Eight-Element Microstrip Series Feed Antennas with Air Vias For 5G Applications

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Abstract: - This study presents the design and fabrication of a novel series feed array antenna structure consisting of eight elements, each integrated with 0.5mm air vias and separated by 0.9mm distances. The research investigates the impact of air vias on millimeter wave 5G applications, utilizing Roger 5880 substrate (εr = 2.2, loss tangent = 0.0009, thickness = 0.508mm) for resonance within the 26-28 GHz range. The inclusion of air vias demonstrates a reduction in interference, evidenced by changes in current density, surface current distribution, and VSWR. The antennas, configured with 20 x 60 mm substrates and λ/2 element spacing, exhibit improved return loss (32 dB to 38 dB) and closer alignment with desired VSWR values upon integrating air vias. The study also reveals heightened surface current and density at the radiating element edges due to the vias' dielectric properties. Computational simulations utilizing CST studio validate the structural designs.

Key-Words: - CST, Millimetre wave,5G, series feed antenna, Array antenna, Air vias. Automotive Radar.

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1 Introduction

An array antenna with air vias in the millimeter wave communication system, especially in 5G applications, is very efficient. This integration is crucial in high-speed data transmission and increasing the system capacity, [1]. Generally, fifth-generation devices operate with 24GHz frequency and above. These antennas meet desirable requirements for fulfilling fifth-generation systems. Array antennas consist of a group arranged differently depending on the suitable shape to generate one beam and attached to the beamformer circuit to steer it, [2]. Different array structures, such as antenna gain evaluation, beamforming capabilities, and spatial resolution, can achieve various benefits. These advantages prove instrumental in addressing the challenges associated with 5G mm-wave systems, particularly in achieving high data rates and minimizing signal attenuation. In the context of array antenna design, air visas play an acritical role. These apertures (air vias) within the antenna structure facilitate the propagation of electromagnetic waves by enabling the passage of electromagnetic wave energy. By incorporating air vias, the array antenna minimizes signal losses and maximizes overall performance, [3].

The array antennas and air vias in 5G mm-wave systems effectively enhance the path loss and signal attenuation encountered when operating in the mm-Wave frequency range. It is essential Due to the susceptibility problem of short mm-wave wavelengths to atmospheric absorption and obstruction caused by environmental objects, [4], [5]. Integrating series feed array antennas with air vias combat these challenges by enabling highly efficient beamforming and enhancing the antenna gain, compensating for signal losses. The precise arrangement of the air vias at the radiation element's edges is designed to optimize the radiation patterns and the directivity. Phased arrays and beamforming algorithms are advanced techniques for achieving electronic beam steering and allowing the signal to seek specific users or coverage areas, [6].

In conclusion, the integration of the array antennas and air vias assumes a critical significance within 5G mm-wave systems, facilitating the realization of high-rate data, efficient network capacity, and signal coverage. By effectively contending with the concerns inherent to mm-wave signal propagation and investigating the current density, surface current distribution, and voltage standing wave ratio (VSWR), these antenna configurations conduce to the elevated efficiency and dependability of the overarching 5G communication infrastructure.

2 Series Feed Antennas Design

The design process began with a regular microstrip patch antenna, which had specific dimensions for the width (wp) and length (Lp) as in Equations (1-5). However, it was found that this initial design needed more bandwidth and gain. A series feed was developed by adding more elements to the antenna. These additional elements were placed at a separation distance of half a wavelength (lambda) between each element. This modification was made to improve the antenna's performance in terms of bandwidth and gain, [7].

$$wp = \frac{c}{2fo^2\sqrt{\frac{(\varepsilon r+1)}{2}}} \quad (1)$$

$$Leff = \frac{c}{2fo^2\sqrt{\varepsilon reff}} \quad (2)$$

$$\varepsilon reff = \frac{\varepsilon r+1}{2} + \frac{\varepsilon r-1}{2}\left[1+12\frac{h}{wp}\right]^{-\frac{1}{2}} \quad (3)$$

$$\Delta L = 0.412h\frac{(\varepsilon reff+0.3)\left(\frac{wp}{h}+0.264\right)}{(\varepsilon reff-0.258)\left(\frac{wp}{h}+0.8\right)} \quad (4)$$

$$Lp = Leff - 2\Delta L \quad (5)$$

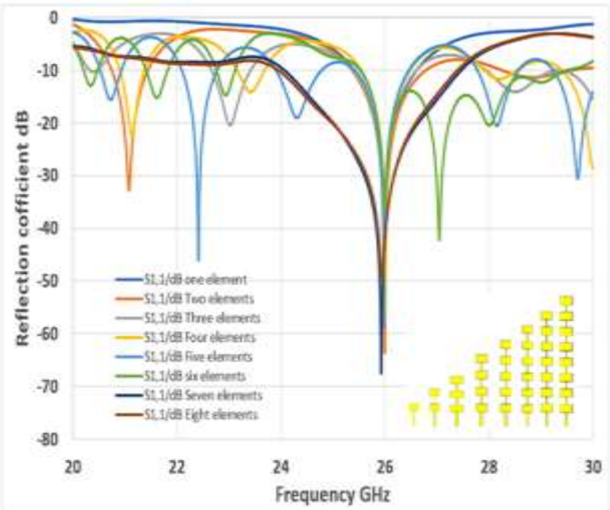
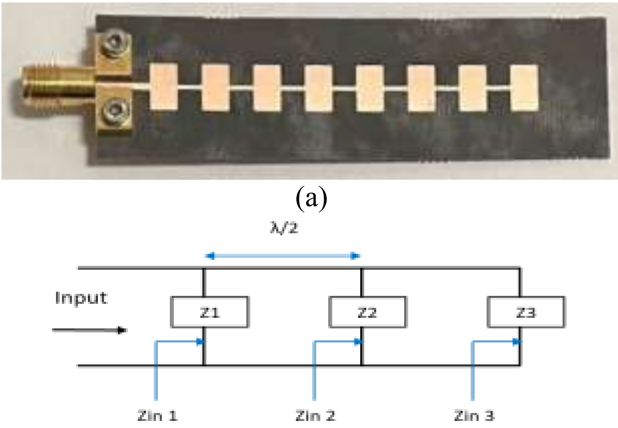


Fig. 1: Reflection coefficient (S11) of one to eight series feed array antenna

Series feed array antennas are a type of antenna where each element is connected in series with the same feed to form a sequential chain in Figure 1. This configuration is commonly used in various applications such as wireless communication systems and radar systems, [8]. The theory behind the series feed array antennas involves the understanding of radiation patterns, spacing between the elements, and impedance matching. Designing the series feed array antennas involves many steps starting with single elements and calculations of suitable dimensions to determine crucial parameters, [9], [10], [11]. Figure 2(a), (b) shows the fabricated eight elements series feed array antenna without SIW, and general equivalent circuit respectively. The spacing between adjacent antenna elements within the array can be determined using Equation (6).



(a)

(b)

Fig. 2: (a) Fabricated microstrip Series feed antenna resonating at 26-28GHz (b) Equivalent circuit

$$S = \frac{\lambda}{2\,x\sin(\theta)} \quad (6)$$

Where S is the space between elements, θ denotes the desired beam steering angle and λ represent the wavelength at 26GHz. The characteristic impedance of the feed network can be computed utilizing the ensuing Equation (7)

$$Zo = \sqrt{Zin * Zout} \quad (7)$$

where (Zin) denotes the input impedance of each antenna element, (Zout) represents the output impedance of the preceding element or the feed network. To ensure equitable power is distributed among the eight elements, the power division factor is calculated by employing Equation (8).

$$Power\ Division\ Factor = \sqrt{\frac{1}{N}} \quad (8)$$

Where N shows the total number of antenna elements in the array, eight elements in this work, phase shifters can accomplish beam steering or beamforming within a series feed array. The requisite phase shift can be determined through Equation (9)

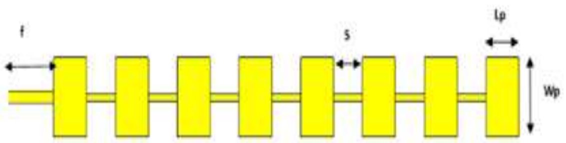
$$Phase\ Shift = 2\,\pi\,x\,dx\frac{\sin(\theta)}{\lambda} \quad (9)$$

Where d clarifies the element's distance from the reference element, θ denotes the desired beam steering angle, and λ represents the wavelength of the operating frequency.

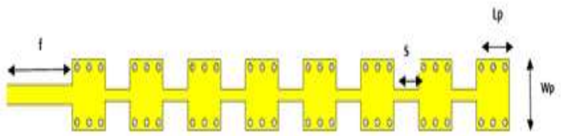
The previous equations serve as an initial foundation for series feed antenna design. However, it is essential to acknowledge that the design process can include another additional complexity, necessitating considerations such as impedance matching, radiation pattern synthesis, and mutual coupling between radiating elements.

3 Series Feed Antennas with Air Vias

Integrating series feed array antennas with air vias necessitates a comprehensive consideration of their impact on various aspects such as radiation pattern, crosstalk, impedance, and bandwidth, [12], [13]. The existence of air vias can introduce impedance variations, which can affect the efficiency of the antenna system and lead to signal reflections. Furthermore, the small distances between these vias to radiating elements can significantly change the radiation pattern lobes, potentially resulting in beam squint, sidelobe distortion, or reduced gain, [14]. In addition, the coupling between adjacent elements can give rise to crosstalk, reducing the isolation and degradation of antenna performance. It is important to acknowledge that air vias also impose limitations on the bandwidth of the array antenna system due to impedance variations and coupling effects, [15].



(a)



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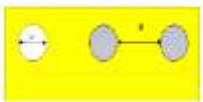

(c)

Fig. 3: (a) Series feed antennas without air vias (b) with air vias (c) close look of air vias

Designing air vias with antennas involves considering their placement, dimensions, and impact on the antenna's performance. When integrating air vias with antennas, it is essential to consider their location, as shown in Figure 3 (a), (b), (c). Vias should be positioned away from the antenna's radiating elements to minimize potential interference. Placing vias in the ground plane or near the edges of the PCB can help maintain the antenna's radiation pattern and minimize coupling [16]. Moreover, the dimensions of the air vias are crucial to minimize their impact on the antenna's performance. These dimensions as in Table 1 show that a smaller diameter helps reduce the impact on the RF current flow. Generally, vias with diameters around 0.3-0.4 times the wavelength of the highest frequency of interest are recommended.

Table 1. The dimensions of the Series Feed Antennas design structure. (All dimensions are in mm units)

Dimensions	Value(mm)	Explanations
W	4.60	Substrate width
L	3.45	Substrate length
Wp	4.60	Patch antenna width
Lp	3.45	Patch antenna length
S	2.60	Distance between antenna elements
f	7.48	The First feed of series feed antennas
V	0.5	Air vias diameter
P	0.9	Space between air vias
λ	7.49	Wavelength at (27GHz)
εr	2.2	Dielectric constant
h	0.508	Substrate thickness

4 Results and Discussions

The proposed structural configuration has been emulated utilizing CST software, with performance evaluation conducted by assessing various parameters, including return loss, gain, bandwidth, radiation pattern, and current density. Figure 5 (a), (b) visually represents the physically realized eight-element front and back structures, with a 5-cent coin included for scale comparison. Concurrently, Figure 6 (a), (b) illustrates the reflection coefficient and compares the simulated and fabricated outcomes, elucidating the bandwidth characteristics. In contrast, the effect of air vias on series feed antennas was studied before fabrication. Table 2 illustrates the improvements in parameters for series feed array antennas following the addition of air vias. Figure 4 shows how gain increased until the peak and dropped by adding more elements. By

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adding the air vias at the eight elements, the gain has enhanced again at the eight elements. These enhancements are significant and contribute to the overall performance of the antennas. The air visa improves the Reflection coefficient S11, increasing the bandwidth, surface current, and current density. These improvements are achieved by minimizing the surface wave losses and optimizing the radiation efficiency.

Table 2. Series feed antennas with and without an air vias at (26GHz)

Antennas parameters	No vias	With Vias
Reflection coefficient/ dB	22	35
Bandwidth dB	4.58	4.97
Surface current A/m	98.2	112
Current density A/m^2	67.5	71.4

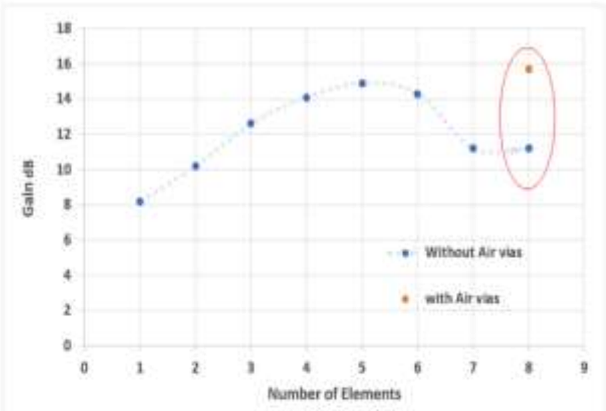
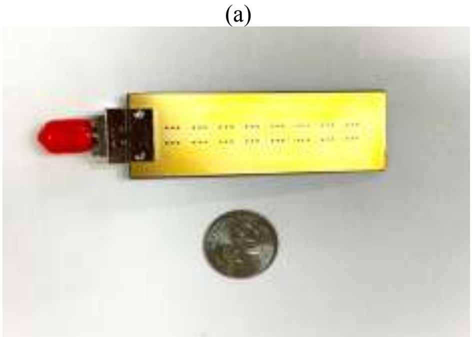


Fig. 4: Gain in dB for (1 to 8) elements and the eight series feed antennas with Air vias

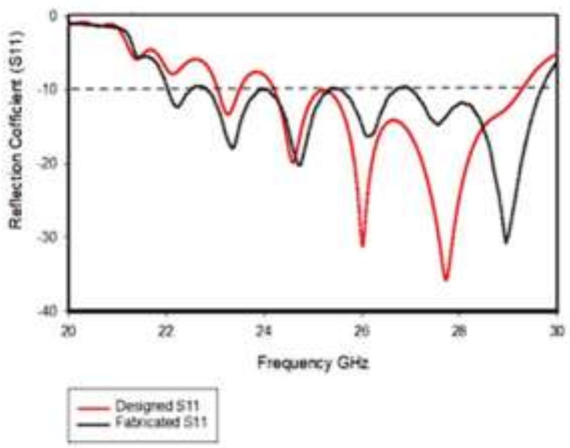
Through rigorous analysis, it is evident that the results obtained from the fabricated structure closely align with the initially designed parameters. Specifically, the reflection coefficient S11 registers at approximately 30 dB for the fabricated structure, whereas it reaches approximately 35 dB for the designed structure. Moreover, the bandwidth examination reveals a value of approximately 3.9 dB, with some marginal shifts in frequency coverage, while both configurations effectively encompass the desired frequency range of 26/28 GHz.

(a)

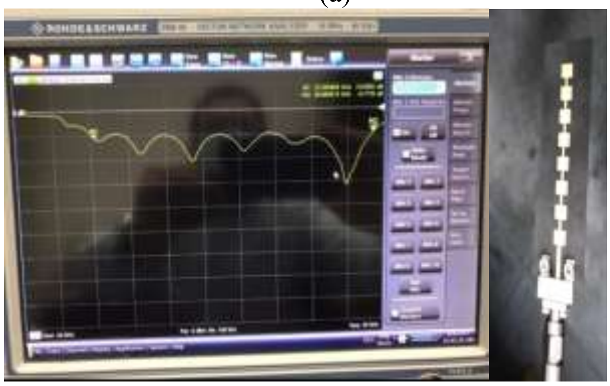


(b)

Fig. 5: Eight elements' Series feed array antennas (a) Front (b) Back



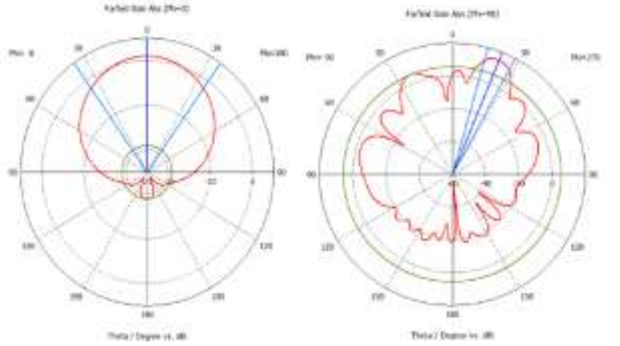
(a)



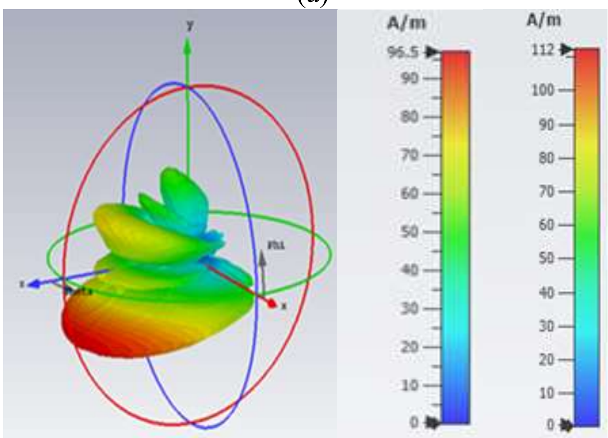
(b)

Fig. 6: (a) Reflection coefficient of fabricated Series Feed Antennas with and without air vias (b) VNA used to measure the performance of the antenna

Figure 7 (a), (b) depicts the ultimate proposed structure's 2D and 3D radiation pattern with surface current. This assessment was carried out at a frequency of 26 GHz, with varying Phi (Φ) values set at 0 degrees and 90 degrees. The radiation pattern offers valuable insights into the directional characteristics and intensity distribution of the electromagnetic waves emanating from the structure.



(a)



(b)

Fig. 7: (a) 2D radiation Phi=0 and 90 at 26GHz (b) 3D radiation pattern with surface current

Figure 7 (b) shows that 0.5mm air vias exerts 0.9 mm distance separation within antennas, exerts a discernible impact on surface currents, and gives 112 A/M at 26GHz and 96.5 A/M at 28GHz. Thus, engendering noteworthy alterations in radiation patterns, impedance characteristics, and interference phenomena. Their presence facilitates the precise modulation of electromagnetic fields, thereby enabling the refinement of beamforming capabilities and the mitigation of undesired radiation. Appropriately engineered costless 0.5mm air vias substantively augment antenna performance by endowing it with the capacity to be finely tuned to optimize wireless communication parameters. As in Table 3, this structure has been compared with up-to-date references to prove this procedure's benefits.

Table 3. The performance of a final structure with a comparison with other references

	Ref			
Variable	This work	(14)	(15)	(16)
Frequency /GHz	26/28	28	76.5	79
Return Loss/(dB)	>-34	>-15	>-35	>-35
Bandwidth (dB)	3.9	1.3	3	4.75
Gain /(dB)	14.7/15.7	10.2	13	13.38
SLL /(dB)	-9.2/-7.6	-15	-18	-14

5 Conclusion

In conclusion, the series-fed array antennas exhibit significant parameter enhancements, featuring 0.5mm diameter air vias and a 0.9mm inter-via separation distance. At the specific frequencies of 26GHz and 28GHz, these antennas manifest notable gains of 14.7 dB and 15.7 dB, respectively. Furthermore, their bandwidth is estimated to be approximately 4.58 dB before attaching the air vias and it became close to 4.97 dB, and they demonstrate a substantial reflection coefficient of approximately -34 dB. These outcomes underscore the commendable performance of these antennas in terms of both gain and bandwidth. It is essential to mention that our design has been successfully fabricated and has achieved results almost similar to those of the originally designed work. Moreover, it is crucial to highlight that this work has a comparative analysis with other high-impact published works in the field. This assessment indicates that this series-fed array antennas with the air vias design achieve competitive results when juxtaposed with existing research. This comparison underscores the innovation and efficacy of the proposed design, further solidifying its position as a noteworthy contribution to the realm of high-frequency communication systems and wireless technologies. In the future, this structure has the potential to be expanded to achieve (8x8) array antennas. This expansion would allow it to meet the Massive MIMO requirements that require a minimum of 64 radiating elements.

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Conflict of Interest

The authors have no conflicts of interest to declare.