Application of Orthogonal dual/Quad port Wearable MIMO for sub-6 GHz 5G and WLAN/Wi-Max/Wi-Fi Technology in Food Processing System

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Abstract:

The recent trends in food processing industry are demanding the IOT based automation and high-speed transmission of food related metadata over wireless channel. MIMO (multiple-input and multiple-output) antennas with orthogonal dual/quad ports have been proposed for wideband applications which include sub-6 GHz 5G and WLAN/Wi-Max/Wi-Fi. The Ansys HFSS simulator is used to evaluate a wideband single antenna with a frequency range of 2.89 GHz to 6.72 GHz (79.7 %). Then, to address many practical issues, such as signal attenuation, masking, and electromagnetic wave diffraction, a wideband dual/quad-element MIMO antenna is developed. To optimize isolation between radiating patches, antenna elements are arranged orthogonally to achieve greater than 25 dB isolation over the application band. It has been discovered an acceptable range for MIMO diversity parameters such as the envelope correlation coefficient (ECC), diversity gain (DG), mean effective gain (MEG), and channel capacity loss (CCL). This proposed methodology can be applied to diverse fields of engineering science including agriculture, food and environmental science, and health sciences for improving communication effectively.

Keywords: Wideband, MIMO antenna, Envelope Correlation Coefficient, Diversity Gain, Mean Effective Gain.

1. Introduction

New wireless communication technologies and innovative 5G applications are being developed rapidly to address the anomalies pertaining to achieve significantly high bandwidth and minimal jitter in communication [1]. Because single antenna-aided systems cannot match these criteria due to limited channel capacity, MIMO antenna technology was progressed, which facilitates high data rate due to multipath transmission [2]. When multiple radiating elements work together in close vicinity using MIMO technology, there is a high degree of

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coupling between them. Various decoupling techniques were delineated to mitigate the mutual coupling, and an extensive investigation has been undertaken to explain the decoupling method from the state of art techniques [3-6]. A tree-shaped decoupling element was used in an ultra-wideband MIMO antenna [3]. An inter MIMO antenna with a superstrate-based decoupling technique for 3.5 GHz applications has been presented [4]. Jiang et al. demonstrated another MIMO antenna with a cross decoupling structure for mobile applications [5]. Zhang et al established the pattern and polarization diversity of a MIMO antenna in addition to the physical decoupling structure [6]. The antenna is essential for optimal communication in a wearable and implantable environment. The electronic gadget will be more appropriate if it can be incorporated and constructed in a wearable substrate. Wearable technologies are used in telehealth [7], paramedic applications [8, health care, mobile router apps [9], IoT (Internet of Things), and other applications. In wide band communication scenarios, wearable antennas are significant [10].

In the present work, Wide band textile MIMO antenna with reduced mutual coupling is proposed. Antenna with a single element for wideband uses, such as 5G, Wi-Max, and WLAN at frequencies below 6 GHz. MIMO antennas with enhanced isolation (>20 dB) for wideband scenarios have been built and analyzed to increase the performance of the antennas. The proposed orthogonal quad port MIMO antenna has a volume of $70\times74\times1$ mm^3. The diversity performance parameters of MIMO antenna analyzed by using commercially available electromagnetic suite ANSYS HFSS.

2. Design of Basic wideband antenna

The simplest wideband antenna is constructed from a bendable substrate material called jeans with a thickness, ϵ_r , loss tangent and a bulk conductivity of 1mm, 1.77, 0.083 and 0.034S/m respectively. To maximize the wideband bandwidth, multiple T-shaped slots are first incorporated into the rectangular microstrip patch antenna design on a partial ground plane. Figure 1 shows how a radiating element develops over time. As shown in Fig 2 (a), the antenna radiates in the frequency range of 2.89 GHz – 6.72 GHz with a respectable reflection coefficient of -30 dB. The antenna's applications include sub-6GHz 5G (n77/n78/n79), 3.5 GHz Wi-Max, and 5/5.2/5.5/5.8 GHz WLAN/Wi-Max/Wi-Fi. As demonstrated in Fig 2 (b), the antenna has a good radiating efficiency of more than 95 percent across its operational frequency range, and its peak gain is 4 dB.

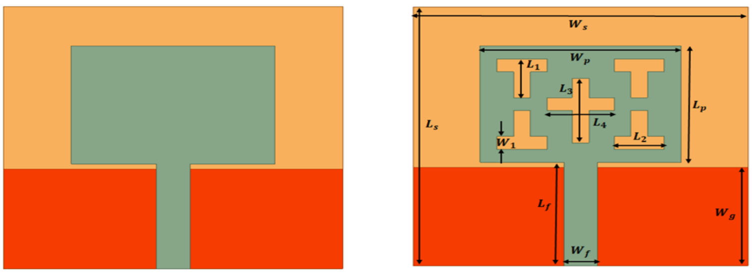

Fig 1. Step by step evolution of basic antenna (design parameters (mm) $L_s = W_s = 40$, $L_p = 18$, $W_p = 24$, $L_f = 16$, $W_f = 3$, $W_g = 15.2$, $W_1 = 2$, $L_1 = L2 = 6$, $L_3 = 10$, $L_4 = 8$)

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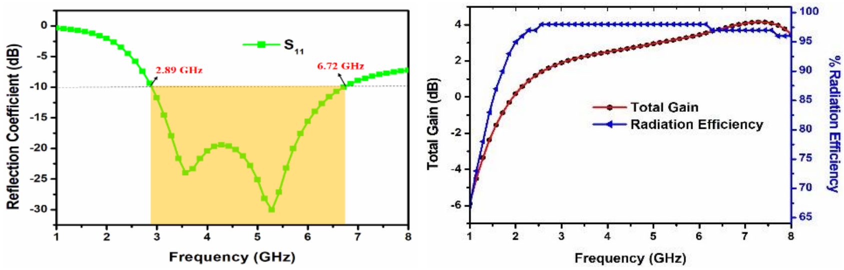
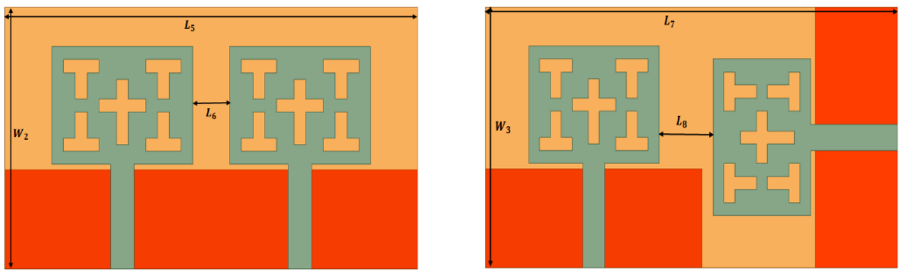


(a) (b)

Fig 2. Simulated (a) Reflection Coefficient (b) gain & radiation efficiency of the basic antenna

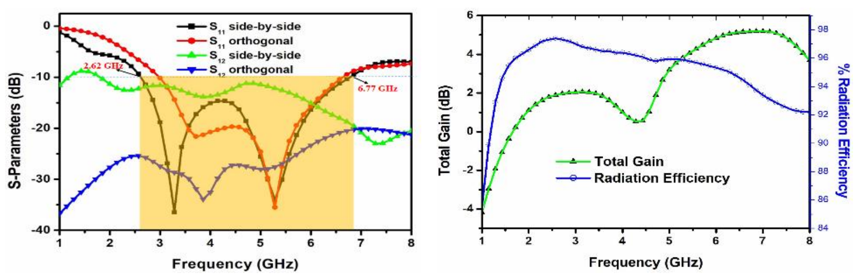
3. Design of dual-element wideband MIMO antenna

There are two ways to construct a dual-port MIMO antenna: side-by-side and orthogonal, as shown in Fig 3. Radiating elements are separated by an inter-element spacing of L6 = L8 = 6.24 mm. However, due to mutual coupling, the side-by-side structure of antennas suffers from inadequate isolation over a wide frequency range (2.62 GHz-6.77 GHz). An orthogonal construction has been proposed to improve port isolation. As can be seen in Fig. 4 (a), which compares the scattering properties of the two structures, port isolation in the orthogonal structure is enhanced by |25| dB. As depicted in Fig 4(b), the antenna's simulated radiation efficiency and peak gain are greater than 94 percent and 5 dB correspondingly. When the surface current distribution is plotted in Fig 5, it can be seen that the second element has a greater effect on structure 1 than on structure 2 because of mutual coupling. The most current is connected to element 1 because of orthogonality.



(a) (b)

Fig 3. Design of dual-port MIMO antenna (a) side-by-side (b) orthogonal structure (design parameters (mm) $W_2 = W_3 = 40$, $L_5 = L_7 = 70$)



(a) (b)

Fig 4. Simulated (a) comparison of S-parameters (b) gain & radiation of the orthogonal MIMO antenna

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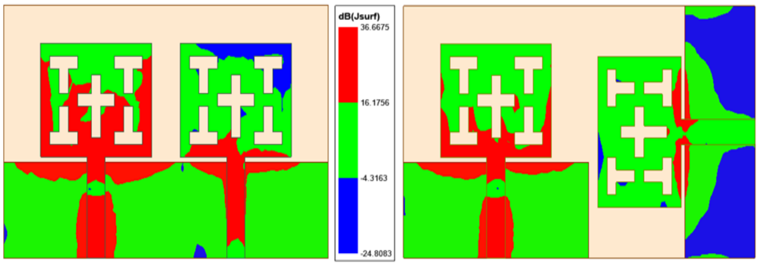
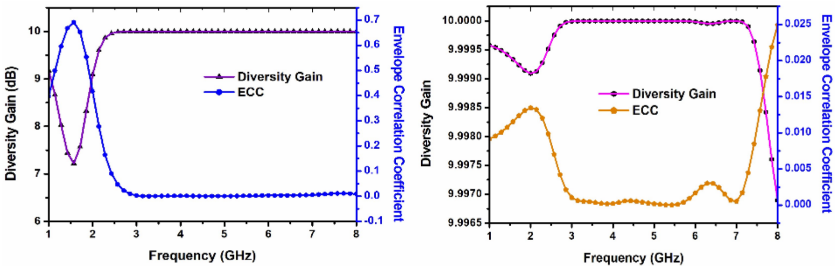


Fig. 5. Comparison of surface current distribution at 5.2 GHz

Envelope Correlation Coefficient (ECC), Diversity Gain (DG), and Mean Effective Gain (MEG), Channel Capacity Loss (CCL), are key parameters to assess the performance of MIMO antenna. The ECC is an essential fundamental constraint that examines the degree to which concurrently transmitted communication channels are separated or connected with one another. It can be determined precisely using the radiation method; the formula is shown in equation (1). In actual applications, the maximum ECC value is 0.5. Diversity is attained by the receiver when it receives various versions of the transmitted stream across distinct channels, and the value of diversity gain (DG) is always near to 10 and can be calculated using the equation (2). As depicted in Fig. 6 (a) and (b), the simulated correlation coefficient of an orthogonal construction is significantly lower (<0.005) than that of a side-by-side structure (<0.1), and the DG value is closer to 10 in the impedance bandwidth.

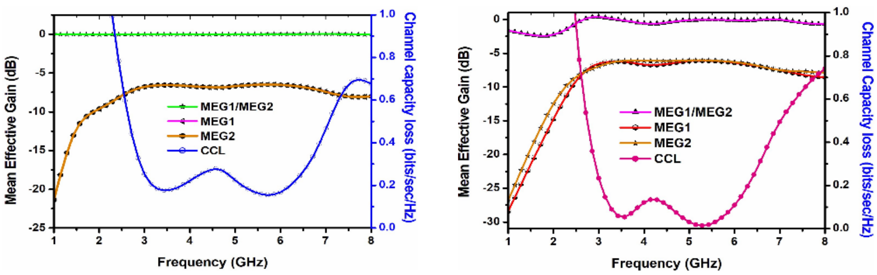
$$\rho_e = \frac{\left| \iint_0^{4\pi} [E_1(\theta,\emptyset) * E_2(\theta,\emptyset) d\Omega] \right|^2}{\iint_0^{4\pi} |E_1(\theta,\emptyset)|^2 \, d\Omega \iint_0^{4\pi} |E_2(\theta,\emptyset)|^2 \, d\Omega} \quad (1)$$

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



(a) (b)

Fig. 6. Simulated ECC and DG of the (a) side-by-side (b) orthogonal structure



(a) (b)

Fig. 7. Simulated MEG and CCL of the (a) side-by-side (b) orthogonal structure

Another measure used to describe MIMO antennas is MEG (mean effective gain). By taking into account the effects of the surrounding environment, MEG measures the antenna's performance. For two-port MIMO antenna MEGs calculated using equations (3 and 4) for equal power levels, the ratio between MEGs must be lower than ±0.3 dB.

$$MEG_1 = 0.5[1 - |S_{11}|^2 - |S_{12}|^2] \quad (3)$$

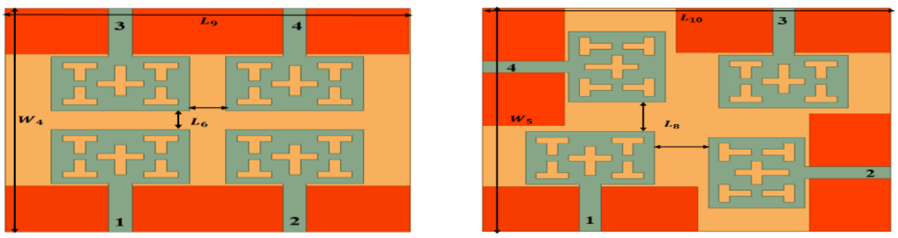
$$MEG_2 = 0.5\,[1 - |S_{22}|^2 - |S_{21}|^2] \quad (4)$$

Furthermore, the CCL (channel capacity loss) parameter provides an insight into the maximum message rate that may be continuously carried via a communication channel. It is recommended that the CCL be smaller than 0.5 bits/s/Hz for optimal MIMO performance. The formula for CCL of the two-port MIMO is described in equation (5). Fig. 7 (a, b) shows the desired values for the simulated CCL and MEG for both designs over the entire operating frequency band. The next section discusses the quad-port MIMO antenna in greater detail.

$$C_{loss} = -log_2 \det(\beta^R) \quad (5)$$

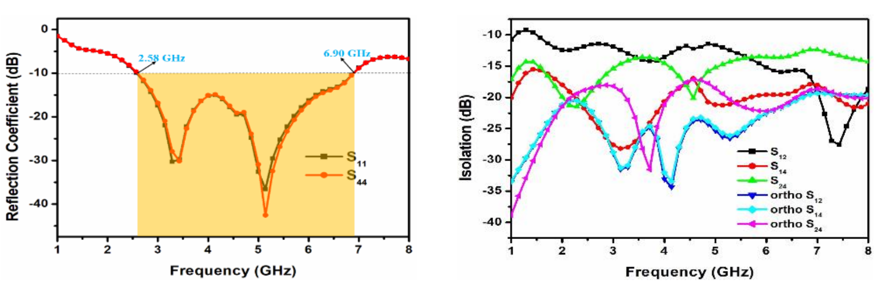
4. Design of quad element wideband MIMO antenna

The quad-port MIMO antenna of both structures are depicted in Fig. 8 (a, b). The simulated scattering parameters are good impedance bandwidth of 4.32 GHz (2.58 GHz -6.90 GHz) is illustrated in Fig. 9, which enhances the isolation among antenna elements by more than 20 dB. Figure 10 shows the surface current distribution of the quad-port MIMO antenna to assess the improvement in isolation. Antenna elements in the relevant frequency range can be isolated from each other in an orthogonal way.



(a) (b)

Fig. 8. Graphical layout of quad element MIMO antenna (a) side-by-side structure (b) orthogonal structure (design parameters (mm) $W_4 = 74$, $L_9 = 70$, $W_5 = L_{10} = 76$, $L_6 = L_8 = 6.24$)



(a) (b)

Fig. 9. Simulates (a) reflection coefficient (b) comparison of transmission coefficient

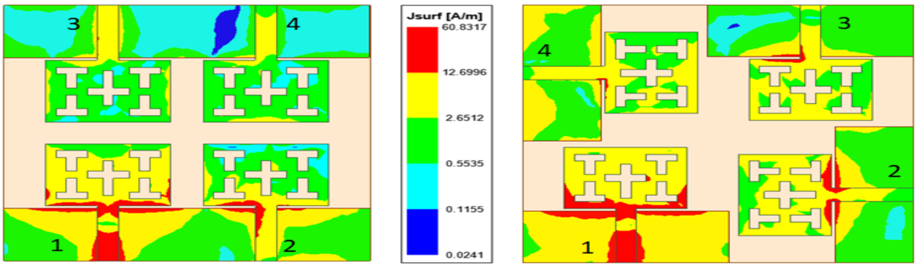
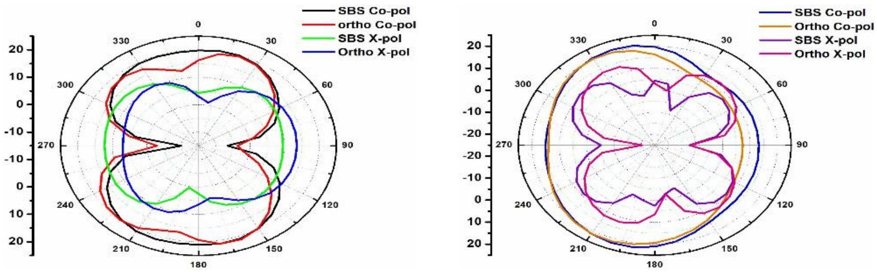


Fig. 10. Comparison of 4-element surface current distribution at 5.2 GHz

The representation of the antenna's radiation distribution is critical since several antennas are used in a single antenna system. Fig. 11 shows the proposed antenna's radiation pattern. In the E and H planes, the antenna emits radiation in a dipole and a monopole pattern respectively. In addition, cross-pole has a substantially lower in the operating frequency than co-pole.



(a) (b)

Fig. 11. Simulated radiation pattern at 5.2 GHz (a) E-plane (b) H-plane

Analysis of the MIMO antenna's ECC, DG, MEG and CCL in detail is necessary for an effective diversity presentation analysis. Figures 12 and 13 show the comparison of the computed ECC and DG. For an orthogonal structure, the ECC is less than 0.1 and the DG is more than 9.98. Because of the improved isolation provided by the proposed antenna, the MEG and CCL are demonstrated in Figs. 14 and 15, respectively, to be within practical limits.

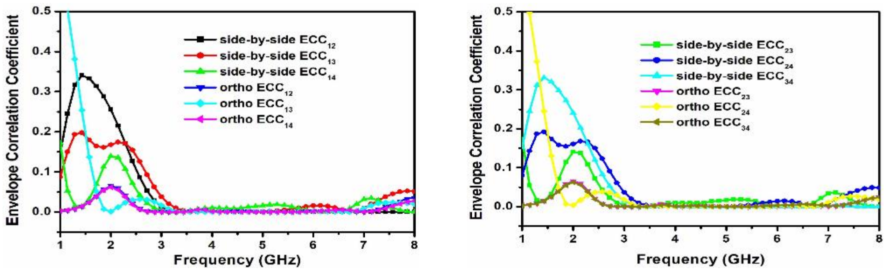


Fig. 12. Comparison of simulated ECC of both four element MIMO antenna

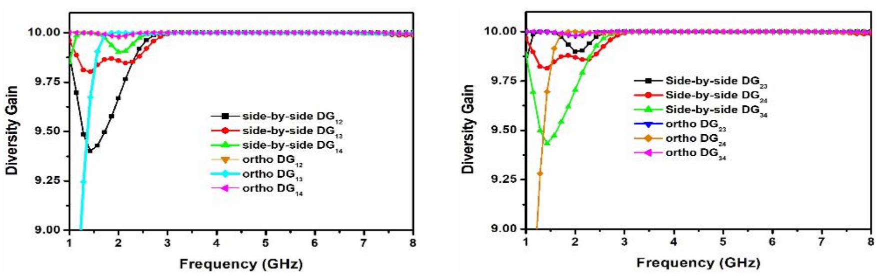


Fig. 13. Comparison of simulated DG of both four element MIMO antenna

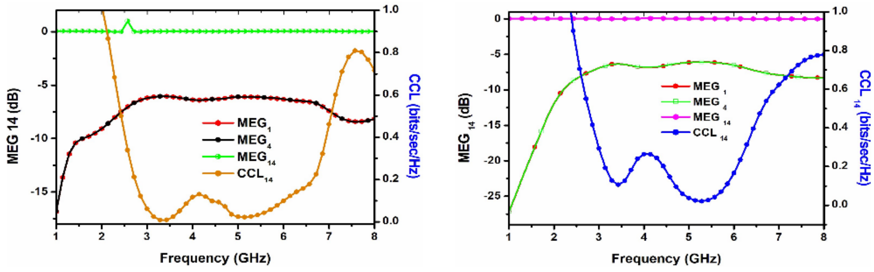


Fig. 14. Simulated MEG_{14} and CCL_{14} of (a) side-by-side (b) orthogonal structure

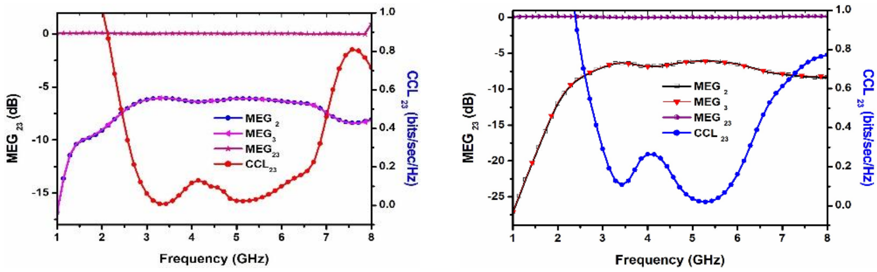


Fig. 15. Simulated MEG_{23} and CCL_{23} of (a) side-by-side (b) orthogonal structure

5. Conclusion

An inexpensive textile wideband MIMO antenna for upcoming sub-6GHz 5G, Wi-Max, WLAN, and Wi-Fi applications is included in this article. It is necessary to construct a basic, wideband antenna before moving on to more advanced MIMO antennas, such as dual port and quad port MIMO antenna, which can cover the frequency range from 2.58 GHz to 6.90 GHz and have better isolation (>20 dB) across the spectrum. For the MIMO antennas, the diversity performance parameters are ECC < 0.01, DG> 9.98, MEG<-3 dB, and CCL < 0.1 bits/sec/Hz, implying an enrichment of the operating band. The proposed scheme may be instrumental in making effective communication in the various field of science and engineering applications spanning from agricultural sector to modern health care systems.

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