

The Design, Manufacture and Test of a Four Octave Dual Polarised Array Antenna

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Abstract

The paper describes a three year programme that was devoted to producing a viable 4:1 bandwidth, dual polarised array antenna with a full $\pm 60^\circ$ off boresight scan capability. The tasks undertaken during this process are described chronologically as they took place over the full three years of the programme. Details of the testing and resultant data that confirmed the capability of the array antenna are introduced along with conclusions as to how the successful completion of this area of the programme in concert with other areas has substantially increased TRL levels in the UK for this class of array antenna.

Introduction

The overall aims of the programme were:

- To manufacture and test a design developed over the course of the programme for a wide band dual polarized array antenna
- To discover the fundamental design principles for such wide band array antennas that can be used in the design of other as yet unspecified array antennas and highlight possible military and civilian exploitation routes
- To provide analytical and experimental critical proof of function and demonstrate an array in a laboratory environment raising the Technology Readiness Level to TRL 4, for such technology and to illustrate the way forward for further development

At the initial stage of the programme the manufacture of an array with a bandwidth of 4:1 and a full scan capability out to $\pm 60^\circ$ off boresight was defined as the

criteria for successfully meeting the many of the programmes aims. Thus, these bandwidth and scan capability aims were adopted as the requirements for the array to be manufactured. This meant that dual polarisation would be considered to be a secondary requirement.

Additionally, to meet these aims the overall programme was designed to be a cooperation between SELEX Sensors and Airborne Systems, (Edinburgh) and Queen Mary's University London where, each organisation would address separate but complimentary areas of the programme.

As a result of SELEX's extensive experience and expertise in design, manufacture and test, the majority of these tasks were undertaken by SELEX. However, both organisations were involved in all areas of the programme and the evolution of the design principles upon which this, and future, array designs could be based was an aim closely integrated into all areas of the full three year programme.

Year One: Array Element Investigations

The first tasks to be undertaken in year one of the programme revolved around the examination of a range of existing potential array elements to identify those which would be most suitable for further investigation and candidates for use in the wideband array antenna. Initially, a wide variety of potential candidate elements were examined ranging from patches to bowtie structures and log periodic antennas. This initial examination identified a much smaller range of candidate elements that were worthy of further investigation.

Additionally, the possibility of incorporating band gap materials, to reduce the coupling between elements, and the practicality of using dynamically reconfigurable elements to increase the available overall bandwidth was also investigated.

The down selection was based on the type of elements, pattern, directivity, polarisation response, feed requirements, physical size and potential bandwidth. The elements down selected for further investigation were:

- Spiral structures, sinuous and conventional
- Transverse slot line antennas/(TSAs). simple slots, bunny ears and Vivaldi types
- Quasi Yagis, variations of printed micro strip structures

Only band gap structures compatible with tile or patch architectures were identified and these had not been selected for further investigation. Although reconfigurable architectures that were compatible with TSAs were identified an initial examination of TSA elements suggested that reconfiguration might not be necessary to achieve the required bandwidths. Thus, further investigation of these candidates was suspended till and if the time came

when existing TSA designs proved to be unable to meet the design aims.

At this early stage it was recognised that the success of any array element in meeting the design aims was heavily dependant the ability to design a wide band feed mechanism. To this end as well as extensive modelling and simulation of the remaining candidate elements an investigation of possible feed mechanisms was undertaken.

The results of the investigations into the candidate elements suggested that sufficient bandwidth could not be achieved at the grid pitch required using the quasi yagi structure and that only very high loss spiral structures could be designed that satisfied the bandwidth and grid pitch constrains.

This suggested that some kind of TSA was the most suitable candidate. This decision was reinforced by the beginnings of an understanding as to how the close coupling of the separate array elements could be used to enhance the bandwidth of the array, TSAs being particularly suitable to achieve such coupling, and the realisation that the TSA architecture allowed a range of possible concepts for wide band feeds,[1].

Detailed modelling of the transition into the element, the feed structure, was undertaken and two main candidates were identified:

- Marchand baluns
- Double-Y baluns

Each of these candidates offered a potential wide bandwidth and a viable interface to a TSA structure. Detailed modelling constrained by the required grid pitch for 4:1 arrays, and the availability of substrate materials pointed towards the Marchand balun as the most promising candidate. Additionally, the marchand balun was more amenable to optimisation.

Figures 1 and 2 below illustrate the feed structure that could be modelled by an equivalent circuit and was optimised using only four parameters.

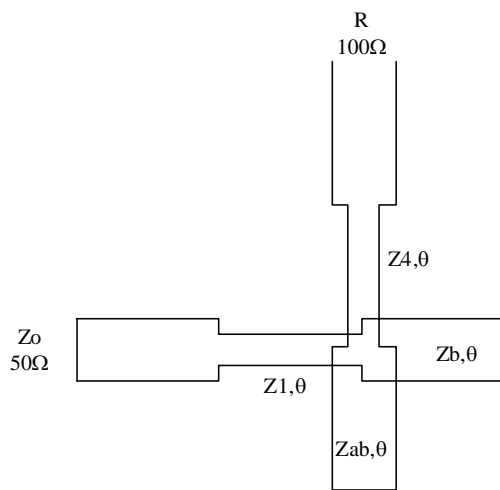


Figure1: Standard Marchand Balun realisation

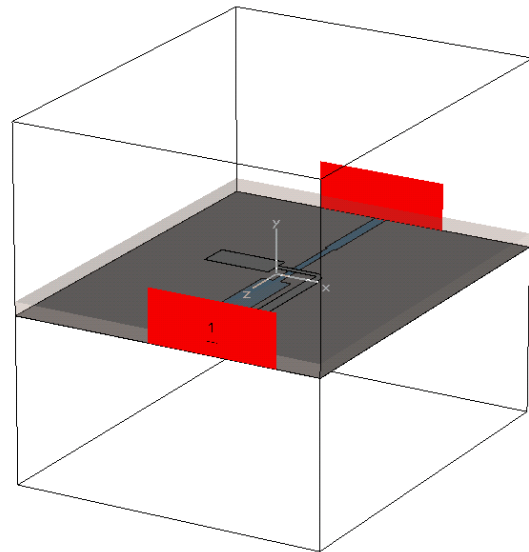


Figure 3: 90° bend in transition to accommodate the required grid pitch

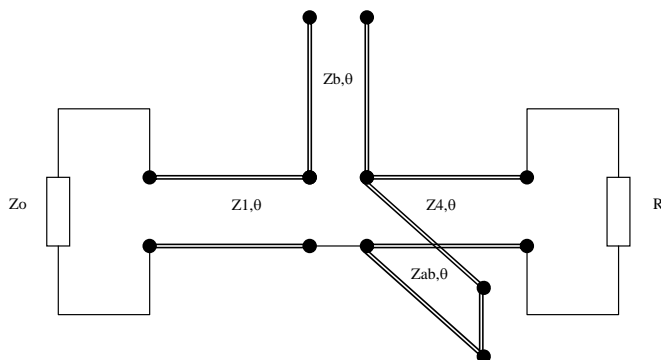


Figure2: Marchand Balun Equivalent Circuit

After optimisation and the realisation of a design that included a right angled bend in the transition, as shown below, figure 3, a direct comparison between the insertion loss of the marchand balun and the double Y transition could be made. This is shown below in figure 4

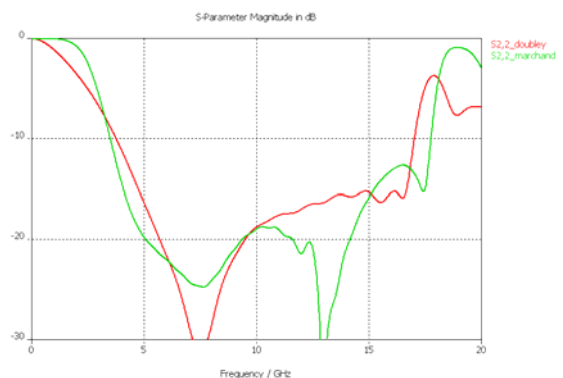


Figure 4: Comparison of marchand and double y balun response

Following this, extensive investigations were undertaken to optimise a TSA design

that could take maximum advantage of the very wideband transition, *i.e.* better than 10dB return loss over the entire frequency band. Eventually a Vivald type radiating structure was selected.

Following this selection, an exercise designed to examine the impact of all the design parameters that could be varied to optimise the element performance was undertaken, these being:

- The length of the element
- The flare rate of the element
- Width of the aperture
- Grid in the E plane
- Grid in the H plane
- Grid in the E and H simultaneously
- Slot width
- Substrate thickness
- Substrate ϵ_r .

This exercise provided sufficient data to allow the development of a detailed design in the second year of the programme.

Year Two Array and Array Element Design

At the start of year two a number of decisions had to be taken to allow detailed design to begin. Firstly a generic concept that could develop a 4:1 bandwidth array had been produced but an actual bandwidth in GHz was required. Secondly all the generic designs so far examined could be realised in microstrip and stripline, one of these alternatives would need to be identified as the basis for the final detailed design.

Under direction from the EMRS DTC a decision was made to optimise the design for the array antenna over the 4:1 bandwidth, 4.5 GHz to 18.0 GHz,[2]. Initial modelling of the generic array element showed little difference in the

element response, if optimised to use suitable dielectrics, for either the microstrip or the stripline variants. Additional modelling of the cross polar response of the generic element design indicated that there were differences in this response with the stripline variant having a higher inter-cardinal response but a better cardinal plane response. Based up these results and the perceived additional complexities associated with designing a dual polarised structure in microstrip a decision was made to go ahead with a detailed design based on the stripline variant.

At this stage, and in the light of the considerations relating to the availability and utility of test elements that were to be manufactured to refine the design, again under the direction of the EMRS DTC, it was decided to manufacture both a linearly polarised version of the array and a smaller dual polarised version.

Based on the data that was produced in the first year of the programme a detailed design exercise was then undertaken to produce an element design that would be used in the dual and linearly polarised array demonstrators. Additionally, an overall design for the full array demonstrator was also commenced.

The design settled upon for the linear array was a 31 x 31 element array based on an 8.93 mm rectangular grid pitch. The size of the array was primarily selected to maximise the number of elements that would not have their performance degraded by edge effects. In year one of the programme it had become clear that the design of the array elements was critically related to the overall design of the array as it was the very high levels of mutual coupling between the individual array elements that was the source of the very wide bandwidths that could be accomplished.

The grid pitch was determined by the highest frequency and maximum scan angles required and the rectangular grid was chosen so that both the linear and dual polarised versions could exploit the same element design. Finally, an odd number of array elements in both dimensions were chosen in the light of considerations related to the measurements that would be undertaken to assess the array. It was thought that having a central element on the array face would make the design of a suitable measurement campaign easier.

The programme only allowed for the design manufacture and test of an antenna array. There were to be no interfacing electronic components available to power the individual array elements so it was decided that the array elements would be terminated by matched loads. Some of these were in the form of connectors that could be removed so that measurements could be performed and the rest would be integral to the boards on which the elements were fabricated. This meant that the overall design of the array would need to allow the placement and subsequent movement of boards to different positions in the array if a full set of measurements were required. This in turn meant that any dual polarised array could not be manufactured for an 8.93 mm grid pitch as there was insufficient space to allow two connectors per element. As a result it was decided to manufacture two arrays, one linearly polarised array of 31 x 31 elements optimised over 4.5 GHz to 18.0 GHz, and a second smaller dual polarised array optimised over the 4:1 bandwidth of 2.7 GHz to 10.8 GHz. It was considered that this would be possible as the TSA design was in theory scalable to a range of 4:1 bandwidths.

With these constraints in place, detailed design modelling and simulation of the array element response was undertaken and a final design established. A modular array design allowed placement and

repositioning of boards within the array was developed.

Figure 5 below illustrates the match of the final element design as a function of E plane scan angle and frequency.

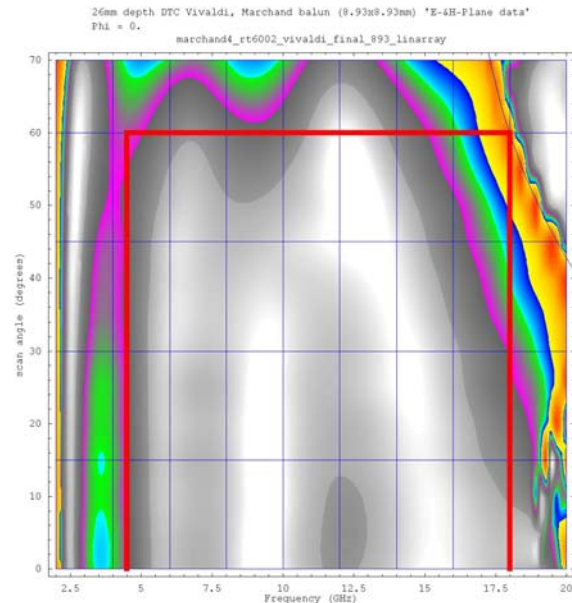


Figure 5: E plane match of the array element

From the above figure it is clear that element match is better than the design aim of -10dB over the vast majority of the complete specified frequency and scan range. Only at extreme scan angles and above 17 GHz did the match degrade to as little as -6dB.

At this time it was decided to manufacture a single 31 element test board to verify the design that would be used for the full array. A range of coupling and pattern measurements could be made to assess the design and the accuracy of the modelling predictions via measurement. Figures 6 and 7 below show the single board and its active match.

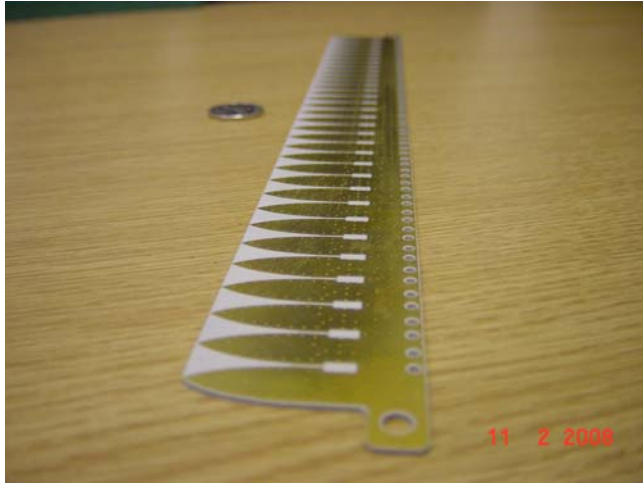


Figure 6: 31 element board next to 10p coin to show scale

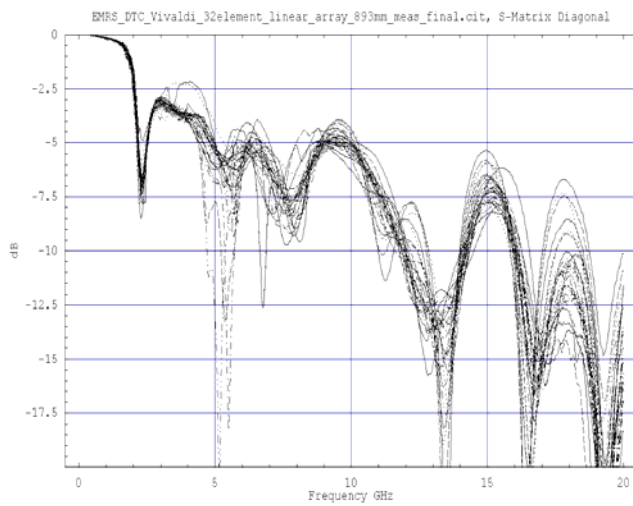


Figure7: active match for a16 element on the single array board

Figure 7 above shows the active match for 16 of the elements on the single element board. This is very different from the match that would be expected if the board was immersed in a full array, but did match the predictions for a single linear array. Additionally, it highlighted a range of connector issues including the resonances at 5GHz that could subsequently be overcome in the testing of the full array.

Year Three Array manufacture and test

Year three commenced with a procurement exercise to acquire all the necessary

components required to assemble the full 31 x 31 linearly polarised array. At the same time design for the smaller 7 x 7 dual polarised array was completed and model based simulations of its performance undertaken.

After the successful completion of the linear array manufacture a series of coupling measurements were undertaken to determine the active reflection coefficients. (ARC), for the centre elements of the array. Figures 8 below shows the array mount used to make coupling measurements

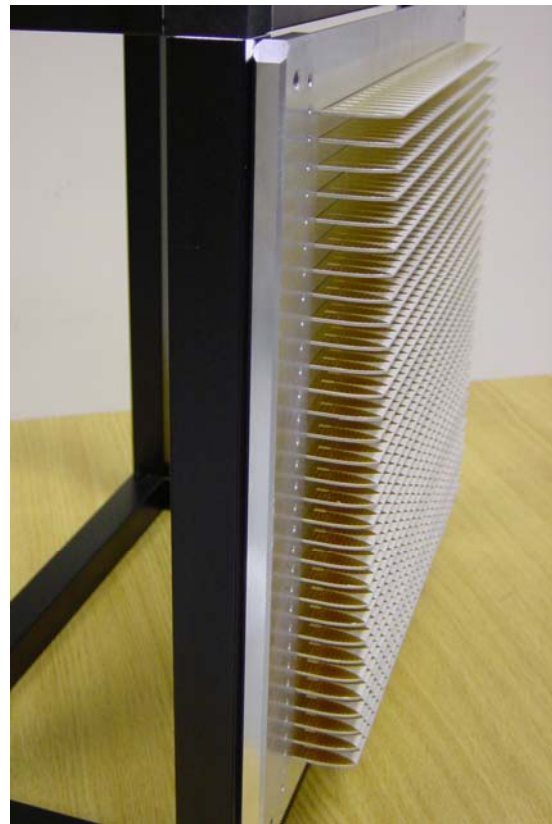


Figure 8: linearly polarised array

Figure 9 below illustrates the processed results of these measurements showing the ARC of the array elements as a function of frequency and scan angle. Where, as predicted, only above 17.5 GHz and scan angles greater than 50° does the active match fall much below 10dB.

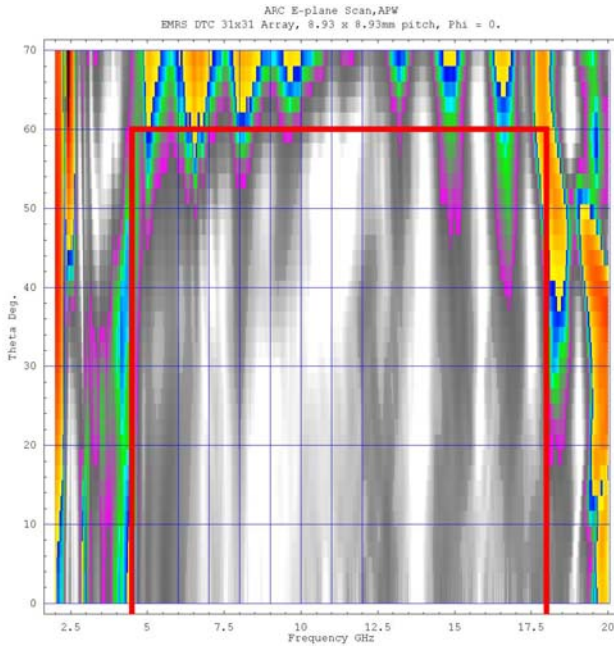


Figure 9: Active match for 31x31 array

As well as the match of the 31 x 31 array meeting the design aims, figure 10 below, shows the accuracy with which the predicted antenna patterns, from simulations of the individual array elements, matched the measured response.

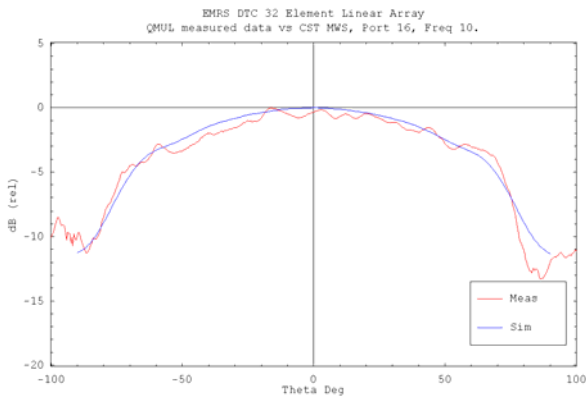


Figure 10: Array element pattern predicted and measured

As part of the array manufacturing exercise in year three, a smaller dual polarised array was also manufactured. Under direction from the DTC it was decided that this array would be optimised over the bandwidth 2.8 GHz to 10.8 GHz and would only comprise 7 x 7 elements.

Figure 11 illustrates the basic structure of the array designed and figure 12 illustrates the comparison between the active match of such a dual polarised antenna and linearly polarised variety using the same element design.

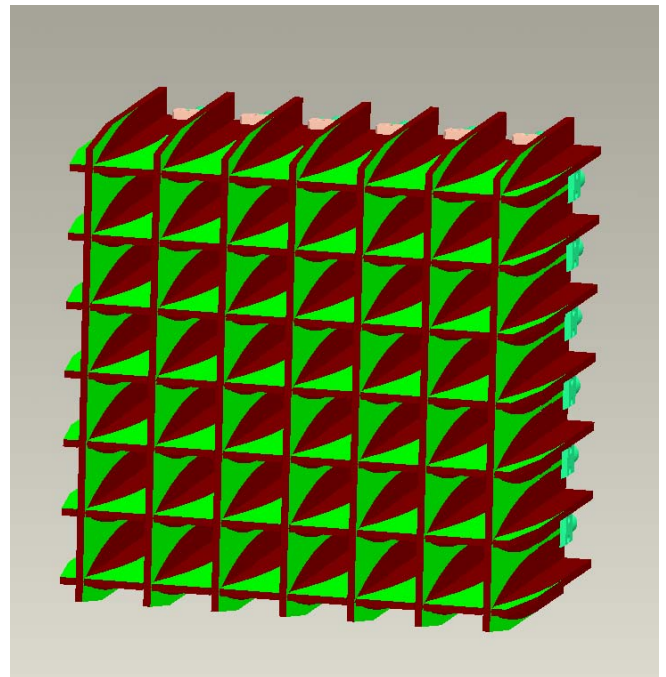


Figure 11: Overall dual polarised array structure

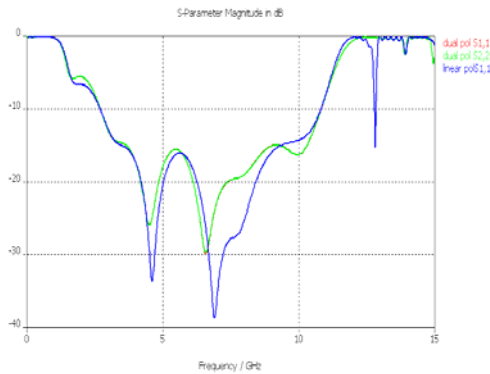


Figure 12: Comparison of linear and dual polarised array active match for same element design

Conclusions

Overall the programme has illustrated that the design and manufacture of linearly and dual polarised arrays that can achieve the full $\pm 60^\circ$ scan over a 4:1 bandwidth. In the course of the programme the strategy of initially establishing a practical feed mechanism for the radiation structure has been vindicated.

Considerable insight into the nature and usefulness of the utilisation of very closely coupled array elements has been provided and the utility of designs based on this very close coupling has also been proved.

However, the designs produced in the programme were essentially optimised to prove the electromagnetic performance of the arrays and no attention was paid to the practicality of the designs in terms of the manufacture or maintenance of real array antennas that could be used in sensing systems. Thus considerable further development would be required to allow the utilisation of such array designs in practical remote electromagnetic sensing systems.

Acknowledgements

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References

- [1] McCormick J., "Wideband Dual Polarised Array Antennas", SELEX report AP50008352, EMRS DTC final year report, 2007.
- [2] Byrne G., "Wideband Dual polarised Array Antennas", SELEX report AP50016020, EMRS DTC final year report, 2008.