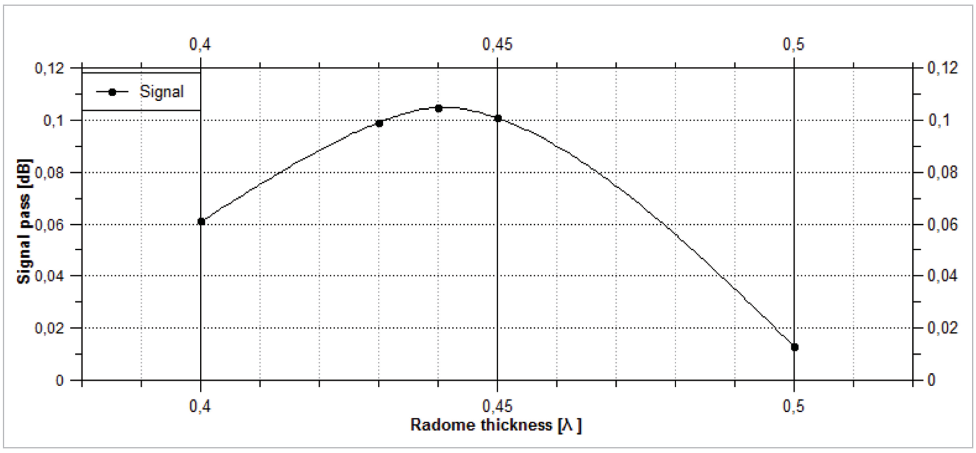

Figure 3 Detailed view on the peak signal strength

As the Fig. 3 shows, the simulated peak of signal strength perceived outside the dome is in case of radome thickness of 0,44λ. This does not completely correspond to known information, as described in the introduction chapter of this paper. Other interesting fact is that the signal is not attenuated at this material thickness as expected, but is rather slightly amplified. As the total input power of the radiating element remained constant during all simulations, this signal amplification in horizontal plane should manifest as deeper attenuation in other angular positions. This subject was assessed as change of gain in the vertical plane. A signal pass of dipole with no radome, a signal pass of dipole with a 0,44λ thick radome and with a 0,5λ thick radome is displayed in Fig. 4to better illustrate this firm change. The signal pass is shown in linear scale for the same reason.

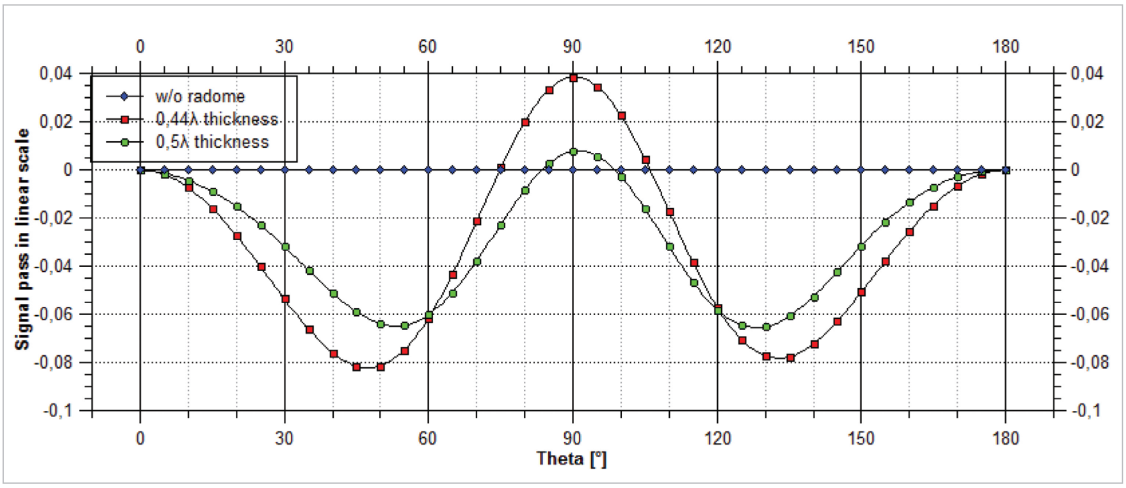

Figure 4 Signal pass in vertical plane

Data from Fig. 4 indicate stronger signal in elevation positions around the horizontal plane (θ = 90°) at the expense of other angular positions, which confirms the slight difference in radiation pattern caused by the dielectric dome around the dipole. Average of signal pass for the 0,44λ thickness was approximately -0,0299 and for the 0,5λ approximately -0,0283. This results shows that even though the peak gain of the 0,44λ thick radome is higher, the overall gain is better for the 0,5λradome, which is in compliance with the knowledge presented in the introduction chapter of this paper. An apparent conclusion based on the obtained results can be made.

CONCLUSION

The presented paper dealt with the variable radome thickness of spherical shape and its effect on the radar antenna gain in the horizontal plane. In this plane the antenna's main lobe axis and the dome wall were perpendicular to each other. Main attention was drawn to the half-wavelength monolithic type of radome. The obtained results of computer simulation declared that the maximum gain is achieved when 0,44 wavelength thick radome is used, as opposed to theoretically most suitable 0,5 wavelength thickradome.It is shown later in the paper that this is due to the slight alteration of the antenna's radiation pattern caused by the spherical dome, specifically the antenna beam narrowing in the vertical plane. The best overall spatial gain is achieved by using the 0,5 wavelength thick radome as expected by theory. Theacquired information of radar beam narrowing could possibly be used in radome construction, where this difference in thickness would be used with advantage, concerning the maximum achievable antenna gain in the desired angular direction. However, this premise has yet to be verified by measurements in real conditions, which gives foundation for the future work.

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