FILTERING ANTENNA ARRAY FOR OFF-BODY COMMUNICATION

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Abstract

The paper is focused on the design of a three-element filtering antenna array fed by apertures which can be used on a human body for off-body communication. The filtering array was designed for the ISM band (5.8 GHz). The filtering array was simulated in CST Microwave Studio using a three-layer model of a human tissue. The three-layer phantom was manufactured to verify simulated results. The filtering antenna was fabricated and measured in a free space and on the phantom. Simulations and measurements were in good agreement.

Keywords

filtering antenna, filtenna, equivalent model, off-body communication, human tissue, phantom

Introduction

Wireless body area networks (WBAN) connect sensors of living functions by electromagnetic waves propagating along the surface of human body (so called on-body communication). Signals from sensors are collected by a central unit which can send information to a remote unit (off-body communication) [1]–[2].

Both for an on-body communication and an off-body one, transmitter and receiver systems should be of compact dimensions, low cost, low weight and should be easily manipulated. The size of the whole system can be reduced by exploiting a filtering antenna (so called filtenna) [3]–[5].

Frequency response of gain of the filtering antenna is equivalent to the frequency response of the transmission coefficient of a band-pass filter. Direction of the main lobe of the filtenna is fixed. Out of band, the filtenna does not radiate. Due to the integration of the antenna and the filter, we can design a smaller transmit-receive system.

Exploitation of the filtering antenna for off-body communication is described in [6].

This paper presents the design of a filtering antenna array for off-body communication operating in ISM frequency band (5.8 GHz). The design procedure uses an equivalent-circuit approach.

Filtering Antenna Fed by Apertures

The equivalent-circuit approach to the design of filtering antenna arrays fed by apertures was described in [7] in detail. Here, we investigate the operation of the designed filtering antenna in proximity of a human tissue.

The filtering antenna is composed from three layers of the microwave substrate ARLON 25N with relative permittivity 3.38 and thickness of each dielectric layer 1.524 mm. Surfaces of layers are covered by copper layers (Fig. 1). The array of three patch antennas is located on the top metallic layer. The second metallic layer plays the role of the ground plane with apertures exciting patches. A microstrip feeder is created from the third metallic layer. And finally, the fourth metallic layer acts as a shield. Thanks to the shield, the filtering antenna array can be used both in free space and on a human body.

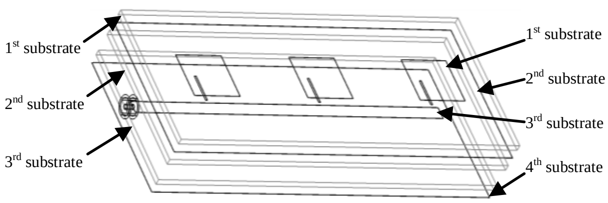

Fig. 1: Structure of three-element filtering antenna array fed by apertures.

Dimensions of the described filtering antenna are shown in Tab. 1. The length of patches is *L* and width of patches is *W*. The length of apertures is represented by L_a and the width of apertures is represented by W_a. The symbol *w* indicates the width of the feeder, *d* is the distance between neighboring patches and l_o denotes the length of an open end of the feeder. The total dimensions of the whole antenna structure are 90 mm × 40 mm.

Tab. 1: Dimensions of the filtering antenna array fed by apertures (values in millimeters)

L	W	L_a	W_a	w	d	l_o
12.0	12.6	7.5	0.5	3.4	30.0	7.0

Influence of human tissue

Properties of the filtering antenna array fed by apertures were characterized by frequency response of reflection coefficient, frequency response of realized gain and frequency response of main lobe direction. First, the filtering antenna was located in free space, and second, the antenna was placed on a model of human tissue of the dimensions 140 mm × 80 mm (see Fig. 2).

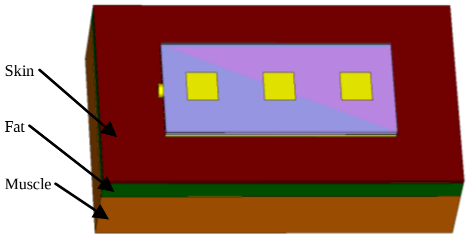

Fig. 2: Filtering antenna on a model of human tissue.

The model of human tissue consists of three dielectric layers. The first layer represents a skin, the second plays the role of a fat and the last layer corresponds to a muscle. All the layers in the model of the human tissue are frequency-dependent dielectric materials. Properties of the skin, the fat and the muscle at frequency 5.8 GHz are listed in Tab. 2. Here, ε_r is relative permittivity, σ is electrical conductivity, tan δ is loss factor and h denotes thickness of layers.

Tab. 2: Dielectric parameters of the model of human tissue at frequency 5.8 GHz.

	ε_r [-]	σ [S/m]	tan δ [-]	h [mm]
Skin	35.114	3.717	0.328	2.0
Fat	4.954	0.293	0.138	10.0
Muscle	48.751	4.961	0.317	28.0

In Fig. 3, we compare the simulated frequency response of the reflection coefficient at the input of the filtering antenna in free space (blue line) and the antenna on the model of human tissue (red line). Both the responses show the resonance at the frequency 5.8 GHz. In both cases, the impedance bandwidth $|S_{11}| < -10$ dB is the same and equals 172 MHz. The filtering antenna on the model of human tissue shows a slightly better impedance matching at the resonance than the filtering antenna in free space (–35.6 dB versus –35.2 dB).

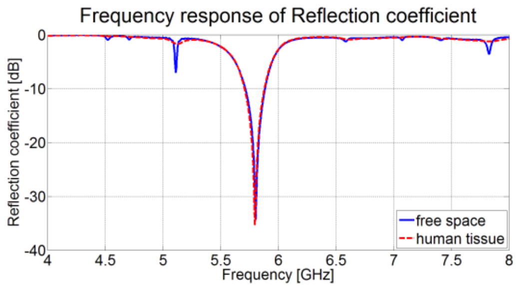

Fig 3: Simulated frequency responses of reflection coefficient at the input of filtering antenna in free space (solid blue line) and on human tissue (dashed red line).

Fig. 4 compares simulated frequency responses of the normalized realized gain of the filtering antenna in free space (blue line) and on the model of human tissue (red line). Obviously, the patch array fed by apertures radiates in frequency range from 5.5 GHz to 6.1 GHz only (–3 dB decrease of gain defines the pass-band).

In the pass-band, the human tissue does not influence frequency response of the realized gain. The realized gain is 11.3 dB in maximum both in free space and on a human tissue. The pass-band is 400 MHz in the both cases. Suppression in the stop band is better than 20 dB.

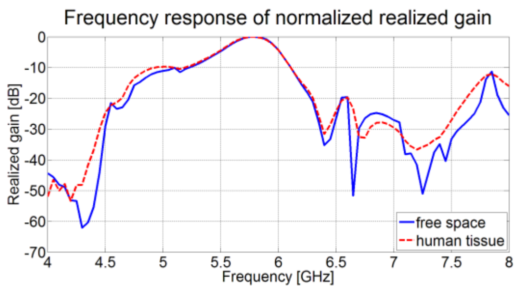

Fig. 4: Simulated frequency responses of normalized realized gain of the filtering antenna in free space (solid blue line) and on human tissue (dashed red line).

Figure 5 shows frequency response of the main lobe direction where blue line is for case location in free space and red one for human tissue. The shift of the main lobe in the working band is from 0° to 5° only.

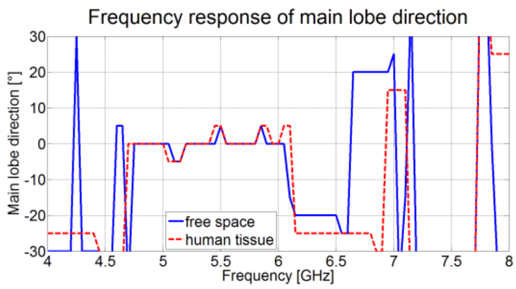

Fig. 5: Simulated frequency response of the main lobe direction of the filtering antenna in free space (solid blue line) and on human tissue (dashed red line).

Measurements

The designed filtering antenna was tested both in free space and on the model of human tissue (phantom). When preparing the phantom, we mixed the deionized water and a modified agar gelatin [8]. In Tab. 3, we present amounts of ingredients for 1 dm^3 volume of mass.

Tab. 3: Amounts of ingredients for 1 dm^3 volume of agar phantom.

Ingredients	*Weight [g]*
Deionized water	430
Agar gelatin	572

The ingredients were mixed at the temperature around 90 °C (a higher temperature could destroy the agar gelatin). The mixed ingredients were poured into a form with the same shape as the simulated model. The prepared phantom exhibited relative permittivity 48 and conductivity 4.6 S/m at the frequency 5.8 GHz.

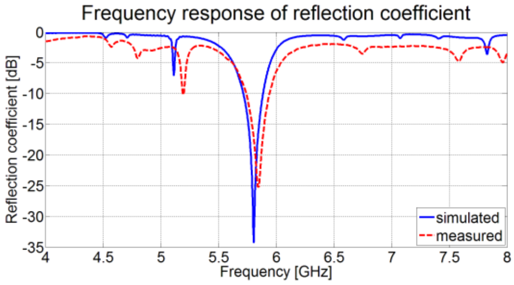

Fig. 6: Frequency response of reflection coefficient at the input of the filtering antenna in free space: simulation (solid blue line) versus measurement (dashed red line).

Fig. 6 compares the simulated frequency response of the reflection coefficient at the input of the filtering antenna (solid blue line) and the measured one (dashed red line). The antenna was in free space. The measured resonant frequency was shifted from 5.80 GHz (simulation) to 5.84 GHz (measurement). In resonance, the measured $|S_{11}|$ was for 10 dB higher compared to the simulation. The impedance bandwidth of the measured antenna was slightly wider (200 MHz in measurements versus 172 MHz in simulation).

For the filtering antenna on the phantom, the comparison of the simulated frequency response of the reflection coefficient at the input of the filtering antenna (solid blue line) and the measured one (dashed red line) is shown in Fig. 7.

Frequency response of reflection coefficient at the input of the filtering antenna measured on the phantom shows a frequency shift about 40 MHz. In the resonance, $|S_{11}|$ was –28.8 dB compared to –35.2 dB (simulation of the antenna on the phantom). The impedance bandwidth was 200 MHZ as well as in the free space configuration.

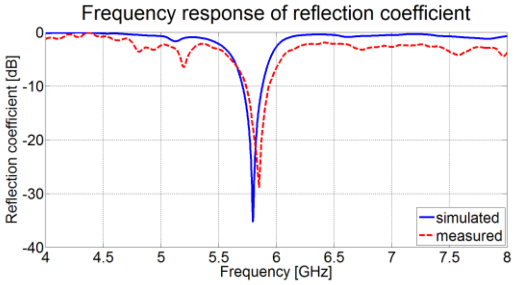

Fig. 7: Frequency response of reflection coefficient at the input of the filtering antenna on the phantom: simulation (solid blue line) versus measurement (dashed red line).

Figures 6 and 7 show that the model of human body does not have any dramatic influence on parameters and behavior of the filtering antenna array.

The measurement setup is shown in Fig. 8.

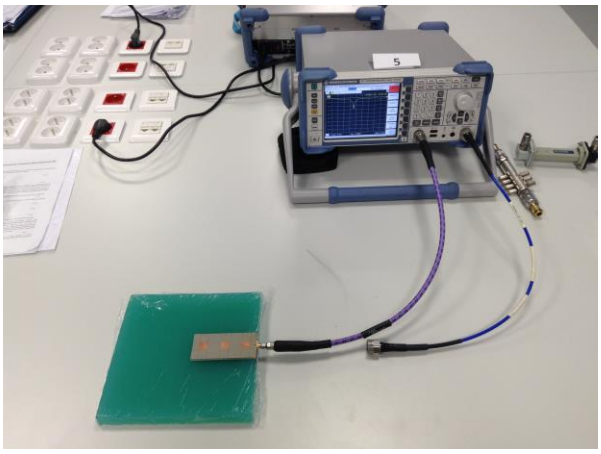

Fig. 8: Measurement setup for the characterization of the filtering array on the phantom.

Conclusion

In the paper, we described the filtering antenna array consisting of three patch elements. Since the antenna is not influenced by the proximity of human body significantly, the designed filtering antenna can be used both for free space communication and the off-body communication. The filtering antenna was designed for the operation in the ISM band 5.8 GHz.

The designed antenna can be characterized by the following parameters:

- Impedance bandwidth of the antenna is 200 MHz;
- Pass-band of the filtenna is 400 MHz;
- Realized gain of the antenna is 11.3 dB;
- Suppression in the stop-band is better than 20 dB;
- Deflection of the main lobe direction varies from 0° to 5° in band of operating frequencies.

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