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Investigation of a Four-element Textile Multiple Input Multiple Output Antenna for Ku-Band Applications

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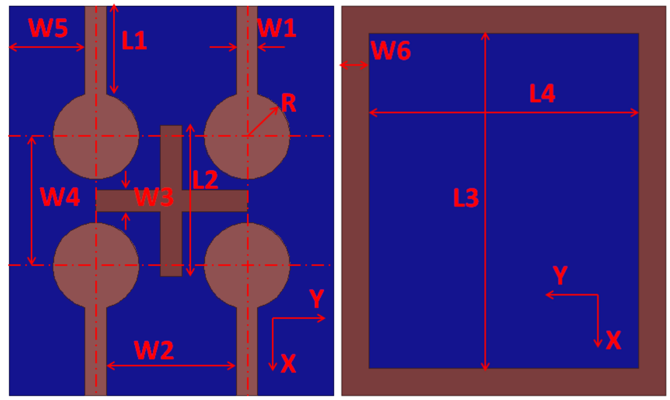
***Abstract*—A compact four-element multiple input multiple output (MIMO) antenna designed on a textile substrate is presented. The MIMO antenna consists of a planar structure and operates in the frequency range from 11.87 to 19.05 GHz for full Ku (12 GHz to 18 GHz) application band. A 'plus' shaped small structure is used to achieve high port isolation (> 17 dB) among all four antenna elements over whole operating frequency band. Diversity parameters and radiation parameters of the proposed antenna are also fully investigated. These investigations confirm the antenna an appropriate multi-element MIMO antenna for the desired Ku-band applications.**

Keywords— Textile antenna, Multiple input multiple output (MIMO), planar structure, Ku-band, channel capacity loss (CCL).

I. Introduction

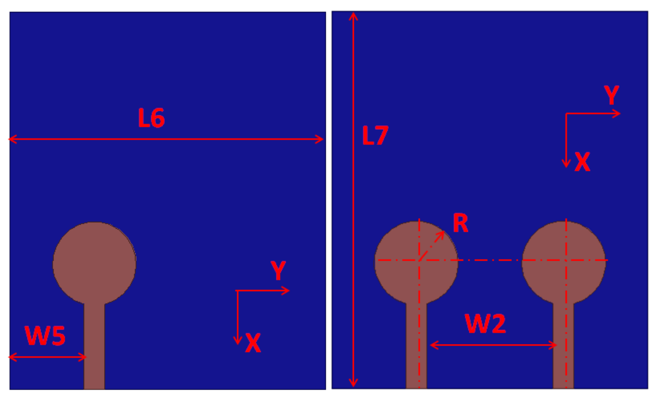
With the fast advancement in wireless communication system, MIMO antenna turns into more prevalent, which is used to improve data rate, high system throughput, proficient spectrum utilization, great channel capacity, wide band and reliability of the system [1-4]. Additionally, this scheme settles down enhanced network experience, and link reliabilities using the restricted level of power and bandwidth deployment [5-6]. While MIMO antenna system affords advances over single element antenna, it may be more compatible to use in various unusual situations if it is designed with wearable material [7]. Recently, MIMO antenna design with wearable structures becomes an incredible demanding trend to the antenna researcher [8]. However, special attention is to be given to design of such wearable MIMO antenna due to the fact that surroundings of the wearable substances may affect to degrade the performances of the antenna [9]. In this context, textile MIMO antenna is very much important and this antenna should be designed with careful devotions such that essential properties may be included in the design [10, 11].

In this paper, a four-element textile MIMO antenna with 4 ports is proposed. The elements of the antenna are of circular shaped. A 'plus'-shaped isolator is used at the center on the top surface of the MIMO antenna to enhance the port isolation. The antenna works over the full Ku-band (12 GHz to 18 GHz) with a very high port isolation of about 17 dB among the all four ports. The evaluated envelope correlation coefficient (ECC<0.08), diversity gain (DG>9.96 dB) and channel capacity loss (CCL<0.15 bits/s/Hz) are very appropriate to function the antenna as a good MIMO antenna. Mean effective gain (MEG=±0.2 dB) and radiation patterns are also suitably investigated.



(a) (b)

Fig.1 Structure of the proposed MIMO antenna (a) top and (b) back views.



(a) (b)

Fig.2 Top views- (a) single-element and (b) double-element antenna.

II. Antenna Structure

Fig. 1 illustrates the construction of the proposed compact four-element antenna in detail. Fig.1 (a) shows the top view of the proposed antenna. Four antenna elements are etched on a 1 mm thick Jeans substrate where two elements are placed at lower side and rest two are at opposite side like mirror image of first two. A 'plus'-shaped metallic structure is also integrated to achieve high port isolation. The relative permittivity (ε_r) and loss tangent of the substrate are 1.6 and 0.02 as considered according to ref. [12]. The bottom view of the antenna structure is shown in Fig.1 (b). The ground plane consists of only a narrow strip circulating around the boundary. Middle portion of the structure is fully suppressed. The proposed MIMO structure is optimized using Ansys High Frequency Structure Simulator (HFSS) [13]. The overall volume of the structure is 36 × 30 × 1 mm^3. The dimensions of the assessed parameters of the antenna are abridged in TABLE 1.

TABLE 1 antenna parameters

Parameters	Dimensions (mm)	Parameters	Dimensions (mm)
R	4	L1	8.13
W1	2	L2	14
W2	12	L3	31
W3	2	L4	25
W4	12	L6	30
W5	7	L7	36

III. RESULTS AND DISCUSSIONS

We have first designed a basic antenna which consists of a single element as shown in Fig. 2(a). To achieve our desired frequency band of operation we have investigate it and change its parameters accordingly. The back view of the antenna is shown in Fig. 1(b). This single element antenna covers the frequency range from 12.03 to 18.96 GHz. Again, with the help of this basic antenna, a dual-element antenna is designed as shown in Fig. 2(b). The ground plane remains same as earlier. The antenna offers the frequency band from 11.83 to 18.97. Fig. 3 illustrates the S-parameters of the basic and dual-element antenna.

A. Four-element antenna design

Again, using the basic and dual-element antenna, we have designed and investigated a four-element MIMO antenna. This structure is modification of dual element antenna where 3rd and 4th elements are like mirror image of 2nd and 1st antenna elements respectively. It is explored using computer simulation and found the similar operating bands from all ports as previous structures. The antenna operates in the frequency range from 11.96 to 18.99 GHz with a maximum port isolation of around 13 dB. S-parameters of this structure are depicted in Fig. 4(a).

TABLE 2 Comparison with similar recent articles

Ref.	No. of Ports	Substrate, ε_r	Op. Freq. (GHz)	Min. Port Iso. (dB)
[5]	4	RO-4350, 3.48	0.75-7.65	12
[6]	2	Jeans, 1.6	3.14-9.73	32
[9]	2	Jeans, 1.6	1.83-8	22
[12]	2	Jeans, 1.6	3.1-10.6	25
[19]	4	FR4, 4.4	3.1-10.6	15
Prop.	4	Jeans, 1.6	12-18	17

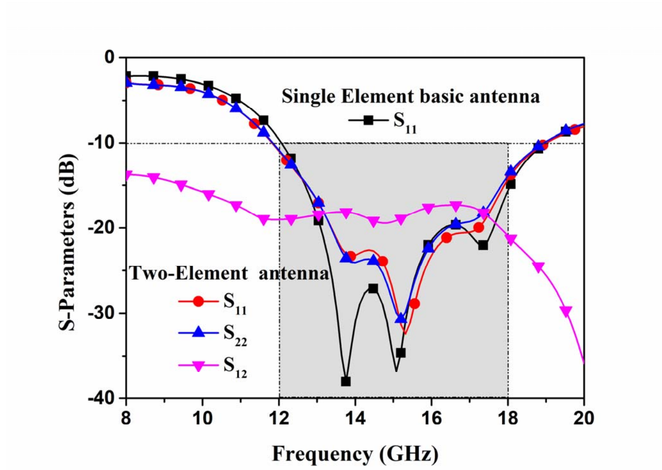
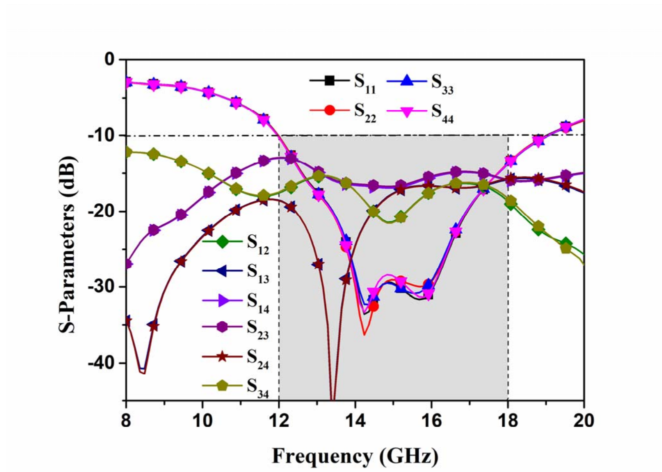
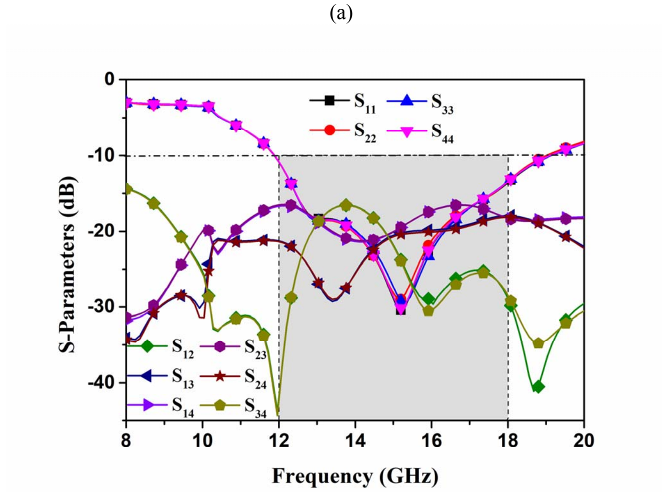


Fig.3. Simulated S-parameters of the single and dual-element antenna.



(a)



(b)

Fig.4. Simulated S-parameters of the (a) antenna without isolator (b) proposed antenna.

B. MIMO antenna with a 'Plus'-Shaped Isolator

The four-element antenna as discussed in previous section shows poor port isolation. Therefore, an isolator is imprinted at center of the MIMO antenna to enhance the port isolation. The isolator is 'plus'-shaped and placed on the top surface of the structure. The top and back views of the antenna are depicted in Fig. 1(a,b). After, investigation of this structure, it is observed that the port isolation is enhanced up to about 17 dB. Fig. 4(b) illustrates the simulated S-parameters of the four-element MIMO antenna with isolator. The figure approves that it covers the similar frequency variety from 11.87 to 19.05 GHz. Now, to conclude the structure as proposed antenna we have paid attention to investigate the diversity parameters for its suitability.

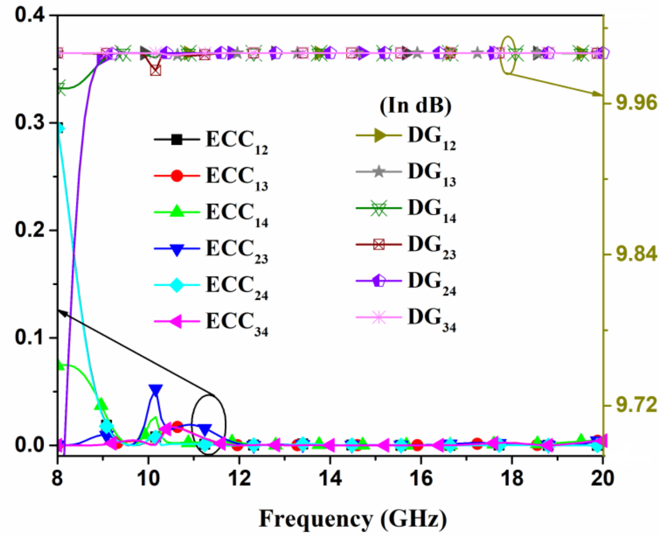


Fig.5. Simulated ECC and DG of the proposed MIMO antenna.

C. Diversity parameters

Diversity parameters are the crucial parameters for a MIMO antenna. MIMO characterizations are determined by these parameters. We have deliberated the ECC and DG in the context of all ports from the equation 1 and 2 [14].

$$ECC = \frac{|S_{aa}^* S_{ab} + S_{ba}^* S_{bb}|^2}{(1-|S_{aa}|^2 - |S_{ba}|^2)(1-|S_{bb}|^2 - |S_{ab}|^2)} \quad (1),$$

$$DG = 10\sqrt{1-(ECC)^2} \quad (2)$$

Fig. 5 demonstrates the ECC and DG of the designed MIMO antenna. It shows low values of ECC and high value of DG. It is found from these values that the correlations between the adjacent antenna elements are very nominal.

Channel capacity loss (CCL) is also very fundamental parameter for MIMO characterization. This parameter is evaluated using equation [15, 16] given below.

$$CCL = -\log_2 \det(\Psi^R) \quad (3)$$

Here, the elements of the correlation-matrix Ψ^R at receiver are as follows:

$$\rho_{aa} = 1-(|S_{aa}|^2 + |S_{ab}|^2)$$

and $\rho_{ab} = -(S_{aa}^* S_{ab} + S_{ba}^* S_{ab})$.

CCL corresponding to designed four-element MIMO antenna is illustrated in Fig. 6. The figure ensures all calculated CCL values are less than 0.15 bits/s/Hz over the full working band. Normally, for effective MIMO operation the value of CCL should be less than or equal to 0.4 bits/s/Hz [17]. Therefore, our investigated CCLs confirm the MIMO antenna is suitable in the context of channel capacity loss.

MEG is another important diversity parameter. To investigate the MIMO characteristics, it should be ensured that the ratio of mean effective gain of two ports will be a limit of equal to ±3 dB for efficient MIMO performance. We have calculated the parameters using following relation [18]:

$$MEG_a = 0.5\eta_{a,rad} = 0.5(1-\sum_{b=1}^{M}|S_{ab}|^2) \quad (4)$$

Where, a and b signify as ports and M signifies the number of elements in the antenna with $|S_{ab}|$ as the corresponding S-parameters. Fig. 6 depicts the MEG curve of the proposed MIMO antenna. The figure ensures very suitable values (±0.2 dB) of MEG. This exposes proper performance associated to the gain of the antenna.

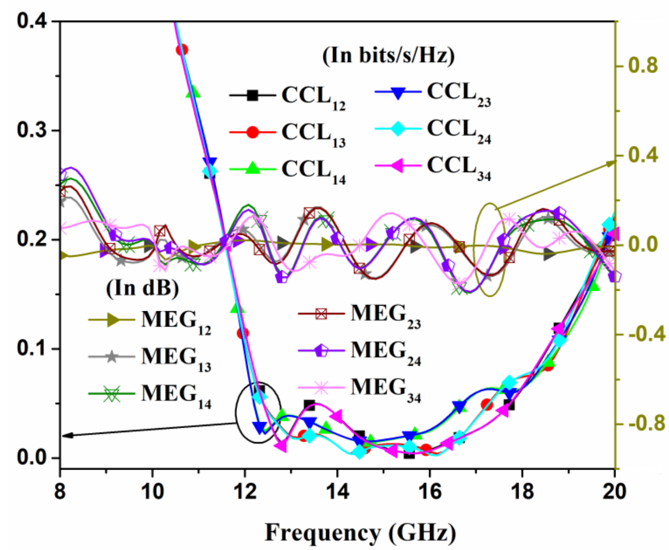


Fig.6. CCL and MEG characteristics of the antenna.

D. Surface current distributions and radiation performances

Surface current distributions of the antenna without and with isolator are observed. Fig. 7 (a, b) illustrates these at 12 and 18 GHz. Port isolation is clearly observed by inspecting the amount of current coupling is less in case of antenna with isolator with respect to without isolator. Both co and cross pol radiation patterns in E and H-plane at 12 and 18 GHz are investigated. Cross polarization is better at 18 GHz than 12 GHz. Fig. 8 (a, b) depicts the radiation patterns. It is perceived from the figure that the patterns are good enough to permit the textile antenna as very noble contender in MIMO applications. The proposed work is compared with similar recent works in TABLE 2.

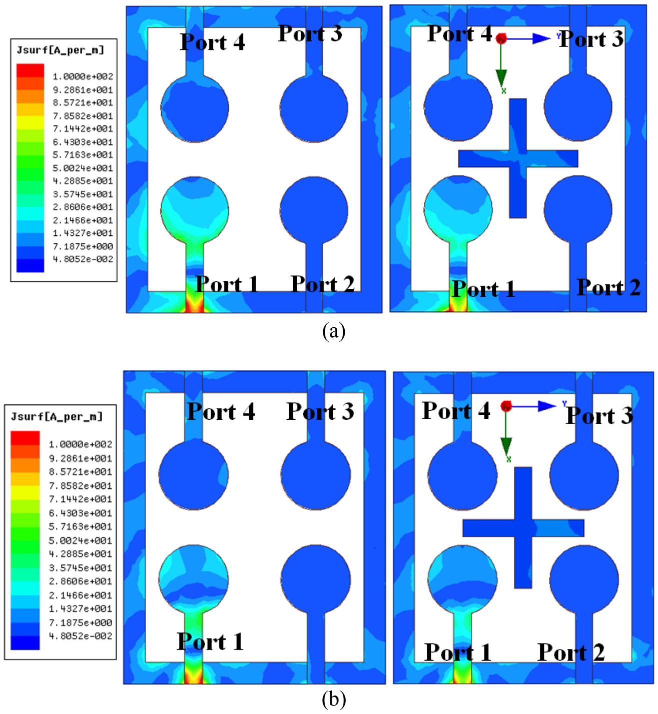


Fig.7. Surface current distributions at (a) 12 and (b) 18 GHz.

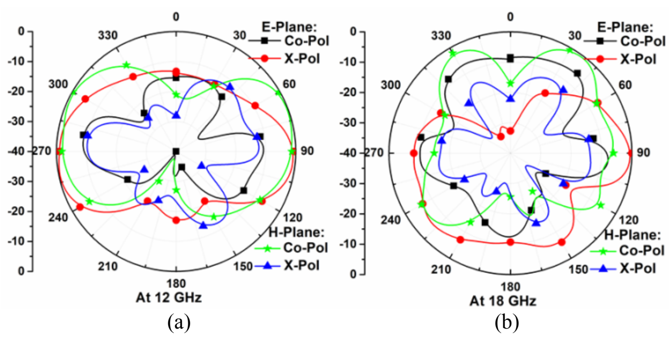


Fig.8. Radiation patterns at (a) 8 and (b) 12 GHz.

IV. CONCLUSIONS

A four-port MIMO antenna with four circular shaped antenna elements is presented in this communication. The proposed antenna is designed with a Jeans substrate. The ground plane of the antenna consists of boundary strip only where middle area is completely suppressed. A ‘plus’-shaped metal isolator is imprinted on the top surface of the antenna to achieve high port isolation. The antenna offers the frequency range from 11.87 to 19.05 GHz covering full Ku-band (12 GHz to 18 GHz) with a port isolation of greater than 17 dB. ECC (<0.08), DG (>9.96 dB), CCL (<0.15 bits/s/Hz) and MEG (±0.2 dB) of the proposed antenna are very significant to perform as a MIMO antenna. Overall, the antenna is very compact, low profile and reliable textile MIMO antenna for desired application band.

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