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REGULAR ARTICLE

Design and Analysis of Dual Band PIFA Antenna Using Metasurface at 8-10 GHz for High Frequency Sensor Applications

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This article discusses the design and performance of a compact, low-profile Planar Inverted-F Antenna (PIFA) integrated with a meta-surface structure. It operates in the X-band frequency range of 8 to 10 GHz and resonates at 9.75GHz. The antenna design aims at better performance of bandwidth, reflection coefficient, and impedance matching while maintaining a miniaturized structure. One subwavelength unit cell periodic meta-surface has been placed beneath the radiating PIFA which controls the electromagnetic field, conceal surface waves, and improve radiation efficiency. The proposed antenna is built on a normal rectangular dielectric substrate with dimensions 12.5 mm × 12.5 mm and about – 27.8 dB of return loss obtained at 9.6 GHz and also got a VSWR of approximately 1 at the same frequency. CST Studio Suite 2024 is used to model and optimize the antenna and evaluate its performance based on reflection coefficient (S_{11}), voltage standing wave ratio (VSWR), radiation pattern, and gain. The simulation results show that the meta-surface-integrated PIFA gives superior impedance matching and better reflection coefficient compared to a standard PIFA antenna design. This structure is normally suitable for X-band wireless applications like radar systems, satellite communication, and high-frequency sensors, where compactness and high performance are crucial parameters.

Keywords: Antenna, Dual-band, Metasurface, Gain, X-Band frequency, Sensor.

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1. INTRODUCTION

In recent past the Planar Inverted-F Antenna (PIFA) has become one of the most common antenna types for researchers in current wireless communication systems. It has become popular since its compact size, low profile, and good impedance matching properties. PIFA antennas performance is good in situations like, space requirement is limited, for example in mobile devices, satellite communications, and radar systems. Besides these advantages, however, their performances can be limited in terms of bandwidth, gain, and radiation efficiency, clearly with larger frequencies for example the X-band (8-12 GHz). To overcome above challenges, many of the researchers have pioneered integrating metasurfaces. These structures are specially designed and exhibit unique electromagnetic properties. Meta-surfaces can control electromagnetic waves in some new ways, allow improved handling of reflection, refraction, and phase angle distribution. With integration of a PIFA structure, a meta-surface can greatly enhance antenna features, including impedance bandwidth, gain, directivity, and surface wave suppression.

This paper concentrates on designing and analyzing a PIFA antenna that is integrated with a meta-surface, operating at 8-10 GHz. The surface serves as an additional layer to improve radiation efficiency and achieve better impedance matching within the mentioned frequency range. The performance parameters of the antenna – including return loss (S_{11}), VSWR, radiation pattern and gain are analyzed through simulations and optimized through electromagnetic design software CST Studio Suite. The primary and main goal of this study is to recreate a compact, high-performance PIFA antenna that works with efficiency in the X-band. This makes it suitable for applications in radar, satellite communication, and wireless sensor networks. The use of meta-surface technology gives a promising way to get miniaturization without forfeiting antenna execution.

Rajeev Kumar and Surinder Singh [1] proposed a CPW-fed conformal PIFA antenna for implantable IoMT applications. The proposed design used a flexible substrate to keep constant impedance and minimize detuning in wearable situations. This also shown wideband operation and better efficiency, which is required for systems. Layla Wakrim and Khairyah F. Alhadar [2] designed a multiband PIFA antenna with an optimized defected ground structure (DGS) using a Genetic Algorithm. Use of this method shows improvements in impedance matching and required bandwidth. It has shown multi-resonant operation for LTE, Wi-Fi, and 5G communication bands, besides having a compact form. Shawraa Moghnieh, Mohammad Rammal, Rabih Barakeh, and Elias Rachid [3-5] proposed and analyzed the interaction between handset antennas and the human head by using ground plane corrugation. This

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analysis displayed effective SAR reduction and reduced electromagnetic coupling which is the main goal for wearable devices. This work improved user safety with stable gain and impedance. Haoxuan Sheng, Quanyuan Feng, Yankai Ma, and Qiang Sun [6-8] designed a wideband meta-surface antenna with a ceramic dielectric overlay for in-band full-duplex systems. The proposed meta-surface increased port isolation, bandwidth, and impedance stability. It has also shown strong potential for integration in high-performance X-band antenna applications.

In this study the design of the Planar Inverted-F Antenna (PIFA) starts by first giving the target operating frequency range of 8 GHz to 10 GHz, which corresponds to the X-band. Its basic operating assumption revolves around quarter-wavelength resonance, where the effective electrical length of the radiating patch is about one-fourth of the wavelength at the desired frequency.

1.1 Antenna Design Configuration

Fig. 1 shows the basic PIF antenna is designed on a rectangular dielectric substrate with measurement values of 12.5 mm × 12.5 mm. This design makes it a good fit for compact, high-frequency systems. The radiating patch, shown in yellow, has a multi-fold (meandered) configuration which can improve the current path length in a small area, which will allow the resonance at the desired frequency while maintaining the antenna size compact. The meandered patch structure creates multiple folded paths as the name suggests, that extend the effective electrical length. This structure diminishes the resonating frequency and improves impedance matching within the 8-10 GHz range. The wideband performance can be achieved using the stepped or nested layout.

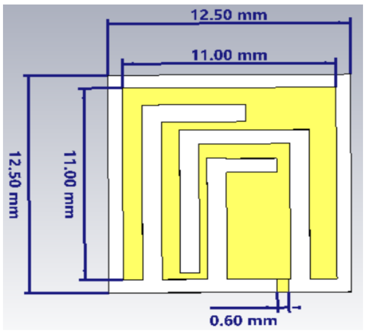

Fig. 1 – Geometric configuration of the proposed antenna design

In the lower part of the patch, there is a feed line which is microstrip line and a shorting strip. The feed point activates the antenna by giving power, while the shorting pin or strip links the radiating element to the ground. This is nothing but the inverted-F configuration, which ensures the antenna remains compact and can show better matching properties. The periodic meandered shape also acts as a meta-surface, controlling how electromagnetic waves move and reducing surface waves. This unique feature increases the antenna's radiation efficiency, directivity, and gain. The meta-surface effect leads to good electromagnetic field uniformity and a controlled phase distribution across the patch. The antenna is made on a low-loss dielectric substrate, typically FR-4 ($\varepsilon_r = 4.4$, tan $\delta = 0.02$). The thickness of the substrate is optimized at 1.6 mm to balance compactness, bandwidth, and mechanical strength.

1.2 Implementation of Slots

The slots, displayed in the designed structure, are carefully etched on the radiating patch to lengthen the current path without increasing the antenna's overall size. This meandered structure lowers the resonant frequency and allows the antenna to resonate within the desired X-band range while keeping a small physical footprint of 12.5 mm × 12.5 mm. The slots shown create compound folded paths that form contracted metallic strips and gaps within the radiating patch. These narrow slots have an advantage of introducing distributed inductance and capacitance, which will maximize the antenna’s impedance matching and radiation efficiency. The inner rectangular bends guide the surface current along a stretched path, resulting in a small and compact yet electrically long structure. The slot width and spacing are around 0.6 mm, are optimized to control electromagnetic coupling between the adjacent arms and adjust the operating frequency.

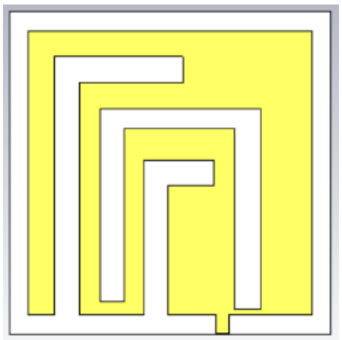

Fig. 2 – Evolution of the proposed antenna design model

The addition of slots also gives better antenna meta-surface properties. The regular and symmetrical arrangement of the meandered slots changes the current distribution and reflection phase. This will suppress surface waves and increase inward radiation. As a result of this the antenna could be able to achieve better gain, larger directivity, and less mutual coupling. The feed line and shorting strip at the lower section of the patch work together with the slots to meet the desired impedance characteristics, reducing reflection loss ($S_{11} < -18$ dB) and also stabilizes radiation pattern. Differing in the number, length, and spacings of the slots, the antenna could be tuned for multi-resonating behavior, providing a broader bandwidth. The proposed slot design also increases current confinement and enhances field uniformity across the patch surface.

1.3 PIFA Integrated with Meta-Surface

The integration of a Planar Inverted-F Antenna (PIFA) and a conducting meta-surface is an effective way to improve the antenna's performance, especially regarding bandwidth, gain, and radiation efficiency. In the present proposed design, the PIFA works with a meta-surface to perform better in the 8-10 GHz X-band range.

When the PIFA is activated through its feed, surface currents and electromagnetic waves interact with the conducting meta-surface layer. This interaction leads to change the reflection phase and redistributes the surface currents. Obviously, this arrangement leads to improved impedance matching and reduced surface wave propagation. The meta-surface works as an artificial magnetic conductor (AMC) or high-impedance surface (HIS), reflecting waves in sync with the radiating patch, which strengthens the forward radiation.

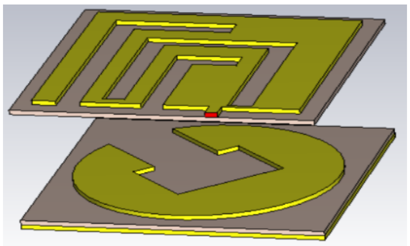

Fig. 3 – Integration of PIFA and metasurface

The integration of the Planar Inverted-F Antenna (PIFA) with a metasurface, as shown in the CST Studio Suite model Fig. 3, is designed to enhance antenna performance in the 8-10 GHz frequency range. Above configuration, the upper layer consists of a compact meandered PIFA structure, while the down layer is a metasurface composed of a circular split or C-shaped pattern. The metasurface, placed just below the antenna, serves as an artificial electromagnetic layer which can control the reflection phase of the radiated waves and suppresses surface wave propagation. The close coupling between the PIFA and metasurface layers allows efficient electromagnetic interaction, which enhances the impedance matching and overall antenna performance. Thus, the integrated PIFA–metasurface design offers a low-profile, high-gain, and broadband solution suitable for X-band applications such as radar, satellite communication, and high-speed wireless systems.

Table 1 – Dimensions of the proposed antenna

Parameters	Values(mm)
Ls	12.5
Ws	12.5
Ts	0.254
Lp	11
Wp	11
Tp	0.254
Radius (*R*)	5.5
Lr	5
Wr	3.5
Feed	0.60

Table 1 shows the Planar Inverted-F Antenna (PIFA) dimensions which were in mm as shown. The antenna is built on a dielectric substrate that is 0.254 mm thick and has dimensions of 12.5 × 12.5 mm. The radiating patch has a length of 11 mm, a width of 11 mm, and a thickness of 0.254 mm, which is about a quarter-wavelength at the center frequency of 9 GHz. The shorting post has a radius of 5.5 mm and connects the patch to the ground plane. A rectangular slot of dimensions 5 mm in length and 3.5 mm in width is added to the patch to adjust the resonance and raise the bandwidth. The antenna is fed using a microstrip line, with a feed offset of 0.6 mm. This ensures a good impedance match to any 50 Ω source device.

2. RESULTS AND DISCUSSION

The proposed Planar Inverted-F Antenna (PIFA), designed for operation in the 8 to 10 GHz frequency range, was simulated and analyzed using CST Studio Suite. The simulation results show that the antenna works well, with good impedance matching, stable radiation characteristics. The S_{11} (reflection coefficient) plot reveals a clear resonance at around 9.6 GHz, with a minimum value of – 32 dB. This indicates efficient impedance matching and minimal reflection at the feed point. The – 10 dB bandwidth of the antenna ranges from about 8.1 GHz to 10.0 GHz. This provides a usable bandwidth of nearly 2.1 GHz, effectively covering the targeted X-band range.

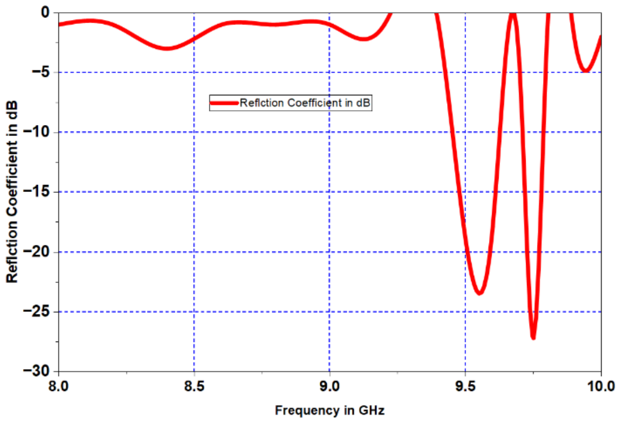

Fig. 4 – Reflection coefficient vs Frequency of PIFA

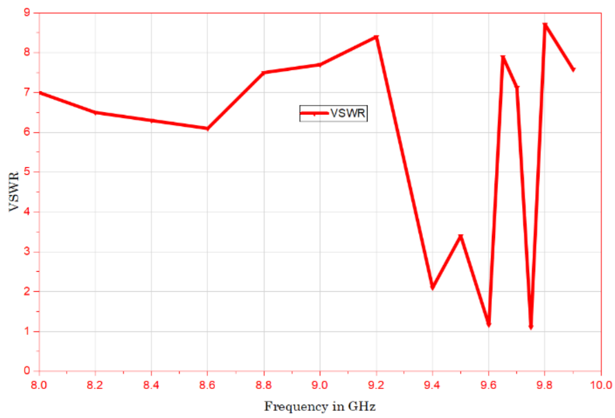

Fig. 5 – VSWR vs Frequency of PIFA

The Voltage Standing Wave Ratio (VSWR) stays near to 1.19 throughout the operational band. From this one can understand good matching characteristics and efficient power transfer from the feed to the radiating antenna element. The simulated radiation pattern shows a stable omnidirectional or broadside radiation characteristic, making it suitable for wireless and radar-type applications. The peak gain of the proposed PIFA antenna is about 4.8 dBi at 9 GHz, and the radiation efficiency exceeds 80 %. This highlights the antenna's ability to effectively radiate most of the input power. Overall, the simulation results agree that the proposed PIFA antenna has a compact design and optimized design parameters. It has achieved wideband operation, satisfied impedance matching, and better radiation characteristics in the 8 to 10 GHz band. This could make it very much suitable for X-band communication systems and sensing applications.

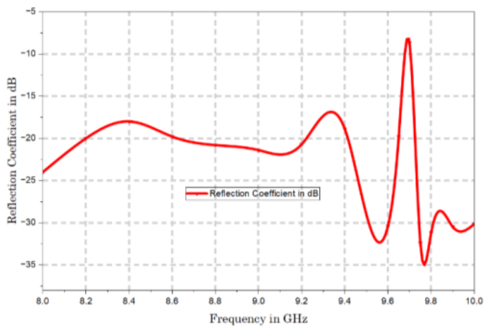

Fig. 6 – Reflection coefficient vs Frequency of PIFA with metasurface

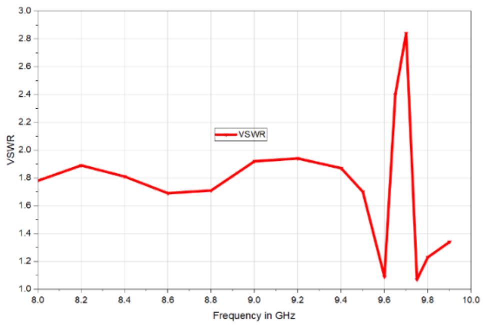

Fig. 7 – VSWR Vs Frequency of PIFA with Meta-surface

The S-parameter (S_{11}) plot of Fig. 6 shows that the integrated antenna has a better resonating response within the target band. The minimum return loss drops below 25 dB around 9 GHz, which confirms better impedance matching between the feed line and the radiating patch structure. The operating bandwidth, defined for $S_{11} < 18$ dB, stretches from about 8.2 GHz to 9.8 GHz. This provides a commendable range of nearly 1.6 GHz, which exceeds that of a customary PIFA. The wider bandwidth comes from the meta-surface's ability to create multiple resonance modes through its periodic structure, allowing it to couple more effectively with the radiating patch.

The VSWR performance in Fig. 7 also delivers good results, staying around 1.1 to 1.3 throughout the resonating band. This indicates strong impedance matching and little reflection loss at the input port. The realized gain of the integrated antenna rises from about 3.8 dB for the conventional PIFA to roughly 6.2 dB after incorporating the meta-surface. This increase in gain comes from the in-phase reflection of radiated waves by the meta-surface, which directs more energy towards the forward radiation direction and reduces back radiation.

In summary, the simulation results show that combining the PIFA with a meta-surface significantly improves overall antenna performance. From this one can see it is easily suitable for X-band applications like radar sensing, satellite communication, and high-speed wireless systems.

3. CONCLUSION

A compact Planar Inverted-F Antenna (PIFA), integrated with a meta-surface, has been successfully designed and analyzed for operation in the 8 to 10 GHz X-band frequency range. Simulation results confirmed that the integrated design achieved a broader bandwidth, better return loss ($S_{11} < -25$ dB), and superior gain compared to a conventional PIFA. These improvements make the antenna highly suitable for radar, satellite communication, and high-speed wireless systems that operate within the X-band. This paper shows the potential of using meta-surface technology in developing normal antenna structures and lays a strong foundation for future research in smaller microwave antenna systems.

REFERENCES

1. R. Kumar, S. Singh, *IEEE Trans. Antennas Propag.* **70** No 2, 231 (2024).
2. L. Wakrim, K.F. Alhadar, *IEEE Antennas Wireless Propag. Lett.* (2024).
3. Shawraa, H. Moghnieh, M. Rammal, R. Barakeh, E. Rachid, *IEEE Antennas Wireless Propag. Lett.* (2024).
4. H. Sheng, Q. Feng, S. Member, Y. Ma, Q. Sun, *IEEE Antennas Wireless Propag. Lett.* **24** No 8, 2232 (2025) https://doi.org/10.1109/LAWP.2025.3559579.
5. B. Cheng, Z. Du, *IEEE Trans. Antennas Propag.* **70** No 2, 1476 (2022) https://doi.org/10.1109/TAP.2021.3111330.
6. S.R. Yang, Q.L. Yang, *IEEE Antennas Wireless Propag. Lett.* **21** No 6, 1075 (2022) https://doi.org/10.1109/LAWP.2022.3155248.
7. S.M. Patil, et al., *IEEE Wireless Antenna and Microwave Symposium (WAMS)* (2022) https://doi.org/10.1109/WAMS54719.2022.9847734.
8. S. Mudda, G. Km, M. Mallikarjun, *Prog. Electromagn. Res. C* **118**, 2541 (2022).

Проєктування та аналіз дводіапазонної антени PIFA з використанням метаповерхні на частоті 8-10 ГГц для застосування високочастотних датчиків

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У статті розглядається конструкція та продуктивність компактної, низькопрофільної планарної інвертованої F-антени (PIFA), інтегрованої з метаповерхневою структурою. Вона працює в діапазоні частот X-діапазону від 8 до 10 ГГц та резонує на частоті 9,75 ГГц. Конструкція антени спрямована на покращення продуктивності пропускної здатності, коефіцієнта відбиття та узгодження імпедансу, зберігаючи при цьому мініатюрну структуру. Одна субхвильова періодична метаповерхня елементарної комірки була розміщена під випромінюючою PIFA, яка контролює електромагнітне поле, маскує поверхневі хвилі та покращує ефективність випромінювання. Запропонована антена побудована на звичайній прямокутній діелектричній підкладці з розмірами 12,5 мм × 12,5 мм та втратами на відбиття приблизно – 27,8 дБ, отриманими на частоті 9,6 ГГц, а також отримала КСХН приблизно 1 на тій самій частоті. CST Studio Suite 2024 використовується для моделювання та оптимізації антени та оцінки її продуктивності на основі коефіцієнта відбиття (S_{11}), коефіцієнта стоячої хвилі за напругою (КСХН), діаграми спрямованості та коефіцієнта посилення. Результати моделювання показують, що PIFA з мета-поверхнею забезпечує чудове узгодження імпедансу та кращий коефіцієнт відбиття порівняно зі стандартною конструкцією антени PIFA. Ця структура зазвичай підходить для бездротових застосувань X-діапазону, таких як радарні системи, супутниковий зв'язок та високочастотні датчики, де компактність та висока продуктивність є вирішальними параметрами.

Ключові слова: Антена, Дводіапазонна, Метаповерхня, Коефіцієнт посилення, Частота X-діапазону, Датчик.