A novel concept of a dual-orthogonal polarized ultra wideband antenna for medical applications

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Abstract— **This paper describes a concept of a dual-orthogonal, linearly polarized ultra wideband (UWB) antenna. The radiation principle and feeding scheme is described. Subsequently the prototype is introduced and the theoretical assumptions are verified by the measurements. A very good polarization purity was achieved over very wide frequency range.**

I. Introduction

In the recent years in the literature many ultra wideband (UWB) antennas were introduced [1,2,3]. Most of them exhibit either linear or circular polarization. However many applications can benefit from the polarization diversity. For example specific polarization signature of some object can be used for the recognition of its shape or structure. Especially in the medical applications the polarization diversity can be of big interest. Dual polarization can enhance the performance of the medical systems for health monitoring, where the antenna can be placed either in some distance from the patient or where the electromagnetic signal has to be coupled into the human body. The here presented antenna was designed for the radiation into the free space, but it has also a very big potential in the coupling into the human tissue.

In the following a novel concept of broadband dual-orthogonal, linearly polarized antenna is introduced. It bases on the interference of the waves in the antenna structure. The correctly arranged interference results in radiation of pure linear polarization and electrical decoupling of the ports for orthogonal polarization. The radiation from the antenna does not base on the resonance principle with very high quality factor. It allows for the good polarization purity and decoupling of the ports over very wide frequency range.

Since the release of the regulation for the UWB mask in Europe [4], the research in the UWB area was partly focused on the frequencies between 6 GHz – 8.5 GHz. The design of the here introduced antenna was dedicated for the European regulation, however the principle can be applied for the frequency ranges wider than the one specified by the European frequency mask.

II. Principle of Radiation

The shape of the radiating part of the antenna is introduced in Fig.1. The coloured parts mark the metallization. The antenna for single linear polarization has to be fed at two ports laying oppositely to each other. The signals are propagated in the slots toward the middle of the structure, where they interfere with each other. The phase of the both signals is always the same in the middle of the antenna. It implies the similar behavior of the radiation over very wide frequency range. In order to achieve such a performance the signals fed to the ports of the antenna must be exactly the same considering the amplitude and phase, whereas the phase equality of the signals is crucial.

The schematical distribution of the electric field lines propagating in the structure is marked in the Fig. 2. It can be observed that the electric field vectors at the places other than middle of the antenna possess both, co- and cross-polarized components. During interference the copolarized components coming from different ports (Co2.1 and Co.2.2 in Fig. 2) interfere constructively. The cross-polarized components (X2.1 and X2.2 in Fig. 2) interfere destructively and annihilate each other. It results in the very good polarization purity.

The electric field vector in the middle of the antenna is oriented longitudinally with respect to the slot lines for the second, orthogonal polarization. Such oriented vector is not able to propagate in the slot line. From this reason a complete electrical decoupling of the ports for orthogonal polarizations is carried out.

Such feeding technique has another extremely important advantage for UWB systems, namely the phase center of radiation does not move at all over the whole frequency range. Additionally both polarizations possess the phase center exactly in the same point. This results in very short impulse response of the antenna, which is respectively the same for both polarizations.

As can be concluded from the field line distribution the antenna radiates perpendicular to the substrate surface. The radiation is nearly symmetrical with respect to the surface, i.e.

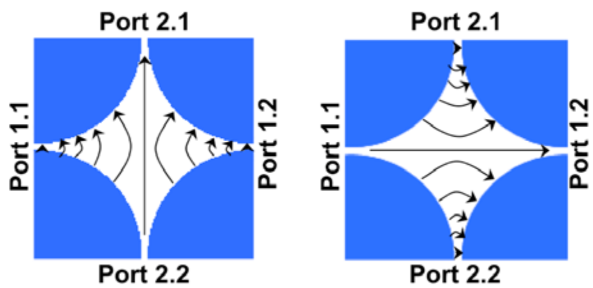

Fig. 1 Schematics of the antenna. (filled surface mark the metallic parts, arrows introduce the electric field vectors).

two nearly symmetrical beams are present. Such a radiation characteristic allows for potential placement of the antenna on the skin of the patient for coupling of the electromagnetic signal into the body. This is advantegous in comparison to e.g. Vivaldi antennas, which have to placed orthogonally to the surface of the body and need additional holder to keep its orientation relatively to the body.

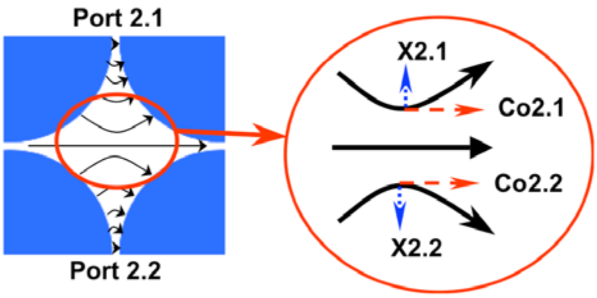

Fig. 2 Schematics of the electric field ditribution in the radiating zone of the antenna.

III. Feeding Network

As already mentioned, in order to radiate a single polarization the antenna has to be fed at opposite ports with the same signals. For this purpose for each polarization a 3 dB power divider has to be applied. The outputs of the dividers are connected to the corresponding ports in the way shown in Fig. 3. The cables must have exactly the same length in order to guarantee the same phase behavior of the signals fed to the antenna.

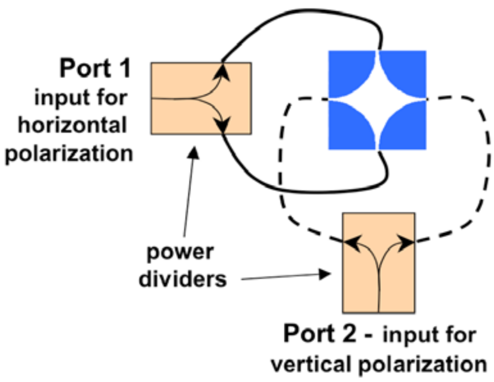

Fig. 3 Schematics of the feeding network

IV. Antenna Fabrication

The antenna is fed by four microstrip lines. In order to convert the microstrips to the slot lines, four aperture coupled baluns are applied. Such transitions are commonly used in the UWB technique [5]. The antenna was simulated and optimized with CST Microwave Studio [6]. As a substrate Duroid 5880 with ε_r=2.2 and thickness 0.79 mm was chosen.

In order to satisfy the condition of the equality of the amplitude and phase at both ports, the structure is arranged symmetrically to the axis crossing the middle of the structure

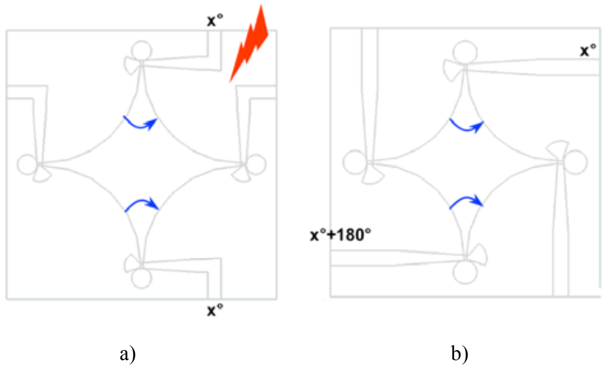

Fig. 3 Sketch of the antenmna

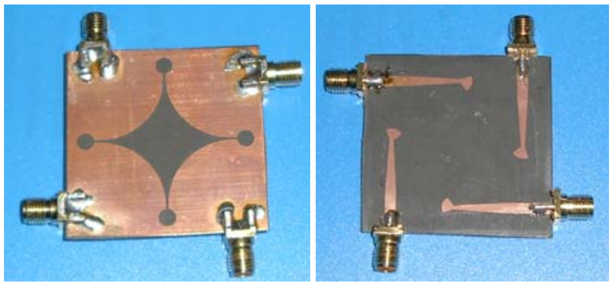

Fig. 4 Foto of the prototype antenna (left: top view, right: bottom view).

and perpendicular to the fed slots. Such a structure is introduced in Fig. 3a). The simulations show that such a configuration does not deliver expected decoupling between co- and cross-polarization. The field distribution plots show that the reason for this is the coupling between two microstrip lines marked in Fig. 3a) by a bolt. The coupling influences firstly the direct signal, which is not anymore the same in the amplitude and phase as the equivalent one. Secondly the part of the power coupled to the second microstrip line is delivered to the antenna. It leads to the unsymmetrical field distribution in the antenna and at last to the high cross-polarized components.

Due to this reason another arrangement of the feeding lines is considered. It has to guarantee the symmetrical design and the maximal distance between microstrip lines. For this purpose the symmetry to the middle point of the structure is applied. A scheme of such arrangement is shown in the Fig. 3b). The problem in this solution is that the equal signals given to the oppositely laying slots are exactly out of phase when propagating in the slots. In order to deliver the signals to the antenna, which have the same amplitude and phase, a differential power divider is needed. The power divider has to split the input signal in such way, that the outputs have the same amplitude but the phase difference is exactly 180° for the whole desired frequency range. The power divider meeting these requirements was presented in [7]. Similar solution is used also in this work. The outputs of the power divider are connected by 50 cm long microwave cables with the respective inputs of the antenna.

A photo of the optimized and realized antenna can be seen in Fig. 4. In the top view of the structure the four circles of the baluns can be observed. On the other side four feeding microstrip lines are present. The micrsotrip lines are connected with the microwave cables by the SMA connectors.

V. Results

A. Input matching

The whole structure including power dividers and cables exhibits a matching better than -10 dB in the desired frequency range from 6 GHz to 8.5 GHz (cf. Fig. 5). The matching was measured including power dividers and cables. The amplitude oscillation of the S_{11}-parameter is due to the resonances between power divider and the antenna. In the simulation it was not possible to model the whole structure including power dividers and cables. For this reason in Fig. 5 the simulated curve is a result of the simulation of the antenna only. The coupling between ports is lower than 35 dB. Hence it is negligible and will not be here specifically shown.

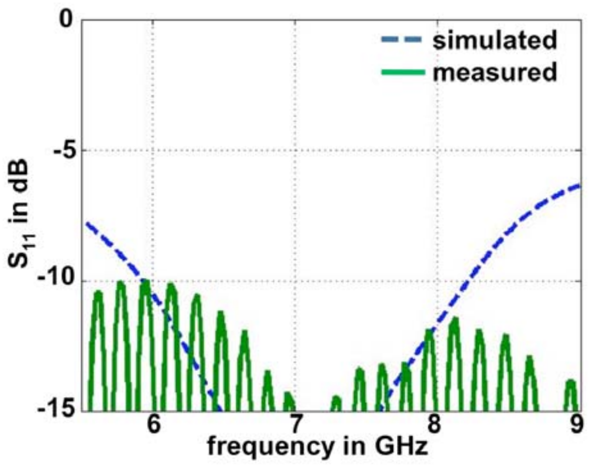

Fig. 5 Input matching of the antenna in Fig. 4 .

B. Gain and radiation pattern

The simulation shows a presence of some currents on the edges of the structure. These currents radiate also the electromagnetic wave, of which polarization is not clearly defined. Since the purpose of the measurement was to show the performance of the new method it was decided to attenuate the current at the edges with the absorbers. It results in a slightly smaller gain for the co-polarization and significant suppression of the cross-polarized components. The results presented in the following were conducted with the absorber strips put at the outer edges of the antenna.

The radiation characteristics of the antenna were measured in an anechoic chamber in the frequency domain using a Vector Network Analyser. The results of the gain measurements in the E-Plane for Co-Polarization are depicted in the Fig. 6. It can be seen that the antenna, as expected, radiates symmetrically in direction 0° and 180°. In the orthogonal direction (+/-90°) the antenna radiates very weak.

The measurements of the cross polarization (Fig. 7) show very good polarization decoupling, which is measured to be better than 20 dB in the main beam direction. The cross

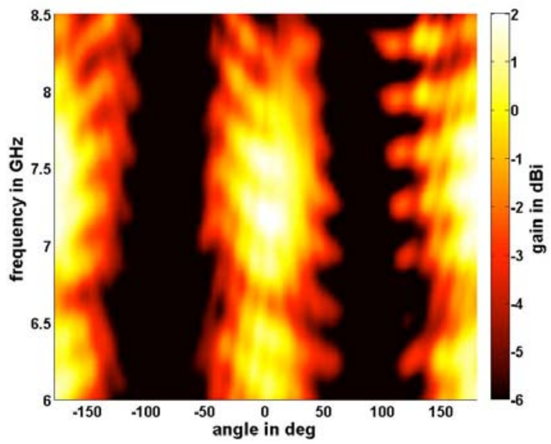

Fig. 6 Measured gain of the antenna in the E-Plane for Co-polarization over angle and frequency.

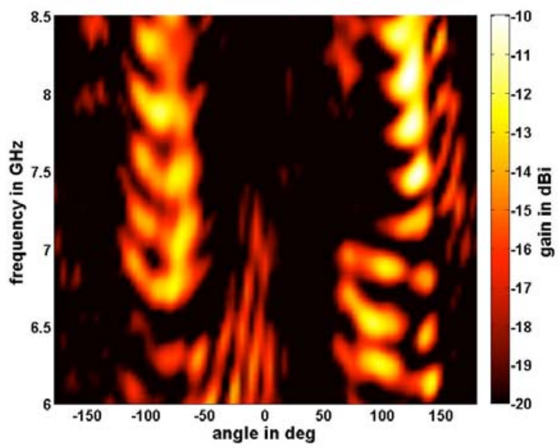

Fig. 7 Measured gain of the antenna in the E-Plane for X-polarization over angle and frequency.

polarized components arise slightly in the direction +/-90 degree, which are far away of the main beam (please note the scale at Fig. 6 and Fig. 7)

C. Impulse response

The broadband signals are often generated by proper shaped, very short electromagnetic pulses. From the antenna it is expected that it distorts the pulse as weak as possible. It means that the requirement on the antenna is not only good matching and proper radiation pattern, but also suitable time domain behavior. A very intuitive quality that describes the distorting properties of the antenna in the time domain is impulse response.

The impulse response can be measured either in the frequency or in the time domain. In the measurement in the time domain the result can be obtained directly by a proper calibration of the system. In order to obtain the impulse response from the frequency domain measurements an additional mathematical operation is needed. After the proper calibration of the system the complex transfer function of the antenna can be obtained. This transfer function contains all information about the radiation properties of the antenna i.e. amplitude and phase response. This complex transfer function has to be transformed into the time domain with the help of the Fourier Transform. By repetition of the operation for different angles, the angle dependent impulse response in the specified plane can be obtained. An example of such calculated impulse response is presented in Fig. 8. Introduced is the same measurement result as in Fig. 6 (E-Plane, Co-Pol).

Mathematical description of the time domain pulse transmission yields, that the radiated pulse is a result of the convolution of the derivated input pulse and the antenna impulse response. It implies that the shorter is the antenna impulse response, the less distorted is the radiated pulse. Also the amplitude of the impulse response is directly related to the amplitude of the radiated pulse.

The shape of the pulse proves a very good applicability of the antenna for pulse based wireless systems. The impulse response is short, which implies small distorting properties of the device. The main factors that influence the width of the impulse response are the aperture couplings (two in the power divider and one in the antenna). Each aperture coupling distorts slightly the pulse. It means that the impulse response of the antenna itself is expected to be even shorter, than the one presented in Fig. 8. However in this configuration the power divider is an indispensable part of the antenna and for this reason was not excluded from the measurements.

The amplitude distribution can be compared with the results from Fig. 6. The maxima occur at 0° and 180°, which are the directions perpendicular to the surface of the substrate. In the directions +/-90° the minimum of the radiation is visible.

After the main peak some weak, remaining radiation is visible. It is called ringing of the antenna and is an undesired effect, which results in spreading of the pulse over the time. The ringing of the presented antenna is weak and short.

It can be noted that the main peak is delayed by approx. 3 ns in the 0°-direction. This delay is caused by the power divider, connecting cables and antenna itself. Furthermore some variation of the impulse response delay over the angle can be observed. This delay difference is caused by the fact that during the measurement the antenna could not have been placed in the rotational axis of the rotating tower. During rotation the distance between antenna and reference antenna was variable, which results in the varying delay of the impulse response.

In the range between 0 ns and 1 ns on the left side of the plot some spurious radiation is visible. This radiation comes from the power divider. During the measurement the power divider was wrapped by the absorber. It was however not possible to attenuate the undesired radiation completely. This radiation contributes also to the cross-polarization and is also included in the Fig. 7.

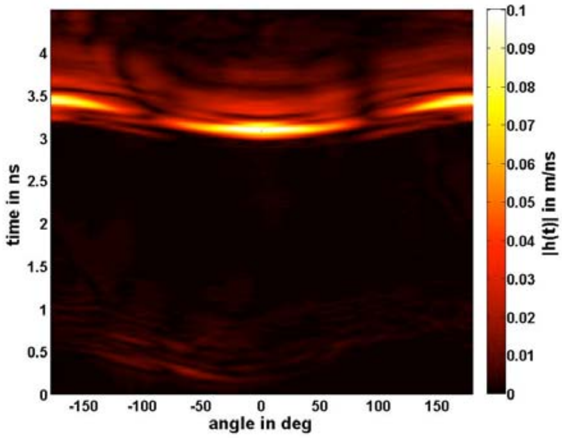

Fig. 8 Measured impulse response over the time and angle (E-Plane, Co-Pol).

VI. Conclusions

In this paper a novel very promising concept of the ultra wideband, dual orthogonal linearly polarized antenna was introduced. The antenna principle supports a destructive interference of the cross polarized components. It results in very good polarization purity over very wide bandwidth. The feeding principle allows for complete decoupling of the ports for orthogonal polarization, which avoids undesired transfer of the energy to the second port of the antenna. Furthermore the design assures that the phase center of radiation remains constant over ultra wide bandwidth. It allows for the application of the antenna in pulse-based techniques. Other big advantage is that the both polarizations have exactly the same phase center of radiation, which is important for the imaging and radar applications. The principle of the antenna has a big potential for further developments of the dual polarized UWB antennas for the medical applications.

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