Theoretical and Experimental Analysis of the Impact of Conformal Surface on Parameters of Microstrip Antennas

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Abstract— The article presents analysis of the impact of conformal antennas radius of curvature on their basic parameters and characteristics of radiation. In order to verify the numerical results there were built models of practically analyzed conformal antennas, their measurements were taken in anechoic chamber and compared to those of planar antennas. Numerical analysis has been carried out (for basic shapes: cylinder, sphere, toroid) using CST Studio Suite software. Analysed antenna worked within frequency range between 2200–2300 MHz (aviation, in telemetry systems).

1. INTRODUCTION

The main reason for intensive development of conformal microstrip antennas is the fact that it is relatively easy to integrate them with the shape of the surface on which they are installed [11, 15, 16, 24]. Mainly this applies to aircraft, spacecraft, high-speed trains, rockets and missiles in which each projecting element affects adversely aerodynamics, fuel consumption, etc., while conformal antenna can be in a simple way mounted on the aircraft wings or on the outer surface of the hull. This is particularly important as on the surfaces of modern aircraft there are often more than 30 different antenna systems installed.

Another reason for rapid development of conformal microstrip antennas is their easy incorporation into existing elements of urban architecture. Antennas are an essential element of the plurality of measurement [5–8, 10, 19–21]. In microstrip antennas are important parameters of the dielectric, which can be explored to measure in accordance with the methods described in the [1, 2, 9, 12, 16].

2. ANALYZED MODELS OF ANTENNAS

To analyze the impact of conformal antennas radius of curvature on their basic parameters and characteristics of radiation there was selected frequency ranges: 2200–2300 MHz. This range is used in aviation, in telemetry systems.

For selected frequency was designed planar coaxially fed microstrip antenna. Then each antenna was placed sequentially on conformal surfaces: cylinder, sphere, torus, where for each of them full-wave analysis of antennas numerical parameters was carried out in CST Studio Suite.

Figure 1 shows analyzed conformal antenna placed on the side surface of the cylinder. Radiating element has a rectangular shape with dimensions $2L = 38.0$ mm and $2b\Phi = 39.4$ mm (width of radiating element as seen from inside of the cylinder). This element is placed on a dielectric of thickness $h = R - b = 3.048$ mm, dielectric permittivity $\varepsilon = 2.55$. The antenna is fed by a $50\,\Omega$ coaxial probe ($\Phi_p = 5.54$ mm; $Z_p = 5.84$ mm). Around the cylinder of R radius there is vacuum of parameters: $\varepsilon_0\, i\, \mu_0$.

For each conformal surface radius length was varied in the range 30–10000 mm. It took on average about 1 hour to perform antenna analysis for selected single radius length by applying distribution of analysed antenna's structure in the programme CST Studio Suite at about 6 million meshcells and using PC with processor Intel Core Duo (E4500, 2.2 GHz, 2 GB RAM). Each antenna was analysed for 30 different radius length of conformal surface. Results of conformal antenna analysis for subsequent changes of the radius of curvature R are presented on consecutive figures. Obtained results of the analysis are plotted on graphs as red "×" (for each R change) and connected with each other by B-spline curves (Basis spline function). Dashed line marks value of the parameter for corresponding planar antenna.

3. CONFORMAL ANTENNA ON THE SIDE SURFACE OF THE CYLINDER

The chapter presents analysis of conformal coaxially fed antenna (shown on Figure 1) working in the frequency range between 2200–2300 MHz and placed on the side surface of the cylinder with radius R, which value was changed within the range 30 mm–10000 mm ($0.227\lambda_0$–$75.717\lambda_0$). The aim of this analysis is to examine impact of curvature of the side surface of the cylinder on antenna's basic parameters.

The graph in Figure 2 shows dependence of antenna resonance frequency f_0 on cylinder radius R. Almost for all changes of radius length the value of antenna resonance frequency is maintained at the level of planar antenna resonance frequency $f_0 = 2.27\,\text{MHz}$ (dashed line). Only in the range of low values of radius $R < \lambda_0$ we can observe increase in resonance frequency.

Next Figure 3 shows dependence of reflection coefficient S_{11} for conformal antenna resonance frequency placed on cylinder side surface depending on cylinder radius R. On the graph we can see that value of reflection coefficient S_{11} for $R > 12\lambda_0$ is almost constant and equals $S_{11} = -19.74\,\text{dB}$. For radius value $R < \lambda_0$ this coefficient decreases its value even to the level of $S_{11} = -43.5\,\text{dB}$.

Dependence of reflection coefficient S_{11} of low values of cylinder radius $r < 1.5\lambda_0$ of conformal antenna placed on the cylinder side surface is shown in Figure 4.

Figure 5 presents bandwidth of cylindrical conformal antenna Δf depending on cylinder radius R.

4. CONFORMAL ANTENNA OF THE SPHERE SURFACE

Antenna shown in Figure 1 was next placed on the sphere surface with radius R. Analysis results for antenna working in the frequency range 2200–2300 MHz placed on the surface of the sphere are shown in Figures 6–9.

The graph in Figure 6 shows dependence of antenna resonance frequency f_0 of the sphere radius R. Almost for all changes of radius R resonance frequency of the antenna is maintained at the level of planar antenna resonance frequency $f_0 = 2.27\,\text{MHz}$. Only in the range $R < \lambda_0$ we can observe

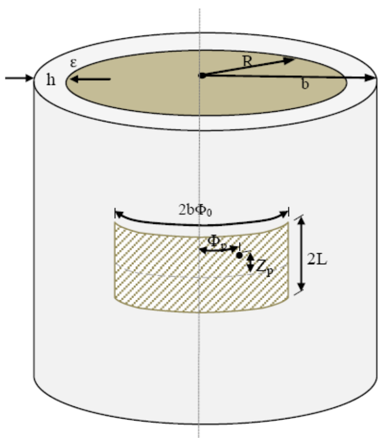

Figure 1: Analyzed conformal antenna on the side surface of the cylinder.

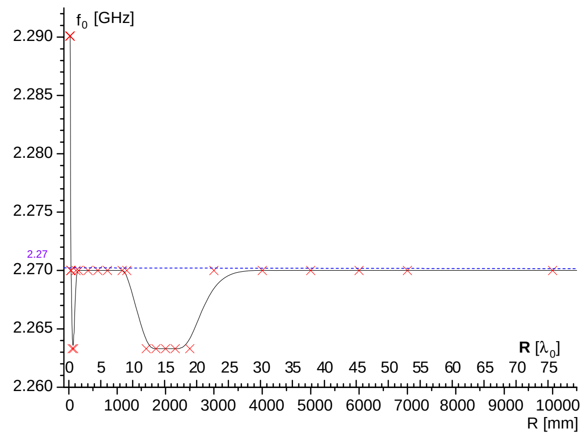

Figure 2: Resonance frequencies of conformal cylindrical antenna depending on length of cylinder radius R.

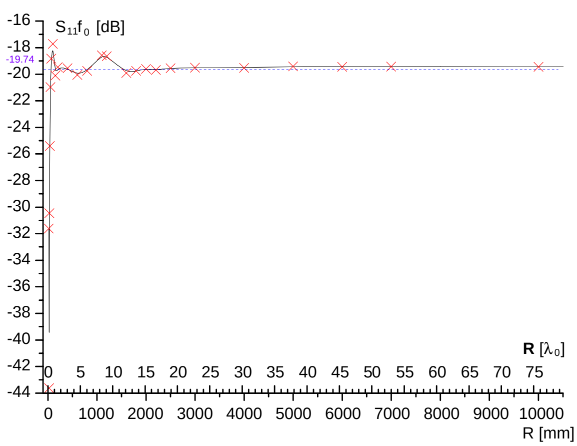

Figure 3: Reflection coefficient S_{11} of cylindrical conformal antenna depending on length of cylinder radius R.

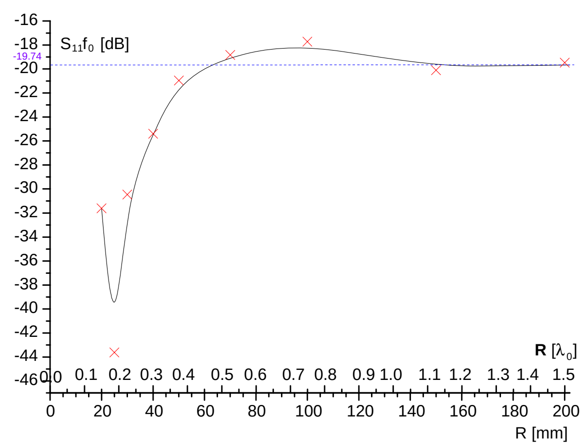

Figure 4: Reflection coefficient S_{11} of cylindrical conformal antenna depending on length of cylinder radius ($R < 1.5\lambda_0$).

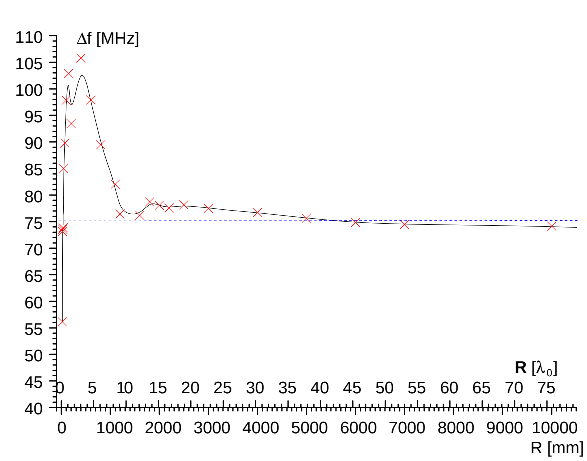

Figure 5: Bandwidth depending on length of cylinder radius R.

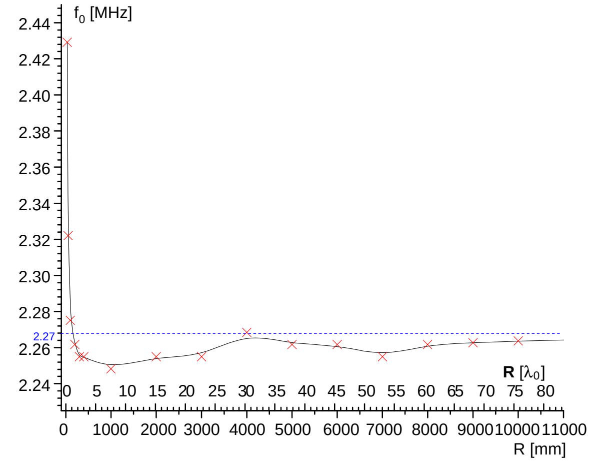

Figure 6: Resonance frequencies of conformal antenna depending on length of sphere radius R.

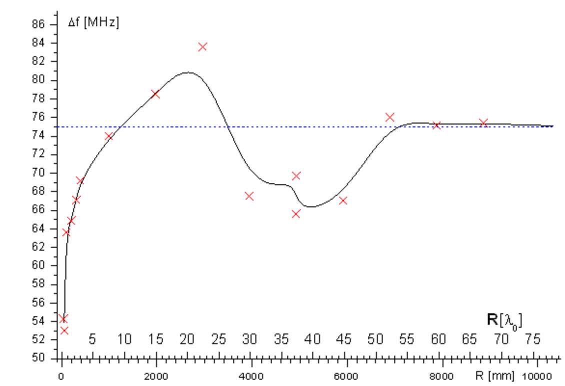

Figure 7: Bandwidth depending on length of sphere radius R.

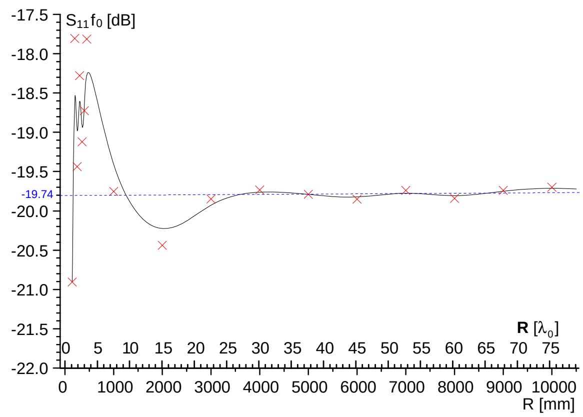

Figure 8: Reflection coefficient S_{11} of conformal antenna depending on length of of torus radius R.

dramatic increase in resonance frequency.

Figure 7 shows bandwidth of antenna Δf depending on radius R of the sphere on which the antenna is placed.

5. CONFORMAL ANTENNA ON THE TORUS SURFACE

Antenna shown in Figure 1 was next placed on the torus surface with internal radius $r = 0.379\lambda_0$ (50 mm) and external radius R which was changed in the range 30 mm–10000 mm ($0.227\lambda_0$–$75.717\lambda_0$).

Figure 8 shows dependence of reflection coefficient S_{11} of torus radius R for antenna resonance frequency f_0. We can observe in the graph that value of reflection coefficient for resonance frequency is practically constant for $R > 23\lambda_0$. For radius length range $R = 3$–$7\lambda_0$ value of reflection coefficient for resonance coefficient is set at the highest values, approx. -18.0 dB.

6. CONCLUSIONS

In order to verify if numerical analysis carried out in previous chapters are correct some models of antennas were built practically and their basic parameters were measured. As part of research the following antennas were built: planar and three cylindrical antennas with radius of curvature $R = \lambda$, 2λ, 4λ.

Practically built antennas have very similar conditions to results obtained during computer-aided numerical simulation in CST Studio. Discrepancies between resonance frequencies of built antennas and simulation results stay at the level of a single percent.

The research presents analysis results of impact of conformal antenna radius of curvature antennas (for shapes: cylinder, sphere, torus) on their basic parameters. In order to verify obtained numerical results some models of conformal antennas were built and tested.

As results from presented analysis the radius of curvature of the surface on which microstrip antenna was placed clearly affects the performance of this antenna for low values of $R < \lambda_0$. For large values of the radius of surface curvature the impact is negligibly low, for the transition areas it stays at several or ten-odd percent.

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