

Isolation Enhancement Between Two Packed Antennas With Coupling Element

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Abstract—This letter introduces a coupling element to enhance the isolation between two closely packed antennas for 2.4-GHz wireless local area network (WLAN) application. The proposed structure occupies two antenna elements and a coupling element in between. By putting a coupling element that artificially creates an additional coupling path between the antenna elements, the antenna isolation can be enhanced. The advantage of this design is that no extra space is needed for antenna elements. With the proposed design, more than 15 dB isolation can be achieved for two parallel individual inverted-F antennas (IFAs) with 5-mm spacing. Parametric studies for the design are also included to show how to increase isolation bandwidth and control the isolation frequency.

Index Terms—Coupling element, inverted-F antennas (IFAs), isolation, wireless local area network (WLAN).

I. INTRODUCTION

THE ISOLATION between antennas is a critical parameter in many practical applications such as antenna arrays, diversity antennas, and also multiple-input-multiple-output (MIMO) communication systems. However, when antennas are closely packed, strong mutual coupling will degrade radiation patterns and decrease antenna efficiency, which will cause deterioration in signal-to-noise ratio and signal to-interference-plus-noise ratio of the systems [1]. For planar inverted-F antennas (PIFAs) oriented either collinear, orthogonal, or parallel above a single ground plane with air substrate, it is often stated that the interelement spacing should be at least greater than half of the free space in order to achieve high isolation [2]. Many papers have been presented for isolation enhancement between packed antennas. For example, mushroom-like electromagnetic band-gap (EBG) structures can suppress the surface wave between antenna elements [3] and thus reduce the mutual coupling between antenna elements. In [4], the method of using lumped circuit networks on the input ports is proposed to decouple two closely spaced PIFAs. With the decoupling circuit networks, the isolation between the two PIFAs can be improved up to 30 dB. In [5], a suspended neutralization strip is inserted and physically connected to the antenna elements for improving isolation. This line samples a certain amount of the signal on one antenna element and

delivers to the other antenna element in order to cancel out the existing mutual coupling. In [6], a novel way to achieve neutralization of the antenna through folded lines connected to a printed circuit board (PCB) was proposed for antenna isolation. In [7] and [8], a coupling element is introduced to improve the antenna isolation. However, extra space is needed for this design. In [9], the embedded strip resonator between two PIFAs is used for antenna isolation improvement. However, the proposed design occupied a large space between the antennas.

In this letter, we propose a new coupling element between the antennas in order to create an additional coupling path for enhancing the isolation. The coupling element is placed between antennas and therefore no extra space is needed with this design. This coupling element is not physically connected to the antenna elements and is flexible for controlling the center frequency, bandwidth, and level of isolation. To demonstrate the idea, two antenna elements for using in 2.4 GHz WLAN band are studied. From this study, it is found that the design can achieve more than 15 dB isolation improvement with 5 mm antenna spacing. The detail parametric studies are provided, which show the design of the proposed structure.

II. ANTENNA DESIGN

The details of our proposed design are shown in Fig. 1. It can be seen that two identical antenna elements operated at 2.4 GHz are integrated on a low-cost FR4 substrate with a PCB thickness of 1.6 mm and relative permittivity is 4.3. Their edge-to-edge separation is just 5 mm ($0.04 \lambda_0$). The antennas are located on the top left-hand side and right-hand side of the PCB, respectively, and the resonant length is approximately a quarter-wavelength. The coupling element is introduced for enhancing isolation. It is located between the two antenna elements and occupies the dimension of $5 \times 13 \text{ mm}^2$. The proposed coupling element is formed by a coupling pad and a thin wire connected to backside ground. The advantage of this design is that no extra space is needed for antenna elements. The concept for isolation enhancement with this design is discussed briefly.

Assume the excited current is fed into Antenna 1. Since Antenna 2 is placed very close to Antenna 1, the strong coupled current on Antenna 2 is approximately 180° out of phase with the excited current. The proposed coupling element is placed between the two antennas. In this condition, the coupling starts from Antenna 1, through to the coupling element, which, in turn, couples to Antenna 2. The coupled current on coupling element is approximately in phase with excited current on Antenna 1. If the coupling element in this path is adjusted properly, the two coupled currents can be canceled out so that the overall resultant coupled current is canceled. The addition

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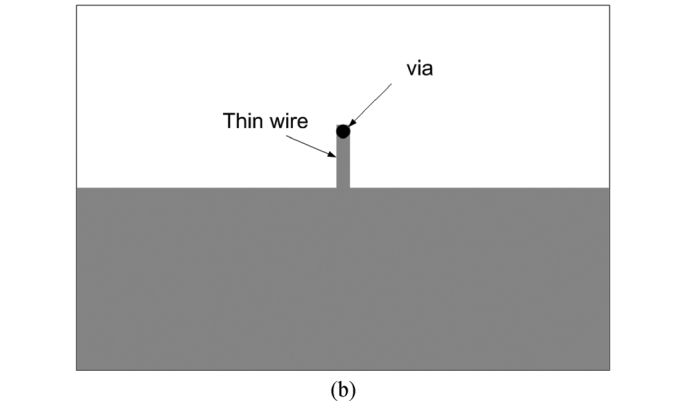
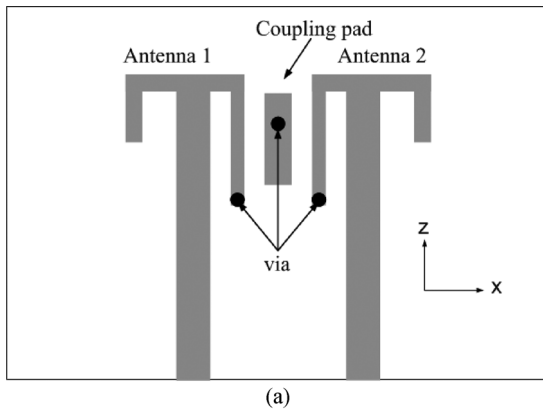


Fig. 1. Geometry of two antennas using coupling element for isolation enhancement. (a) Front side. (b) Back side.

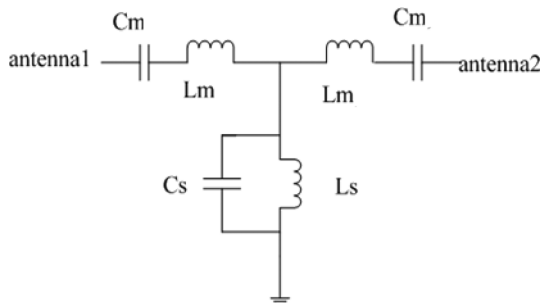


Fig. 2. Equivalent circuit model of the coupling element.

of the coupling element will also affect the self-impedance of the antennas, and this effect can be handled by adjusting the antenna matching appropriately.

III. PARAMETRIC COUPLING ELEMENT STUDY

We have performed the parametric studies, and they explain how to control the center frequency, bandwidth, and level of isolation. The coupling element structure will significantly affect isolation improvement. The circuit model of the proposed design is shown in Fig. 2. The L_s and C_s are the ground inductance and self-capacitance of the coupling element. The L_m and C_m represent the mutual inductance and mutual capacitance between the antenna and the coupling element. The parameters of the equivalent circuit are studied. The capacitance C_m and ground inductance L_s will significantly affect the isolation level

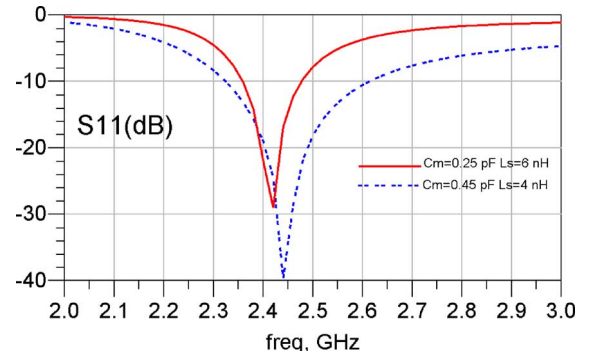


Fig. 3. Simulated S -parameters for equivalent circuit model.

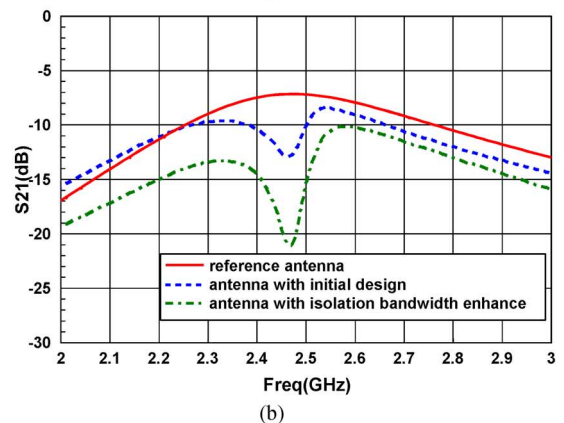
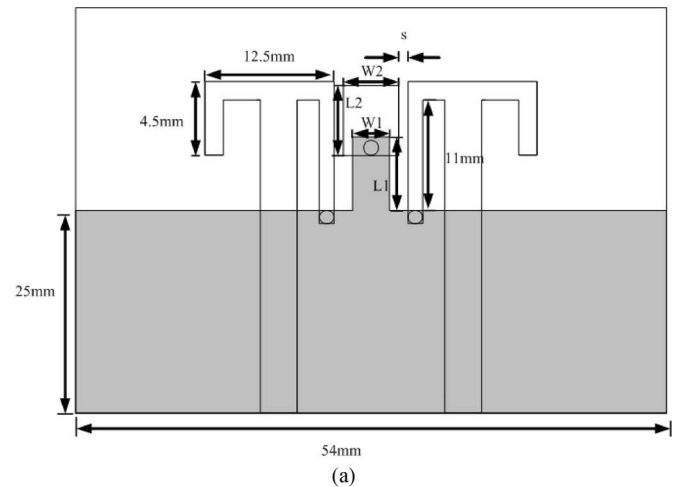


Fig. 4. (a) Proposed design for isolation bandwidth enhancement. (b) Simulated S -parameters for the proposed design.

and bandwidth. In this letter, L_m and C_s are extracted from the Ansoft Q3D Extractor, and they are 1.5 nH and 0.2 pF, respectively. Similar L_m and C_s values also can be obtained from analytical formula. First, the $C_m = 0.25$ pF and $L_s = 6$ nH are used for operation at 2.4-GHz band. The simulated S_{11} based on the Agilent ADS commercial tool is shown in Fig. 3. The increase of the mutual capacitance and reduction of the ground inductance are considered. The C_m and L_s are changed to be 0.45 pF and 4 nH, respectively. From this circuit model, it is found that the bandwidth of the coupling element can be improved with increasing the mutual capacitance.

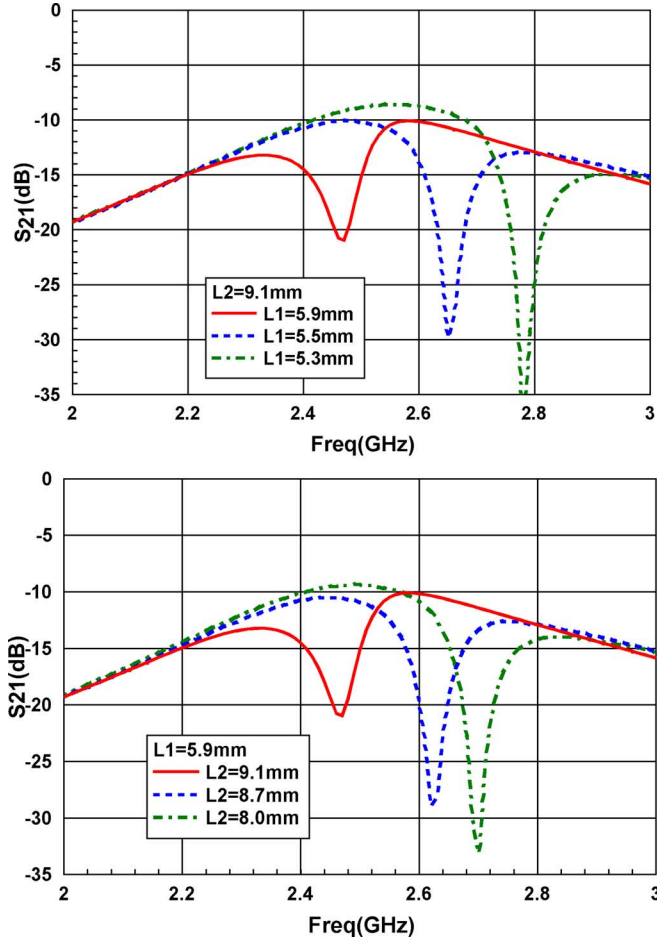


Fig. 5. Parametric study of the coupling element.

Increasing the bandwidth of the coupling element will also increase the isolation level. The reason is that increase the capacitance will increase the field strength of the coupling element, which cancels out the mutual coupling between antenna elements and thus enhances the isolation. To verify the effect of isolation bandwidth improvement, the antenna structure of Fig. 4 is studied. By controlling the size of the coupling pad and thin wire, the coupling element can be operated at 2.4-GHz WLAN band. The detailed geometry of the coupling element is shown in Fig. 4. For the initial design, the geometry parameters $L_1 = 7$ mm, $W_1 = 1$ mm, $L_2 = 9.5$ mm, and $W_2 = 2.6$ mm. The corresponding gap s between the coupling element and antenna is 1.2 mm. The coupling element is then modified to increase the capacitance between the antenna and coupling element. The width of the ground wire W_1 is also increased to reduce the ground inductance for operation at 2.4 GHz. The proposed design with $L_1 = 5.9$ mm, $W_1 = 4$ mm, $L_2 = 9.1$ mm, and $W_2 = 4.5$ mm is studied. The gap s is changed to be 0.25 mm. The simulated isolation for the proposed design is shown in Fig. 4. The results are compared to reference antenna elements without coupling element. From the simulation results, it is found the bandwidth of this design can be significantly improved and the isolation can be above 15 dB for 2.4-GHz WLAN band.

The parametric study is based on the geometry given in Fig. 4. Referring to Fig. 4, the coupling element has two key param-

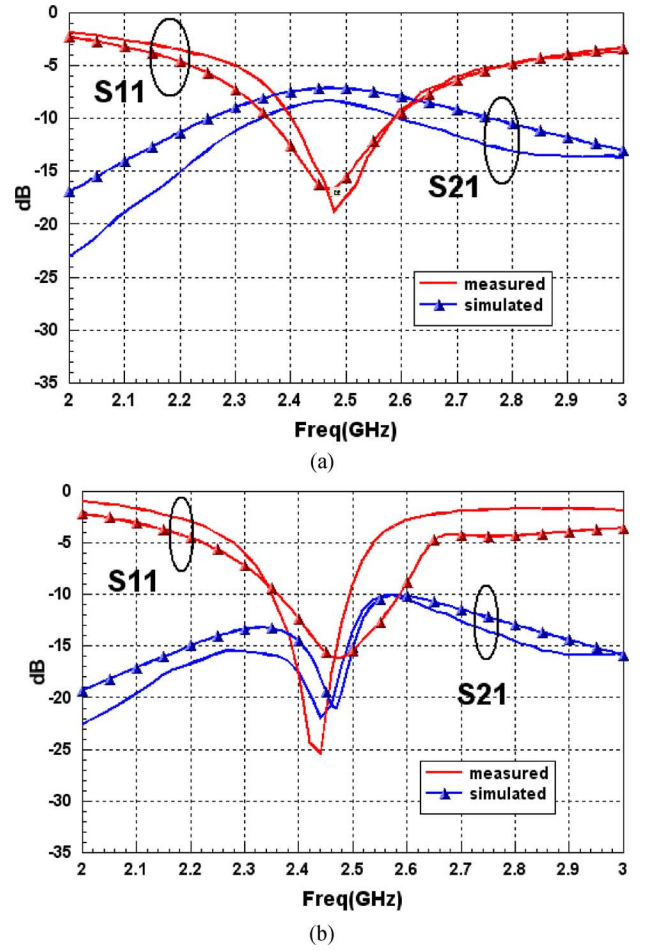


Fig. 6. (a) Measured S -parameters for the reference antenna elements. (b) Measured S -parameters of the proposed design with isolation enhancement.

eters, which we refer to the L_1 and L_2 as labeled in Fig. 4. We simulate the proposed structure in Fig. 4 and vary these two parameters to understand how to control the structure. For the studies on the effect of L_1 , first we fix the value L_2 and vary the L_1 from 5.3 to 5.9 mm. Increasing L_1 will increase the parasitic inductance. In Fig. 5, we can observe that the position of the maximum isolation shifts to a lower frequency when the L_1 increases. Second, we fix the value of L_1 and vary L_2 from 9.1 to 8.0 mm. The parasitic capacitance between the coupling element and antennas will be decreased after decreasing the L_2 length. In Fig. 5, we can observe that the position of the maximum isolation shifts to higher frequency when the L_2 decreases. From the result, we can notice that both the L_1 and L_2 have a significant effect on the position of maximum isolation. It is found that they control the resonant length of the coupling element and shift the position of maximum isolation in the frequency range.

IV. MEASUREMENT RESULTS

The simulated and measured results are shown in Fig. 6. The isolation between the two antennas is 8 dB at 2.45 GHz for the reference antenna without coupling element. With the proposed coupling element occupied between the antennas, a maximum isolation above 22 dB for 2.4-GHz WLAN band can be obtained. Although there is a slight frequency shift of the S_{11} ,

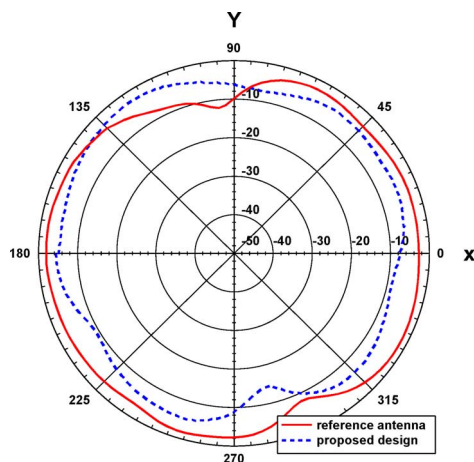


Fig. 7. Measured radiation pattern comparison for reference antenna element and proposed design.

this effect can be compensated by modifying the antenna length. According to the measurement result, it shows that the antenna isolation can be above 15 dB from 2.4 to 2.5 GHz.

To further confirm the performance of the design, the measured antenna gain pattern is also carried out. The antenna patterns for exciting Port 1 (left port) at 2.4 GHz are shown in Fig. 7. The peak gain for the reference antenna and the proposed design are -1.93 and -2.5 dB, respectively. Although the antenna pattern will be somewhat affected with the additional coupling element, the maximum antenna gain can be less affected with the proposed design. The radiation efficiency of the proposed antenna is 79% from simulation, and this design can be useful for practical internal laptop antenna application.

V. CONCLUSION

In this letter, a coupling element to enhance isolation for closely packed antennas operating at 2.4-GHz WLAN band is

proposed. We artificially create an additional coupling path by utilizing a coupling element to enhance the coupling between the antenna elements. The concept of improving isolation for the proposed coupling element is discussed. The antenna isolation above 15 dB can be achieved with their spacing just 5 mm. The parameters of the proposed coupling element are evaluated to control the frequency band of the maximum isolation, peak isolation, and the bandwidth of the transmission reduction.

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