79 GHz Hemispherical Dielectric Resonator Antenna Design for Millimeter Wave Automotive Sensors

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Abstract. This paper presents the design and performance evaluation of a Hemispherical shaped Dielectric Resonator Antenna (HDRA) intended for automotive Short-Range Radar (SRR) applications operating at millimetre wave frequencies. The proposed antenna employs a Hemispherical shaped Dielectric Resonator. with a relative permittivity of Eps=24, chosen to ensure compact size and stable radiation characteristics. The HDRA is excited using a simple 50 Ω microstrip feed-line mechanism printed in the substrate' top of the substrate, which enables efficient electromagnetic coupling while maintaining a low-profile structure. Numerical simulations demonstrate that the proposed antenna resonates at 79.2 GHz and exhibits a high realized gain of approximately 13.2dBi, along with a radiation efficiency reaching 92.4 %. In addition, the antenna produces a stable and highly directional radiation pattern at the resonant frequency (79 GHz), which is a key requirement for reliable target detection in automotive radar systems. Owing to its compact geometry, high efficiency, and favourable radiation performance, the proposed HDRA represents a promising candidate for next-generation millimeter wave SRR applications.

1 Introduction

In recent years, the integration of radar-based anti-collision systems in modern vehicles has expanded significantly, with the antenna serving as a crucial component of these systems. Automotive radar systems are typically classified into two categories: 77 GHz Long Range Radar (LRR), commonly used in Adaptive Cruise Control (ACC) applications [1–2], and 24/79 GHz Short Range Radar (SRR) systems [3–4], which support a variety of safety features such as stop-and-go functionality, parking assistance, blind-spot detection, and rear-end collision mitigation.

While microstrip patch antennas are widely employed in these applications [5–8], Dielectric Resonator Antennas (DRAs) are emerging as a promising alternative due to their numerous advantages. DRAs are particularly suitable for microwave [9–10] and millimeter-wave [11–13] frequency bands because of their low dielectric loss, high radiation efficiency, and compact size.

Among the different DRA geometries, the hemispherical shape stands out due to its symmetrical structure, which provides uniform radiation patterns and improved impedance bandwidth [14]. Additionally, the hemispherical DRA offers ease of excitation, better mode confinement, and reduced cross-polarization [15], making it an ideal candidate for high frequency and high-performance applications in automotive radar systems.

The remainder of this paper is organized as follows: Section 2 details the geometric design of the proposed hemispherical DRA. Section 3 presents and analyses the simulation results, and Section 4 concludes the study.

2 Antenna configuration

The geometry of the proposed design is shown in figure 1. It consists of a Hemispherical shaped Dielectric Resonator (HDR) with a radius of R=1.5 mm. It is fed by a microstrip line which has a length of L=5 mm, and a width of W=0.5 mm. The DRA is made up of ceramic material (Eps=24), and is placed on a ground plane that has a size of 10 x10 mm^2. FR4 substrate (Eps= 4.3) has the same size of the ground plane with a thickness of 0.4 mm.

3 Results and discussions

3.1 Parametric analysis

Several parameters can be explored to achieve an optimal design characterized by low return loss at 79 GHz and desirable directional radiation properties at the same frequency band. However, in this study, we have limited our investigation to the influence of three key parameters: the substrate thickness, the dielectric constant of the HDRA, and its height.

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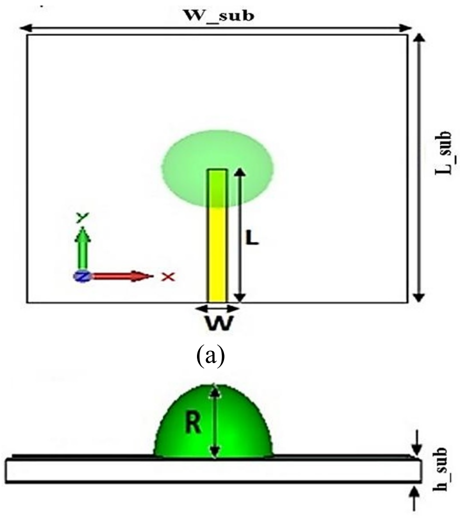

Fig. 1. Configuration of the proposed HDRA, (a) top view , and (b) side view.

3.1.1 Effect of HDRA' permittivity

The single HDRA return loss magnitude versus different HDRA' permittivity values are presented in figure 2 when substrate thickness is fixed at h_sub=0.4mm. We found the best antenna's gain value has been achieved for Eps=24 with a return loss parameter of -14.7 dB.

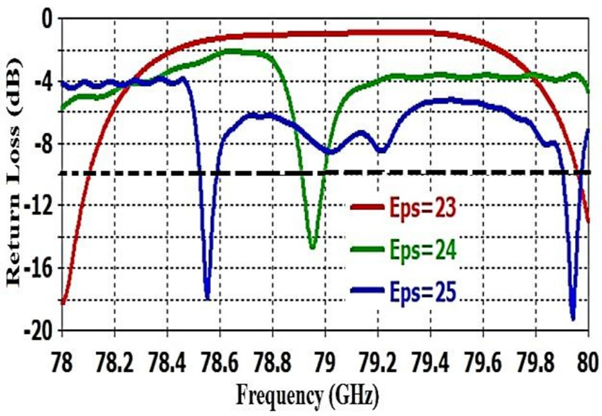

Fig.2. Return loss of HDRA vs. different values of Eps.

3.1.2 Effect of substrate's thickness

The substrate thickness value of 0.4 mm gives a reasonable value of S_{11} parameter (less than -14 dB) around 79 GHz as shown in figure 3.

3.1.3 Effect of the radius of HDRA

The radius of HDRA plays a crucial role in determining its impedance matching and resonant behavior. To investigate this effect, a parametric analysis was conducted by varying the radius of the hemispherical resonator while keeping all other design parameters unchanged. Three different radius values were considered, denoted as $R1$=1mm, R2=1.5mm, and $R3$=2mm, in order to evaluate their influence on the return loss characteristics.

The simulated results indicate that changing the HDRA radius leads to noticeable shifts in the resonant frequency as well as variations in the depth of the return loss minimum. For the smallest radius R1, the antenna exhibits weaker impedance matching, with a relatively shallow return loss minimum and a noticeable deviation from the desired operating frequency. This results in poor energy coupling between the feed and the dielectric resonator. When the radius is increased to R2, a significant improvement in impedance matching is observed. The return loss reaches a deeper minimum, and the resonant frequency aligns more closely with the target value. This indicates better energy transfer and reduced reflection at the input port. Although R3 also provides a certain level of matching, the response is less stable across the frequency band, with a return loss minimum that is either shallower or slightly detuned compared to R2. As illustrated in figure 4, the configuration corresponding to R2 achieves the best overall impedance matching, with the deepest and most centered return loss dip at the desired operating frequency. Therefore, R2 is selected as the optimal radius for the proposed HDRA design.

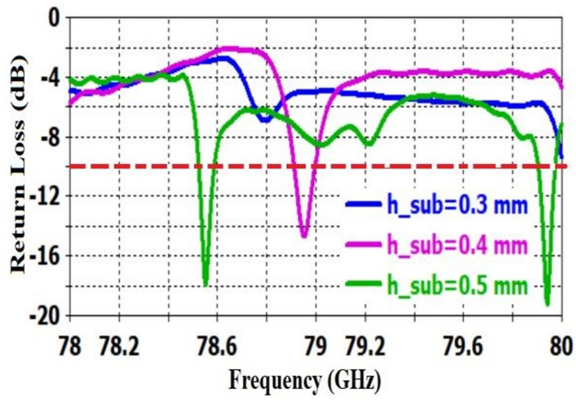

Fig.3. Return loss vs. different values of h_sub.

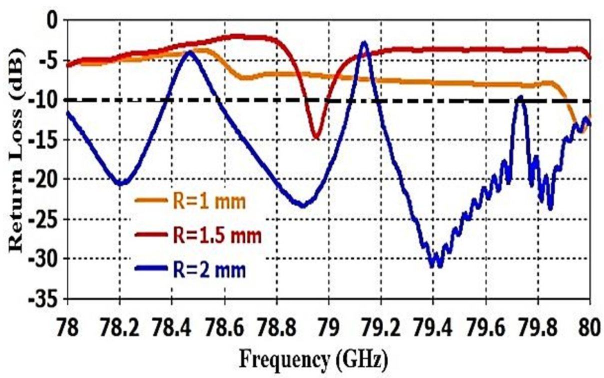

Fig.4. Return loss vs. different values of R

3.2 Return loss and VSWR

Based on the previously defined parameters, the final antenna configuration was extracted from the parametric analysis and simulated using both CST and HFSS software. As illustrated in figure 5, the return loss (S_{11}) results from the two simulators show a good level of agreement, with only a slight variation in the depth and shape of the resonant dip. This discrepancy can be attributed to the different numerical methods used by each tool. CST relies on the Finite Difference Time Domain (FDTD) technique, which discretizes Maxwell's curl equations specifically Faraday's and Ampere's laws in both time and space domains. The electric and magnetic fields are then calculated iteratively at each time step using an explicit leap-frog scheme. In contrast, HFSS uses the Finite Element Method (FEM), which divides the complex simulation domain into smaller, simpler elements where the field equations are solved using localized approximations.

In the figure 5, the green curve represents the CST results, showing a minimum S11 of -15.63 dB at the resonant frequency of 79 GHz, with a bandwidth of 92 MHz defined at the -10 dB threshold. The red curve, obtained from HFSS, shows a slightly deeper and narrower resonance, reflecting the differences between the two numerical approaches. Despite these minor differences, the results are consistent and validate the accuracy of the proposed design across both simulation platforms.

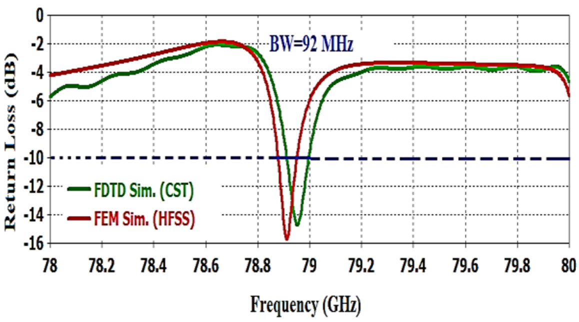

Fig. 5. Return loss of the optimal HDRA.

To ensure the reliability and accuracy of the proposed antenna design, two well established full-wave electromagnetic simulation tools were employed in this study, namely CST Studio Suite and HFSS. These solvers are based on different numerical techniques Finite Difference Time Domain (FDTD) for CST and Finite Element Method (FEM) for HFSS which makes their combined use particularly valuable for cross-verification purposes. By analyzing the antenna performance using both platforms, potential solver dependent effects such as meshing strategies, boundary conditions, and numerical approximations can be identified and minimized.

In the figure 6, the green curve obtained from CST results shows an excellent impedance matching at the target frequency of 79 GHz, where the VSWR reaches a value close to 1, indicating nearly ideal power transfer between the feed line and the radiating structure. In comparison, the red curve obtained from HFSS shows predicts a higher VSWR value of approximately 1.2, occurring at a marginally shifted frequency of 79.2 GHz. Despite this small deviation, the antenna remains well matched in both cases, as the VSWR values are significantly below the commonly accepted threshold of 2.

The close correspondence between the results obtained from CST and HFSS confirms the robustness of the proposed design and increases confidence in the reported performance metrics. Minor discrepancies observed between the two solvers are expected and remain within acceptable limits, as they originate from the inherent differences in numerical formulations rather than from design inconsistencies. Overall, the use of both CST and HFSS provides a comprehensive and trustworthy validation framework, ensuring that the antenna performance is not dependent on a single simulation environment and is suitable for practical millimeter wave radar applications.

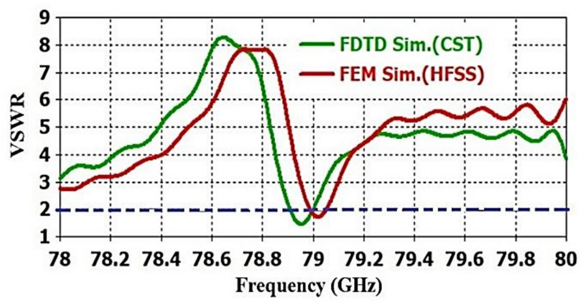

Fig. 6. VSWR of the optimal HDRA.

3.3 Radiation pattern

In radar antenna design, the radiation pattern is a critical parameter, particularly for SRR and LRR applications. Figure 7 (a) presents the 2D radiation pattern at 79 GHz in the YZ-plane (Theta = 90°) of the proposed HDRA. A remarkable overlap is observed between the simulated results from HFSS (FEM) and CST (FDTD), confirming the model's robustness. The structure exhibits pronounced directional behavior, with a simulated peak gain of 9.89 dB (HFSS) and a -3dB angular width of 69.3° at 79 GHz. This beamwidth could be reduced by integrating the antenna into an appropriate array network, thereby optimizing radar performance.

The three-dimensional (3D) radiation pattern of the proposed antenna provides a comprehensive view of its radiating behavior and gain performance at different operating frequencies. As illustrated in Fig. 7, the antenna exhibits a well-defined directional radiation pattern with the main lobe oriented along the boresight direction. At 79.2 GHz, the antenna achieves its highest realized gain, reaching a value of 13.2dBi, which indicates strong radiation concentration and efficient energy transmission in the desired direction. at frequency 79 GHz, the antenna maintains a stable directional pattern, with a reduced gain of 9.98 dBi. This variation in gain with frequency is mainly attributed to changes in the resonant field distribution within the dielectric resonator. Nevertheless, the antenna preserves good radiation stability across the considered frequency range, confirming its suitability for millimeter-wave radar applications.

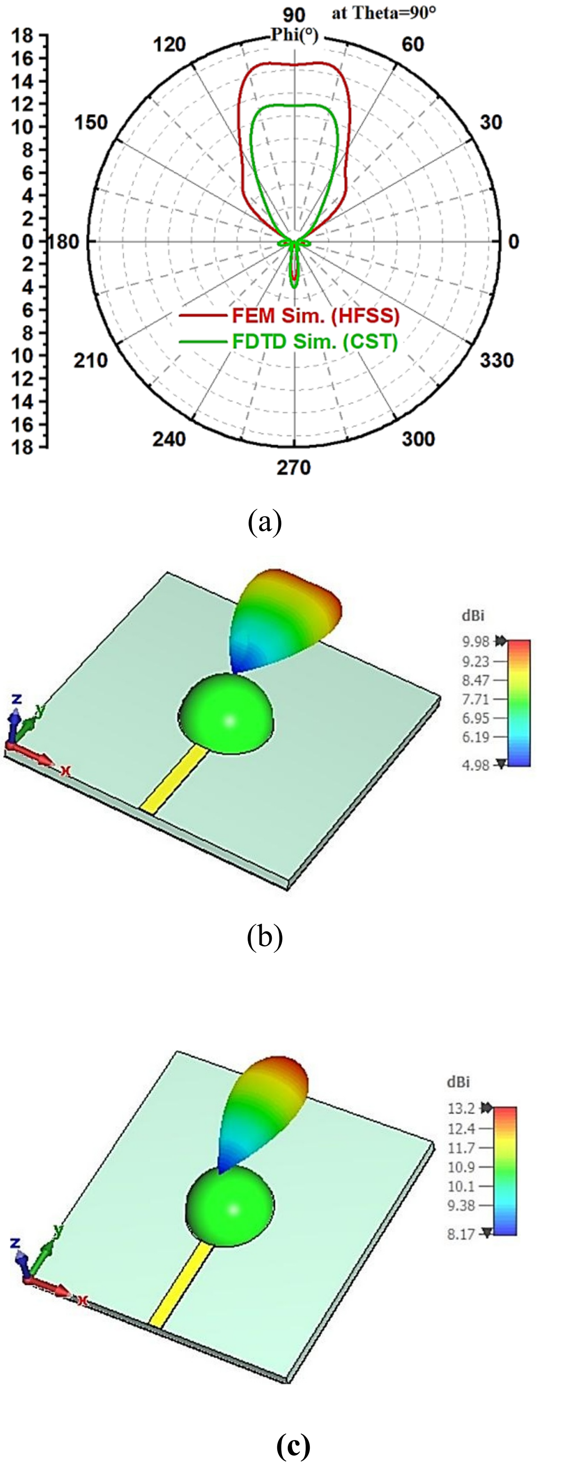

Fig.7. (a) Radiation pattern in YZ-plane at 79 GHz, (b) 3-D radiation pattern of gain at 79 GHz, and (c) 3D radiation pattern of gain at 79.2 GHz.

3.4 Surface current distribution

At the operating frequency of 79 GHz, as shown in figure 8, the surface current distribution of the proposed HDRA is mainly concentrated around the microstrip feed region and the lower surface of the resonator. The maximum surface current density reaches approximately 656 A/m, indicating strong electromagnetic coupling and efficient excitation of the resonant mode. This current behavior supports the antenna's high efficiency and directional radiation performance.

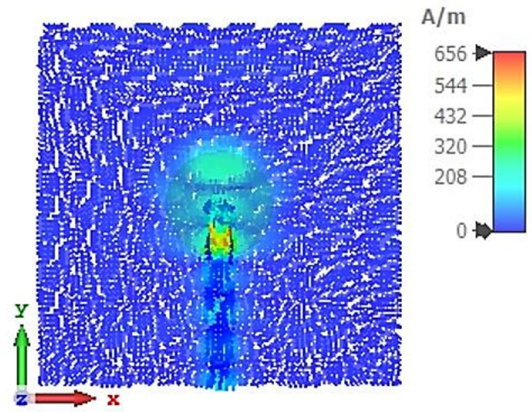

Fig.8. Surface current distribution at 79 GHz.

3.5 Gain, directivity, and efficiency

As shown in figure 9, the proposed HDRA demonstrates strong radiation performance at 79 GHz. At this frequency, the realized gain reaches 9.89dBi, indicating efficient power radiation in the desired direction, while the corresponding directivity attains 10.8dBi, confirming a highly focused main beam. The close relationship between these two values suggests that most of the radiated energy is effectively concentrated along the boresight, which is desirable for automotive short range radar systems requiring directional coverage and high sensitivity.

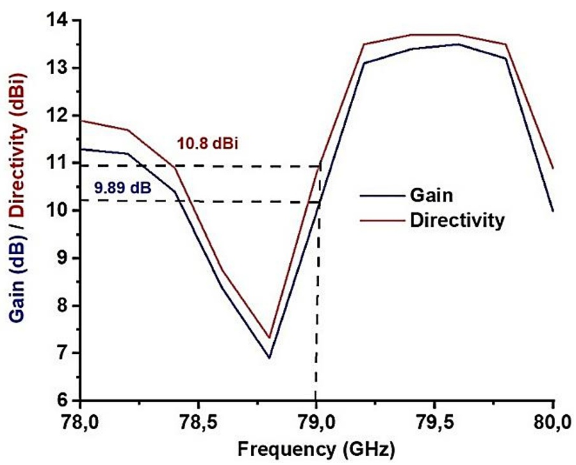

Fig.9. Gain and directivity of the optimal HDRA vs Frequency.

As illustrated in the figure 10, the proposed HDRA exhibits a high radiation efficiency at the operating frequency of 79GHz. The efficiency reaches 92.4%, indicating that most of the input power is effectively converted into radiated electromagnetic energy. This high efficiency reflects the low loss nature of the dielectric resonator and the effective coupling provided by the feeding structure, which together contribute to reliable and stable antenna performance for millimeter wave radar applications.

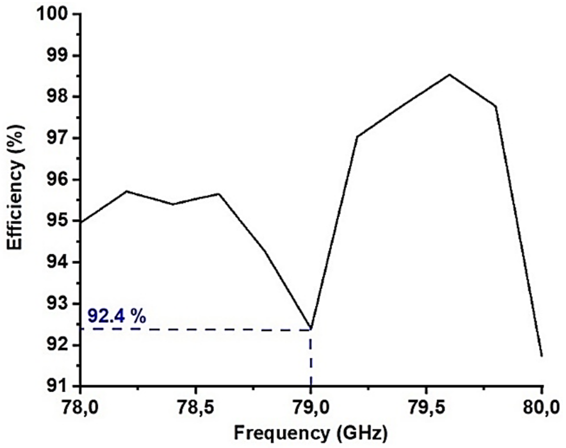

Fig.10. Efficiency of the optimal HDRA vs Frequency.

4 Conclusion

This paper has presented the design and numerical investigation of a Hemispherical shaped Dielectric Resonator Antenna (HDRA) intended for automotive short-range radar (SRR) applications operating in the millimeter wave band. The proposed antenna is designed to operate around 79 GHz and is excited using a simple microstrip feed-line, which contributes to a compact and practical configuration suitable for integration into automotive radar modules.

Simulation results confirm that the HDRA exhibits highly directional radiation characteristics at the operating frequency, ensuring focused energy transmission and improved target detection capability. The antenna also demonstrates a very high radiation efficiency of approximately 92.4 %, along with a high realized gain reaching 13.2dBi at 79.2 GHz. These performance features are essential for short range radar systems, where high efficiency and directional behavior directly enhance detection accuracy and reliability.

Overall, the proposed HDRA combines compact size, simple feeding architecture, high efficiency, and strong directional radiation, making it a promising candidate for practical implementation in automotive SRR anti-collision radar applications. Future work may include experimental validation and integration with radar front-end systems to further assess its real-world performance.

References

1. P. Giuseppe et al., "CMOS IC Solutions for the 77 GHz Radar Sensor in Automotive Applications" Electronics, vol. 13, no. 11: 2104, May 2024.
2. Chen L. et al., 2024. "A 26.4-dB gain 15.82-dBm 77-GHz CMOS power amplifier with 15.9% PAE using transformer-based quadrature coupler network", IEEE Microw. Wirel. Compon. Lett., vol. 30, pp. 78–81, Jan. 2020.
3. Y. Wang et al., "High-Quality Short-Range Radar Imaging with Coprime Sampling," Remote Sensing, vol. 16, no. 24, p. 4657, Dec. 2024.
4. P. Aust et al., "Radar vehicle signatures: comparison of up-to-date automotive radar sensors with different characteristics," IEEE Sensors Letters, vol. 9, no. 3, pp. 1-4, Mar. 2025.
5. M. Klotz and H. Rohling, "24 GHz radar sensors for automotive applications", JTIT, vol. 6, no. 4, pp. 11–14, Dec. 2001.
6. A. HADDAD et al.,"1×16 Rectangular dielectric resonator antenna array for 24 GHz automotive radar system", Bulletin of Electrical Engineering and Informatics, Vol. 11, No. 4, pp.2115~2123, Aug. 2022.
7. A. HADDAD et al., "Design of High Gain Novel Dielectric Resonator Antenna Array for 24 GHz Short Range Radar Systems ", Advanced Electromagnetics, vol.7(4), pp. 12-18, Aug. 2018.
8. A. HADDAD et al.,"79 GHz Three Stacked Cylindrical Dielectric Resonator Antenna Array for Automotive Radar Systems", TELKOMNIKA, Telecommunication Computing Electronics and Control, Vol. 23, No 1, pp. 11~21, Feb. 2025.
9. Mirmehdi Seyyedesfahlan and Ibrahim Tekin , "Integrating 77 Ghz Lna/Phase Shifter Chip With Pcb Microstrip Patch Antenna For Array Applications", ARMMS ,April 2015.
10. U. A. Dash, S. Sahu and J. R. Panda, "A compact truncated conical Dielectric Resonator Antenna with concentric cylindrical air gap for microwave application," in Proceedings of the International Conference on Microwave, Optical and Communication Engineering (ICMOCE), Bhubaneswar, India, December 18-20 (2015).
11. Y. Zhang et al., "Advanced Dielectric Resonator Antenna Technology for 5G and 6G Applications, " *Sensors*, vol. 24, no. 5, p. 1413, Jan. 2024.
12. S. K. K. Dash et al., "5G millimeter-wave MIMO DRAs with reduced mutual coupling, " Microw. Opt. Technol. Lett., vol. 66, no. 1, pp. e33989, Jan. 2024.
13. H. Ahmad, et al., "A novel compact four-port MIMO dielectric resonator antenna with wideband operation for 5G mm-wave applications," Phys. Scr., vol. 100, no. 7, p. 075564, Jul. 2025.
14. M.D Alanazi, and S.K Khamas, "Wideband mm-Wave Hemispherical Dielectric

Resonator Antenna with Simple Alignment and Assembly Procedures," Electronics, vol.11, pp. 2917, Sept. 2022.

15. W. Albakosh, R. Asfour, Y. Khalil, and S. K. Khamas, "Wideband Millimeter-Wave Perforated Hemispherical Dielectric Resonator Antenna," Electronics, vol. 13, no. 9, p. 1694, Apr. 2024.