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EFFECTS OF AN EPOXY-RESIN-FIBER SUBSTRATE FOR A Ω-SHAPED MICROSTRIP ANTENNA

VPLIV Z VLAKNI OJAČANE EPOKSI PODLAGE PRI Ω-OBLIKI MIKROTRAKASTE ANTENE

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A Ω-shaped microstrip antenna using an epoxy-resin-fibre substrate is presented. The proposed antenna consists of a circular slot and two rectangular slots printed on a dielectric resin-fibre substrate and is excited by a 50-Ω microstrip transmission line. A commercially available, high-frequency structural simulator (HFSS) based on the finite-element method (FEM) was used in this investigation. The nearly omni-directional and bidirectional radiation pattern exhibited average gains of 3.12 dBi and 5.44 dBi for the lower band and upper band, respectively. The effects of epoxy-resin-fiber are discussed through comparisons of different substrate materials.

Keywords: epoxy resin-fibre, microstrip line, Ω-shaped

Predstavljena je mikrotrakasta antena Ω-oblike na epoksi podlagi, ojačani z vlakni. Predlagana antena sestoji iz krožne reže in dveh pravokotnih rež, natiskanih na dielektrični podlagi iz smole z vlakni in sta vzbujani s 50 Ω mikrotrakastim vodnikom. V tej preiskavi je bil uporabljen komercialno razpoložljiv visoko frekvenčni strukturni simulator (HFSS), ki temelji na metodi končnih elementov (FEM).V spodnjem in zgornjem pasu je vsesmerno sevanje kazalo 3,12 dBi, dvosmerno sevanje pa 5,44 dBi. Vpliv vlaken za ojačanje je bil prikazan s primerjavo različnih materialov podlage.

Ključne besede: vlakna za ojačanje epoksija, mikrotrakasta linija, Ω-oblika

1 INTRODUCTION

The microstrip patch antenna plays an important role as a harbinger in wireless communication systems and is now being used to address the changing demands of future antenna technology. The microstrip patch antenna has been extensively used in wireless communication systems, because they are conformal, have a low profile, are easy to fabricate with integrated circuits (ICs), and enable easy integration with array and electronic components. Many researchers have an interest in designing microstrip antennas and still face a major challenge to implement these applications. Currently, various types of antennas have been proposed to face the increasing requirements for a modern bearable wireless communication device that has the capability of consolidating more than one communication system into a single module.[1–6]

In[7], a rectangular slot antenna was proposed for dual-frequency operation. Su et al.[8] presented a printed dipole antenna using U-slot arms to enable dual-band operation. Suh and Chang[9] reported a low-cost microstrip dipole antenna for wireless communications. In[10], a PIFA antenna with a U-slot was presented for dual-band operation. Lin et al.[11] mentioned a dual-loop antenna for use with a 2.4/5 GHz Wireless LAN. A monopole antenna with double-T was presented in[12] for 2.4/5.2-GHz WLAN operations. A planar antenna was investigated with bandwidth enhancement for X-band applications[13]. An E-shaped patch antenna of wideband circularly polarized was presented for wireless applications[14]. A Compact 5.5-GHz Band-Rejected UWB Antenna was proposed using Complementary Split Ring Resonators[15]. A new double L-shaped multiband patch antenna was presented on a polymer resin material substrate[16].

In this study, a Ω-shaped microstrip antenna was designed on a 1.6-mm-thick epoxy-resin-fibre substrate material. The downlink frequency range is from 4.74 GHz to 4.87 GHz and the uplink frequency range is from 8.42 GHz to 8.73 GHz. The results will be discussed in detail with a parametric study.

2 ANTENNA GEOMETRY AND PARAMETRIC STUDY

High-Frequency Structure Simulator (HFSS), a commercially available Ansoft package, is a powerful and efficient three-dimensional (3D) full-wave simulation software that solves EM equations through the subdivision of a large problem into easy constituent units and then consolidating the solution as a matrix of simultaneous equations for the complete problem space, which provides a numerical solution to Maxwell's equations using the FEM. Hence, HFSS was used in this study.

The geometry of the proposed antenna is shown in **Figure 1**. The antenna comprises three conducting slots on the patch and two on the ground. A circular slot and two similar lateral rectangular slots are on the patch and two rectangular slots are on the ground of the proposed antenna. The two rectangular slots are of equal length L_P and width W_P. R is the radius of the circular slot. The design procedure begins with the radiating patch, along with the substrate, the ground plane and a feed line. The antenna was printed on a FR4 substrate with 1.6 mm in thickness that exhibits a relative permittivity of 4.60, a relative permeability of 1, and a dielectric loss tangent of 0.02. One circular slot and two rectangular slots are cut from the rectangular copper patch. Another two rectangular slots are also cut from the ground plane. In this manner, the proposed slotted circle patch antenna is produced. Two resonant frequencies of 4.51 GHz and 8.35 GHz are obtained by adjusting the length and width of the slots of the proposed antenna. Here, a microstrip line is used to feed the RF signal into the proposed antenna. The Sub Miniature version A (SMA) connector is used at the end of antenna feeding line for the input RF signal.

Finally, the optimal dimensions were determined as follows: L = 40 mm, L_p = 12 mm, L_g = 40 mm, L_s = 4 mm, R = 12 mm, W = 40 mm, W_p = 4 mm, W_g = 40 mm, M_l =17 mm, and M_w = 6 mm.

The epoxy-resin-fibre consists of reinforcing insulation material. There are various types of epoxy-resin-fibre material for use as an antenna substrate. In this study, we have used FR4 as the epoxy-resin-fibre substrate material that is impregnated with thermoset resin. FR4 has superior mechanical and dielectric properties, good moisture/heat resistance, stable electrical performance at high temperature, good flatness and a smooth surface. FR4 is widely used to produce printed-circuit boards (PCBs).

The length, width, *VSWR*, return loss of the patch antenna can be calculated from Equations (1) to (6) presented in[17], where L and W are the length and width of the patch, respectively, c is the velocity of light, ε_r is the dielectric constant of substrate, h is the thickness of the substrate, f_0 is the target centre frequency, ε_e is the effective dielectric constant and ρ is the radiation coefficient:

$$W=\frac{c}{2f_0}\sqrt{\frac{\varepsilon_r+1}{2}} \tag{1}$$

$$L=\frac{c}{2f_0\sqrt{\varepsilon_r}}-2\Delta l \tag{2}$$

$$\varepsilon_e=\frac{1}{2}(\varepsilon_r+1)+\frac{1}{2}(\varepsilon_r-1)\sqrt{\left(1+\frac{10h}{W}\right)} \tag{3}$$

$$\Delta l=0.412h\frac{(\varepsilon_e+0.3)(W/h+0.8)}{(\varepsilon_e-0.258)(W/h+0.8)} \tag{4}$$

$$VSWR=\frac{1+\rho}{1-\rho} \tag{5}$$

$$\text{Return loss}=-10\lg\left(\frac{1}{\rho^2}\right) \tag{6}$$

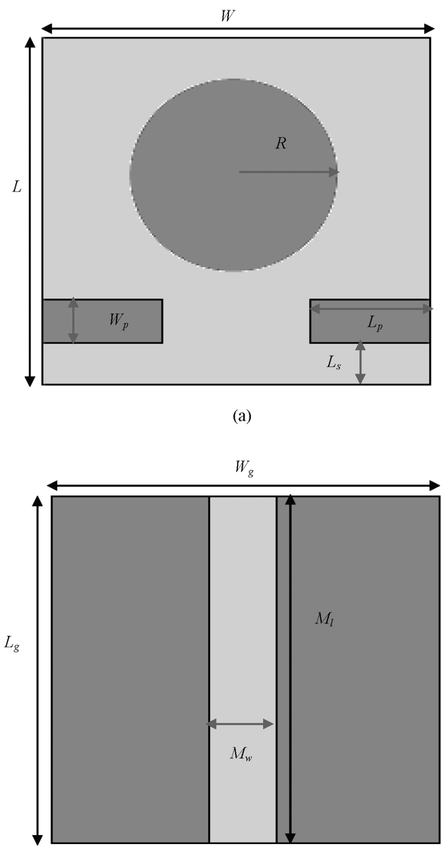

Figure 1: Proposed antenna: a) top view and b) bottom view
Slika 1: Predlagana antena: a) pogled iz vrha in b) pogled iz dna

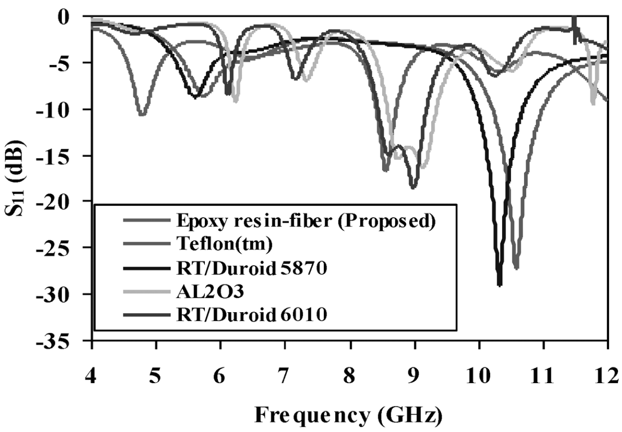

Figure 2: Return loss of simulation using different substrate materials
Slika 2: Povratne izgube pri simulaciji z uporabo različnih materialov podlage

Table 1: Dielectric properties of the different substrates
Tabela 1: Dielektrične lastnosti različnih podlag

Material	Permittivity	Loss Tangent
Teflon (tm)	2.1	0.01
RT/Duroid 5870	2.33	0.0023
Epoxy resin-fiber (Proposed)	4.66	0.02
Al_2O_3	9.8	0.0009
RT/Duroid 6010	10.2	0.0023

The return losses determined by the simulation using different substrate materials are shown in **Figure 2**. No resonance was found on the lower band when we used the high-permittivity materials of Duroid 6010, and Al_2O_3 ceramic and the low permittivity materials of Duroid 5870, and Teflon as a substrate. Finally, FR4 was used in the proposed design as the epoxy-resin-fiber substrate material and two strong resonances were achieved, with the desired bandwidth and high gain. The 10-dB bandwidths of 130 MHz from 4.74 GHz to 4.87 GHz and of 310 MHz from 8.42 GHz to 8.73 GHz were achieved. The dielectric properties of the materials are listed in **Table 1**.

A parametric study was performed to observe the effects of the proposed antenna parameters. In particular, the effects of the different parameters on the return loss were observed.

Figure 3 shows the return loss of the simulation for different values of *R*. The simulation includes L = 40 mm, L_p = 12 mm, L_g = 40 mm, L_s = 4 mm, W = 40 mm, W_p = 4 mm, W_g = 40 mm, M_l = 17 mm, and M_w = 6 mm with the different values of *R*. The graph indicates that better coupling is obtained for the upper band using the value of radius as 11 mm and 13 mm. By using R = 12 mm, the desired dual-band operation was obtained, with a better coupling on both the lower and upper bands.

The return loss of the simulation for different values of M_l is shown in **Figure 4**. The simulation includes L = 40 mm, L_p = 12 mm, L_g = 40 mm, L_s = 4 mm, R = 12 mm, W = 40 mm, W_p = 4 mm, W_g = 40 mm and M_w = 6

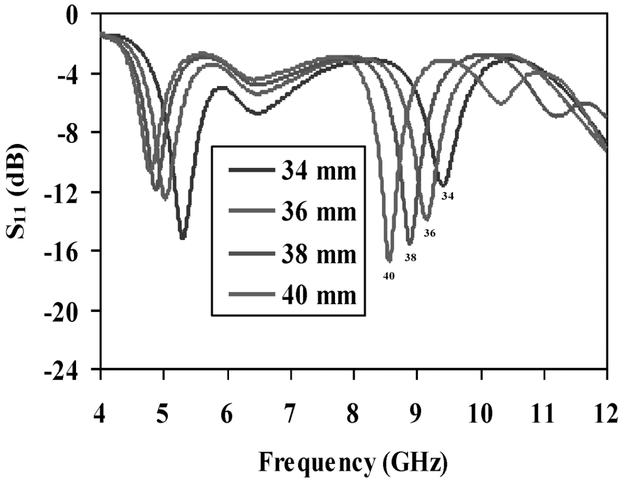

Figure 4: Return loss of the simulation using different values of M_l
Slika 4: Povratne izgube pri simulaciji z uporabo različnih vrednosti M_l

mm with M_l. The results presented in the graph clearly indicate that improved coupling was achieved at the upper band when using the value of M_l as 40 mm. As a result, the optimized value is 40 mm.

Figure 5 shows the return loss simulation for different values of M_w. The simulation includes L = 40 mm, L_p = 12 mm, L_g = 40 mm, L_s = 4 mm, R = 12 mm, W = 40 mm, W_p = 4 mm, W_g = 40 mm, M_l =17 mm, and with the different values of M_w. The width of the microstrip line has a greater effect on the coupling for both the lower- and upper-band frequencies. This coupling can be achieved when M_w is 6 mm.

3 RESULTS AND DISCUSSION

The gain of the proposed antenna is shown in **Figure 6**. An average gain of 3.12 dBi is achieved with the first resonance of 4.80 GHz and 5.44 dBi is achieved with the second resonance of 8.57 GHz. In addition, the gain for the upper band is greater than that for the lower band. **Figure 7** shows the radiation efficiency of the proposed

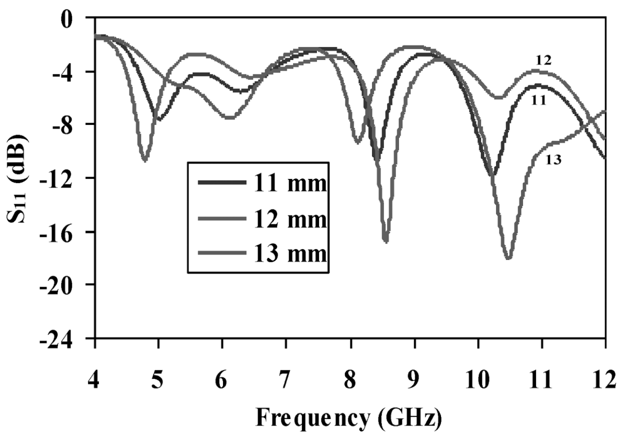

Figure 3: Return loss of the simulation using different values of *R*
Slika 3: Povratne izgube pri simulaciji z uporabo različnih vrednosti *R*

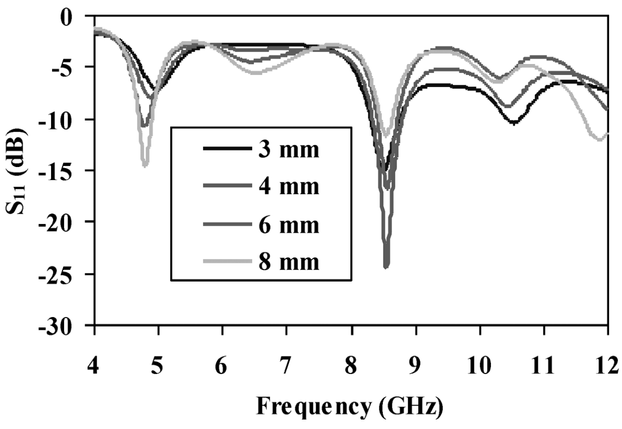

Figure 5: Return loss of the simulation using different values of M_w
Slika 5: Povratne izgube pri simulaciji z uporabo različnih vrednosti M_w

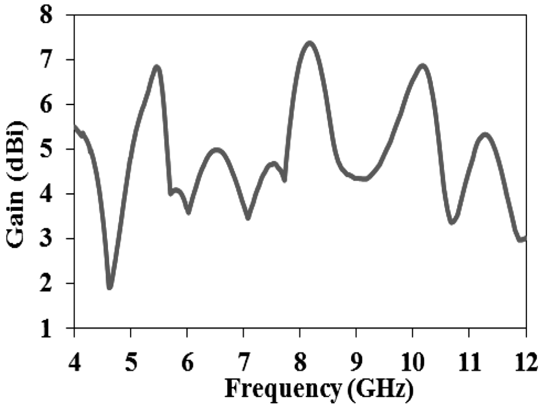

Figure 6: Gain of the proposed antenna
Slika 6: Izkoristek predlagane antene

antenna. The average lower-band efficiency is 75.18 % and the higher-band efficiency is 81.35 %, i.e., the lower-band radiation efficiency is smaller than the higher-band efficiency.

The radiation pattern of the proposed antenna is shown in **Figure 8** for: a) 4.80 GHz at the E-plane, b) 4.80 GHz at the H-plane, c) 8.57 GHz at the E-plane, d) 8.57 GHz at the H-plane. The E_φ and E_θ fields indicate the cross-polar and co-polar components, respectively. The effect of cross-polarization in the radiation pattern is due to the lower microstrip antenna. The cross polarization effect is higher in the H-plane for both resonances. When the frequency increases, the effect increases, enabling simple interpretation from the radiation pattern. Moreover, nearly omni-directional and symmetrical radiation patterns were attained along both the E-plane and the H-plane. The same radiation pattern was found to exist over the C and X-bands. The obtained radiation patterns indicate that the proposed antenna delivers linear polarization, where the level of cross-polarization is lower than that of the co-polarization in all of the simulated radiation patterns. When the radiation pattern of a microstrip antenna is symmetric and omni-directional, it provides some reasonable benefits. One benefit is that the resonance does not shift for different directions, so a large amount

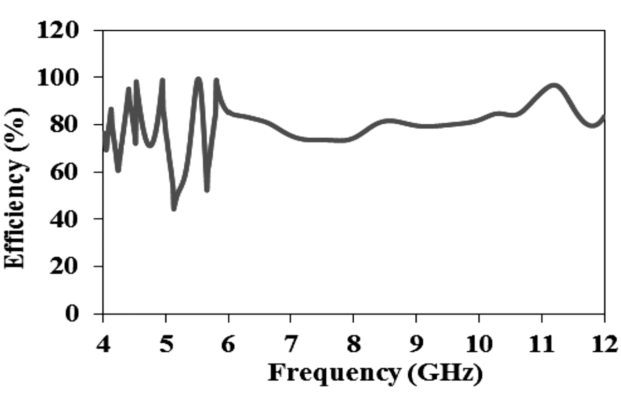

Figure 7: Radiation efficiency of the proposed antenna
Slika 7: Učinkovitost sevanja predlagane antene

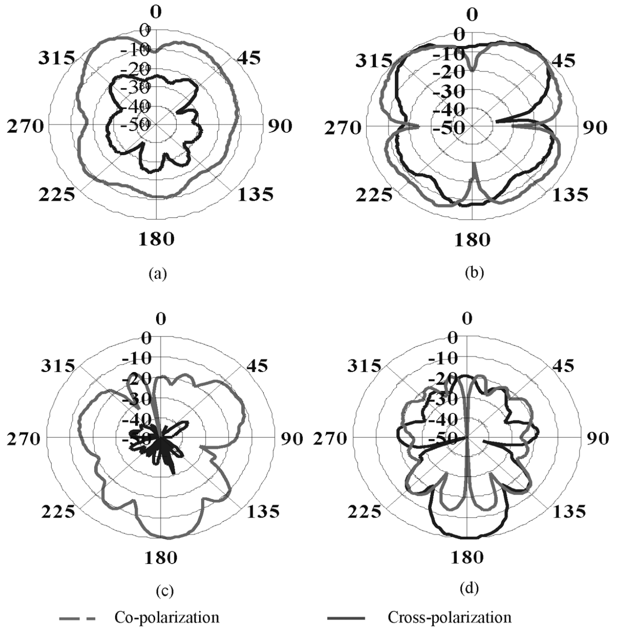

Figure 8: Radiation pattern of the proposed antenna: a) 4.80 GHz at the E-plane, b) 4.80 GHz at the H-plane, c) 8.57 GHz at the E-plane and d) 8.57 GHz at the H-plane
Slika 8: Sevalni diagram predlagane antene: a) 4,80 GHz v ravnini E, b) 4,80 GHz v ravnini H, c) 8,57 GHz v ravnini E in d) 8,57 GHz v ravnini H

of stable power is in the direction of the broadside beam. Another advantage is that the radiation pattern is more reliable on the operational bands.

Figure 9 shows the current distribution of the proposed antenna for: a) 4.51 GHz and b) 8.35 GHz. A large amount of current flows through the feeding line. The

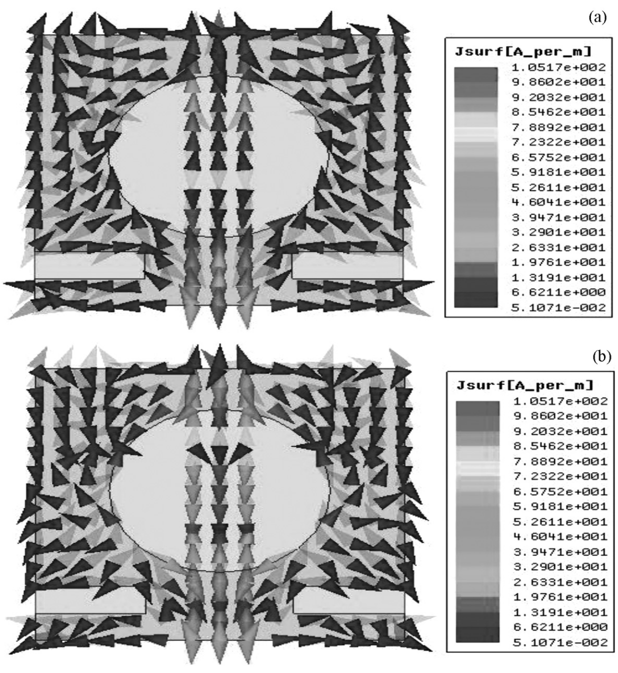

Figure 9: Current distribution at: a) 4.80 GHz and b) 8.57 GHz
Slika 9: Razporeditev toka pri: a) 4,80 GHz in b) 8,57 GHz

electric field was initiated at this point. The current distribution is more stable in the lower band than in the upper band. The creation of the electric field near the slots is reasonable. As a result, the excitation is strong over all parts of the antenna for both the lower and upper bands.

4 CONCLUSION

A Ω-shaped microstrip antenna using an epoxy-resin-fibre substrate was proposed in this paper. A simple Ω-shaped patch was proposed to miniaturize the antenna and to obtain a new operating band resonant mode. An antenna structure was designed, simulated and finally characterized. The Ω-shaped resonator, compact size, stable nearly omni-directional and directional radiation patterns, low cross-polarization, and efficiency with improved bandwidth and higher gain make the proposed Ω-shaped dual band antenna a candidate for use in C-band and X-band applications.

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