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HEMISPHERIC SCAN COVERAGE STUDY

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The objective ~~of the contract~~ is to investigate techniques for achieving hemispheric scan coverage by means of a phased array of elements flush mounted on a cylindrical surface. The studies included a theoretical investigation and an experimental program, the latter having the purpose of verifying the results of the analysis.

The theoretical investigation has brought general methods of analyzing infinite periodic and finite cylindrical arrays. The experimental program has proved that the analytical methods give results in close agreement with experimental measurements.

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1. INTRODUCTION AND SUMMARY

The present report briefly summarizes the studies performed under AFCRL Contract No. F19628-70-C-0226, during the years 1970 and 1971. Detailed accounts of the studies can be found in Scientific Reports No. 1 (AFCRL No. 70-0682), No. 2 (AFCRL-71-0322) and No. 3 (AFCRL No. 72-0232). The objective of the contract is to investigate techniques applicable to the problem of achieving wide angle scan coverage by a phased array of elements flush mounted on a cylindrical surface and to establish relevant engineering design guidelines. Ultimate goal of the investigation is to establish the feasibility of a cylindrical array having a maximum gain fluctuation or dropoff versus scan angle no more than 6 dB on a hemispheric sector. The studies included a theoretical investigation and an experimental program, the latter having the purpose of verifying the results of the analysis. The theoretical investigation has been articulated in distinct phases.

Phase I) Infinite Cylindrical Arrays

The study has lead to effective techniques for the analysis of infinite cylindrical arrays. A finite size array is represented by an excited portion of the infinite periodic structure. This analysis gives reliable results in the coverage region around the array broadside. The infinite periodical model, of course, totally fails to predict the array performance in regions close to endfire.

Phase II) Finite Cylindrical Arrays

The analysis has been extended beyond the level of Phase I to include the edge effects due to the finite size of practical arrays. The antenna models developed during this phase are shown to predict endfire gain of arrays with accuracy good for all practical purposes.

During the experimental investigation, a cylindrical array of 284 elements was built and tested. The cylinder radius is 16 in. and the array extends over a sector of about 50 deg. The array elements are circular waveguides load terminated. The tests consisted of feeding one element at a time and taking its gain pattern in the array environment. The information on the radiative properties of these array elements collected experimentally is in excellent agreement with the results from the analytical studies, thus proving that the methods developed to predict cylindrical array performance are indeed reliable.

2. THEORETICAL INVESTIGATION

2.1 General Considerations

In order to investigate techniques to achieve hemispheric scan coverage by means of a cylindrical array, it is necessary to establish effective methods to predict array performance. This way techniques can be devised and their effects on array coverage quickly evaluated.

The theoretical studies performed under this AFCRL contract have been directed toward advancing cylindrical array analysis, taking into account mutual coupling among elements. In a first approach to cylindrical array analysis, the structures investigated were infinite periodic in the axial direction. A similar approach (infinite periodic model) was used by several authors[1][2][3] in the analysis of plane phased arrays.

The infinite array model was refined in a subsequent phase of the theoretical studies so as to include edge effects due to finite array dimensions. During this phase of the investigation the endfire coverage obtainable by a cylindrical array was carefully analyzed. In both phases of the theoretical studies the main technique considered for achieving hemispheric coverage was off-broadside matching. Results show that indeed a considerable improvement of array coverage can be obtained this way.

2.2 Infinite Array Studies

The approach used during this study consists in modelling the array as the finite excited portion of an infinite periodic structure. The array consists of flush mounted elements arranged in a triangular lattice. The method of analysis is based on a systematic exploitation of the translational and rotational symmetry of the infinite periodic array. Every "free" array excitation[4] is decomposed in a set of elementary excitations matching the symmetry of the structure (eigenexcitations). The analysis of the array radiation for the eigenexcitations is much simpler than the general case, which can be obtained from the eigenexcitations by simple superposition. The analysis has been conducted rigorously, using several waveguide modes in matching the boundary conditions at the cylinder surface. The usefulness of the method of analysis introduced has been illustrated by a number of numerical examples[5]. Radiation from cylinders with radii ranging from 10λ to 100λ has been analyzed. The effects of different matching conditions on wide angle scan performance have been investigated. It has been shown that, by off-broadside matching, element patterns can be obtained, which have a gain fall of less than 6 dB up to 80 deg from broadside. It has also been checked that these desirable wide angle characteristics are preserved over a band of ± 5 percent around center frequency. For several cylinders the coverage of two arrays having broadside gains of approximately 20 and 30 dB has been calculated. The effectiveness of the off-broadside matching techniques in improving coverage is shown for both arrays. A result from this investigation is a method of shaping the array element pattern by means of a suitable matching network. The array models developed during this phase of the theoretical studies fail to give the correct gain of the array in the endfire direction. However, the infinite periodic array approach has helped considerably in gaining insight into the physical phenomena taking place in cylindrical structures.

2.3 Finite Array Studies

The analysis of plane and cylindrical arrays is usually based on the infinite array model[6]. This way the difficult problems related to the "edge effects" are avoided. However, the infinite array approach has the serious handicap of failing to give correct gain values in the regions close to endfire. To include edge effects in the array model, the finite array was taken into account, by applying a perturbation technique[7], in which the results of the infinite array are used as zero order approximations of the solution. This technique avoids the inversion of the large matrices usually involved in finite array analysis. The voltages of the array elements are obtained by a Neuman series, which converges faster as the array size is increased. However, even small arrays (20 dB gain) can be analyzed by this method.

The finite array analysis has brought two interesting results. It has shown that arrays radiate substantially in the endfire direction. This radiation could not be evaluated by means of the infinite array approach. Another interesting effect is that a long "spatial transient"[8] is present in the array illumination when scanning at extreme angles. The aperture reflection coefficients vary along the array tending to the short condition typical of infinite arrays. By applying the finite array model, an analysis of the coverage obtainable by a cylindrical array of about 30 dB gain was performed. Computations have shown that, if the array is matched at broadside, a loss of about 7 dB is present when scanning to endfire in the plane of the polarization. If the array is matched for radiation at 80 deg from broadside in the plane of polarization, a scan loss of about 4 dB is present in the endfire direction of the same plane. The smaller scan loss is paid for by a lower broadside gain. If the polarization loss of 3 dB[5] is added to the 4 dB minimum scan loss obtainable, it can be seen that hemispheric scan coverage (6 dB maximum loss) cannot be obtained from a 30 dB array by off-broadside matching techniques. On the other hand, computations show that the desired hemispheric coverage can be obtained by 20 dB gain arrays on large cylinders, since they appear to have a scan loss of less than 3 dB over the scan region. These results, along with the methods of analyzing cylindrical arrays, can be considered as the major output of the studies.

3. EXPERIMENTAL INVESTIGATION

The experimental investigation has been aimed at checking the correctness of the analytical evaluations of the element patterns in the array environment. In particular, experimental evidence was sought of the widening of the element patterns (indication of increased coverage) due to a suitable matching network inside the element waveguide. The check on the element pattern predictions gives proof of the correctness of the computations for the array coverage.

The structure used for the tests is a hemicylindrical metal surface of 16-in. radius and 18-in. height. The array has 284 circular elements of 0.3-in. radius, disposed on a triangular lattice with 0.8-in. spacing. The array has an angular extent of about 50 deg and is square shaped. The elements are loaded with rexolite ($\epsilon_r = 2.54$) and are match terminated with the exception of one element which is fed and its patterns monitored.

Three different matching networks for the element pattern shaping were implemented by suitably changing the penetration and the distance from the radiating aperture of two copper-plated tabs. The tests consisted simply of taking the gain patterns of the excited element. To detect edge effects, the active element was positioned in different locations within the array. The frequency of operation was 8.3 GHz. The experimental results have been in close agreement with the theoretical predictions of the element patterns. A great amount of experimental data was collected and a detailed account of the results can be found in Scientific Report No. 3 (AFCRL No. 77-0232).

4. CONCLUSIONS

The hemispheric scan coverage study has produced the following concrete end results:

1) It has advanced the methods of analysis of infinite cylindrical arrays to a state of refinement equal to the well-established methods for plane arrays.

2) It has introduced new methods for the analysis of planar and cylindrical arrays taking into account edge effects.

3) It has established the limits (about 30 dB) on the gain of arrays which can perform hemispheric scan coverage, if only conventional off-broadside matching techniques are applied.

4) It has checked the accuracy of the analytical methods developed in 1) and 2) by an extensive experimental investigation.

The information collected during the study period forms a solid basis for any future cylindrical array program.

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