Conformal Antenna Array Modelling, FDTD Predictions and Measurements for Dual Circular Patch in Variable Geometry Conformal Antenna Array Test Rig

T.G. Pelham[1], G. Hilton[2], E. Mellios[2], C. Railton[2] R. Lewis[3]
[1]Centre for Doctoral Training in Communications, University of Bristol, Bristol, UK
[2]Department of Electrical Engineering, University of Bristol, Bristol, UK
[3]BAE Systems, Advanced Technology Center, Great Baddow, UK

***Abstract*—A comparison of Finite Difference Time Domain (FDTD) methods, for conformal antenna array modelling. This study includes the measurement of Dual Feed Dual Circular Patch Antenna elements mounted in the Variable Geometry Conformal Antenna Array Test Rig. These measurements together with predictions from the Bristol FDTD Model, allows a comparison of antenna array measurements with model predictions over a range of conformal curvatures, with an aim to reducing technical risks in conformal antenna array design.**

***Index Terms*—antenna, propagation, FDTD,, Circular Patch, measurement.**

I. INTRODUCTION

Phased Antenna Arrays have a wide range of applications, aerospace & defence, communications, and medical imaging. Conformal Antenna Arrays in particular 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 or mechanically steered reflector [2], 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 could provide greater functionality in these environments, a larger coverage area and multiple beams for high throughput communications standards such as the emerging 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.

However, the conventional design process for a conformal antenna array is to specify a planar antenna array of approximately the right specifications, and then to warp the aperture to fit the conformance required. This method involves increased technical risk, as the qualitative design decisions required can promote repeated design reviews to ensure that the array meets is performance specifications. This study proposes that given the development of sophisticated Finite Difference Time Domain (FDTD) modelling tools, it is now possible to design a conformal array directly for a set of requirements, based on the surface geometry available. Dependant upon the frequency and geometry of interest the difference between a true 'conformal' array of conformal antenna elements such as presented by Liu et al [3], and Schippers et al [2], and a conformal array of modular 'facets' may become increasingly irrelevant.

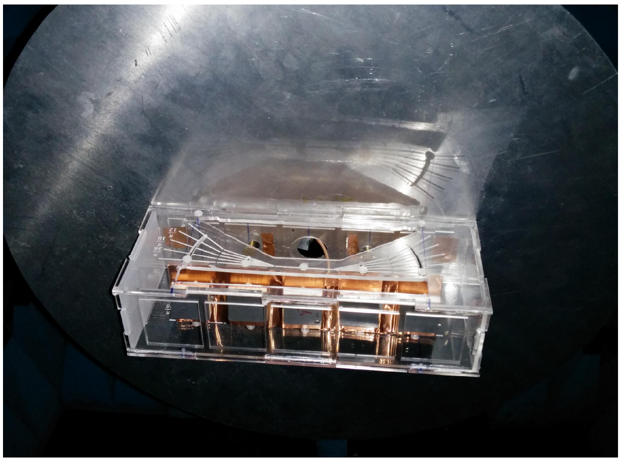

Fig. 1. Dual Patch Element in Variable Geometry Test Rig

II. VARIABLE GEOMETRY CONFORMAL ARRAY TEST RIG

A. *Variable Geometry Conformal Antenna Array Test Rig*

The Variable Geometry Conformal Array Test Rig (Figure 2), was designed to allow consistent testing of a range of antenna elements at a range of inter-element angles, while maintaining a consistent inter-element spacing.

The Test Rig was used in combination with the Dual Patch Elements, and the Cavity Slot Elements [1], to investigate the FDTD methodology, and with these results, give confidence to the investigation of the expanded range of Conformal Antenna Arrays, chosen to contrast the properties of the different antenna types in a conformal array, currently awaiting publication.

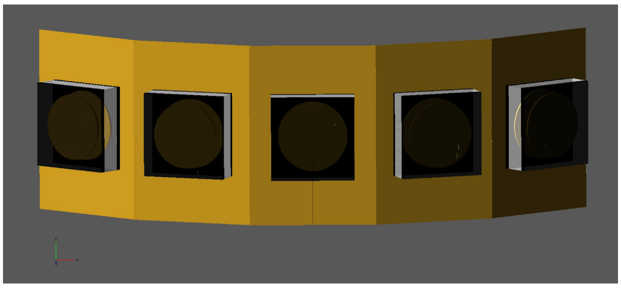

Fig. 2. Dual Patch Antenna Elements, rendered transparently to show internal detail

B. Dual Feed Dual Circular Patch Elements

The Dual Patch antenna element shown in Figure 2, consists of a driven element, a circular patch mounted on a copper backed substrate, and separated by an insulator a parasitic circular patch, of slightly reduced diameter. This stacked plate construction provides a higher directivity than might otherwise be obtained from a conventional patch. The driven element is fed by two coaxial feeds, separated by 90 degrees, and providing the dual polarisation functionality. These modular antenna elements were initially presented in a fixed 17 element faceted conformal array by Railton et al [4], and have now been re-purposed for use in the Variable Geometry Conformal Antenna Array Test Rig. The Dual Patch Antenna can be enclosed within a volume with a radius a, $ka = 4.08$. For clarity the feeds for each element are refereed to via dominant polarisation and element number, e.g. 3V (Element 3, Vertical Feed).

III. Simulation and Measurement Setup

In an effort to isolate the far field response of each element from the chamber rotator mount, a large shielding ground plane was placed behind the Variable Geometry Test Rig, as shown in Figure 1, and the modelled environment was limited to the extent of this ground plane.

A. Bristol FDTD Model

Bristol FDTD is an EM solver used within the university of Bristol for applications from Optics [6], to Medical Imaging [7]. Based upon the work by Yee et al [5] the model includes a variable FDTD mesh, which allows snapping of mesh lines to material boundaries for a more accurate model. In addition this program supports rotation of Time Domain Huygens snapshots, sources, and port templates. which is exploited to improve the computational efficiency of the model using a three stage modelling process [8].

IV. Array Patterns and S Parameters

A. Array Pattern

When the array is operated in the Horizontal mode, there is overall a good agreement between the array antenna pattern measurements and model predictions, as can be seen in Fig 4, and 6 for the Planar antenna array, and in the polar $\phi = 0$ cut in Fig 13. The Vertical mode however shows less agreement,

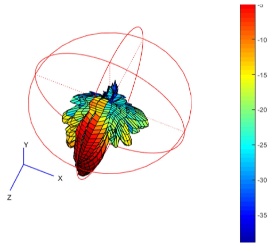

Fig. 3. Measured Planar Array pattern in Vertical Mode

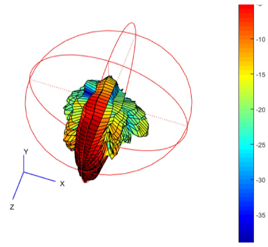

Fig. 4. Measured Planar Array pattern in Horizontal Mode

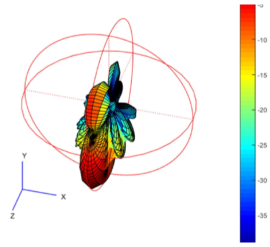

Fig. 5. Modelled Planar Array pattern in Vertical Mode

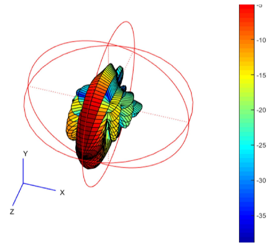

Fig. 6. Modelled Planar Array pattern in Horizontal Mode

the same general array function can be observed, but there is a pronounced beam squint towards $\phi = -90$. Thie effects of this are readily visible when comparing the planar 3D polar plots in Fig 3, and 5, and also by observation of the reduced main beam gain in Fig 13.

As the radius of curvature is reduced the normalised patterns show the expected trend for a conformal aperture of this type with a reduction in main beam gain, while the pronounced beam squint predicted by the FDTD model results in continued low main beam gain in the $\theta = 0$ direction for the FDTD model Vertical mode pattern. Based upon the inter-element coupling, and the comparisons between the measured and model data, the origin of the squint can be clearly linked to the difference in the mutual coupling which is greatest for Vertical-Vertical cross coupling, as might be expected for parallel excitation modes. This effect is reduced with the reduction in the radius of the conformal surface.

B. Inter-Element Coupling

To give an accurate understanding of the relationship between the measurements and the EM model predictions, a statistical basis is required for comparison of such a large data set. Each array angle set measured comprises 100 coupling measures, for a total of 600 S parameters from 1 to 9 GHz. A brief sample has been included here as Figures 7,8,9,10,11,12. But to give a true comparison a statistical measure of similarity is required. To this end normalised Kullback-Leibler divergence has been employed from information theory as the logarithmic distance between two variables P and Q, as shown in Equation 1, [9]. This measure when normalised over the datasets of interest gives a comparative measure of the difference from zero to one. Zero representing identical datasets, and one representing the maximum logarithmic distance calculated. The results of this analysis over the three

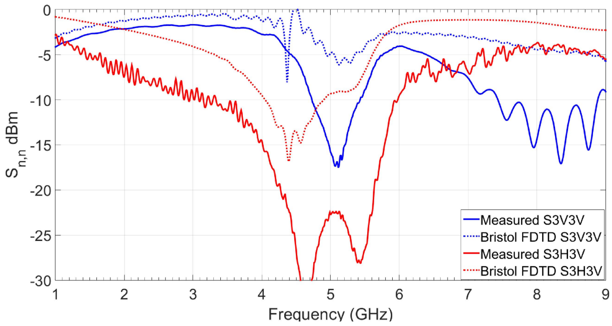

Fig. 7. Central Element Copolar and Cross Polar Response for Planar Array

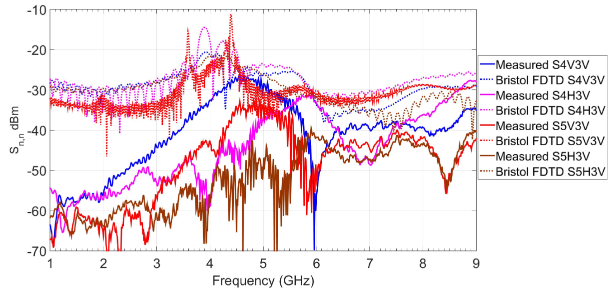

Fig. 8. Intra-Element Coupling for Planar Array

Variable Geometry Array Test Rig Angle Sets examined are shown in Table I.

While the results are normalised relative to the largest Kullback-Leibler Divergence, there is a slight trend of increasing divergence as the inter-element angle is increased. However, when the S11 for each element is examined in isolation there is very little variation between angle sets. It is also clear from the measurements that for these modular antennas, there is little variation in the S11 as the conformal surface geometry changes.

$$D_{KL}(P||Q) = \sum_i P(i) log \frac{P(i)}{Q(i)} \tag{1}$$

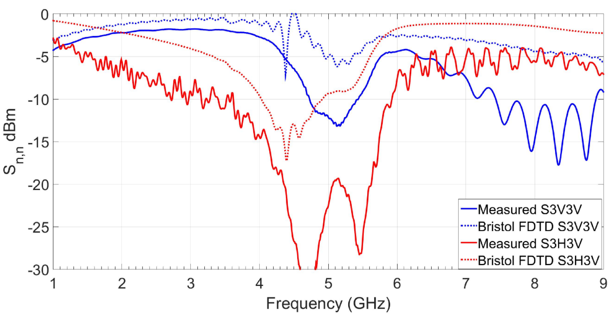

Fig. 9. Central Element Copolar and Cross Polar Response for Conformal Array with 5 degree inter element angle

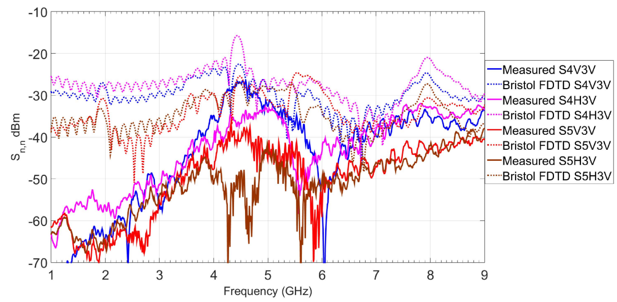

Fig. 10. Intra-Element Coupling for Conformal Array with 5 degree inter element angle

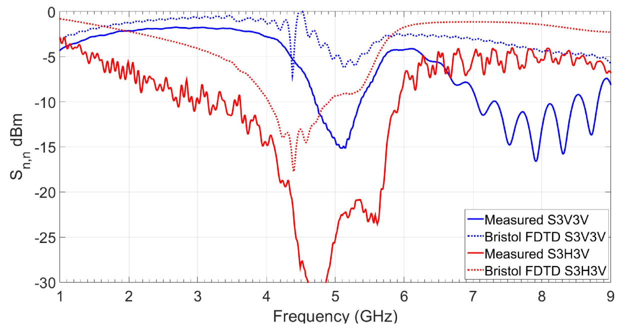

Fig. 11. Central Element Copolar and Cross Polar Response for Conformal Array with 10 degree inter element angle

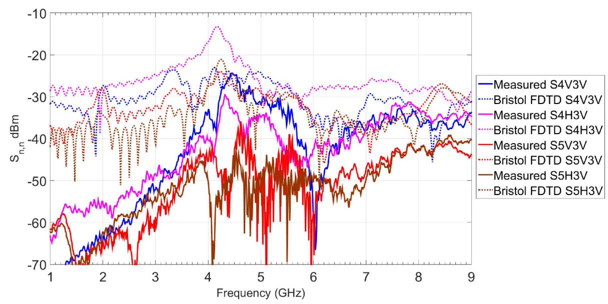

Fig. 12. Intra-Element Coupling for Conformal Array with 10 degree inter element angle

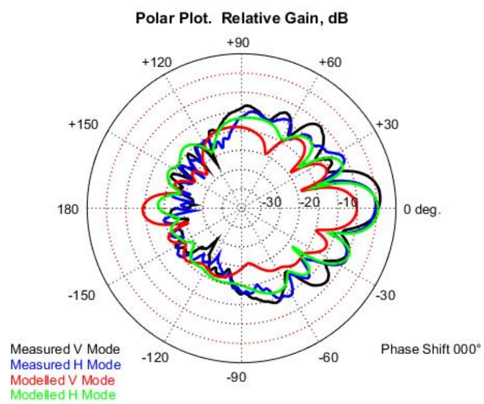

Fig. 13. Polar Plot of normalised Array Directivity for the Planar Array

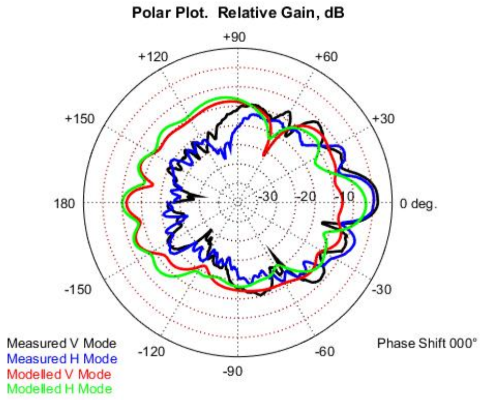

Fig. 14. Polar Plot of normalised Array Directivity for Conformal Array with 5 degree inter element angle

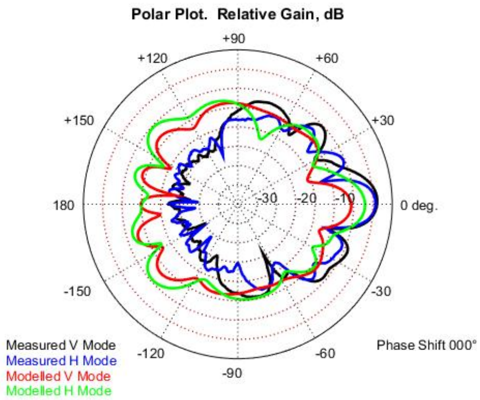

Fig. 15. Polar Plot of normalised Array Directivity for Conformal Array with 10 degree inter element angle

Inter-Element Angle	0d	5d	10d
Bristol FDTD	0.3953	0.4775	0.4991

TABLE I
MEAN NORMALISED KULLBACK-LEIBLER DIVERGENCE FOR ALL S PARAMETERS

Inter-Element Angle	0d	5d	10d
Bristol FDTD	0.0712	0.0728	0.0629

TABLE II
MEAN NORMALISED KULLBACK-LEIBLER DIVERGENCE FOR SELF RESONANCE S PARAMETERS

V. CONCLUSION

When designing conformal antenna arrays, the variation in antenna element S parameters as the elements are warped to fit the surface geometry required introduces a great deal of uncertainty. One consequence of this research is to propose that unless the wavelength of interest is large compared to the radius of curvature required, it is highly advantageous to employ a modular antenna element design philosophy, using a faceted conformal array. The low variation observed in the S parameters of the Dual Patch antenna array for different inter-element angles supports this.

However, the FDTD model, while producing good agreement in the Horizontal mode, predicted higher levels of cross-coupling than measured for this array, and this had an obvious effect on the antenna array pattern results. It is thought that this may be due to the lossless nature of the model used for this study, that perhaps the introduction of appropriate loss tangents for the materials used would yield increased fidelity.

REFERENCES

[1] T. Pelham, G. Hilton, R. Lewis, and C. Railton, "Variable geometry conformal antenna array for element comparison," in *Vehicular Technology Conference (VTC Spring), 2015 IEEE 81st*, May 2015, pp. 1–5.

[2] H. Schippers, J. Verpoorte, P. Jorna, A. Hulzinga, A. Meijerink, C. Roeloffzen, R. Heideman, A. Leinse, and M. Wintels, "Conformal phased array with beam forming for airborne satellite communication," in *Smart Antennas, 2008. WSA 2008. International ITG Workshop on*, Feb 2008, pp. 343–350.

[3] M. Liu, Q. Wu, and Z.-R. Feng, "A millimeter-wave 4x4 conical conformal and dual-band microstrip array," in *Microwave Conference, 2008. APMC 2008. Asia-Pacific*, Dec 2008, pp. 1–4.

[4] C. Railton, D. Paul, and I. Craddock, "Analysis of a 17 element conformal array of stacked circular patch elements using an enhanced fdtd approach," *Microwaves, Antennas and Propagation, IEE Proceedings*, vol. 150, no. 3, pp. 153–158, June 2003.

[5] K. Yee, "Numerical solution of initial boundary value problems involving maxwell's equations in isotropic media," *Antennas and Propagation, IEEE Transactions on*, vol. 14, no. 3, pp. 302–307, May 1966.

[6] J. Rarity, Y.-L. Ho, R. Gibson, C. Hu, M. Cryan, I. Craddock, C. Railton, D. Sanvitto, A. Darei, M. Hopkinson, J. Timpson, A. Fox, and M. Skolnick, "Experiments versus modelling in quantum dot pillar microcavities," in *Transparent Optical Networks, 2006 International Conference on*, vol. 1, June 2006, pp. 67–70.

[7] C. Christodoulou, C. J. Railton, M. Klemm, D. Gibbins, and I. J. Craddock, "Analysis of a uwb hemispherical antenna array in fdtd with a time domain huygens method," *Antennas and Propagation, IEEE Transactions on*, vol. 60, no. 11, pp. 5251–5258, Nov 2012.

[8] T. G. Pelham, G. Hilton, C. Railton, and R. Lewis, "Fdtd model performance analysis for a cavity slot antenna array in a variable geometry conformal test rig," in *Antennas and Propagation USNC/URSI National Radio Science Meeting, 2015 IEEE International Symposium on*, July 2015, pp. 1836–1837.

[9] S. Kullback and R. A. Leibler, "On information and sufficiency," *Ann. Math. Statist.*, vol. 22, no. 1, pp. 79–86, 03 1951. [Online]. Available: http://dx.doi.org/10.1214/aoms/1177729694