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RECONFIGURABLE TRIPLE-BAND ANTENNA INSPIRED BY METAMATERIALS FOR WIRELESS COMMUNICATIONS

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Abstract

In this study, we introduce a compact antenna inspired by metamaterials that is capable of operating across three bands: fixed microwave communication at 2 GHz, WiMAX at 3.5 GHz, and WLAN at 5.5 GHz. The design for the lower band features an external square metallic loop, enabling the patch to emit similar to a conventional magnetic current loop. The integration of a metamaterial element adjacent to the patch's leads generates additional magnetic current loops in the higher band. This 22.5 x 22.5 mm² metamaterial-based antenna is designed to be compatible with wireless devices. We conducted the design and numerical analysis of this antenna using the HFSS high-frequency structure simulator, which utilizes a finite integral method. The antenna's lumped circuit model was formulated through precise mathematical derivations. Our metamaterial antennas demonstrate triple-band functionality within the ranges of 1.91 GHz – 2.15 GHz, 3.25 GHz – 3.85 GHz, and 5 GHz - 7 GHz, in contrast to the triple-band performance of traditional antennas, which is typically between 0.561 GHz ~ 0.578 GHz, 2.346~2.906 GHz, and 2.91~3.49 GHz. Consequently, LTE and WiMAX applications can benefit from the use of metamaterial antennas. Additionally, the metamaterial antenna showcased gains of 0.15–3.81 dBi and 3.47–3.75 dBi within the frequency bands of 2.67–3.40 GHz and 3.61–3.67 GHz, respectively.

Keywords – Metamaterials, HFSS high-frequency structure simulator ,Triple - Band.

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Introduction

The contemporary surge in the utilization of patch antennas can be attributed to their economical and streamlined design. These antennas are advantageous due to their seamless integration with planar and non-planar circuits within the microwave frequency spectrum. The evolving landscape of wireless communication technology necessitates multiband capabilities from a singular radiating source to enhance device portability. Focused research has been directed towards specific frequency bands, notably 2 GHz for fixed microwave communication, 3.45 GHz for WiMAX, 5.25 GHz/5.8 GHz for WLAN, and 8.25 GHz within ITU Band. A variety of design strategies, such as employing slotted ground planes, slotted radiating elements, parasitic strips, meandered structures, and particularly metamaterials, are utilized to attain multiband functionality. Metamaterials are engineered structures with distinctive properties not naturally occurring, characterized by negative permittivity and permeability, which facilitate innovative antenna designs. This paper introduces a square patch antenna inspired by metamaterials, distinguished by its straightforward architecture, effective radiation patterns, impedance matching, and diminutive size, rendering it ideal for incorporation into contemporary wireless communication apparatus. Simulated on an FR4 substrate, this antenna is anticipated to deliver enhanced performance.

Metamaterial Inspired Antenna Design:

Our proposed antenna design has three stages of evolution. Antenna A, Antenna B and Antenna C are three stages. All three stages are fed with lumpedport feed. Antenna A is a simple square patch designed to operatein 2.45 GHzwhichisaBluetooth band. Our proposed antenna is designed on a low-cost FR4 substrate with 22.5 mm x 22.5 mm x 1.6 mm as its total size. Antenna B is designed by meandering the sides of antenna A andfinally,antenna C isdesignedby including a Complementary omega-shaped metamaterial structure in the radiating element of antenna B and a square-shaped slot. Figure 1, 2 & 3 depicts the threeevolutionstagesofourproposed metamaterial-inspired antenna. Figure 2 clearly shows the parameters of the projected metamaterial-inspired antenna and Table 1 gives the parameter values of our proposed antenna

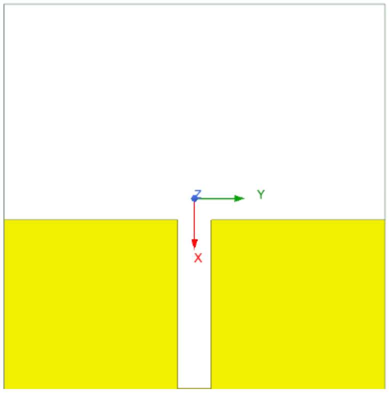


Fig. 1 - Ground

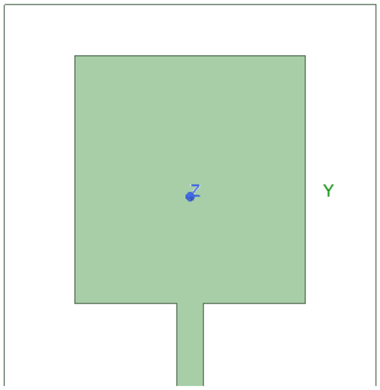


Fig. 2 - Antenna A

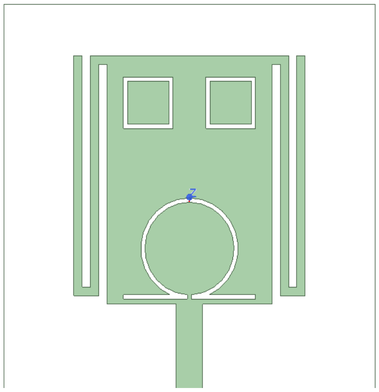


Fig. 3 - Antenna B

Evaluation of our Proposed Antenna

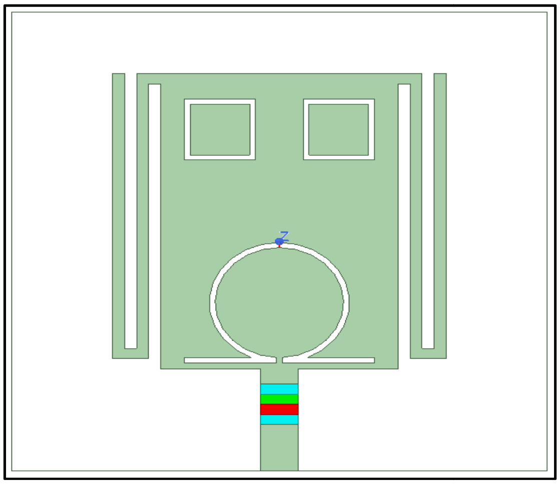


Fig. 4 - Antenna C

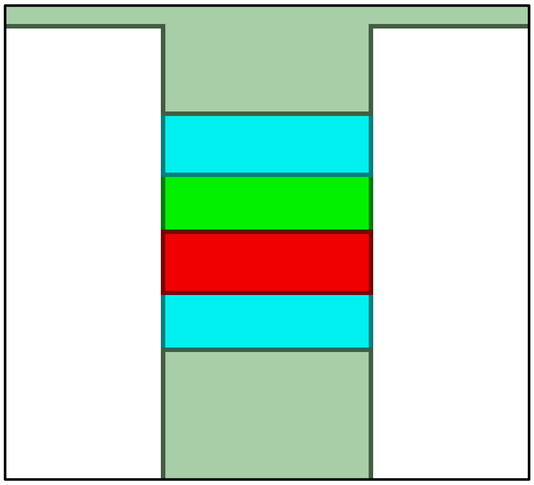


Fig. 5 - Pin Diode In Antenna

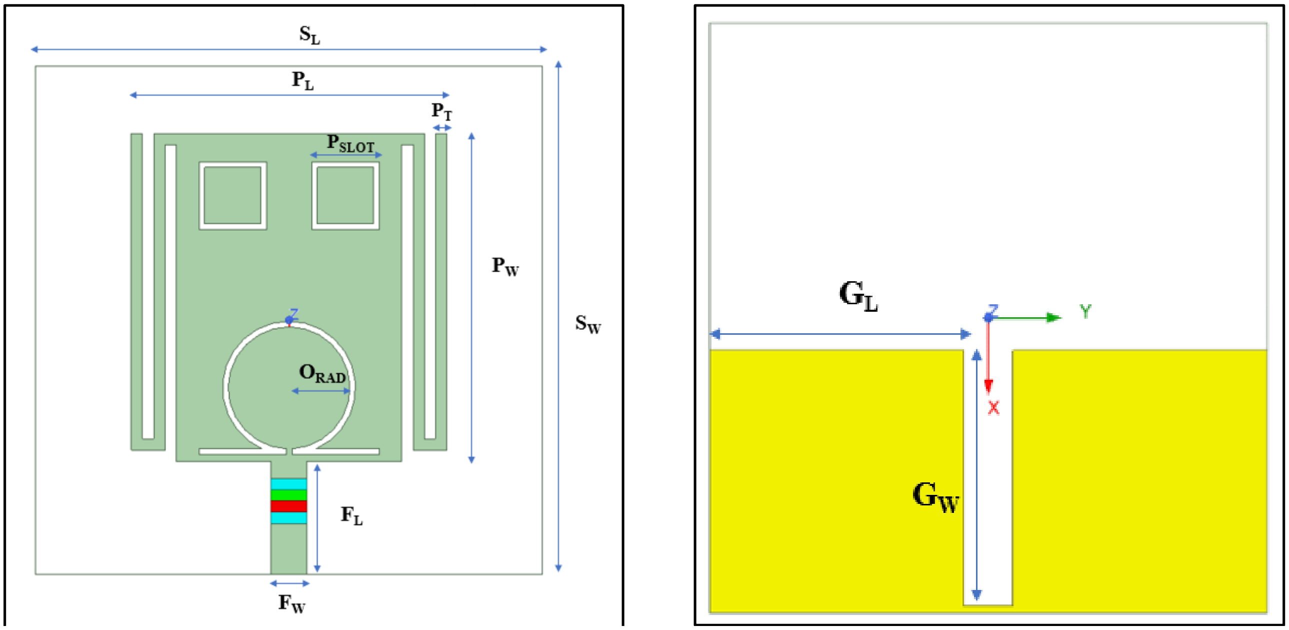


Fig. 6 – Antenna Parameters

S_L	S_W	P_L	P_T	P_W	F_L	F_W	P_{SLOT}	O_{RAD}	G_L	G_W
22.5 mm	22.5 Mm	14 mm	0.5 Mm	14.5 mm	5 mm	1.6 mm	3 mm^2	2.7 mm	10.25 mm	10 Mm

S_l -Length of Substrate
S_w -Width of Substrate
P_l -Length of Patch
P_t -Width of Patch Slot
P_w -Width of Patch
F_l -Length of Feed
F_w - Width of Feed
P_{slot} - Square Slot Area
O_{rad} - Radius of Omega Slot
G_l - Length of Ground
G_w - Width of Ground

PARAMETRIC ANALYSIS

Parametricanalysis is performed to determine the value of the parameters that are essential for the suggested metamaterial-inspired antenna design. The parameters that were selected are the complementary omega slot radius (O_{RAD}), ground height (G_L), and feed width (F_W). The feed width is first set at 1.6 mm. It is discovered that this value of F_W = 1.6 mm provides good impedance matching in all operating bands, so it is selected as the ideal value for feed width and is shown in Figure 6. Next, the ground height is adjusted in increments of 0.25 mm from 10 mm to 10.5 mm. The value of 10.25 mm is selected as the ground height because it exhibits both enhanced impedance bandwidth and acceptable impedance matching, as seen in Figure 9.Next, it is determined that the complementary omega slit width of d = 0.25 mm is the ideal value.Since it can achieve good impedance matching in all working bands, 0.25 mm is selected as the omega slot width. Figure 10 presents all of the aforementioned analyses.Thedesigned antenna A is resonating at the Bluetooth operatingbandfrom 2.15 GHzto

3.21 GHz, whichis depicted in Figure3. The return loss value in the resonant frequency 2.45 GHzis about -17.13 dB.Antenna B is designed by meandering the sides of antenna A to form the strips. The antenna B operates in triple band frequencies 1.91 GHz – 2.15 GHz, 3.25 GHz – 3.85 GHz and 5 GHz -7 GHz which are theoperatingbands of Fixed microwave communication, WiMAX and WLAN application respectively which is depicted in Figure 4. The return loss of the above frequency bands is -11.5 dB, -16.2 dB and -14.8 dB. Antenna C is designed by including the complementary omega-shaped metamaterialintheradiating element where the surface current is maximum. The inclusion of a Complementary omega shaped metamaterial structure improves the impedance matching of the proposed structure in the WLAN band from -14.8 dB to -18.2 dB, which is depicted in Figure 5

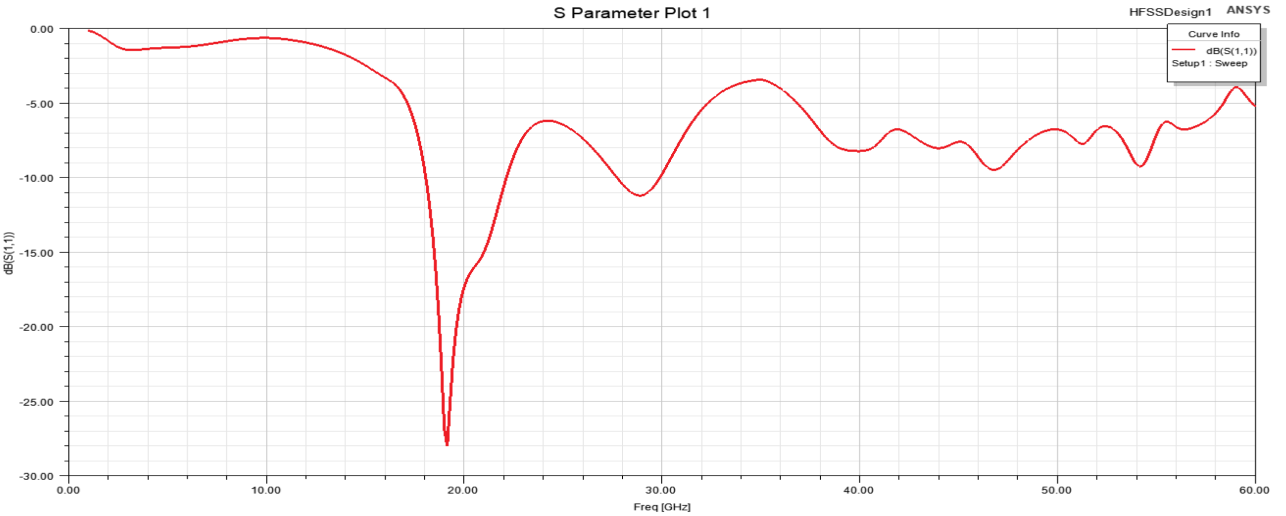


Fig. 7 - S11 Parameter of Antenna A

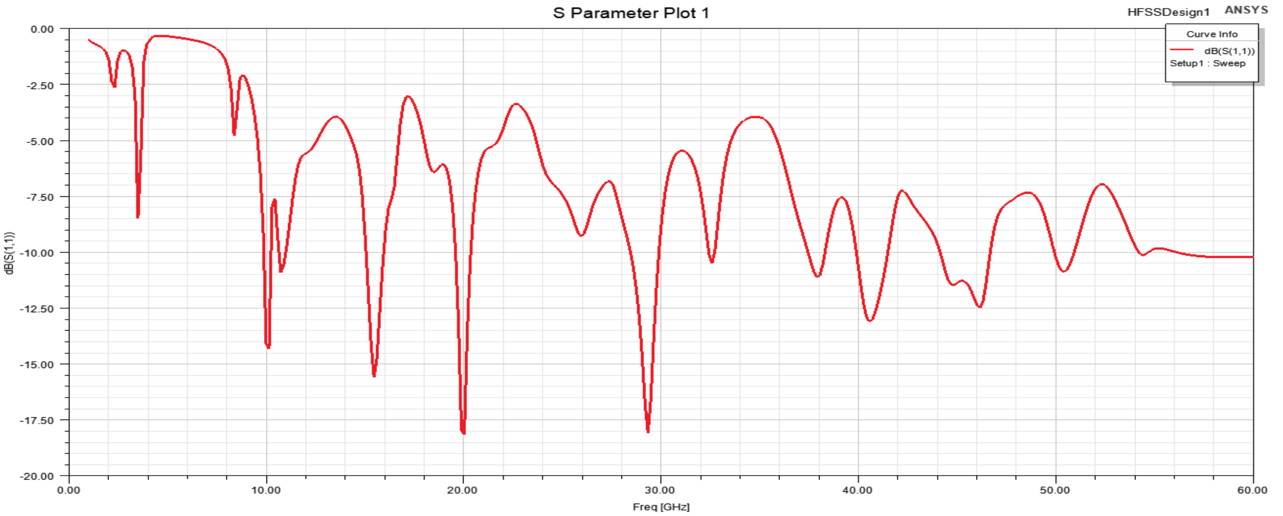


Fig. 8 - S11 PARAMETER OF ANTENNA B

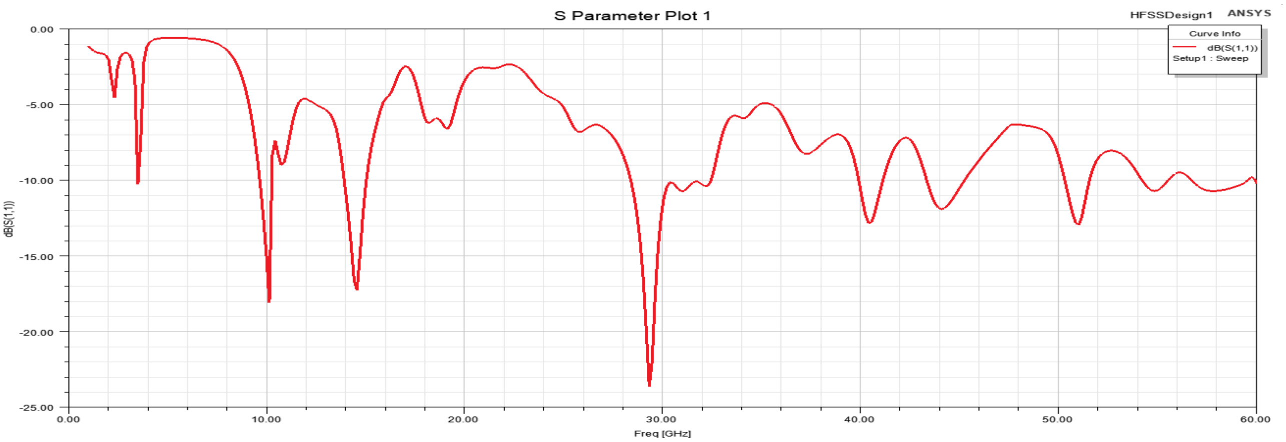


Fig. 9 - S11 Parameter of Antenna C

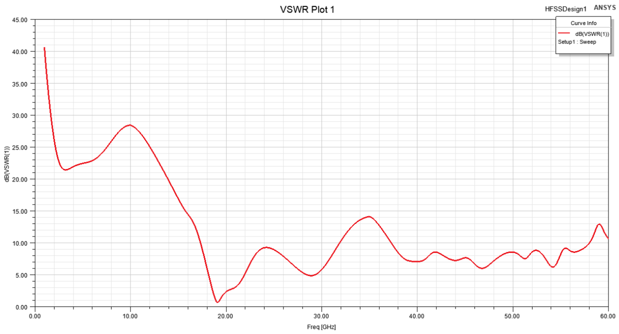


Fig. 10 - VSWR Of Antenna A

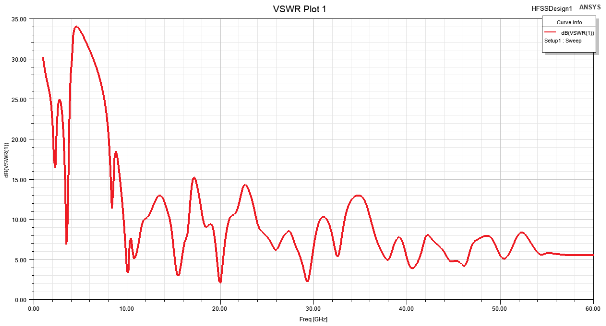


Fig. 11 - VSWR Of Antenna B

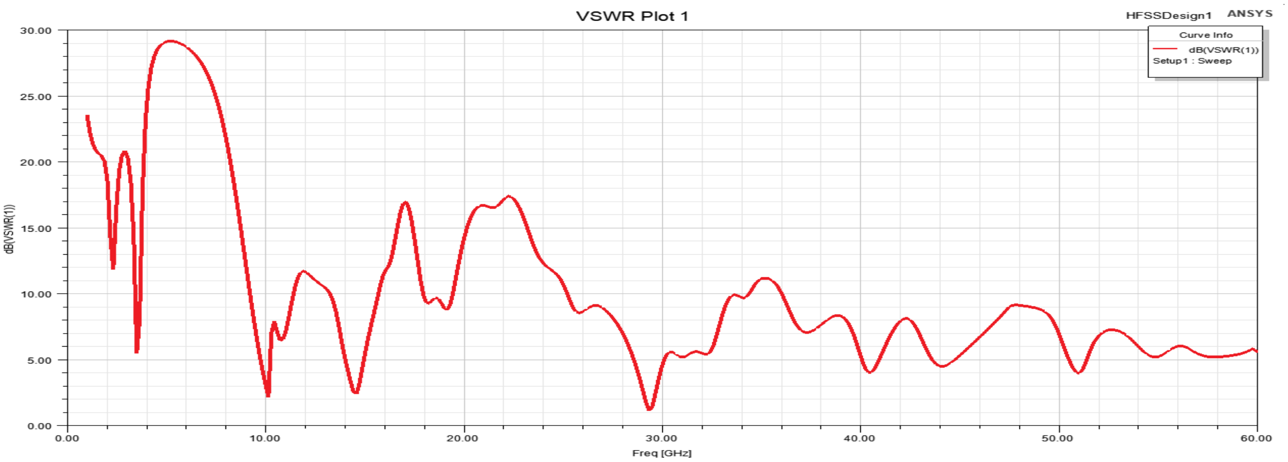
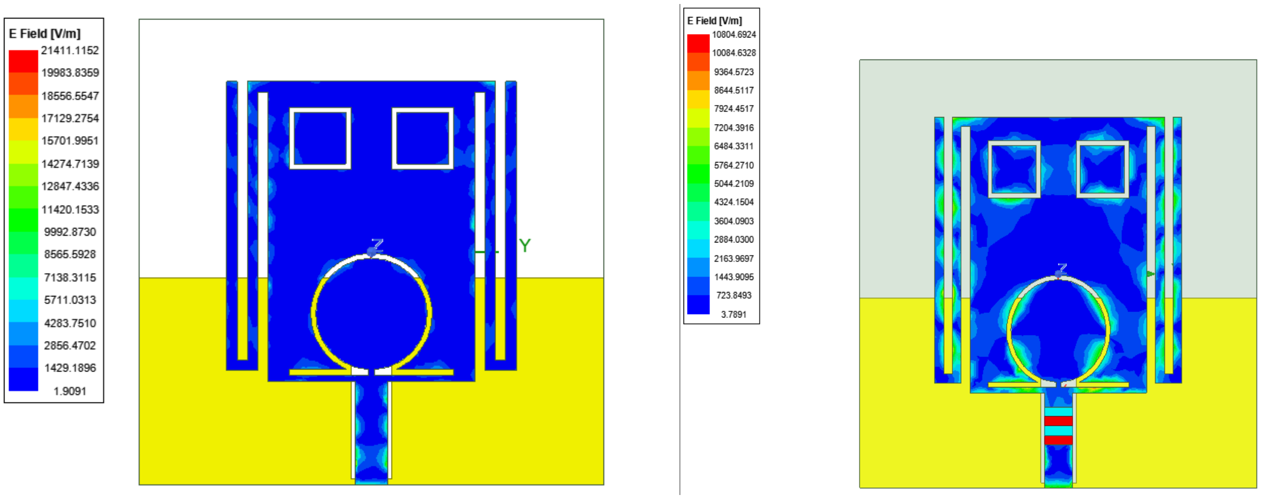


Fig. 12 - VSWR of Proposed Antenna C

In Figure 12, the VSWR plot of the antennas that evolvedduringthedesignprocessofourproposed metamaterial-inspired antenna is depicted, from that we can observe that the value of VSWR is within VSWR =1. From this, we can conclude that our proposed antenna has very good impedance matching. Figure 7 depicts the surfaceE-Fielddistributionwhichclearlyshowsthatthe maximumsurfacecurrentisdistributedaroundthe meanderedstripsand mega-shaped metamaterial. This distribution of surface current which alters the current path is responsible for the multiband characteristics.



E – Field Distribution on Antenna B

E – Field Distribution on Antenna C

Fig. 12 - Surface Electric Field Distribution

RESULTS AND DISCUSSION

Antenna A is a basic square patch that functions in a single Bluetooth band. Antenna B operates in a triple band and features meandering strips on the adjacent side. Antenna C uses an auxiliary omega-shaped metamaterial to improve impedance matching. The surface E-field distribution of the suggested design is depicted in Figure 12, which makes it abundantly evident that the patch's meandering sides, which form the strips, change the current distribution. The present course is further altered by the addition of the Complementary omega-shaped metamaterial.The majority of the current is gathered in the radiating element, as seen by the surface current distribution at 2.03 GHz. The greatest current that can flow through the meandered strips at 3.47 GHz is obtained by meandering the sides of the radiating element. The current is then focused at 5.96 GHz around the complementary omega-shaped slot in the radiating element following the inclusion of the complementary omega-shaped metamaterial element. Figure 12 displays the surface E-Field distribution at each operational band, demonstrating that the meandering is responsible for the multiple band feature and the presence of the complementary omega-shaped metamaterial is responsible for the impedance matching.

CONCLUSION

In this study, we present a compact triple-band antenna designed for multiple applications. The antenna operates at 2 GHz for fixed microwave communication, 3.4 GHz for WiMAX, and 5.5 GHz for WLAN. Its radiating element is a simple square shape, with meandered sides to achieve the desired triple-band functionality. Additionally, we incorporate a complementary omega-shaped metamaterial and a pin diode to ensure excellent impedance matching. The proposed antenna boasts several advantages, including its small size, good radiation pattern, wide impedance bandwidth, low cost, and seamless integration with MMICs. Overall, it stands as a strong candidate for various communication devices.

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