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COMPUTER MODELING OF ANTENNAS FOR SMALL SPACECRAFTS

Abstract

Antenna systems used in small spacecraft are a very important element of the spacecraft. The limited size and operating features of these devices adjust the development processes of subsystems for them. In this work, wire and microstrip antennas for small spacecraft will be modeled and studied. The software environment chosen for modeling was CST Microwave Studio, which allows modeling antennas and ultra-high-frequency devices as close to reality as possible. In this work, a wire dipole antenna operating at a frequency of 433 MHz and a microstrip antenna operating at a frequency of 2200 MHz will be simulated. The dimensions of the antenna will be selected according to calculations, materials will be selected as close as possible to those available to the authors. The results of the study will be useful for further prototyping and research of these antennas.

Key words: antenna, CubeSat, modeling, dipole, microstrip antenna.

Inroduction

Currently, one of the trends in the development of science and technology is the use of small spacecraft to carry out various missions, including scientific research, education, remote sensing and imaging of the Earth's surface, etc. The relatively low cost of small spacecraft makes it possible to attract small businesses and enterprises for their creation higher technical educational institutions, that is, contributes to the creation of a "border zone" development/education [1].

Limited size and communication resources require advanced solutions in this area. Efficient use of space on board the small spacecraft is very important in this case. Therefore, optimization of the physical dimensions of small spacecraft components, including antenna devices, is an urgent task.

To transmit and receive data (tracking, telemetry and control (TT&C), imagery, etc.) many CubeSats in service or in service use different types of antennas, depending on the mission, spacecraft capabilities, and frequency range. design. Most CubeSat missions used VHF and UHF radio frequency (RF) communications with typical data rates of 1.2 and 9.6 Kbps for both telemetry and payload data transmission. Typically, wire, ribbon monopole and dipole antennas are widely used in the VHF and UHF bands due to the ease of their manufacture [2, 3]. Patch antennas, which primarily operate in the L- and S-bands, are the second most popular due to their low profile, light weight, and lack of additional deployment mechanisms [4, 5, 6, 7]. Review papers [8–10] list and describe modern antennas of various types used in small spacecraft. In practice, depending on the mission, deployable and protruding antennas are most often used [11–15]. The work [16] presents the concept of a tunable antenna, implemented using polyamide tape for operation in the S band. A feature of this antenna is the ability to change the configuration of the diagram. At the same time, for full operation, the authors propose to use a servomotor, which has a certain mass and occupies a certain place. The antennas studied and proposed in these works have fairly good characteristics, but the need for additional mechanical, software actions and resources increase the likelihood of failure of the small spacecraft mission. As is known, small spacecraft usually use several separate communication channels to transmit signals in the Earth-to-space and space-to-Earth directions, where antenna systems are used that cover and operate in several frequency ranges. Studies [17–20] proposed antennas for operation in multi-band and wideband frequency ranges. In [17], a star-shaped fractal antenna structure for operation in two bands was developed, modeled and manufactured. The geometric shape of this antenna starts with two conductive squares forming an octagonal star, which makes this antenna multi-band. [18] describes a multi-band miniature fractal microstrip antenna with high gain for modern communication systems. In the proposed design, a hexagonal Sierpinski pad is loaded onto a square microstrip antenna, which allows the spot area to be reduced by 68.4% and the perimeter to be increased by 168.8% by loading multiple triangular slots of different sizes in different iterations. [19] used dual fractal techniques to design a fractal Koch-Sierpinski microstrip antenna (KSFM) for wireless applications. The Koch fractal concept is applied to the outer periphery of the rectangular region, and the Sierpinski gasket concept is applied to the inner segment of the square region to reduce the influence of surface currents. The frequency characteristics of these antennas are achieved by fractal geometry, cutouts of different shapes and lengths. It should be noted that when developing these antennas, classical fractals were mainly used, in which large changes occur in all directions as the iteration number increases. This feature can degrade the basic characteristics of antenna systems.

Main provisions

This article performs computer modeling and research of wire and microstrip antennas for small spacecraft. The results of the study will be useful for understanding methods for modeling antenna systems for this type of device and for further research and development of effective antenna systems taking into account the limitations and requirements of this technology.

Methodology

CST Microwave Studio (CST MWS) is a program designed for fast and accurate numerical simulation of high-frequency devices (antennas, filters, power couplers, planar and multilayer structures), as well as analysis of signal integrity and electromagnetic compatibility problems in the time and frequency domains using rectangular or tetrahedral partition meshes.

A whip dipole antenna, also called a Hertz vibrator, consists of two identical arms made of metal pins. Most often, the total length of the antenna is half the wavelength of the 0.95 λ radio signal. The full wave is calculated using the formula:

$$\lambda = \frac{c}{f}, \quad (1)$$

where c – is the speed of propagation of an electromagnetic wave in vacuum, f – is the frequency of the signal.

For a frequency of 433 MHz, the wavelength is 693 mm, respectively, the length of the half-wave dipole will be 329 mm.

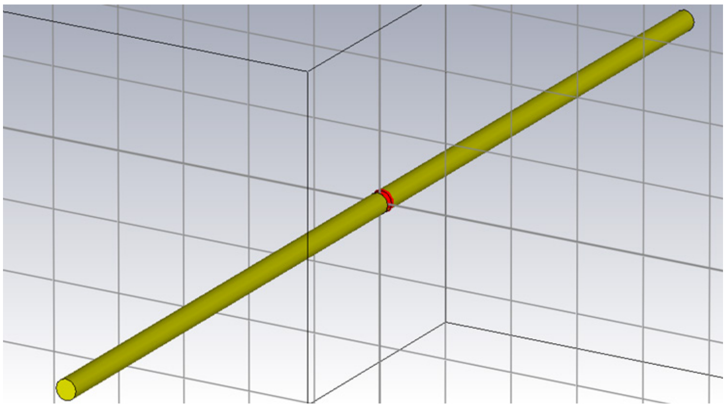

Figure 1 – Modeling of a half-wave dipole antenna

The distance between the two shoulders is 1–2 mm. Wire thickness 3 mm, material – copper. All antenna characteristics are defined in the software environment, which makes it possible.

Microstrip antennas, along with monopoles and dipoles, are probably the easiest to design. These antennas are also so easy to integrate on a printed circuit board that they are widely used in advanced systems such as 5G antenna arrays and radars. These antenna arrays are described by a simple set of design equations for the fundamental and higher order modes, so they can be designed without even using a simulation tool.

A microstrip antenna is essentially an open resonator. The antenna is located above the ground plane and the field limitation between the strip antenna and the ground plane determines the set of eigenmodes on which the antenna can operate (similar to longitudinal wave transmission lines). The eigenmodes correspond to certain modal field distributions within the resonant cavity created by the antenna, although such antennas usually operate on the fundamental mode. A microstrip antenna consists of an emitter, a dielectric substrate and a ground plane (figure 2, p. 210).

The main dimensions of a microstrip antenna are calculated using formulas (2) and (3), where c is the speed of propagation of the electromagnetic wave, f0 is the signal frequency, ε_R is the dielectric constant of the substrate, h is the thickness of the dielectric substrate.

$$W = \frac{c}{2f_0\sqrt{\frac{\varepsilon_R+1}{2}}} \quad (2)$$

$$L = \frac{c}{2f_0\sqrt{\varepsilon_{eff}}} - 0.824h\left(\frac{(\varepsilon_{eff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_{eff}-0.258)\left(\frac{W}{h}+0.8\right)}\right) \quad (3)$$

$$\varepsilon_{eff} = \frac{\varepsilon_R+1}{2} + \frac{\varepsilon_R+1}{2}\left[\frac{1}{\sqrt{1+12\left(\frac{h}{w}\right)}}\right] \quad (4)$$

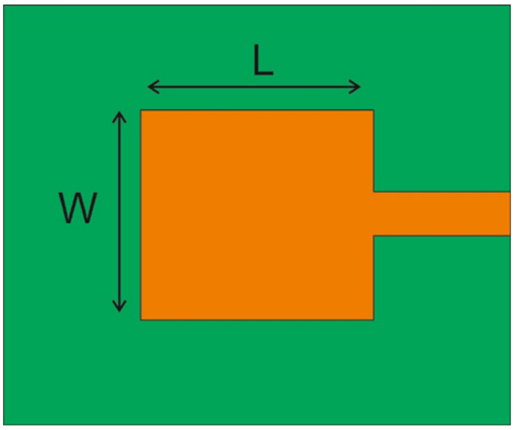

Figure 2 – Microstrip antenna structure

In the CST MWS software environment, a patch antenna was simulated to operate at a frequency of f_0=2200MHz (figure 3).

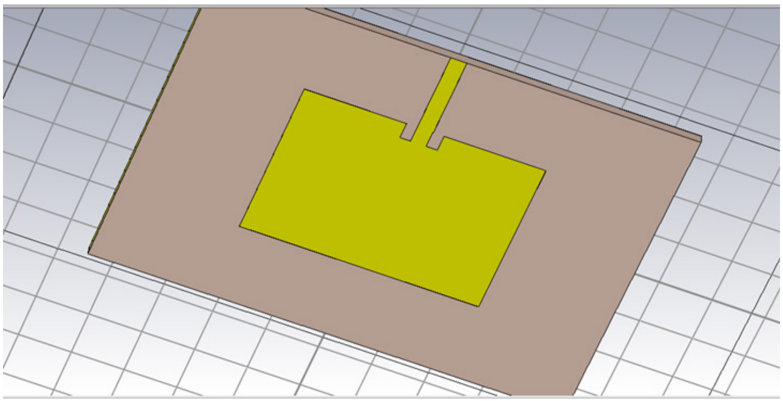

Figure 3 – Modeling a microstrip antenna

According to calculations for an antenna with substrate material FR-4 with a substrate thickness of 3 mm, the radiator size is W=82 mm and L=62 mm. In addition, matching cutouts were made at the junction of the emitter and the power line.

Results and discussion

This section shows and describes the results of modeling antenna systems. One of the most important characteristics of antennas is parameter S_{11}, shown in Figure 4 (p. 218), where the working area is taken as the area where the reflection coefficient is below -10. According to the graph, the dipole antenna operates in the range 390-442 MHz, maximum resonance 420 MHz.

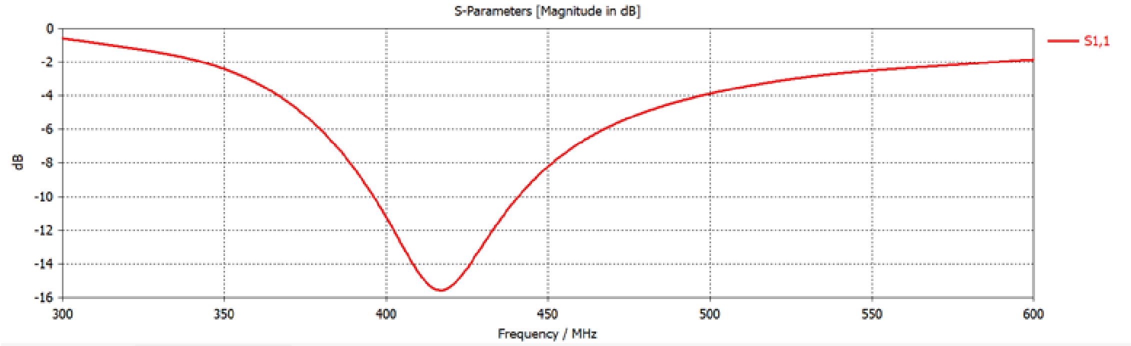

Figure 4 – S_{11} of a half-wave dipole antenna

Figure 5 shows the radiation pattern of a dipole antenna, showing the antenna's ability to direct the main energy in the desired direction. According to the figure, the dipole antenna directs the main beam of the signal along the arm, while in the transverse direction the signal shows minimal radiation. This means that this antenna is close to omnidirectional in directional characteristics. The maximum gain is 2.26 dB, which corresponds to the performance of a dipole antenna (figure 5).

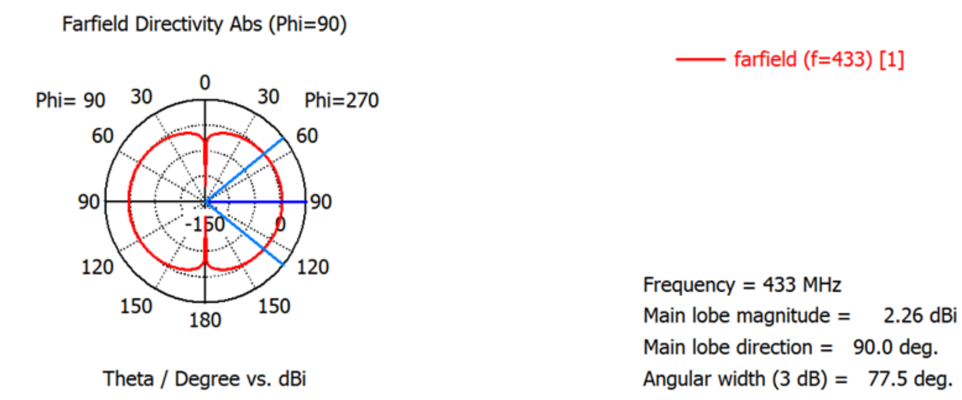

Figure 5 – Radiation pattern of a half-wave dipole antenna at a frequency of 433 MHz

Figure 6 shows parameter S_{11} of a microstrip antenna, according to which this antenna operates in the range of 2150-2260 MHz with a maximum reflection coefficient of – 34 dB. In addition, there is a second resonance with a central frequency of 3450 MHz.

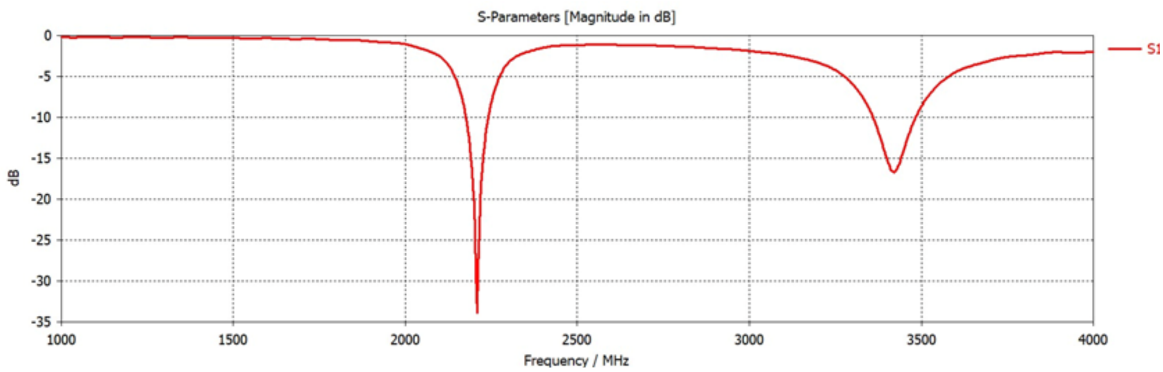

Figure 6 – S_{11} of microstrip antenna

Figure 7 shows the radiation pattern of a micropolka antenna at the fundamental frequency of 2200 MHz, according to which the antenna has more directional characteristics at this frequency.

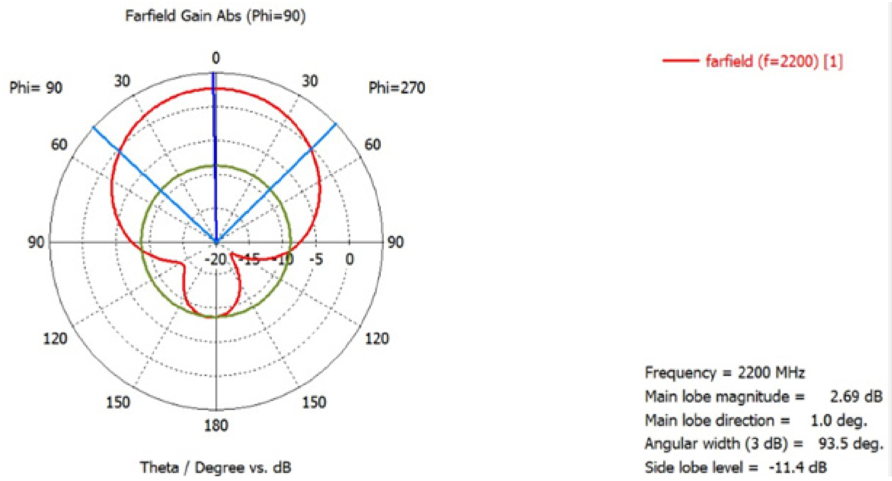

Figure 7 – Radiation pattern of a microstrip antenna at a frequency of 2200 MHz.

The main beam of the diagram corresponds to the direction of the antenna, the maximum gain at the frequency in question is 2.69 dB. The data obtained correspond to the calculations and show the performance of the antenna in this range.

Conclusion

In this work, antenna systems for small spacecraft of the wire and microstrip types were produced and studied. The research method chosen was computer modeling in compliance with the requirements of boundary conditions. A simulated wire dipole antenna for operation at 433 MHz shows performance at this frequency and has a maximum gain of 2.26 dB. Also, a simulated microstrip antenna for operation at a frequency of 2200 MHz shows performance at the required frequency with a maximum gain of 2.69 dB. In general, the characteristics of the antenna systems modeled for small spacecraft correspond to the calculations and are suitable for prototyping for further research.

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ШАҒЫН ҒАРЫШ АППАРАТТАРЫНА АРНАЛҒАН АНТЕННАЛАРДЫ КОМПЬЮТЕРЛІК ЖОБАЛАУ

Аңдатпа

Шағын ғарыш аппараттарында қолданылатын антенналық жүйелер ғарыш аппаратының өте маңызды элементі. Бұл құрылғылардың шектеулі мөлшері мен жұмыс мүмкіндіктері олар үшін ішкі жүйелерді әзірлеу процестеріне түзетулер енгізеді. Бұл жұмыста шағын ғарыш аппараттарына арналған сымды және микрожолақты антенналар модельделеді және зерттеледі. Модельдеу үшін таңдалған бағдарламалық орта – CST Microwave Studio. Ол антенналар мен ультра жоғары жиілікті құрылғыларды барынша шынайы модельдеуге мүмкіндік береді. Бұл жұмыста 433 МГц жиілікте жұмыс істейтін сымды дипольді антенна және 2200 МГц жиілікте жұмыс істейтін микрожолақты антенна имитацияланады. Антеннаның өлшемдері есептеулерге сәйкес таңдалады, ал материалдар авторлардың қолындағы материалдармен ұқсастырылып таңдалады. Зерттеу нәтижелері осы антенналарды одан әрі прототиптеу мен зерттеуде пайдалы.

Тірек сөздер: антенна, CubeSat, жобалау, диполь, микрожолақты антенна.

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КОМПЬЮТЕРНОЕ МОДЕЛИРОВАНИЕ АНТЕНН ДЛЯ МАЛЫХ КОСМИЧЕСКИХ АППАРАТОВ

Аннотация

Антенные системы, используемые в малых космических аппаратах, являются очень важным элементом космического аппарата. Ограниченность размеров и особенности работы данных аппаратов вносят коррективы в процессы разработки подсистем для них. В данной работе будут смоделированы и исследованы проволочная и микрополосковые антенны для малых космических аппаратов. Программной средой для моделирования выбрана CST Microwave Studio, позволяющая моделировать антенны и сверхвысокочастотные устройства максимально приближенными к реальности. В данной работе будут смоделированы проволочная дипольная антенна, работающая на частоте 433 МГц, и микрополосковая антенна, работающая на частоте 2200 МГц. Размеры антенны будут подобраны согласно расчетам, материалы будут выбраны максимально приближенными к имеющимся у авторов. Результаты исследования будут полезны для дальнейшего прототипирования и исследования данных антенн.

Ключевые слова: антенна, CubeSat, моделирование, диполь, микрополосковая антенна.