Bandwidth and Radiation Effects of Symmetry Breaking in Stacked Patches

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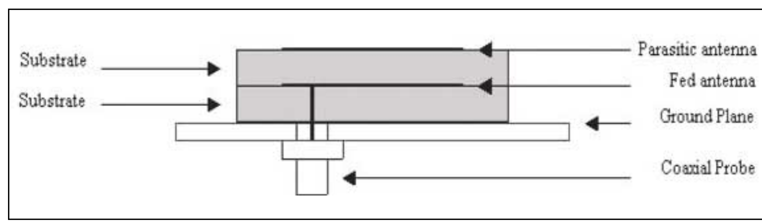
Stacked patch antennas offer many performance features [1]. Several methods to obtain a larger bandwidth for such antennas have been carried out; most of them are based on special feeding techniques, variations of the size of the two patches or different dielectric layers [2, 3]. The two radiators forming the antenna are usually centered.



▲ **Figure 1. Structure of the stacked patches.**

This article presents results of experimental research of a new method to achieve bandwidth broadening through displacing the upper patch in front of the bottom patch. Also discussed will be the effect on bandwidth of these small displacements in several directions for different upper patch sizes. Finally, the effects on the radiation pattern are tested and analyzed.

E-plane displacements

Figure 1 shows that the analyzed structures are stacked patches fed by a coaxial probe. The position of the upper patch has been changed only along the E-plane (see Figure 2), which corresponds to the resonant side.

After studying the behavior of the two existing resonant frequencies, we can expect that movement along this plane will cause a variation in the effective length of both patches (upper and lower), which will affect their resonant frequencies. Therefore, the H-plane offset will be not considered.

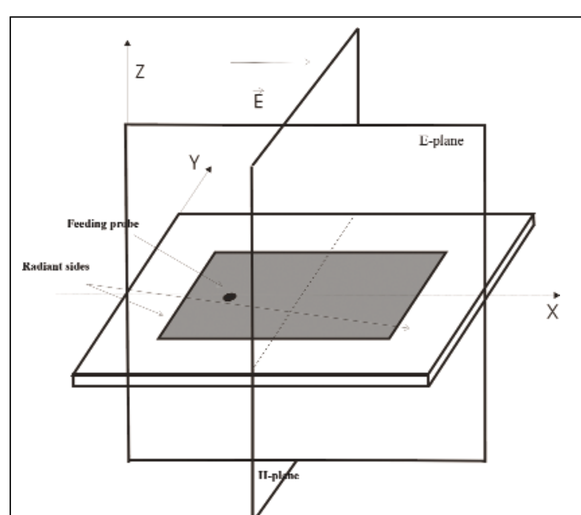
First, we define the sense for movements. Figure 3 shows that the offset will be negative when the upper patch moves toward the side where the feeding probe is placed and positive if it moves the opposite direction.

Bandwidth effects

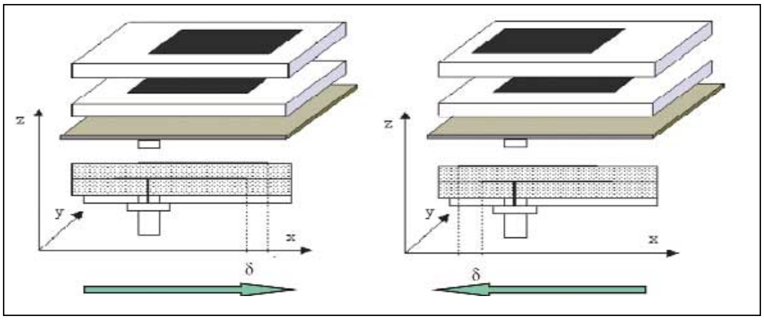
Rectangular stacked patches

Figure 4 shows the measured reflection coefficient if patches are square. The tested offsets were between 1 and 10 mm for both senses: positive and negative.

The two natural resonant frequencies tend to break apart when the upper patch is displaced. This happens for both positive and negative displacements. The behavior is not the same for



▲ **Figure 2. Main radiation planes.**



▲ **Figure 3. Offset design definition.**

each sense because of the natural asymmetry of the structure due to the feeding position.

There are several common features in both graphs. In the central band of frequencies, the impedance mismatch increases with displacement since the probe position is not changed.

Circular stacked patches

Similar results were found for circular stacked patches. Figures 5 and 6 show example measurements. The increase in bandwidth is evident for both senses. The mismatch in the central frequency band could be used to make a dual-band antenna instead of a broadband one.

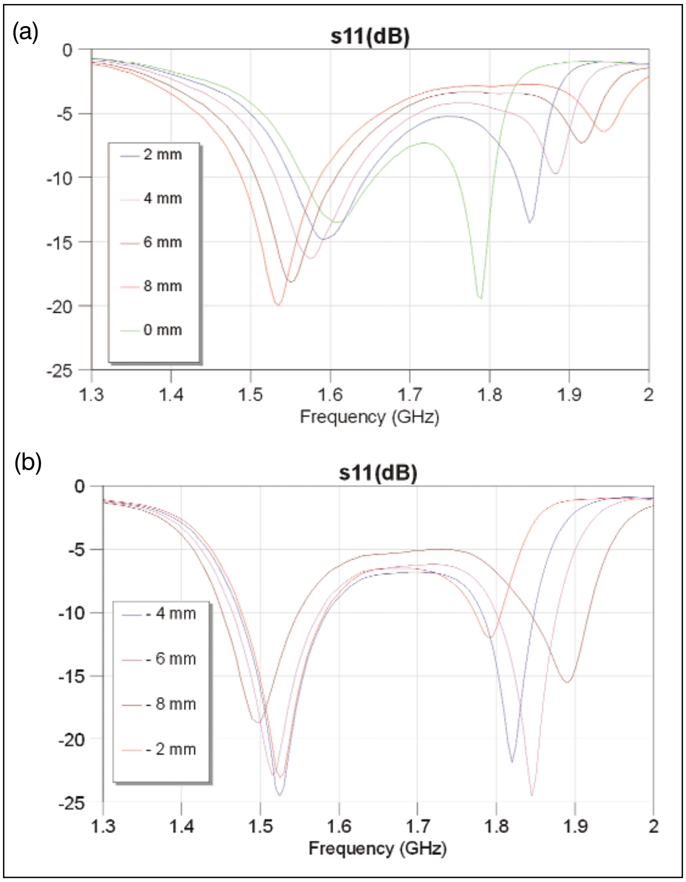
Figure 6 shows the same measurements represented on a Smith chart. In the case of positive offsets, the impedance locus defines a line when displacements increase while for negative offsets, the impedance locus describe a curve. In both cases, bandwidth broadening is achieved (the size of the loop increases with displacement) and a dual-band antenna is possible.

Figure 7 shows the influence of certain antenna parameters on impedance matching and how the variation of these parameters helps to move the impedance locus to a desired position in the chart.

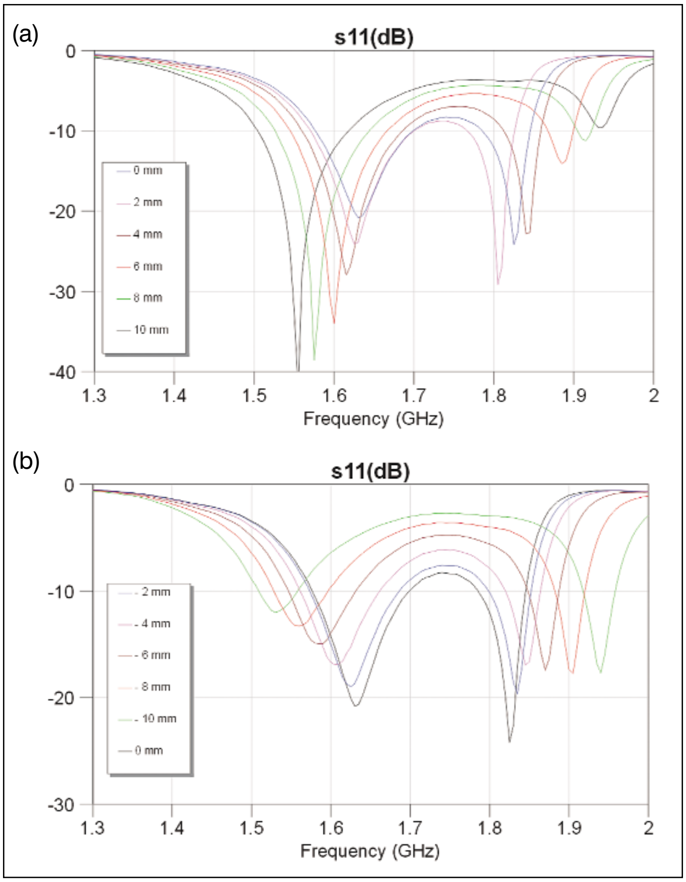
In all presented results, the patch sizes (upper and lower) were very similar. Next, we varied the upper patch size and studied its influence including its displacement.

Parasitic size influence

The next step in this study combined two effects: the resonant frequency as a function of displacement when the upper patch has several different sizes [4]. A graph-



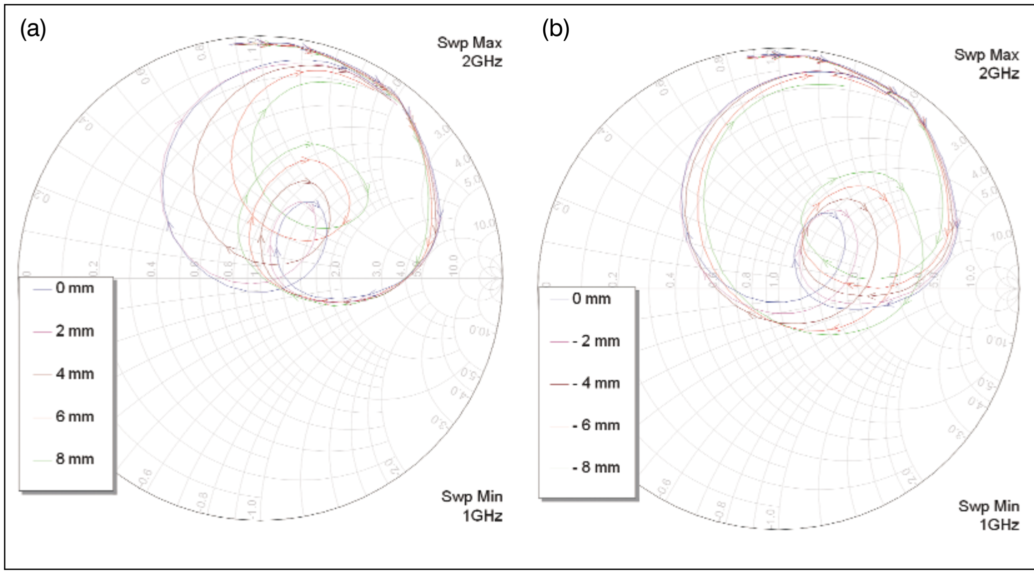
▲ **Figure 4. Measured reflection coefficient for square stacked patch (upper patch size: 47 mm, lower patch size: 50 mm, $\varepsilon_r = 3$, $h = 6$ mm) for several offsets: (a) positive offsets; (b) negative offsets.**



▲ **Figure 5. Measured reflection coefficient for circular stacked patch (upper patch radius 28 mm, lower patch radius 30 mm, $\varepsilon_r = 3$, $h = 6$ mm) for several offsets: (a) positive offsets; (b) negative offsets.**

ical summary of these measurement is presented in Figure 8 for all the studied cases: square and circular patches for both displacements senses. In Figure 8, the x-axis represents the upper patch size in mm (the lower is fixed) and the y-axis represents the two resonant frequencies of the antenna while each symbol corresponds to an offset.

In all cases, for a given size, displacement always separates the natural resonant frequencies. The upper resonant frequency shifts further and in the limiting case when the upper patch is sufficiently large, only it varies.



▲ **Figure 6. Measured reflection coefficient for circular stacked patch (upper patch radius: 28 mm, lower patch radius: 30 mm, ε_r = 3, *h* = 6 mm) for several offsets: (a) positive offsets, (b) negative offsets.**

Radiation effects

Rectangular stacked patches

A second set of results was gathered by measuring radiation patterns were also measured across the band of frequencies. The main beam is slightly off axis in the E-plane of these antennas [5, 6] even when they are centered because of the asymmetry. Therefore, in this case, the mispointing can increase.

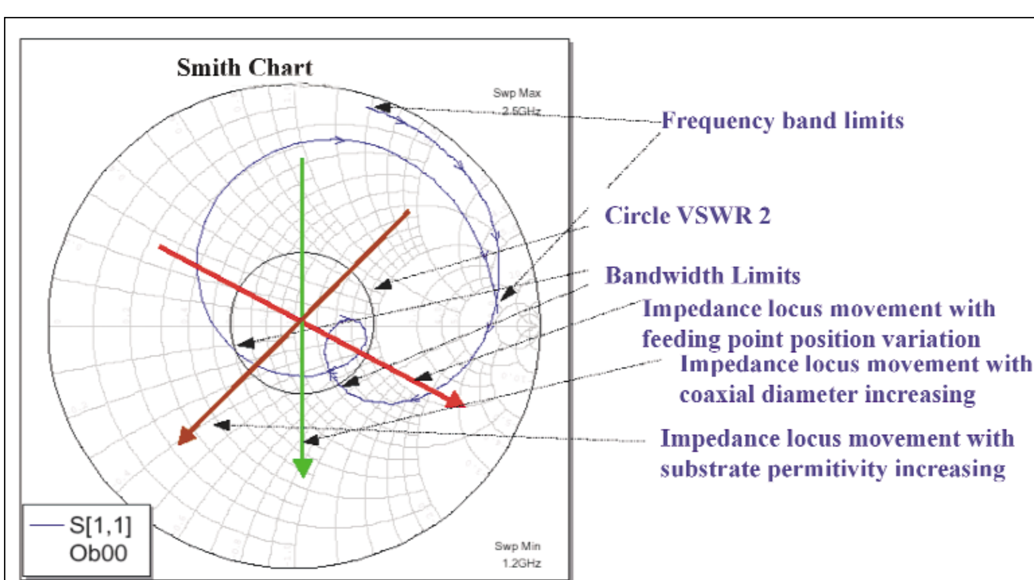
An example radiation pattern is shown in Figure 9(a) for the squared patch. The radiation patterns in E-plane for three cases are shown: the two largest positive and negative displacements and zero displacement for a fixed frequency. The off-axis pointing of the beam is clearly seen. Figure 9(b) shows that the studied offsets do not influence the H-plane pointing.

Circular stacked patches

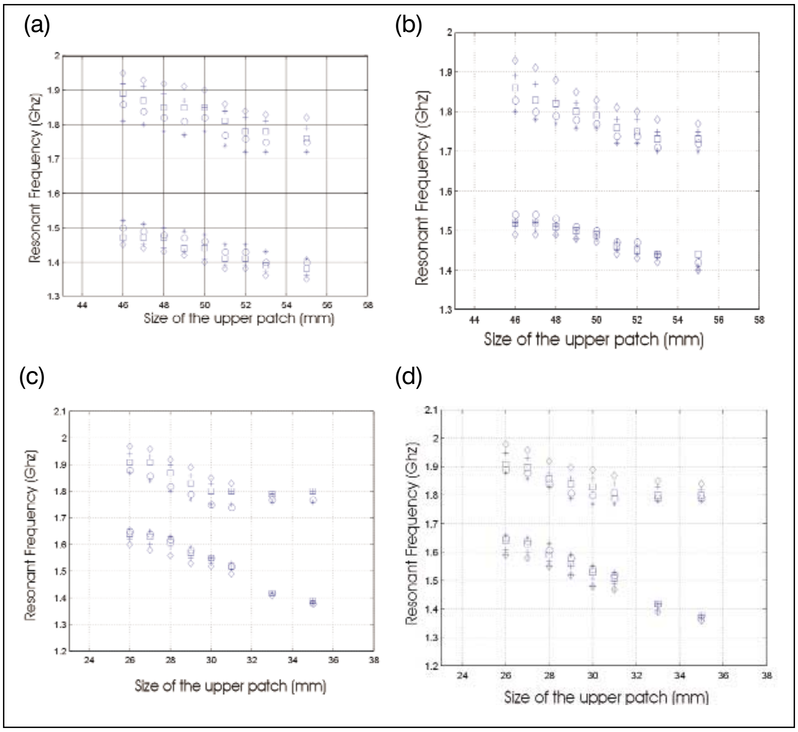
The results for circular patches are similar. Figures 10(a) and 10(b) show an example of the measured E-plane and H-plane radiation patterns for three offsets: the extreme positive (green) and negative (red) displacement and the symmetrical case (blue). The E-plane displacements have no beam mispointing effect in H-plane, but significant effect in E-plane.

Slots array model

The shifting of the main beam was shown to be a function of the position of the upper patch. If we apply the well-known radiation model of two slots for each patch of the antenna, we can analyze the radiation proprieties of the structure as an array of non-equally spaced four elements with varying amplitude and phase. For example, with displacement, one of the lower slots is completely covered by the upper patch and, therefore, has an amplitude of 0.



▲ **Figure 7. Influence of main antenna parameters on impedance locus position.**



▲ **Figure 8. (a) Positive displacements and (b) negative displacements of a square patch with a 50 mm lower patch size; (c) positive displacements and (d) negative displacements of a circular patch with a 30 mm lower patch radius.**

After many simulations, we added two elements at the edges of the ground plane to simulate the diffraction effects. The amplitude of these elements were considerably smaller than the other four. An optimization method was used to match the measured radiation patterns. Figure 11 shows this model: the rectangular elements correspond to the slots that model the upper and lower patch, while circular elements correspond to the elements to model a finite length ground plane.

This study is still in progress. This model will be useful to study off-axis pointing of stacked patches. This will help model the excitation of surface waves in the substrate and the interlevel coupling.

Conclusion

A new stacked patch structure has been analyzed. The upper patch was displaced and its size was varied. Results show bandwidth improvement for all cases. Measurements were made for square and circular stacked patches. Radiation patterns for these symmetry structures were also discussed. Finally, the starting point for more advanced radiation modeling was presented. ■

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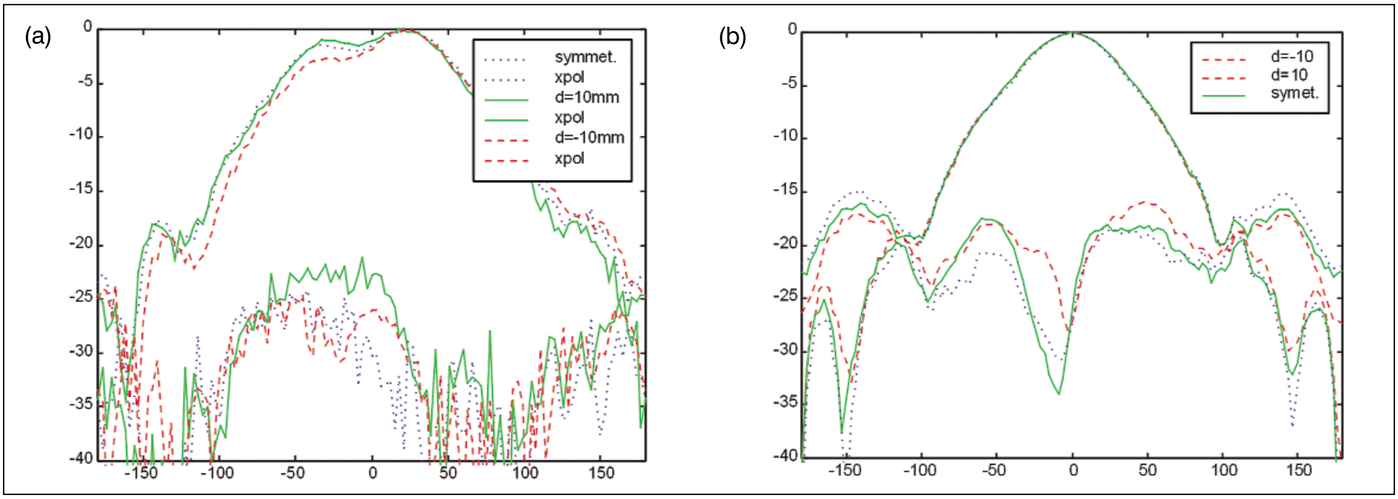

▲ **Figure 9. Squared stacked patches (upper patch size: 47 mm, lower patch size: 50 mm, ε_r = 3, *h* = 6 mm). (a) Measured E-plane radiation pattern for three different displacements; (b) Measured H-plane radiation pattern for three different displacements. Green line: δ = 10 mm, Blue line: δ= 0 mm, Red line: δ = –10 mm.**

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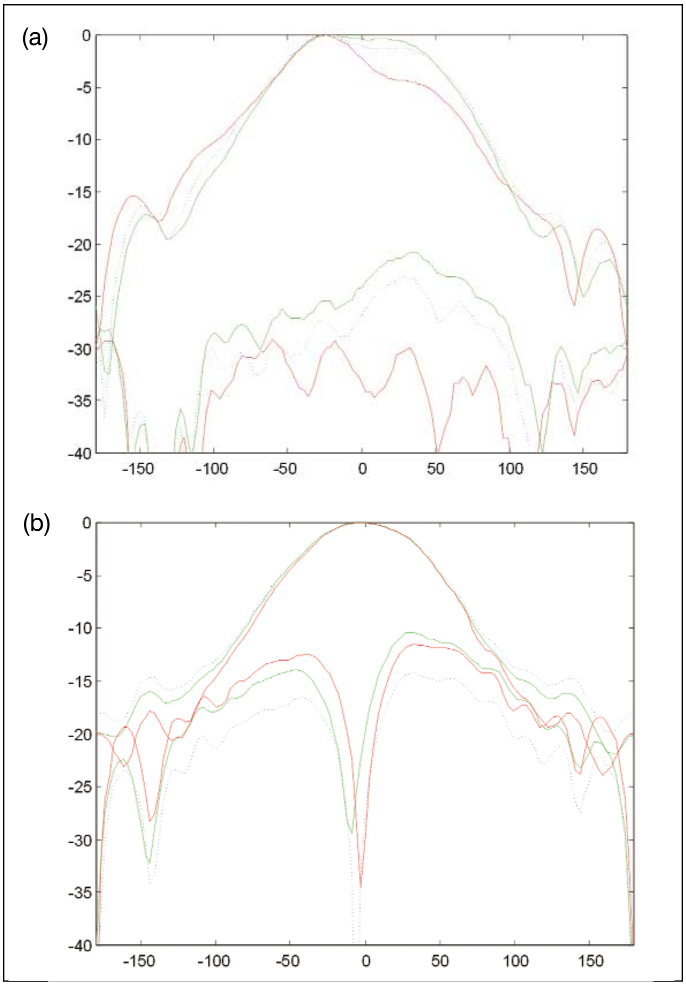
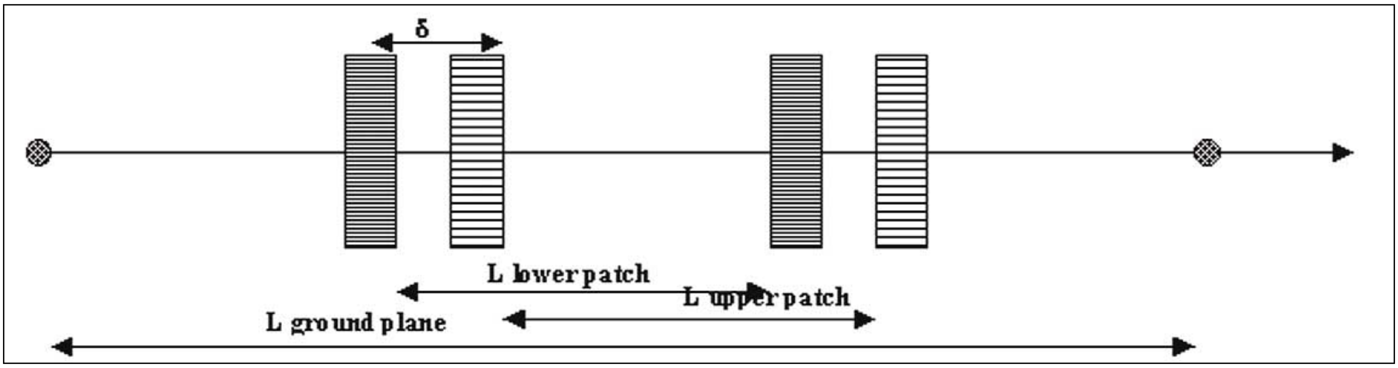


▲ **Figure 10. Circular stacked patches (upper patch size: 28 mm, lower patch size: 30 mm, ε_r = 3, h = 6 mm). (a) Measured E-plane radiation pattern for three different displacements; (b) Measured H-plane radiation pattern for three different displacements. Green line: δ = 10 mm, Blue line: δ= 0 mm, Red line: δ = –10 mm.**



▲ **Figure 11. Four slots radiation model.**