

# Requirements Synthesis for a Smart Antenna Array for Microwave Medical Imaging

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**Abstract**—Requirements for perspective medical system for non-invasive radiation diagnostics of functional state of biological organs and tissues, based on application of microwave sensing techniques, practically implemented in a smart antenna array, are synthesized. Estimates of characteristics of beam pattern and gain factor for the simulated smart antenna array meet the requirements for microwave medical imaging applications. A perspective diagnostic microwave imaging system is supposed to have high functional characteristics, enabling the possibility of precise imaging of biological organs and tissues without using contrast agents, and at a lower cost, compared with existing X-ray, magnetic resonance and positron emission tomography systems on the market.

**Keywords**—requirements synthesis, microwave medical imaging, tomography, complex dielectric permittivity, smart antenna array, Vivaldi antenna, beam pattern, gain factor.

## I. INTRODUCTION

Medical technology has witnessed drastic exponential changes in the field of diagnostic imaging of internal human body organs and tissues. Nowadays, more than half of all diagnoses in Russia are based on the results of non-invasive radiological medical diagnostics (NIRMD) [1].

At present, the following NIRMD tomographic methods are used in clinical practice, and each of them has its own advantages and disadvantages [2].

The proposed new method of NIRMD of the functional state of human organs and tissues [3] is based on application of non-invasive microwave sensing and imaging (NMSI) methods in non-ionizing region of electromagnetic spectrum,

practically implemented, using smart antenna array (SAA), extends the diagnostic approach to screening of socially sensitive diseases, enabling good visualization of organs and tissues of the human body with high enough resolution and without using contrast agents [4].

## II. METHODS OF MICROWAVE SENSING AND IMAGING IN BIOMEDICAL PRACTICE

Non-invasive methods of microwave medical sensing and imaging are relatively new in clinical practice, but they have good prospects for clinical application [5]. The advantages of NIRMD methods are as follows:

- non-invasive and non-contact diagnostic procedure;
- absence of necessity to use contrast agents;
- estimation of functional physiological states of biological objects;
- visualization of distribution of dielectric contrast in biological organs and tissues;
- low radiation and safe dose of emitting power;
- inexpensive in comparison with existing medical tomographic methods.

One of the main advantages of NMSI methods is the ability to obtain high spatial resolution of images, reflecting the physiological state of organs and tissues of human body without using contrast agents. This becomes possible due to the fact, that dielectric properties of biological tissues depend on their current physiological state. In particular, the characteristics of complex relative dielectric permittivity of tumor tissues differ significantly from healthy tissues [6].

Informativeness of diagnostic value of complex dielectric permittivity (CDP), was substantiated in a number of publications, in which it was noted [7], that changes in electrical parameters of biological tissues are caused by resonance absorption of electromagnetic field power by polar molecules (mainly water) [8].

In terms of practical application of NMSI of organs and tissues, the safety of electromagnetic radiation for human body is considered to be important. It enables a wide potential of NMSI methods applications in medical and biological practice. At the same time, it becomes possible to perform effective screening of diseases, associated with morphological and functional pathologies of internal organs and tissues [9].

**III. PRACTICAL IMPLEMENTATION OF MICROWAVE IMAGING AND SENSING METHODS IN SMART ANTENNA ARRAY**

NMSI methods can be practically implemented in biomedical practice, using a planar SAA based on Vivaldi antennas [10]. In this case, images of biological structures of the body are formed as follows [11]. Human body is sensed with a sequence of UWB electromagnetic pulses (EP) with a high time resolution from different angles. At the same time, one antenna element of SAA transmits EP, while others receive the reflected signal as it passes through biological tissues inside the human body. Each antenna element of SAA is subsequently switched to transmit EP while others keep operating in receiving mode. The amplitude and time delay characteristics of the reflected EP are used to visualize the CDP profile from the set viewing angle of SAA antenna elements. Thus, areas with higher CDP values are characterized by higher amplitude estimates of reflected signals. Homogeneous CDP areas of biological tissues are displayed as flat areas with uniform attenuation. Interfaces of media with different CDP values are displayed as characteristic spikes. The utilization of numerous SAA antenna elements, operating in receiving mode during the registration of reflected EP, enables to perform spatial focusing and forming of an image in accordance with the CDP distribution profile [12].

**IV. FUNCTIONAL REQUIREMENTS SYNTHESIS FOR SMART ANTENNA ARRAY FOR MICROWAVE MEDICAL IMAGING**

Perspective NIRMD system can be implemented using SAA consisting of 16 blocks of antenna subarrays (ASAB). Each ASAB consists of an array of 100 Vivaldi antennas. Suitable functional requirements for functional characteristics of the proposed SAA for microwave medical imaging are as follows:

- spatial resolution - 1 mm;
- time resolution - 100 Hz;
- maximum sensing depth - 30 cm;
- frequency range - X-band;
- beam pattern width (by azimuth) - 5°;
- beam pattern width (by elevation angle) - 5°;
- maximum power flux density - 10  $\mu\text{W}/\text{cm}^2$ ;
- average radiation power - 1 mW;
- antenna element gain factor - 30 dB;
- dynamic range - 100 dB;

The advanced NIRMD system, based on SAA application, is considered to provide the possibility of non-invasive microwave medical imaging of the following major pathologies of internal organs (heart, kidney, liver, lungs, brain) and tissues (including blood) of human body with high resolution and without using contrast agents:

- structural violations;
- blood supply violations;
- infectious and inflammatory processes;
- tumor processes.

**V. SIMULATION OF SMART ANTENNA ARRAY CHARACTERISTICS FOR MICROWAVE MEDICAL IMAGING**

The results of computer simulation, performed in ANSYS HFSS [12] for the beam pattern and gain factor of an elementary ASAB of the proposed SAA for microwave medical imaging at the middle frequency of 9.5 GHz, are given in Fig. 1. The antenna system is an adaptive smart antenna array (Vivaldi with linear polarization). The geometric dimension of a single ASAB (one SAA consists of 16 combined ASAB), including 100 Vivaldi antennas is 175x136 mm.

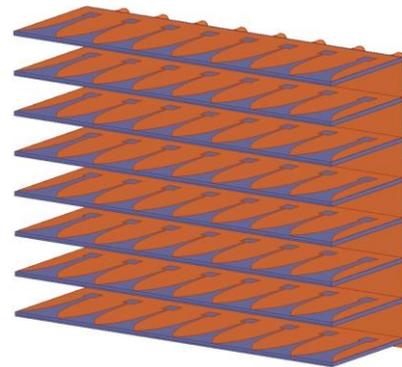


Fig. 1. 3D model of ASAB in ANSYS HFSS.

The beam pattern width of a single ASAB at the middle frequency of 9.5 GHz is 20° (Fig. 2). Therefore, the expected width of the beam pattern of the entire SAA for microwave medical imaging should not exceed 5°.

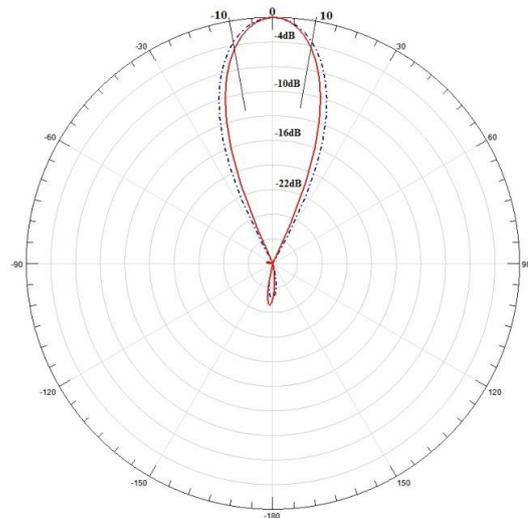


Fig. 2. The beam pattern of a single ASAB at the frequency of 9.5 GHz.

The gain factor for one ASAB at the middle frequency of 9.5 GHz is 19.7 dB (Fig. 3). Therefore, the expected gain factor of the SAA for microwave medical imaging should be at least 35 dB.

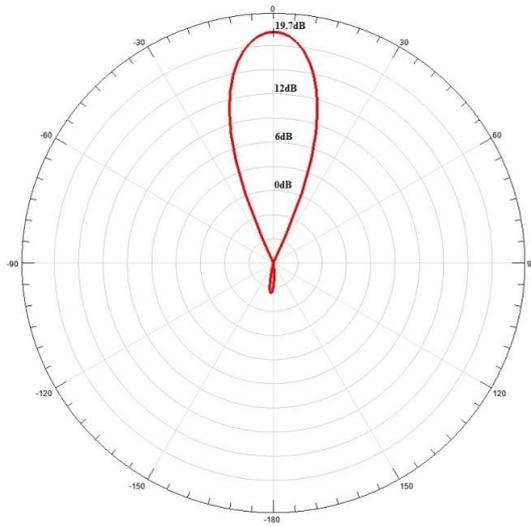


Fig. 3. The gain factor of a single ASAB at the frequency of 9.5 GHz.

## VI. ASSESSMENTS OF PEST ANALYSIS

Consider strategic aspects for development and market introduction of a high-tech medical instrumentation product (non-invasive radiological medical diagnostics) by a private enterprise of Russian military-industrial complex (JSC “RPA “Electronic Device Engineering”) based on a smart antenna array application for non-invasive microwave sensing - a fundamentally new technological solution on the market of high-resolution diagnostic imaging systems [13].

To assess the feasibility of conducting advanced research project [14] on development of perspective NIRMD system apply tools of marketing strategy forming based on classic methods of SWOT (Strengths, Weaknesses, Opportunities, Threats) analysis in Biodesign techniques [15].

### A. Strengths:

- opportunity of consideration of the feedback from the end product users due to the mobility of the staff and absence of high bureaucratic costs of the enterprise;
- potential to work close to the customers identifying current needs which allow considering market responses for developing of the final product;
- cooperation of the enterprise with key opinion leaders in the field of non-invasive radiological medical diagnostics in both in industry and clinics;
- possibility to quickly change and adapt technical characteristics and functionality of the product based on market responses.

### B. Weaknesses:

- size estimate of engineering staff of the enterprise in the field of medical instrumentation is inferior to the leading research and development centers of large companies abroad;

- instability of external cash flow of the enterprise in the early stages of product development in the field of medical instrumentation;
- limited estimate of free capital for acquisition of promising small innovative enterprises in the field of non-invasive radiological medical diagnostics is limited;
- administrative resource in the target healthcare sector concedes to lobbying opportunities of large foreign companies in the field of medical instrumentation.

### C. Opportunities:

- legislative support for domestic manufacturing companies in the sector of high-tech medical instrumentation products in the framework of import substitution policies;
- absence of direct competitors in the niche of high-resolution microwave medical diagnostic imaging systems on domestic market considering scientific backgrounds;
- relatively lower cost microwave medical imaging system for clinical application compared to existing tomographic systems on the market;
- functional characteristics of the proposed microwave medical imaging system complement existing clinical procedures increasing the diagnostic quality.

### D. Threats:

- exponential technological development can lead to a decrease in the ability of the enterprise to adapt to current market needs;
- insignificant changes in the focus of strategies of large competing companies can lead to the decrease of possibility of the enterprise to capture a new market niche to bioinnovate;
- introduction of sanctions for the purchase of certain radio components incorporated at the design stage having no analogues in the Russian Federation;
- sudden rejection by the key opinion leaders of the novel emerging technology unfamiliar to them.

## VII. CONCLUSION

The expected estimates for the proposed characteristics of the beam pattern and the gain factor, based on the results of simulation in ANSYS HFSS, meet the engineered requirements for perspective smart antenna array for high-resolution microwave imaging in the process of innovating medical technologies.

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