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Design of Meta Surface-Based Patch Antenna by Using Multi-Port Power Divider for Wireless Advanced Communications

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ABSTRACT

The compact Multi-Port Power Divider is presented based on the microstrip patch resonator. To explicate its mode of operation, the resonant property of the circular microstrip antenna is illustrated for multi-port power divider operation. This MPPD is constructed with two aligned patch resonators with a meta surface to control the radiation parameters. In this paper, the functional description of the power divider along with the meta surface can be exemplified by the field distributions of the resonating ports. The FR4 epoxy substrate material, with a dielectric constant of 4.4 and a thickness of 1.6, is used for the antenna to operate at a 2.4 GHz resonating frequency, with an antenna size of 0.4 λ_0×0.48 λ_0×0.128 λ_0, also having a bandwidth of 2.2GHz to 2.6GHz with a gain of 5dBi, along with an axial ratio below 3dB at the reflection coefficient of -40dB. The presence of meta surface in microstrip antenna increases the bandwidth and valued gain at certain extent, it further improves the functionality of the overall system. The performance of the proposed antenna was analyzed with the E and H planes of the radiation pattern, with improved gain obtained in the presence of a meta surface-based microstrip antenna. The meta surface appeared in the form of a mesh type of structure, fed by a microstrip antenna revealing a good agreement with the simulated one. The measured result shows that the proposed antenna has the perfect axial ratio along with a 10dB impedance bandwidth achieved with a valued gain of 5to 11dBi.

Keywords: MPPD; MSA; resonance; power distribution; wideband

INTRODUCTION

Dual polarized antennas attracted tremendous attention because of their advantages in the high channel capacity of wireless systems using satellites (Battacharya et al. 2022). Meanwhile, based on these systems, the patches that are mostly used in Microstrip Patch antennas (MSA) could generate more stringent specifications to meet system performance, including the condensed size of an antenna, wide impedance bandwidth, remoteness, and severe radiation patterns (Bi X et al. 2020). The MSA used in power dividers to obtain proximity coupling, direct probe feed, and aperture coupling became the eminent design parameters for the design of the circular polarized antenna (Chi et al. 2020). Moreover, crossed slots and connected joints in an MPMSA are used to improve the isolation of the circular polarization antenna. Nevertheless, the Multiport Power Divider (MPPD) not only provides equal amplitude but is also capable of providing appropriate power division in the feeding network that occurs the processing of MSA (Lee et al. 2015). Power distribution is an enhancing technique of power dividers that can be equivalent to multi-port networks with two directionally located input ports and two equal output ports (Li et al. 2017). In our novel concept, the microstrip antenna is coupled to the meta surface in a common ground plane and placed to one another. The proposed power divider is used for the power distribution between the microstrip and the meta surface. In PDMSA, the radiating element that is present in the assigned frequency range can be transmitted through the meta surface and generate the perfect radiation parameters required to design the antenna (Liu et al. 2020). The specifications of the system not only provide the basic parameters but also the process of power distribution throughout the antenna elements. The side lobe suppression would be done with a meta surface and with that high precision of operation to recreate the possible parameters of the antenna (Zheng et al. 2022). The meta surface acts as a processor to control the radiating elements of the MSA and to generate the required variation of the parameters required to assess the performance of the system. The main determination of this paper is to accomplish the generation of circular polarization. This approach would be obtained for the utilization of orthogonal feed MPPD along with circular polarization could generate high performance of the antenna, which often could improve the characteristics of the patch. Usually, the incessant rotating field, orthogonal field parameters and phase quadrature generates the circular polarization. In this paper, the design of a meta surface-based patch antenna for the alligned power divider applications is presented and its variations

TABLE 1. Antenna parameters for the microstrip antenna.

Parameter	A	B	C	D	E	F	G	H	I	J	W_G	L_G
Dimension in mm	9.94	2	13	15	5	8	7.51	4.16	7.63	15	50	60

on the antenna are presented in Section I. Section II investigates the recital description of the antenna at a wideband multi-port meta surface-based power divider network. The antenna design principles presented in Section III, the functional simulations, and their parametric variations presented in IV, Section V, and VI comprise design challenges and conclusion for this paper.

WIDEBAND MULTI-PORT META SURFACE BASED POWER DIVIDER

Power dividers are passive devices used mostly in the area of wireless sensor technology. The PD couples a certain amount of electromagnetic energy from the MSA to a port, enabling the power signal to be used in the power divider network. The essential feature of the power divider network in an MSA is to couple the power flowing equally throughout all the ports. The best example of a power divider in wireless communications is the directional coupler, which could split power equally between ports. The power dividers are regularly erected from two coupled transmission lines along with a patch set close together for the passing of energy through one port coupled to the other. The meta surface is elongated on the patch to control the radiation properties of the proposed antenna. Many of the power dividers provide signal samples for the designing of the circuit elements for measurement monitoring, and feedback including the design system principles.

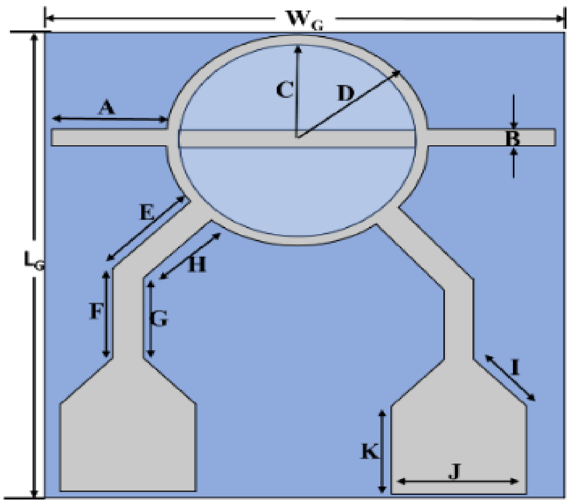


FIGURE 1(a). Proposed PD MSA

The meta surface-based power divider distributes the power equally in all directions and helps meta surface to control the radiation pattern elements for the transmission of radiation wave in a particular direction. The meta surface is considered as the top most layer of the MSA, elongated mainly to control the radiation pattern and provides the specific bandwidth and gain. The power divider is designated by adding studs at the transmission line of port1, and port2, along with two patches, as shown in Figure 1(a), which is the position of the stud used for wideband applications. The power divider, along with the meta surface as shown in Figure 1(b) combines or splits the signals into equal or unequal phases.

The power divider including meta surface has the properties of radiation pattern, these two restrict the functions of radiation properties to generate perfect designated outputs at the output of the antenna system. The two-dimensional meta surface implementation on feed line and patch of the microstrip patch antenna increases bandwidth and directivity. The thick substrate above the radiator with an air gap increases the gain and AR bandwidth. The meta surface based MSA has the ability to produce near field modification for gain optimization and reshape the radiation pattern. The feeds are measured at the edge of the patch with this, the circular polarization radiation would be obtained. A power divider-based meta surface is accessible as a simulation of multiple ports along with a circular patch, which attains several benefits, this analysis was instigated with the HFSS to get the static relation between the radiator and the power divider ports. The side view of the meta surface along with the antenna geometric parameter shown in Figure 1(c) and table 1 having the different layers of abstraction and the necessary parameters required to design the MSA antenna which depicts to explain the performance of the antenna. The meta surface controls the radiation properties of the microstrip patch antenna. It further controls the all the radiating properties required to assess the perfect nature of the meta surface antenna. The antenna is designed for 2.4GHz, radiated by the meta surface based the proposed MSA to improve the gain. The antenna that is required for the power divider having the static coordination between the patch and the power divider network. The patch should be balanced with the feeding elements because it is the essential element in the PDMSA. To balance the power loss among the ports the patch is placed to reinitiate the functioning of the microstrip patch antenna as shown as a S-parameter plot in Figure 2, which elaborates the simulation for the power divider to divide the total power in all ports equally.

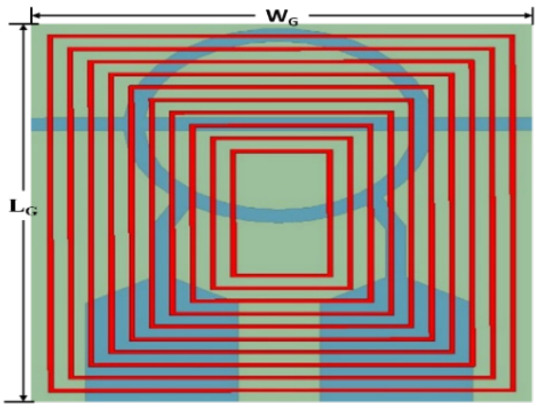


FIGURE 1 (b). Proposed meta surface PD MSA

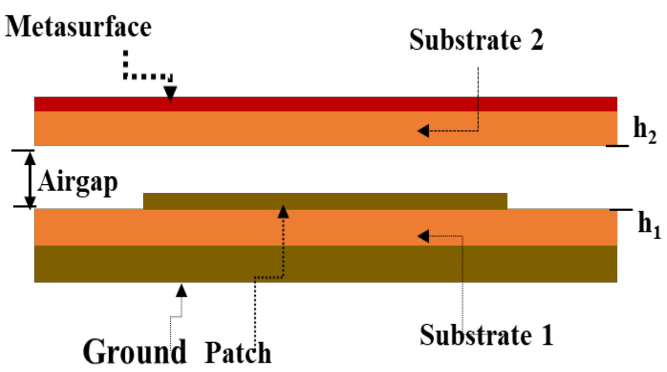


FIGURE 1 (c). Side view of the meta surface

ANTENNA DESIGN

The geometric construction of this work is outlined in two orthogonal feeds associated with the circular patch using a power divider. The prototype design of meta surface-based PDMSA consists of a ground plane with measurements of W_G=50mm, and L_G=60mm. Meanwhile, substrate 1 is grown on the ground plane to design a microstrip patch. Moreover, two ports and two patches are associated with the circular power divider to generate the obligatory antenna parameters. The meta surface-based PDMSA is a multi-layered antenna fabricated with FR4 epoxy with a substrate thickness of 4.4 and a height of 1.6mm to attain better bandwidth. A circular-shaped power divider having two patches and two connected ports is assigned for the performance of the power divider in connection with the meta surface. To improve the performance and to enhance the gain of the antenna, a meta surface is grown on substrate 2 with a width of 0.5mm and a separation between cells of 1mm. Meanwhile, it should be mentioned that the impedance of the antenna differs with the band of frequencies.

However, the electrical length of the transmission line is more delicate in the high-frequency region. The reflection coefficient of the proposed antenna function is enormous only with the impedance bandwidth changing with the noticeable higher frequency. The most important thing behind the design of an antenna with basic power divider ports is to coordinate the power flow among all the ports, with this the gain, Splot, VSWR, axial ratio and also the power handling capability would be easily corrected at a perfect rate. The patch is the basic element of a microstrip antenna to align with all the antenna parameters and it also coordinates all the signals that are passing through the other components of the radiator. The antenna elements including the meta surface structure have the functional control of antenna geometry and all the functions of the antenna to maintain the power at a certain rate. The design of microstrip antenna depends on the ground and substrate parameters which further decides the length of the patch. Most of the antenna geometric parameter designed with the resonating frequency along with the speed of the light to implicit the functionality of the basic design of the MSA which further improves the radiation.

The minimum standard that would be required for the antenna is to design the patch of the power divider can be computed with the following equations, obtain the circular polarization. The main purpose of the power divider is to evenly divide the input power among the output ports while maintaining excellent transfer efficiency with minimum signal loss. This enables the multiple antennas to receive a balanced and equal signal with uniform performance across the wireless communications system. The proposed antenna along with the designed parameters in the presence of a meta surface would gain the performance of the antenna, with this the stability and alignment of the system will adjust. Both E and H planes play a vital role for the radiating the radiation in a defined particular direction with the meta surface. The quadrature hybrid coupler is a highly power-efficient power divider providing equal power division and a 90-degree phase difference between output ports. The side view of the proposed antenna describes the layers of abstraction from the ground to the meta surface, it gives the sequence of steps to simulate the PDMSA. The distributed MSA would be easily assessed with the help of power division characteristics as mentioned in the previous sections. The antenna design, along with reliable equal power distributions, could easily be understood with current distribution variation and these power distributions pertain to the antenna design to describe the performance of the antenna.

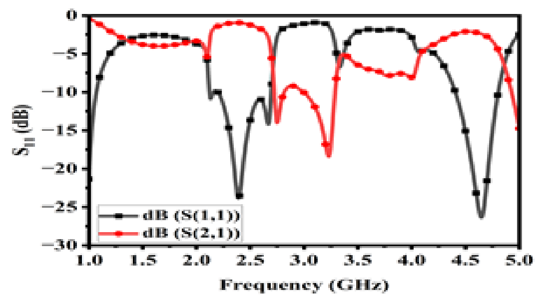


FIGURE 2. S parameter plot for the PD MSA at 2GHz

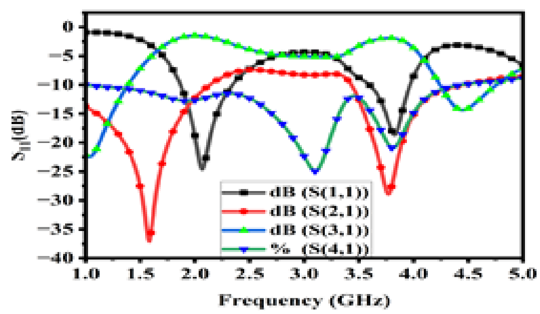


FIGURE 3. S parameter plot for the PD MSA at 2.4 GHz

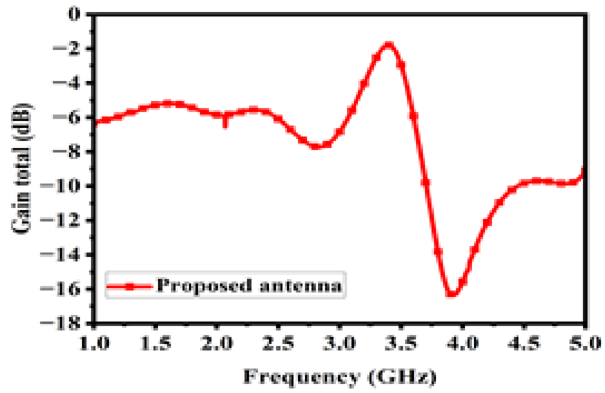


FIGURE 4. Gain plot for the PD MSA at 2GHz

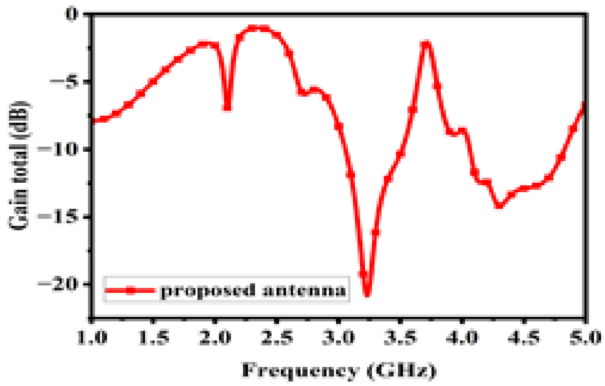


FIGURE 5. Gain plot for the PD MSA at 2.4GHz

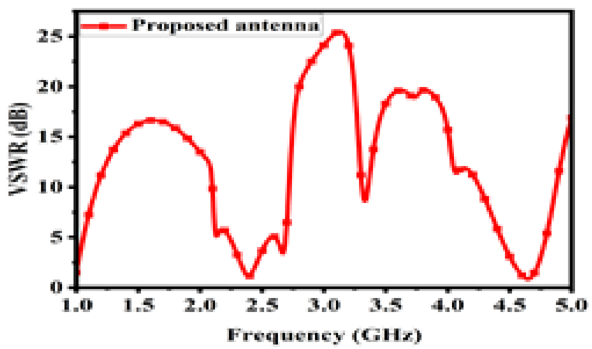


FIGURE 6. VSWR plot for the PD MSA at 2.4GHz

$$L = \frac{C}{2Fr\sqrt{\varepsilon_r}} \tag{1}$$

$$L_p = L + 2\Delta L \tag{2}$$

The ground dimensions of the MSA may be computed as follows,

$$L_g = 6h + L_p \tag{3}$$

$$W_g = 6h + L_p \tag{4}$$

The equation can be used to compute the parameters of the feedline.[9]

$$L_g = \frac{\lambda_g}{4} \tag{5}$$

$$\lambda_g = \frac{C}{2Fr\sqrt{\varepsilon_r}} \mathrm{X}1000 \tag{6}$$

The equation can be calculating the impedance of the MSA, The quarter-wave transformer for the balanced antenna [10]

$$\sqrt{P_{imp}} \mathrm{X} Z_0 \tag{7}$$

The MSA was operated by the dual orthogonal modes TM_{10} and TM_{01} with a power divider used to

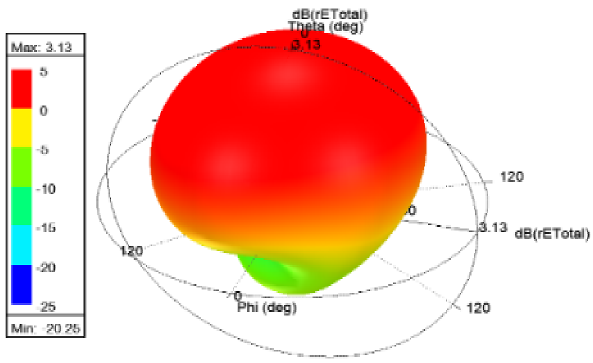
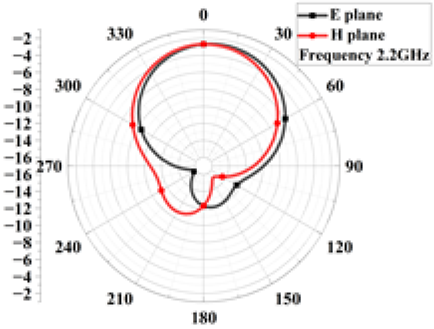
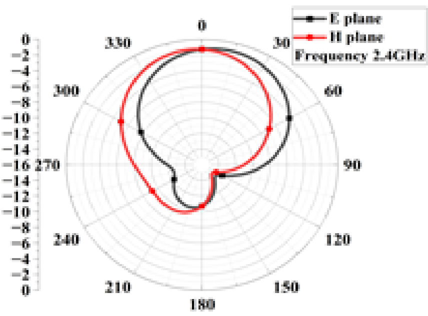


FIGURE 7. 3D radiation plot for the PD MSA at 2.4GHz



a)



b)

FIGURE 8. 2D radiation plot for the PD MSA at (a) 2.2 GHz and (b) 2.4 GHz

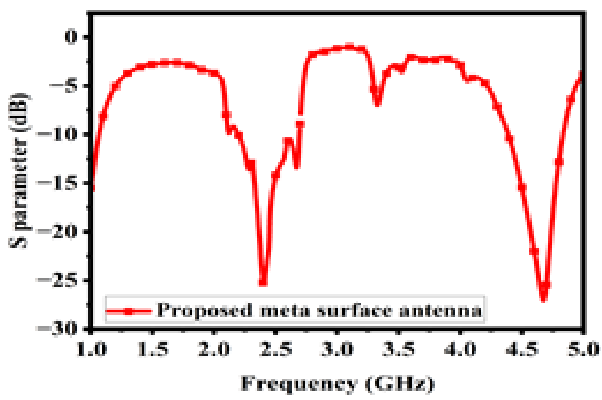


FIGURE 9. S plot for the Meta surface at 2.4GHz

RESULTS AND DISCUSSION

The proposed power divider can be simulated with HFSS and optimized to achieve desired power distribution characteristics, which allows for the analysis of the performance of the power divider along with MSA under specified conditions. To decrease signal reflection and maximize power efficiency, the antenna shape and feed configurations were carefully optimized. Based on the S parameter variation, we can predict the bandwidth and other important parameters of the antenna. The proposed antenna is designed for 2.4 GHz, with a 5dBi transmission gain. The plotted S for both 2.4GHz and 2GHz for a multi-port power divider are shown in Figure 3. It indicates that the radiator has good impedance matching with S_{11}, which is less than -10 dB, having a return loss of 30 dB for the broadband frequency. The S_{11} describes the how much power got reflected from the receiver circuit to the transmitted, if it is less than -10dB the performance of the system would be very poor. The design parameters were adjusted with the help of HFSS analysis, resulting in a well-balanced antenna with perfect gain, as shown in Figs 4, and 5 at 2,4GHz and 2 GHz. The performance of the antenna would be easily seen with the help of VSWR, as shown in Figure 6. It also measures the efficiency of power transfer between the antenna and its feed line. The reflected power can be easily quantized by reflection coefficient, the reflected power should be linearly varying with the VSWR. The basic radiation parameters are the S plot, VSWR, gain and the axial ratio. The function of the meta surface based MSA primarily considered with the variation of the above-mentioned parameters. The meta surface corrects the radiation pattern, and its radiating elements especially gain and the bandwidth. The design of the proposed antenna is verified with the reference antenna, the power divider behaves like a reference antenna to the meta surface. The radiation pattern of the meta surface antenna describes how well the electromagnetic energy varies with direction; it should be stable across the operating frequency. The performance of the power divider and its inclined distributed MSA would be easily assessed with the help of radiation patterns in 3D and 2D, at 2.4GHz and 2GHz as shown in Figure 7 and Figure 8.

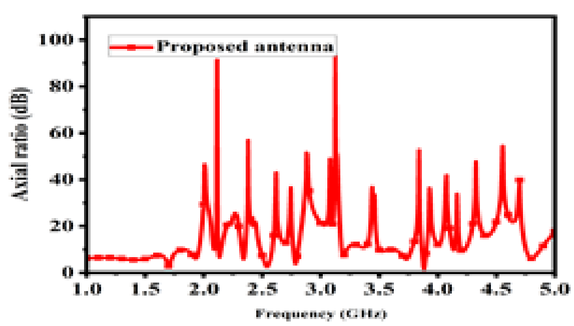
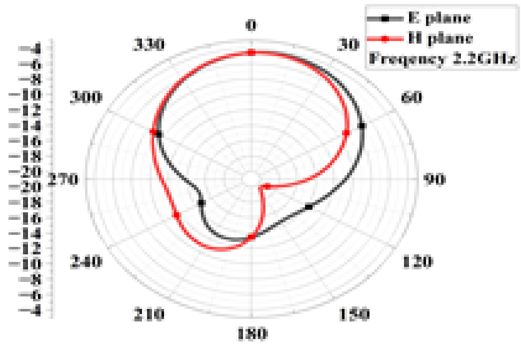
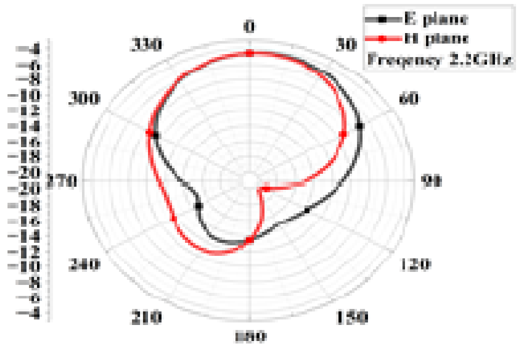


FIGURE 10. Axial ratio for the Meta surface at 2.4 GHz



a)



b)

FIGURE 11. Radiation pattern for Meta surface-based PD MSA at (a) 2.4GHz and (b) 2.2 GHz.

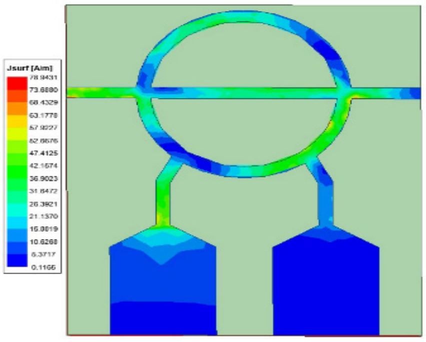


FIGURE 12. current distribution for PD MSA

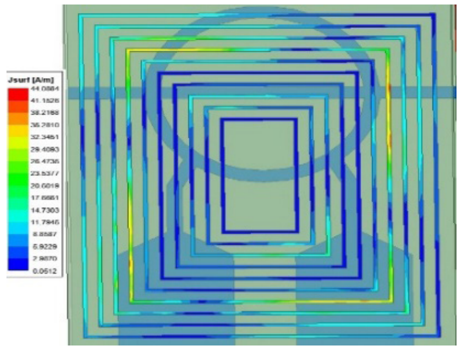
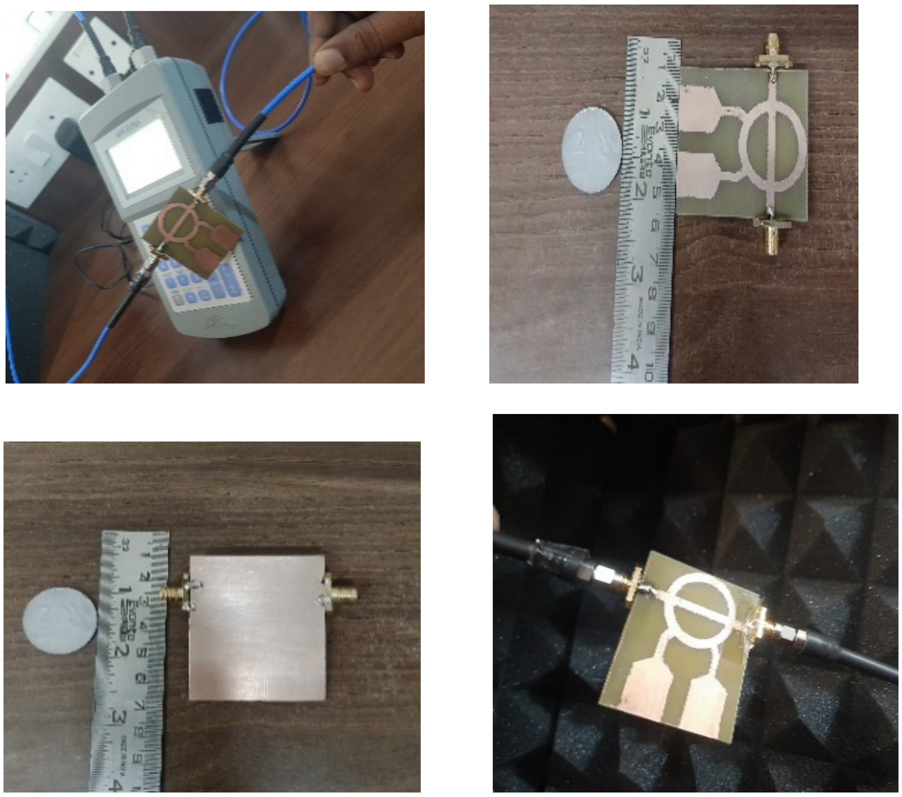


FIGURE 13. Current distribution for meta surface



v

FIGURE 14. Fabrication measurement for PD MSA

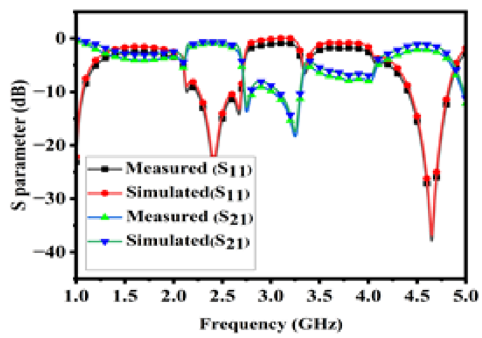


FIGURE 15. Measurement Vs Simulated S11 along with full environment for PDMSA

TABLE 2. The proposed antenna performance comparison with the other works

Ref	Antenna type	Antenna size (λ_0)	Frequency (GHz)	S_{11} (dB)	ARBW	Gain (dBi)	layers
(Asma et al. 2022)	Fabry parot	2.5×2.5×1.48	6	7.5	3.9	4	3
(Jean et al. 2021)	Stacked patch	0.81×0.81×0.09	4	8	10	3	3
(Jiang et al. 2021)	Stacked patch	0.8×0.8×0.20	3	26	5	2	2
(Wen et al. 2017)	Cross dipole	0.56×0.19×0.15	2.8	29	6	6	3
Proposed	Meta surface	0.4×0.48×0.128	2.4	40	7	7	5

The functional performance of the meta surface given in s plot variation, as shown in Figure 9 depicts how it differs with bandwidth and based on Splot and other parameters of MSA needed to be validated, the return loss for the meta surface -30dB with proper impedance matching. The axial ratio of the meta surface along with the MSA defines how well the antenna can transmit and receive circularly polarized radiation waves were explained in Figure 10. The radiation properties of the meta surface with E plane H plane variation as shown in Figure 11. The antenna design, along with reliable equal power distributions could easily be understood with the help of current distribution pattern variation of MSA and meta surface as shown in Figs 12 and 13. The current distribution depends on a specific design, radiation pattern, and the resonating frequency such as the dimensions of the patch. To analyze the implicit functions and their cordial variations the performance of the antenna along with current distribution and its implications play an important role. The power distribution on meta surface-based antenna design describes the antenna with multi-port divider has the extended bandwidth from 2GHz to 2.8 GHz and the gain varies from reference to meta surface from 5dBi to 7dBi.

The performance of radiating parameters varies from without meta surface to with meta surface with improved gain characteristics. The simulation results depict that the impedance bandwidth and isolation are attained with the high-power divider functional characteristics. The most essential part of an antenna design is the fabrication process. It would decide the functioning of an antenna. The proposed antenna was fabricated, and tested, and the perfect fabrication setup measurement is shown in Figure 14. The prototype of empirical configuration is designed and measured to verify the theoretical analysis at the 2.4 resonating frequency as shown in Figure 15. The fabrication setup for simulated and measured results decides the accurate performance of the antenna.

The proposed antenna in comparison with other works has been mentioned in Table 2, based on these variations we can conclude how reliable the analysis is with the accurate performance of the antenna. As per the above explanation, the antenna design and simulations needed a series of actions to obtain the perfect result. The ground plane, substrate1, patch, substrate2, and meta surface are the different layers that determine the performance and fabrication of a PDMSA. The excitation and measurement of the antenna require perfect analysis to coordinate all the features of the antenna. The simulation results explain the S plot, VSWR, gain, axial ratio, and other variations that are required for the performance and fabrication of an antenna. The overall functional variations of PDMSA give the predictor conditions about the antenna radiating parameters. The meta surface retains the values of antenna parameters and controls the abnormal variations of an antenna while simulating at a particular rate.

DESIGN CHALLENGES

The main function of design challenges is to develop new technology-based designs on whatever sufficient data we have from the past to the latest related to antenna properties with HFSS designs. The power dividers and their implementations with meta surface kind of designs needed to be operated at high frequency with more bandwidths, from that it generates high data rates of operation. [11]The microstrip antenna is designed for more ports without any power loss with adequate isolation provides the static performance of the meta surfaced based MSA. The meta surface controls the radiation pattern, bandwidth and gain of the antenna, which further improves the power divider functionality in wireless communication systems.

The perfect designing of the antenna with power-dividing ports not only controls the basic design but also improves the system performance at a certain range to increase the performance of the microstrip antenna.[12] This paper describes multiple ports of operation with adequate bandwidth and gain of MSA with the meta surface-based structure. But for future studies based on the latest technologies, more ports of operation with static design principles are needed, which include meta surface kind of designs, which further improve the basic standards of the design strategies. The main function of the meta surface MSA is to generate proper gain and bandwidth for the implementation of the latest technology with perfect operation of an antenna.

CONCLUSION

This article proposes a multiple feed, low profile method for designing wideband meta surface-based driven antenna along with the inclusion of the power divider. The proposed antenna describes the combinational features of multi-port power divider and meta surface. The integration of the meta surface with the power divider can lead to optimization and adaptation of the radiation features of the microstrip antenna. The antenna attains an impedance bandwidth of 40 percent of S_{11} less than -10dB, a 3dB AR bandwidth of 20 percent along with the broadside gain of 5 dBi, and a radiation efficiency greater than 90 percent was gained with effective bandwidth. The designed antenna shows the characteristics like perfect impedance matching and low gain will adapt the simulation properties of the MSA. The power divider meta surface-based antenna for advanced wireless communications was simulated and fabricated as a perfect gain antenna with an adaptive useful structure. The simulation results indicate that wide band impedance bandwidth and isolation variations are obtained with the high-power divider functional characteristics.

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DECLARATION OF COMPETING INTEREST

None.

REFERENCES

Asma, Djellid, Fadila Benmeddour, Lyliane Bahri. 2022. Novel high gain and compact UWB microstrip antenna for WIFI, WIMAX, WLAN, X band 5G applications. *Optical and Quantum Electronics* 54(441).

Bhattacharya A, B Roy, SK Chowdhury, AK Bhattacharjee. 2022. An isolation enhanced, printed, low-profile UWB-MIMO antenna with unique dual band-notching features for WLAN and WiMAX. *IETE Journal of Research* 68(1): 496-503.

Bi, X. Zeng, and Q. Xu. 2020. Slotline-based balanced filter with ultra- wide stopband and high selectivity. *IEEE Trans. Circuits Syst. II, Exp. Briefs* 67(3): 460–464.

Chi P L, Y. M. Chen, and T. Yang. 2020. Single-layer dual-band balanced substrate-integrated waveguide filtering power divider for 5G millimeter- wave applications. *IEEE Microw. Wireless Compon. Lett.* 30(6): 585–588.

Jean de Dieu Ntawangaheza, Liguo Sun, Zipeng Xie. 2021. A single-layer low-profile broadband metasurface antenna array for sub-6 GHz5G communication systems. *IEEE Trans. and Propagation* 69(4).

Jiang-Feng Lin, Lei Zhu. 2021. Low-profile high-directivity circularly- polarized differential-fed patch antenna with characteristic modes analysis. *IEEE Transactions on Antennas and Propagation* 69(2).

Lee J N, K. C. Lee, and P. J. Song. 2015. The design of a dual-polarized small base station antenna with high isolation having a metallic cube. *IEEE Trans. Antennas Protag.* 63(2): 791–795.

Li H, L. Kang, F. Wei, Y.-M. Cai, and Y.-Z. Yin. 2017. A low-profile dual-polarized microstrip antenna array for dual-mode OAM applications. *IEEE Antennas Wireless Propag. Lett.* 16: 3022–3025.

Liu H, Z. Wang, S. Hu, H.-X. Xu, and B. Ren. 2020. Design of tri-band balanced filter with wideband common-mode suppression and upper stopband using square ring loaded resonator. *IEEE Trans. Circuits Syst. II, Exp. Briefs* 67(10): 1760–1764.

Wen L H et al. 2018. Compact dual-polarized shared-dipole antennas for base station applications. *IEEE Trans. Antennas Propag.* 66(12): 6826–6834.

Zheng Qi, Chenjiang Guo, Jun Ding. 2022. A wideband low-RCS metasurface-inspired circularly polarized slot array based on ai-driven antenna design optimization algorithm. *IEEE Transactions on Antennas and Propagation* 70(9).

Zhan Wang, Yuandan Dong, Zilin Peng. 2022. Hybrid metasurface, dielectric resonator, low-cost, wide-angle beam-scanning antenna for 5G base station application. *IEEE Transactions on Antennas and Propagation* 70(9).