Design a Three-Layer Patch Antenna with Defected Ground Structure (DGS) and 3-Shaped Slot Array

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Abstract. A three-layer patch antenna with 3-shaped slot array and defected ground structure is offered in this paper. The work started with the patch antenna with single structure of 3-shaped slot. Then, it followed by addition of the four set of the 3-shaped slot array twin structures at each layer of patch antenna. The propose antenna had three layers of FR-4 substrate – a upper layer with 3-shaped slot at front and back side, a middle layer with 3-shaped slot at front and back side, while bottom layer contain a rectangular patch with a single 3-shaped slot structure. The last part is to add the defected ground structure (DGS) at the ground plane to optimize the performance of the antenna. The Design D antenna operates at tri-band at 2.452 GHz, 4.996 GHz, and 3.052 GHz with return loss of - 12.111 dB, - 16.138 dB and - 10.175 dB with 4.035 dB, 3.587 dB, and 3.841 dB of gain, respectively.

1. Introduction
Conservative basic microstrip patch antennas had some limits and limitations with single resonant frequency effect, narrow impedance, antenna with low gain and not miniaturized size for many applications. There are several of improvement techniques for conservative basic microstrip patch antennas stated. The example improvement technique is multi-layers’ structure with air gap to increase the antenna gain while slot structure can effect to reduce the size of the antenna. Defected ground structure (DGS) effect the reduction dimension size of the structure, to control the resonant frequencies location of the antenna while also can enhancing the bandwidth performance [1]. Er-rebyiy [2] in his design used DGS to shift the resonant frequency from 10 GHz to 3.5 GHz without change the antenna size. This DGS structure also effect to reduce the mutual coupling reduction in his design. There are several works that apply the DGS structures on the antenna such as in this paper [3-6].

The example of air gap technique used between two substrates in antenna designs is shown in Kasabegoudar work [7]. He compares the performance of an antenna design with and without air gap. This technique allows the antenna to be functioning at lower frequencies due to reactive loading. Ding [8] in his paper stated to apply the multi-layer of different substrate to improve the bandwidth and the gain of the antenna. There are several works that apply the DGS structures on the antenna such as in this paper [3-6].

In this paper, a three-layer patch antenna with 3-shaped slot array and defected ground structure had been design in four steps works of Design A, Design B, Design C and Design D.
2. Antenna Design

Figure 1 illustrates the proposed multi-layer patch antenna with 3-shaped slot array structure and DGS structure in CST Microwave Studio simulation software. These antennas contain three RF-4 substrate layers with minimal height of air gap between all substrate. The initial design (Design A) of this proposed antenna is shown in Figure 1(b) that contains a rectangular patch with the 3-shaped slot at the centre. The Design B follows by the addition of two more layers – middle layer and upper layer. At this stage, also four sets of twin 3-shaped slots were adding to create more resonant frequencies to the antenna design. The dimension of the both FR-4 substrate of middle layer and upper layer is smaller compare with the bottom layer. For the last stage of Design C in Figure 1(c), the DGS structure were add at the ground plane part of the bottom layer to optimize and control the resonant frequency of the antenna.

![Figure 1. Proposed antenna, (a) Design A, (b) Design B, (c) Design C](image)

3. Result

The main results in analysis section of the proposed antenna were done in term of the return loss with the resonant frequency and the antenna gain. Figure 2 shows the return loss and resonant frequencies for three stages of proposed antenna – Design A, Design B and Design C. The first stage of Design A effect to creates two resonant frequency, effect by the patch structure at 2.4 GHz region with −26.918 dB of resonant frequency while the 3-shaped structure at the patch effect to resonate at 5.668 GHz with −20.494 dB.

For Design B, it shows that there four narrowband frequencies, but in case, only two are accepted because other two not achieve better than −10 dB performance. At 2.392 GHz and 5.668 GHz, it shows the performance of −26.918 dB and −20.494 dB, with gain of 3.537 dB and 3.339 dB respectively. For the last design of Design C, it shows the improvement of the gain performance for all resonant frequency with 4.035 dB, 3.587 dB and 3.841 dB at 2.452 GHz, 4.996 GHz and 6.052 GHz.
Table 1 shows the resonant frequency; return loss and gain of proposed antenna of Design A, Design B and Design C.

| Design | Resonant frequency (GHz) | Return loss (dB) | Gain (dB) |
|--------|--------------------------|------------------|-----------|
| A      | 2.398                    | -32.006          | 3.348     |
|        | 4.084                    | -10.880          | 2.152     |
|        | 4.708                    | -11.622          | 2.531     |
| B      | 2.392                    | -26.918          | 3.537     |
|        | 5.668                    | -20.494          | 3.339     |
| C      | 2.452                    | -12.111          | 4.035     |
|        | 4.996                    | -16.138          | 3.587     |
|        | 6.052                    | -10.175          | 3.841     |

Figure 2. (a) Comparison of the return loss of fractal patch antenna of Design A, Design B, Design C, and Design D

Table 1. Resonant frequency, return loss and gain of proposed antenna of Design A, Design B and Design C.

Figure 3 shows surface current of proposed antenna of Design C at 2.452 GHz, 4.996 GHz, and 6.052 GHz. It shows that, for the resonant frequency at 2.452 GHz, the current is focus at the defected ground structure at ground plane of the antenna. Figure 4 shows the radiation pattern at phi = 0 for several resonant frequencies.
4. Conclusion

After simulation work done, it shows that the proposed antenna operates at a multi-band frequency at 2.452 GHz, 4.996 GHz, and 6.052 GHz with higher gain compared with the basic design. It shows also the improvement of the gain of the antenna effect of the air gap and three-layer substrate.
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