Parametric Study of the Low-Profile Foam Dielectric Over-the-Shoulder Antenna Based on Coupled Patches Technique

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***Abstract*—The paper presents a parametric study of the over-the-shoulder foam dielectric antenna based on coupled patches technique for 380 ÷ 390 MHz frequency band. Despite having a very low profile (0.0072 λ_0), it shows the satisfactory radiation efficiency and very good immunity from the negative influences of the human body. Influence of the antenna elements to the radiation efficiency, gain, frequency bandwith and impedance matching is evaluated by means of the parametric study.**

***Index Terms*—body centric communication, coupled patches, low-profile antenna, wearable antenna**

I. Introduction

For wearable antennas it is required to provide as the highest possible immunity from influences of a human body on antenna properties. From the mechanical point of view it is required to have small size and low profile above all. Eventually the antenna could show a low weight and good flexibility. To reach of the above mentioned properties is not crucial problem at higher RF and microwave frequency bands, however design of effective low-profile wearable antenna at UHF frequency band has not been satisfactory solved yet.

In case of common antennas (e.g. dipole type antenna), the presence of a human body causes significant detuning and absorption of the radiated energy; [1-4]. This phenomenon results in low radiation efficiency. The problem of frequency detuning and energy absorption can be, on principle, solved by insertion of a screening metallic plate. The plate can act as an additional shielding or can form an inherent part of the antenna; [1]. Coupled patches technique presented by the authors in [5] for RFID TAG antenna application is a representant of the second mentioned shielding principle.

The presented technique, which enables to design extremely low profile antenna with satisfactory radiation efficiency in the close vicinity of the human body compared to standard patch antennas is briefly reviewed in section II-A of the paper. Section II-B, presents a conformal foam dielectric antenna design for over-the-shoulder use based on the coupled patches technique applied in UHF frequency band (380 ÷ 390 MHz). Section III presents parametric study of the antenna with the aim of described influence of the antenna components size to the radiation efficiency, gain, frequency bandwith and impedance matching of the antenna.

II. Over-the-Shoulder Low-Profile Antenna

A. Coupled patches technique

Using of coupled patches structure enables to design extremely low profile antennas with a very good immunity from the influence of a human body situated in the close vicinity. The coupled patches technique is derived from the common patch antenna. Drawbacks of common patch antenna can be eliminated by two half-wavelength long patches those are strongly coupled by a narrow gap; see Fig. 1.

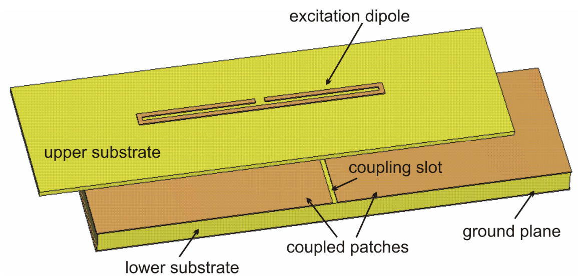

Figure 1. Coupled half-wavelength patches excited by folded dipole.

Radiation properties of this structure are significantly enhanced even in case of low-profile substrates with thicknesses below 0.01 λ_0.

The structure is excited by the folded dipole, placed on a very thin (0.25 mm) substrate. Change of length of the folded dipole enables to tune the antenna input impedance to the required value (50 Ω).

B. Design, realisation and measurement

The test sample of the coupled patches over-the-shoulder antenna in the operational 380 ÷ 390 MHz frequency band was designed and manufactured. In order to ensure its low weight and high flexibility, the foam dielectric was employed as a substrate; see Fig. 2. The metallic components of the test sample were manufactured using a copper adhesive tape.

The total size of the unfolded antenna are 790 × 50 × 5.6 mm (1.014 × 0.064 × 0.0072 λ_0), while the expected diameter of the fold is equal to 150 mm. The thicknesses of the lower and upper substrates reach 4.8 and 0.8 mm, respectively. The dielectric constant of the foam dielectric accounts for $\varepsilon_r = 1.3$, while its loss tangent reaches tg $\delta = 0.02$. The width of coupling slot equals $g = 2.5$ mm and the folded dipole footprint is 570 × 6 mm (0.73 × 0.0077 λ_0). The antenna feeding is ensured by a thin RG-174 flexible micro-coaxial cable terminated with a SMA connector.

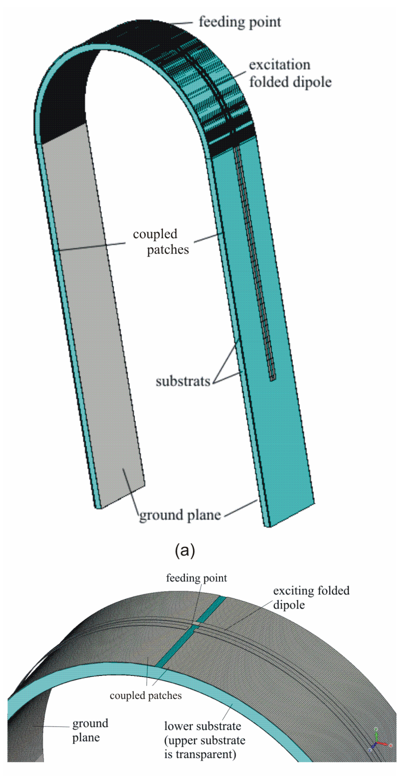

Figure 2. Drawing of designed coupled patches antenna (a) and detail of excitation folded dipole (b).

Figure 3. Photograph of manufactured coupled patches antenna placed over shoulder during tests.

A very good agreement between the simulation and measurement as well as a high immunity from the influence of a human body can be observed in Fig. 4.

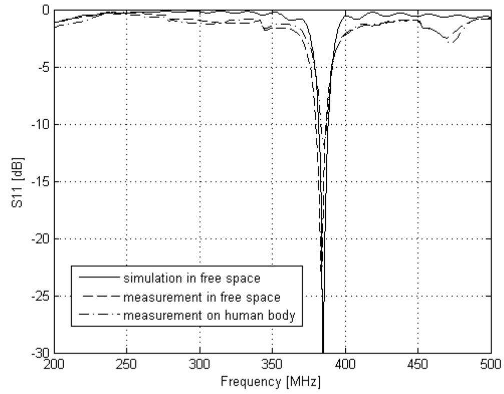

Figure 4. Measurement and simulation of reflection coefficient of coupled patches antenna in a free space and in the close vicinity to the human body.

Fig. 5 shows the simulated and measured radiation patterns in the horizontal (xz) plane. Since it was impossible for the person wearing the antenna to stand at the antenna turntable, the measurements of radiation pattern were performed only from several discrete angles.

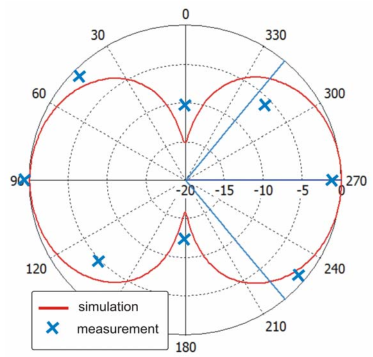

Figure 5. Comparison of simulated and measured radiation patterns in horizontal (xz) plane of coupled patches antenna operated in over-the-shoulder position.

Table 1 provides comparison of simulated and measured parameters of the coupled patches antenna and simple monopole antenna.

TABLE I. COMPARISON OF MAXIMUM GAIN AND -6 DB BANDWIDTH FOR MONOPOLE AND THE OVER-THE-SHOULDER ANTENNA AT F = 385 MHZ

	Gain [dBi]		**BW_{-6dB} [%]**	
	Simulated	***Measured***	***Simulated***	***Measured***
Monopole in free space	1.2	---	16	---
Monopole folded over human shoulder	-11.3	---	0.3	---
Coupled patches antenna in free space	-1.3	-1	2.9	3.1
Coupled patches folded over human shoulder	-2.5	-2.2	3.4	2.9

III. PARAMETRIC STUDY

Parametric study of the over-the-shoulder antenna electric properties dependence on the antenna components size (substrates thicknesses, coupling slot and the antenna width) has been performed. Table 2 describes the influence of variations of the aforementioned parameters with step ±2.5 %, ±10 % and ±50 % on the radiation efficiency, gain and frequency bandwith.

TABLE II. PARAMETRIC STUDY OF THE OVER-THE-SHOULDER ANTENNA

Parameter		Radiation efficiency [dB]	Directivity [dBi]	Gain [dBi]	BW_{-6dB} [%]
Basic geometry		-6.9	5.6	-1.3	2.9
h_1	+2.5%	-6.4	5.5	-0.9	2.7
	+10%	-4.3	6.1	1.8	2.8
	+50%	-3.3	6.1	2.8	2.5
	-2.5%	-6.6	6.0	-0.6	2.8
	-10%	-7.1	5.6	-1.5	2.8
	-50%	-9.0	5.3	-3.7	2.9
h_2	+2.5%	-6.8	5.4	-1.4	2.8
	+10%	-6.3	5.7	-0.6	2.7
	+50%	-5.7	5.5	-0.2	2.9
	-2.5%	-6.7	5.4	-1.3	2.7
	-10%	-7.3	5.8	0.2	2.7
	-50%	-14	5.6	-8.4	---
s	+2.5%	-6.8	5.4	-1.4	2.8
	+10%	-6.8	5.4	-1.4	2.8
	+50%	-6.1	5.5	-0.6	2.8
	-2.5%	-6.9	5.4	-1.5	2.8
	-10%	-6.7	5.5	-1.2	2.8
	-50%	-7.1	5.6	-1.5	2.8
w	+2.5%	-6.1	5.1	-1	2.8
	+10%	-6.6	5.4	-1.2	2.8
	+50%	-6.3	5.3	-1	3.2
	-2.5%	-6.5	5.4	-1.1	2.8
	-10%	-6.7	5.5	-1.2	2.8
	-50%	-8.0	5.7	-2.3	1.7

h_1 - lower substrate thickness, **h_2** - upper substrate thickness, **s** - coupling slot width, **w** - antenna width

Frequency bandwith is affected negligible in most cases. The bandwith can be affected more significantly only by marked variance of antenna width (±50 %). Radiation efficiency is the crucial parameter affecting antenna gain, accordingly it deserves corresponding attention. Lower antenna substrate is the most important parameter affecting the radiation efficiency. Reducing of the lower substrate thickness causes significantly efficiency fall. On the contrary higher substrate thickness deteriorates antenna mechanical and wearable properties. Therefore compromise solution has to be chosen. The upper substrate thickness is relatively account small. Substantial radiation efficiency fall comes on for very small thickness (less than approx. 0.5 mm ~ 0.0006 λ_0). Influence of the coupling slot and the antenna width is negligible too; see. Table 2. Substantial radiation efficiency fall comes on for relatively small antenna width (less than approx. 20 mm ~ 0.025 λ_0). In addition the antenna width reducing causes increasing of the human body influence on the antenna properties.

The corresponding resonant frequency detuning and impedance mismatching are depicted in Fig 6. The impedance mismatching can be corrected by tuning the excitation folded dipole length.

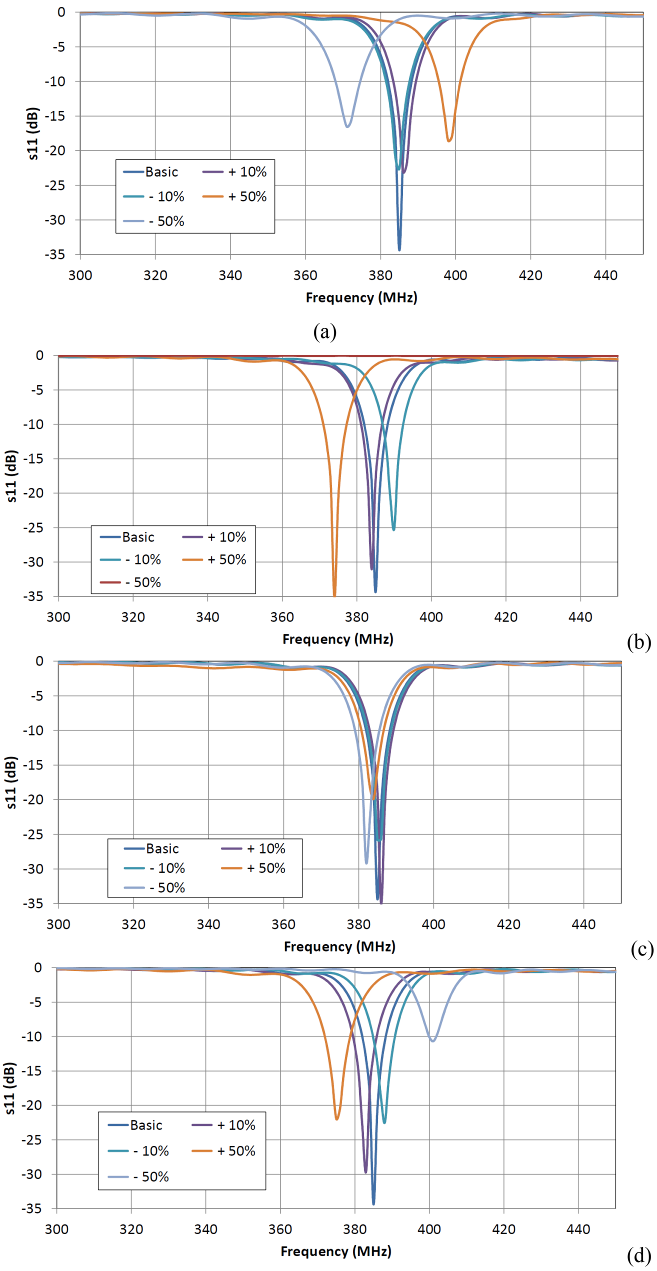

Figure 6. Impedance matching of the over-the-shoulder antenna with parameters: lower substrate thickness (a), upper substrate thickness (b), coupling slot width (c) and antenna width (d).

IV. CONCLUSION

The over-the-shoulder foam dielectric antenna based on coupled patches technique for 380 ÷ 390 MHz frequency band was developed and verified by measurement. Despite having a very low profile (0.0072 λ_0), it shows the satisfactory radiation efficiency and very good immunity from the negative influences of the human body. The antenna radiation patterns have two nearly identical maxima oriented to the forward and backward directions, where the communication traffic maxima can be expected.

The parametric study of the radiation efficiency, gain and frequency bandwith dependence on the over-the-shoulder antenna variations shows a significant influence of the lower substrate thickness on the radiation efficiency and gain. On the contrary, the impact of the coupling slot, higher substrate thickness and antenna width on the radiation efficiency is insignificant. Hence the reduction of the antenna width (at the expense of directivity decreasing) is possible. All parameters affect the antenna input impedance, which can be tuned by the excitation dipole length.

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