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13. ABSTRACT *(Maximum 200 words)*

The modified dialkoptic theory is extended and further developed so that it can be used to analyze antenna arrays comprising both microstrip-fed, microstrip radiator elements on grounded substrates and stripline-fed, slot-in-plane radiator elements. Analysis of such structures by the modified diakoptic theory is a very efficient antenna array solution method. Results obtained on model arrays are in close agreement with those computed by the method of moments as well as with data measured in the laboratory, confirming that the technique is also accurate. In addition, a new stripline-fed slot antenna element has been introduced and investigated analytically as well as experimentally. This array element is amenable to theoretical analysis and does not suffer from the parallel plate resonances typically associated with the finite-size of the parallel plates of a practical stripline. The computed data agree closely with measured results and provide the basis for accurate design of stripline-fed slot arrays without excessive experimental trial and error.

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Development of the Modified Diakoptic Theory: Analysis of Microstrip- and Stripline-Fed Arrays

Final Progress Report

Chalmers M. Butler, PI

April 1996

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Foreword

In the research work reported here, the investigators undertook to extend a recently developed method for solving antenna problems, known as the *modified diakoptic theory*, to the point that it could be used to analyze two types of modern antennas of interest to the U.S. Army. These antennas possess electromagnetic characteristics which cause them to be fundamentally different from the type antennas that have been analyzed by the modified diakoptic theory in the past. The undertaking was successful. Model antennas have been analyzed by means of the methods developed and the theoretical results obtained have been verified in the laboratory by experimental studies performed on the models. In many cases of interest, analyses by the modified diakoptic theory are more efficient than are those carried out by means of other available methods.

Statement of Problem Studied

The primary purpose of the research project reported upon here was to develop the underlying theory and methods needed to render the *modified diakoptic theory* applicable to the analysis of microstrip- and stripline-fed antenna arrays. The antennas of interest were large (many element) arrays of microstrip dipole elements fed by microstrip transmission lines and large arrays of narrow slots fed by striplines. The major thrust of the research was further development and refinement of the modified diakoptic theory for application to the above-mentioned types of antennas and arrays. It was not an effort to undertake yet another analysis of these antennas. Due to added contributions from an additional graduate student supported by an EPSCoR grant (DAAL03-92-G-0363), it was also possible to contribute to the understanding of a stripline-fed slot antenna element and to enhance the operating properties of these important elements.

The classes of antenna structures addressed in this work are large (many element) arrays of microstrip dipole elements fed by microstrip transmission lines and large arrays of narrow slots fed by striplines. The microstrip components are those that can be fabricated from narrow strip conductors or traces on grounded substrates, while the stripline components are those which comprise conducting strips located between parallel conducting planes. It was for this class of antennas that the MDT was developed and refined.

Summary of Important Results

The *diakoptic theory* was first developed by Goubau [1,2] in an attempt to analyze small antennas efficiently and simply. His efforts were successful but his method was more complex in concept than necessary, so in 1986 the *modified diakoptic theory* [3] was introduced. The modified theory is an extension of the original theory and is physically more appealing to engineers than is Goubau's original technique. It is closely related to the well known method of moments (MoM), but for many antenna structures of interest it can be made more efficient than the MoM. Its major advantage is that it can be employed to solve a given problem with a smaller matrix than would be needed in a solution technique based upon the traditional MoM. Consequently, the modified diakoptic technique allows one either to achieve greater accuracy or to analyze larger structures than is possible with other methods. In addition, as a minor by-product, the modified diakoptic theory (MDT) is more understandable to a typical antenna engineer than is the MoM.

The MDT is based in part on microwave network theory and makes use either of the open-port impedance or the closed-port admittance description. The latter is involved in the analysis of an aperture antenna but both types were brought to bear in the case of an antenna or "circuit" comprising both conductor and aperture elements. In the MDT a structure of interest is diakopted into sub-units or elements, which results in the introduction of artificial ports. The actual structure is subsequently recovered by short-circuiting the artificially-introduced ports. (When an aperture is involved in the structure, new ports result from artificially introducing short circuits and the original structure is recovered by "opening" these shorts.) The introduction of ports with attendant port voltages and port currents allows one to view the diakopted structure as a network whose port properties can be characterized by an open-port impedance matrix. We have developed an efficient iteration scheme for computing structure currents of sufficient accuracy for use in computing network impedances or admittances from variational expressions for these quantities. The diakopting -- opening of additional ports -- serves to significantly reduce the coupling from element to element and thereby assures rapid convergence of the iteration procedure.

In general we have developed the MDT to a point that the following types of antennas have been successfully analyzed: curved and bent wires, wire loops, top-loaded monopoles, Yagi-Uda arrays, wires over two-media interfaces and over grounded substrates, conducting traces on grounded substrates, slots and slot arrays, and stripline-fed slot arrays. For those cases in which size was not prohibitively large, the same structures have been analyzed by the moment method, and in numerous cases experimental results have been obtained from laboratory models. In all cases the agreement among data obtained from these three methods has been excellent. In addition, even though a thorough study has not been undertaken, it has been observed that a typical reduction of the rank of the matrix needed in the MDT compared to that of the MoM has been significant.

In the course of our analysis of the stripline-fed array, we encountered a feature of this radiator which renders design without supporting experiment very difficult. Consequently, we have pursued the analysis of a modified stripline-fed slot radiator element which is practical in a phased array slot antenna, which exhibits improved input impedance/admittance properties, and which is amenable to theoretical design. In addition, it became necessary to investigate via structures for striplines and microstrips.

We have acquired a good understanding of the type structures that lend themselves to efficient modified diakoptic analysis and the type which do not. In many antenna analyses, the modified diakoptic theory is more efficient than the method of moments in the sense that the former requires less computer time to solve a specified problem. In other cases little or no improvement in efficiency is realized. After acquiring considerable experience with the diakoptic theory, we conclude that, when the computation of system matrix elements is far more time-consuming than is the solution of the matrix equation, there is no gain to be achieved by the diakoptic theory. On the other hand, in antenna problems in which the time needed to solve the set of linear equations far exceeds that needed to fill the matrix, the diakoptic theory offers significant advantage in computational efficiency.

The large arrays of traces on a grounded substrate fed by an embedded stripline are highly amenable to analysis by means of the MDT developed for these structures. Measurements have been conducted on simple antenna models made up of microstrip feed lines and coupled microstrip radiating elements, which have enabled us to demonstrate the high accuracy of results obtained from the modified diakoptic theory. The theoretical and experimental results are in close agreement for these antenna array structures comprising microstrip feed lines coupled to trace-type radiating elements.

It has been possible in many cases of practical interest to compute accurate results from a systematically-determined effective permittivity as opposed to employing the laborious Sommerfeld integrals. This technique can be utilized in determining (accurately) the approximate open-port currents needed in the diakoptic theory and it leads to a very large savings in computer time. The structure parameters for which this method will yield sufficiently accurate open-port currents for use in the diakoptic theory has been investigated. By making use of perturbation, we can also account for conductor losses which has enabled us to obtain far closer agreement between measured and calculated data. For example, theoretical input admittance at the antenna feed, determined by our improved technique which incorporates conductor losses, has a significant real part in agreement with the measured real part even in the ranges of frequency where radiation losses are not particularly strong. Without the improvement the real part of admittance can be in significant error over some ranges of frequency.

The modified diakoptic theory has been adapted to the problem of radiation by (and penetration through) narrow slots and to the more difficult structure of the stripline-fed slotted array. A stationary expression for the short-circuit admittance between slot "ports" has been formulated to accommodate slots. As is expected, one arrives at a short-circuit admittance (Y-parameter) matrix description for the n-port slot structure -- in contrast to an open-circuit description in the case of a "metallic" antenna. The slotted stripline problem, which is a building block for the stripline-fed slotted array, entails the coupling of slots to strips between plates so a stationary expression for coupling between slot ports and strip ports has been developed too. This expression may be interpreted as a generalization of h-parameters from 2-port theory to n-port theory. The diakoptic theory has been applied successfully to the case of a slot in a ground plane, arrays of slots in a conducting plane, and stripline-fed slots. The theoretical calculations yield results that are in close agreement in most frequency ranges of operation.

In our investigation of the stripline-fed slotted array, we encountered a very undesirable feature. The unavoidable excitation of what amounts to an open circuited parallel plate resonator, i.e., the upper and lower plates of the stripline guide sans the center trace, and the subsequent coupling back to the center trace of the stripline guide cause anomalous behavior of the characteristics of the array antenna. This behavior manifests itself in the input impedance or admittance and radiation pattern of the array at the multiple resonance frequencies of the parallel plate cavity. Of course, these anomalies are not observed in the computed theoretical results because, to render the analysis manageable, the parallel plates of the stripline guide are taken to be infinitely wide. Nevertheless, real antennas are of finite size and this problem warranted attention. In present practice, these unwanted features are eliminated by placing shorting posts at various points in the parallel-plate guide, but, unfortunately, doing so renders the array element too complex to be amenable to analysis. Without analysis, design based on predicted properties is very difficult to realize.

To address this problem, we designed a new array element by modifying the stripline feed system. The modified feed discriminates against the parallel-plate cavity resonances and eliminates the anomalous behavior of the input impedance and radiation pattern. Also the modifications of the feed were designed in keeping with the desire to be able to predict the behavior of the antenna from theory. We conducted a theoretical and experimental analysis of this new slot element with the modified feed. An experimental model of the modified-feed array element was fabricated and tested, and the theoretical and experimental results are in close agreement.

The theoretical investigation of the new element is based upon integral equation methods. A significant effort was devoted to the matter of accelerating the convergence of a double infinite series that occurs in the Green's function of the integral equation for the new array element. We derived different forms of this Green's function, all with different convergence properties, in order to take advantage of the different convergence rates exhibited by the different forms as a function the parameters which change in the integral equations. This was done in order to arrive at the most efficient procedure for numerically representing the Green's function.

With the new array element available and solution technique developed, one can make far more theoretical progress in designing stripline-fed slotted arrays.

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C. L. Freeman and C. M. Butler, "Analysis of a stripline-fed slot antenna," **IEEE Trans. on Ant. and Prop.**, (to be submitted by April 29, 1996)

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Scientific Personnel

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C. C. Courtney	supported by project	earned Ph.D., May 1992
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A. W. Mathis	supported by grant	earned M.S., May 1993
D. F. Taylor	not supported by grant	earned M.S., Dec. 1990
C. L. Freeman	not supported by grant	earned Ph.D., May 1996

Notes:

1. Mr. Dowling assisted Mr. Mathis for a short period of time.
2. Mr. Taylor participated in the project and wrote his M.S. thesis on the diakoptic theory but was not supported by the grant.
3. Mrs. Freeman participated in the project and wrote her Ph.D. thesis on the stripline-slot element but was not supported by the grant. She was supported by an EPSCoR grant whose purpose was to enhance the present grant research. She is the former C. L. Levinson (was married in August, 1995) indicated as an author in the above publication list.

Inventions

none

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