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Microstrip Patch Antennas with 3-Dimensional Substrates

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Abstract— This paper investigates the concept of replacing conventional flat 2-D patch antennas with 3-D versions where the substrate height is not uniform. The hypothesis of this work is that the electric fields are not evenly distributed under the patch and hence increasing the height in specific locations can be beneficial in terms of size of performance.

I. INTRODUCTION

We live in a world where people want 24-7 connectivity and we want this without the inconvenience of having wires. This means that antennas are essential to our quality of life. Consumers demand that new technology is smaller, lighter, can transmit more information, uses less battery power and look aesthetically attractive. Furthermore, we must consider smaller ground planes, more complex operating platforms and interferences from nearby electronics. These design pressures are then passed onto antennas designers. As the antenna size is related to the wavelength, it is not straight forward to continually miniaturize the antenna and increasingly innovative techniques are being considered to address this. This paper will consider the idea of optimizing the 3-D shape of the substrate.

Microstrip patch antennas are popular because they are intuitive to design, have a ground plane which shields the antenna and have a hemispherical pattern. Professors Jim James and Peter Hall have created a large body of work on this topic [1–9]. This work has since been extended by other authors [10–13]. The size of the patch antenna can be reduced by using shorting pins; shorting walls; slots; ceramic materials; fractals and folded patches and ground planes [14–18].

There is an inherent trade-off between antenna size, bandwidth and efficiency [19–22]. It is common knowledge that increasing the height of a microstrip antenna increases the efficiency and bandwidth. Other methods of increasing the bandwidth include parasitic elements; stacked patches and U-slots [23].

The electric fields are not uniformly distributed underneath the patch antenna and this enables the material composition of the substrate to be optimised and can lead to electromagnetic advantages. The term ‘textured dielectrics’ was coined by Professor Volakis and his colleagues at Ohio University and

refers to a substrate where the permittivity is varied as a function of location [24–27]. In this work, holes were cut into the substrate and different materials were manually inserted to create heterogeneous substrates. This laborious process increased the bandwidth by matching the low permittivity regions to areas with high electric fields. Previously, it was shown that a high bandwidth, high gain and low specific absorption rate (SAR) antenna can be created by matching the permittivity and permeability of the substrate [28] which provides further evidence that optimising the substrate can be advantageous.

In a related area, the author of this paper is considering manufacturing antenna systems with heterogeneous substrates using emerging nanotechnology fabrication processes [29–33].

The concept of 3-D substrates may be particularly relevant to wearable antennas [34][35]. It is also hypothesized that the use of 3-D substrates may reduce the specific absorption rates (SAR) in the body [36].

II. GEOMETRY

The patch antennas in this paper were simulated using EMPIRE XCcel finite-difference time-domain (FDTD) software. The patch was designed to resonate at 2.4GHz. The dimensions used were as follow: width in X axis = 41.39mm; length in Y axis = 49.41mm; substrate size = 80 × 80mm; substrate height = 0.5mm; permittivity = 2.2 and tan delta = 0.0009. The patch was fed with a probe feed and the distance of the probe from the side of the patch was varied to obtain a good 50 ohm match.

The geometry and the electric fields are shown in Fig. 1. The figure demonstrates how the electric fields are not uniformly distributed below the patch. As expected the largest electric fields occur to the left and right hand sides of the substrate below the patch antenna. The electric fields are small along the central axis of the patch (parallel to the Y axis). The maximum surface currents occur where the electric fields are smallest. The surface currents decrease symmetrically as we move in the positive or negative X directions.

The substrate height was then increased in selected locations as shown in Fig. 2:- (a) two rectangular ridges at the edge of the substrate: 0.9mm high × 4mm wide × 49.41mm;

(b) one rectangular ridges at the centre of the substrate: 0.9mm high \times 8mm wide \times 49.41mm; (c) one triangular ridge at centre: 2mm high \times 8mm wide \times 49.41mm; (d) flat continuous patch with central groove in ground plane: 1mm deep \times 8mm wide \times 49.41mm and (e) flat continuous patch with two grooves in ground plane below edges of patch: 1mm deep \times 4mm wide \times 49.41mm. Note in (d) and (e) the patch antenna is continuous but has been drawn as a transparent object to show the grooves in the ground plane and the thickness of the ground was increased and therefore the grooves did not form holes in the ground plane. These grooves were then filled with the substrate material.

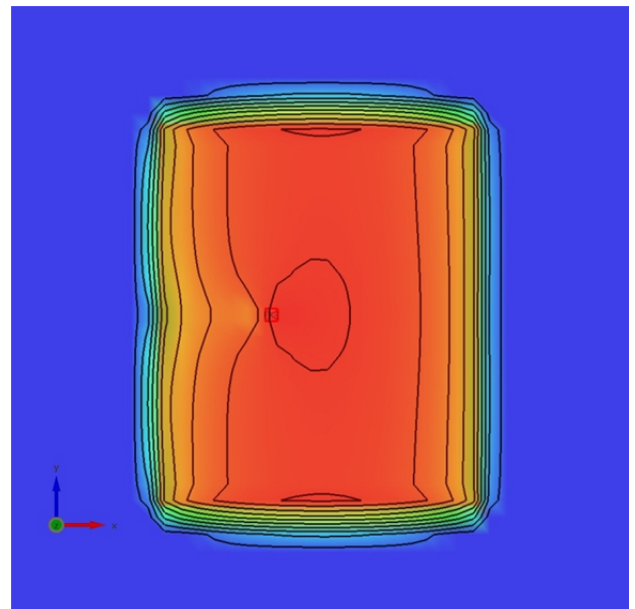
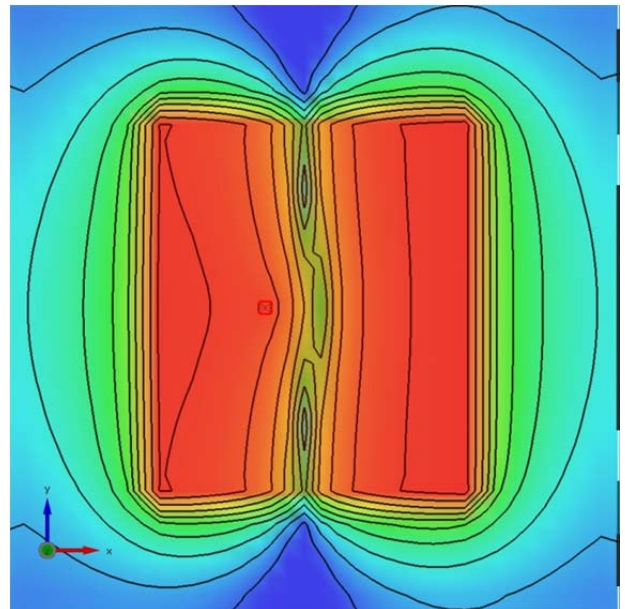


Fig. 1. Patch antenna with (a) electric fields in the substrate and (b) surface currents on the patch.

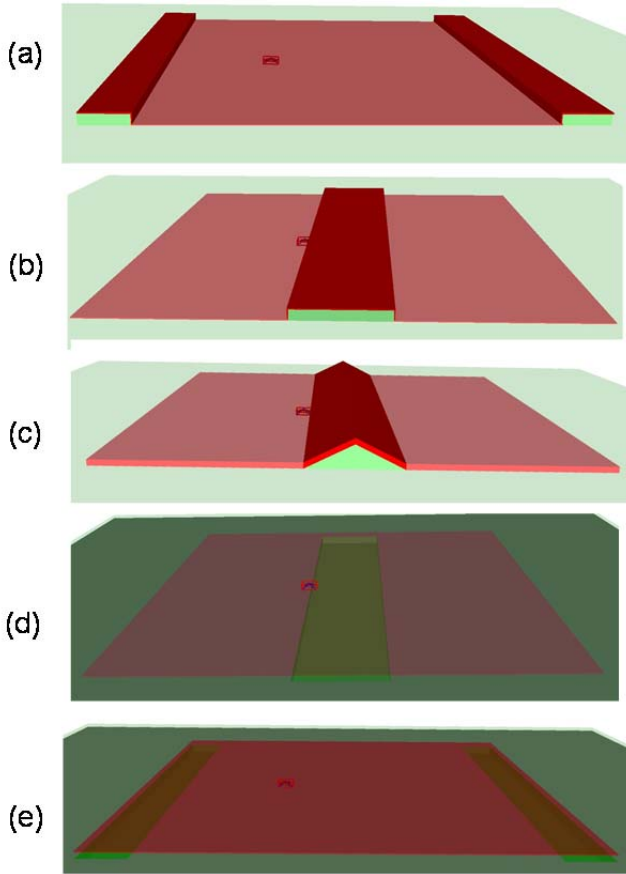


Fig. 2. Geometries of 3-D substrate. See Section II for more details.

III. RESULTS

The geometries in Fig. 2 were simulated. The original flat patch resonated at 2.37GHz, see Fig. 3. When ridges were added at the sides of the patch, the frequency increased. This is due to the step change in height not causing a continuous path for the currents. When the 8mm ridge was placed at the centre of the patch, the frequency decreased to 1.82GHz. Similar results were obtained with a triangular ridge at the centre of the patch. In these geometries, the patch had the same dimensions as seen from above and hence the total surface area of the patch is increased. An alternative method of increasing the local substrate height is to add a groove in the ground plane and thus the patch remains flat. This produced similar results to adding ridges in the substrate and indicates that the decrease in frequency observed with ridges at the centre of patch is due to the increased substrate height and not the increased surface area of the patch.

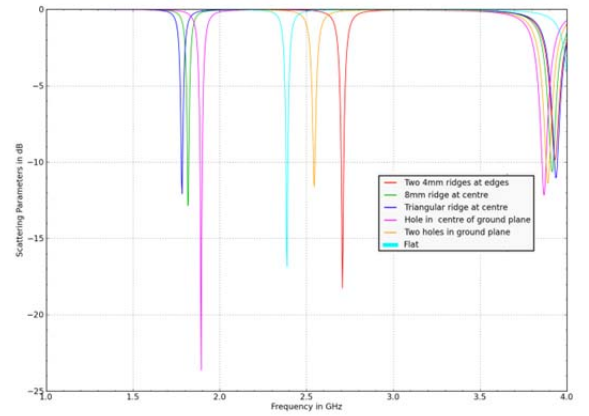


Fig. 3. The S11 results using the geometries in Fig. 2.

The frequency, bandwidth and efficiency results for the geometries in Fig. 2 are shown in Table 1. Note to allow a fair comparison these efficiency values do not include the return loss which can be improved by moving the feed position. The results indicate that the triangular ridge has an improved efficiency compared to the rectangular ridge at the centre. Furthermore, efficiency results were superior with the grooves in the ground plane compared to the ridges. This is due to currents preferring smooth contours as opposed to distinct boundaries.

Table 1. Frequency, bandwidth and efficiency for 3-D substrate geometries.

Geometry	Freq (GHz)	10dB BW (MHz)	Fractional BW (%)	Efficiency (%)
Flat 0.5mm substrate	2.39	11	0.46	53.8
Fig. 2 (a)	2.71	15	0.55	41.3
Fig. 2 (b)	1.82	8	0.44	43.3
Fig. 2 (c)	1.79	7	0.39	74.3
Fig. 2 (d)	1.89	14	0.74	67.3
Fig. 2 (e)	2.54	9	0.35	59.0

IV. CONCLUSIONS

This paper has investigated the concept of designing antennas with 3-D substrates. The electric fields underneath the patch antenna are not uniformly distributed and hence increasing the substrate height in specific locations has been shown to be a more effective use of volume and materials. Increasing the substrate height where the electric fields are small and the currents are large reduced the frequency. The

results have indicated that smooth transitions in the substrate shape will produce better results in terms of efficiency. This work is currently extended into a journal publication. The final version of this paper will be amended accordingly.

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