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Design and characteristics of dual-band antenna with parasitic elements for Wi-Fi applications

***Abstract**. The paper presents results of a computer design and simulation of a dual-band antenna for Wi-Fi applications. The antenna design algorithm is described. Two parasitic elements have been appended to obtain the dual-band performance. Frequency characteristics of the antenna impedance, voltage SWR and radiation patterns are shown.*

***Streszczenie.** W artykule zostały przedstawione wyniki komputerowego projektowania i symulacji dwupasmowej anteny do zastosowania w systemie Wi-Fi. W celu uzyskania pracy anteny w obu pasmach systemu Wi-Fi w konstrukcji anteny zostały zastosowane dwa elementy pasożytnicze. W pracy pokazano charakterystyki częstotliwościowe impedancji anteny, WFS oraz charakterystyki promieniowania. (**Projektowanie i charakterystyki dwupasmowej anteny z elementami pasożytniczymi dla systemu Wi-Fi**).*

Keywords: antenna, multiband antenna, Wi-Fi, parasitic elements.
Słowa kluczowe: antena, antena wielopasmowa, Wi-Fi, elementy pasożytnicze.

Introduction

Using various devices operating in different systems and technologies is very common nowadays. The antenna is a very important part of each wireless equipment. It plays an especially valid role regarding to electromagnetic compatibility and electromagnetic disturbance requirements. The right project of the antenna can protect against different EMC and EMD issues.

The work of mobile devices in different systems requires the use of multi-band antennas or wideband antennas, whose operation bandwidth covers entirely bandwidth of proper systems. The description of requirements for portable devices and examples of different antennas can be found in [1-3].

Designers deal with the problem of a multi-band antenna design in different ways. Among many projects, there were studies on the designs of microstrip multiband antennas [4], ceramic PIFA (Planar Inverted F Antenna) ultra-wideband antennas [5], multiband PIFA antennas [6] or multiband PIFA antennas with parasitic elements [7] operating in different radiocommunication systems.

The paper presents the design of a dual-band antenna for Wi-Fi applications. The dual-band antenna is an example of multiband functionality that can be achieved using additional different parasitic elements [7]. The presented antenna operates in two Wi-Fi frequency bands, commonly described as 2,4 GHz and 5 GHz. It must be noticed that standardized operation Wi-Fi bands are 2,401 – 2,484 GHz and 5,180 – 5,825 GHz.

More details concerning the presented antenna, including the whole time-consuming design procedure and its computer analysis, can be found in [8].

Computer model of the antenna

The considered antenna is a PIFA antenna. A dual-band performance has been achieved using additional parasitic elements. The structure of the considered antenna is shown in Fig.1 (an overall view from the bottom of the antenna – Fig.1,a and two main projections – Fig.1,b-c). The ground plane is placed in a x-y plane of the assumed coordinate system, as shown in Fig.1. Dimensions of the ground plane are 25 x 50 mm (Wg x Lg). The radiator, with dimensions 18 x 20,5 mm (Wr x Lr), is parallel to the ground plane and is located symmetrically to the ground plane along x-axis, 5 mm above it (Hr). Such small dimensions make possible to use the designed antenna in almost every handheld device. In the projection on x-y plane the bottom edges of both ground plane and the radiator overlap. Antenna's shorting plate (SP in Fig.1) (contained in a x-z plane) is located on the left side of the bottom edge of the radiator, while on its right side there is a feeding point (generator Gen.). The width of the shorting plate width (SPw) is 2 mm. Two parasitic elements PE1 and PE2, both parallel to the ground plane, are located slightly below the radiator on both sides of it. These elements are connected to the ground plane with vertical (contained in a y-z plane) strips.

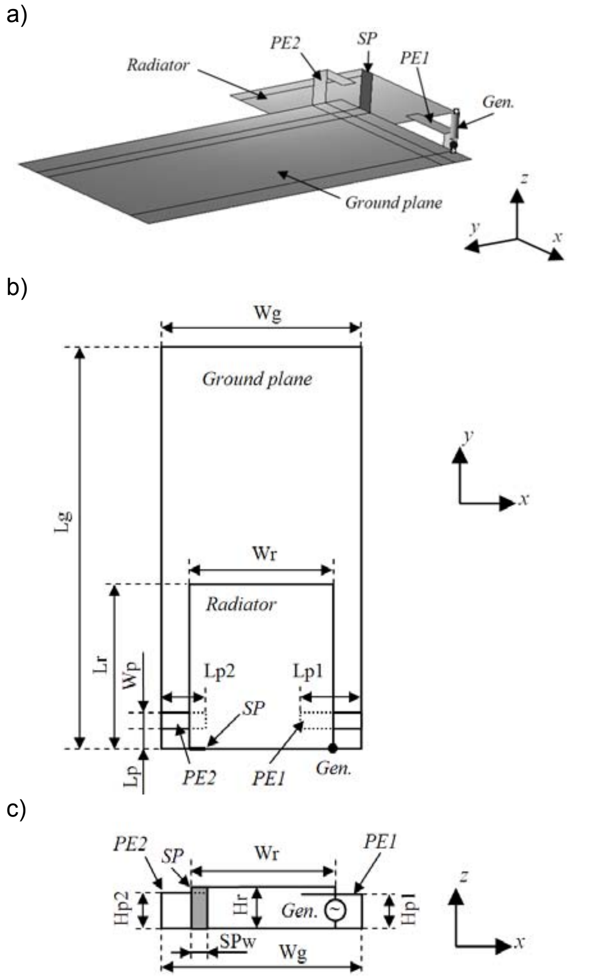

Fig.1. The structure of the analyzed antenna: an overall view from the bottom of the antenna (a) and the projection on x-y plane (b) and x-z plane (c)

Parasitic elements are positioned 4 mm (Hp1) and 4,25 mm (Hp2) above the ground plane, respectively. The first one, with the length of 5,5 mm (Lp1), is located on the right side of the ground plane (PE1), while the other (PE2), with the length of 7,5 mm (Lp2) – on the left. The distance between the bottom edges of both ground plane and parasitic elements in the projection on x-y plane (Lp) is 2,5 mm. Both parasitic elements are 2 mm wide (Wp). The presented dimensions concern the final structure of the designed antenna and were obtained by the implementation of the design algorithm shown in next section.

For simplification of considerations and due to some limitations of computer software used for computations, the designed antenna contains no dielectrics. In case of using dielectric elements in the antenna structure the design procedure stays the same. This would only cause a significant increase of the computer model complication regarding numerical calculations and resources.

Design procedure

While designing the analyzed antenna a specific design algorithm was executed. Multi-band functionality was achieved by the use of two parasitic elements electromagnetically coupled to the radiator.

The assumption adopted in the antenna design for its electrical parameters was that value of VSWR was lower than 2 in both Wi-Fi operation bands. It must be noticed that this assumption is not critical, in case of portable terminals, a VSWR value slightly larger than 2 is often accepted. The second assumption was to obtain nearly omnidirectional radiation patterns in both Wi-Fi bands. The user using a mobile device should not feel uncomfortable and a deterioration of transmission parameters depending on the position of the device relative to the transmit antenna. In this place assumptions about geometry were less relevant and can be described as obtaining of relatively small the antenna's dimensions. Due to some limitations of the computer software used for numerical calculations, the structure of the antenna containing no dielectrics materials was considered.

The first step in the design algorithm was to design a basic antenna working in one of the two Wi-Fi bands. For this purpose the first Wi-Fi band 2,4GHz was chosen. At this stage, an initial antenna design containing only reference ground plane, the radiator (both of rectangular shape), the shorting plate and the generator connection without parasitic elements were developed. This basic, initial model of the antenna is a typical PIFA antenna. The generator is connected between two layers of the structure, the ground plane and the radiator, exactly in the corner of the radiator (Fig.1). The initial dimensions of the radiator Wr and Lr meet the known dependence that their sum is close to a quarter of the wavelength of a given operating frequency (2,4 GHz in this place). The rectangular shape of the reference ground plane and its dimensions were also proposed. Generally, these dimensions are not critical and depend on the specific design of the mobile device but if they were determined they should not be changed later on because they greatly affect the antenna parameters. As a result of the optimization, the dimensions of the radiator and its distance from the ground plane (the antenna height Hr) were found to provide the desired low value of VSWR in the 2,4 GHz frequency band.

This initial antenna model has a nearly omnidirectional radiation pattern (very close to that presented in Fig.3,a), the maximum antenna gain in the direction perpendicular to the antenna surface (along z-axis) is 2.12 (3,26 dB). It should be noted that in spite of the considerable dimensions of the ground plane its dimensions had also a quite significant effect on the matching of the antenna. Similarly, the distance between the generator and the shorting plate and its width were quite critical for optimal antenna impedance.

In the next step in the antenna design, the first parasitic element PE1 was assigned to the initial structure. It is responsible for getting the antenna to work in the 5 GHz frequency band. At this stage, the optimum dimensions of the first parasitic element and its position were determined (length Lp1, width Wp, height Hp1, the distance from the bottom edge of the structure Lp). The addition of the first parasitic element almost did not change the values of the antenna parameters in the first 2,4 GHz band. The value of the maximum gain in the first band increased slightly to 2,14 (3,30 dB), while in the second band the radiation characteristics were also close to the final one shown in Fig.4 with the maximum gain of 4,48 (6,51 dB) (the direction of the maximum radiation was the same - perpendicular to the surface of the antenna). The value of the antenna maximum gain in the second operation band was satisfactory, while the width of the second operation band was not sufficient enough. For this reason, the second parasitic element EP2 was added to the antenna structure. Dimensions of EP2 were established to reach the center frequency of its operation band slightly lower than that of the first parasitic element. As a result, the existence of the second parasitic element PE2 practically did not change the characteristics and parameters of the antenna in the first operation band 2,4 GHz, but slightly extended the width of the second operation band of 5 GHz.

The next part of the paper presents the characteristics of the final antenna model including both parasitic elements with its all optimum dimensions.

Numerical analysis

All computations were made using WIPL-D Electromagnetic Solver. The computer model of the antenna, taking into account the rules of creating a computer model in the used software, is composed of several metallic plates in the form of quadrangle. Neighbouring plates share one common edge, which is roughly visible in Fig.1,a. As the results, regarding the antenna topology, the computer model of the antenna contains 19 plates that were defined using 34 nodes. All calculations were made in frequency band 2 – 6 GHz. For these assumptions number of unknowns is only 95. All of them are used to compute electric currents in the Method of Moments that is used by WIPL-D software. For this type of the antenna model, which contains no dielectrics in its structure, such moderate number of unknowns provides accurate results. A generator used as the source of excitation was typically set as Eg = 1V and Rg = 50 Ω.

Fig.2. shows frequency characteristics of the antenna's input impedance and voltage SWR, calculated in the relation to 50 Ω impedance. Characteristics of the antenna's input impedances were shown separately for both operation bands: in the frequency range 2 – 3 GHz (Fig.2,a,b) and in the frequency range 5 – 6 GHz (Fig.2,c,d). Between these two frequency bands the value of input impedance, and also VSWR, reaches significantly greater values. In both Wi-Fi operation bands values of antenna impedances are quite close to 50 Ω that causes a good antenna matching.

The first antenna's operation band 2,4 GHz mostly depends on the dimensions of the antenna radiator. The second Wi-Fi operation band 5 GHz was achieved by using only one – the first parasitic element PE1. In this kind of antenna structure each parasitic element corresponds to another frequency band in an overall multi-band functionality. As it was described in previous section, the second parasitic element PE2 makes it possible to reach required width of the second frequency band 5 GHz.

Frequency characteristics of voltage SWR are shown in Fig.2,b,d. The value of VSWR is less than 2 in almost both Wi-Fi operation bands: 2,15 – 2,66 GHz and 5,19 – 5,60 GHz. The width of the first frequency band that is defined by the level of VSWR ≤ 2 is 510 MHz (2,4 GHz) and the second is 410 MHz (5 GHz). Beyond these frequency borders within Wi-Fi standardized operation bands (2,401 – 2,484 GHz and 5,180 – 5,825 GHz) the value of VSWR slightly exceeds the level of two that is commonly acceptable. Fig.3 presents radiation patterns of the antenna gain calculated at about center frequency at lower operation band 2,4 GHz. Fig.3,a shows 3D radiation patterns calculated in linear scale and Fig.3,b-d show cross sections of the antenna gain that were calculated in three main planes of the assumed coordinate system, perpendicular to each other: x-z, y-z and x-y plane.

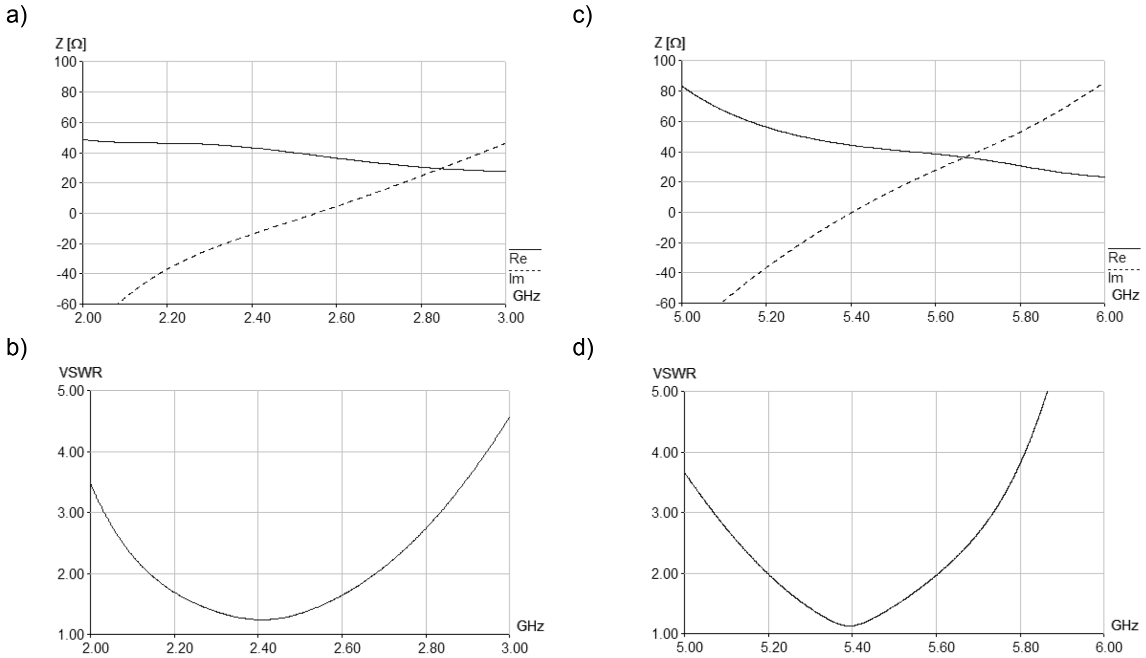

Fig.2. Frequency characteristics of the antenna impedance in lower 2,4 GHz (a) and upper 5 GHz (c) frequency band and corresponding characteristics of voltage SWR of the analyzed antenna (b,d)

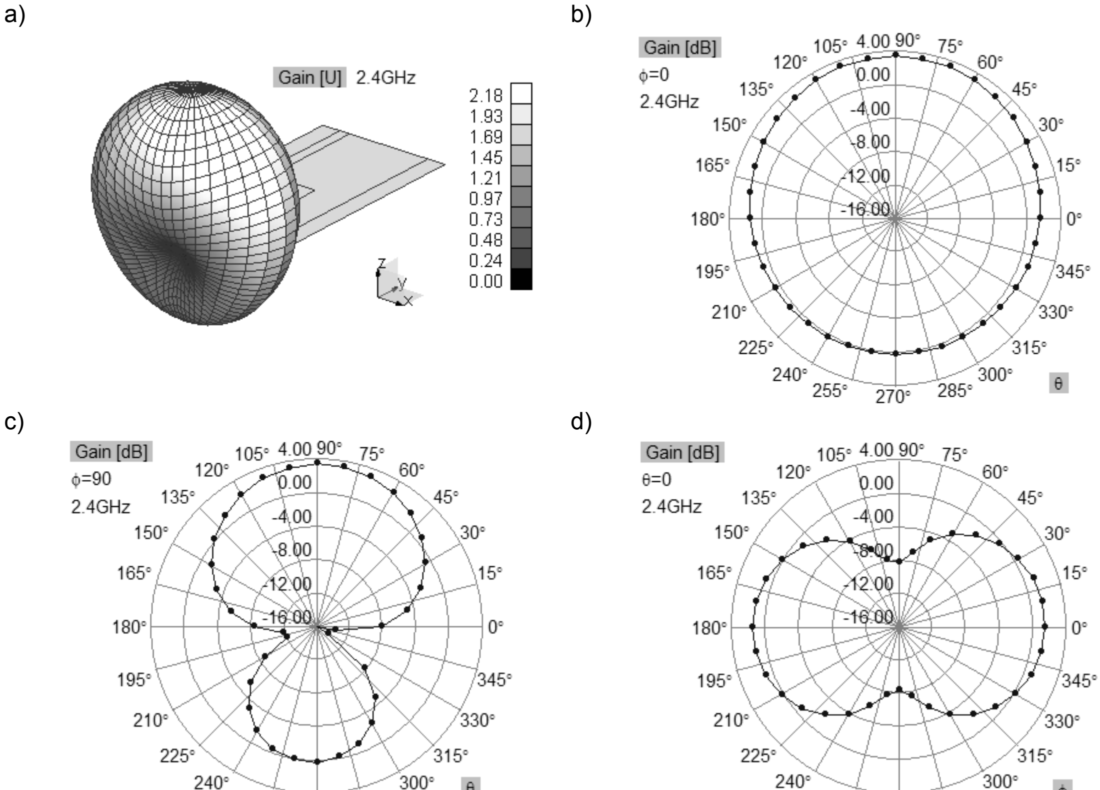

Fig.3. 3D radiation pattern of the antenna at 2,4 GHz operation band in a linear scale (a) and the main cross-sections of radiation patterns of the antenna: x-z plane (b), y-z plane (c) and x-y plane (d)

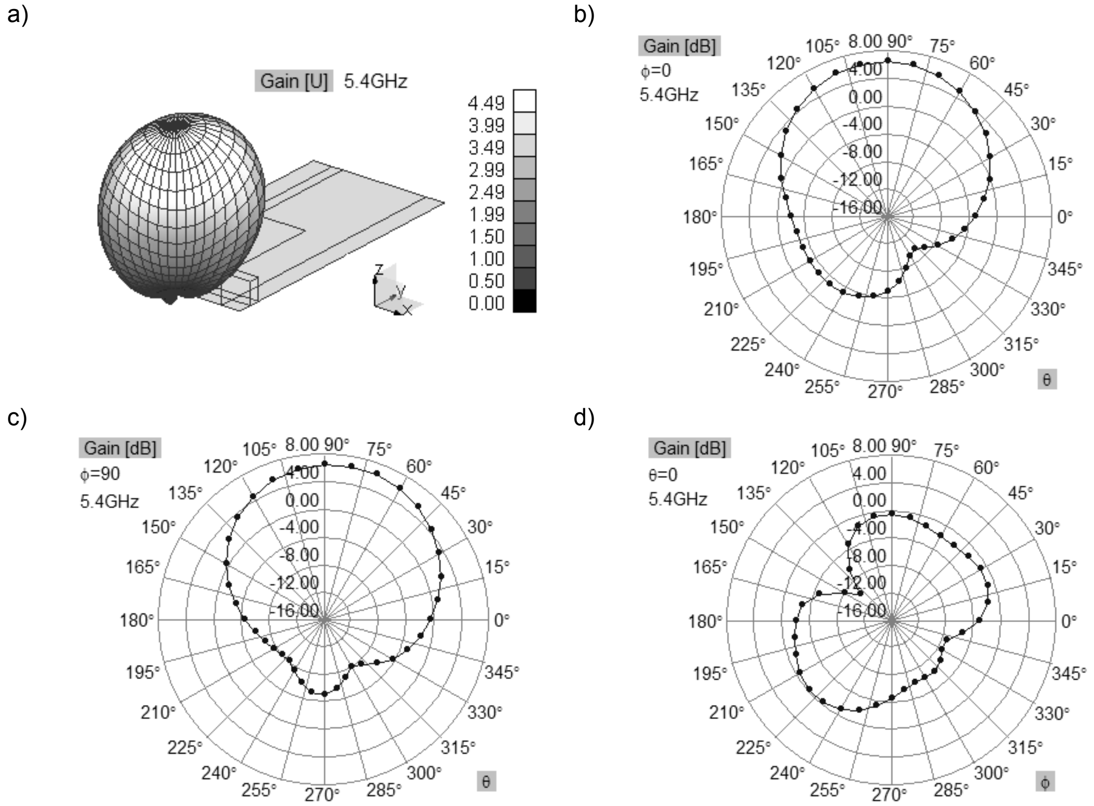

Fig.4. 3D radiation pattern of the antenna at 5 GHz operation band in a linear scale (a) and the main cross-sections of radiation patterns of the antenna: x-z plane (b), y-z plane (c) and x-y plane (d)

3D radiation pattern in Fig.3,a is close to omnidirectional one that is generally welcomed in handheld devices. It can be noticed that the direction of maximum radiation is oriented along positive direction of z-axis. At 2,4 GHz in lower frequency band the maximum value of the antenna gain is 2,18 (3,38 dB). For another directions of radiation the values of the antenna gain are lower but this is typical for this type of the antenna construction applied for handheld devices. Fig.4. presents corresponding radiation patterns calculated at about center frequency 5 GHz of upper operation band. The maximum value of the antenna gain is slightly higher and equals 4,49 (6,52 dB) and the radiation pattern becomes more directional.

The maximum values of the antenna gain at both ends in two operation bands vary quite slightly. In lower 2,4 GHz band this difference equals only 0,14 dB but in upper 5 GHz band this is 0,65 dB. It must be noticed that upper 5 GHz Wi-Fi band is much wider and the antenna parameters change more. In the whole two operation Wi-Fi bands the direction of the maximum radiation is still perpendicular to the antenna surface.

Conclusions

The designed antenna presents sustainable parameters regarding matching, radiation patterns and the overall performance. The use of two parasitic elements in the antenna structure enables the desired impedance and matching characteristics. The lower 2,4 GHz operation band was shaped fundamentally by the dimensions of the main radiator of the antenna whilst both parasitic elements affect the upper 5 GHz Wi-Fi operation band. Larger values of VSWR outside both operation Wi-Fi bands protect the device in which the antenna is built-in from different unwanted disturbing signals outside the two main frequency bands.

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