Variable Geometry Conformal Antenna Array for Element Comparison

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***Abstract*—The design of conformal antenna arrays has historically been carried out by warping suitable planar antenna arrays to the desired radius of curvature. There has been little investigation into the effects of characteristic antenna performance on conformal array performance as the radii of curvature is varied. This paper presents a Variable Geometry Conformal Antenna Array Test Rig, designed to allow the investigation of the performance of a variety of antenna types (cavity slot, patch, etc) in a controlled environment. This approach allows direct comparisons to be drawn between each set of antenna elements in the test rig, and also simplifies the model space for Finite Difference Time Domain (FDTD) modelling, allowing an additional comparison between measured antenna pattern and coupling measurements and modelled results. In this paper measurements of Conformal Cavity Slot antenna elements and Dual Feed Dual Patch antenna elements are presented.**

I. Introduction

Low Cost, High Gain, Phased Antenna Arrays have a wide range of applications, including the aerospace, communications, and medical industries. Conformal Antenna Arrays support the same wide range of applications while reducing the requirements on the supporting structure. In the aerospace sector Conformal Antenna Arrays may be chosen to eliminate the drag from the radome required for a planar antenna array, while in the communications sector, a conformal array capable of wide angle beam steering would allow a low profile Base Station installation on the corner of a building. A Low cost, modular conformal antenna array design would provide greater functionality in these environments. A mobile phone base station would benefit from a larger coverage area and multiple beams for high throughput communications standards such as 5G standard. While in the aerospace combined sensors and communications arena, a low cost conformal antenna array would offer an enlarged field of regard and reduced airframe drag. In addition to aerospace sensors such as Synthetic Aperture Radar (SAR), there is new research into the possibility of replacing the mechanically actuated planar antenna array used in tactical radar with an all electrically scanned conical phased array radar [1].

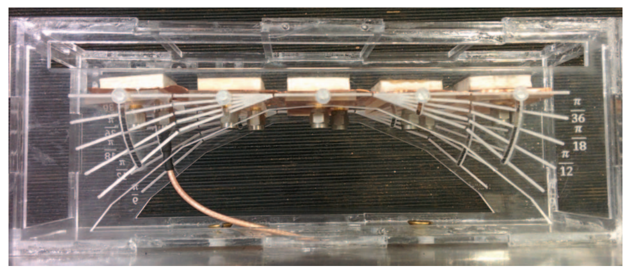

Fig. 1. Variable Geometry Conformal Antenna Array Test Rig, showing angle alignment markers

II. Variable Geometry Conformal Antenna Array Test Rig

In order to investigate the performance characteristics of different antenna arrays over a range of radii of curvature, a consistent geometry between each element type is very important. To allow such comparisons, a Conformal Antenna Array Test Rig was produced, with mounting screws and laser etched alignment lines (Fig. 1). The use of laser cut transparent acrylic allows quick alignment of each element at the correct position and angle. Two antenna types were chosen, Conformal Cavity Slots (Fig. 2a), and Dual Feed Dual Circular Patch (Fig. 2b). The alignment markings allow five inter-element angle sets of 0, 5, 10, 15, 20 degrees corresponding to radii of curvature of Infinite, 0.46m, 0.23m, 0.15m, 0.11m. The test rig was designed to be mounted flush on an external ground plane on the Anechoic Chamber motorized antenna mount. The external ground plane was included to minimise the effect of the antenna mount on the array antenna patterns and to simplify any FDTD model [2], of the arrays in the Conformal Antenna Array Test Rig, and is shown in Fig. 4.

A. *Conformal Cavity Slot Antenna Elements*

The Conformal Cavity Slot Antenna Array is comprised of five Cavity Slots, side fed and resonant at 5.2GHz (Fig. 2a). These elements are mounted in the Conformal Array Test Rig using pairs of custom 3D printed brackets for each element. A copper shim with pre-cut slots is laid over the front face and copper foil is the used to secure the slots to

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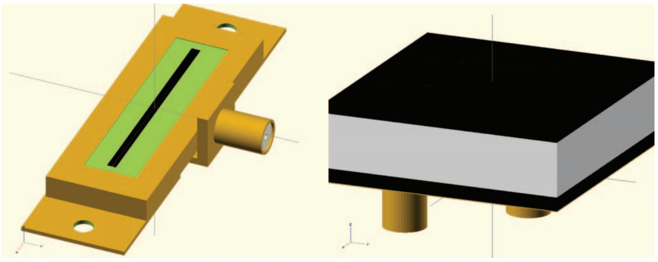

(a) (b)

Fig. 2. Cavity Slot (a) and Dual Feed Dual Patch (b) Antenna Elements

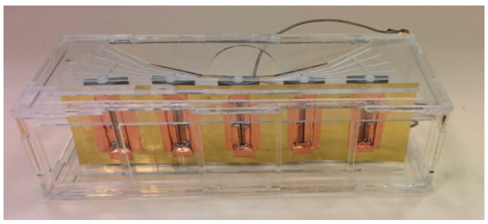

Fig. 3. Conformal Cavity Slot Elements

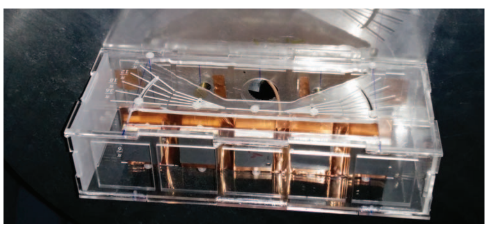

Fig. 4. Dual Feed Dual Patch Antenna Elements

the conformal ground plane and then soldered to ensure a consistent connection as the array is distorted. The Conformal Ground plane is also glued to the brackets to ensure an even curvature as the inter-element angle is increased. The full array is shown dismounted from the motorized mount in Fig. 3.

B. Dual Feed Dual Patch Antenna Elements

The Conformal Dual Feed Dual Patch Antenna Array is comprised of five dual feed dual circular patch elements, resonant at 5.2GHz (Fig. 2b). The driven element is back fed with each feed exciting a separate mode. The second circular patch is separated by a layer of insulator, serving as a director, increasing the directivity. The antenna elements are mounted on sheets of 4mm acrylic which is covered with copper foil which forms the conformal ground plane for this array. The acrylic supports are drilled and tapped for the Conformal Test Rig securing screws. The full array in planar configuration is shown mounted in the anechoic chamber in Fig. 4.

III. Results

A. Array Patterns

The individual array element patterns were measured, and combined using simple beam forming, taking account of the small changes in the x,z, axis as elements 1,2,4, & 5 shift for each new array configuration as marked on the test rig. The beam forming mathematics [3], allow the pointing of the array pattern main beam in a specific direction, along vector (v_0, u_0, w_0), for which the steering phase for element n with position (x_n, y_n, z_n) is given in Equation 1. This can be simplified as the arrays under investigation are comprised of a single row of elements only, so the y axis components may be ignored.

$$n = \frac{2\pi}{\lambda}(u_0 x_n + v_0 y_n + w_0 z_n) \tag{1}$$

Upon examination of the full array patterns, the trend for both antenna types (Conformal Cavity Slot Antenna Array in Black, Dual Feed Dual Patch (Vertical) in Blue, Dual Feed Dual Patch (Horizontal) in Red) is recognised as the classical pattern for a transition from planar to decreasing radii of curvature. In the planar configuration, (Fig. 5) both the Conformal Cavity Slots and both modes of the Dual Feed Dual Patch arrays show a main beam in the +z direction, with the first sidelobes 10dB down. As the inter-element angle is increased to 5^o (Fig. 6) the main beamwidth increases. In the 10^o configuration (Fig. 7) the main beam has largely merged with the sidelobes in all patterns. However the Conformal Cavity Slot Array does show increasing antisymmetric behaviour as the inter-element angle increases, this is thought to be due to the construction of the array itself, as the Cavity Slot elements are fed from the -X side on each element, and the feed for Element 1 is very close to the edge of the conformal ground plane, while the Dual Feed Dual Patch elements are back fed, which minimises any effects on the pattern. If a larger conformal ground plane was used this effect would be eliminated.

Once the array has been configured into the 15^o inter-element angle (Fig. 8), the array pattern approaches a uniform beam over 180^o. Interestingly, at 20^o (Fig. 9) the array patterns display a more directive response, which is thought to be due to the shadowing effects starting to play a much large role. The antenna pattern measurements were carried out at 5.2GHz, corresponding to a wavelength of 0.057m, in future measurements the relationship between wavelength, and radii of curvature in the role shadowing plays in the array pattern would be worth investigation.

B. Inter-Element Coupling

In addition to the array patterns the reflection coefficients and inter-element coupling for each array were measured between 1 and 9 GHz. This data will be used in future with the antenna patterns in two areas, investigation of the effects of different ‘optimised’ beam forming schemes, and as a comparison with the prediction of FDTD models for each array. The reflection coefficients for the Conformal Cavity Slot array are shown in Fig. 10. Given the modular nature of the array construction, it is not surprising that there is very little variation in reflection coefficient as the inter-element angle is increased. The only notable exception is Fig. 10d which shows an additional resonance at 6.8GHz in the 10^o angle set. It is

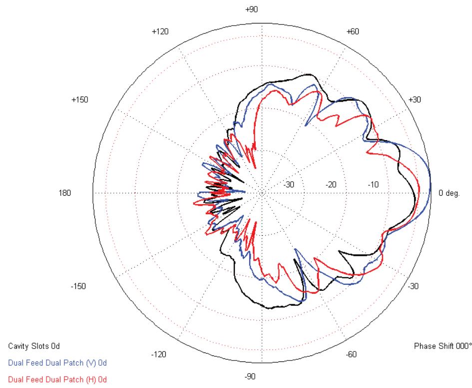

Fig. 5. Planar Array Pattern Comparison (dBi)

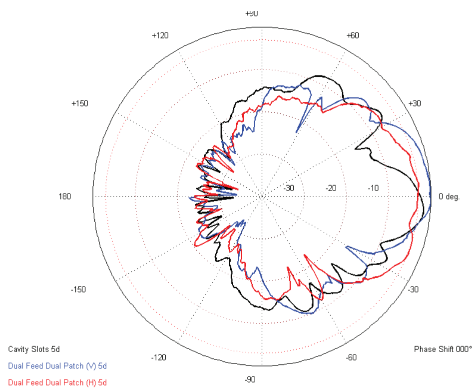

Fig. 6. 5^o Array Pattern Comparison (dBi)

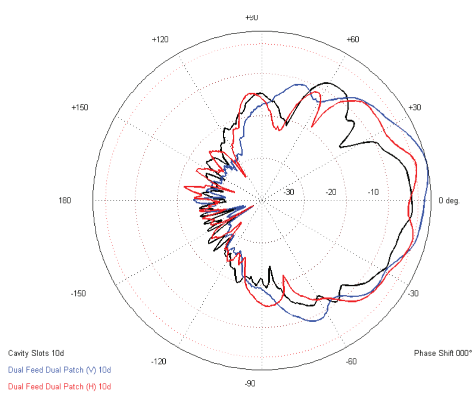

Fig. 7. 10^o Array Pattern Comparison (dBi)

assumed that this is due to distortion of the copper foil which connects the cavity slot case to the conformal ground plane (Fig. 2a).

The Dual Feed Dual Patch Antenna Array reflection coefficients are shown in Fig. 11 (Horizontal Mode), and Fig. 12 (Vertical Mode). These measurements have been presented with some interpolation between angle sets to improve the legibility. There is some variation as the inter-element angle is increased, but there is no consistent trend. Given the modular nature of the array construction this level of variation is surprising. The main resonance at 5.2GHz exhibits variation

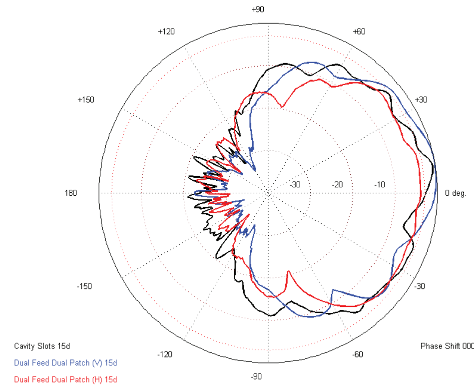

Fig. 8. 15^o Array Pattern Comparison (dBi)

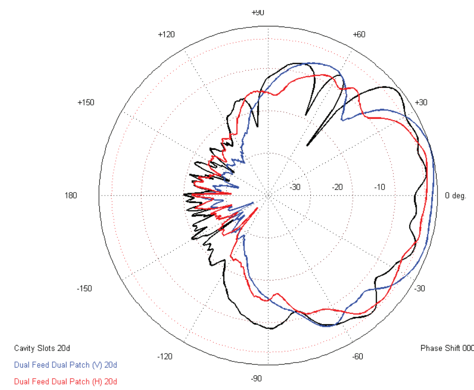

Fig. 9. 20^o Array Pattern Comparison (dBi)

in magnitude and bandwidth (Fig. 11b, Fig. 12b & Fig. 12d) However this major variation is largely confined to Elements 2 and 4, which suggests some variation in construction is the cause of these effects, rather than array distortion.

IV. Conclusion

The Variable Geometry Conformal Antenna Array Test Rig has enabled a direct comparison between two antenna types, and the results thus far are encouraging. In the future the intention is to construct and measure a larger variety of different antenna types in this Variable Geometry Conformal Antenna Array Test Rig. This will allow a systematic comparison of the characteristic performance of antenna types in a conformal array environment, and their suitability for different applications such as SAR and communications. FDTD modelling of the two measured arrays is expected to provide an avenue for cost-effective prediction of this performance, and will be used in future to supplement and guide array construction.

References

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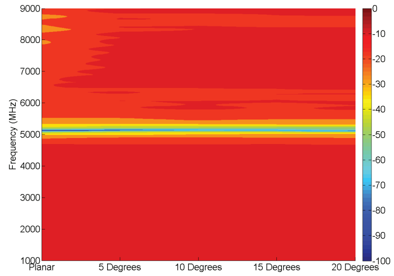
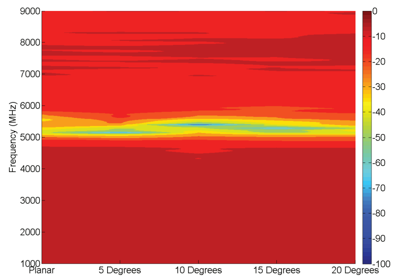
[2] S. Dumanli, C. Railton, and D. Paul et al, "FDTD Channel Modelling with Time Domain Huygens Technique," in *5th European Conference on Antennas and Propagation*, 2011.

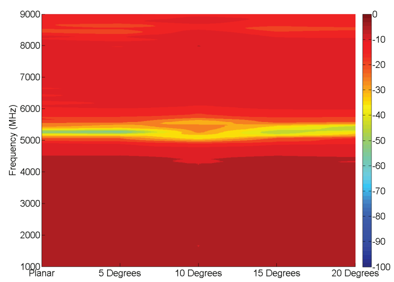
[3] W.-D. Wirth, *Radar Techniques using Array Antennas*. Institution of Electrical Engineers, 2001.



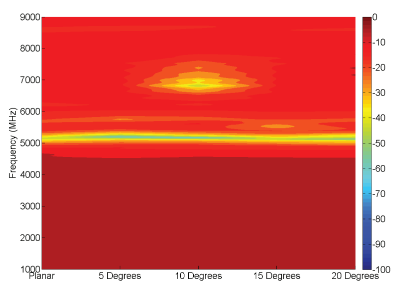
(a) Cavity Slot 1



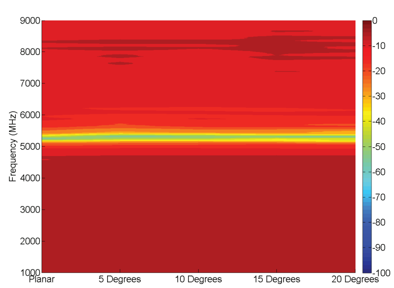
(b) Cavity Slot 2



(c) Cavity Slot 3

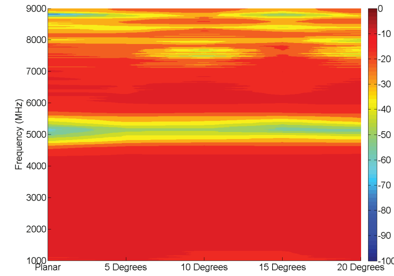


(d) Cavity Slot 4

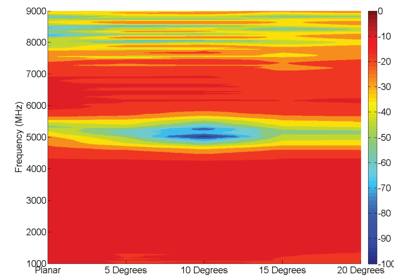


(e) Cavity Slot 5

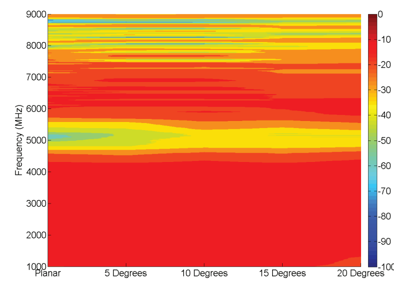
Fig. 10. Reflection Coefficients (dB) for Conformal Cavity Slots in Variable Geometry Test Rig (1GHz-9GHz) against Inter-Element Angle (0,5,10,15,20 Degrees)



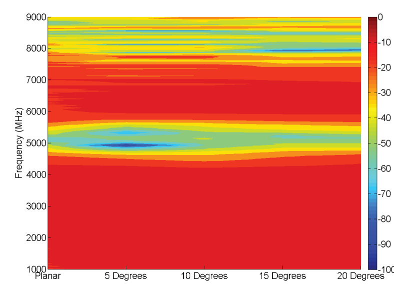
(a) 1H1H



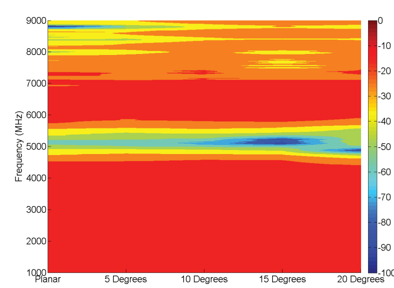
(b) 2H2H



(c) 3H3H

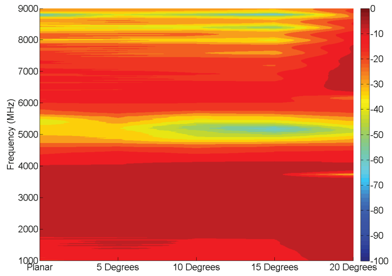


(d) 4H4H

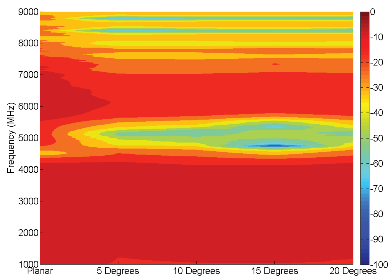


(e) 5H5H

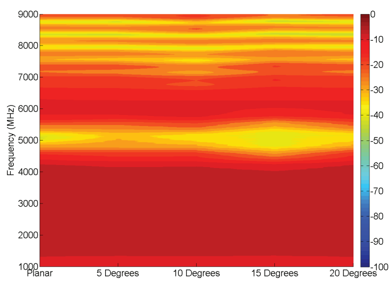
Fig. 11. Reflection Coefficients (dB) for Circular Dual Patch, Dual Feed (Horizontal Mode) Elements in Variable Geometry Test Rig (1GHz-9GHz) against Inter-Element Angle (0,5,10,15,20 Degrees)



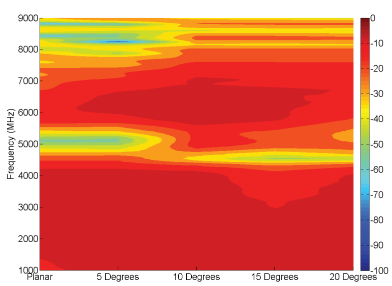
(a) 1V1V



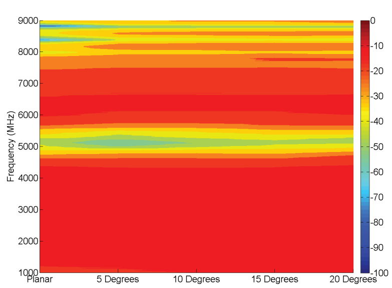
(b) 2V2V



(c) 3V3V



(d) 4V4V



(e) 5V5V

Fig. 12. Reflection Coefficients (dB) for Circular Dual Patch, Dual Feed (Vertical Mode) Elements in Variable Geometry Test Rig (1GHz-9GHz) against Inter-Element Angle (0,5,10,15,20 Degrees)