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Designing Multi-Band and High Bandwidth Antennas with Heterogeneous Substrates

(Invited Paper)

W. G. Whittow¹, C. C. Njoku¹, J. C. Vardaxoglou¹ and J. Joubert²

Abstract – This paper investigates the concept of creating substrates with heterogeneous dielectric properties. By suitably locating areas of low and high permittivity, the second resonance can be moved closer to the 1st resonance and multiband antennas can be created. By combining the resonances, the bandwidth of the antenna can be increased.

1 INTRODUCTION

Since the original work by Profs Jim James and Peter Hall [1], [2], microstrip patch antennas have been widely studied [3–5]. Lee and Luk's recent textbook has summarized some of the methods for enhancing the bandwidth including increasing the substrate height; parasitic elements; stacked patches and U-slots [6].

Conventional microstrip patch antennas are restricted by existing manufacturing capabilities as the antenna design is typically etched on a printed circuit board that has a fixed homogeneous permittivity. However, electromagnetic advantages can be obtained by varying the substrate material. The concept of textured dielectrics involves varying the permittivity of the substrate as a function of location [7–10]. This work showed that the bandwidth of the patch antenna could be increased by analyzing the distribution of the electric fields and placing a low permittivity where the electric fields were largest and vice-versa.

The authors have previously considered the possibility of fabricating synthetic substrate materials using emerging nanotechnology. This has potential advantages in terms of providing an alternative to traditional destructive printed circuit board manufacturing techniques which use environmentally damaging chemicals to destroy unwanted copper. In the near future, it is expected that nanotechnology will be able to create antennas systems consisting of metallic and dielectric materials where the feedlines and radomes can be fabricated in one integrated process. This can also lead to electromagnetic advantages as heterogeneous

substrates can be considered where the permittivity varies in three dimensions.

The local permittivity can be controlled by varying the volume density of small scale inclusions [11]. This theoretical work has been validated by simulations and measurements [12], [13].

In this paper, we will investigate the concept of creating multi-band antennas using heterogeneous substrates. Areas with a low permittivity (or slots if the material is air) can introduce new bands dependent on the geometry. Similar effects could be obtained by using different permittivity values and the option of grading the dielectric transition would add another degree of freedom into the design process.

2 GEOMETRY

The homogenous patch antenna with inset feed is shown in see Figure 1. The antenna has been designed to resonate at 2.4GHz with dimensions of 50mm long in the Y axis and 40.5mm wide in the X axis. Vertical slots were cut in the substrate. Simulations were completed using EMPIRE XCcel FDTD software. As expected the electric fields are largest at the sides of the patch and are smallest along a strip at the center of the patch.

¹ School of Electronic, Electrical and Systems Engineering, Loughborough University, Loughborough, LE11 4 SL, UK
Email: w.g.whittow@lboro.ac.uk; c.c.njoku@lboro.ac.uk; j.c.vardaxoglou@lboro.ac.uk

² Department of Electrical, Electronic and Computer Engineering, University of Pretoria, South Africa
Email: jjoubert@up.ac.za

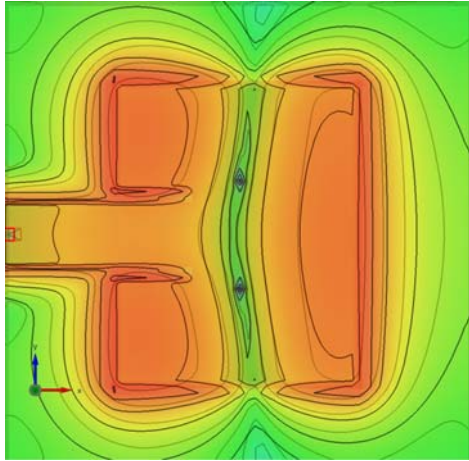


Figure 1. The patch antenna with inset feed. The Electric fields magnitudes are also included.

3 RESULTS

In this section slots were cut into the substrate below the patch, see Figure 2. Two geometries were considered: i) a slot at the center of patch and ii) two slots at the edges of the substrate. In the fabricated antennas, the slots were filled with Rohacell (shown as white in Figure 2). This ensured that the patch which was printed on a flexible dielectric film would lay flat. In Sections 3.1 and 3.2, the substrate has a fixed permittivity of 2.2. In Section 3.3, the permittivity of the substrate is altered to maintain the resonance at 2.4GHz.



Figure 2. (a) 8mm wide slot at center of patch and (b) two 8mm wide slots at edges of patch.

3.1 Slot at the center of patch

In this section, slots of varying widths were placed in the substrate at the center of the patch; see Figure 2

(a). The substrate was 3.5mm thick with a permittivity of 2.2 and a loss tangent of 0.0009. The results in Figure 3 show that the slots have little effect on the first resonance at 2.4GHz. As expected, changing the dielectric loading where the electric fields are small has negligible significance. This could be an interesting method of reducing the weight of an antenna. The second resonance is shifted in frequency dependent on the size of the slot.

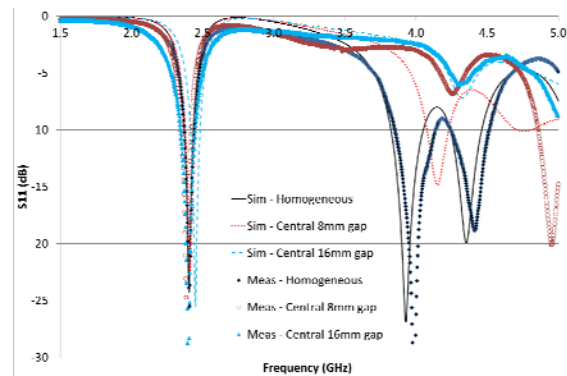


Figure 3. Simulated and measured S11 results with slots at center of patch.

3.2 Slots at the sides of patch

Adding slots or changing the local permittivity in regions which have high electric fields has a greater effect on the antenna performance. In this case, the decreased dielectric loading, increases the frequency as shown in Figure 4. The substrate was 3.5mm thick with a permittivity of 2.2 and a loss tangent of 0.0009.

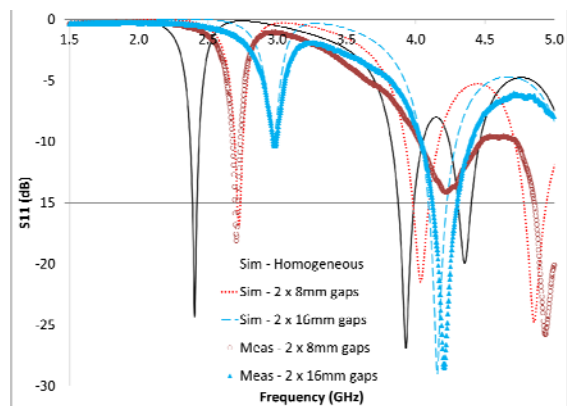


Figure 4. Simulated and measured S11 results with two slots at edges of patch.

3.3 Varying the permittivity to maintain the 2.4 GHz frequency

In this section, simulations were carried out with a probe feed by the side of the patch, see Figure 5. In Section 3.2, the frequency was increased when slots were cut in the sides of the substrate. Therefore to compensate, the permittivity of the substrate was increased to maintain the original 2.4GHz resonance:- 8mm slots: $\epsilon_r = 3.1$; 16mm slots: $\epsilon_r = 5.3$; 20mm slots: $\epsilon_r = 6.7$ and 22mm slots: $\epsilon_r = 9.0$. Wide slots where the electric fields are largest requires a high permittivity elsewhere to maintain the same overall dielectric loading. The tan delta of the substrate was 0.015 and was not altered. The substrate was 1.524mm thick.

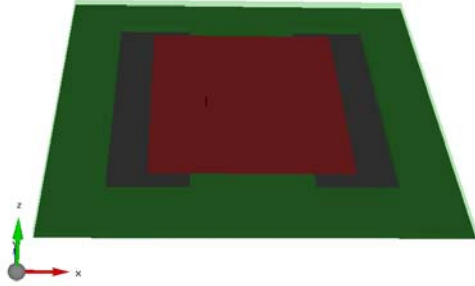


Figure 5. The patch antenna is fed with a probe feed, positioned 12mm from the left hand side of the patch. 16mm wide vertical slots have been cut into the substrate.

As the width of the slots increased, the 2nd and 3rd resonances decreased in frequency and thus the new 3rd resonance approached the original 2nd resonance. Therefore, an extra band is introduced within the same frequency range, see Figure 6. Furthermore, by carefully manipulating the width of the slots and the permittivity of the substrate, two resonances can be combined. This allows the bandwidth of the antenna to be increased from 2.5% for the original homogeneous case to 6% for the 22mm wide slots while the size is maintained. The simulated antenna efficiency reduces slightly from 48.2% to 40.0%.

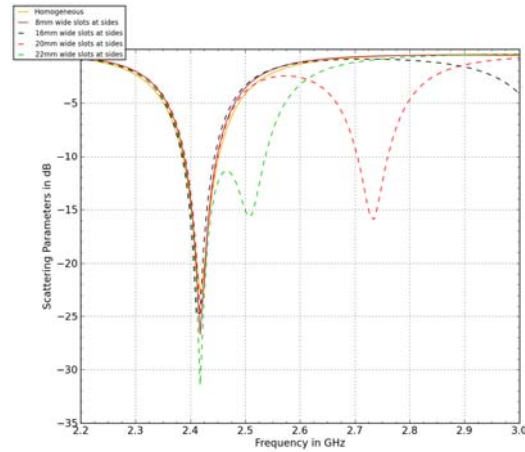
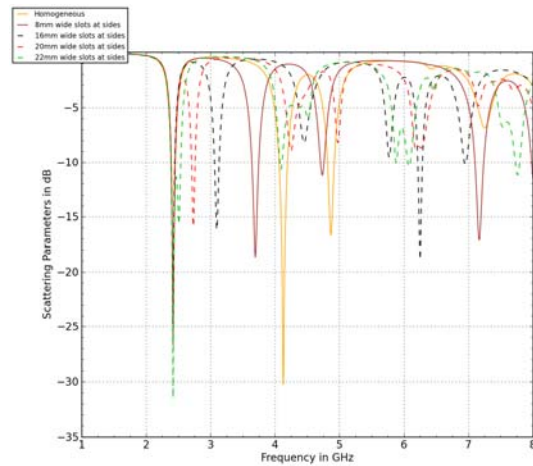


Figure 6. (a) Simulated S11 results with different slot widths and permittivity's and (b) zoomed in view.

4 CONCLUSIONS

This paper has shown that the resonant frequency of a patch antenna can be altered by varying the permittivity. As the electric fields within the substrate are not uniformly distributed, controlling the permittivity in certain locations has greater effect. The local permittivity can be reduced where the electric fields are small without affecting the first resonance. Reducing the permittivity at the sides where the electric fields are largest has a more pronounced effect. Simulated and measurements showed reasonable agreement, however, the higher frequencies were sensitive to manufacturing tolerances. Reducing the permittivity where the electric fields were small and increasing the permittivity elsewhere

allowed the higher resonances to move down in frequency to the point where an extra band was covered and by combining two nulls, the bandwidth could be increased.

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