NOVEL LOW-PROFILE FOAM DIELECTRIC OVER-THE-SHOULDER ANTENNA BASED ON COUPLED PATCHES TECHNIQUE

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Abstract: *The paper presents a novel wearable antenna composed of two coupled patches excited by an overlapping folded dipole. In spite of being operated in a relatively low frequency band 380 ÷ 390 MHz, the antenna shows a very low profile and other dimensions are acceptable as well. Besides a very low absorption of the radiated RF power by any nearby human body, it also ensures a very good immunity against influence on antenna parameters. In comparison to commonly used simple conformal monopole antennas, the presented solution provides a double-side radiation pattern and a substantially higher gain. The antenna can be manufactured using very light and twistable foam dielectric and conductive fabric, and can be worn as a strap placed over the shoulder. It is intended to be used together with personal radio communication transceivers operated in the given frequency band.*

Keywords: *body centric communication, coupled patches, low-profile antenna, wearable antenna.*

1. INTRODUCTION

The research in the field of wearable antennas to be operated in a close vicinity of a human body represents a topical issue. Antennas of this kind should fulfil the following requirements. Firstly, it is required to provide as the highest possible immunity from undesirable influences of a nearby human body on antenna parameters. Accordingly, it should ensure as low irradiation of the communicating person by the RF power as possible. Eventually, it is required to have small dimensions and show a low weight and good flexibility.

To date, possible applications range from special RFID systems to body-centric communications intended especially for paramedics, fire-fighters, military personnel, etc.; [1-3]. Although at higher RF and microwave frequencies, a number of very good solutions fulfilling all the above-stated requirements have been presented, so far, the design of flexible conformal radiators for communications in the UHF band has not been tackled in a satisfactory manner.

In case of common antennas (e.g. monopole or dipole types), the presence of a nearby human body causes significant frequency detuning and absorption of the radiated or received RF energy, which results in low radiation efficiency and gain; [4-7]. Both problems can be, in principle, solved by inserting a screening metallic plate. The latter can act as an additional shielding or an inherent part of the antenna; [4]. The coupled patches structure presented by the authors in [8], represents the mentioned shielding principle.

This technique can be applied for minimizing the majority of disadvantages of simple (2*n*+1) λ/4 long monopole antennas that are frequently used in connection with personal radio transceivers. An example of such antenna and 380 ÷ 390 MHz personal transceiver can be seen in Fig. 1. The radio transceiver is placed in the underarm holder, which is fixed to a shoulder strap. An approx. ¾ λ long wire installed in the strap is used as an antenna (see the first connector from the left).

The operation of this type of monopole antennas in a very close vicinity to the human body gives rise to several major problems. Usually, a non-negligible absorption of the RF power by the human body, together with the detuning of antenna input impedance and significant decrease in its radiation efficiency result in a substantial drop in the antenna gain; see Tab.1. Moreover, the resulting radiation pattern is hard to predict and often attains minima in the forward and backward directions, where the maxima of communication traffic can be expected.

The presented coupled patches structure solves the majority of the aforementioned problems. This technique enables to design and manufacture low-profile wearable antennas with satisfactory radiation efficiency and a very low level of frequency detuning even if it is located directly on the human body. Besides, the antenna shows two identical radiation maxima targeted at the mostly required forward and backward directions.

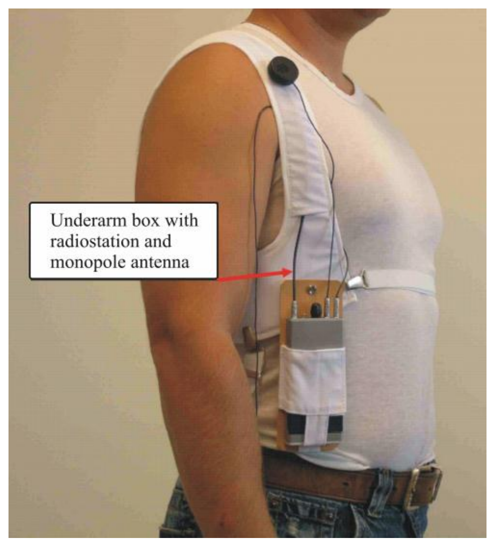

Figure 1. Underarm holder with radio transceiver and simple monopole antenna hidden in shoulder strap.

2. COUPLED PATCHES TECHNIQUE

As mentioned above, the employment 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 structure was derived from the standard patch antenna. Despite many virtues, the latter suffers from a significant fall in its radiation efficiency (under 50 %) if the relative thickness of the used substrate drops below approx. 0.01 λ_0 (i.e. 8 mm@385 MHz); see [4]. This phenomenon can be eliminated provided that two half-wavelength long patches that are strongly coupled by a narrow gap are utilized; see Fig. 2.

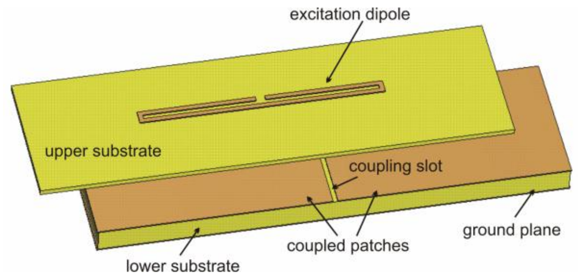

Figure 2. Coupled half-wavelength patches excited by folded dipole.

Radiation properties of this coupled structure are significantly enhanced even in case of low-profile substrates with thicknesses below 0.01 λ_0 and are, to a large extent, insensitive to the width of coupling gap. The electric field distribution of the coupled structure is demonstrated in Fig. 3. Due to the strong coupling of the two half-wavelength patches, three radiating slots are present, (out of which two are located on the outer sides, while the third one is situated within the coupling gap).

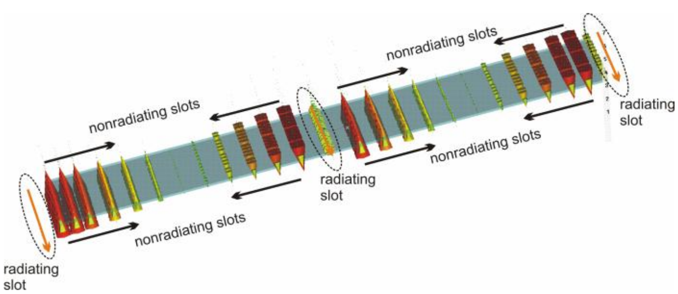

Figure 3. Electric field distribution of coupled half-wavelength patches antenna. Orange arrows indicate orientation of fictive magnetic currents in radiating slots.

The structure is excited by the folded dipole, etched on a very thin (0.25 mm) separate upper substrate. For these purposes, even other radiator shapes might be considered, such as meander dipole, loop antenna, etc.; see [8-10]. Change of length of the folded dipole enables to tune the antenna input impedance to the required level (50 Ω).

The following paragraph shows that antenna based on the coupled patches structure with a profile thinner than 0.003 λ_0 enables to reach approx. 50 % radiation efficiency, which is about four times better than the radiation efficiency of the common patch antenna made of comparable substrate and showing similar dimensions.

3. DESIGN, REALIZATION AND MEASUREMENT

In order to verify parameters of the coupled patches antenna for the over-the-shoulder application in the operational 380 ÷ 390 MHz frequency band, the test sample was designed and manufactured. The antenna takes the form of a strap to be placed over the shoulder. In order to ensure its low weight and high flexibility, the foam dielectric was employed as a substrate; see Fig. 4. While the metallic layers of the test sample were manufactured using a copper adhesive tape, the practical implementation is intended to be based on more flexible and resistant conductive fabric.

The total size of the unfolded antenna amounts to 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.

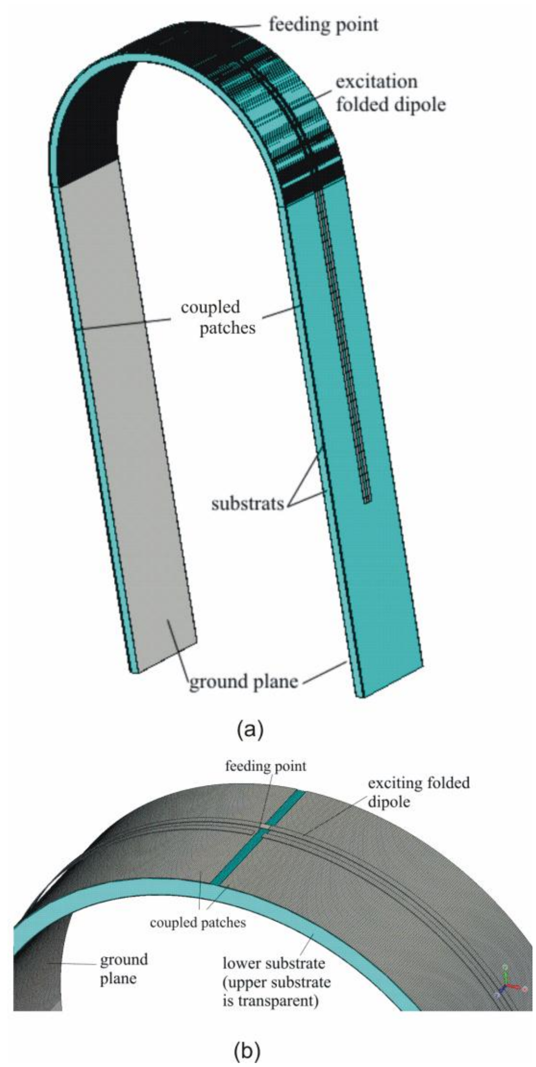

Figure 4. Drawing of designed coupled patches antenna (a) and detail of excitation folded dipole (b).

Fig. 5 involves the photograph of manufactured sample in the intended position over the human shoulder. Fig. 6 compares the simulated and measured input reflection coefficients, both in free space and in the close vicinity of a human body. A very good agreement between the simulation and measurement as well as a high immunity from the impact of a nearby human body can be observed.

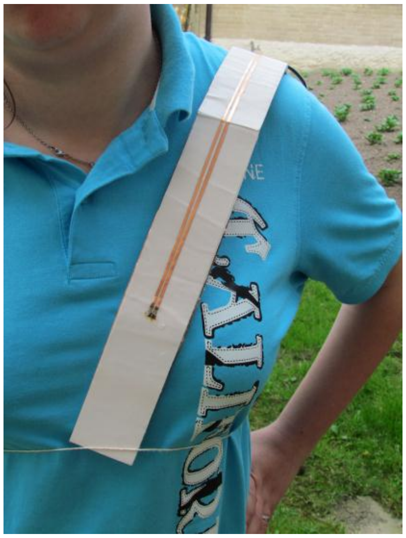

Figure 5. Photograph of manufactured coupled patches antenna placed over shoulder during tests.

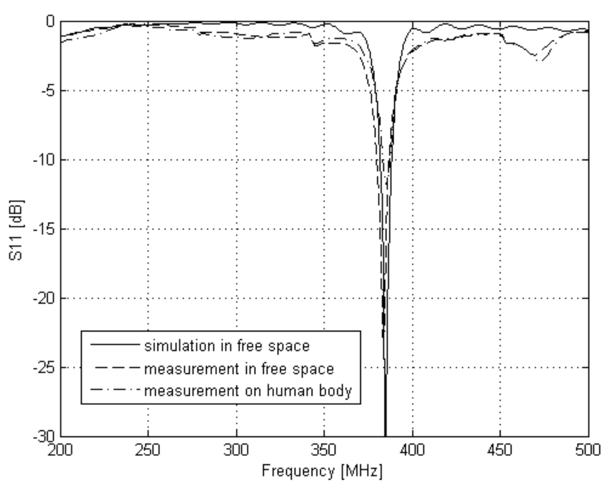

Figure 6. Measurement and simulation of reflection coefficient of coupled patches antenna in a free space and in the close vicinity to the human body.

Fig. 7 present the simulated antenna radiation patterns, both in free-space and in the close vicinity of a human body, which were modelled as a definite volume that is merely slightly exceeding the dimensions of folded antenna. They are filled with a material having in principle the same parameters as human body. The maxima of radiation in the forward and backward directions are very well defined and are nearly identical in both cases. Fig. 8 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. Taking into account a small tilt caused by the asymmetrical position of antenna with respect to the body, the agreement between the measurement and simulation is also fairly good. The antenna feeding cable was connected directly to ends of the folded dipole. Since the antenna is operated in a very complex environment, the implementation of symmetrization was neither used nor advisable.

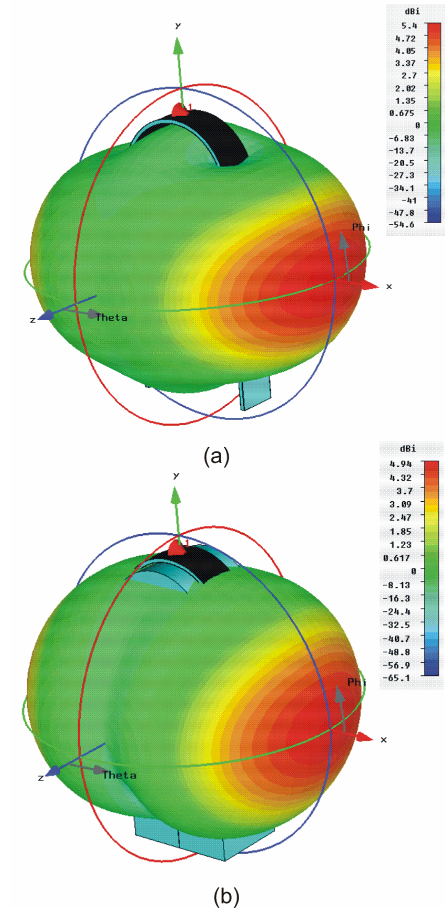

Figure 7. Simulated 3D radiation pattern (directivity) of coupled patches antenna in free space (a), in the close vicinity of human body phantom (b).

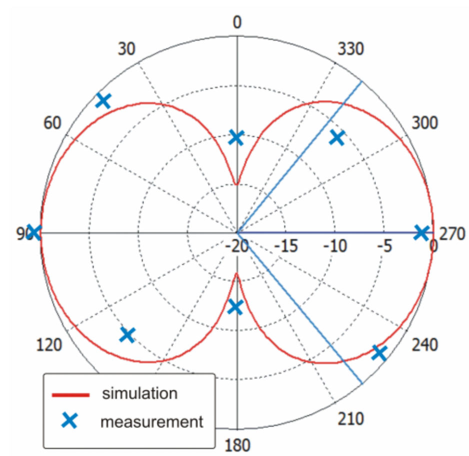

Figure 8. Comparison of simulated and measured radiation patterns in horizontal (xz) plane of coupled patches antenna operated in over-the-shoulder position.

Table 1 provides comparison of simulated and measured parameters of both, the coupled patches antenna and simple monopole antenna described in Section 1. The obtained results show a very good agreement of simulations and measurement. Furthermore, in comparison to simple monopole types, the novel antenna shows obvious advantages.

TABLE 1 Comparison of maximum gain and -6 dB bandwidth for simple monopole antenna and proposed coupled patches antenna in the over-the-shoulder application 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

4. CONCLUSION

The novel wearable antenna based on coupled patches technique for the over-the-shoulder application in the 380 ÷ 390 MHz frequency band was developed and its parameters were subject to verification. Despite having a very low profile (0.0072 λ_0), it shows the satisfactory radiation efficiency and very good immunity from the presence of nearby human body. The resulting gain reaches -1 dBi in free space and -2.2 dBi in the over-the-shoulder application, which can exceed by up to 8.8 dB the gain of the simple monopole antenna operated under similar conditions. 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 antenna is very light, twistable and can be worn as a separate fixable over-the-shoulder strap. Alternatively, it can be incorporated into the article of clothing. It is intended to be used together with personal communication transceivers operated e.g. by paramedics, fire-fighters or military personnel.

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