Klemm, M., Kovacs, IZ., Pedersen, GF., & Troester, G. (2005). Comparison of directlional and omnl-directlonal UWB antennas for Wireless Body Area Network applications. In *18th International Conference on Applied Electromagnetics and Communications, 2005 (ICECom 2005), Dubrovnik* (pp. 1 - 4). Institute of Electrical and Electronics Engineers (IEEE). https://doi.org/10.1109/ICECOM.2005.205038

Comparison of directional and omni-directional UWB antennas for Wireless Body Area Network applications

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Abstract

In this paper we present a low-profile directional UWB antenna with improved radiation efficiency when operating in close vicinity to a biological tissue. This antenna is intended for the use in UWB Wireless Body Area Network (WBAN) applications, between 3 and 6 GHz. A novel design is based on a UWB slot antenna structure with an added radiator/reflector element in order to achieve directional radiation pattern. We compare results of our novel design, to those of the omni-directional UWB monopole antenna (currently the most commonly used in UWB studies). Measurement and simulation results show that the developed directional UWB slot antenna has the improved radiation efficiency in the vicinity of human body. Moreover, proximity of the human body much less influences its transfer functions (the most important antenna parameter in UWB radio), compared to the omni-directional UWB monopole antenna.

1. INTRODUCTION

In the past few years UWB technology has received increasing attention in the wireless world. Its main envisioned advantages over conventional (narrowband) wireless communications systems are: low transmit power levels, high-data rates, and possibly simpler hardware configurations. Wireless personal area networks (WPAN) and wireless body area networks (WBAN) are seen as one of the major fields where the previously mentioned UWB characteristics can be potentially exploited [1, 2]. The choice for a specific UWB antenna design has to be based on the main implementation requirements. As we will show later in this paper, this aspect is especially important in the UWB WBAN/WPAN applications.

Most of the antenna designs presented so far for UWB WPAN/WBAN, present radiation patterns similar to the traditional monopole/dipole antennas. However, a *directional radiation pattern* of an antenna would be desirable for body-worn devices (WBAN) in order to minimize the effects of the human body proximity and body exposure to electromagnetic (EM) radiation [3].

In this paper we present a small-size directional antenna for UWB systems, with the main aim at the WBAN (body-worn) applications. It is based on the omni-directional UWB slot antenna design [4] and utilizes the reflecting patch element to achieve a directional radiation pattern. The performance of the directional antenna is compared to an omni-directional UWB monopole antenna, presented also in [4], currently the most popular antenna in studies of UWB radios. Characteristics of both antennas are studied by examining the S_{11} and S_{21} (transfer function), when antennas were operating in free space and when close to the human body. During the measurements antennas were placed in two different positions on the body (hand, heart). In full-wave EM simulations on body-worn antennas, two different tissue compositions, presented in section 3, were examined.

2. ANTENNA DESIGNS

In this section we present the design of directional UWB antenna, as well as an omni-directional UWB printed monopole antenna. Commercial software, CST Microwave Studio (FIT method), was used during design.

2.1 Low-profile directional UWB antenna

The geometry of the proposed antenna is shown in Fig.1. It is based on the slot antenna, fed by a fork-like microstrip lines. To improve the front-to-back ratio, we have added another radiating (reflecting) element below the feed line. Antenna is printed on a 1.58mm thick Rogers Duroid 5880 substrate (dielectric1 in Fig.1a), with dielectric constant ε_r=2.2 and loss tangent tanδ=0.0009. Reflecting patch element is realized on a high epsilon (ε_r=10.2) material (Rogers Duroid 6000, dielectric3 in Fig.1a), with thickness of 2.5mm. Reflector is separated from the antenna feeding structure using Rohacell foam with dielectric constant of ε_r=1.07 and thickness of 3.5mm. It gives the 6mm distance between the metallic reflector element and an antenna microstrip feed. As not difficult to predict, such a small spacing has a great impact not only on the radiation pattern, but also on the input impedance of the antenna.

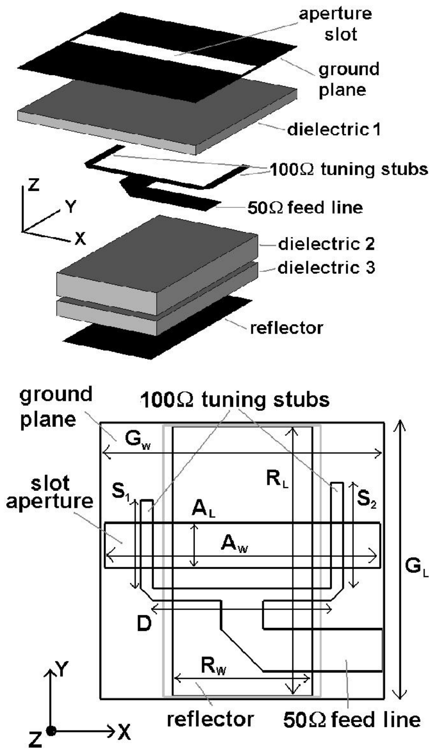


Fig.1. Directional UWB slot antenna geometry.

To understand the influence of different antenna (slot antenna plus reflector) parameters on its impedance bandwidth and radiation characteristics, a systematic parametric study was performed via EM simulations. The final antenna dimensions are presented in Tab.1. Overall, the antenna size is 32x31x7.58mm^3 (0.32λx0.31λx0.0758λ at 3 GHz).

2.2 Omni-directional UWB monopole antenna

Different kinds of monopole antennas are commonly used in UWB applications, thus we decided to include into our studies, as the reference case. We designed the UWB disc monopole, with criteria of 10dB impedance bandwidth from 3 to 6 GHz and the size comparable to the one of the slot antenna. The antenna geometry is shown in Fig.2. Its dimensions are: ground plane G_W=G_L=20mm, disc diameter D=16mm. Gap between a ground plane and a disc is 0.75mm.

GND width- G_W	32 mm
GND length- G_L	31 mm
Aperture width- A_W	30 mm
Aperture length- A_L	5 mm
Reflector width- R_W	9 mm
Reflector length- R_L	31 mm
Stub length- S_1	10 mm
Stub length- S_2	12 mm
Stub spacing- D	20.2 mm
Reflector-Feed spacing	6 mm

Tab.1. Antenna dimensions (ref .to Fig.1b).

Monopole was realized on the 0.5mm thick FR4 substrate (ε_r=4.4) and is fed from a 50Ω microstrip line. Overall size of antenna is 36.75x20x0.5 mm^3.

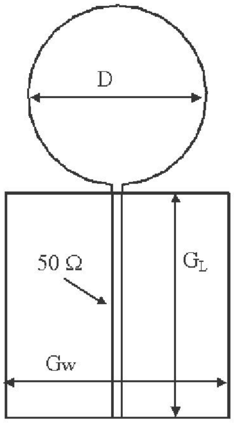


Fig.2. Omni-directional UWB monopole antenna.

3. HUMAN BODY MODELS

When operating in a UWB WBAN, the antenna is mounted on the human body. It is known that the body has a significant impact on the antenna characteristics (radiation pattern, efficiency and input impedance). Therefore, it is important to include the human body in the EM simulations. We have included two different truncated models of the human body:

- **Model 1**: 3-tissue model, consisting of layers of skin (1mm thick), fat (3 mm thick) and a muscle tissue (40mm thick)
- **Model 2**: homogeneous model composed of a muscle tissue (44 mm thick)

Overall dimensions of both models are the same: 120x110x44 mm^3. The size of this truncated body model was found by comparing the simulation results in terms of antenna radiation characteristics when a larger (by 50%) model was used. No significant differences were noticed. The human tissues are dispersive and their electrical properties are therefore changing over frequencies. The influence of these changes on the antenna characteristics was investigated by an EM code (also CST Microwave Studio) which could include frequency dispersion and it was found to have a minor influence (e.g. radiation efficiency changes <5%), thus in all further investigations the electrical parameters of the tissues were assumed to be non-dispersive and have values as at the center frequency of 4.5 GHz were used [6]: skin- εr=38, σ=3 S/m; fat- εr=5.1, σ=0.18 S/m; muscle- εr=50.1, σ=2.7 S/m.

4. MEASUREMENT AND SIMULATION RESULTS

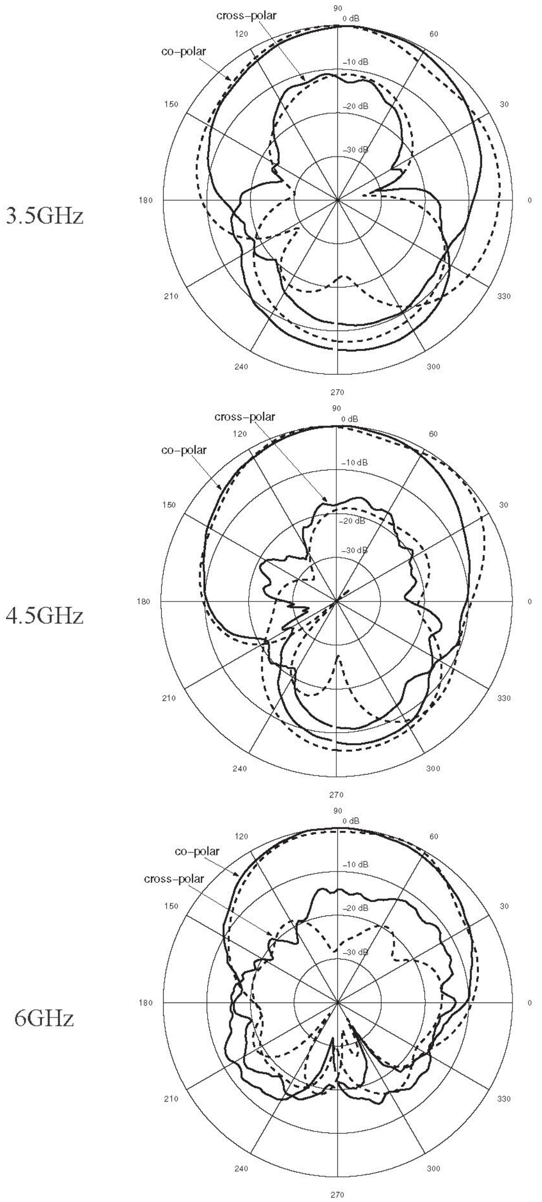


Fig.3. Measured and simulated radiation patterns of the antenna from Fig.1, XZ cut-plane.

4.1 Radiation patterns

In Fig.3 and Fig.4 we present measured and simulated radiation patterns of the directional UWB slot antenna in XZ and YZ cut-planes, respectively. Because in the real measurements metallic cables were used, they were also included in the simulations. Very good agreement between simulation and measurement is observed, for both polarization components. Observed front-to-back ratio (co-polar) higher than 10dB at all frequencies confirms that our goal of directional radiation was achieved. Relatively strong cross-polar field, especially in backward radiation, is due to the mentioned above measurement cables.

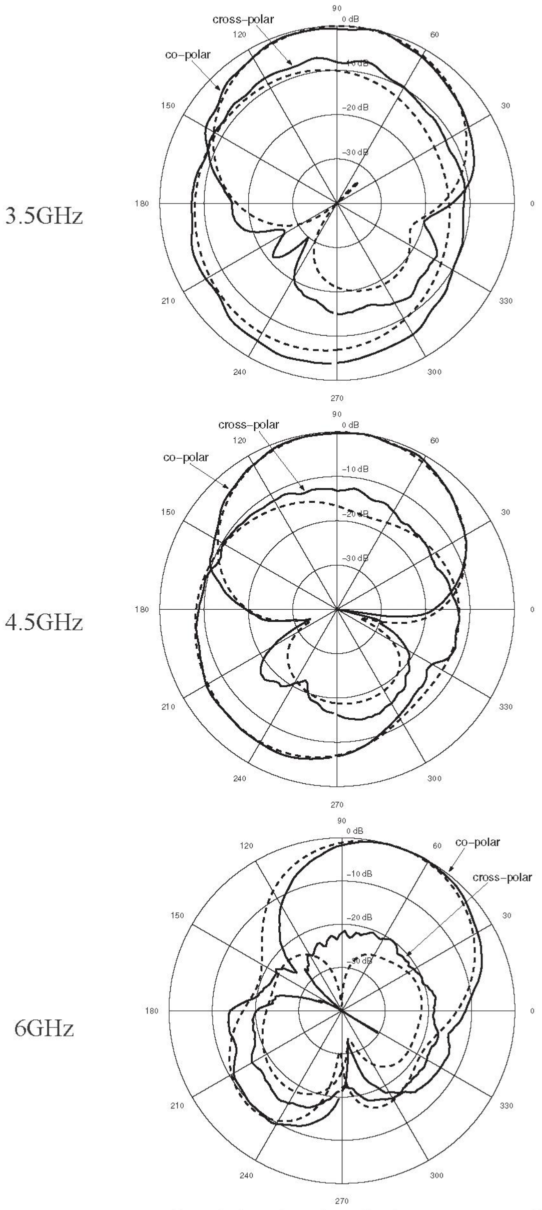
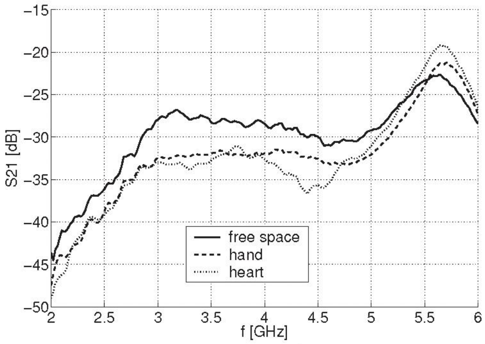


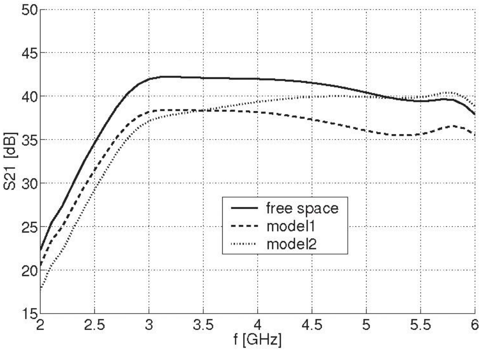
Fig.4. Measured and simulated radiation patterns of the antenna from Fig.1, YZ cut-plane.

4.2 Transfer function

To disclose advantages of the developed directional UWB antenna, we have measured transfer function (S_{21}), when our antennas under test where used as Tx antennas. For Rx we used the antenna presented in [1]. Tx and Rx antennas were separated by 30cm distance. The measured S_{21} is actually the multiplication of transfer functions of Tx and Rx antennas, thus we did the same with data obtained from simulations. In case of body-mounted antennas, directional antenna was placed 1mm from the body, monopole antenna was placed 3mm away from the body. Results are shown in Fig.5 and 6 for the omni-directional monopole and directional slot antenna, respectively.



a) Measured.



b) Simulated

Fig.5. S_{21} for the monopole UWB antenna.

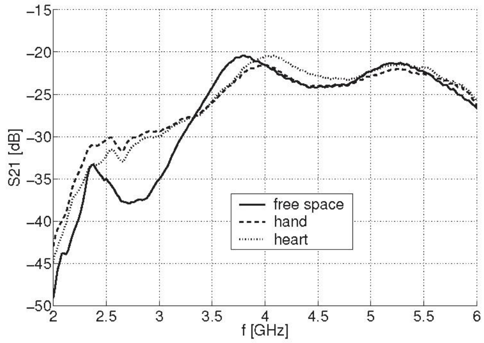
We can see that the human body has much smaller impact on S_{21} characteristics of the developed directional UWB antenna, when compared to the monopole antenna. This is observed both in measured and simulated data. We should also appreciate the fact that the frequency behavior of simulated characteristics of antennas close to the body agrees well with measurements. The small discrepancy (between simulation and measurement) in S_{21} curve exists for the monopole antenna above 5 GHz. We can observe that for both antennas, the body impact is greater at lower frequencies, as it was expected. Comparing absolute values of measured S_{21}, we can see that within 3.5-5 GHz we gain around 7dB by using directional antenna.

4.3 Radiation efficiency (simulations)

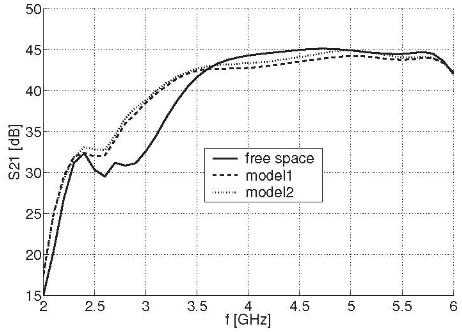
Below, in Tab.2, we present the radiation efficiency obtained from simulations. Results confirm findings from S_{21} measurements, and a greatly improved efficiency of the directional UWB slot antenna is observed, compared to the monopole.

	directional antenna		omni-direct. antenna	
	Model 1	Model 2	Model 1	Model 2
3.5 GHz	51	58	13	12
4.5 GHz	57	72	11	20
6 GHz	74	81	14	33

Tab.2. Simulated radiation efficiency [%] of body-worn antennas.



a) Measured.



b) Simulated

Fig.6. S_{21} for the directional UWB antenna.

5. CONCLUSIONS

In this paper we have presented the novel low profile, small-size directional UWB slot antenna for wearable applications. Between 3 and 6 GHz its transfer function is only slightly changed when operating in free space and close (1mm) to the human body. By using this antenna in a body-mounted Tx terminal, the link transmission is improved by 7 dB (within 3.5-5GHz), compared to the UWB monopole as a Tx antenna.

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