Fabrication of a Multi-Octave Phased Array Aperture

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Abstract

A wide band planar phased array antenna consisting of 21 by 21 Highly-Coupled Dipole (HCD) elements was designed using a combination of the 'AGATE' in-house FDTD based prediction tool and commercial microwave circuit design software. This paper discusses the challenges presented during the manufacture of this array antenna, specifically the impact of practical manufacturing considerations and their influence on the design, and the effect of manufacturing variations, relative to the 'ideal' design, on the performance of the antenna as produced.

Keywords: antenna, phased array, mutual coupling, multi-octave bandwidth

Introduction

With space at a premium and a need for increasing functionality at lower cost, multi-octave phased arrays will enable shared aperture systems to be designed incorporating multiple RF functions. To support the development of such arrays requires an understanding of the array environment.

For a multi-octave array, the element spacing will be very small at the lowest frequency. For a 4:1 frequency range, this corresponds to an element spacing of $\lambda_{max}/8$. This proximity means that, rather than something to be minimised or avoided, mutual coupling is a significant factor in achieving very wide bandwidths of operation for phased arrays [1].

Previous work [2], has investigated the design parameters for the selected radiating element, the Highly-Coupled Dipole (HCD), using models of both large finite arrays and individual elements immersed in an infinite array. This made use of the BAE SYSTEMS ATC Finite-Difference Time-Domain (FDTD) code 'AGATE'. The advantage of time domain codes like AGATE is that they provide results at all required frequencies within the specified bandwidth. This is significant when predicting the performance of the array over multiple octaves. A subsequent optimisation of the design parameters, using the Micro-Genetic Algorithm [3] resulted in the design for a 21 by 21 element array. This paper summarises the design and predicted performance, then describes some of the key aspects of the manufacture of a prototype array.

Radiating Element Design

The array is based upon the HCD radiating element and this was optimised as part of previous work [2]. An example of an HCD is shown in Figure 1. This shows a dual polarised implementation using co-axial cables. However, initial investigations prior to the design optimisation indicated that a stripline feed is easier to fabricate. Sketches in Figure 2 show the basic structure for a singly polarised implementation.

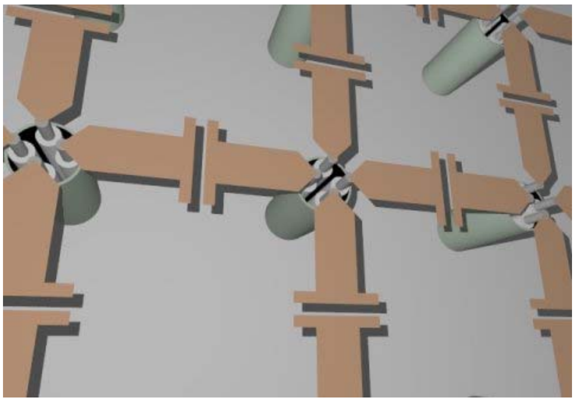

Figure 1 *An example of an array of Highly-Coupled Dipole (HCD) radiating elements*

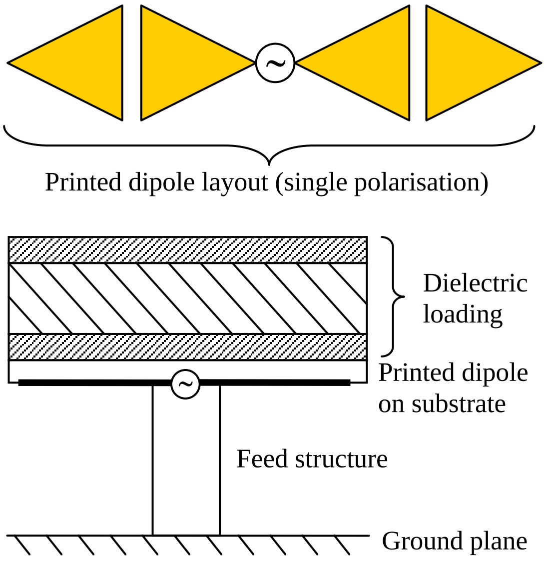

Figure 2 *Structure of the HCD radiating element*

The predicted active voltage standing wave ratio (VSWR) of the radiating element in the frequency range of 2.7 to 10.8GHz (4:1) and array scan angle of up to 60° in all three planes (E-plane, H-plane and Inter-cardinal plane [ϕ = 45°]) meets the acceptable target requirement. An active VSWR of 2:1 is achieved over most of the frequency/scan volume. At some frequencies this level of performance is achieved at array scan angles of up to 70°. If the maximum array scan angle is relaxed then the bandwidth achieved is in excess of 4.5:1.

Array Structure

The basic layout is shown in Figure 4 and consists of a ground plane box machined from a single aluminium billet, into which a series of castellated ‘pillar boards’ are fitted. These printed circuit boards are multilayer structures which feed the elements and contain integrated broad-band baluns. The dipole elements are photolithographically patterned onto a thin (0.25mm) copper clad liquid crystal polymer (LCP) multilayer, complete with bonding pads to which the tops of the pillar boards are electrically connected. Figure 4 essentially shows the array inverted and thus viewed from the back side. Hence, a layer of foam and an outer skin material exist beneath the LCP layer effectively forming a radome-like structure to protect the elements. These are attached as part of the final assembly using an acrylic film adhesive.

Pillar boards

The construction of the pillar boards allows pairs of dipoles, associated with orthogonal polarisations, to be fed from a single board. This is a significant benefit when compared with other dual-polarised arrays. A 13 by 13 element sub-array was connectorised in order to allow the electrical performance to be measured. This necessitated three board types, 13 off 13-way connectorised boards forming the sub-array, 8 off 13-way element boards with integrated matched loads, and 21 off 8-way element boards with matched loads to complete the array. The 13- and 8-way boards are joined together using aluminium connector blocks. For a given row, once the 13- and 8-way boards are joined and the connector block attached, these are then placed in the ground plane box with the pillars (as shown in Figure 3) protruding through the ground plane and a 9mm thick foam layer.

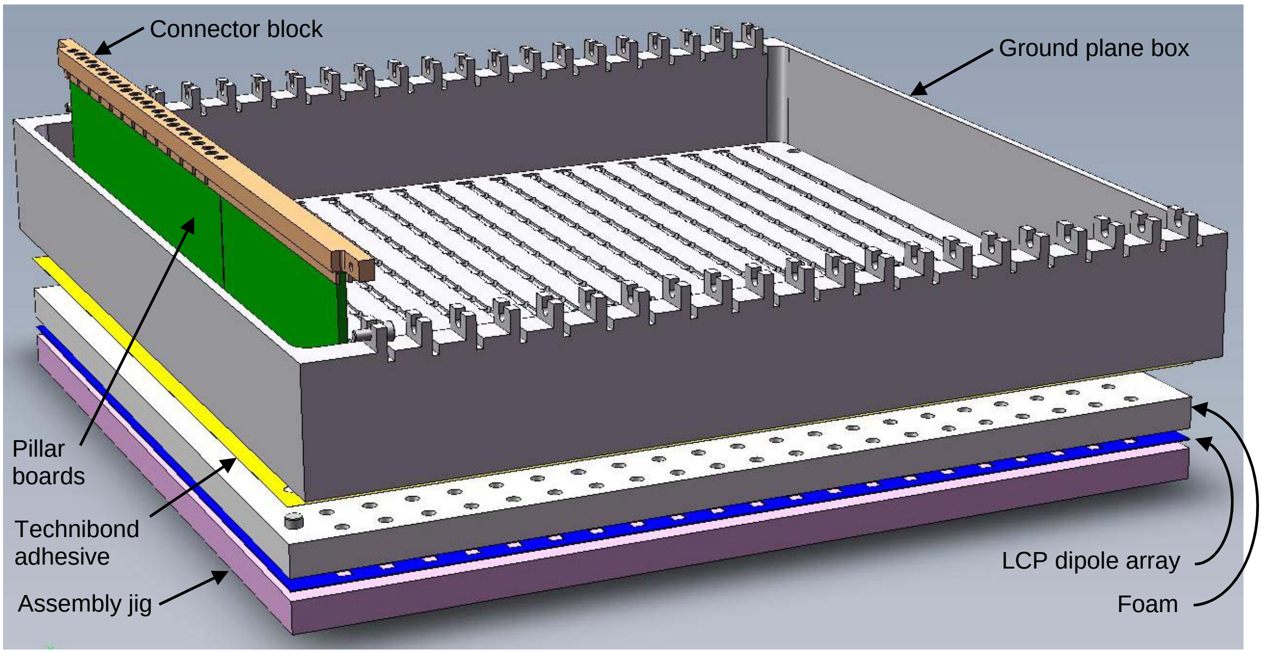

Figure 4 *Exploded view of the array assembly*

This approach required different board types to be joined, end to end, in a precise and repeatable way and the alignment of adjacent boards to also be precisely controlled.

Having inserted all of the 21 way pillar boards, the LCP layer containing the radiating elements is then applied with adhesive to the foam and the ends of the pillars connected to the dipole arms via the pads.

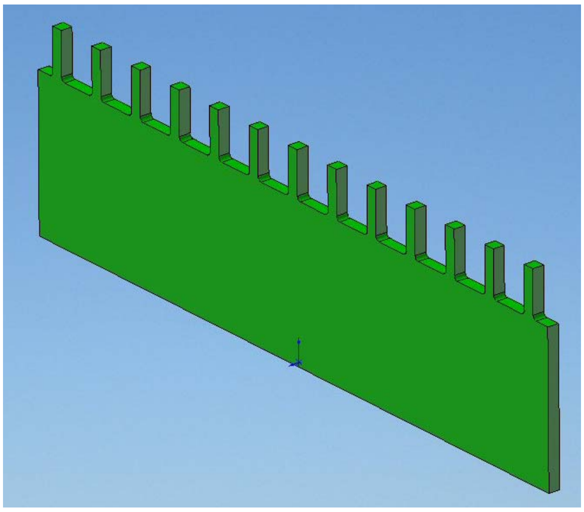

Figure 3 *Schematic of 13 way pillar board (without connector block)*

Effect of Tolerances

Good control of tolerances is required to ensure alignment of pillar boards with the dipole arms. The establishment of these connections was a critical manufacturing step where mis-alignment of around 200µm over approximately 300mm side length of the array would render numbers of elements with no electrical connection.

Movement in the processing of the dipole LCP substrate has to be allowed for. The first manufacturing iteration gave movement close to the limit of allowable manufacturing variation but subsequent layers produced showed a greatly decreased deviation from nominal dimensions.

Critical to the manufacture of the pillar boards was the tolerance associated with the tracks forming the balun within the stacked layers of the PCB. Copper tracks on adjacent layers of the PCB were required to have a registration of better than ±50µm, in order to preserve the characteristic impedance of the stripline formed between adjacent copper layers sandwiching the dielectric.

Process Improvements

The multilayer construction of the pillar boards necessitates conductive vias between various layers in the design. During the early stages of manufacturing process development, these vias, which are formed by copper plating of machined holes between different copper layers, were not found to be formed correctly. In particular, the degree of copper plating was insufficient to form a reliable electrical connection, as can be seen from a sectioned via in Figure 5.

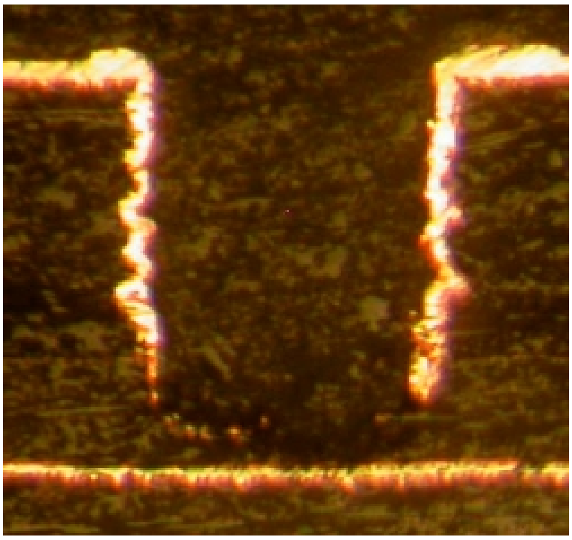

Figure 5 *An example of the over-etched plating on via side-walls*

Several approaches were employed to overcome this difficulty. Where possible, high aspect ratio vias were widened to improve via plating with depth. In addition, further etching processes are used following via construction and these have the potential to attack the copper already deposited in the via. To reduce the risk of the copper in each via being etched away, additional copper was put down to make the deposit thicker and a photoresist 'tent' applied during the later etching steps.

Finally, test coupons were introduced into the panel design so that micro-sections could be taken at each bonding stage to allow examination at successive fabrication steps.

Conclusions

The fabrication of a multi-octave phased array based upon the Highly-Coupled Dipole (HCD) radiating element has been described. The design provides a route to realising a dual polarised broad-band capability for shared aperture communications or remote sensing applications. Some manufacturing steps, notably the pillar board manufacture and LCP dipole layer fabrication require particularly tight manufacturing tolerances. Although these were demonstrated to be feasible for proof of concept demonstration, further manufacturing process developments are required to improve the feasibility of the design for volume manufacture, in addition to consideration of maintenance and repair schemes.

References

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