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MODELING OF A CIRCULAR DISK MONOPOLE ANTENNA FED FROM A MICROWAVE BROADBAND COPLANAR WAVEGUIDE

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Abstract. In the article, using the High Frequency Structure Simulator (HFSS) software package and the finite element method, the modeling of a circular disk-shaped monopole antenna fed by a microwave and wide-band coplanar waveguide is performed. As a result of the modeling, the structural parameters and material properties of the circular disk-shaped monopole antenna fed by the coplanar waveguide were determined, its electrical, structural, magnetic parameters and characteristics and the 3D model were determined. The main parameters of the circular disk-shaped monopole antenna fed by a coplanar waveguide operating in the frequency range of 2,3 GHz - 12 GHz, such as reflection coefficient, directivity diagram and gain coefficient have been determined. At the same time, mathematical modeling of a circular disc-shaped monopole antenna fed by a microwave and wide-band coplanar waveguide was performed and the results obtained for optimal evaluation of the antenna's performance were analyzed in detail. The simulated microwave and wideband coplanar monopole antenna with circular disk transducer consists of a single radiating element, often used in applications requiring omnidirectional coverage, such as wireless communication systems. These antennas are relatively easy to design and manufacture, making them suitable for compact applications

Keywords: Microwave monopole antenna, coplanar waveguide, circular disc monopole antenna, high frequency structure simulator, ultra-wide band.

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1 Introduction

Ultra-wideband (UWB) technology is becoming increasingly widespread in modern radio engineering systems due to its advantages such as a wide frequency range and low power consumption Ajetrao et al. (2024), Nakprasit et al. (2020). The development of modern radio engineering systems is directly related to the modeling of antennas and their components, which are considered as their main devices. Recently, circular disk-shaped monopole antennas fed by microwave and wide-band coplanar waveguides have been widely used in ultra-wideband frequency ranges due to their excellent features such as almost omnidirectional pattern, simple structure, and low cost Islamov et.al. (2022), Kumar & Kushwaha (2017), Saha et.al. (2020). UWB technology is widely used in applications that require high signal transmission speed and wide frequency range, and has the advantages of low power consumption and high resolution Ojaroudi et.al. (2020), Ojaroudi et.al. (2014), Shaik et.al. (2022), Ghouz et.al. (2020). Designing antennas for UWB applications is critical to maximizing these advantages and achieving the desired useful performance. Wide bandwidth and good impedance matching of antennas increase the possibility of their use in modern radio engineering systems Prabhu et.al. (2013), Islamov & Aslanzadeh (2023), Luo et.al. (2023), Ellis et.al. (2014).

Circular disk-shaped monopole antennas fed by microwave and wide-band coplanar waveguides can easily increase the useful performance of a wide-band radio technical system Nejdi et.al. (2023), Srivastava et.al. (2021), Islamov & Aslanzadeh (2023), Shukoor et.al. (2024), Tan et.al. (2024). Circular disc monopole antennas provide advantages such as low cost and simple structure in broadband applications Ooi et.al. (2023), Shao & Zhang (2019), Islamov & Safarli (2023), Abhishek & Suraj (2024). Since the electrodynamic modeling of antennas, including the analytical solution of the problems of antennas with complex structures, is difficult, there is a great need to apply electromagnetic field theory to obtain the results Zhang et. al. (2024), Islamov & Humbataliyev (2022), Altaf & Seo (2018), Cheng et. al. (2004). For this reason, it is more appropriate to use Maxwell's equations, including the HFSS software complex. Thus, the modeling of a circular disc-shaped monopole antenna fed by a coplanar waveguide using the HFSS software complex is considered one of the most pressing problems of radio engineering. In this paper, the modeling of a circular disk-shaped monopole antenna with a reflection coefficient lower than 10 dB fed by a coplanar waveguide using the HFSS software package is performed.

Coplanar waveguide fed antennas are notable for their easy manufacturing processes and wide bandwidth capabilities Chen et. al. (2004). HFSS is a complex program that provides modeling of microwave structures based on the finite element method (Finite Element Method-FEM) Islamov & Aslanzadeh (2023). In this case, the computational domain must be limited in the applied finite element method. Thus, it will not be possible to apply the method to radiation problems without combining it with a boundary integral equation. On the other hand, it is effective in areas such as analysis of microwave devices, modeling, modeling of antennas, modeling of photonic structures and analysis of radio frequency circuits by the finite element method Elabd et. al. (2024), Islamov et. al. (2025).

The use of the HFSS software complex plays an important role in solving electromagnetic problems during antenna modeling in terms of accuracy and efficiency. These methods are used to evaluate and optimize antenna parameters. In the presented paper, the modeling results are analyzed based on parameters such as antenna reflection coefficient, directivity diagram and gain coefficient. Modeling of complex antenna structures is not possible without using a complex of software and electromagnetic solvers such as HFSS. By applying this software complex, unnecessary costs in the production phase are eliminated and the best result is achieved in the production phase. In this study, the characteristics, 3D model, and gain graphs of a circular disc-shaped monopole antenna fed by a coplanar waveguide operating in the frequency range of 2,3 GHz to 12 GHz are analyzed.

2 Statement of the issue

This article details the modeling steps and performance analysis of a circular disc monopole antenna fed by a coplanar waveguide operating in the frequency range of 2,3 GHz to 12 GHz with a coplanar waveguide. We consider the following requirements for a monopole antenna:

1. 9,7 GHz bandwidth in the range from 2,3 GHz to 12 GHz, where reasonable efficiency and a satisfactory omnidirectional pattern are required.

2. In the considered passband, the highest level of radiation power must be ensured.

3. The antenna transmits a signal with short pulses with minimal distortion throughout the entire frequency range.

The first point is the most important for antenna designers, which is reflected in the requirement that the antenna have a wide matching bandwidth in which $VSWR < 2$. Such high-impedance bandwidth is only realized when using a multi-resonant printed monopole antenna, as typically demonstrated by the pass impedance characteristics. For such a broadband antenna, in contrast to dipole antennas tuned to a single resonance, it is necessary to take into account some design features. The design parameters of these printed monopole antennas are not the resonant or operating frequency, but the lower cutoff frequency and the overall bandwidth. The low-band frequency depends primarily on the maximum monopole height, while the antenna bandwidth depends on how the impedance of the various modes is matched to the microstrip or coplanar feedline. As can be seen from Figure 1, the modeled antenna structure is built on a circular radiating cover. A circular enclosure is one of the most commonly used configurations due to its ease of analysis. In the modeling of this type of antennas, various parameters related to the resonant frequency and bandwidth of the antenna should be taken into account. Co-planar waveguide feeding provides the antenna with wide frequency bandwidth and easy integration with planar circuits. The radius r of the circle determines the operating frequency and input resistance of the antenna and is considered one of the main parameters. The radius r of the circle is determined by the following formula:

$$r = \frac{F}{\left(1 + \frac{2H}{\pi \varepsilon_r F}\left[\ln\left(\frac{\pi F}{2H}\right) + 1,7726\right]\right)^{\frac{1}{2}}}, \tag{1}$$

where

$$F = \frac{8,791 \times 10^9}{f_r \sqrt{\varepsilon_r}}, \tag{2}$$

f_r - resonance frequency, H - the thickness of the dielectric, $?_r$ - is the relative dielectric constant of the substrate.

To create mathematical models of a circular disk monopole antenna fed from a coplanar waveguide, one can use approaches that include:

1. Resonant frequencies:

- for a circular disk, the resonant frequency is determined by the relation:

$$f_{res} = \frac{c}{2\pi R \sqrt{\varepsilon_{eff}}}, \tag{3}$$

where R is the radius of the disk, ε_{eff} is the effective permittivity, which depends on the substrate.

2. Antenna impedance:

- the input impedance can be approximated as:

$$Z_{in}(f) = R_{rad}(f) + jX(f), \tag{4}$$

where $R_{rad}(f)$ is the radiation resistance, and $X(f)$ is the reactive part.

3. Coplanar waveguide model:

- the coplanar waveguide is modeled through capacitance and inductance, which depend on the central stripe width, gaps, and substrate:

$$Z_0 = \sqrt{\frac{L}{C}}, \quad \varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \frac{1}{\sqrt{1 + 12h/W_{eff}}}, \tag{5}$$

where W_{eff} is the effective central stripe width.

4. Radiation pattern:

- to estimate the normalized radiation pattern:

$$F(\theta, f) = \left|\sin\left(\frac{2\pi R}{\lambda}\sin\theta\right)\right|^2, \tag{6}$$

where λ is the wavelength.

5. Broadband characteristics (S_{11}):

- reflectivity characteristics can be described in terms of the return loss coefficient:

$$S_{11}(f) = 20 \log_{10} \left| \frac{Z_{in} - Z_0}{Z_{in} + Z_0} \right|, \tag{7}$$

where Z_0 is the characteristic impedance of the feedline.

From the modeling results, it is observed that the resonance frequency increases with the decrease of the disk radius. The antenna's low weight and high efficiency make it ideal for portable installations. The relationship between diameter (print) and first resonances is given in Table 1. The bandwidth at which the antenna operates depends on the feed span (g), the ground plane width (W) and the disk radius (r). Therefore, these parameters should be optimized for maximum bandwidth in antenna modeling.

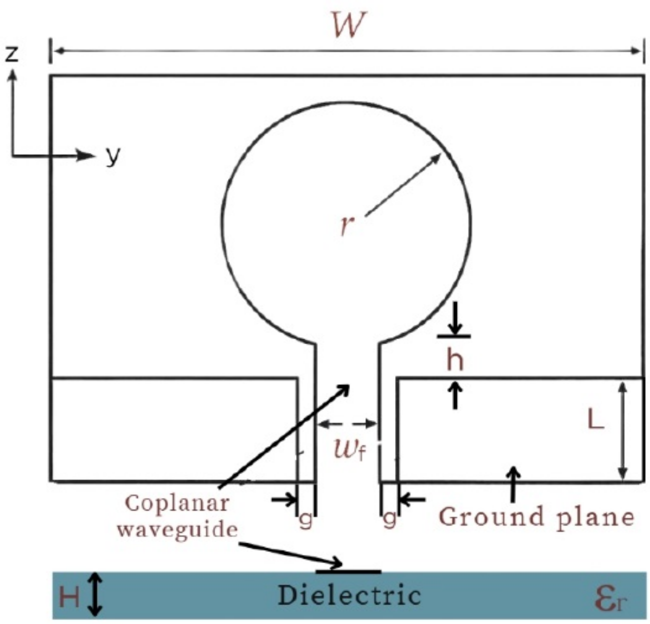


Figure 1: Structural design of a circular disc-shaped monopole antenna fed by a coplanar waveguide

Table 1: Relationships Between Diameters and First Resonances of Monopole Antennas

Diameter, $2r, mm$	**The first resonant frequency,** f, GHz	**Wave length,** λ, mm	$2r\lambda$
50	1,52	197,4	0,25
30	2,57	116,7	0,26
25	3,01	99,7	0,25
15	5,09	58,9	0,25

The circular disc-shaped monopole antenna fed by the same plane coplanar waveguide proposed in this study has a single-layer metallic structure as shown in Figure 1. A circular disc monopole with radius $r = 12{,}5$ *mm* and a 50 *Ohm*-CPW is placed on the same side of a dielectric substrate. In this study, a substrate with a thickness of $H = 1{,}6$ *mm* and a dielectric constant of $\varepsilon_r = 3$ was used. The width of the metal strip is $W_f = 4mm$ and the distance between the strip and the coplanar ground surface is fixed at $g = 0{,}33$ *mm* to obtain a resistance of 50 *Ohm*. $W = 47$ *mm* and $L = 15$ *mm* indicate the width and length of the soil surface, respectively. $h = 0{,}3$ *mm* is the distance between the disc and the soil surface.

3 Antenna modeling and determination of characteristics using the HFSS software complex

Designed for ultra-wideband applications, the circular disc-shaped monopole antenna has frequency and polarization tunable characteristics. Circular disc-shaped monopole antennas working with a coplanar waveguide were evaluated on parameters such as bandwidth, reflection coefficient (S_{11}), directivity diagram and gain coefficient. Therefore, let's visualize the results obtained from the modeling of a circular disk-shaped monopole antenna fed by a coplanar waveguide operating in the frequency range of 2,3 GHz - 12 GHz using the HFSS software complex. Figure 2 shows the developed model of a circular disc-shaped monopole antenna fed by a coplanar waveguide. These elements have a wide impedance band, which can be expanded by increasing the radius of the cylindrical element. This is true until the step radius from the feed sensor to the cylindrical element becomes sharp.

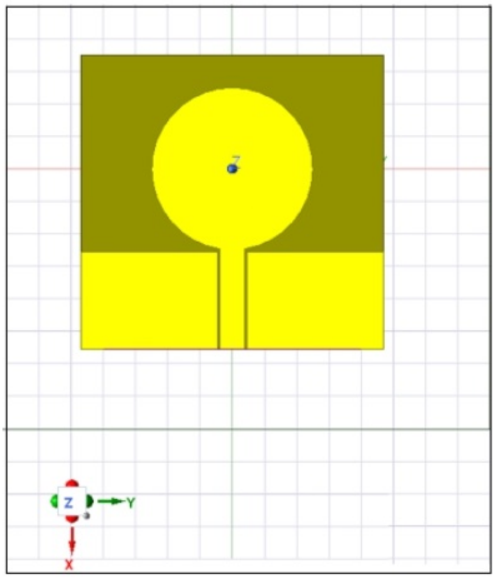


Figure 2: Model developed at HFSS of circular disc monopole antenna fed by coplanar waveguide

The dependences of the reflection coefficient of a circular disk-shaped monopole antenna fed by a coplanar waveguide at different values of the frequency are shown in Figure 3.

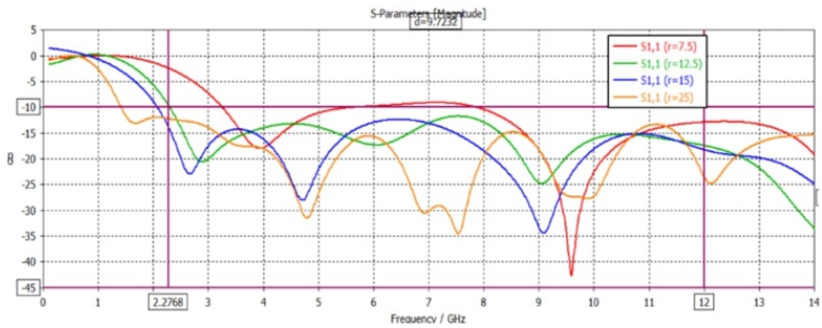


Figure 3: Dependencies of the reflection coefficient of a circular disk-shaped monopole antenna fed by a coplanar waveguide at different values of the frequency

Dependences of the S-parameter of a circular disk-shaped monopole antenna fed by a coplanar waveguide at different values of the frequency are shown in Figure 4.

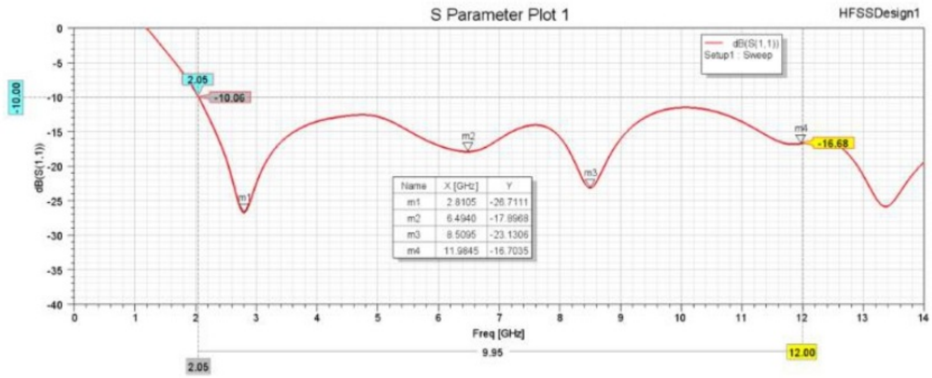


Figure 4: Dependencies of the S-parameter of a circular disk-shaped monopole antenna fed by a coplanar waveguide at different values of the frequency

As can be seen from Figure 4, the measured reflectance curve fits in the HFSS. In general, the -10 dB bandwidth also covers an extremely wide frequency range in HFSS. The modeled frequency bandwidth is from 2,3 GHz to 12 GHz. Here, the voltage standing wave ratio (VSWR) curve according to the modeling result is shown in Figure 5. It is found to be below 2 in the HFSS range from 2,3 GHz to 12 GHz and 1,02 at the first resonant frequency, i.e., 2,9 GHz

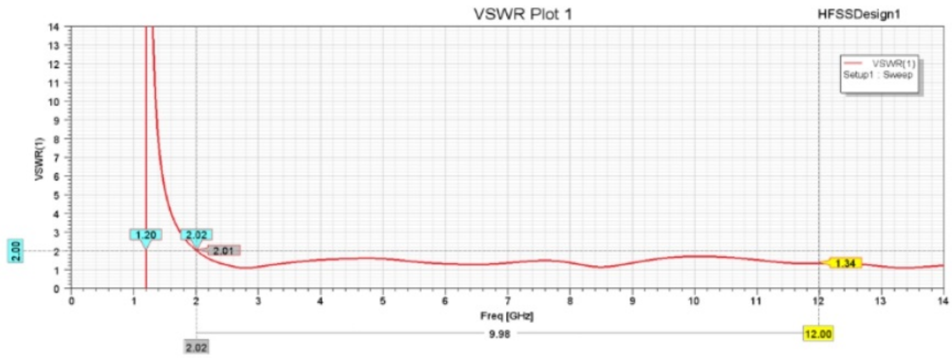


Figure 5: Dependencies of standing wave coefficient

A 3D model of the directional pattern of a circular disc-shaped monopole antenna fed by a coplanar waveguide in the far zone is shown in Figure 6. The directivity coefficient obtained by HFSS was determined as 2,41 dB.

The amplification factor obtained as a result of modeling is shown in Figure 7. The amplification factor obtained by HFSS was determined as 2,34 dB. As can be seen from Figure 6 and Figure 7, the small difference between the gain and direction diagrams modeled using HFSS is due to the different numerical techniques used in the program. Figure 8 shows the plot of the elevation angle of a circular disc-shaped monopole antenna fed by a coplanar waveguide modeled by HFSS. Thus, the numerical results obtained from the modeling of a circular disk-shaped monopole antenna fed by a coplanar waveguide are shown in Table 2.

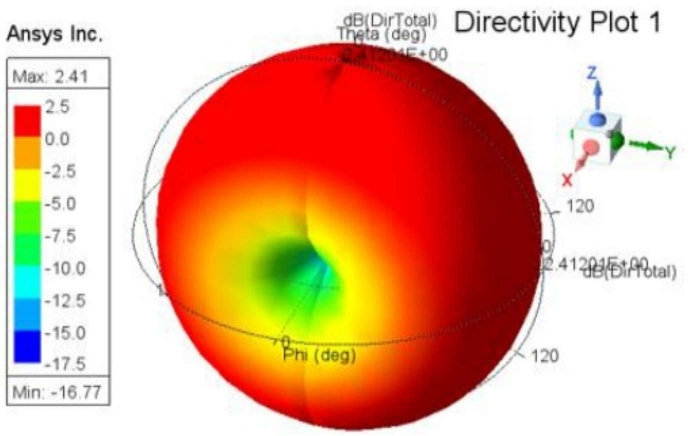


Figure 6: 3D model of the directional pattern of a circular disc-shaped monopole antenna fed by a coplanar waveguide in the far zone

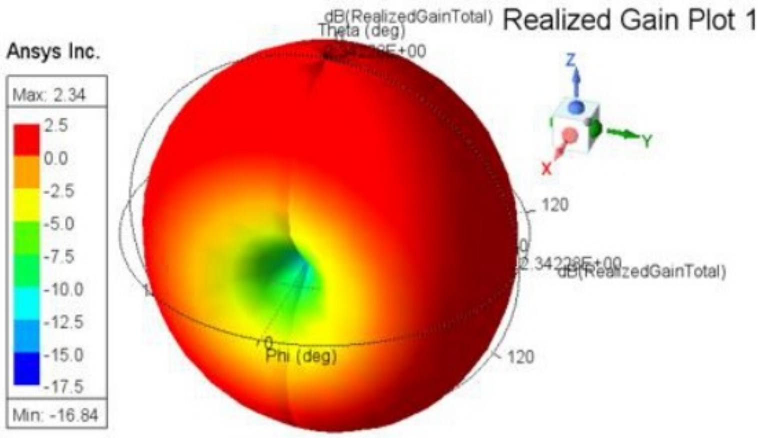
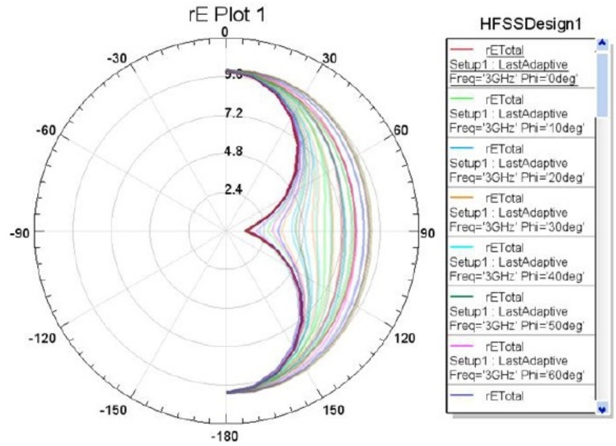


Figure 7: 3D model of the gain of a circular disc-shaped monopole antenna fed by a coplanar waveguide in the far zone

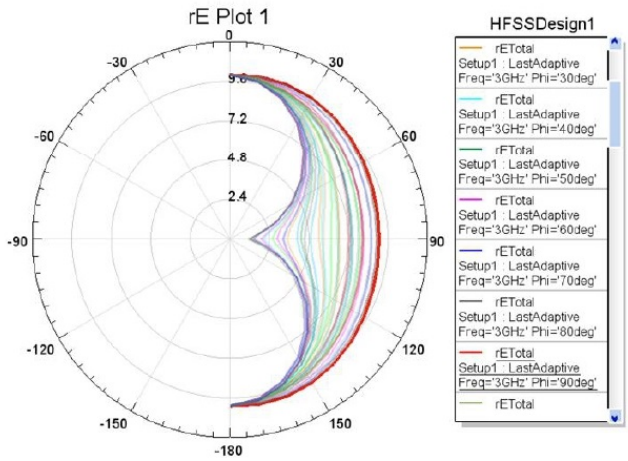
The design parameters of these printed monopole antennas are not the resonant or operating frequency, but the lower cutoff frequency and the overall bandwidth. The low-band frequency depends primarily on the maximum monopole height, while the antenna bandwidth depends on how the impedance of the various modes is matched to the microstrip or coplanar feedline.

Table 2: Numerical Results from the Modeling of a Circular Disc Monopole Antenna fed by a Coplanar Waveguide

Parameter	**Prices determined by HFSS**	**Unit of measurement**
Employee frequency (f_r)	2,05 ÷ 12	GHz
Directivity coefficient	2,41	dB
Amplification factor	2,34	dB
The reflection coefficient at the first resonant frequency	- 26,7111	dB
$VSWR$ at the first resonant frequency	1,02	-



a)



b)

Figure 8: The graph of the variation of the ground angle of a circular disk-shaped monopole antenna fed by a coplanar waveguide: a) in the horizontal plane; b) in the vertical plane

Figure 9 shows the reflectivity characteristics of the S_{11} circular disk monopole antenna in the 2-12 GHz range. The red line at the -10 dB level shows the boundary of good matching. The antenna demonstrates matching near the resonant frequencies, which depend on the disk radius and the substrate properties.

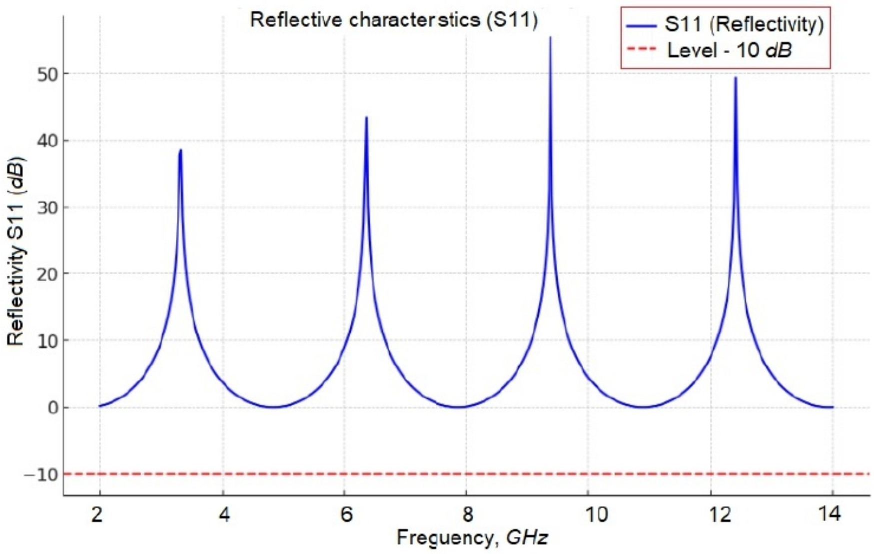


Figure 9: Reflective characteristics of the S11 circular disk monopole antenna in the frequency range of 2-12 GHz

Figure 10 shows the normalized radiation patterns of the circular disk monopole antenna for frequencies of 2 GHz, 5 GHz, and 8 GHz.

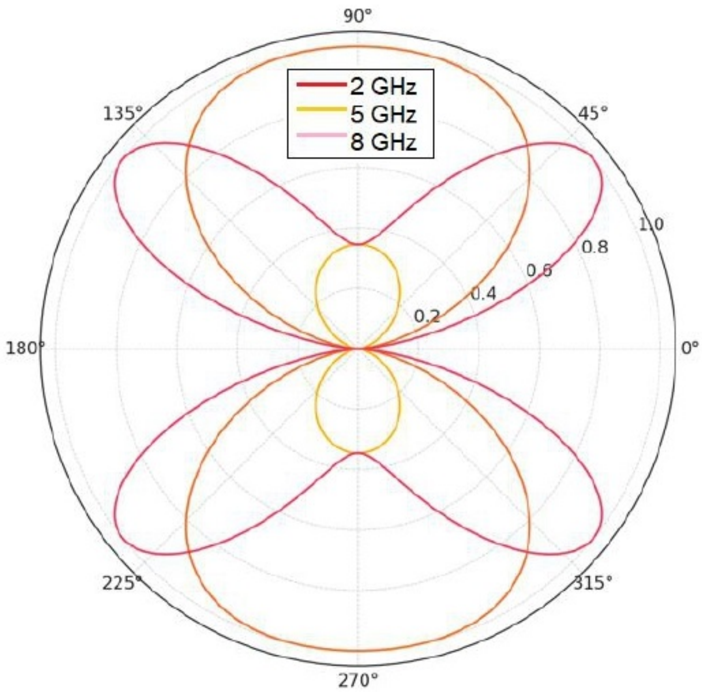


Figure 10: Normalized radiation patterns of a circular disk monopole antenna for frequencies of 2 GHz, 5 GHz and 8 GHz

The antenna demonstrates almost omnidirectional radiation in the horizontal plane (typical of monopole antennas). The amplitude of the radiation patterns decreases with increasing frequency, which is due to the influence of the disk size relative to the wavelength.

4 Conclusion

Using the HFSS software complex and the finite element method, the modeling of a circular disk-shaped monopole antenna fed by a microwave and wide-band coplanar waveguide was performed. As a result of modeling, the structural parameters and material properties of the circular disc-shaped monopole antenna fed by a coplanar waveguide were determined, its electrical, structural, magnetic parameters and characteristics, including the 3D model of its structure, were determined. The main parameters of the circular disk-shaped monopole antenna fed by a coplanar waveguide operating in the frequency range of 2,3 GHz - 12 GHz, such as reflection coefficient, directivity diagram and gain coefficient have been determined. The graph of the ground angle change in the horizontal and vertical planes of the circular disk-shaped monopole antenna fed by the coplanar waveguide, the 3D models of the directivity diagram and the gain coefficient of the circular disk-shaped monopole antenna fed by the coplanar waveguide in the far zone were constructed. At the same time, mathematical modeling of a circular disc-shaped monopole antenna fed by an extremely high-frequency and wide-band coplanar waveguide was performed and the results obtained for optimal evaluation of the antenna's performance were analyzed in detail. The problem of finding an electrodynamic limitation for estimating the ultimate characteristics of the antenna under study is considered. Limits on the ultimate characteristics of antennas are derived, which are formulated in terms of the lower frequency and the ratio of the limiting frequencies of the antenna operating range, and can be used for the case of antenna tuning, and are of a fundamental nature. The scattering theory used in the derivation and the polarizability tensor of the geometric shape of the antenna made it possible to calculate the ultimate characteristics for most types of antennas. A comparison of the numerically calculated polarizability tensors for various geometric shapes and different polarizations is given. This made it possible to show that the differences from the ultimate values calculated by the Chu method can be significant for antennas with large stored energy inside the Chu sphere, which describes the antenna structure.

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