Planer Circular Slot Antenna for Obtaining Possibility of Received Signals from All Directions

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ABSTRACT

This paper presents the results of design of antennas and antenna arrays for High Precision-Localization-System. Several structures, meeting particular requirements of the system, have been designed, realized and measured. Depending on the system configuration different types of antennas have been proposed for the base stations and mobile terminals in the system. Antennas realized as planar structures have been preferred due to their advantages: easy fabrication and integration with Tx/Rx modules, low profile and lightweight. Also analysis of dependence of distance determination error in localization system based on time of arrival measurements, on beam width of antenna radiation pattern has been presented. Using narrow beam antennas some multipath components with small delays, causing errors of calculation of distance between antennas, can be eliminated and accuracy of the system can be increased. This improvement depends on detection method implemented in the system. When leading edge detection, resistant to multipath propagation, is used influence of antenna radiation characteristics is smaller.

KEYWORDS: *Optimization, frequency band, simulated value, Radiation pattern, Major/minor lobes, Impedance characteristics.*

1. INTRODUCTION

Based on the OFDM signal transmission, we apply the adaptive beam forming methods to improve the performance of underwater communications. More specifically, the adaptive beam formers can be used to estimate direction of arrival (DoA) information and separate arriving signals from the multipath. According to the DoA information, time-delay and Doppler can be accurately compensated, which improves the demodulation performance. We use the experimental data obtained in the Pacific Ocean in 1989 [33, 36]. The OFDM signals were transmitted by a fast moving (at a speed of 5 m/s) underwater transducer at a depth of 250 m. A linear vertical antenna array of omnidirectional elements, positioned at a depth of 420, was used for receiving the signals. The transmission data efficiency were 0.5 bit/s/Hz and 1 bit/s/Hz.

Optimisation process is presented in details in Fig. 1. Optimisation script generates vector containing values of dimensions of structure, then runs structure editor, that rebuilds structure model using the vector of values, then simulator is running and after termination of simulation results are stored into file. Optimisation script reads the file and computes desirable parameters as values of goal function, i.e. reflection coefficient in specified frequency band as well as radiation pattern in specified plane, or other parameter, or any of them combined. The computed parameters are taken back to the optimisation function as a current iteration result, afterwards the function makes decision about further search using a sequential quadratic programming (SQP) method.

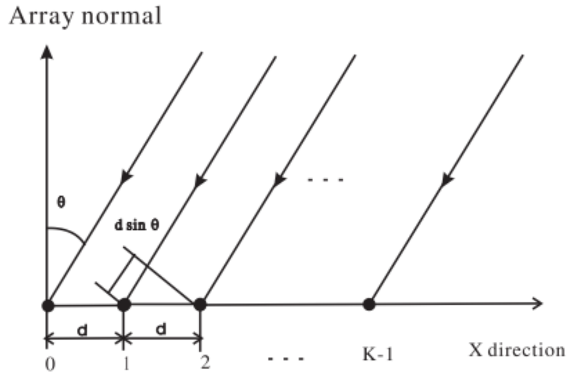

Fig. 1 Antenna array representation.

Optimisation takes significant amount of time. Each iteration typically takes half an hour up to a few hours on a single-processor workstation. Single optimisation procedure needs about 20 up to several hundred iterations to find a solution, depending on structure complexity, number of optimised variables and starting point of optimisation. Typically optimisation procedure takes one or two days, but if it fails to find acceptable solution the procedure needs to be executed again. By using two simulation environments based on different methods for designing purposes, self-verification route is able to be introduced, just before physical realization and measurement verification will be executed.

2. E-SHAPED PATCH ANTENNA

E-shaped patch antenna with operating frequency 5.150 – 5.875 GHz (with bandgap 5.350 – 5.470 GHz) was designed and performed. After literature survey, an E-shaped patch antenna has been chosen to design due to its simple construction, conformability to mounting in system and expected characteristics satisfying the project requirements. Patch of the investigated antenna is located on the dielectric substrate, and the substrate is located on metallic ground surface. Fig. 2 and Fig. 3 show structure of the antenna. The antenna has been realized and measured recently. Fig. 4 shows performed structure.

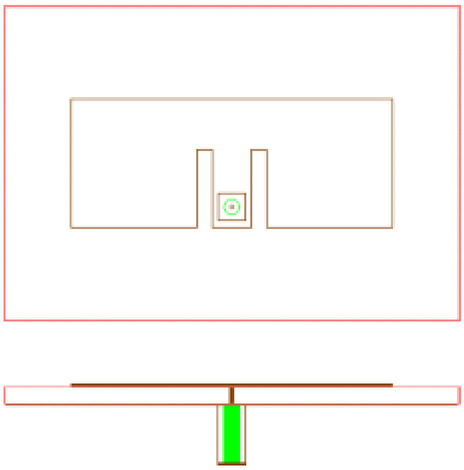

Fig. 2 Structure of E-shaped patch antenna, top view and side view.

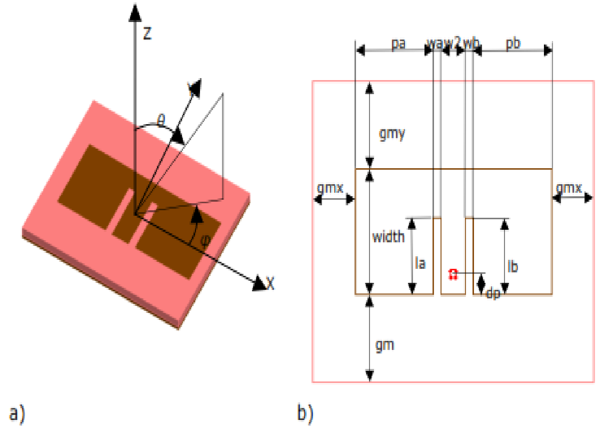

Fig. 3 Coordinates (a) and symbols designation (b) for E-shaped patch antenna.

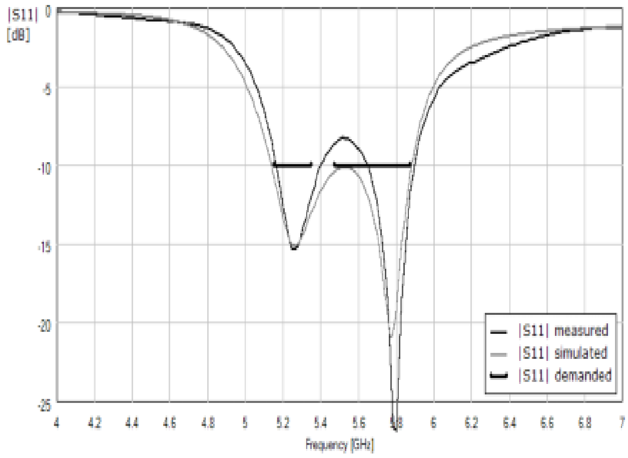

Fig. 4 Reflection coefficient of the antenna

3. MONOPOLE ANTENNA

Structure of monopole antenna is not convenient to perform and practical application because of its high profile. That was a reason why alternative planar antenna structure is proposed. The antenna has low profile with similar transversal dimensions. Radiation pattern of the planar antenna and monopole antenna are almost identical. Because of that these structures can be considered to be electromagnetically complementary. However frequency band of the planar antenna is much narrow. The complementary planar structure consists of circular patch fed in the centre and metallic surface separated by a slot from the patch. There is ground plane at the bottom side of substrate and the outer metallic surface lying on the top is short-circuited to the ground plane by means of a number of metallic vias. Structure of considered antenna is presented in the Fig. 2.23, and Tab. 2.4 contains parameters and dimensions of designed antenna. The antenna structure has been optimised in order to ensure frequency band of the antenna in the range 5.725 – 5.875 GHz (bandwidth equals 150MHz).

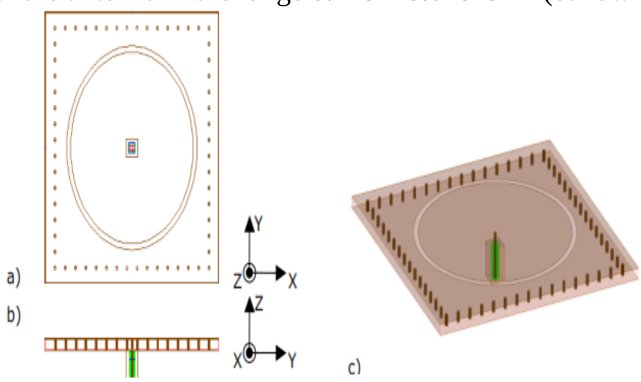

Fig. 5 Structure of single planar antenna with circular slot (in scale 1:1): a) top view; b) side view; c) 3-D view

Parameter	Value
laminate	RO3003
substrate thickness	1.524 mm
substrate permittivity	3.023
substrate conductance	0.0014 S/m
metal thickness	35 μm
metal conductance	5.847e7 S/m
antenna feed	RG-405, semi-rigid
circular patch diameter	31.9 mm
slot size	1.0 mm
length of side of vias	40.0 mm × 40.0 mm
vias radius	0.25 mm
substrate dimensions	45 mm × 45 mm

In order to find the reason of this disagreement further simulation has been executed. The structure has been simulated again in the Quick Wave 3D environment but using higher mesh density (200 cells per wavelength in the dielectric instead of 100 cells per wavelength in the dielectric). Also there was performed simulation of the same structure in FEKO electromagnetic simulator. All of the simulation results are presented in Fig. 7. Simulation results presented in Fig.7, Fig. 1 allow drawing conclusion that mesh density used in simulations has been not enough for that purpose, nevertheless density 100 cells per wavelength is commonly sufficient in the most of simulated electromagnetic problems.

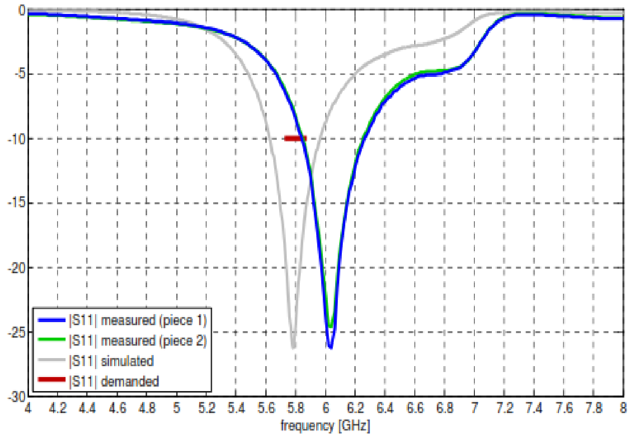

Fig. 6 Measured reflection coefficient of the antenna

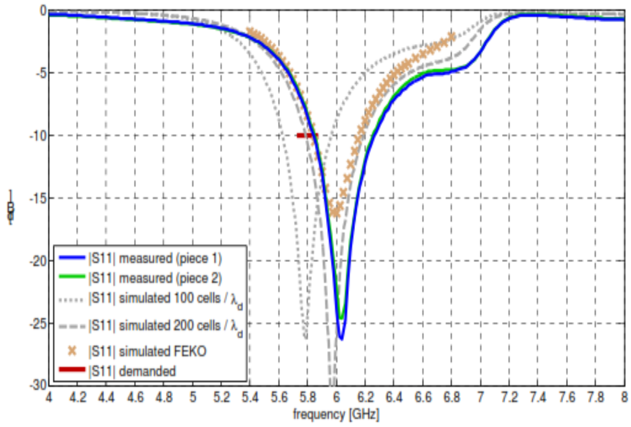

Fig. 7 Measured and simulated reflection coefficient the antenna.

Figure presents measured reflection coefficient of two pieces of performed antennas as well as simulation results obtained on the QuickWave 3D software at 100 and 200 cells per wave length inside dielectric and simulation results obtained on the FEKO electromagnetic simulator.

Fig. 8 shows measured and simulated XZ-plane cross-section of radiation pattern at 5.8 GHz. Results are roughly similar. Differences in the back radiation results from an antenna under test mounting system. Parameters of the antenna are optimal in order to applying the structure in mobile stations in the system. In particular, upraised radiation pattern is very adequate for system with highly located base stations. The radiation pattern causes reduction of rays reflected from the floor.

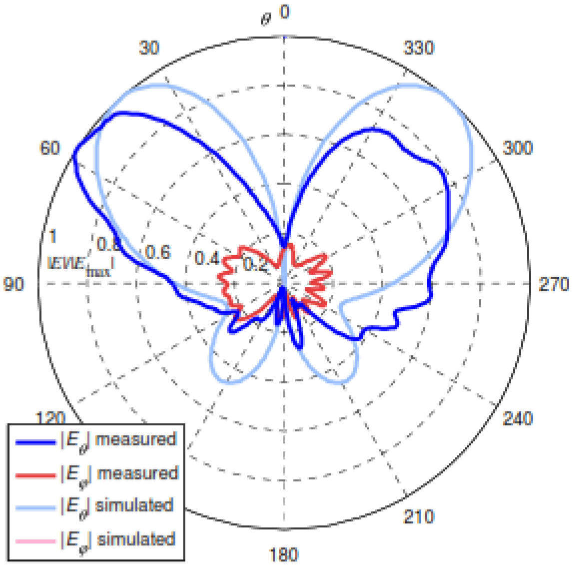

Fig. 8 Measured and simulated XZ-plane cross-section of radiation pattern

4. ANALYSIS OF ANTENNA BEAM

Multipath propagation can cause degradation of accuracy of distance determination in localization system based on time of arrival (TOA) method. Due to existence in the received signal multipath components with small delays and large amplitudes, in relation to line-of – sight LOS component (closely spaced paths - CSP), distance between transmitting and receiving antennas is calculated with error. This error depends on the system bandwidth: the larger bandwidth, the smaller error. Additional decreasing of the distance error can be obtained by:

- Use of appropriate method of detection of time of TOA, resistant to CSP
- Elimination of some multipath components with small delays using antennas with narrow beam of radiation pattern – steered antenna arrays.

Using the narrow beam antenna multipath components received from directions different from direction of LOS one can be attenuated (Fig. 9) and accuracy of distance calculation can be increased. Degree of improvement depends on spatial distribution of received multipath components and width of antenna radiation patterns. Report D3 [2] presents analysis of the indoor mutlipath propagation channel for scenarios typical for planed HPLS.

Special attention has been paid to determine existence of small delay multipath components for different configurations of propagation environment (factory and office halls). It has been shown that significant part of such components arrived from directions different from

LOS direction, so such components can be eliminated by narrow beam antenna.

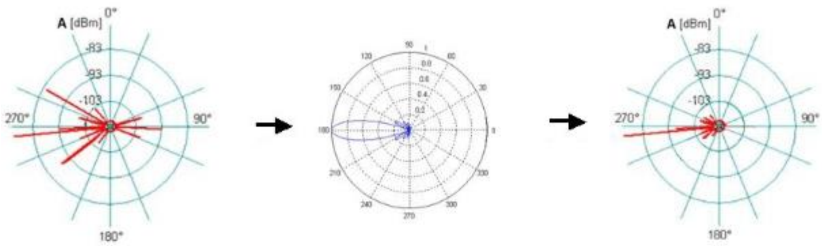

Fig. 9 Elimination of some multipath components using narrow beam antenna in the receiver

This analysis bases on results of D13 and presents influence of beam width of antenna radiation patterns on error of calculated distance between antennas. Special software (DEES – Distance Error Estimator) has been implemented in Matlab to calculate distance between antennas using the channel impulse responses (CIR) obtained from simulations or measurements. Different detection methods of TOA of LOS component have been considered during the analysis

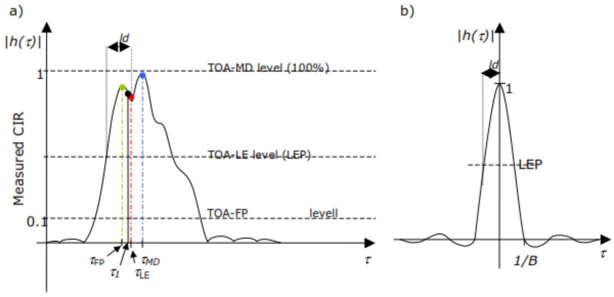

Fig. 10 Measured CIR value analysis with the system function.

- Detection of maximum of the entire signal – TOA-MD, component of the channel impulse response with largest amplitude is considered as LOS signal, when there are multipath components with amplitude larger than amplitude of LOS one , errors occurs
- Detection of first peak of the signal – TOA-FP, first pick above the assumed threshold in the channel impulse response is detected as LOS leading edge detection – TOA-LE, first signal above assumed threshold is detected and TOA of LOS signal is calculated considering time correction (adequate for direct clear LOS signal delay with the same threshold) TOA-LE detection method is resistant to existence of strong multipath signals with small delays, but it needs to calculate proper approximation of correction time parameter ld that depends on signal shape (modulation, Tx and Rx filters bandwidths, which are responsibl for side lobes levels, and main lobe width). Such detection method is implemented in designed HPLS. Analysis of influence of antenna radiation patterns on accuracy of localization bases on results of ray-tracing propagation simulator RPS. Following steps are performed during this analysis
- Simulations of the propagation channel in RPS propagation software for omnidirectional antennas and chosen location of Tx antenna and Rx antennas uniformly distributed in all the room
- Influence of antenna characteristics is calculated in Matlab, using simple models of antenna radiation patterns based on sin(x)/x function and the channel impulse responses (CIR's) obtained from RPS.
- Iinfluence of the system bandwidth is calculated using Root-Raised-Cosine (RRC) filtering as band limiting filter - convolution of two RRC filters with CIR gives band limited representation of the received signal (In simulation filter with 0.5 roll-off have been used)
- Distance measurement error (DME) is calculated using developed DEES software, considering three different TOA detection techniques
- Statistics of obtained DME (mean, median, standard deviation) have been calculated for obtained data in Matlab

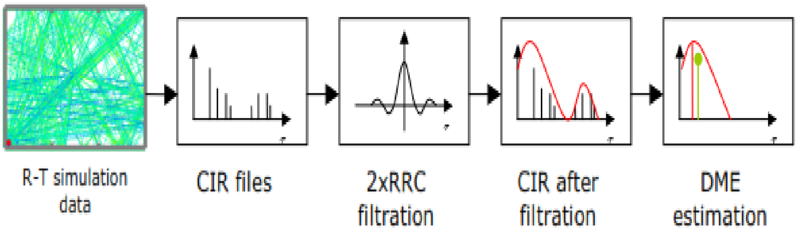

Fig. 11 CIR generation and filtering process using DEES program

In the first step average channel impulse responses for considered propagation environment and for different types of the receiver antennas has been calculated, basing on results from RPS. In calculations for each point of the receiver it was assumed that the antenna was always pointed towards the transmitter (model of scanning antenna array). In the transmitter that was placed near a wall, sector antenna, allowing to coverage all the room, was used. It is seen that when antenna with narrower beam is used, multipath components with small delays (having largest impact on accuracy of distance determination) are attenuated. The use of antenna with beam width in a range 60-90o can already significantly decreases amplitude of small delay components in the channel impulse response.
Analysis of dependence of error of distance measurement on characteristics of antennas has been done, basing on results of propagation analysis presented in D3 [2]. The use of leading edge TOA-LE detection technique allows minimizing errors caused by multipath propagation. Additionally increasing of accuracy of localization system can be achieved by using narrow beam antennas (steered antenna arrays) in the mobile terminal or the base station, depending on system configuration. Performed investigations show that the use of narrow beam antennas can improve accuracy of the system based on measurements of time of arrival (TOA), independent on used method to detect direct LOS component delay. But When TOA-LE detection is implemented in localization system influence of antenna radiation patterns is smaller in comparison to classical maximum pick TOA-MD detection. Distance measurement error DME decreases about 20-30% when antenna with beam width in a range $60\text{-}100^{o}$ is used in the mobile terminal in HPLS. It is good compromise between dimensions and complication of used antenna array and increasing of positioning accuracy.

5. CONCLUSION

To achieve possibility of mobile terminal of receiving signals from all directions the use of omnidirectional antenna has been proposed. Quarter wavelength monopole antenna could be used in this case for wideband transmission, or in narrowband case planar complementary solution – circular slot antenna (that has the same characteristics as monopole antenna, but it is narrowband solution) could be used. The use of such antenna in the mobile terminal has additional advantage – attenuation of waves reflected from floor, due to tilt of radiation pattern in elevation plane.
Antenna arrays can be used in the system to improve its characteristics. Array with electronically steered narrow beam can increase power of the received signal (increasing coverage range of the system) and attenuate some strong multipath components with small delays, causing errors of position determination in localization system. The use of antenna arrays depends on HPLS configuration. If localization is realized using active reflector in the mobile terminal STA, antenna arrays could be used in the BS (to received signal retransmitted by STA) and in STA (to receive signal from chosen BS and retransmit it in the same direction). In case of STA a simple switching array seems to be a good solution. If localization is realized basing on GPS concept with unidirectional down-link transmission from the BS to the mobile terminal STA, sector antennas could be used in the BS and antenna arrays could be used in the STA to receive signal from each BS. To obtain possibility of receiving signals from all directions four-element array with planar circular slot antennas has been proposed.

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