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Near-field multiple input multiple output: single vs. folded dipole antennas on Rogers and FR4 substrates

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ABSTRACT

In this paper, a 2×2 near-field multiple input multiple output (NFMIMO) wireless links are studied taking single and folded dipole antennas as examples. The study has carried out an investigation on the impact of substrates (FR4 and Rogers RT/Duriod 5880) and effect of incorporating decoupling and matching network (DMN) on the impedance matching and mutual coupling in NFMIMO cases. Dipole array with FR4 has proved useful since it has shown improvement in return loss and good decrease in the mutual coupling between adjacent ports. On the other hand, folded dipole antennas with FR4 and Rogers RT/Duriod 5880 substrates have shown marginal improvement in impedance matching and port isolation. This study highlights the fact that mutual coupling in near-field and antenna geometry have strong influence on the system performance in comparison with the dielectric substrate materials. This is in contrast to the far-field behaviour where low-loss Rogers give better performance.

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1. INTRODUCTION

There is increased demand for versatile antenna systems due to the advancements in wireless communication technologies. Multiple input multiple output (MIMO) technology is an integral part of recent wireless communication due to its ability to enhance data rates, signal reliability and spectral efficiency. Researchers have delved deep into the far-field MIMO configurations very well. Near-field MIMO (NFMIMO) is being researched nowadays due to its applications in contactless power transfer, RFID and many near-field communication (NFC) applications [1], [2]. However, NFMIMO design comes with many challenges such as mutual coupling, impedance matching and complex electrical behaviour of the substrate material.

Various techniques have been proposed in the literature to overcome the above-mentioned challenges. Few of the noteworthy techniques include introduction of decoupling structures, modification of antenna geometries. These techniques have been proven suitable for miniaturised MIMO configurations [1], [2]. Couple of front runners in this field are dipole and folded dipole antennas due to their simple geometry and suitable radiation behaviour, especially in portable communication systems [3]. One important factor that influences the performance is the selection of the substrate. Few of the popular choices are Rogers which offers increased bandwidth and radiation efficiency [4] and FR4 which is cost effective and available in abundance [5]–[8].

Few works on NFMIMO have focused on optimising the geometry of antenna, decreasing mutual coupling and selection of suitable substrate to improve the performance. NFMIMO array systems are in demand due to the emergence of NFC applications in which reduction of the mutual coupling can significantly enhance isolation and radiation properties [9]–[12]. The main motivation for this work is that few researchers have carried out comparative studies on NFMIMO array configurations with single and folded dipoles using both FR4 and Rogers's substrates.

A comparative analysis of antenna performance considering various substrate materials is important for deciding cost and efficiency in real NFMIMO networks. Rogers RT/Duriod and FR4 have their own advantages and disadvantages. A thorough evaluation of these materials with comparative study provides a design trade-off for different NFC applications. It is convenient to experiment on simple or basic antenna configurations such as simple dipoles and folded dipoles [13]–[15].

Low profile, efficient and adaptable to different substrates - single and folded dipole antennas are suitable for NFMIMO networks. Single dipole is suitable for low-cost design with moderate performance. Folded dipole comes with good impedance matching, enhanced bandwidth and decreased mutual coupling [1], [2]. Both single dipole and folded dipoles exhibit good near-field patterns. These antennas are compatible with Rogers and FR4 substrates for high-performance. Hence, both single dipole and folded dipoles are suitable for mm wave NFMIMO applications especially in IoT applications.

In this work, performance analysis of 2×2 NFMIMO antenna array with single dipole and folded dipoles is carried on key parameters mutual coupling, impedance bandwidth and near-field distribution. To suit chip-to-chip communication in printed circuit board layouts mm wave frequency of 30 GHz is selected. This is in line with near-field operation [16]–[19]. To decrease mutual coupling and improve power transfer a decoupling and matching network (DMN) is incorporated with inductor-capacitor (LC)-circuits. A systematic comparative study is performed to weigh the impact of DMN incorporation [20]–[29]. The objective of this study is to come up with design guidelines for NFC applications.

The rest of the paper is arranged as follows: in section 2, the antenna design considerations are discussed. In section 3, the simulation results with the help of S-parameters and near-field distribution are shown. In section 4, a detailed discussion on the results is given. In section 5, summary of the findings is presented with future work.

2. METHOD

The approach used to evaluate and compare the performance of NFMIMO wireless networks using single dipole and folded dipole antennas with Rogers RT/Duroid 5880 and FR4 substrates is outlined. The methodology consists of antenna design, simulation setup, S-parameter analysis with and without DMN and near-field intensity distributions of single dipole and folded dipole antennas.

2.1. Antenna design methodology

The design of the single-element dipole antenna was carried out at a target resonance frequency of 30 GHz. The dipole was designed as a half-wavelength radiator on a dielectric substrate with a relative permittivity (ϵ_r) of 4.6. The effective wavelength (λ_{eff}) within the dielectric medium is expressed as in (1).

$$\lambda_{eff} = \frac{c}{f\sqrt{\epsilon_{eff}}} \tag{1}$$

Where c is the velocity of light 3×10^8 m/s, f is called the resonance frequency, and ϵ_{eff} is known as the effective dielectric constant given by (2).

$$\epsilon_{eff} = \frac{\epsilon_r+1}{2} \tag{2}$$

The length of the dipole is given by (3).

$$L_d = \frac{\lambda_{eff}}{2} \tag{3}$$

The dipole length is calculated to be $L_d = 4.54$ mm after substituting $f = 30\ GHz$ and $\epsilon_r = 4.6$. The radius of the dipole is selected as $r = \lambda/100$ to have conduction losses low and radiation resistance sufficiently high. The total arm length of the folded dipole was taken same as that of the single dipole. The spacing between the conductors is kept as 0.2 mm to get good impedance matching and enhanced bandwidth. Altair Feko was used for full-wave simulations using the method of moments (MoM) method. The antennas were placed on two

dielectric substrates Rogers RT/Duroid 5880 ($\epsilon_r = 2.2, tan\ \delta = 0.0009$) and FR4 ($\varepsilon_r = 4.6, tan\ \delta = 0.02$) to evaluate the influence of substrate parameters on antenna performance.

Antenna was excited with 50 Ω at the feed gap. To suppress back scattering, the radiation boundary was pushed beyond $\lambda/4$. Triangular surface mesh was used with maximum edge length of $\lambda/30$ to make sure numerical stability and dependable convergence. The continuous frequency range was selected between 24 GHz to 36 GHz with an interval of 0.2 GHz.

Mutual coupling S_{12} and impedance bandwidth ($|S_{11}|$≤-10 dB) and near-field distribution were the performance parameters used for the comparative study. Collectively, these factors determined the suitability of the proposed antennas for NFMIMO operation. The comparative assessment between Rogers and FR4 substrates further highlighted the trade-off between enhanced performance and implementation cost in compact mm wave MIMO systems.

3. SIMULATION RESULTS

Near-field simulations are carried out for three different antenna configurations, such as single dipole, folded dipole with FR4 substrate, and folded dipole with Roger RT/Duriod 5880 substrate. The aim of this study is to carry out a comparative analysis of the three different antenna configurations and conclude on the suitability of the same for the milli-metric applications in NFMIMO applications.

3.1. Single dipole

The resonance of the single-element dipole is checked. Frequency of 30 GHz, length = 4.54231 mm, dielectric constant = 4.6, dipole radius = λ/100, and frequency range of 24 GHz to 36 GHz is selected. The designed antenna is as shown in Figure 1.

Figure 2 shows that a resonance is observed at 29.9593 GHz with a S11 of -15.9308 dB. The single-dipole antenna configuration may be extended to develop a 2×2 NFMIMO antenna. The antenna resonates at a frequency determined by its length, typically half of the operating wavelength (λ/2). This enables efficient radiation and reception at the intended frequency. The single dipole produces an omnidirectional radiation pattern in the horizontal plane (perpendicular to its axis), making it suitable for applications requiring broad coverage.

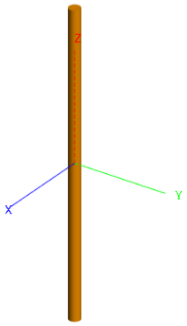


Figure 1. Geometry of the single-dipole antenna

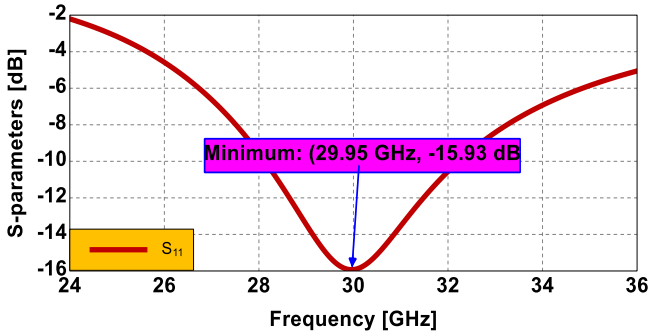


Figure 2. Single antenna resonance of the single dipole antenna

3.2. 2×2 NFMIMO with single dipole antenna

The designed antenna geometry is shown in Figure 3. The geometric specifications used in the simulation work are shown in Table 1. The geometric specifications used in the design of the 2×2 NFMIMO based on a single dipole antenna are shown in Table 2. The DMN for the 2×2 NFMIMO based on a single dipole is shown in Figure 4. The designed values of the DMN used in the 2×2 NFMIMO based on the single dipole antenna are shown in Table 3. The simulation results of the 2×2 NFMIMO based on the single dipole antenna without DMN are shown in Figure 5. The simulation results of the 2×2 NFMIMO based on the single dipole antenna with DMN are shown in Figure 6. A comparison of the S-parameters obtained from the simulation results is shown in Table 4.

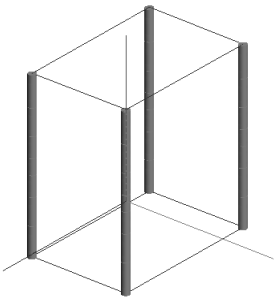


Figure 3. Geometry of single dipole-based 2×2 NFMIMO array

Table 1. Geometric specifications of the printed folded dipole antenna

Specification of geometry	Value with SI unit
Frequency ($\boldsymbol{f}$)	30 GHz
Effective wavelength ($\boldsymbol{\lambda_{eff}}$)	0.645 cm
Effective permittivity ($\boldsymbol{\epsilon_{eff}}$)	2.4
Gap size at the port	0.00716 cm
Length of the folded element ($\boldsymbol{L}$)	0.358 cm
Substrate permittivity ($\boldsymbol{\epsilon_{sub}}$)	3.8
Distance between the outer edges of the folded arms	0.08 cm
Substrate length	0.358 cm
Substrate thickness	0.00999 cm
Substrate width	0.161 cm
Width of the antenna trace	0.0112 cm
Wire radius	0.0005 cm

Table 2. Geometric specifications of the 2×2 NFMIMO antenna

Specification of the geometry	Value with SI unit
Frequency ($\boldsymbol{f}$)	30 GHz
Wavelength ($\boldsymbol{\lambda}$)	1 cm
Length of the dipole ($\boldsymbol{L}$)	$\lambda/_{2.2}$
Inter-element spacing ($\boldsymbol{D}$)	0.373 λ
Intra-element spacing ($\boldsymbol{d}$)	0.25 λ
Radius of the dipole ($\boldsymbol{r}$)	$\lambda/_{100}$
Number of elements at the transmitter and receiver	2
Mesh radius	$L/_{11}$

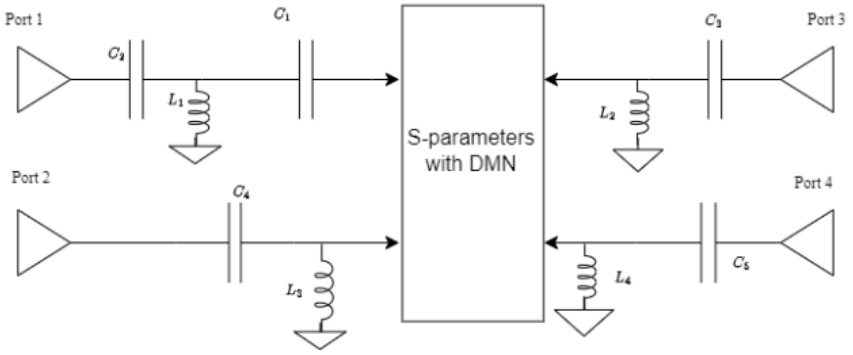


Figure 4. DMN for the 2×2 NFMIMO based on single dipole

Table 3. Designed values of the DMN for 2×2 NFMIMO using dipoles

Capacitance (pF)	Inductance (nH)
C1 = 97.3	L1 = 0.441
C2 = 0.169	L2 = 0.543
C3 = 0.0257	L3 = 0.388
C4 = 0.0665	L4 = 0.382
C5 = 0.0662	-

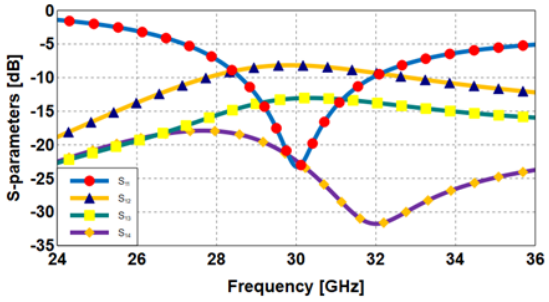


Figure 5. Dipole-based 2×2 NFMIMO array results without DMN

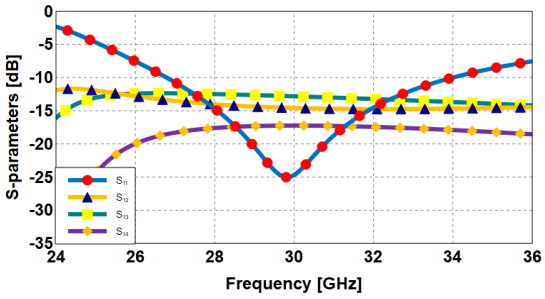


Figure 6. Dipole-based 2×2 NFMIMO array results with DMN

Table 4. Comparison of S-parameters for 2×2 NFWMIMO using dipoles with and without DMN

S-parameter (S_{12})	S_{ij} without DMN in dB	S_{ij} with DMN in dB
S_{11}	-23.3	-24.7
S_{12}	-8.17	-14.6
S_{13}	-13.1	-12.8
S_{14}	-22.4	-17.2

3.3. Folded dipole antenna with FR4 as substrate

The resonance of the single-element folded dipole antenna with FR4 substrate is checked. Frequency of 30 GHz, length = 2.01 mm, dielectric constant = 4.6, substrate thickness = 1.52 mm, loss tangent = 0.02, spacing between the folded dipoles = $\lambda_{eff}/4$ and frequency range of 24 GHz to 36 GHz is selected. The designed antenna is as shown in Figure 7. The folded dipole antenna is a popular variation of the standard dipole antenna, offering specific advantages in terms of impedance, bandwidth, and flexibility in design. The folded dipole consists of two parallel conductive elements connected at their ends, resembling a ladder. Figure 8 shows that a resonance is observed at 30.1546 GHz with a S_{11} of -21.7786 dB. The single-folded dipole antenna with FR4 substrate configuration may be extended to develop a 2×2 NFMIMO antenna.

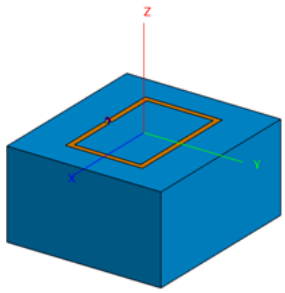


Figure 7. Single-folded dipole antenna with FR4 substrate

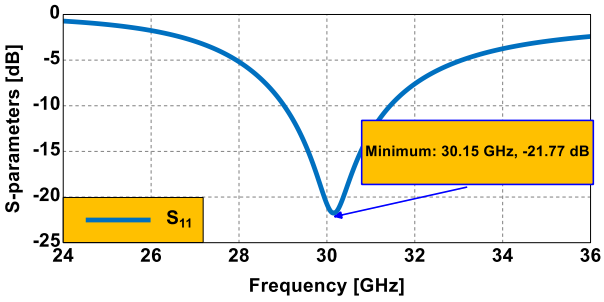


Figure 8. Single antenna resonance of the folded dipole antenna with FR4 substrate

3.4. 2×2 NFMIMO with folded dipole antenna on FR4 substrate

A vertical-oriented folded dipole antenna with FR4 substrate is constructed, and a 2×2 MIMO configuration is set up in the near-field as shown in Figure 9. Vertical orientation of the antenna elements is considered to improve the power coupling between the transmitter antennas and receiver antennas. The antenna elements at the transmitter and the receiver are separated with an inter-element spacing of 2 mm. The intra-element spacing between the adjacent antennas, either transmitter or receiver antennas, is kept at 0.79 mm. The close spacing between the antenna elements is maintained to meet the near-field conditions. Simulation is carried out for the designed 2×2 NFMIMO folded dipole with FR4 substrate. The simulation results without DMN is in Figure 10. The S-parameters of the obtained simulation results shows that S_{11} of -11 dB, S_{12} of -24.7 dB, S_{13} of -5.4 dB, and S_{14} of -22.2 dB is observed at 30 GHz.

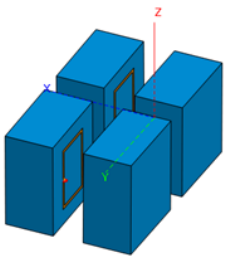


Figure 9. 2×2 vertical-oriented folded dipole FR4 substrate array

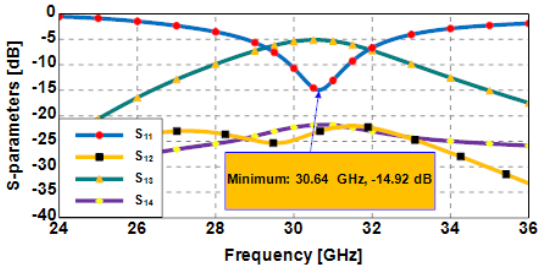


Figure 10. S-parameters of folded dipole with FR4 2×2 NFMIMO without DMN

A DMN based on the LC components is designed and incorporated at all ports in the antenna array. Two capacitors of 100 pF each and an inductor of 100 nH are connected in parallel combination at all ports of the antenna array network. The simulation results of the S-parameters with the DMN network is shown in Figure 11. The S-parameters of the obtained simulation results show that an S_{11} of -10.63 dB, S_{12} of -24.88 dB, S_{13} of -5.458 dB, and S_{14} of -21.7 dB is observed at 30 GHz. The introduction of the DMN clearly indicates the improvement in the power transfer and port isolation between the transmitter and the receiver antennas.

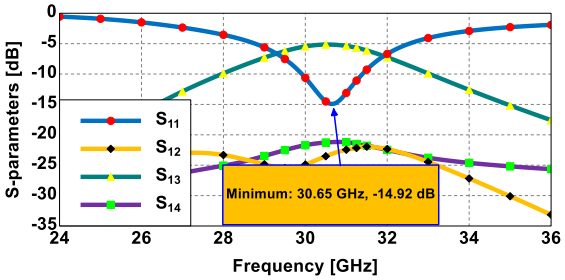


Figure 11. S-parameters of folded dipole with FR4 2X2 NFMIMO with DMN

3.5. Rogers RT/Duroid 5880

Single antenna resonance: the resonance of the single-element folded dipole antenna with Rogers RT/Duroid 5880 substrate is checked. Frequency = 30 GHz, length = 2.0179 mm, dielectric constant = 2.2, substrate thickness = 1.58 mm, loss tangent = 0.0009, spacing between the folded dipoles = $\lambda_{eff}/2.2$ and frequency range of 24 GHz to 36 GHz is selected. The designed antenna is as shown in Figure 12. The performance of an antenna array heavily depends on the individual elements. A non-resonant antenna in the array can lead to poor radiation efficiency, impedance mismatch, and reduced overall gain. Ensuring that single antennas are resonant and well-matched helps mitigate unexpected mutual coupling effects when antennas are placed in close proximity within an array. Figure 13 shows that a resonance is observed at 30.513 GHz with a S_{11} of -22.115 dB. The single-folded dipole antenna with Rogers RT/Duroid 5880 substrate configuration may be extended to develop a 2×2 NFMIMO antenna.

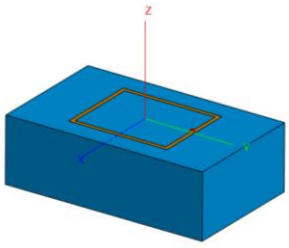


Figure 12. Geometry of single folded dipole with Rogers RT/Duroid 5880 substrate

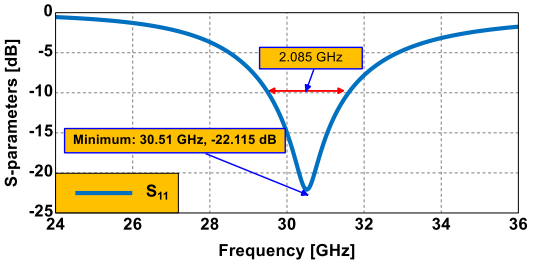


Figure 13. Single antenna resonance of the folded dipole antenna with Rogers RT/Duroid substrate

3.6. NFMIMO antenna without DMN

A vertical-oriented folded dipole antenna with Rogers RT/Duroid 5880 substrate is constructed, and a 2×2 MIMO configuration is set up in the near-field as shown in Figure 14. Vertical orientation of the antenna elements is considered to improve the power coupling between the transmitter antennas and receiver antennas [22]. The antenna elements at the transmitter and the receiver is separated with an inter-element spacing of 1 mm. The intra-element spacing between the adjacent antennas, either transmitter or receiver antennas, is kept at 0.9531 mm. The close spacing between the antenna elements is maintained to meet the near-field conditions. Simulation is carried out for the designed 2×2 NFMIMO folded dipole with Rogers RT/Duroid 5880 substrate. The simulation results without DMN is shown in Figure 15. The S-parameters of the obtained simulation results show that an S_{11} of -14.1 dB, S_{12} of -13.7 dB, S_{13} of -21.9 dB, and S_{14} of -5.11 dB is observed at 30 GHz.

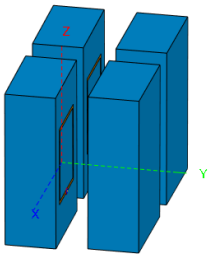


Figure 14. 2×2 vertical-oriented folded dipole Rogers RT/Duriod 5880 substrate array

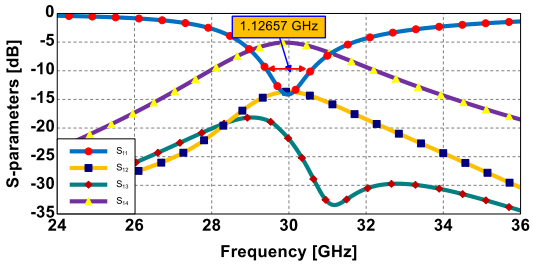


Figure 15. S-parameters of folded dipole with Rogers RT/Duriod 5880 substrate 2×2 NFMIMO without DMN

3.7. NFMIMO antenna with DMN

A DMN based on the LC components is designed and incorporated at all ports in the antenna array. Two capacitors of 100 pF each and an inductor of 100 nH are connected in parallel combination at all ports of the antenna array network. The simulation results of the S-parameters with the DMN network is shown in Figure 16. The S-parameters of the obtained simulation results show that an S_{11} of -14.1 dB, S_{12} of -13.7 dB, S_{13} of -21.9 dB, and S_{14} of -5.11 dB is observed at 30 GHz.

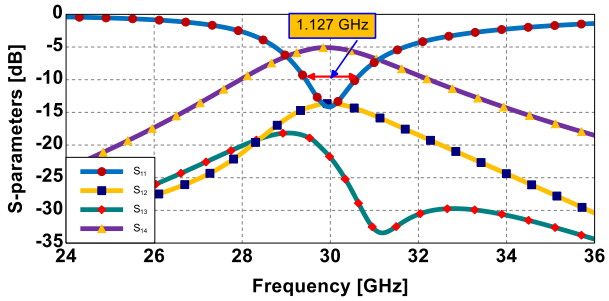


Figure 16. S-parameters of folded dipole with Rogers RT/Duriod 5880 substrate 2×2 NFMIMO with DMN

3.8. Radiation gain analysis

To further characterize the far-field performance of the designed antenna arrays, the realized gain patterns were extracted from the full-wave FEKO simulations for both FR4 and Rogers RT/Duroid 5880 substrates [23]. Figure 17 shows the gain of the single dipole array on FR4 substrate, while Figure 18 depicts the gain for the folded dipole array on Rogers. The FR4-based dipole array achieves a peak realized gain of approximately 5.1 dBi, demonstrating a more directive radiation pattern in the broadside direction. In contrast, the folded dipole on Rogers's substrate exhibits a slightly lower gain of about 4.5 dBi, consistent with its more distributed near-field intensity. This comparative gain analysis supports the conclusion that in NFMIMO scenarios, the antenna geometry has a greater impact on system performance than the substrate choice, reinforcing earlier findings from the S-parameter and field distribution results [24]–[27].

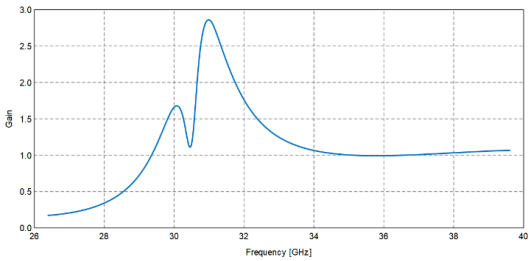


Figure 17. Realized gain of single dipole array on FR4 substrate

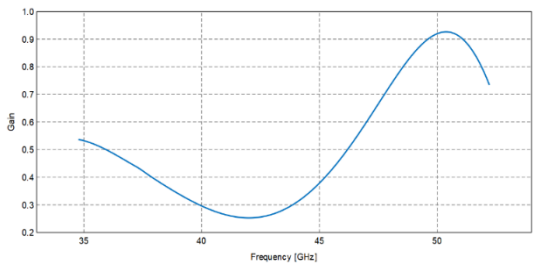


Figure 18. Realized gain of folded dipole array on Rogers substrate

A graph comparing the near-field intensity distributions of single dipole and folded dipole antennas is shown in Figure 19. The folded dipole antenna exhibits a more focused intensity distribution due to its geometry, while the single dipole has a broader distribution [28], [29].

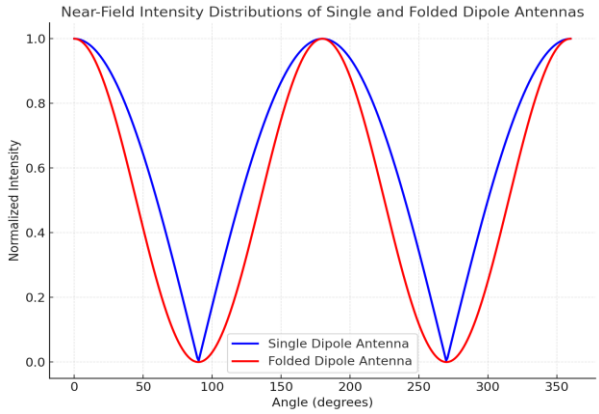


Figure 19. Graph comparing near-field intensity distributions of single dipole and folded dipole antennas

4. RESULTS AND DISCUSSION

4.1. Comparative analysis of DMN performance

The incorporation of the DMN has proven to be effective in the following aspects in case of a dipole based 2×2 NFMIMO with FR4 as the substrate. The S11 dip from -23.3 dB to -24.7 dB indicates improvement in impedance matching for better power transfer. A sharp dip in S12 from -8.17 dB to -14.6 dB indicates good port isolation or reduced mutual coupling. An increase in S13 from -13.1 dB to -12.8 dB indicates better power coupling between port1 of transmitter to port3 of the receiver. Similarly, an increase in S14 from -22.4 dB to -17.2 dB indicates improved power coupling between port1 of transmitter to port4 of the receiver.

From Figures 10 and 11, it is clear that, for 2×2 NFMIMO based on folded dipole with FR4 substrate S11 has changed from -11 dB to -10.63 dB, S12 from -24.7 dB to -24.88 dB, S13 from -5.4 dB to -5.458 dB and S14 from -22.2 dB to -21.7 dB. These results show not so great improvement in the S-parameters after the incorporation of the DMN in the case of folded dipole NFMIMO with FR4 as the substrate. From Figures 15 and 16, it is clear that, for 2×2 NFMIMO based on folded dipole with Rogers RT/Duriod 5880 substrate, S11 has changed from -14.1 dB to -14.15 dB, S12 from -13.7 dB to -13.65 dB, S13 from -21.9 dB to -21.83 dB and S14 from -5.11 dB to -5.107 dB. These results show not so great improvement in the S-parameters after the incorporation of the DMN in the case of folded dipole NFMIMO with Rogers RT/Duriod 5880 substrate. The comparison of all the results clearly indicates that for NFMIMO communication link, the dipole with FR4 substrate does significantly well compared to the folded dipole version with FR4 and folded dipole version with Rogers RT/Duriod 5880 substrate.

4.2. Comparative analysis with existing works

Several recent studies have investigated the influence of substrate materials on antenna performance, consistently reporting that Rogers-based laminates outperform FR4 due to their lower dielectric

loss tangent and stable permittivity. Tütüncü and Kösem [9] demonstrated that Rogers RT/Duroid substrates provide higher isolation and lower mutual coupling than FR4 in MIMO antenna arrays, while Phang *et al.* [8] and Liu *et al.* [22] observed enhanced impedance matching and radiation efficiency in Rogers-based patch and CPW-fed antennas. However, these studies are primarily limited to far-field MIMO systems, and the impact of substrate materials in NFMIMO scenarios has not been comprehensively explored.

In the present work, three antenna configurations: (i) dipole-based 2×2 NFMIMO on FR4, (ii) folded dipole-based 2×2 NFMIMO on FR4, and (iii) folded dipole-based 2×2 NFMIMO on Rogers RT/Duroid 5880 were evaluated before and after the integration of a DMN. Table 5 suggests that the dipole array fabricated on an FR4 substrate displays the highest performance improvement after introducing the DMN. The return loss (S11) increased from -23.3 dB to -24.7 dB, and the mutual coupling (S12) reduced significantly from -8.17 dB to -14.6 dB. These findings clearly demonstrate better impedance matching and strong isolation between the antenna ports. In comparison, the folded dipole designs on both FR4 and Rogers's substrates showed only slight performance gains after the DMN was incorporated.

It is important to note that this behaviour contrasts with prior far-field investigations, where Rogers's substrates typically outperform FR4 because of their lower dielectric loss characteristics. At 30 GHz in the near-field region, the dipole array on FR4 demonstrated supreme isolation and more advantageous coupling behaviour. This enhancement is likely due to the refined current distribution and the localised confinement of reactive fields within the FR4 substrate. The findings indicate that, in compact NFMIMO arrays, the antenna's geometry plays a more dominant role in determining performance than the choice of substrate. Therefore, with appropriate optimization, low-cost FR4 substrates can achieve the performance typically associated with premium Rogers's materials, making them a viable and economical choice for mm wave near-field systems.

While previous studies [8], [9], [22] established Rogers materials as more efficient in far-field MIMO systems, the current results reveal that at 30 GHz, FR4 dipole arrays achieve improved near-field coupling and isolation. The findings reveal that, in the near-field, suitable geometries and decoupling designs can compensate for FR4's dielectric weaknesses, supporting its use as an economical substrate for high-frequency NFMIMO applications.

Table 5. Comparison of S-parameters before and after DMN incorporation

Antenna configuration	Substrate	S_{11} (dB)	S_{12} (dB)	S_{13} (dB)	S_{14} (dB)	Key observation
Dipole (2×2 NFMIMO)	FR4	−23.3 → −24.7	−8.17→ −14.6	−13.1 → −12.8	−22.4 → −17.2	Significant improvement in matching and isolation; enhanced coupling
Folded dipole (2×2 NFMIMO)	FR4	−11 → −10.63	−24.7→ −24.88	−5.4 → −5.46	−22.2 → −21.7	Minor change; DMN impact negligible
Folded dipole (2×2 NFMIMO)	Rogers RT/Duroid 5880	−14.1 → −14.15	−13.7→ −13.65	−21.9 → −21.83	−5.11 → −5.11	Very small variation; geometry dominates response

5. CONCLUSION

The study compared single and folded dipole antennas in a 2×2 NFMIMO array at 30 GHz, realized on FR4 and Rogers RT/Duroid 5880 materials. The study closely analysed how the DMN contributes to better matching, isolation, and power delivery. Simulations reveal that the FR4-based dipole array experienced the largest performance boost with the DMN, improving S_{11} from −23.3 dB to −24.7 dB and increasing isolation from −8.17 dB to −14.6 dB. In contrast, the folded dipole versions on both materials displayed minimal variation, indicating that the DMN impacts conventional dipoles more strongly.

This outcome deviates from conventional far-field MIMO observations, where Rogers and other low-loss substrates typically outperform alternatives. In near-field operation, geometry and coupling dominate performance more than the substrate's dielectric parameters. Thus, an optimized FR4-based dipole array can match or even outperform designs that rely on higher-grade substrates. The findings emphasize that FR4 provides a practical, economical platform for mm-wave NFMIMO implementations. The study links far-field substrate performance with near-field coupling behaviour, offering direction for designing upcoming high-frequency MIMO systems.

Further investigation could include building prototypes to confirm the simulations and examine fabrication-related variations. Evaluating larger arrays (e.g., 4×4 or 8×8) may reveal additional details on how array scaling impacts isolation and correlation. Further gains may be achieved by exploring hybrid/anisotropic substrates, meta surface-inspired DMNs, and broadband matching methods. Deploying the improved arrays in real-time testbeds would help evaluate capacity, latency, and diversity in practical scenarios.

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

The data that support the findings of this study are available on request from the corresponding author.

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