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Synthesis of Omnidirectional Circular Cylindrical Stacked Patch Antenna

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Original scientific paper

The stacked conformal omnidirectional patch antenna, manufactured on cylindrical multilayered structure is presented. In order to obtain good wideband matching as well as omnidirectional azimuthal radiation pattern, the numerical simulation is used in conjunction with optimization procedure. The antenna was built and its gain and radiation pattern were measured. These measurements, including the measured radiation pattern with 4 dB omnidirectionality approved the idea of applying stacked patch configuration for wideband operation of circular cylindrical patch antennas.

Key words: antennas, method of moments, microstrip antennas

1 INTRODUCTION

The antenna research today is continuously encouraged by new demands in mobile communications industry, as well as in other wireless topics, such as Bluetooth or WLAN. Challenging demands are put at different antenna properties, ranging from antenna bandwidth, polarization, radiation pattern or size reduction to economic aspects such as production costs.

In this paper, the stacked conformal patch antenna manufactured on cylindrical multilayered structure is presented. The aim was to create wideband antenna in 1.9 GHz band with omnidirectional radiation pattern in azimuthal plane. The previous work [1] was carried out as a single patch configuration and it lacked on a narrow bandwidth. In order to obtain good wideband matching as well as omnidirectional radiation pattern in azimuthal direction, the rigorous moment method program was developed [2] and applied in conjunction with optimization procedure.

The optimized antenna was built and its input impedance, gain and azimuthal radiation pattern were measured.

2 ANTENNA DESIGN

The antenna (Figure 1) consists of metallic ground cylinder, equivalent to ground plane in planar microstrip layout, and of two coaxial circular cylindrical dielectric shells with rectangular patches printed on them. The space between shells is filled with air. The patches are centered, i.e. their centers lay on a line perpendicular to the axis of the cylinder. The driven patch (inner patch) is fed by a coax probe.

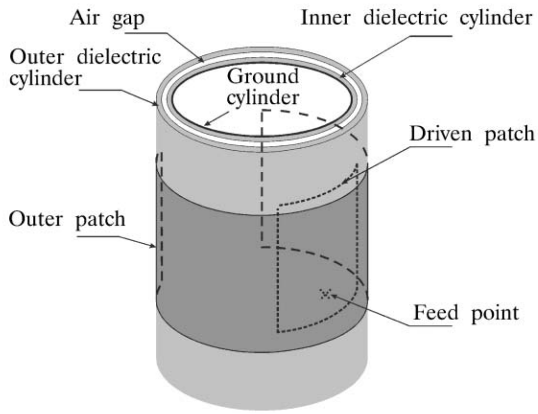

Fig. 1 The sketch of the antenna

The design consisted of optimization of all patch dimensions and feed position in order to obtain well matched and omnidirectional antenna. For that purpose, a rigorous program was developed [2].

The numerical simulation is based on EFIE (*Electric Field Integral Equation*) approach, where the component of total electric field tangential to patch surface must equal zero:

$$\hat{n}\times(\mathbf{E}^{scat}+\mathbf{E}^{inc})=0. \qquad (1)$$

Here, $\mathbf{E}^{inc}$ represents the incident field and $\mathbf{E}^{scat}$ is the field excited by the patch current. By using the dyadic Green's function $\bar{\bar{\mathbf{G}}}$ for circular-cylindrical structure we get the following equation:

$$\iint_{\text{patch}} \overline{\overline{\mathbf{G}}}(\phi,z,\rho_{\text{patch}} \,|\, \phi,z,\rho_{\text{patch}}) \cdot \mathbf{J}_{\text{patch}}(\phi,z)\, \mathrm{d}S \,+$$

$$+ \iiint_{\text{feed}} \overline{\overline{\mathbf{G}}}(\phi,z,\rho_{\text{patch}} \,|\, \phi,z,\rho) \cdot \mathbf{J}_{\text{feed}}(\phi,z,\rho)\, \mathrm{d}V = 0 \qquad (2)$$

on patches.

Here $\mathbf{J}_{\text{patch}}$ and $\mathbf{J}_{\text{feed}}$ denote the current on the patch and on the feeding line, respectively.

The patch current is expanded into weighted sum of basis functions:

$$\mathbf{J}_{\text{patch}}(\phi,z) = \sum_i \alpha_i \mathbf{J}_i(\phi,z), \qquad (3)$$

where α_i represents complex amplitude of each current mode that was taken into account. The values of α_i are determined by applying the moment method (MoM). As basis functions we have used the entire-domain basis functions, i.e., the basis functions which are defined on the whole patch. They are sinusoidal in the current direction and they are of constant/sinusoidal distribution in the perpendicular direction, which is a common approximation since patch antennas are resonant structures. For test functions we have used the basis functions (Galerkin method). The elements of the MoM matrix are evaluated in spectral domain, since the Green's functions are also determined in spectral domain. We use the one-dimensional Fourier transformation in the z direction and the Fourier series in the φ direction, defined by

$$\tilde{f}(m,k_z,\rho) = \int_{-\infty}^{\infty} \int_{-\pi}^{\infty} f(\phi,z,\rho)\, e^{jm\phi} e^{jk_z z}\, \mathrm{d}\phi\, \mathrm{d}z, \qquad (4a)$$

$$f(\phi,z,\rho) = \frac{1}{4\pi^2} \sum_{-\infty}^{\infty} \int_{-\infty}^{\infty} \tilde{f}(m,k_z,\rho)\, e^{-jm\phi} e^{-jk_z z}\, \mathrm{d}k_z. \qquad (4b)$$

The elements of the impedance matrix $[Z]$ and voltage vector $[V]$ can be expressed as:

$$Z_{ij} = \frac{1}{4\pi^2} \sum_{-\infty}^{\infty} \int_{-\infty}^{\infty} \tilde{\mathbf{J}}_i(-m,-k_z)\, \overline{\overline{\tilde{\mathbf{G}}}}(m,k_z,\rho_{\text{patch}} \,|\, \rho_{\text{patch}}) \cdot$$
$$\cdot \tilde{\mathbf{J}}_j(m,k_z)\, \mathrm{d}k_z,$$
$$V_i = \frac{1}{4\pi^2} \sum_{-\infty}^{\infty} \int_{-\infty}^{\infty} \int_{\text{feed}} \tilde{\mathbf{J}}_i(-m,-k_z)\, \overline{\overline{\tilde{\mathbf{G}}}}(m,k_z,\rho_{\text{patch}} \,|\, \rho') \cdot \qquad (5)$$
$$\cdot \hat{\rho}\, e^{jk_z Z_{\text{feed}}^n} e^{jm\phi_{\text{feed}}^n}\, \mathrm{d}\rho'\, \mathrm{d}k_z.$$

We have used the G1DMULT algorithm [3–5] for numerical calculation of Green's functions of general multilayer circular-cylindrical structure. The considered antenna is a three layer structure, and it is almost impossible to derive an analytical expression of Green's function for such a structure. Furthermore, when using general approach of calculating the Green's functions we can easily change the structure. For example, if a dielectric cylinder radome is needed for atmospheric and mechanical protection of the antenna, it can be included in calculation as another dielectric layer (superstrate of the antenna). However, the general algorithm for calculating Green's function needs more CPU time than algorithm which uses the coded analytical expressions.

The optimization was performed using quasi-Newton direct search method [6]. The optimized variables are length and width of both patches and the probe position. The cost function took into account matching at five frequencies: 1.885 GHz, 1.915 GHz, 1.945 GHz, 1.9775 GHz, 2.005 GHz using the formula:

$$\text{cost} = \sum_{i=1}^{5} \begin{cases} |\Gamma_i| & \text{if } |\Gamma_i| \le 0.3162 \\ 10 \cdot |\Gamma_i| & \text{if } |\Gamma_i| > 0.3162 \end{cases} \qquad (6)$$

where Γ_i represents input reflection coefficient. The value of 0.3162 for $|\Gamma_i|$ corresponds to the return loss of −10 dB. In order to avoid additional complexity of cost function, the omnidirectionality was forced by setting the large value for minimal width of outer patch. In more detail, minimal width of outer patch was set to be 10 cm, i.e. at least 285 degrees around the antenna. Furthermore, we experimentally checked if better omnidirectionality can be obtained by varying the width of the outer patch. The measurement results showed that the possible improvement is about 0.2 dB.

3 MEASUREMENT RESULTS

The structure of the built antenna is shown in Figure 1. The relative permitivity of dielectric material is $\varepsilon_r = 2.3$ with $\mathrm{tg}\,\delta = 0.0073$. The radii of the antenna layers are shown in Table 1. The dimensions of both patches, are shown in Table 2. The feed was placed at the azimuthal symmetry line, in order to obtain linear polarization in axial direction.

Notice that the inner patch is quite narrow, and the outer patch is quite wide. This is due to a fact that we wanted to get omnidirectionality (determined mostly due to the wide outer patch) and impedance matching (the radiation resistance of both patches should not be too low) simultaneously. Therefore the width of the inner patch in the presence of wide outer patch should be small. The input standing wave ratio (SWR) of the antenna is

Table 1 **The radii of the structure**

Ground tube	outer radius	1.4225 cm
Inner dielectric shell	inner radius	1.4225 cm
	outer radius	1.6025 cm
Outer dielectric shell	inner radius	1.8525 cm
	outer radius	2.0125 cm

Table 2 **Patch dimensions**

	Antenna dimensions	
	Axial direction	Azimuthal direction
Inner patch	5.30 cm	2.53 cm (90.10)
Outer patch	5.42 cm	10.0 cm (284.80)
Feed position (from center of inner patch)	2.18 cm	0 cm

shown in Figure 2, including the comparison with the numerically predicted values. The antenna is matched with SWR < 2 from 1.81 to 2.07 GHz, i.e. the relative bandwidth of the antenna is 13.4 %.

The measure of omnidirectionality is calculated as ratio between maximum and minimum of the relative radiation pattern. The omnidirectionality of the antenna, both simulated and measured is shown in Figure 3.

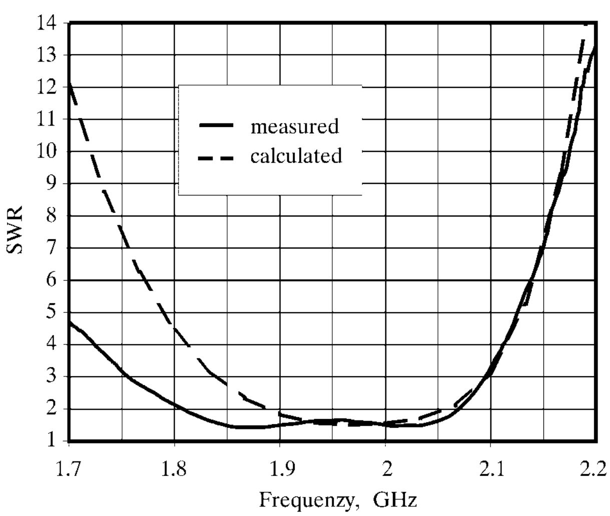

Fig. 2 Comparison of calculated and measured input SWR of the antenna

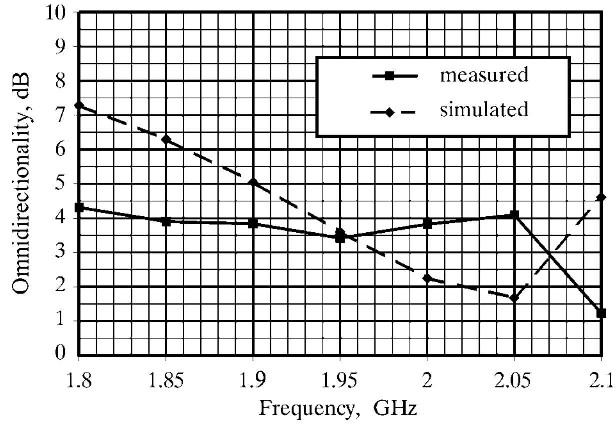

Fig. 3 Calculated and measured omnidirectionality in azimuthal plane

In Figure 4 the measured gain is shown. The gain was measured in radial direction which passes through patch centers and is perpendicular to cylinder axis. The gain varies between –3 and 1.5 dB within the band 1.8–2.1 GHz. When estimating the radiation efficiency based on the antenna gain, the fact that the radiation pattern maximum is slightly shifted at some frequencies, must be taken into account.

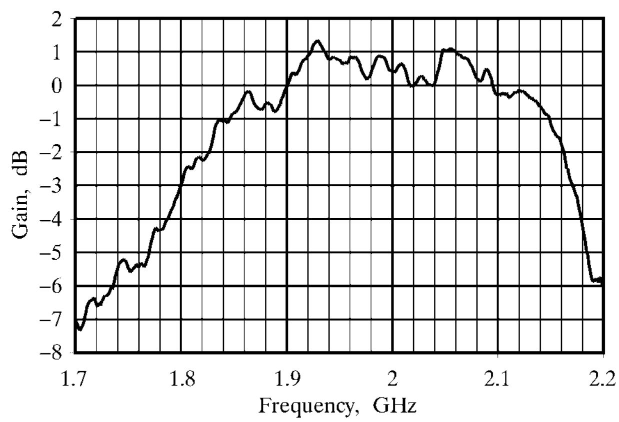

Fig. 4 The measured gain of the antenna

The measured azimuthal radiation pattern within the band of 1.8 to 2.1 GHz with steps of 50 MHz is shown in Figure 5. Cross-polarization pattern is also shown. A small asymmetry in radiation pattern at some frequencies is due to small inaccuracy of relative azimuthal alignment between the driven and the parasitic patch. It is observed that even small azimuthal shift between patches causes asymmetry in radiation pattern, due to excitation of TM_{11} mode on the upper patch. The measured cross-polarization level was around –20 dB.

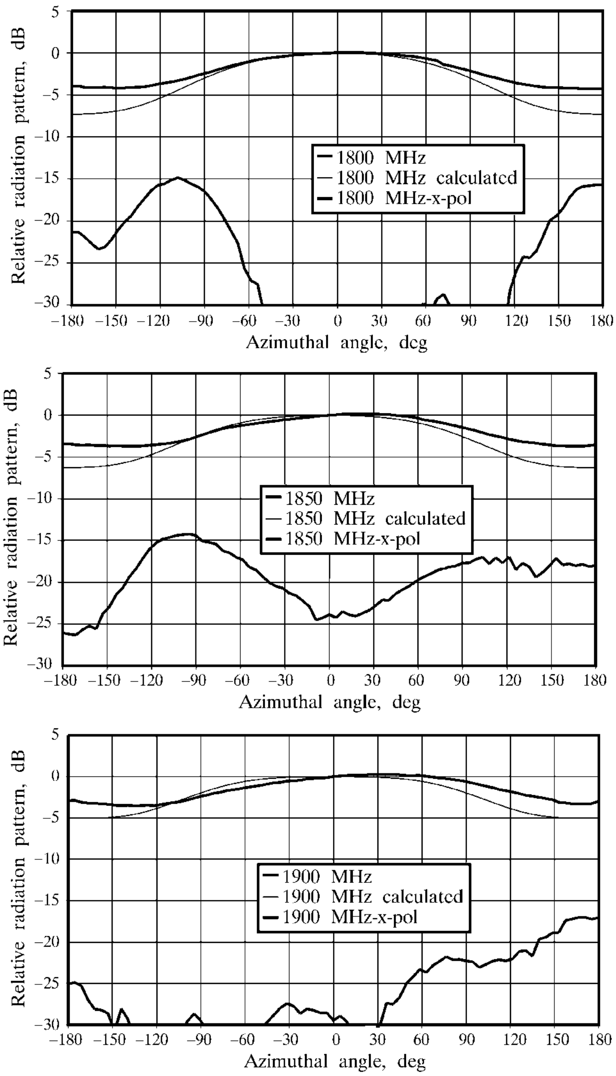

Fig. 5a The measured relative radiation pattern of the antenna in azimuthal plane (at 1800, 1850 and 1900 MHz)

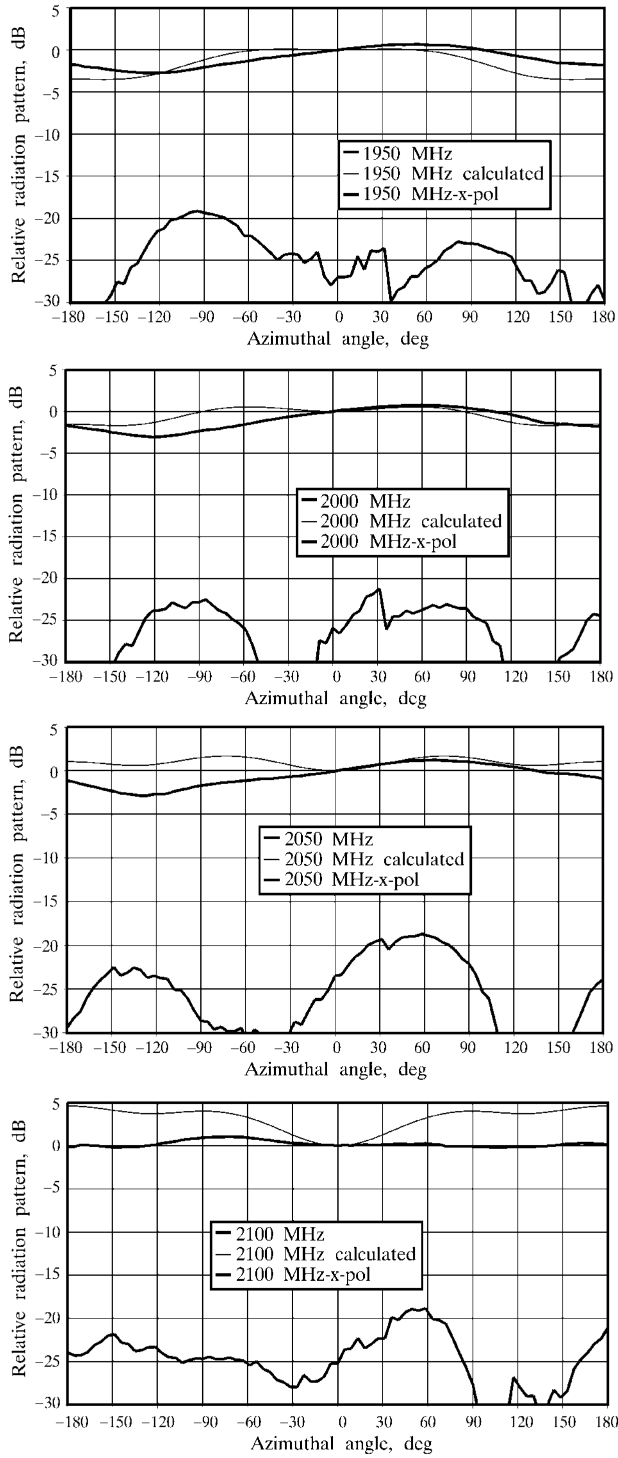

Fig. 5b The measured relative radiation pattern of the antenna in azimuthal plane (at 1950, 2000, 2050 and 2100 MHz)

4 CONCLUSIONS

The circular cylindrical multilayer stacked patch antenna with omnidirectional radiation pattern was considered. The antenna is rigorously analyzed by using MoM program, where the antenna structure is rigorously taken into account by using proper Green's functions and where the elements needed for MoM procedure and the Green's functions of multilayer cylindrical structure are calculated in spectral domain. In order to obtain omnidirectional radiation pattern and impedance matching, the patch dimensions and feed position were optimized. The antenna was built and its input impedance, gain and radiation pattern were measured. The measurement results presented in this paper, including the radiation pattern with approximately 4 dB omnidirectionality, approved the idea of applying stacked patch configuration for the wideband operation of circular cylindrical patch antennas.

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Sinteza neusmjerene cilindrične mikrotrakaste antene s parazitskim rezonatorom. Prikazana je neusmjerena mikrotrakasta antena s parazitskim rezonatorom, izvedena na višeslojnoj cilindričnoj strukturi. Upotrijebljen je numerički simulator povezan s optimizacijskim algoritmom, kako bi se ostvarilo dobro prilagođenje i neusmjeren dijagram zračenja u azimutalnoj ravnini. Antena je izrađena, te su na njoj provedena mjerenja dobitka i dijagrama zračenja. Izmjereni dijagram zračenja ima valovitost od 4 dB, što pokazuje opravdanost rabljenja mikrotrakaste antene s parazitskim rezonatorom na višeslojnoj cilindričnoj strukturi za postizanje neusmjerenog dijagrama zračenja.

Ključne riječi: antene, metoda momenata, mikrotrakaste antene

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