Antenna for Wi-Fi Analytics

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Abstract. The paper discusses the technological elements that improve the work of Wi-Fi-analytics – a new direction of marketing. This direction allows you to acquire additional information about customers using wireless technologies Wi-Fi, and without the knowledge of the customers themselves. This information using Data-Mining algorithms and CRM-systems can significantly improve sales efficiency. For efficient operation of business intelligence algorithms, variants of dual-band microstrip antennas operating in the IEEE 802.11n standard frequency band have been proposed. The main electrodynamic characteristics of the proposed antenna version are presented. A comparative analysis of the efficiency of numerical modeling of antenna system, carried out on the basis of the finite element method, the finite integration technique and the method of moments, is carried out.

Keywords: Wi-Fi-Analytics, Patch Antenna, Finite Element Method, Finite Integration Technique, Method of Moments.

1 Introduction

Currently, an effective business uses new technologies. Equally important for business are communication technologies that allow you to quickly transfer large amounts of information, or allow for effective business management. Often, new technologies make it possible to open business areas or effectively use existing resources, which make it possible to generate additional profits. This paper discusses the construction of technological elements used in the new trend of marketing – Wi-Fi-analytics [1, 2], allowing to significantly increase the number of potential buyers.

Every contemporary smartphone has a Wi-Fi module, and if it is turned on (which happens more often), then without the knowledge of the owner, the smartphone starts sending multiple signals. The signal contains a number of characteristics: MAC address, signal strength, signal transmission time. This approach [3] allows you to get a number of metrics [4, 5] that allow you to extract additional information about customers. As a rule, these include: the number of people in a certain location, customer movement routes (which can be grouped into different categories), the average time spent in a location (as a rule, the more time, the more profit the business), number of customer returns (which allows assessing the potential of the business).

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Another method [6] integrates Wi-Fi analytics into the CRM system, linking the client's MAC address and its phone number. This approach allows you to transfer information to the client on the phone number upon the occurrence of a certain event, most often the presence of the client in a certain location. For example, when a regular customer is located in a location of a highly specialized store, information about a special offer is transmitted to his phone number.

However, when implementing such approaches, developers solve a number of tasks related to the implementation of compound Data-Mining algorithms, the calibration of objects, and also the elimination of noise and interference. Also important is the technical equipment, which allows to eliminate a number of problems that arise. So the use of special antenna elements of the device can work in all frequency bands of Wi-Fi and implement spatial selection of interference.

But the experience of developing compound antenna-feeder systems [7, 8] shows that the implementation of full-scale breadboarding is too complicated and expensive. While the use of computer (electrodynamics simulation) modeling and, accordingly, the exclusion at various stages of experimental measurements, can significantly improve the efficiency and speed of development of complex antennas.

2 Numerical Electrodynamics Methods

Analysis of existing methods of numerical electrodynamics identifies the most effective of them: finite element method, finite integral method, moment method with asymptotic methods of physical optics and geometric diffraction theory.

The finite element method is based on solving differential equations in the considered domain, which is divided into a finite number of elements [9]. The values of the functions at the borders of the elements (in nodes) are unknown in advance. The solution is based on the use of approximating functions, the coefficients of which are usually sought from the condition of equality of the value of neighboring functions at the boundaries between the elements (at the nodes). The composed system of linear algebraic equations determines the solution.

The finite integration technique is based on the use of Maxwell's equations in the integral form, described in a spatial grid, taking into account the energy conservation law [10]. For a numerical solution, the calculation area is determined, which is divided into cells (primary grid). On the basis of the cells obtained, a secondary grid is formed, orthogonal to the primary one. Spatial discretization is performed on these two orthogonal grids, that is, matrix operators are formed that contain all the topological information of the object. The advantage of the method is the type of partitioning grid used – for three-dimensional configurations of high complexity, a non-orthogonal grid, for example, a tetrahedral one, can be used, which allows choosing the optimal solution method and partitioning method.

In **the method of moments** the electromagnetic fields in the structure are expressed through electric and magnetic currents [11]. Moreover, the field in the structure is described by continuous values, within the cell division. The advantage of the moment method is that it is a “source method”, that is, when discretization, the volume of the structure under consideration is divided, and not the free space, as in the methods of finite elements or finite integrals. In this case, the boundary conditions are not required, and the used memory is proportional to the geometry of the problem and the frequency. The disadvantage of this method is the need to select basic functions for each specific structure. In this connection, complex objects are represented by planar structures whenever possible, or universal basic functions are used, even to the detriment of solution convergence.

Often the solution of physical problems by numerical methods, as well as the use of complex computational algorithms leads to the need to have ways to control the reliability of the results [12]. Moreover, the use of several different methods for finding the desired solution is an effective way to control the reliability of the results obtained.

3 Dual Band IEEE 802.11n Antenna

The antennas used for WI-FI technologies, due to the limiting radiation power of 20 dBm (100 mW) according to the IEEE 802.11 standard, must meet several requirements: have high efficiency (gain) and excellent matching with the power line, besides physically receiving / transmissions (access point) are often located near the walls, and therefore the maximum of the radiation pattern must be directed away from the geometric center. The 802.11n standard [13] assumes the operation of equipment operating on the internationally unlicensed ISM (Industrial, Scientific and Medical) frequency band – 2.4 GHz and the UNII (National Information Infrastructure Unlicensed Band) – 5 GHz (see Table 1, Table 2) with the maximum possible speed of up to 600 Mbps.

Table 1. ISM international frequency band.

channel number	lower frequency, GHz	upper frequency, GHz	channel number	lower frequency, GHz	upper frequency, GHz
1	2.401	2.423	8	2.436	2.458
2	2.406	2.428	9	2.441	2.463
3	2.411	2.433	10	2.446	2.468
4	2.416	2.438	11	2.451	2.473
5	2.421	2.443	12	2.456	2.478
6	2.426	2.448	13	2.461	2.483
7	2.431	2.453			

For the implementation of the above requirements, the proposed optimal design of a dual-band microstrip antenna (see Fig. 1) with an operating frequency band $\Delta f = 2.25\text{-}2.85$ GHz in the ISM band and $\Delta f = 5.07–5.63$ GHz in the UNII band by the level of 10% reflected power (see Fig. 2). The proposed antenna has the necessary Wi-Fi band of the IEEE 802.11n standard in the ISM band and works in the UNII band with channels 36 to 120, which are most in demand when used.

Table 2. UNII international frequency band.

channel number	frequency, GHz	channel number	frequency, GHz	channel number	frequency, GHz
36	5.18	50	5.25	100	5.5
38	5.19	52	5.26	104	5.52
40	5.2	54	5.27	108	5.54
42	5.21	56	5.28	112	5.56
44	5.22	60	5.3	116	5.58
46	5.23	62	5.31	…	…
48	5.24	64	5.32	180	5.905
UNII-1		UNII-2		UNII-3	

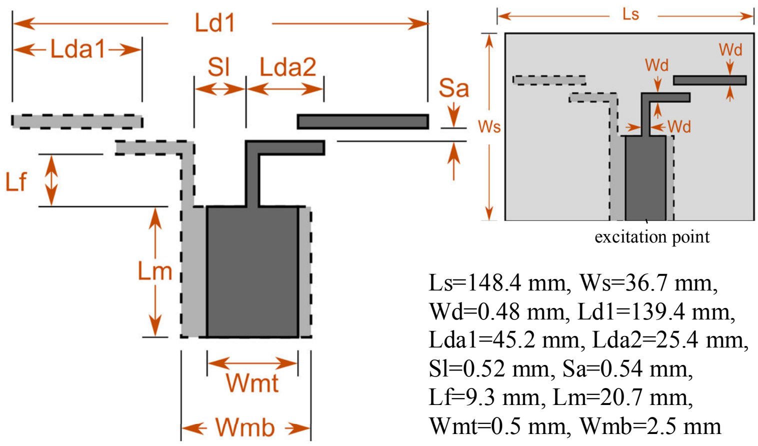

Fig. 1. Design of Wi-Fi dual band microstrip antenna.

The calculation of the characteristics of matching with the power line was carried out by three methods: the finite element method (FEM), the finite integration technique (FIT) in the time domain and the method of moments (MoM). In applied electrodynamics, the most difficult from the point of view of computation is the determination of the impedance of the structure, than the determination of the characteristics in the far field. In this connection, the test of the accuracy of calculations is the determination of the coefficient of the reflected wave S_{11}, and the criterion of convergence, as a rule, is chosen the invariance of this characteristic. It is acceptable to change the reflection coefficient by no more than the value of 0.02. For the finite element method, the solution required 5 passes and 14944 partitions of the structure into tetrahedral elements; for the finite integration technique – 4 passes and 771100 partitions into tetrahedral elements; for the method of moments – 1 pass and 892 triangular partitions to obtain a convergent solution (see Table 3).

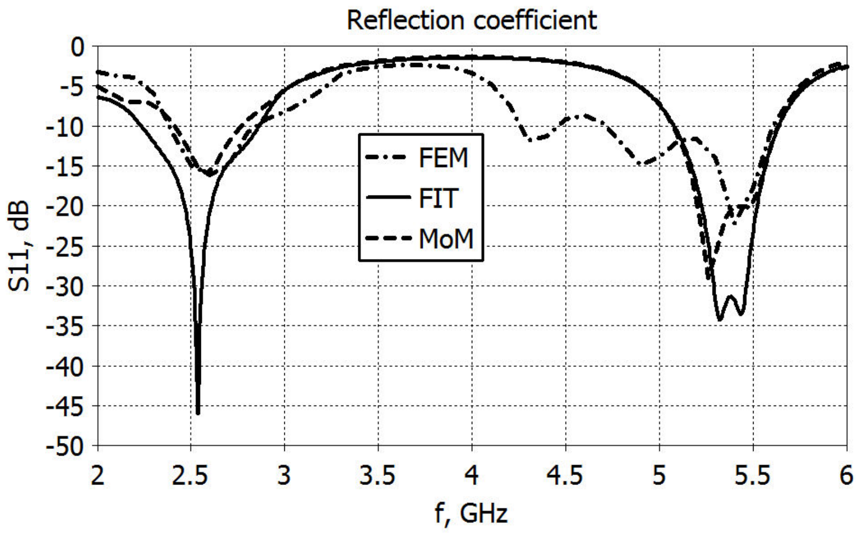

Fig. 2. The results of the calculation of the reflection coefficient S_{11}.

Table 3. Solution convergence.

passes / number of decomposition									
FEM					FIT				MoM
1	2	3	4	5	1	2	3	4	1
5351	6919	8957	11587	14944	146090	257020	447000	771100	892

Comparison of the results obtained by the three considered methods (see Fig. 2) showed good agreement between the dependence of the reflection coefficient and frequency. In the lower part of the frequency range, there is almost complete coincidence of the results obtained by the finite element method and the method of moments. However, at the point of the first resonance at the frequency f = 2.55 GHz, a deep minimum is observed only for results obtained by the finite integral method, which can be explained by a much larger number of splitting elements (more than 50 times) compared to the other two methods. With increasing frequency (f = 4-5.5 GHz), the method of moments showed the worst match because it has the smallest number of discrete element. In the upper part of the frequency range, the finite integration technique and the finite element method showed good agreement except for the second resonance region in the vicinity of the frequency f = 5.35 GHz, which is also explained by the insufficient number of partitioning elements of the structure under study.

Nevertheless, as practice shows, the results obtained by the finite-integral method should be considered as the most reliable due to the large number of elements used in splitting. Of course, the amount of resources required for the implementation of the method of finite integrals in this case is several times greater than for the other two methods. From the computational point of view, the most preferred method is the moment method, which requires the least number of passes and splits, in addition, the obtained accuracy of calculations is much better than that of the finite element method.

Fig. 3 and Fig.4 shows the antenna gain versus frequency in the ISM and UNII bands. Antenna gain is a universal characteristic showing the directional properties of the antenna, as well as losses arising from matching the antenna with the power line. This design is characterized by an increase in the gain with increasing frequency. In the UNII band, there is a local minimum at the frequency f = 5.32 GHz that reduces the gain to a value of 2.63 dB. The calculated gain values for all three methods almost coincide.

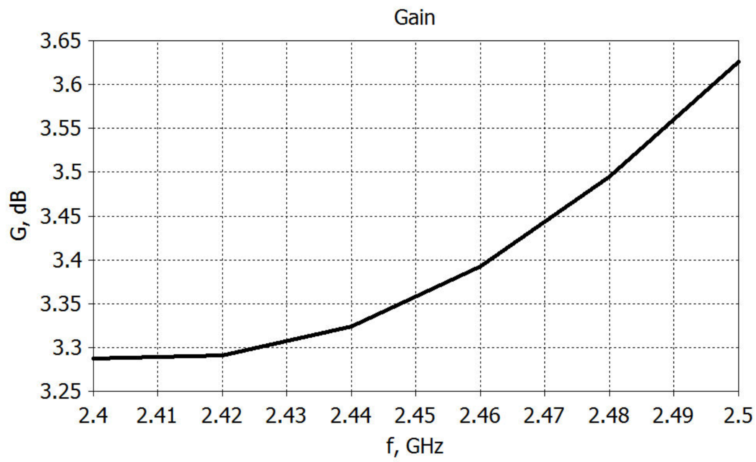

Fig. 3. Gain in the ISM band.

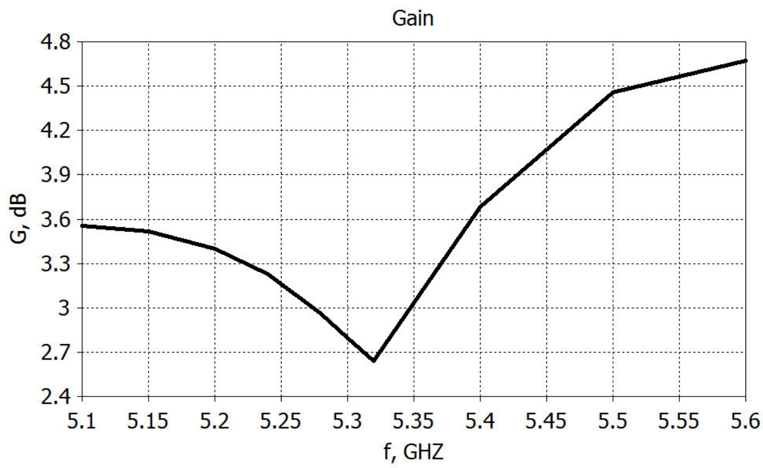

Fig. 4. Gain in the UNII band.

The radiation pattern has the shape of a torus. Fig. 5 and Fig. 6 respectively show the cross sections of the radiation pattern in the vertical (θ=90°) and horizontal (φ=0°) planes, respectively (the solid line is the ISM band f = 2.4 GHz, the dotted line is the UNII band f = 5.3 GHz). In the UNII band, the antenna pattern is transformed: a torus has sharp protrusions at angles of ±30° and ±60°. However, this does not affect the performance of Wi-Fi since the unevenness is no more than 3-6 dB.

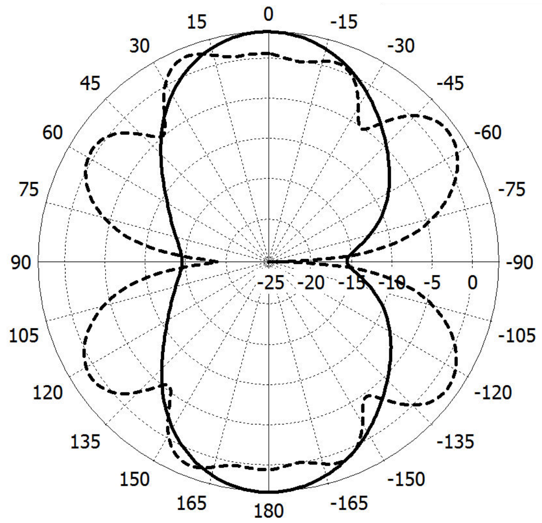

Fig. 5. The cross section of radiation pattern in the vertical plane θ=90°.

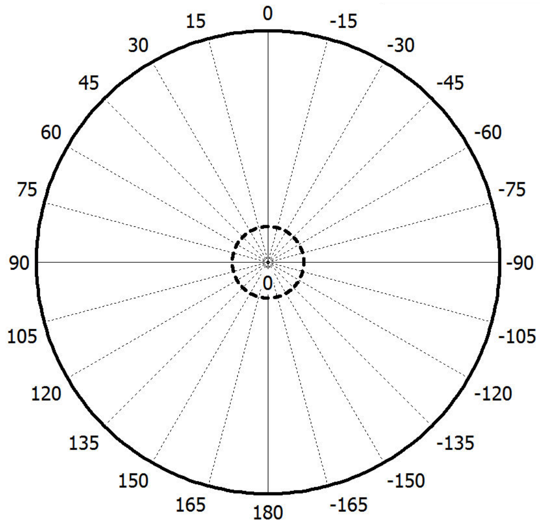

Fig. 6. The cross section of radiation pattern in the horizontal plane φ=0°.

4 Conclusion

For use in Wi-Fi-analytics, an effective microstrip antenna design has been proposed for a working frequency band of the IEEE 802.11n standard having a gain of at least 3.27 dB in the ISM band and at least 2.6 dB in the UNII band. A comparative analysis of the accuracy of calculations of the antenna reflection coefficient, obtained by three methods: finite elements, finite integration technique, and moments, is carried out. The most advantageous in terms of memory usage, speed of calculation is the method of moments, but at the same time its effectiveness is observed only for planar structures. For tridimensional structures, the methods of finite elements and finite integration technique are effective, the accuracy of calculations of which directly depends on the quality of the partitioning grid of the studied region of space.

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