Study and Design of A 64-Element Millimeter Radar Antenna For Automotive Applications

EL Haiddad Mohamed Lemine[1] , Jamal Zbitou[1,2], ER- Rebyiy Ridouane [3], Mostafa Hefnawi[4], Salaheddine aourik[1]

[1]LabTIC, ENSAT, UAE, Tétouan, Morocco
[2]ENSATé, UAE, Tétouan, Morocco
[3]LAMIGEP, EMSI , Marrakech, Morocco
[4]Royal Military College, Kingston Canada

Mohamed.lemine@etu.uae.ac.ma, J.zbitou@uae.ac.ma,

Abstract— This paper introduces the design and measurement of a 64-element microstrip antenna array optimized for automotive radar applications operating at 24 GHz. The antenna array are used to improve the gain and directivity of radars, particularly in the millimetre frequency bands. Our approach involves the use of a multi-element antenna array, offering high gain and superior performance in terms of radiation pattern and directivity. The study incorporates a Rogers RT5880 substrate with a height of 0.508 mm, a dielectric constant (Er) of 2.2, and a loss tangent of 0.0009. We used two different calculation tools: CST MICROWAVE STUDIO and Advanced Design System (ADS).

Keyword: Microstrip antenna array, 24 GHz, automotive radar, 64-elements, Gain.

I. Introduction

Recently, Radar technology has gained significant prominence, particularly in the aerospace industry, where it plays a crucial role in security and imaging applications. Radar, an acronym for radio detection and ranging, functions by emitting radio waves and analyzing the returning echoes to locate distant objects. Its capabilities extend to determining range, speed, angle, and even the shape of detected objects [5].
However, patch antennas, commonly employed in radar systems, often encounter a major limitation in the form of narrow bandwidth. This limitation arises due to losses caused by surface waves and the necessity for larger patch sizes to achieve optimal performance. Consequently, various techniques have been proposed to address this bandwidth limitation [4]. These techniques encompass structural modifications and short-circuiting methods, where microstrip lines or patches are short-circuited with the antenna's ground plane, aiming to reduce antenna size.
In addition to structural adjustments, different loading techniques have been explored, such as the integration of external packaged components to minimize antenna dimensions. However, it's essential to note that such modifications may potentially compromise overall performance and gain, while also contributing to increased costs.

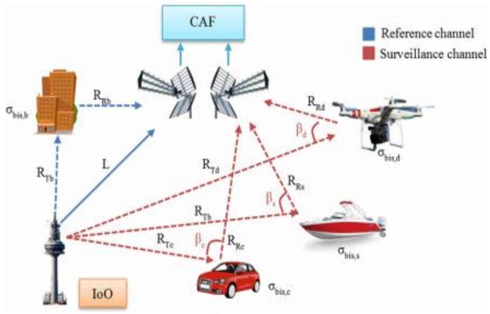

Fig.1: Geometry of the passive biostatic radar system and main elements relating to a building, a car, a drone and a ship.

RADAR stands for Radio Detection and Ranging. It is a system for detecting and tracking objects at a distance. Microstrip patch array antennas are widely used in RADAR because of their high gain, low profile, and light weight, ease of integration and cost-effectiveness, as well as precise control of their radiation pattern [1-3].

II. THEORY AND DESIGN

❖ The structure and its characteristics

The antenna array is printed on a Rogers RT 5880 substrate with relative permittivity ε= 2.2, loss tangent tan (δ) =0.0009, and height 0.508 mm. Figure 2 (a) and Figure 2 show the geometry of the structure proposed in ADS with dimensions of 3.89 mm × 4.938 mm.

❖ Design steps for a single antenna

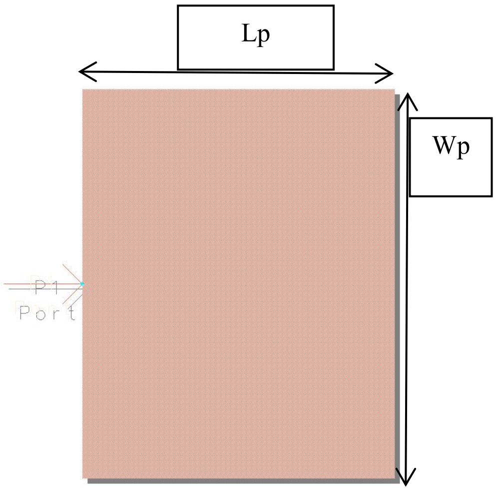

Fig.2: The structure without feeder

We must determine the input impedance of the antenna at resonance (Zin) for **resonance frequency 24GHZ**

- **Input impedance**

$$\mathbf{S11}=\frac{Zin-Z0}{Zin-Z0} \Rightarrow Zin = Z0\frac{1+S11}{1-S11} \quad \textbf{(1)}$$

- **Adaptation**

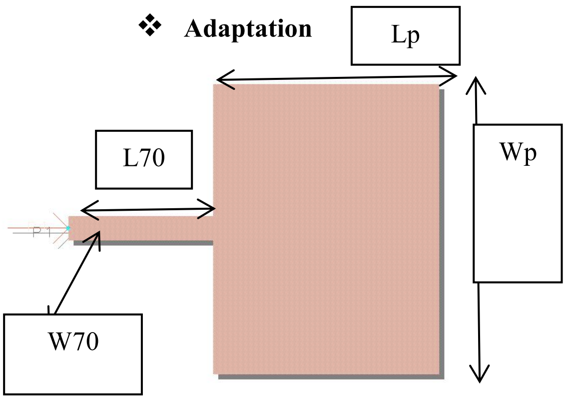

Fig 3: The structure with feeder

To achieve the desired match, we used a quarter-wave transformer.

- Calculation of **Lf** and **Wf**

$$\text{Lf}=\frac{\lambda}{4}=\frac{\lambda g}{4}=\frac{\lambda 0}{4\sqrt{\varepsilon eff}}=\frac{C}{4fr\sqrt{\varepsilon eff}} \quad (2)$$

- Electrical length θ

$$\theta = \beta * \text{Lf} = \frac{2\pi}{\lambda}\frac{\lambda}{4} = \frac{\pi}{2}\,(\text{rad})=(90°) \quad (3)$$

- Characteristic impedance **Zc**

$$\text{Zc} = \sqrt{Za * Zin} \quad (4)$$

With Za = 50Ω (antenna impedance) and Zin = antenna input impedance, we have determined the value of Zc. Subsequently, employing the linc calculation method, we ascertain the values of Lf and Wf as follows: Lf = 2.4mm and Wf = 0.4mm.

- **Design of a 64-element antenna array**

Figure 3 shows the final shape of the 64-element antenna array, which depends mainly on the distribution of power between similar antennas in order to improve antenna gain and to position the antennas so as to exploit space and reduce antenna dimensions.

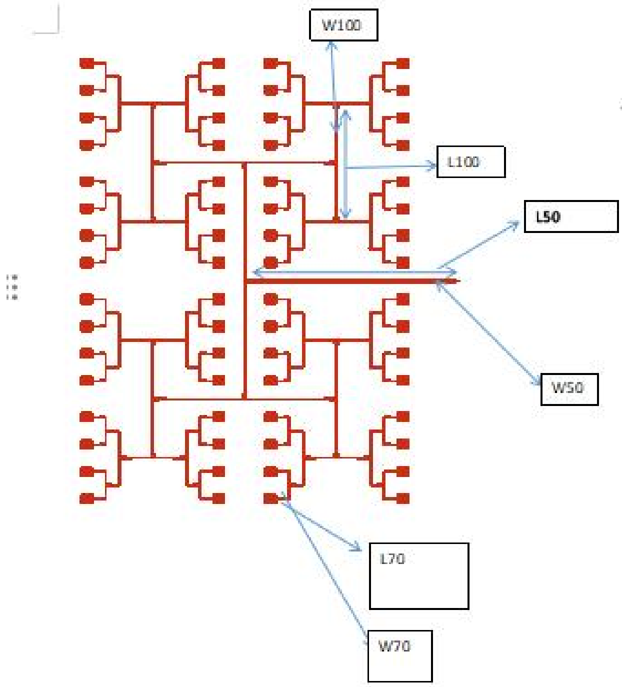

Figure 3: A 64-element antenna array

Table 1: Antenna dimensions

Dimensions	Values by (mm)
Lp	3.89
Wp	4.938
Lf70	2.4
Wf70	0.3
Lf50	2.3
Wf50	0.87
L100	14.4
W100	0.426

III. Results and discussion

Figure 4 shows the response of the antenna at the desired frequency 24 GHz, obtaining S11 with a value equivalent to -35dB. Figure 5 shows the antenna radiation pattern in 3D.

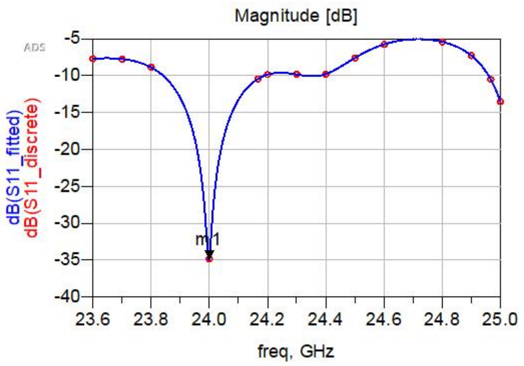

Figure 4: Reflection coefficient S11

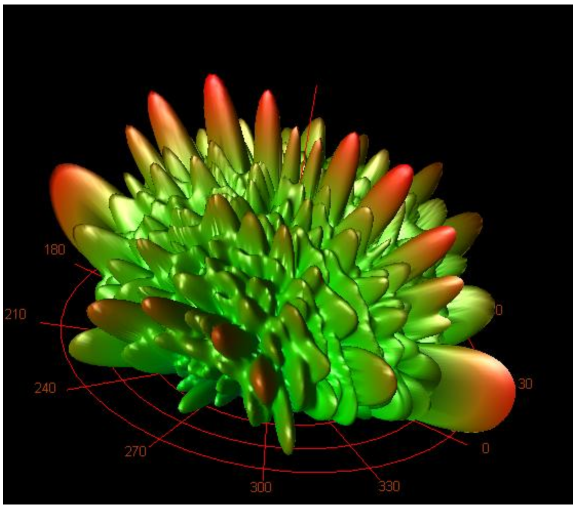

Figure 5 : Radiation diagram

After modelling this 64-element identical patch antenna array using ADS. In order to validate our results, we used another method of calculation using the CST MW tool. The general structure is shown in Figure 6.

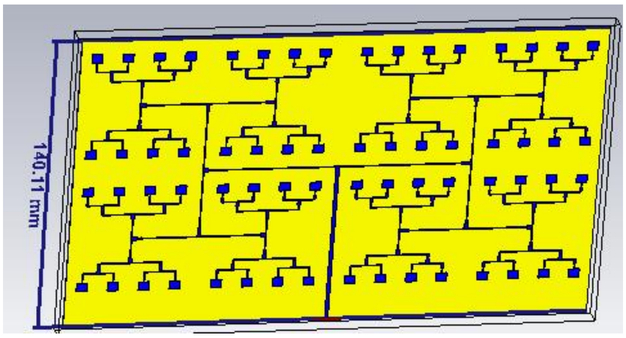

Figure 6: Structure via CST Microwave Studio

Following simulation of the reflection coefficient (Figure 7), we can deduce that the antenna array has been matched to the desired frequency, even if a different calculation method has been used.

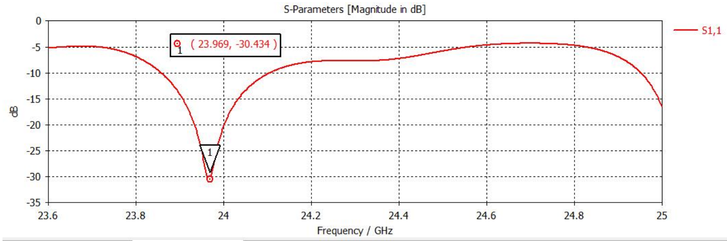

Figure 7: Reflection coefficient S11

The gain and directivity of the antenna array are depicted in Figure 8, indicating values of 21.64 dBi and 23.68 dBi, respectively, at the center frequency of 24 GHz. These results highlight the high gain and directivity achieved by the proposed antenna, crucial for RADAR and satellite applications. Therefore, this antenna array offers superior performance

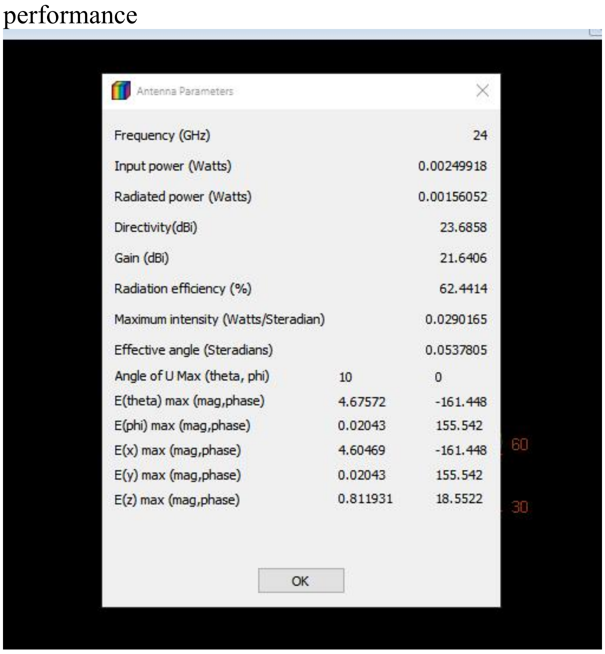

Figure 8: Antenna array performance

Figure 9 shows a comparison between the reflection coefficients obtained by the two tools, CST and ADS, and shows that they are almost in agreement.

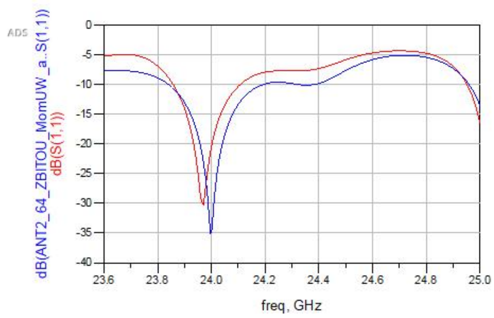

Figure 9: Comparison of Reflection coefficients results using two software programs CST and ADS.

One of the most important things is to simulate the antenna using a different calculation method in order to guarantee the validity of the results. Figure 9 shows the comparison between the antenna results using different calculation methods Ads and CST, as we can clearly see that the results are compatible, and confirm the desired result at the frequency 24 GHz.

IV. Conclusion

This article presents the design of an antenna array for radar applications. More specifically, our study focuses on evaluating the performance of 64-element millimetre-wave antenna arrays in terms of bandwidth, radiation pattern and gain. The results presented here offer valuable insights and may inspire the development of innovative millimetre-wave antenna structures suitable for radar applications, thus contributing to the advancement of radar technology.

REFERENCES:

[1] C.A. Balanis, Antenna theory analysis and design, 2nd ed., Wiley, New York, 1997.

[2] Liton Chandra Paul, Md. Ibnul Hasan ; Design of High Gain Microstrip Array Antenna and Beam Steering for X Band RADAR Application ; 978-1-7281-9331-1/20/$31.00 ©2020 IEEE.

[3] Anim, K.; Danuor, P.; Park, S.-O.; Jung, Y.-B. High-Efficiency Broadband Planar Array Antenna With Suspended Microstrip Slab for X-Band SAR Onboard Small Satellites. Sensors 2022, 22, 252. https://doi.org/10.3390/s22010252

[4] Soheil Yasini, Karim Mohammadpour-Aghdam, and Mahmoud Mohammad-Taheri, "Low-Cost Comb-Line-Fed Microstrip Antenna Arrays with Low Sidelobe Level for 77 GHz Automotive Radar Applications," Progress In Electromagnetics Research M, Vol. 94, 179-187, 2020. doi:10.2528/PIERM19110205

[5] Metzler, T. Microstrip series array. IEEE Trans. Antennas Propag. 1981, 29, 174–178. [CrossRef]

[6] K. Tekkouk, M. Ettorre, R. Sauleau and M. Casaletti, "Folded Rotman lens multibeam antenna in SIW technology at 24 GHz,"

6th European Conference on Antenna and Propagation, Prague, Czech, 26-30 Mar. 2012, pp. 2308-2310.

[7] Slomian, P. Kaminski, J. Sorocki, I. Piekaiz, K. Wincza and S. Gruszczynski, "Multi-beam and multi-range antenna array for 24 GHz radar applications," *20th International Conference on Microwave, Radar, and Wireless Communication*, Gdansk, Poland, 16-18 Jun. 2014, pp. 1-4

[8] R. Conti, J. Toth, and T. Dowling, and J. Weiss, "The wire-grid microstrip antenna," *IEEE Trans. Antennas Propagat.*, vol 29,pp. 157-166, Jan. 1981.

[9] K. D. Palmer and J. H. Cloete, "Synthesis of the microstrip wire grid array," *10th International Conference on Antennas and Propagation,* London, UK., 14-17 Apr. 1997, pp. 114-118.

[10] Y. P. Zhang, M. Sun, D. Liu, and Y. L. Lu, "Dual grid array antennas in a thin-profile package for flip-chip interconnection to highly-integrated 60-GHz radio," *IEEE Trans. Antennas and Propagat.*, vol. 59, no. 4, pp. 1191-1199, 2011.