

Koch Slot DRA Antenna Array for Enhanced X-Band Applications

K. Anantha Lakshmi^{1*}, Valluri Dhana Raj², Ch. Sridevi³

Abstract

This work introduces an innovative method aimed at improving the gain of Dielectric Resonator Antenna (DRA) arrays functioning within the X-band spectrum. The design features a Koch-shaped slot-coupled feeding structure, utilising the properties of a short-ended microstrip line to enhance radiation directionality. The results of the simulation show that compared to conventional rectangular and V-shaped slot designs, the suggested antenna array provides a notable gain enhancement. This performance boost demonstrates how well-suited it is for cutting-edge uses like automobile traffic monitoring and defence tracking systems. It is a very useful option in settings where accuracy and dependability are essential because of its streamlined architecture, which guarantees more efficient signal transmission and reception. All things considered, the antenna's enhanced features make it a better option for such demanding application situations.

Keywords: Dielectric resonator antenna (DRA), Koch slot, antenna array, X-band, high gain, microstrip feeding, HFSS simulation

INTRODUCTION

Dielectric Resonator Antennas (DRAs) have attracted significant interest because of features including minimal footprint and reduced mass design, broad bandwidth, excellent radiation efficiency, affordability, and reduced losses. Dielectric Resonator Antennas utilize resonating structures to convert guided electromagnetic waves into free-space RF radiation. Although DRAs generally display wide radiation patterns and modest gain, employing array configurations can successfully address this drawback. Different feeding methods, including microstrip lines, coplanar waveguides, and slotted waveguides [1], have been utilised to activate linear DRA arrays. Among these, aperture coupling with a microstrip feed line is particularly notable for its straightforward fabrication process, compatibility

with Monolithic Microwave Integrated Circuits (MMICs), and the natural isolation it provides between the antenna and the feeding network [2, 3]. This study presents an innovative design of a DRA array that incorporates Koch-shaped slots to improve gain performance in the X-band applications. X band is a microwave band which lies between frequency range 8.0 and 12.0 GHz [4]. The main advantages of DRAs are summarized as follows:

In the design of Dielectric Resonator Antennas (DRAs), materials with a higher dielectric constant (ϵ_r) are typically selected due to their beneficial impact on antenna size and performance. The size of a DRA is inversely proportional to the square root of the dielectric constant and is approximately given by $\lambda_0/\sqrt{\epsilon_r}$, where λ_0 is the free-space wavelength

*Author for Correspondence

K. Anantha Lakshmi
E-mail: ananthalakshmi3131@gmail.com

¹PG Scholar, Department of Electronics and Communication Engineering, Bonam Venkata Chalamayya Engineering College, Autonomous, Odalarevu, Andhra Pradesh, India

²Professor of Department of Electronics and Communication Engineering, Bonam Venkata Chalamayya Engineering College (Autonomous), Odalarevu, Andhra Pradesh, India

³Associate Professor of Department of Electronics and Communication Engineering, Bonam Venkata Chalamayya Engineering College (Autonomous), Odalarevu, Andhra Pradesh, India

Received Date: April 21, 2025
Accepted Date: May 06, 2025
Published Date: June 09, 2025

Citation: K. Anantha Lakshmi, Valluri Dhana Raj, Ch. Sridevi. Koch Slot DRA Antenna Array for Enhanced X-Band Applications. Recent Trends in Electronics & Communication Systems. 2025; 12(2): 8–20p.

corresponding to the antenna's resonant frequency f_0 . The free-space wavelength λ_0 can be calculated using the relation $\lambda_0=c/f_0$, where c denotes the speed of light in vacuum. A higher ϵ_r allows for a smaller physical size of the antenna for a given resonant frequency, making the antenna more compact and suitable for applications where space is a constraint [5]. Additionally, using a high dielectric constant material helps in confining the electromagnetic fields within the dielectric structure, which enhances radiation efficiency and reduces losses. This property makes DRAs with high ϵ_r particularly advantageous in modern wireless communication systems, including satellite communications, radar, and mobile networks, where compactness, efficiency, and high-frequency operation are critical performance factors.

Dielectric resonator antennas (DRAs), composed entirely of non-conductive materials, inherently lack conductive losses. As a result, they exhibit high radiation efficiency, especially when fabricated from low-loss dielectric substances. This efficiency makes DRAs highly suitable for high-frequency applications, where minimizing power loss is critical. Their material composition also reduces ohmic losses typically associated with metallic components in conventional antennas. Consequently, DRAs offer a compelling alternative in modern communication systems, particularly where compact size and high performance are both essential [6].

Because the right resonator size and dielectric materials may be chosen, Dielectric Resonator Antennas (DRAs) provide noticeably wider impedance bandwidths than conventional microstrip patch antennas. Many different design optimizations are made possible by this flexibility. Engineers may fine-tune the antenna's performance properties, including gain, bandwidth, and polarization, by carefully altering these parameters. As a result, DRAs have gained popularity in contemporary wireless communication systems where small size and excellent performance are crucial. Their versatility across many frequency bands and applications is further improved by a variety of design techniques, including material selection and shape modification. DRAs' improved bandwidth and adaptable features make them ideal for next-generation antenna systems [7, 8].

Because of its flexible design and fabrication-friendly shape, rectangular dielectric resonator antennas, or DRAs, are frequently chosen in antenna design. Because of these features, they are particularly well-suited for uses where resonance frequency and quality factor adjustment are crucial. More control over the distribution of electromagnetic fields is possible thanks to the rectangular shape, which lets designers tailor antenna properties to meet particular performance needs. As a result, a lot of research has been done to improve DRAs' important performance characteristics, namely gain optimization and bandwidth augmentation. To satisfy the requirements of contemporary wireless and communication systems, a number of strategies have been investigated, including the incorporation of various feeding methods, material selections, and structural alterations. Rectangular DRAs are now firmly established as a dependable and effective choice in cutting-edge antenna designs [9].

ANTENNA DESIGN AND CONFIGURATION

Each of the four dielectric resonator components in the Dielectric Resonator Antenna (DRA) array is electromagnetically connected to a 50- Ω microstrip feed line via Koch-shaped slots carved into the ground plane. The FR4_Epoxy substrate, which has a thickness of 0.813 mm and a dielectric constant (ϵ_r) of 4.4, is used to install the microstrip line. The DRA array's performance is maximized by the Koch-shaped slots, which provide effective electromagnetic coupling between the resonators and the feed line. A compromise between cost, availability, and appropriate dielectric qualities for the specified application is provided by the selection of the FR4_Epoxy substrate. This design strategy improves the antenna system's overall performance by guaranteeing dependable signal transmission and effective energy coupling. The dielectric resonators (DRs) are made of Alumina (Al_2O_3) ceramic with a dielectric constant (ϵ_r) of 9.8. The dimensions of the DR elements are tailored to achieve a directive radiation pattern. The first and last DR elements measure 5 mm in width, 5 mm in length, and 2 mm in height, while the central elements are 6 mm in width, 6 mm in length, and 4.5 mm in height. The Koch slots

are 13 mm in length and 1 mm in width. A stub of length $\lambda_g/4$ is used, with X set to 4 mm, effectively preventing antinodes along the feeder. A summary of the design parameters is provided in Table 1.

The application of Koch fractal geometry in slot antenna design enhances the effective length of the radiating element. By utilizing the fractal's space-filling properties, the antenna's directivity and gain are improved without a substantial increase in its overall physical size. The self-similar and recursive nature of the Koch fractal allows for a more compact structure that maximizes the use of available space, optimizing electromagnetic performance. This results in antennas with higher efficiency and better radiation characteristics, particularly in applications where space constraints are crucial. The incorporation of Koch fractals offers a promising approach to designing advanced antennas with improved performance metrics while maintaining a smaller form factor, making it an ideal solution for modern wireless communication systems and miniaturized devices [10].

Figure 1 illustrates the design of the Koch slot array antenna using HFSS software. The fabricated antenna model is shown in Figure 2, with the top view in Figure 2(a) and the bottom view in Figure 2(b), highlighting the practical realization of the simulated design.

Table 1. Antenna design parameters.

Parameter	Value
Substrate Material	FR4_Epoxy
Substrate Dielectric Constant	4.4
Substrate Thickness	0.813 mm
DRA Material	Al ₂ O ₃ Ceramic
DRA Dielectric Constant	9.8
DRA Dimensions (Element 1 & 4)	5 mm×5 mm×2 mm
DRA Dimensions (Element 2 & 3)	6 mm×6 mm×4.5 mm
Koch Slot Length	13 mm
Koch Slot Width	1 mm
Microstrip Feedline Width	1.7 mm

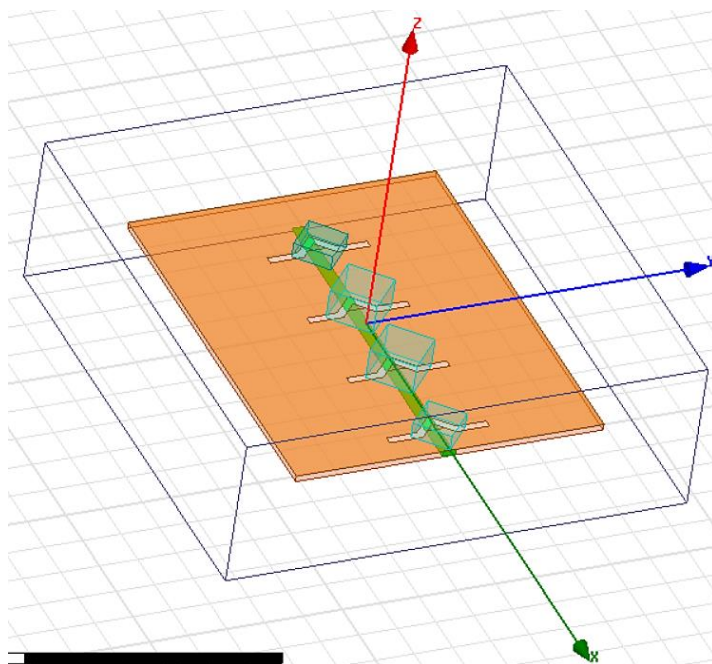


Figure 1. Design of Koch slot Array antenna using HFSS.

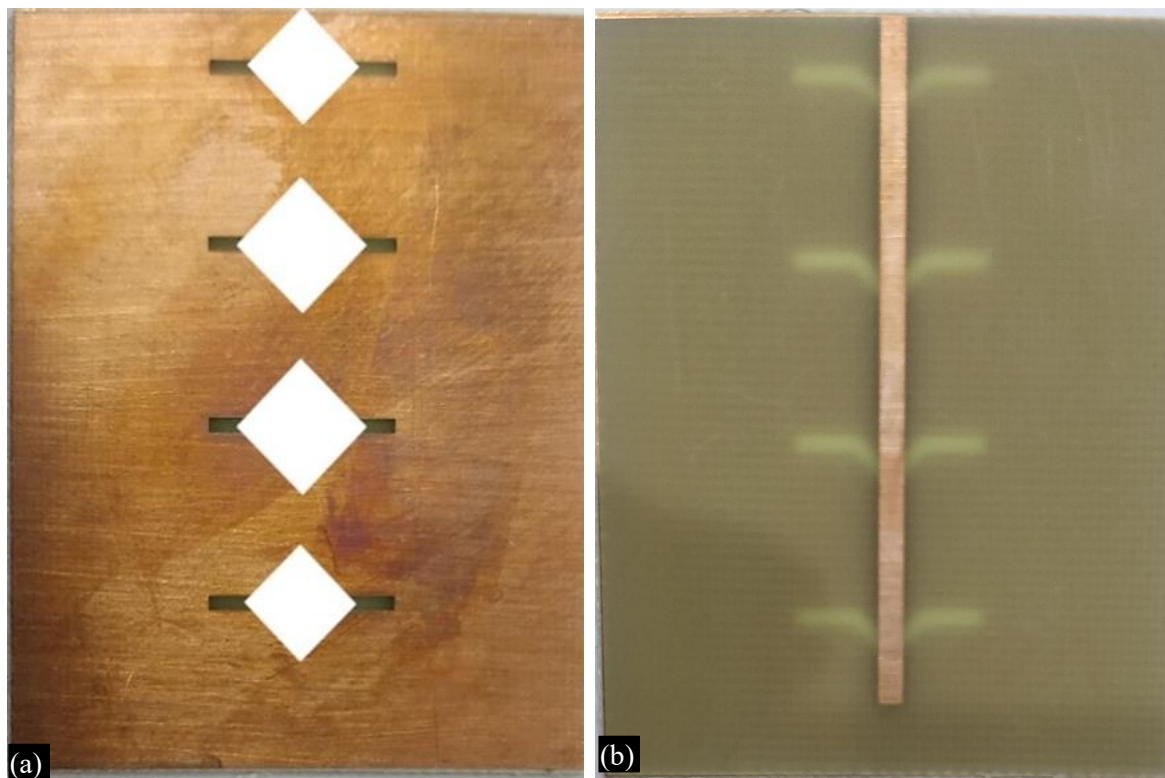


Figure 2. (a). Top view; (b) Bottom view.



Figure 3. (a) Koch slot array antenna; (b). Antenna with power supply.

Figure 3(a) illustrates the fabricated model of Koch slot array antenna, while Figure 3(b) shows the antenna along with its power supply.

SIMULATION RESULTS AND DISCUSSION

The antenna array was simulated using Ansys HFSS to evaluate its performance characteristics. The main simulated parameters used to assess antenna performance are gain, which shows how well the antenna radiates power; radiation pattern, which shows how the radiated power is distributed spatially; directivity, which shows how well the antenna focuses energy in a specific direction; return loss, which shows how much signal power is reflected; and voltage standing wave ratio (VSWR), which measures impedance matching. In communication systems, these metrics are crucial for evaluating the overall efficacy and performance of the antenna design.

These findings provide important information on the antenna's efficiency, directional behaviour, and impedance matching, all of which are critical for assessing how well it works in wireless communication applications. While efficiency and directional qualities affect the antenna's capacity to transmit and receive signals efficiently, impedance matching guarantees the least amount of signal reflection and maximum power transmission.

Return Loss and VSWR

Figure 4(a and b) illustrates the simulated return loss (S11) of the Koch slot DRA array, alongside the return loss of similar arrays that utilise rectangular and inverted V-shaped slots. The Koch slot design demonstrates a return loss of -12.6472 dB at 10.0 GHz and -15.9234 dB at 12.2 GHz, reflecting effective impedance matching.

Figure 5(a and b) illustrates the Voltage Standing Wave Ratio (VSWR). The measured VSWR values of 1.6081 at 10.0 GHz and 1.3806 at 12.2 GHz fall within the acceptable range for practical use.

Gain and Directivity

The simulated three-dimensional gain performance of the Koch slot dielectric resonator antenna (DRA) array is shown in Figure 6(a and b). Figure 6(a) illustrates the antenna's gain of 6.0415 dB at a frequency of 10.0 GHz, while Figure 6(b) shows a gain of 10.622 dB at a frequency of 12.2 GHz. The novel Koch slot design, which raises the antenna's overall radiation efficiency and performance, is principally responsible for the increased gain across these frequencies.

Figure 7(a and b) illustrates the directivity plots, showing a directivity of 7.5013 dB at 10.0 GHz and 10.829 dB at 12.2 GHz.

Radiation Pattern

Figure 8(a and b) depict the radiation patterns of the array at operating frequencies of 10.0 and 12.2 GHz. These patterns are presented for azimuthal angles of 0 and 90°, highlighting the array's directional characteristics.

The comparison illustrates how frequency and orientation influence the beam shaping and directivity of the radiation. Such analysis is crucial in evaluating the performance and suitability of the antenna array for targeted applications requiring specific angular coverage and beam steering capabilities. Additionally, Table 2 highlights the simulated performance summary.

Table 2. Simulated performance summary.

Parameter	10.0 GHz	12.2 GHz
Return Loss	-12.6472 dB	-15.9234 dB
VSWR	1.6081	1.3806
Gain	6.0415 dB	10.622 dB
Directivity	7.5013 dB	10.829 dB

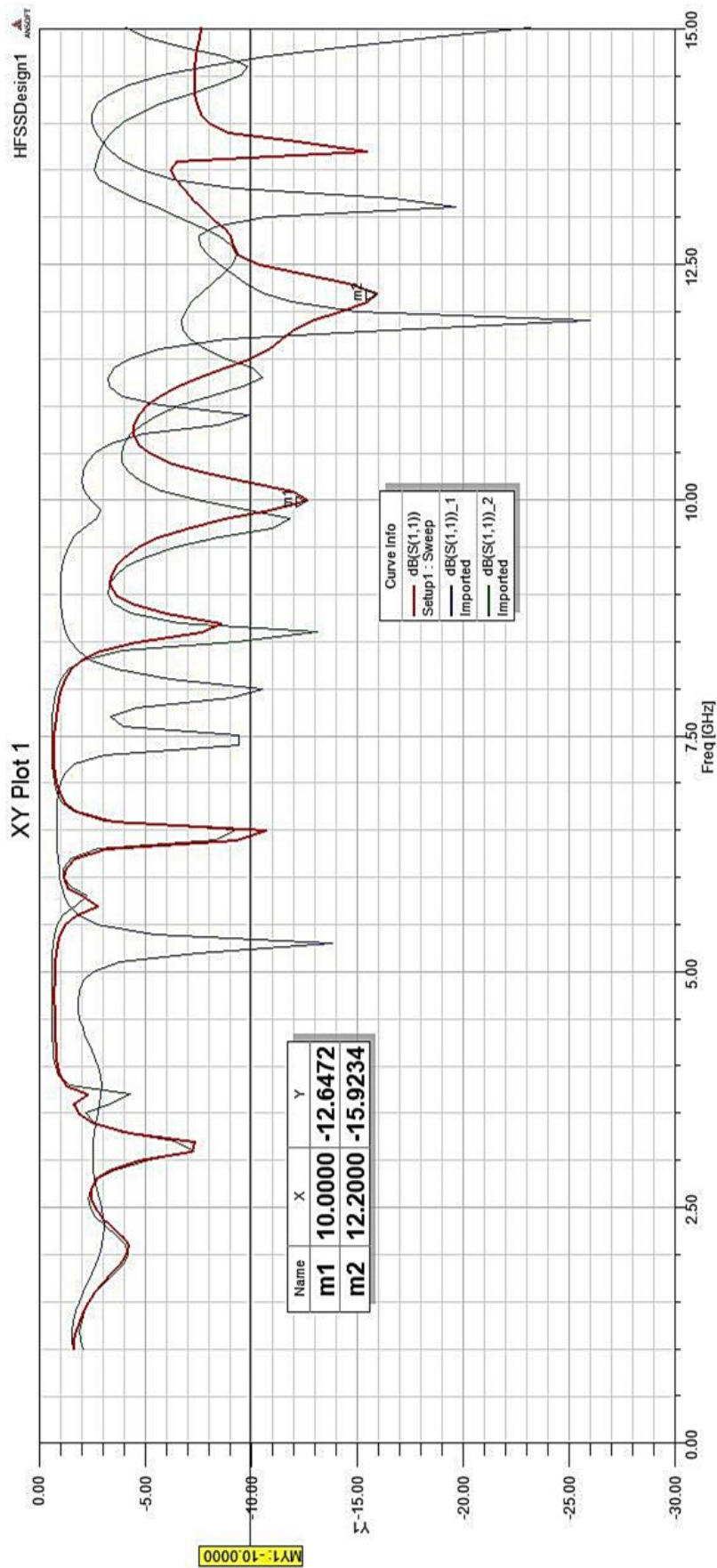


Figure 4(a). Return loss generated from HFSS.

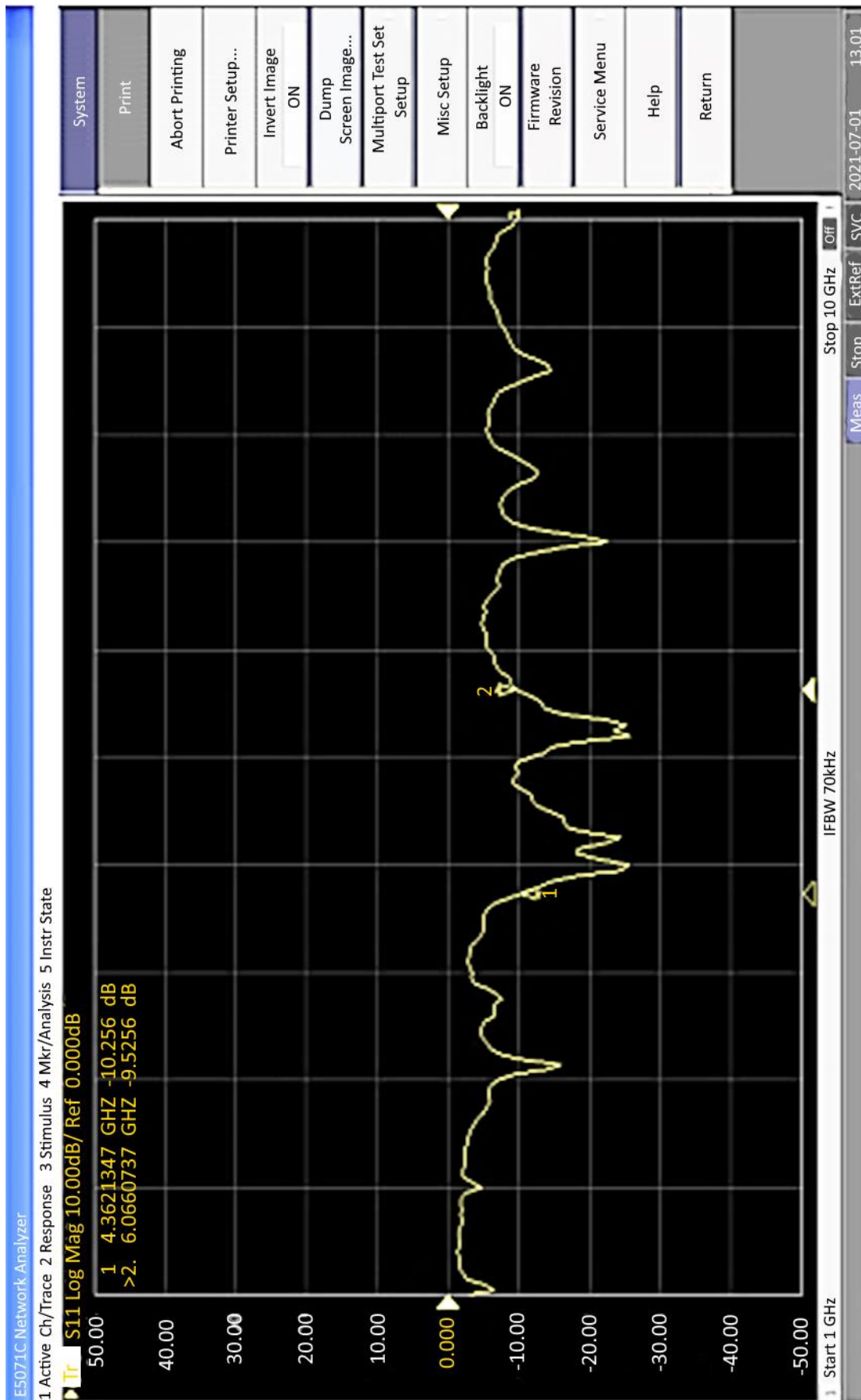


Figure 4(b). Return loss from vector network analyzer (VNA).

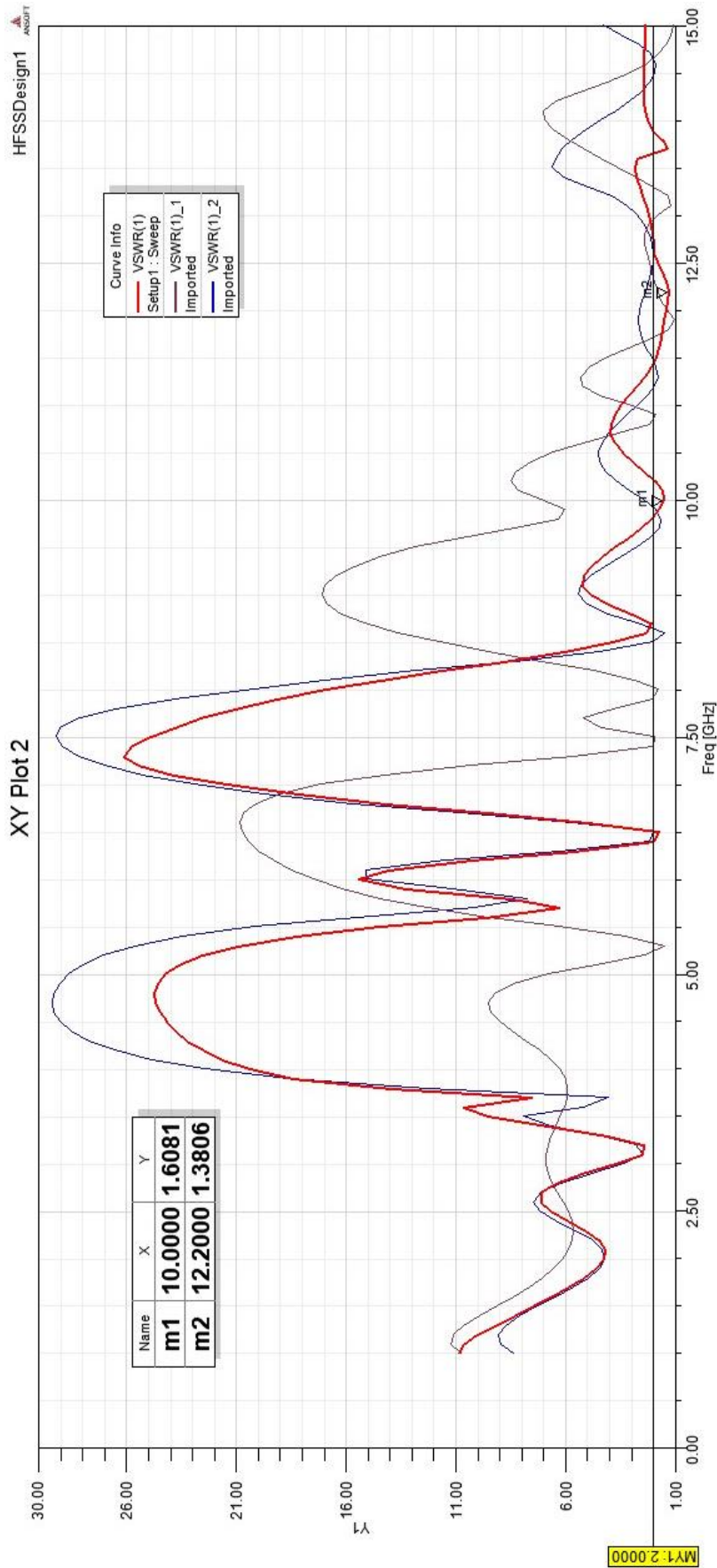


Figure 5(a). Voltage standing wave ratio (VSWR) from HFSS.

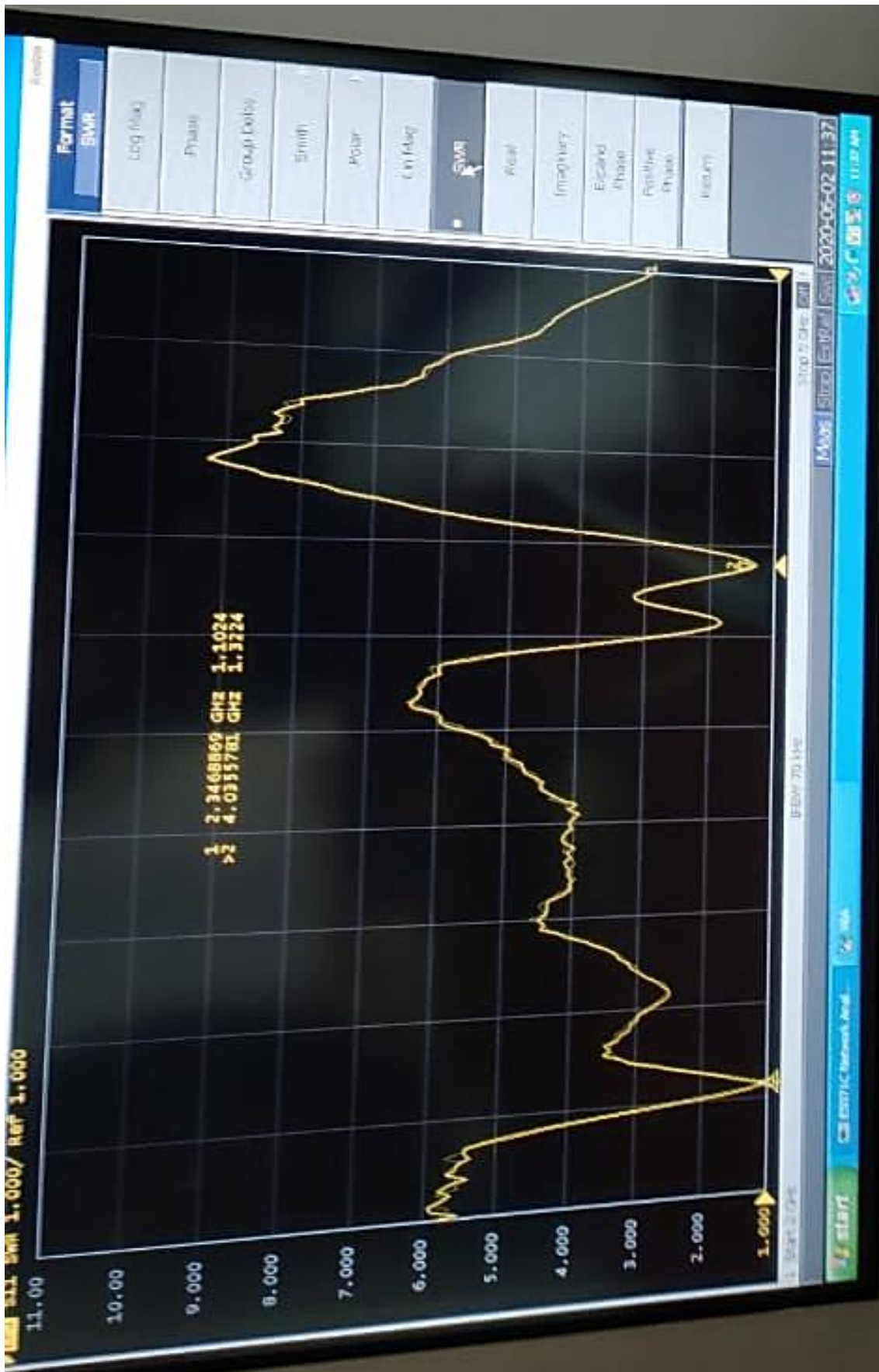


Figure 5(b). Voltage standing wave ratio (VSWR) from VNA.

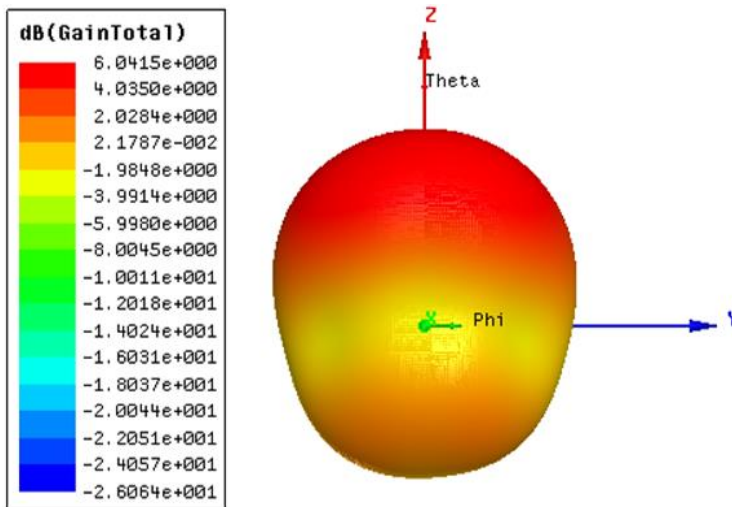


Figure 6(a). Gain at 10.0 GHz.

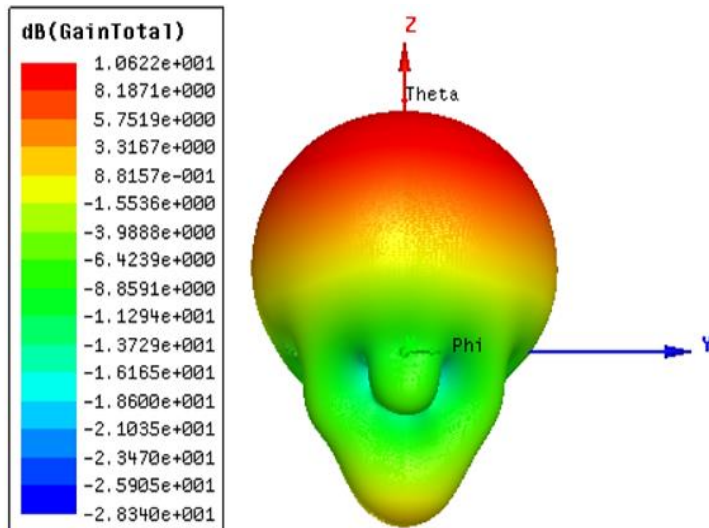


Figure 6(b). Gain at 12.2 GHz.

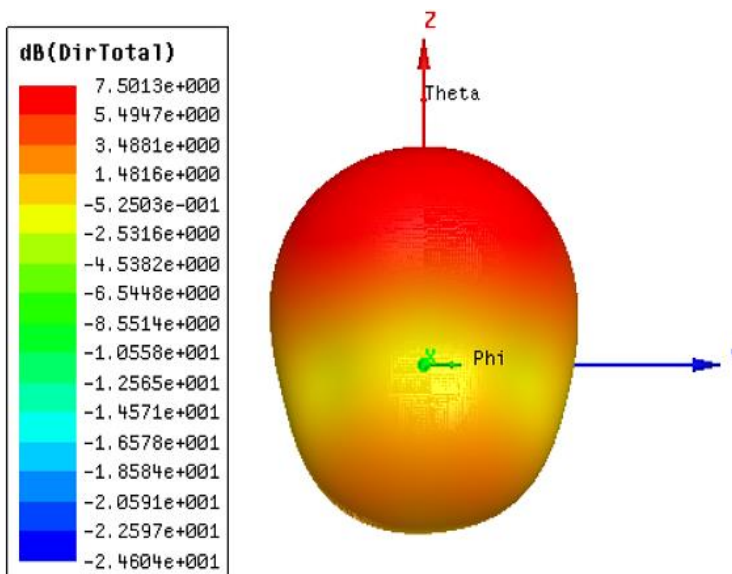


Figure 7(a). Directivity at 10.0 GHz.

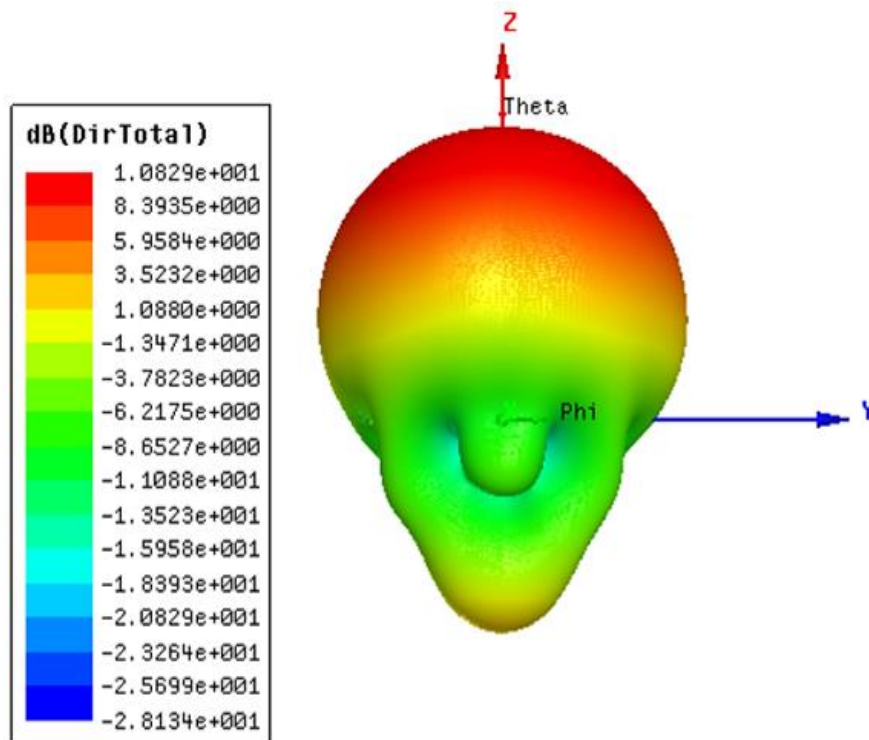


Figure 7(b). Directivity at 12.2 GHz.

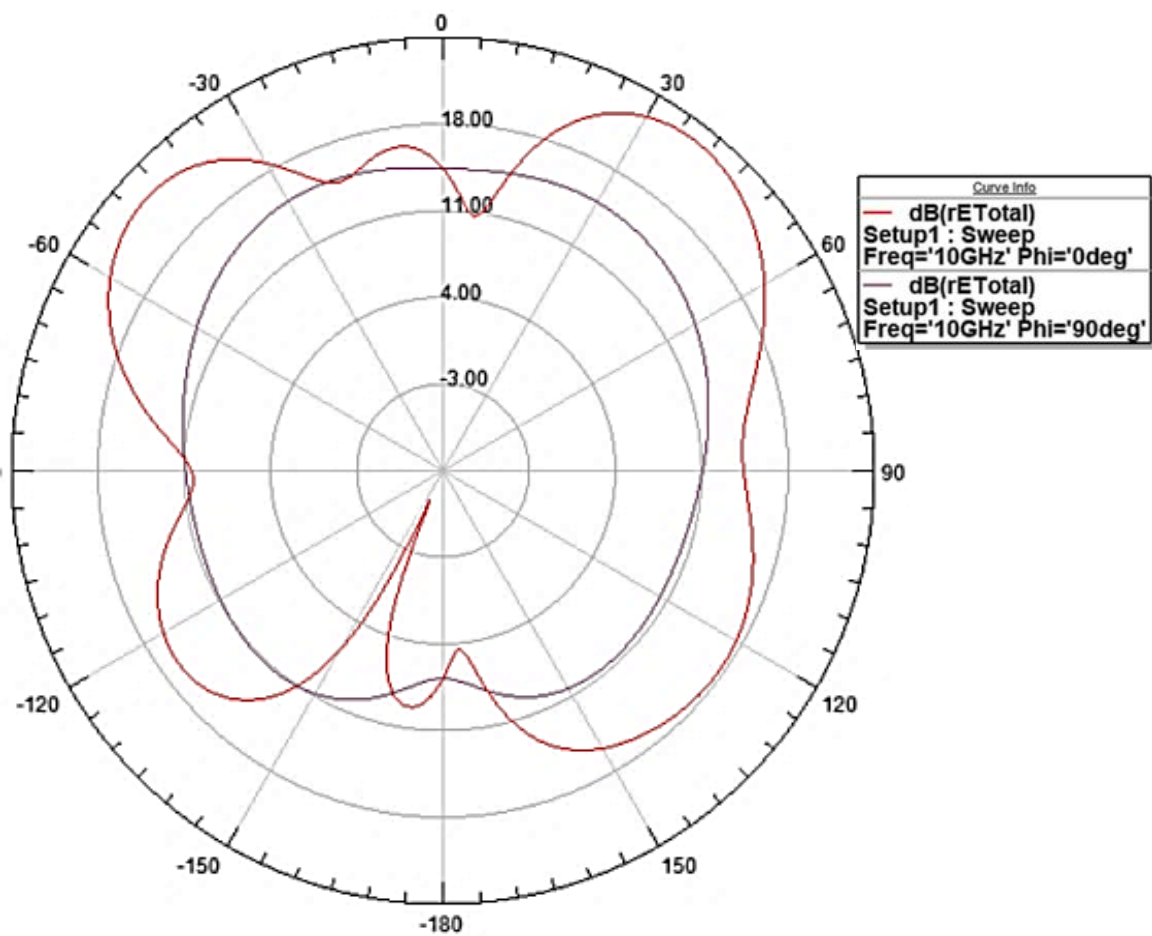


Figure 8(a). Radiation Pattern at 10.0 GHz.

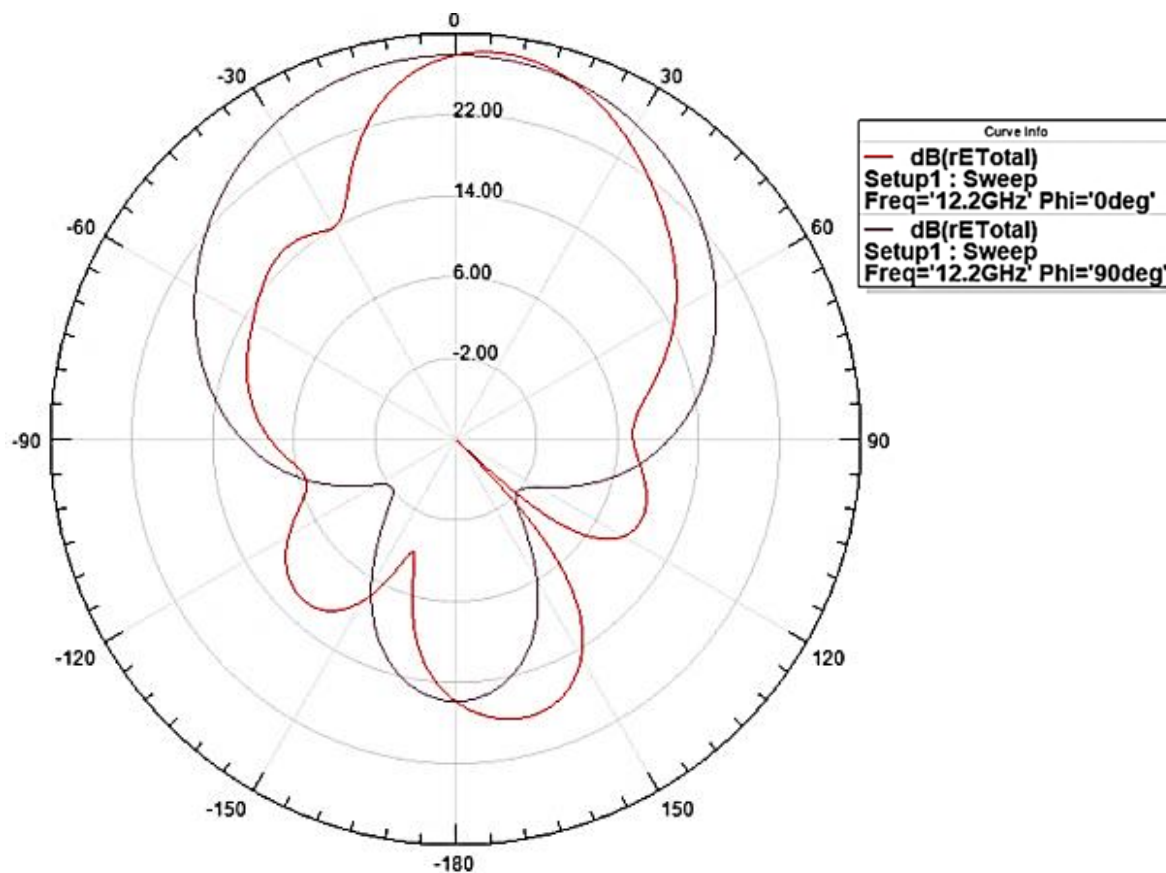


Figure 8(b). Radiation pattern at 12.2 GHz.

CONCLUSION

The design and simulation of a high-gain DRA array that employs Koch-shaped slot coupling for applications in the X-band spectrum has been proposed in this study. The simulation outcomes illustrate the success of the suggested design in attaining improved gain and directivity. The Koch slot DRA array presents a compelling option for scenarios that demand high-performance antennas, including defence tracking systems and vehicle traffic detection. The next steps will involve the development and experimental testing of the suggested antenna array.

REFERENCES

1. Balanis CA. Antenna theory: analysis and design. John Wiley & Sons; New Jersey, United States. 2016 Feb 1.
2. Kumari R, Behera SK. Wideband log-periodic dielectric resonator array with overlaid microstrip feed line. *IET Microw Antennas Propag*. 2013 May; 7(7): 582–7.
3. Chemweno EK, Kumar P, Afullo TJ. Design of high-gain wideband substrate integrated waveguide dielectric resonator antenna for D-band applications. *Optik*. 2023 Feb 1; 272: 170261.
4. Lincy BH, Srinivasan A, Rajyalakshmi B. X-band fractal microstrip antenna for wireless application. *Int J Comput Appl*. 2013 Jan 1; 68(3): 25–29.
5. Sharma A, Khare K, Shrivastava SC. Dielectric resonator antenna for X band microwave application. *International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering (IJAREEIE)*. 2013 Jun; 2(6): 2247–2252.
6. Harkare AH, Kothari AG, Bhurane AA. Evolution of gain enhancement techniques in dielectric resonator antenna: applications and challenges. *Int J Microw Wirel Technol*. 2023 Jun; 15(5): 891–905.
7. Zhang Y, Ogurtsov S, Vasilev V, Kishk AA, Caratelli D. Advanced dielectric resonator antenna technology for 5G and 6G applications. *Sensors*. 2024 Feb 22; 24(5): 1413.

8. Keyrouz S, Caratelli D. Dielectric resonator antennas: basic concepts, design guidelines, and recent developments at millimeter-wave frequencies. *Int J Antennas Propag.* 2016; 2016(1): 6075680.
9. Mythili S, Akshaya K, Charanya B, Ayyappan K. Design and analysis of Koch fractal antenna for WLAN applications. *ICTACT J Microelectron.* 2020; 6(2): 923–7.
10. Fonseca D, Pereira F, Vitor UR. Study of patch antennas with Koch curve form slots. *J Microwaves, Optoelectron Electromagn Appl.* 2019 Sep 12; 18(3): 399–407.