Compact 4 × 4 UWB-MIMO antenna with WLAN band rejected operation

M.S. Khan✉, A.D. Capobianco, S. Asif, A. Iftikhar, B. Ijaz and B.D. Braaten

A compact planar UWB-MIMO antenna array with WLAN band rejection is presented. The array consists of four monopole radiators and a common ground plane. These monopoles are placed in such a way that the polarisation diversity of nearly placed radiators is exploited, resulting in high isolation. The proposed MIMO antenna array is electrically small (50×39.8 mm^2), printed on a low loss 1.524 mm thick Rogers TMM4 laminate with a dielectric constant of 4.5 and a loss tangent of 0.002. A band-stop design was inserted on the ground plane to behave similar to a LC band-stop filter and reject the WLAN band. Simulation and measurement results satisfy the return loss requirement of better than 10 dB and isolation better than 17 dB over the entire 2.7–5.1 and 5.9–12 GHz bandwidths.

Introduction: The transmission capacity and reliability of a system can be improved by using diversity techniques without increasing the bandwidth and power. Various techniques have been investigated to combine UWB technology with MIMO techniques to reduce the mutual coupling between elements while attaining compact size. Owing to the overlap of the existing WLAN service bands (5.15–5.35 and 5.75–5.825 GHz) with that of the UWB (3.1–10.6 GHz), radio signals can interfere. To mitigate this problem, UWB antennas with good band-stop characteristics have been reported [1–6]. In [1], a stub structure acting as a band-stop filter was used to suppress the coupling between the four elements and an electromagnetic bandgap structure was used to reject the WLAN band. A short stub was inserted to reject the WLAN band and parasitic meander lines were used to improve isolation between the elements in [2]. In [3], polarisation diversity was exploited between nearly placed radiators and different types of resonators were used to realise band notch characteristics at three different bands. High isolation was obtained by exploiting polarisation diversity and an extended ground plane; also, slots were etched in the radiators to reject the 5 GHz band [4]. Again, polarisation diversity was used to enhance the mutual coupling and slots were used to reject the WLAN band in [5, 6].

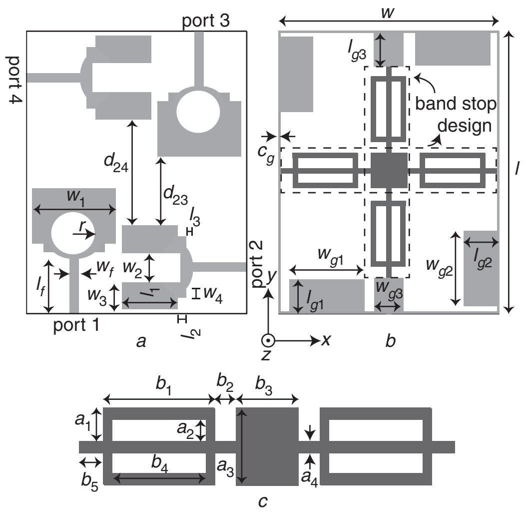

Fig. 1 *Geometry of proposed UWB-MIMO antenna*

a Top view; *b* bottom view; *c* band-stop design
Optimised dimensions in millimetres are: $w = 39.8$, $l = 50$, $w_1 = 15$, $w_2 = 5$, $w_3 = 5$, $w_4 = 2.26$, $l_1 = 10$, $l_2 = 1.5$, $l_3 = 1.1$, $w_f = 1.5$, $l_f = 9.85$, $d_{23} = 12$, $d_{24} = 18.95$, $w_{g1} = w_{g2} = 13.5$, $w_{g3} = 5$, $l_{g1} = l_{g2} = 6.25$, $l_{g3} = 5.1$, $c_g = 0.5$, $a_1 = 2$, $a_2 = 1$, $a_3 = 5$, $a_4 = 1$, $b_1 = 13.7$, $b_2 = 1.7$, $b_3 = 5$, $b_4 = 11.7$, $b_5 = 1.5$

In this Letter, a compact, four-element planar UWB-MIMO antenna array with WLAN band rejection is presented. The band rejection characteristics are achieved by etching a band-stop design on the ground plane. These four elements are placed such that the polarisation diversity of nearly placed elements is exploited to reduce the mutual coupling between them. Compared with the four-element UWB-MIMO antennas reported in [1, 3], the proposed antenna has a compact size of $39.8 \times 50 = 1990$ mm^2, which is about 45% smaller than reported designs. A detailed description of the design, and simulated and measured results, are discussed in the following Sections.

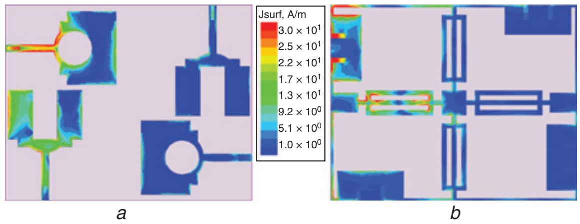

Fig. 2 *Simulated surface current distribution at 5.5 GHz while feeding only port 1*

a Top view; *b* bottom view

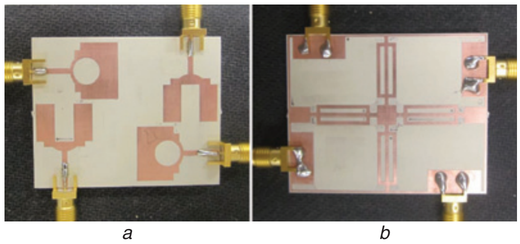

Fig. 3 *Fabricated photograph of proposed prototype*

a Top view; *b* bottom view

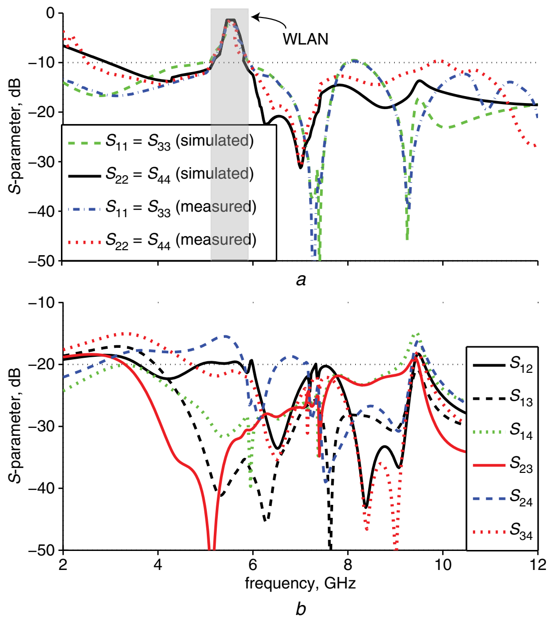

Fig. 4 *Simulated and measured S-parameters of antenna*

a Simulated and measured S_{11} and S_{22}; *b* measured mutual coupling

Antenna design: Fig. 1 shows the geometry and dimensions of the proposed UWB-MIMO antenna. Initially, a wideband monopole with a partial ground plane, having a circular slot in the radiator, was designed in the high-frequency structure simulator. A second radiator was then placed perpendicularly to the first element to exploit the polarisation diversity. A U-shaped slot was inserted to improve the wideband matching. The ground planes of both radiators were connected through a strip of width c_g. In similar fashion, two more radiators were placed and the ground planes were connected through strips. A wideband matching from 2.7 to 12 GHz and isolation of more than −20 dB were achieved. Next, the stop-band design comprising the stubs was connected to the ground plane. The dimensions of these stubs are approximately $b_1 = (\lambda/2) = (c/(2f_o.\sqrt{\epsilon_r}))$ where $f_o = 5.5$ GHz is the central frequency of the rejected band and ε_r is the relative permittivity of the substrate. The stop-band design provides an extra path for the current to flow and acts as a LC band-stop resonator, since the gap between the stubs acts as a capacitor and the stubs themselves act as inductors, resulting in a structure that can be thought of as an equivalent band-stop filter. To show the effectiveness of the band-stop design, the surface currents at 5.5 GHz are shown in Fig. 2, when port 1 was excited. The currents on the ground travelled through the band-stop design which is close and along the direction of element 1 on the ground plane as shown in Fig. 2*b*. This current produces the resonance and rejects the band; similarly, other parts of the design reject the band when the other elements are excited.

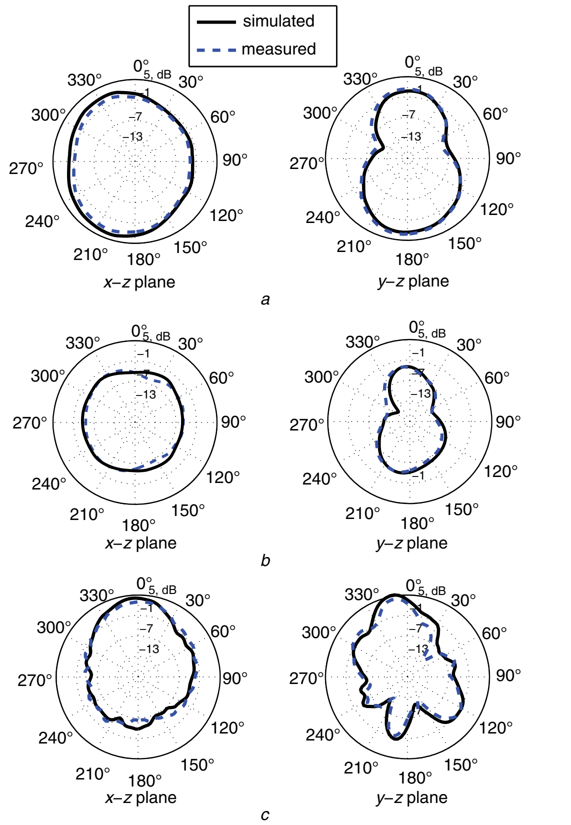

Fig. 5 *Simulated and measured radiation patterns of proposed antenna, only port 1 was excited*

a 3 GHz; *b* 5.5 GHz; *c* 9 GHz

Results and discussion: The proposed antenna was fabricated on a 1.524 mm-thick Rogers TMM4 laminate with a relative permittivity of 4.5 and a loss tangent of 0.002, as shown in Fig. 3. The measurements were taken using an Agilent network analyser. The measured return loss was better than 10 dB in the complete band of 2.7–12 GHz except from 5.1 to 5.9 GHz and the measured isolation was better than 17 dB. The simulated return loss is plotted along with the measured return loss in Fig. 4*a*. Slight variations were observed when compared with the simulated results, which is attributed to the fabrication imperfection and lossy connectors. For clarity, only the measured isolation is plotted in Fig. 4*b*. It is shown that isolation between elements 2 and 4 is minimum because both antennas are on the same axis but it is still <−17 dB. The radiation patterns of the proposed antenna were measured at 3.0, 5.5 and 9.0 GHz and are plotted in Fig. 5 along with the simulated patterns. During the measurements, only port 1 was excited and the other ports were terminated with a 50 Ω load. At lower frequencies, the patterns are omnidirectional in the *x*–*z*-plane (*H*-plane) for element 1.

However, at the higher frequencies the patterns are less omnidirectional, this is due to the combined ground plane and stop-band design, which changes the current path on the ground plane, hence modifying the pattern. Similarly for the *y*–*z*-plane (*E*-plane), the patterns are fairly dumb-bell shaped at lower frequencies but at higher frequencies the patterns are not, due to the modified ground plane. Note that the level of patterns at 5.5 GHz are low in both the *x*–*z* and the *y*–*z* planes due to band rejected characteristics, as shown in Fig. 5*b*. Overall, good agreement was observed at the lower frequencies while slight variations at the higher frequencies arise due to the SMA connector losses.

Fig. 6 shows the gain variation of the proposed antenna over the complete operating band. Good agreement between simulated and measured results can be observed. In the rejected band of 5.5 GHz, the peak gain reduces to −3.5 dBi. In the remaining band, the gain of the antenna varies from 2.5 to 6 dBi. The performance of the MIMO system can be estimated by the envelope correlation coefficient (ECC). The ECC between antennas i and j in the (N, N) MIMO antenna system can be computed from the S-parameters using equation (5) in [7]. Considering a case when $i = 1$, $j = 2$ or 3 and $N = 4$, the computed values of the ECC from the measured S-parameters were found to be below 0.01 across the operating band. This demonstrates that the proposed antenna is a good candidate for diversity applications.

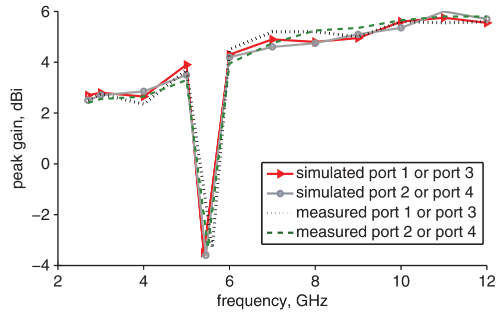

Fig. 6 *Simulated and measured peak gain of proposed antenna over complete radiating band*

Conclusion: A compact four-element UWB-MIMO antenna array with WLAN rejection is proposed. These four elements are placed on the top side of the substrate. Polarisation diversity between nearly placed elements is exploited. On the bottom side of the substrate a band-stop design is etched to act similar to a LC band-stop filter which rejects the band from 5.1 to 5.9 GHz. Isolation of more than 17 dB, low envelope correlation, good radiation characteristics and good agreement between the simulated and measured results have been achieved, making the proposed antenna a good candidate for small handheld and portable devices.

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One or more of the Figures in this Letter are available in colour online.

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