Printed Two-Antenna Elements for Concurrent 2.4 and 5 GHz Band Operation in MIMO Systems

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1. Introduction

Multiple-input multiple-output (MIMO) technology requiring multiple transmit and/or receive antennas has been increasingly used in mobile devices, notebooks, and access-point (AP) applications to increase data throughput [1-3]. For applications of access points, very few studies are conducted on internal MIMO antennas. In fact, external dipole and/or monopole antennas are still employed generally in the market for MIMO systems, which are not pleasing to the end user from an esthetic viewpoint. In addition, most of the designs are with a single feed for generating two resonant modes for covering the 2.4 and 5 GHz bands. Thus, an external switch circuit is required between the single-feed dual-band antenna and the modules, leading to an increase in the insertion loss over the board. In this Letter, we present a printed two-antenna element with two feeds for MIMO system suitable to be concealed in AP for concurrent dual-band WLAN (2400-2484/5150-5825 MHz) operation. The two-element antenna has one PIFA and one monopole antenna. Both the antennas and ground plane are printed on the same layer of a substrate in a coplanar configuration. The isolation between the two antennas can be decided by the ground-plane length. Further, by combining two or three proposed two-antenna elements, a multi-antenna MIMO system is obtained. Different arrangements of the two elements will be first analyzed, especially in the isolation behavior. Radiation properties for a single two-antenna element and the combination of the two and even three elements are also studied and will be presented.

2. Antenna Design

Fig. 1(a) shows the configuration of the proposed two-antenna element. A photo of a mass-production sample is presented in Fig. 1(b). The two antennas, comprised of one monopole antenna and one PIFA designated for 2.4 and 5 GHz operation respectively, are all printed on the same layer of a 0.4-mm-thick FR4 substrate (size 50 mm × 11 mm) and share a common antenna ground. The two antennas are located at opposite ends of the ground plane, whose length can be favorable to good impedance matching and also affects the isolation between the antennas in both the 2.4 and 5 GHz bands. The antenna-ground length of 30 mm is chosen in this study. Notice that two symmetrical slits are cut out of the monopole antenna to meander the excited surface currents, which leads to a compact size for the 2.4 GHz antenna. For testing in experiments, two short 50-Ω mini-coaxial cables with I-PEX connectors are in use. The inner conductor of the cable is connected to feeding points A and C, and the outer braided shielding is connected to grounding points B and D. Fig. 2 shows possible arrangements, denoted as combinations 1 to 3, of the two proposed elements. Notice that the configuration presented in Fig. 1(a) is for combination 1 arrangement. The two elements are spaced apart at a distance of d in the lateral direction. The obtained MIMO system has a height of 11 mm and can be installed in some space inside the housing of a wireless device. The distance d plays an important role in influencing isolation behavior in the two proposed elements. In general, a larger d can result in better isolation. Between any two of the four antennas, the isolation of less than –15 dB can be achieved when the distance d is larger than 10 mm. The studies in the next section are based on the fixed value 10 mm for the distance d.

3. Results and Discussion

3.1 The S Parameter Analyses

Fig. 3 shows the measured and simulated reflection coefficients. The experimental data compare well with calculated results, which are based on the finite element method. The impedance matching in
both the 2.4 and 5 GHz bands is much less than –10 dB, and the isolation between the antennas remains under –15 dB over the operating bands. The isolation behavior between the antennas of the two elements combinations 1 to 3 was studied, and the results are shown in Fig. 4. For combination 1, the isolation is all less than –15 dB within the bands of interests. Isolation between the same antennas, i.e. the antennas 1 and 3, is the poorest in the antenna’s operating band, i.e. the 2.4 GHz band, as the characteristic is reasonably expected. Also worth noticing that the isolation $S_{32}$ is not better than $S_{41}$ even though the distance between the antennas 2 and 3 is much longer than the distance between the antennas 1 and 4. This is largely because the factor in the influence of isolation in this four-antenna MIMO system is decided more by antenna radiation patterns (pattern diversity) than by the separation distance (spatial diversity) [4]. The maximum radiation of the 5 GHz PIFA has been found to be in the direction of the antenna ground, thus leading to much degraded isolation for the antennas 2 and 3. For combinations 2 and 3, the worst isolation is seen with the two same antennas placed adjacent to each other. The isolation $S_{41}$ and $S_{32}$ are about the same due to the same arrangement for the antennas 1, 4 and 2, 3. The isolation $S_{42}$ in the 5 GHz band is not better in combination 2 than in combination 1, even the combination 2 with a longer separation distance between the two PIFAs. The results also indicate that the isolation property in this MIMO system can be affected more by radiation patterns (maximum radiation of the 5 GHz antennas in combination 2 facing each other) than separation distance. The envelop correlation can be calculated via the relation in terms of $S$ parameters of the multiple antennas described in [5], and the related results will be presented in the Symposium.

3.2 The Radiation Characteristics

Fig. 5 plots the measured and simulated 3-D radiation patterns for the two-antenna element studied in Fig. 1 at 2442 and 5490 MHz respectively. The radiation characteristics for the 2.4 GHz antenna here resemble those of the dipole antenna, in which omnidirectional radiation is obtained in the x-y plane. That’s because the ground-plane length corresponds to a quarter-wavelength at around about center operating frequency of the 2.4 GHz monopole antenna, which is also a quarter-wavelength resonant structure, thus making the antenna system radiate a dipole-like radiation pattern. However, for the 5 GHz PIFA, the ground plane becomes a half-wave-length radiator with null surface currents occurring in the middle between the two antennas, leading to a butterfly-like radiation pattern (with two side-lobes) in the 5 GHz band. The characteristics are similar to those of internal mobile-phone antennas operating in the DCS or PCS band. The measured peak antenna-gain levels are about 4.1 and 3.3 dBi over the 2.4 and 5 GHz bands. Radiation efficiency is seen to be above 75% and 70% for 2.4 and 5 GHz operation. Total radiation of the two proposed two-antenna elements in combination 1 was also studied. When the 2.4 GHz antennas both functions, the total radiation remains dipole-like radiation with smaller beamwidth in the elevation planes and larger gain in the horizontal plane. As for the two 5 GHz antennas, more side lobes in the elevation planes can be seen in the total radiation but still with the maximum radiation in the –z direction. Further, by disposing three proposed elements in the middle of each side of an equilateral triangle (see Fig. 6), a six-antenna MIMO system can be obtained. The total radiation patterns of the three antennas and any two antennas operating at the same frequency have been investigated in 3-D and 2-D forms respectively. The results of the above will be elaborated and discussed in the presentation in the Symposium.

References

Figure 1: (a) Detailed dimensions of the printed coplanar two-WLAN-antenna element (b) Photo of a mass-production sample

Figure 2: Combinations of the two proposed two-antenna elements in MIMO systems

Figure 3: Measured and simulated reflection coefficients ($S_{11}$ for the 2.4 GHz antenna and $S_{22}$ for the 5 GHz antenna) and isolation ($S_{21}$) between the two antennas
Figure 4: Simulated $S$-parameters ($S_{31}$, $S_{41}$, $S_{32}$, $S_{42}$) for the two proposed elements in the four-antenna MIMO system in Fig. 2 with $d = 10$ mm for combinations 1, 2, and 3.

Figure 5: 3-D radiation patterns at 2442 and 5490 MHz for the antennas studied in Figure 3.

Figure 6: The top view of the three two-antenna elements disposed at the three sides of an equilateral triangle for concurrent dual-WLAN-band operation in MIMO systems.