Multi-Band WLAN Antennas based on the Principle of Duality

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Introduction

Several IEEE wireless local area network (WLAN) standards have been developed and implemented to satisfy varying regulations and spectrum availability in various parts of the world. The WLAN standards of interest here are the IEEE 802.11a, 802.11b and 802.11g, as they are the most popular. WLAN systems based on these standards operate in two frequency bands: IEEE 802.11a around 5GHZ frequency and IEEE 802.11b/g around 2.4GHz. To make mobile WLAN devices work with all these standards, multi-band antennas have been developed. They include fractal antennas [1], planar monopoles [2], and printed inverted-F antennas [3].

Another printed multi-band antenna recently proposed for WLAN system consists of multiple conducting bent strips printed on a substrate [4]. The end segments of the strips have been brought closer and purposely coupled, in order to reduce the size of the antenna. By exploiting this concept, it was possible to cover all IEEE WLAN standards with a radiating element that takes an area of only 1cm^2. These printed bent-strip multi-band antennas are compatible with both microstrip and CPW circuits and feeds [5].

In this paper we apply the Principle of Duality to printed-bent-strip multi-band antennas. As the electromagnetic dual of a conducting strip is a slot in a conducting sheet, we explore the possibility of achieving multi-band operation with multiple coupled bent slots in a ground plane. A combination of a multi-band printed strip antenna and a multi-band printed slot antenna would exhibit polarization orthogonality. Such a pair can efficiently provide both space diversity and polarization diversity to combat multi-path fading effects in WLAN systems.

Antenna Configuration

Fig. 1 shows the generic configuration of the proposed multi-band printed antenna with bent slots. A microstrip feedline is shown as an example but other types of feedlines are also possible. The antenna is printed on a substrate with the ground plane and slots on one surface and the microstrip feedline on the opposite surface. There are two bent slots in the example configuration shown in Fig 1 and we intend to achieve two main operating bands with this arrangement. More specifically, the longer slot with length of $S_1 + S_2 + S_3$ is expected to radiate in the lower (2.4GHz) WLAN frequency band, while the shorter slot of length $S_4 + S_5$ is expected to radiate in the upper (5GHz) WLAN frequency band. These two slots are bent such that their final segments can be brought close to each other. Enhanced electromagnetic coupling resulted from a similar exercise has helped the designers to reduce the size of printed strip antenna in the past, and hence we expect to gain a similar advantage with bent coupled slots.

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Parametric Studies and Results

We have conducted several parametric studies and investigated the effect of several parameters on antenna return loss using Ansoft HFSS commercial software. The substrate considered for this study is FR4 (ε_r=4.4) and the ground plane size is 55mm x 35mm. First, the parameter S_1 has been varied while the other parameters are fixed, and the results are shown in Fig. 2. Obviously the length of the longer slot depends on S_1 and hence the upper resonance frequency decreases with increasing S_1 as expected. However, as shown in the figure, the lower resonance frequency also decreases when S_1 is increased. A similar effect has been previously observed with coupled bent strips. This must be due to the enhanced electromagnetic coupling between the two bent slots, created by the overlapping section. This coupling alters the effective electrical length of each slot. When increasing S_1, we increase the overlap, enhance coupling and effectively extend the electrical length of the shorter slot as well. The same behavior is also observed when S_5 is varied. The parameters used for this study are: S_1=6.8 to 8.8mm, S_2=9.5mm, S_3=9.5mm, S_4=7mm, S_5=6.5mm, d=0.5mm, L_f=3.5mm, W_f=0.5mm, W=2mm.

Fig. 3 shows the effect of varying S_2 and S_4. In this study, we change both S_2 and S_4 by the same amount in order to keep the gap d unchanged. Increasing S_2 and S_4 together reduces both resonance frequencies of the antenna because both slots are physically extended without altering electromagnetic coupling between the slots. In this study S_2 has been varied from 10 to 11mm and S_4 has been changed according to $S_4 = S_2 - W - d$ between 7.5 – 8.5mm. In this study, other parameters have been fixed as follows: S_1=6.8mm, S_3=9.5mm, S_5=6.5mm, d=0.5mm, L_f=2mm, W_f=2.5mm, W=2mm.

Fig. 4 shows the return loss of the antenna as S_3 is varied. In this study, S_1 and S_5 lengths have been fixed and therefore changing S_3 affects the overlap between slots, the coupling between them and the physical length of the longer slot. As S_3 is increased in the range of 10mm to 10.5mm, the resonance frequencies of both slots increase. The effect on the upper resonance frequency seems to be due to reduced mutual coupling. However, this effect is observed only for a limited range of S_3. In this study, other parameters have been fixed as follows: S_1=7.8mm, S_2=9.5mm, S_3=10mm, S_5=6mm, d=0.5mm, L_f=2mm, W_f=2.5mm, W=2mm.

Next we changed the parameters to achieve a good return loss bandwidth. Good results have been achieved with the following parameters: S_1=6mm, S_2=13.5mm, S_3=12.5mm, S_5=6mm, S_4=11mm, d=0.5mm, L_f=4mm, W_f=2mm, W=2mm. Fig. 5 shows the return loss of this coupled-bent-slot antenna design. The operating bands (with 10dB return loss) of this design are 2.45-2.55GHz and 5.05-5.6GHz. Although they do not exactly coincide with the IEEE WLAN bands of 2.4-2.4835GHz and 5.15-5.825GHz, coupled-bent-slot antennas show a good promise as a low-cost printed multi-band antenna.

Conclusion

We explored the application of Principle of Duality to printed antennas with coupled bent strips by investigating a novel slot antenna configuration consisting of coupled bent strips. We found that dual-band operation and good (>10 dB return loss) matching to a 50Ω feedline can be achieved from this promising antenna. As in antennas with coupled-bent-strips, the electromagnetic coupling between the slots seems to affect the effective length and resonance frequencies of the coupled slots.

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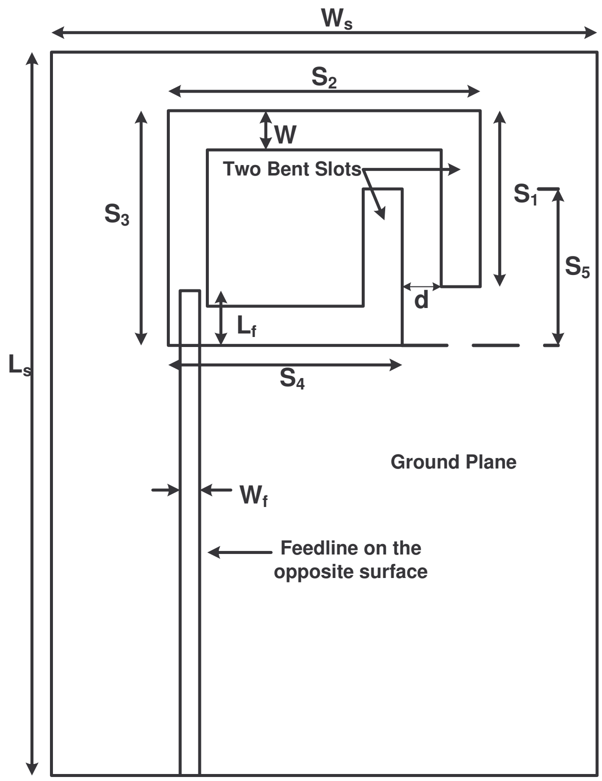

Fig. 1: Configuration of the multi-band printed slot antenna

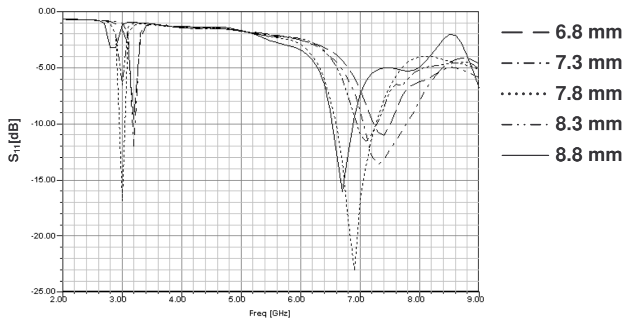

Fig. 2: Return loss versus frequency when S_1 is changed.

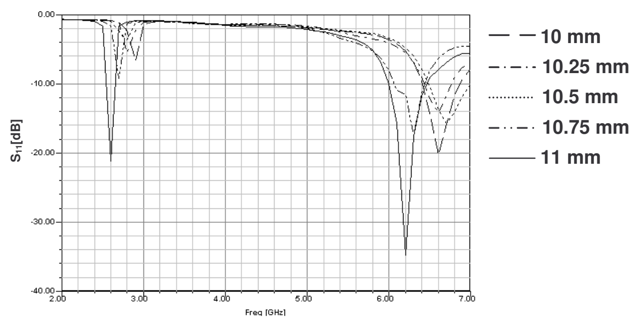

Fig. 3: Return loss when S_2 and S_4 are changed simultaneously.

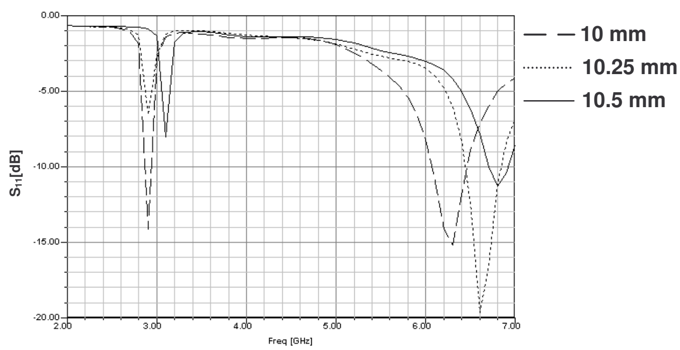

Fig. 4: Return loss when S_3 is varied.

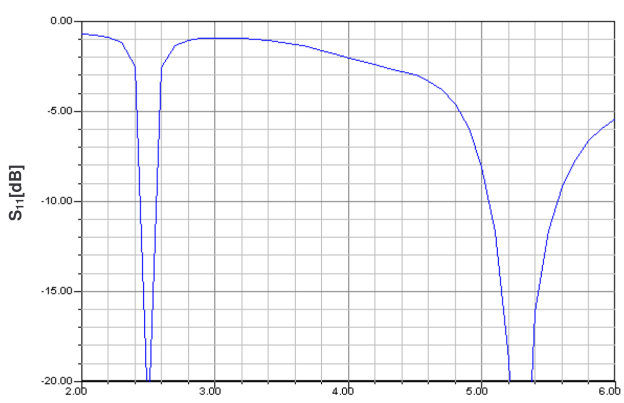

Fig. 5: Return loss versus frequency for one of the best designs.