Dual-band MIMO Antenna with Band-stop Decoupling Network

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Abstract. A dual-band MIMO antenna operating at 2.5 GHz and 5.8 GHz which can be used for WLAN application is presented in this paper. Simulation, fabrication and measurement are accomplished to verify the antenna performance. As a simplified design process, firstly a band-stop filtering network is presented to achieve port isolation. And a MIMO antenna is designed through appropriate adjustments. The antenna can provide more than 20 dB isolation at both operating frequencies.

1. Introduction

In complex environments such as mountainous areas and dense urban buildings, there is a multipath effect in the transmission process of radio waves, which leads to the decline of signal quality and seriously affects the reliability of communication. In 1990s, Bell LABS proposed Multiple-Input Multiple-Output (MIMO) technology [1]. Through different diversity methods, MIMO technology can generate diversity gain, which can effectively suppress the influence of fading, reduce inter-code interference and bit error rate [2-3]. It is proved that MIMO technology can effectively suppress space fading and multipath effect and improve communication reliability throughput without increasing transmission power and communication bandwidth [4].

Recently, MIMO antenna tends to be miniaturized. However, there is strong coupling among adjacent antenna units in finite space, which will reduce the performance of MIMO antenna. Therefore, high isolation among antenna units is the key to ensure the performance of MIMO antenna. Some designs on decoupling method of MIMO antenna were proposed [5-8], including adding stubs or slots on the ground, using neutral line between antenna units and adding decoupling network near the feeding ports. However, these methods need to design the radiator section at first, then the decoupling part should be added, which usually need additional impedance matching structures.

In the previous research [9], a filtering micro-strip antenna with the coupling line structure was proposed. Based on [9], this paper presents a dual frequency MIMO antenna. Firstly a tri-band band-stop filtering structure having port isolation characteristics is proposed, then part of the structure is converted into a monopole which has the ability to radiate. Two stop-bands of the filter structure are adjusted to the operating frequency of the radiator. Thus, a dual-band MIMO antenna worked in WLAN band is obtained, which has more than 20 dB isolation at both frequencies.
2. Design of the band-stop network structure

2.1. Structure and theory of the band-stop network

Based on paper [9], an improved coupling line loading short circuit stepped impedance resonator is proposed, which can provide three stop bands. The Transmission line equivalent circuit is shown in Figure 1. \( Z_i \) \( (i = 1, 2, c, m) \) and \( \theta_j \) \( (j = 1, 2, c, t, m) \) represents the impedance and electrical length of micro-strip lines respectively.

This structure consists of a pair of coupling line and a short circuit stepped impedance resonator (SIR). In order to analyse conveniently, the section in the dashed box is seen as a four-port-network, which has port voltage and current presented as \( v_p \) \( (p = 1, 2, 3, 4) \) and \( i_q \) \( (q = 1, 2, 3, 4) \). And the section of short circuit SIR is seen as the load impedance \( Z_L \). The ABCD parameters of the four-port-network can be expressed as follows [10]:

\[
\begin{bmatrix}
A & B \\
C & D
\end{bmatrix} = \begin{bmatrix}
\cos \theta_c & j Z_c \sin \theta_c \\
\sin \theta_c & \cos \theta_c
\end{bmatrix}
\] (1)

The voltage and current parameters can be expressed as

\[
\begin{bmatrix}
v_1 - v_2 \\
i_1 - i_2
\end{bmatrix} = \begin{bmatrix}
\cos \theta_c & j Z_c \sin \theta_c \\
\sin \theta_c & \cos \theta_c
\end{bmatrix} \begin{bmatrix}
v_4 - v_3 \\
-(i_4 - i_3)
\end{bmatrix}
\] (2)

\[
\begin{bmatrix}
v_1 + v_2 \\
i_1 + i_2
\end{bmatrix} = \begin{bmatrix}
\cos \theta_c & j Z_c \sin \theta_c \\
\sin \theta_c & \cos \theta_c
\end{bmatrix} \begin{bmatrix}
v_3 + v_4 \\
-(i_3 + i_4)
\end{bmatrix}
\] (3)

Where \( Z_{co} = Z_c \left( \frac{1-k}{1+k} \right)^{1/2} \) and \( Z_{ce} = Z_c \left( \frac{1+k}{1-k} \right)^{1/2} \) are odd mode and even mode impedance of the coupling line, \( k \) represents the coupling coefficient. On account of the open end, it can be easily obtained that \( i_2 = 0 \), \( i_3 = 0 \), and \( v_4 = i_4 = Z_L \). Combined with formula (2) and (3), the input impedance of the network can be presented as

\[
Z_{in} = \frac{v_1}{i_1} = \frac{\sqrt{1-k^2} Z_c \tan \theta_c + j Z_c k^2 \tan^2 \theta_c - (1-k^2)}}{\sqrt{1-k^2} Z_c \tan \theta_c + j (1-k^2) Z_c \tan^2 \theta_c}
\] (4)

Where \( Z_{L} \), \( Y_{A} \) and \( Y_{B} \) are the input impedance and admittance seen from the arrows indicated in Figure 1, which can be presented as follows:

\[
Z_{L} = Z_p \left( \frac{Y_{A} + Y_{B}}{Y_{B} + Z_p} \right)^{-1} + j Z_c \tan \theta_c
\] (5)
\[ Y_A = -\frac{j \cot \theta_1}{Z_1}, \quad Y_B = -\frac{Z_2 + Z_3 \tan(\theta - \theta_1) \cot \theta_1}{Z_3 \tan(\theta_1 - \theta) - Z_3 \cot \theta_1} \]  \tag{6}

According to the resonance condition of the band-stop filter, the stop band of the network while \( \text{Im}(Z_{in}) = 0 \), and the operating frequencies can be obtained by solving formula (4) – (6).

2.2. Analysis of the band-stop network

The equivalent circuit of the band-stop structure is established and simulated in software Agilent Advanced Design System. As is shown in Figure 2, three stop bands and two transmission poles are obtained. While the impedance and electrical length of micro-strip lines are set as shown below Figure 2, three stop band \( f_{s1} = 2.7 \text{GHz} \), \( f_{s2} = 5 \text{GHz} \) and \( f_{s3} = 5.86 \text{GHz} \).

![Figure 2](image)

Figure 2. Simulated S parameter of the band-stop network, while \( Z_c = Z_m = Z_1 = 57 \Omega \), \( Z_2 = 37.4 \Omega \), \( \theta_c = 90^{\circ} \), \( \theta_1 = 21.6^{\circ} \), \( \theta_2 = \theta_m = \theta_t = 10.8^{\circ} \).

Through simulation, it is observed that \( f_{s1}, f_{s2} \) and \( f_{s3} \) can be influenced by adjusting \( \theta_c, \theta_1, \theta_2, \theta_t \) and impedance ratio between \( Z_1 \) and \( Z_2 \). While several parameters are set as: \( Z_c = Z_m = Z_1 = 57 \Omega \), \( \theta_m = \theta_t = 10.8^{\circ} \), the stop-band frequency will be affected by \( \theta_c, \theta_1/\theta_2 \) and \( Z_1/Z_2 \). The simulation result is shown in Figure 3.

![Figure 3](image)

Figure 3. Simulated S21 of the band-stop network as a function of the different parameters. (a) \( \theta_c \) from 90 degrees to 130 degrees. (b) \( \alpha = \theta_1/(\theta_1 + \theta_2) \) from 0.6 to 0.8. (c) \( R_z = Z_1/Z_2 \) from 1.5 to 2.5.

From Figure 3(a), it is observed that \( f_{s1}, f_{s2}, f_{s3} \) are all affected by the electrical length of the coupling line \( \theta_c \), when \( \theta_c \) is increased, all stop band tend to the lower direction. And \( \theta_c \) equals approximately 90 degrees at \( f_{s2} \), which means \( \lambda/4 \) wavelength at the second frequency. Figure 3(b) shows that both \( f_{s2} \) and \( f_{s3} \) decrease while the electrical length ratio \( \alpha \) between \( Z_1 \) and \( Z_2 \) increases from 0.6 to 0.8, meanwhile it has a negligible effect on \( f_{s1} \). From Figure 3(c), both \( f_{s2} \) and \( f_{s3} \) decrease while the impedance ratio \( R_z \) between \( Z_1 \) and \( Z_2 \) increases from 1.5 to 2.5.
results mentioned above, it is summarized that the three stop band frequencies $f_{s1}$, $f_{s2}$ and $f_{s3}$ of the band-stop filtering network can be controlled independently and can be adjusted to proper position.

3. Dual-band MIMO antenna design

3.1. Antenna configuration

A coupling line loading short circuit SIR network is proposed in section 2, which can provide three individually controllable stop bands. In order to apply the network to MIMO antenna, several parts of the network should be changed to make it achieve the radiation ability.

![Figure 4](image)

Figure 4. (a) The geometry and dimension of the MIMO antenna. (b) The geometry and dimension of the ground on backside. $w1 = w2 = 1.5$ mm, $w3 = 0.8$ mm, $w4 = 3.5$ mm, $wf = 1.9$ mm, $wg = 25$ mm, $l1 = 16.5$ mm, $l2 = 21.4$ mm, $l3 = 5.5$ mm, $l4 = 21$ mm, $l5 = 13$ mm, $l6 = 19$ mm, $l7 = 1.8$ mm, $l8 = 6.8$ mm, $l9 = 9.5$ mm, $l10 = 7$ mm.

The detail parameters of the proposed antenna are shown in Figure 4. The structure is printed on an FR4 substrate with 1 mm thickness, dielectric constant 4.4 and dielectric loss Angle of tangent 0.02. The dimension of the substrate is $W = 54$ mm, $L = 40$ mm. The structure of the antenna is designed based on the band-stop filtering network proposed in section 2. Part of coupling line and short circuit SIR is transformed into a monopole form, which enables the structure radiation ability. Dimension parameters are different from the original network on account of the structure changes, and they are simulated and optimized with Ansoft High Frequency Structure Simulator (HFSS) software.

3.2. Simulation and measurement result

Figure 5(a) shows the simulation and measurement result of $S11$ and $S21$. The simulated and measured results are well-matched. Two radiation frequencies are obtained as $2.2$ GHz – $2.6$ GHz and $5.6$ GHz – $5.9$ GHz, which can be used for WLAN band. The return loss is more than 20 dB at both of the band. And at each band, $S21$ is more than 15 dB which means well isolation between two antenna ports. It can be observed from Figure 5(a) that only two stop bands are achieved, the second stop band at $5$ GHz is deteriorated and at this band $S21$ is about -10 dB, as a result of the structure changes from filtering network to antenna.

Figure 5(b) gives the circuit distribution at $2.5$ GHz and $5.8$ GHz, two resonant modes are generated at the operating frequencies. At $2.5$ GHz, most circuit distributes on the edge of the whole radiation structure. At $5.8$ GHz, most circuit distributes on the edge of part of coupling line and the short circuit SIR branch connected to ground. While port 1 is active, there is nearly no circuit distribution at port 2 and the right antenna unit, well isolation is achieved.

4. Conclusions

A dual-band MIMO antenna with decoupling network is presented and fabricated in this paper. Two operating frequencies $2.2$ GHz – $2.6$ GHz and $5.6$ GHz – $5.9$ GHz are achieved, which can be used for WLAN band.
Figure 5. (a) The measured and simulated S11 and S21. (b) The circuit distribution at 2.5GHz. (c) The circuit distribution at 5.8GHz

Compared to traditional decoupling methods, a band-stop which has port isolation characteristic is firstly presented, and then the antenna can be obtained by transforming part of the structure into radiation form. The design process can be simplified via this way. However, it is worth noting that while changing part of the band-stop network into radiator, the frequency response changes at same time, parameters should be carefully adjusted.

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