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ANALYSIS OF ANTENNA SYSTEM MODELING WITH THE HELP OF SIMULATION TECHNOLOGY OF NAVIGATION EQUIPMENTS

Abstract. In this paper, a new coplanar waveguide CPW (Coplanar Waveguide) fed circular waveguide for ultra-wideband UWB (Ultra WideBand) applications using High-Frequency Structure Simulator (HFSS) and Computer Simulation Technology (CST) software is presented. A comparison of modeling and simulations of disk monopole antenna is presented. **The purpose of the research** is to first determine the geometric parameters and material properties of the antenna, and then perform simulations using HFSS and CST programs. **The task of the research** is to evaluate the performance by modeling a new coplanar waveguide-fed circular disk monopole antenna for ultra-wideband applications and to compare the results obtained from these two electromagnetic simulation tools. Modeling of a new coplanar waveguide-fed circular disc monopole antenna for ultra-wideband applications used planar patterns and a coplanar waveguide-fed circular disc monopole antenna providing a wide frequency range. Antenna modeling method was used to solve the problem. High-frequency structure simulator and computer simulation technology have been widely used in microwave studio programs, accuracy in solving electromagnetic problems and antenna modeling. The following results were obtained. High frequency structural simulator and Computer simulation technology has been implemented between 2.3 GHz and 12 GHz. Key parameters such as reflection coefficient (S11), directivity pattern and gain coefficient were analyzed to evaluate the antenna performance. **As a result of the research**, a circular disk monopole antenna printed on a dielectric layer and fed by a 50 Ω coplanar waveguide on the same layer is digitally shown to provide an omnidirectional directivity pattern over the entire frequency range.

Keywords: Monopole Antenna; CPW-Fed; Circular Disc Monopole Antenna; CST MWS; HFSS.

Introduction

Ultra-wideband (UWB) technology is increasingly being adopted in modern communication systems due to its advantages of wide frequency range and low power consumption [1]. With advancements in modern communication systems, antenna designs are also becoming more complex. Recently, wideband monopoles have been preferred for UWB applications because of their attractive features such as nearly omnidirectional radiation patterns, simple structure, and low cost [2]. UWB technology is widely used in applications requiring high data transmission rates and wide bandwidth, standing out with its advantages such as low power consumption and high resolution [3]. Antenna design for UWB applications is critical to maximize these advantages and achieve the desired performance. The wide bandwidth and good impedance matching of antennas increase their usability in modern communication systems [4]. CPW-fed antennas can easily provide wideband impedance matching [5]. The CPW-fed microstrip patch antenna stands out with its high bandwidth, low cost, and easy manufacturing processes. These features make the antenna ideal for wideband applications [6]. Circular disk monopole antennas offer advantages such as low cost and simple structure in wideband applications [7].

Since it is difficult to analytically solve these complex antenna problems, computational electromagnetic field applications are needed to visualize our results [8]. Therefore, electromagnetic solvers, which are specialized computer software that directly solve a subset of Maxwell's equations, are used. In this study, the design and simulation comparison of a CPW-fed circular disk monopole antenna using HFSS and CST software were performed. Both software showed that the antenna achieved a return loss below -10 dB in the UWB frequency range, providing good impedance matching. However, slight differences in simulation results can occur due to different computation methods and mesh structures. CST simulations are faster due to the time-domain solver, while HFSS provides more detailed information about the antenna's resonant behavior with its frequency-domain solver.

CPW-fed antennas stand out with their easy manufacturing processes and ability to provide wide bandwidth [9]. HFSS, a high-frequency structure simulator, is based on the finite element method (FEM) [3]. In the FEM method, the solution space must be bounded because the method cannot be applied to radiation and scattering problems without being combined with a boundary integral equation. FEM analysis is effective, especially in areas such as high-frequency applications, microwave design, antenna design, photonic structure simulation, and RF circuit analysis [10]. CST, on the other hand, has multiple solvers in both frequency and time domains. CST Studio Suite uses the finite element method (FEM) in the frequency domain, while in the time domain, it provides access to multiple electromagnetic simulation solvers using methods such as the finite integration technique (FIT) [3] and the transmission line matrix method (TLM). FIT is based on the principle of discretizing Maxwell's equations in time and space, allowing the simulation of how electromagnetic fields change in time and space. The TLM method, used for analyzing the behavior of electromagnetic fields over time, is also suitable for wideband applications. In this method, the space is divided into cells or points, and the transmission line connections between these points are modeled.

During antenna design and simulation, the use of HFSS and CST software plays an important role in terms of accuracy and efficiency in solving electromagnetic problems. These two methods are used to evaluate antenna performance and perform optimization. The simulation results were compared in terms of parameters such as return loss (S11), radiation patterns, and gain of the antenna. The simulation results of HFSS and CST show that the antenna is suitable for UWB applications and that both software are effective tools for verifying antenna performance.

Complex antenna structures cannot be simulated without the use of electromagnetic solvers such as HFSS, CST, and MATLAB. These software tools eliminate unnecessary costs in the fabrication stage by simulating the prototype and contribute to achieving the best result in the production phase.

In the study, the antenna performance, 3D models, and gain graphs of the circular disk monopole antenna in both software were presented and discussed.

2. Antenna Design and Performance

This section details the design stages and performance analysis of a CPW-fed circular disc monopole antenna. The designed antenna structure is based on a circular radiating patch. The circular patch is one of the commonly used configurations due to its ease of analysis. In designing such an antenna, various parameters related to the antenna's resonant frequency and bandwidth need to be considered. The CPW feed allows the antenna to achieve wide bandwidth and easy integration with planar circuits [9]. The radius "r" of the circle is a critical parameter in determining the operating frequency and input impedance of the antenna [11].

The radius “r” of the circle can be calculated using the following formula [9]:

$$r = \frac{F}{\left\{1+\frac{2H}{\pi\varepsilon_r F}\left[\ln\left(\frac{\pi F}{2H}\right)+1.7726\right]\right\}^{\frac{1}{2}}}; \qquad (1)$$

$$F = \frac{8.791\times 10^9}{f_r\sqrt{\varepsilon_r}}, \qquad (2)$$

where f_r is the resonance frequency, H is the thickness of the dielectric, and ε_r is the relative dielectric constant of the substrate.

Simulation results show that as the disk radius decreases, the resonance frequency increases. The antenna's lightweight and high performance make it ideal for portable devices [12–14]. The relationships between diameters and initial resonances are provided in Table 1. The operational bandwidth of the antenna depends on the feed gap (g), the ground plane width (W), and the disc radius (r) [15]. Therefore, these parameters should be optimized for maximum bandwidth in the antenna design.

In CPW-fed circular disc monopole antennas, the ground plane width W and length L are typically optimized based on the resonance frequency and the materials used [16]. To achieve good radiation efficiency, a practical width and length can be calculated using the following formula [9]:

$$W = \frac{c}{2f_r}\sqrt{2/(\varepsilon_r+1)}; \qquad (3)$$

$$L = \frac{c}{2f_r\sqrt{\varepsilon_{reff}}} - 2\Delta L, \qquad (4)$$

where c is the speed of light, ΔL is the extension at the patch ends, and ε_{reff} is the effective dielectric constant of the substrate.

The expression for calculating the amount of extension is as follows [9, 17]:

$$\frac{\Delta L}{H} = 0.412\frac{(\varepsilon_{reff}+0.3)(W/H+0.264)}{(\varepsilon_{reff}-0.258)(W/H+0.8)}. \qquad (5)$$

The effective dielectric constant can be calculated based on the dimensions of the CPW line and the dielectric constant of the substrate using the following formula [9, 18]:

$$\varepsilon_{eff} \approx \frac{\varepsilon_r+1}{2}+\frac{\varepsilon_r-1}{2}\left(1/\sqrt{1+12H/W_f}\right), \qquad (6)$$

where W_f is the width of the metal strip.

The approximate expressions for W_f/H in terms of Z_0 and ε_r for $W_f/H \geq 2$ have been derived by Wheeler and Hammerstad [19]:

$$\frac{W_f}{H} = \frac{2}{\pi}\left\{\begin{aligned}&(B-1)-\ln(2B-1)+\frac{\varepsilon_r-1}{2\varepsilon_r}\times\\ &\times[\ln(B-1)+0.39-0.61/\varepsilon_r]\end{aligned}\right\}; \qquad (7)$$

$$B = 60\pi^2/\left(Z_0\sqrt{\varepsilon_r}\right),$$

where Z_0 is the characteristic impedance.

The proposed CPW-fed circular disc monopole, as shown in Fig. 1, has a single-layer metallic structure. A circular disc monopole with a radius of r = 12.5 mm and a 50 Ω-CPW is printed on the same side of a dielectric substrate. In this study (Fig. 2), a substrate with a thickness of H = 1.6 mm and a dielectric constant of ε_r = 3 was used. The width of the metal strip is W_f = 4 mm, and the gap between the strip and the coplanar ground plane is fixed at g = 0.33 mm to achieve a 50 Ω impedance. W = 47 mm and L = 15 mm represent the width and length of the ground plane, respectively. The distance between the disc and the ground plane is h = 0.3 mm.

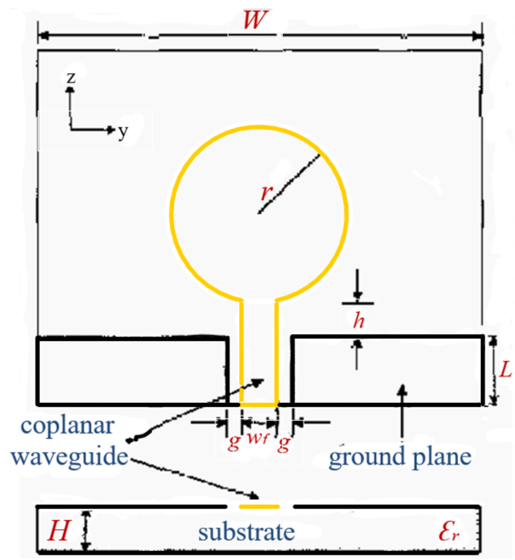


Fig. 1. Geometry of the CPW-Fed Circular Disc Monopole

Table 1 – **Relationships Between the Diameter and the First Resonances of the Monopole Antenna**

Diameter 2*r* (mm)	First Resonance *f* (GHz)	Wavelength λ (mm)	2r/λ
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

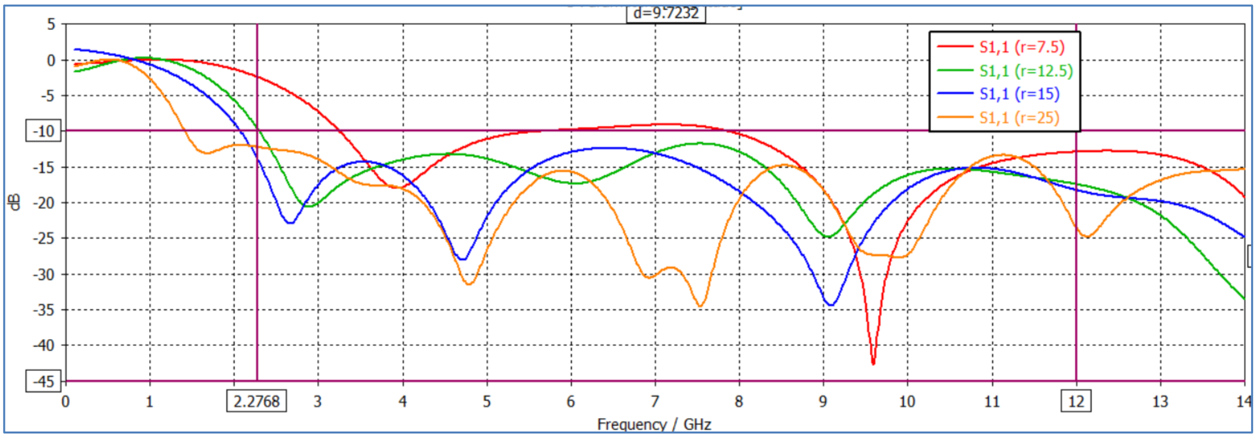


Fig. 2. Simulated Reflection Coefficient Curve for Different Sizes of the Circular Disc with Optimum Designs

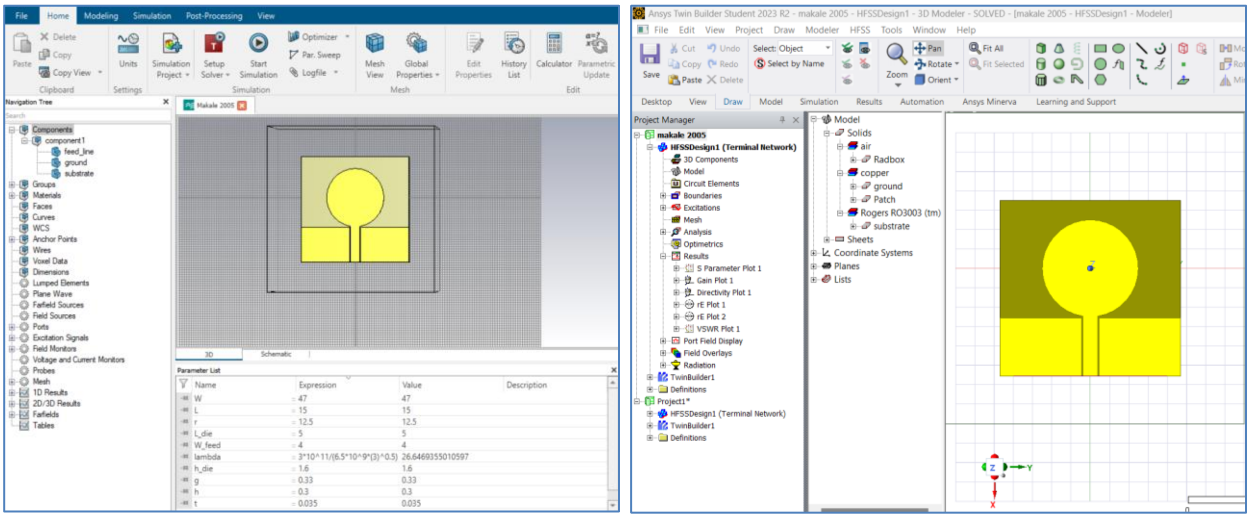
Antenna Simulations and Results in HFSS and CST

The circular disk monopole antenna designed for UWB applications has reconfigurable features in terms of frequency and polarization [20]. This section presents the details and results of the antenna simulations performed using HFSS and CST software. The wideband performance of the CPW-fed circular disc monopole antenna is evaluated based on parameters such as return loss (S11), radiation patterns, and gain.

CST Microwave Studio is a CST module dedicated to fast and highly accurate 3D electromagnetic simulations of high-frequency problems. This module includes different solvers for the simulation of structures in both the time and frequency domains.

HFSS is an electromagnetic field simulator for 3D modeling that utilizes the Microsoft Windows graphical user interface. It integrates simulation, visualization, solid modeling, and automation in an easy-to-learn environment. S parameters, resonant frequency, and fields can be calculated using this software.

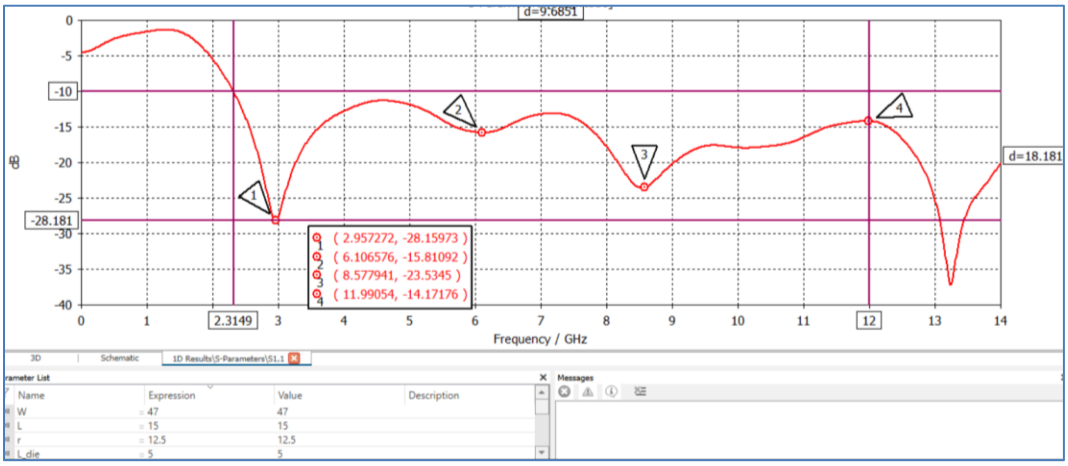
The circular disc monopole antenna designed using CST Microwave Studio is shown in Fig. 3, a, and the circular disc monopole antenna designed using HFSS is shown in Fig. 3, b.



a б

Fig. 3. Circular Disc Monopole Antenna Designed with CST and HFSS

The simulated and measured return loss curves are shown in Fig. 4. As shown in Fig. 4, the measured return loss curve matches in both CST and HFSS. Generally, the -10 dB bandwidth covers an extremely wide frequency range in both CST and HFSS. The simulated bandwidth extends from 2.3 GHz to beyond 12 GHz. According to both simulations, the VSWR curve is shown in Fig. 5. It is found to be below 2 in the range from 2.3 GHz to 12 GHz in both CST and HFSS and is 1.02 at the first resonant frequency, which is 2.9 GHz.



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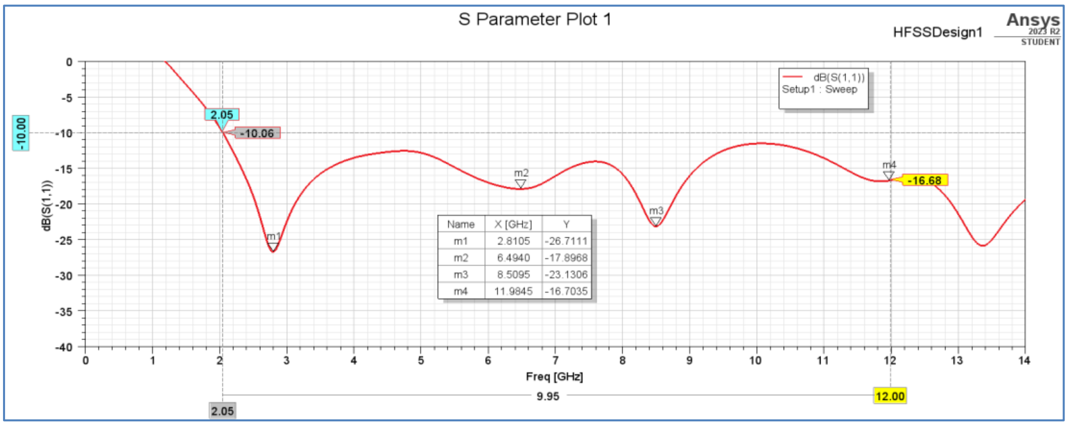
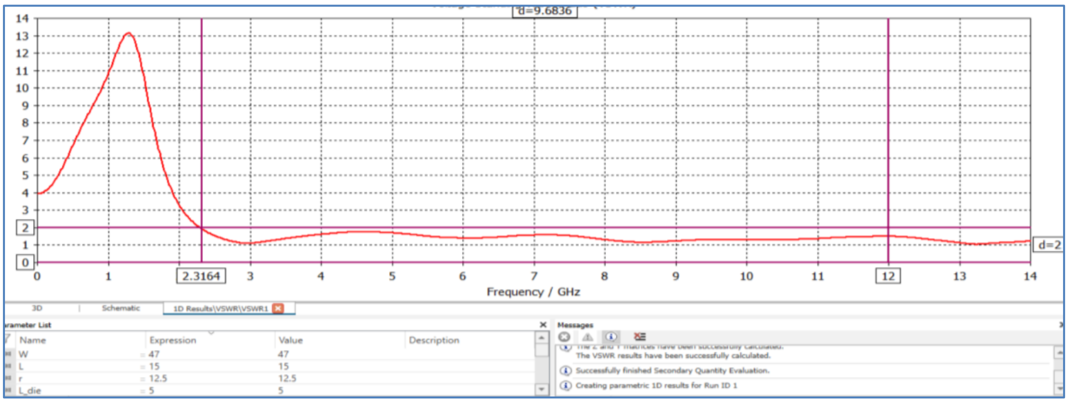


b

Fig. 4. Return Loss of the Circular Disc Monopole Antenna Designed with CST (a) and HFSS (b)



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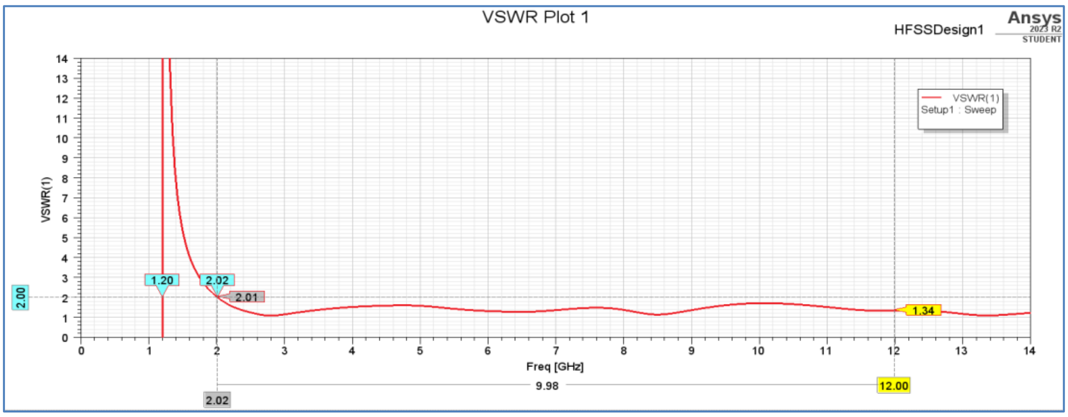


b

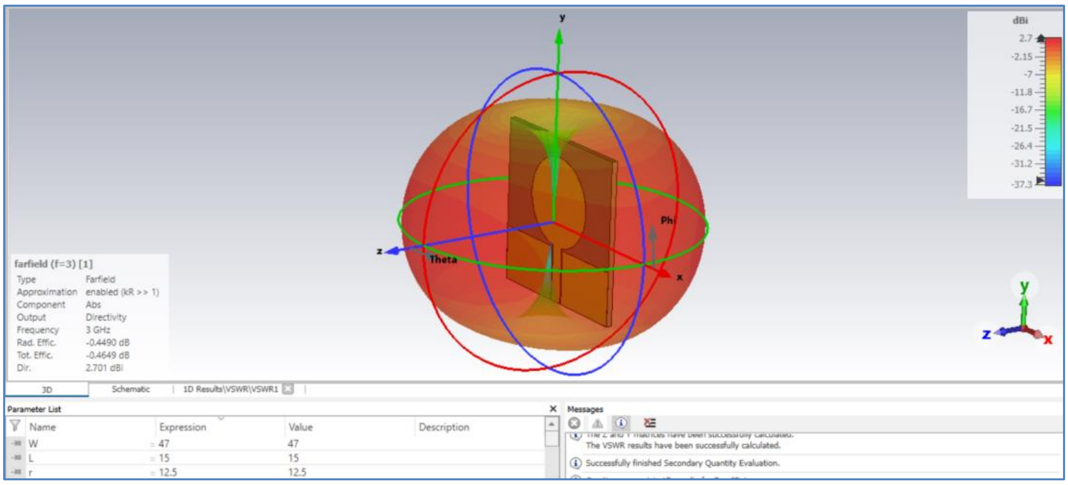
Fig. 5. VSWR Graph Obtained by CST-MW (a) and HFSS (b)

The far-field radiation model is shown in Fig. 6. The directivity obtained with CST is 2.7 dBi, while the directivity obtained with HFSS is 2.41 dBi. The gain from both simulations is shown in Fig. 7. The gain obtained using CST is found to be 2.24 dB, while the gain obtained using HFSS is found to be 2.34 dB.

It can be observed that there is a small difference in gain and radiation efficiency simulated using HFSS and CST MWS. This difference arises from the different numerical techniques used in the software. The Polar Plot of the Elevation Angle for the Monopole Antenna Designed with CST is shown in Fig. 8.

The Polar Plot of the Elevation Angle for the Monopole ntenna Designed with HFSS is shown in Fig. 9.

The Polar Plot of the Azimuth Angle for the Monopole Antenna Designed with CST is shown in Fig. 10.



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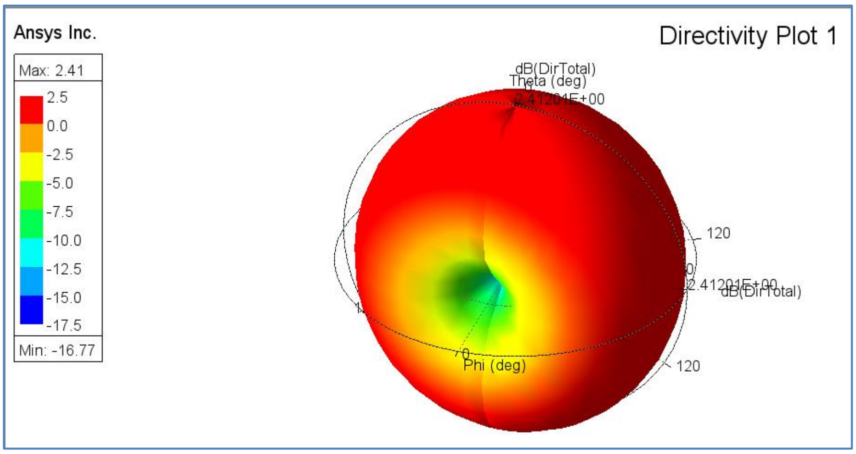

b

Fig. 6. (3D Far-Field Radiation Pattern Model for the Directivity of the Monopole Antenna Designed with CST-MW (a) and HFSS (b)

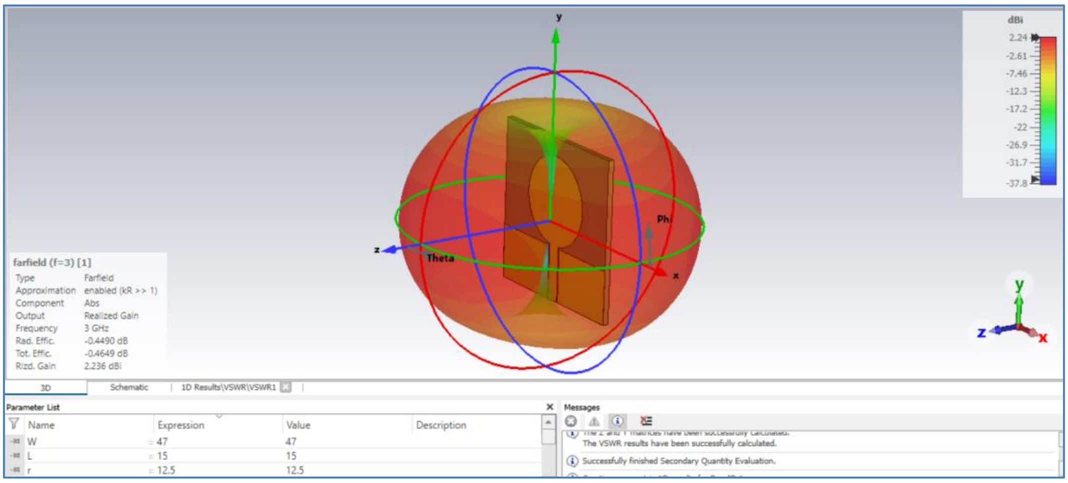

Fig. 7, a. Far-Field Radiation Pattern Model for the Gain of the Monopole Antenna Designed with CST

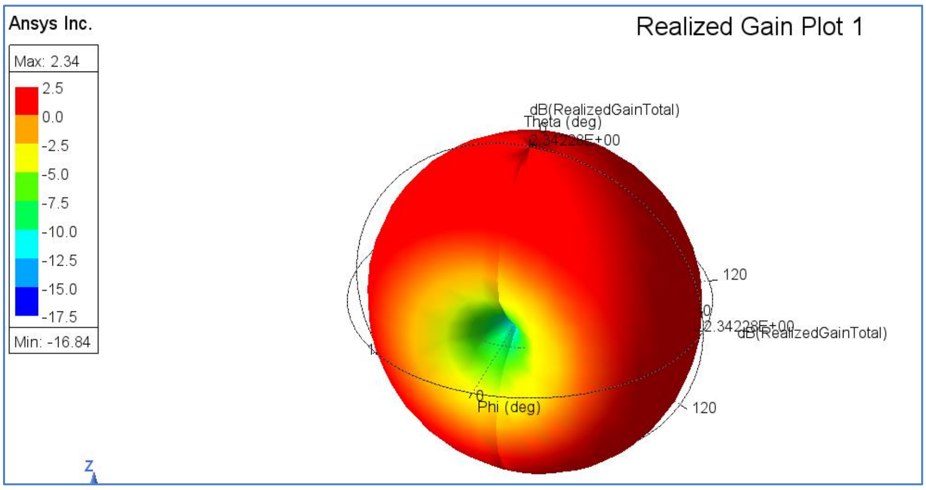

Fig. 7, b. Far-Field Radiation Pattern Model for the Gain of the Monopole Antenna Designed with HFSS

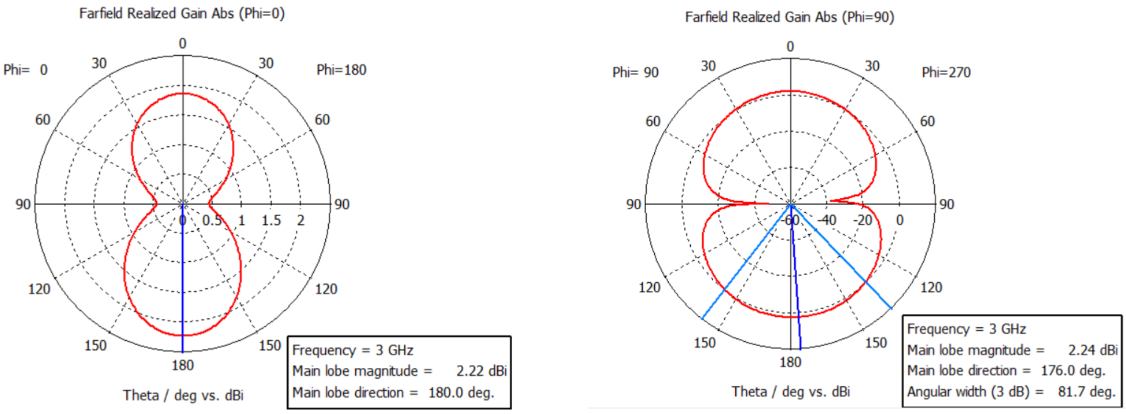

Fig. 8. Polar Plot of the Elevation Angle for the Monopole Antenna Designed with CST

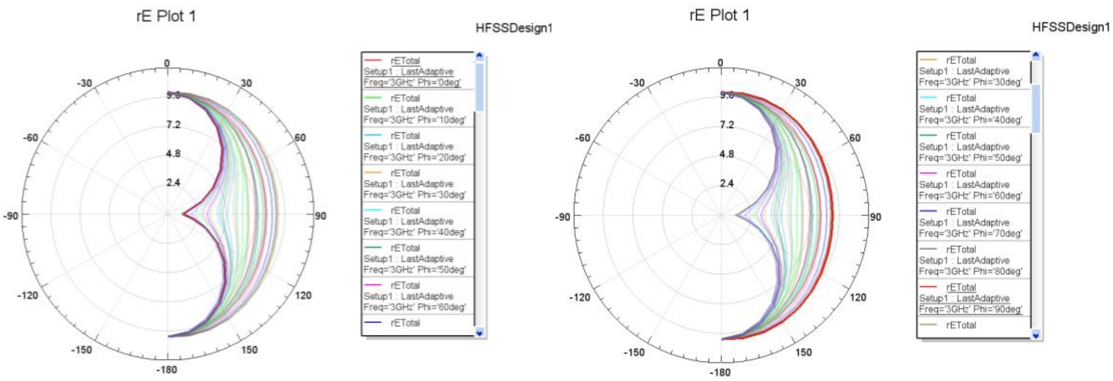

Fig. 9. Polar Plot of the Elevation Angle for the Monopole Antenna Designed with HFSS

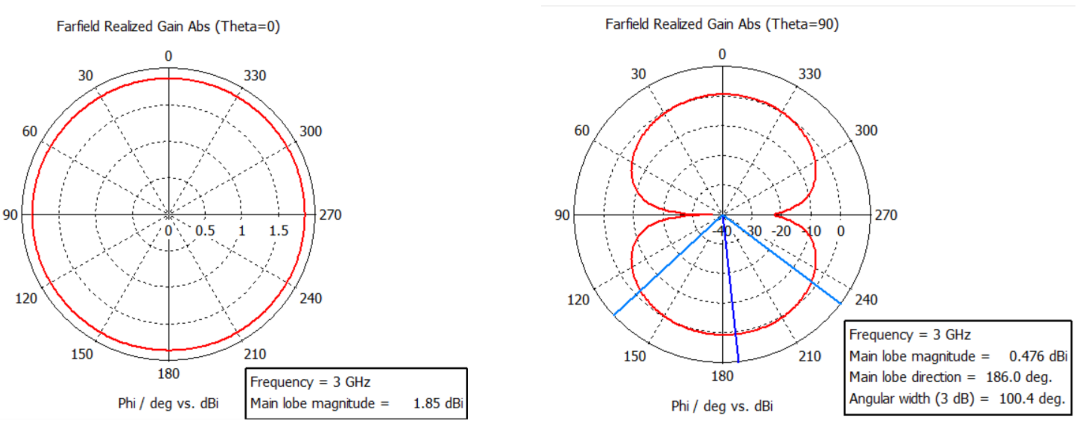

Fig. 10. Polar Plot of the Azimuth Angle for the Monopole Antenna Designed with CST

A summary of the simulated results is provided in Table 2.

Table 2 – **Simulated Results of the Designed Antenna**

Parameter	Value with CST	Value with HFSS	Unit
Operating Frequency (fr)	2.31 ÷ 12	2.05 ÷ 12	GHz
Directivity	2.7	2.41	dbi
Gain	2.24	2.34	dbi
Reflection Coefficient at the First Resonance Frequency	-28.1597	-26.7111	db
VSWR at the First Resonance Frequency	1.02	1.02	-

Conclusions

In this study, the design and performance analysis of a CPW-fed circular disc monopole antenna for ultra-wideband (UWB) applications were carried out using HFSS and CST software. The accuracy and effectiveness of both software tools were used to evaluate and optimize the antenna performance. Although small differences were observed between the results of HFSS and CST, both software tools confirmed the wideband characteristics of the antenna and its suitability for UWB applications.

The simulation results revealed that both CST and HFSS software demonstrated similar performance in terms of key parameters such as return loss (S11), radiation patterns, and gain. CST offers faster simulations due to its time-domain solver, while HFSS provides more detailed resonance behavior analyses with its frequency-domain solver.

It was found that both software tools provide reliable solutions for the design of CPW-fed circular disc monopole antennas and that this antenna is suitable for UWB applications.

This study makes a significant contribution to the comparison of simulation tools used in UWB antenna design and the optimization of antenna performance. HFSS and CST software emerge as effective tools in terms of accuracy and efficiency in solving electromagnetic problems, proving their usability in simulating complex antenna structures.

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Аналіз моделювання антенної системи
за допомогою технології симуляції навігаційного обладнання

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Анотація. У цій роботі представлено нову круглу монопольну антену з живленням через співплощинну хвилевідну лінію (CPW – Coplanar Waveguide) для ультраширокосмугових (UWB – Ultra WideBand) застосувань, змодельовану за допомогою програмного забезпечення High-Frequency Structure Simulator (HFSS) та Computer Simulation Technology (CST). Подано порівняльний аналіз моделювання та симуляцій дискової монопольної антени. **Метою дослідження** є спочатку визначити геометричні параметри та матеріальні властивості антени, а потім провести симуляції за допомогою програм HFSS та CST. **Завдання дослідження** полягає в оцінці ефективності нової дискової монопольної антени з живленням через CPW для ультраширокосмугових застосувань і порівнянні результатів, отриманих за допомогою двох інструментів електромагнітного моделювання. **Результати дослідження.** Для моделювання було використано плоскі структури та дискову монопольну антену з CPW-живленням, що забезпечує широкий діапазон частот. Метод моделювання антени було використано для вирішення проблеми. HFSS і CST широко використовуються в програмах моделювання мікрохвильових пристроїв завдяки високій точності при вирішенні задач електромагнітного моделювання та моделювання антен. Було отримано такі результати: HFSS та CST були реалізовані в діапазоні частот від 2.3 ГГц до 12 ГГц. Було проаналізовано ключові параметри, такі як коефіцієнт відбиття, діаграма спрямованості та коефіцієнт підсилення для оцінки продуктивності антени. **Висновок.** В результаті дослідження було показано, що дискова монопольна антена, змодельована на діелектричному шарі та живлена 50-омною CPW на тому ж шарі, забезпечує всенаправлену діаграму спрямованості в усьому діапазоні частот..

Ключові слова: монопольна антена; CPW-живлення; дискова монопольна антена; CST MWS; HFSS.