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Designing a Planar Antenna for Reading Device of the Capsule Endoscopic Complex

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This article describes the design of a planar antenna, which consists of available small-scale antenna elements and can be used in receivers with adaptive noise reduction algorithms, in particular, the receiving antenna for capsule endoscopic system "Landish". The entire planar antenna simulation results are described, material for common dielectric substrate is chosen. The differences between the characteristics of the radiation field in the far zone, the voltage standing wave ratio and wave resistance depending on the thickness of the substrate is noted. The finite element method was used for numerical calculations.

Key words: Microstrip antenna, Planar antenna, Electrodynamic simulation, Antenna pattern.

Wireless capsule endoscopy is a modern method for noninvasive examination of the digestive tract. It is used to diagnose abnormalities and morphological changes of the gastrointestinal tract[1-3]. For reading information from wireless capsule a miniature reader element is used[4, 5]. The tasks of the portable reader includes:

a) Sending control commands to the endoscopic capsule, such as the settings of the illumination system, the confirmation to begin operation, the confirmation of data packet delivery, the request for the transfer of a new data packet;
b) Receiving video from capsule through wireless data transmitting channel;
c) Recording and storing video data in the internal non-volatile memory;
d) Transferring video from internal memory to a personal computer.

The portable reader of the system is implemented in the form of a mobile device of small size with an array of sensors and is designed to send control commands wirelessly to the endoscopic capsule, to obtain video from the capsule and its subsequent transmission to the automated workplace (AWP) of a physician via USB or USB-mini cable atthe speed of 200 Mbit/sec. The reader is made in the form of a memory module, meaning a portable device in a plastic case and 14 sensors located in different parts of the abdominal body of the patient.

The second generation "Landish" reader[6] comprises of the following elements:

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a) module:
- sensors PCB;
- sensors PCB software;
- storage device PCB;
- storage device PCB software;

b) case;
g) battery;
d) USB memory stick.
e) patient's belt.

The storage devicePCB comprises
a) electrically programmable logic device (EPLD);
b) microcontroller;

The sensors PCB comprises
c) radio frequency (RF) transceiver;
d) antenna;
e) microcontroller.

Technical characteristics of the developed reader of the second generation endoscopic complex "Landish" are comparable to the main characteristics of world analogues[7, 8].

After the procedure a gastroenterologist connects the reader to his personal computer (PC), copies the images received by the capsule and launches software for processing[9, 10]. Therefore, the reader should have a large memory to store images, as well as small power consumption.

Due to the reasons mentioned above, it was advisable to create a specific reader for the capsule endoscopic system "Landish", which would best meet the requirements of the system.

One of the key elements of such a reader is an antenna, through which the exchange of information between the capsule and the reader is carried out[8]. This antenna must be, on the one hand, powerful, on the other hand, have low power consumption, to ensure that the reader functions throughout the scanning procedures of the gastrointestinal tract of the patient[7].

Capsule endoscopic systems manufacturers develop their own antennas for readers or use already existing components. Existing solutions have their advantages and disadvantages[8]. The latter include large size and considerable power consumption. Therefore, for a capsule endoscopic system "Landish" it was decided to develop its own antenna, which would meet the requirements of the system for the operation duration (at least 8 hours), had small dimensions and high sensitivity.

MATERIAL AND METHODS

Let us consider the process of developing antenna for the reader of the capsule endoscopic system "Landish". The designed antenna for endoscopic system "Landish"allows receiving video through a wireless channel from an endoscopic capsule moving in the gastrointestinal tract of a patient.

Microstrip antenna[11] underlying the developing device consists of a metal emitter, which is located above the conductive grounding plate. There is a low loss dielectric substrate between the grounding plate and the emitter. The shape of the emitter defines radiation characteristics of the antenna, which determine the field distribution in the antenna. Therefore, the shape of the emitter determines the method of connecting signal lines. Several simulation variants was proposed to describe the operation principle of the antennas of this type[12].

In a mathematical model describing the antenna, the following structure is considered: the upper and lower electric walls of it correspond to the emitter and the grounding plate. The sides of the structure are defined as magnetic walls equivalent to the boundaries of the open-loop electrical circuit. These boundary conditions allow us to consider this hollow structure a model of a microstrip antenna[13].

The thickness of the *h* substrate, used for microstrip antennas manufacturing, is usually much smaller than the wavelength: $0{,}003\,\lambda < h < 0.05\,\lambda$. Therefore, only a small portion of the waves launched by the emitter inside the hollow structure, reaches its borders, where directed radiation should happen. This explains the low efficiency of microstrip antennas. It is believed that due to the small thickness the field inside the hollow structure is aimed strictly perpendicular to the plane of the emitter. From this assumption it follows that the field distribution is determined by transverse magnetic waves only[14, 15].

From the wave equation for a hollow structure with boundary conditions defined above, the expression for the resonant frequency of the antenna is defined [15-16]:

$$f^{res}_{0,np} = \frac{1}{2\pi(\mu\varepsilon)^{1/2}}\left[\left(\frac{n\pi}{L}\right)^2 + \left(\frac{p\pi}{W}\right)^2\right]^{1/2}$$

where L, W are the geometric dimensions of the emitter (the length and width of the emitter),
μ, ε are magnetic and dielectric constants of the substrate,
n, p are the parameters that define the “En- and “Mn-modes.

$$\begin{cases} E_x = \dfrac{k}{j\omega\mu\varepsilon} A_{0,n,p} \cos\left(k_y y\right)\cos\left(k_z z\right) \\ E_y = E_z = 0 \\ H_x = 0 \\ H_y = \dfrac{k_z}{\mu} A_{0,n,p} \cos\left(k_y y\right)\cos\left(k_z z\right) \\ H_z = \dfrac{k_y}{\mu} A_{0,n,p} \sin\left(k_y y\right)\cos\left(k_z z\right) \end{cases}$$

Where *k* is the wave vector,
μ, ε are magnetic and dielectric constants of the substrate,
k_y, k_z, are the eigenvalues.

Assume that the antenna may be represented as four slots defined by the side walls of the hollow structure with only two of them located at a distance L from each other take part in the radiation. They are called radiating slots, while the radiation from the other two slots are mutually destroyed.

If the two main gaps are represented in the form of a two-element lattice with the distance L between the elements, it is possible to find the total radiation. Radiation field in the remote zone for this case can be described by the following expression:

$$E_\phi = j\frac{2hE_0}{\pi}\frac{e^{-jkr}}{r}\tan\theta\sin\left(\frac{k\omega}{2}\cos\theta\right)\cos\left(\frac{kL_{eff}}{2}\sin\theta\sin\phi\right)$$

where *k* is the wave vector,
L_{eff} is effective distance between the slots,
θ is the angle between the axis of the lattice and the observation point,
r is the radius vector to the observation point,
h is the thickness of the dielectric substrate,
E_0 is the electric field strength,
ϕ is the azimuthal angle.

In the remote zone the rest of the components can be considered as negligible.

Figure 1 shows the antenna elements power circuit used to manufacture the planar antenna and the cross-section of the corresponding region of the electrodynamic model (Figure 2). Coaxial line with an air filling has a wave resistance of 50 Ohms. Note that more significant complication of launching scheme was not carried out due to lack of information about the internal structure of the radio frequency (RF) connector used. This, however, did not prevent from getting good enough electrodynamic parameters of the planar antenna.

RESULTS

HFSS software was used for simulating antennas. HFSS uses three-dimensional full-wave algorithm of electromagnetic fields calculation in the frequency domain, which is based on the well-known Finite Element Method (FEM) for determining the electrical behavior of components. HFSS allows to isolate stray parameters S, Y, Z, visualize electromagnetic fields of the near and far zones to form full-wave SPICE model (Simulation Program with Integrated Circuit Emphasis - electronic circuit simulator) for effective evaluation of signal quality, including losses in the transmission channel, losses due to the varying resistances, stray coupling and radiation[17].

Let us consider the results of electrodynamic simulation (Figures 3-8). In the simulation, two materials were used for dielectric substrates: fire-resistant fiberglass laminate (FR4) and the polyimide with adhesive.

As can be seen from Figures 3-5, at the operating frequencies of 2.3-2.5 GHz antenna on 0.75 mm-thick FR4 dielectric of this configuration has a small gain ≈ 0 dB, the voltage standing wave ratio(VSWR) ≤ 2 and an input resistance of about 42 Ohms.

Dramatic reduction in the thickness of the dielectric substrate increases VSWR, while the wave resistance of the power line of 50 Ohms is still enjoyed, and antenna gain increase is obtained. However, the antenna design is complicated by the fact that you have to use matching serial loops. Thus, the simulation of the planar antenna on a 225μm-thick polyimide with adhesive dielectric

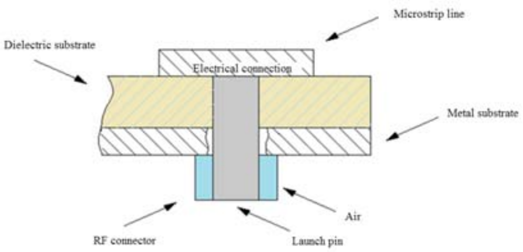


Fig. 1. Power circuit of planar antenna used for simulation

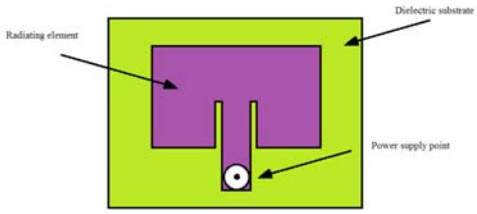


Fig. 2. Radiating element of a planar antenna on a dielectric substrate

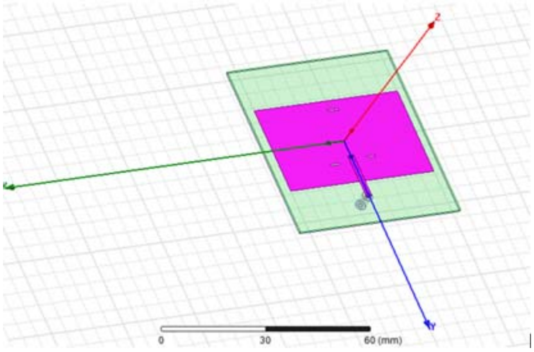


Fig. 3. Planar antenna geometry

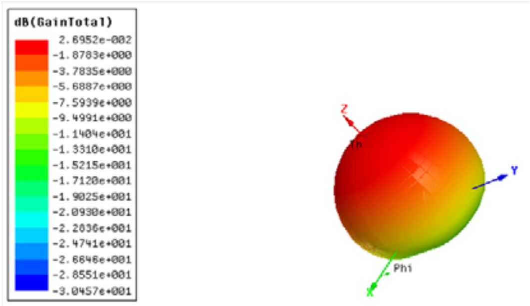


Fig. 4. Directivity of the planar antenna

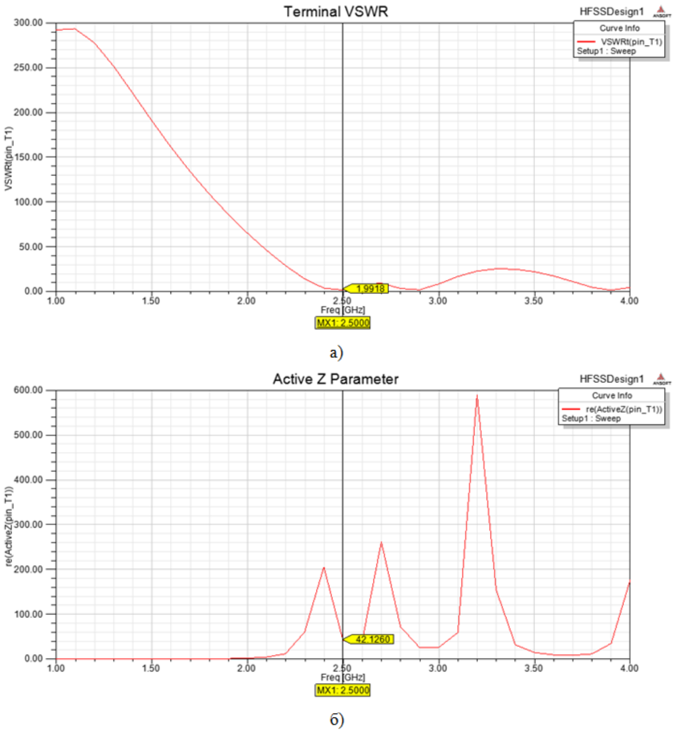


Fig. 5. (a) Standing wave ratio and (b) Impedance of the planar antenna on a 0.75mm-thick FR4 dielectric

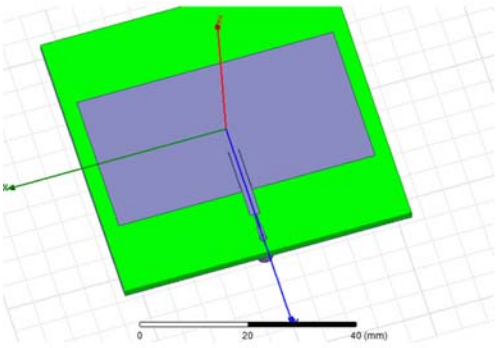


Fig. 6. Geometry of the modified planar antenna

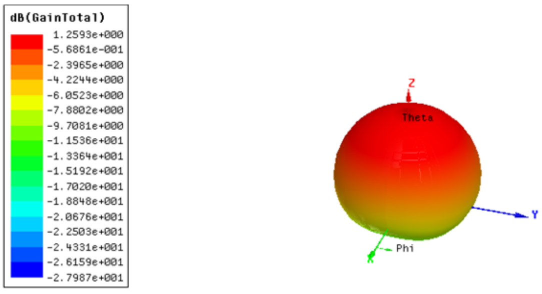
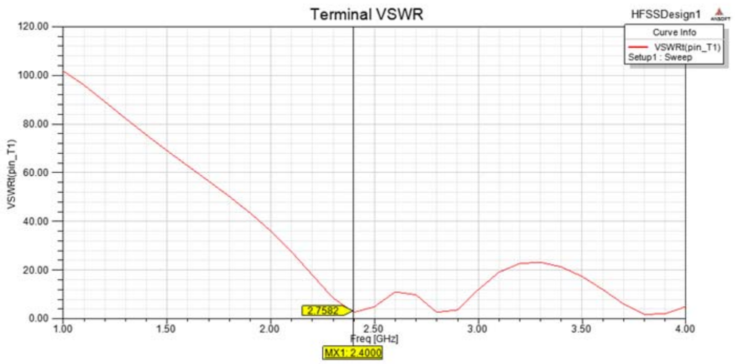
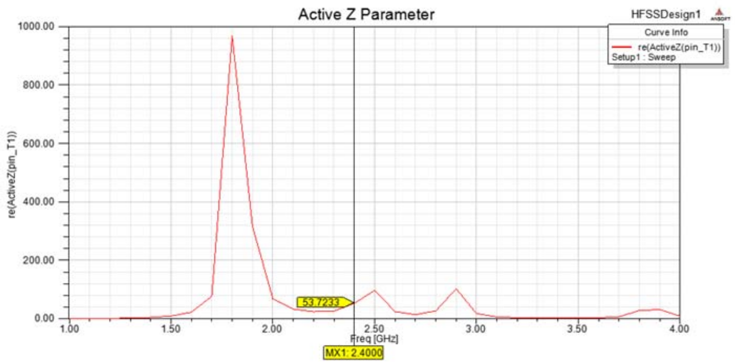


Fig. 7. Pattern of the modified planar antenna



a)



б)

Fig. 8. (a) VSWR and (b) Input resistance of the planar antenna on the dielectric polyimide with adhesive, 0.225 mm thick

substrateshowed that the VSWR at the frequency of 2.4 GHz is 2.7.

At the operating frequencies of 2.3-2.5 GHz receiving antenna on the dielectric polyimide with adhesive 0.225 mm thick of this configuration has a small gain of 1.2 dB, VSWR ≤ 2.75 and an input resistance of about 53 Ohms.

As a possible substrate for the antenna in the reader for "Landish" system based on the requirements for the dimensions of the antenna, it is advisable to use a 225 µm-thick polyimide with adhesive. This will allow to increase the gain more than 50 times for a given geometry of the antenna and to correspond a purely active input resistance using a serial loop with the power line.

DISCUSSION

Thus, this article describes the process of designing planar antenna that can be used in receivers with adaptive algorithms for noise suppression. The difference between the characteristics of the radiation field in the far zone and the coefficients of the scattering matrix for planar antennas on dielectric substrate of the different materials was noted. Numerical calculations were carried out using the finite element method.

In the future we plan to conduct prototyping of the antenna described above, its testing, refining and improving the efficiency of its functioning. Moreover, work and research with the aim of reducing the size of the reader and improvement its ergonomic and functional characteristics is intended.

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