SEMI-ANNUAL REPORT

NASA RESEARCH GRANT NGL-03-002-136

ANALYSIS AND SYNTHESIS OF DISTRIBUTED-LUMPED-ACTIVE NETWORKS BY DIGITAL COMPUTER

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I. Introduction

This research project is concerned with an investigation of the ways in which a modern digital computational facility may be used in the analysis and synthesis of networks whose elements are distributed, lumped, and active. Such networks may be referred to as DLA (Distributed-Lumped-Active) networks. During the six-month period covered by this report, the major emphasis of the research investigation has been in three major areas. These are: (1) the modeling of two-or three-layered distributed RC networks with arbitrary terminal configurations imposed on the resistive layers; (2) a new approach to the synthesizing of DLA networks by the use of optimization techniques which avoids many of the problems of non-convergence frequently encountered in the application of such techniques; and (3) the development of a general synthesis capability permitting the application of complex optimization techniques to arbitrary DLA configurations. A more detailed discussion of these areas and the results which have been accomplished in them follows.

II. Two-Dimensional Modeling of Distributed RC Networks

The basic concept of modeling a one-dimensional distributed RC network by a finite number of "L" or "T" sections utilizing series resistors and shunt capacitors may be readily extended to the two-dimensional case. Such a model is readily applicable to a determination of the properties of multi-terminal networks in which the terminal configuration and geometry may be varied to produce a wide range of magnitude and phase characteristics for both driving-point and transfer functions. A modification of the basic approach

is readily made to extend the technique to the case of a three-layer distributed RC element in which the zero-conductivity ground plane is replaced by a resistive one. During the past contract period an effort to develop a set of digital computer programs for the analysis of the lumped equivalent model for such a network has been successfully completed. The results are described in a report which has been submitted.[14] Several of the three-layer configurations investigated in this report appear to have considerable promise for frequency selective circuits. Considerable more application of the programs and a fuller investigation of the properties of some of the more promising network configurations is planned.

III. Constrained Complex Optimization

One of the results of the investigation of techniques for using optimization strategies to synthesize DLA networks has been the development of a new approach to the use of optimization methods. This approach is referred to as complex optimization. The basic approach was described in a previous semi-annual report.* It is based on maximizing (or minimizing) the magnitude of a network function at specified points on the complex frequency plane, thus, effectively create a dominant pole (or a dominant zero) in the function. Like all optimization strategies complex optimization has the inherent problems of possible non-convergence, convergence rather to a local than a global optimum and convergence to a non-realizable set of parameter values. As one means of reducing the possibility of these

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*Semi-Annual Report, Analysis and Synthesis of Distributed-Lumped-Active Networks by Digital Computer, Research Grant NGL-03-002-136, National Aeronautics and Space Administration, September 1, 1967 to February 28, 1969, pp. 1-3.

malfunctions, during the past contract period a constraint procedure has been developed. The procedure is called constrained complex optimization. It consists of the substitution of a number of small easily-solved optimization problems for a given large one. This is done by sequencing the functional parameters of the problem in discrete steps from a starting point in the complex frequency plane at which the value of the network variables are known to a specified point at which these values are to be determined. The results to date indicate that this approach provides a powerful aid to the optimization tools previously developed for this research grant. A paper describing the basic method has been published.[15] A report giving fuller documentation on the method is currently under preparation.

IV. A General DLA Optimization Program

One of the major computational tools which has been developed in the research effort sponsored by this grant is the software package named GOSPEL (General Optimization Software Package for Electrical Networks). This was originally described in a previous annual report.* This computational tool requires that the user implement the problem being optimized in the form of a separate subroutine. In the applications of GOSPEL to the synthesis of DLA networks which have previously been reported, a separate subroutine was written for each different network configuration which was investigated. To eliminate the necessity of preparing such

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*Annual Report, Analysis and Synthesis of Distributed-Lumped-Active Networks by Digital Computer, Research Grant NGL-03-002-136, National Aeronautics and Space Administration, September 1, 1967 to August 31, 1968, pp. 6-7.

individual subroutines, during the past contract period, a research effort has been made to develop a general subroutine which may be used in connection with the GOSPEL program to optimize any desired DLA network configuration. Such a subroutine named ANLYZ has been prepared and tested and is currently in operation. The capabilities of this subroutine are quite broad. It can be used to treat passive network components which are lumped or distributed. The latter can be uniform or may be described by a variety of tapers such as exponential or polynomial. The active elements may be single input or differential input. Any of the network parameters may be selected as being subject to adjustment by the optimization strategy or they may be treated as invariant parameters. This provision makes it possible to try various optimization combinations on the same network with only a simple change of data cards being required to modify the selection of parameters which are to be optimized. The subroutine ANLYZ is described more fully in a report which has been submitted.[16] Considerable future use of this subroutine is planned.

V. Other Research Efforts

One of the major research efforts currently being conducted under this grant is the intensive application of the research tools developed under the grant to the investigation of the properties of many new DLA network configurations. The power and versatility of these digital computational tools makes it possible to conduct extensive analyses of the capabilities of a wide range of DLA networks to determine which of them have superior characteristics and

properties. One such investigation has resulted in the determination of a simple DLA network configuration suitable for high-Q filtering applications. This network has the desirable property that the real part of the pole sensitivity to the variations in the gain of the active element may be set to zero. Thus, this DLA network is a prime candidate for applications in which high selectivity is required and in which it is also desired to minimize the possibility of instability. The network configuration has been described in a paper which will shortly be published.[17]

VI. Conclusion

As a result of the research supported by this grant, a powerful and versatile set of computational tools have been developed for the modeling, analysis, and synthesis of a broad class of networks comprised of distributed, lumped, and active elements. Three of the results completed during the preceding six-month period, namely, constrained complex optimization, modeling of two-dimensional distributed networks, and the development of the subroutine ANLYZ, represent a major extension of the analysis and synthesis capabilities previously implemented under this grant. Specifically the constrained complex optimization approach makes it possible to successfully attack synthesis problems which were previously not solvable, the two-dimensional modeling capabilities open the door to a large range of potentially useful network configurations which could previously not be modeled, and the subroutine ANLYZ provides a general tool which may be applied to a broad range of DLA analysis and synthesis

problems. Considerable application of these tools is planned during the following contract period.

VII. List of Contract Publications

A. Items Published During Other Contract Years

1. Huelsman, L. P., An Algorithm for the Lowpass to Bandpass Transformation, IEEE Transactions on Education, vol. E-11, no. 1, p. 72, March 1968.

2. Huelsman, L. P., and W. J. Kerwin, Digital Computer Analysis of Distributed-Lumped-Active Networks, IEEE Journal of Solid-State Circuits, vol. SC-3, no. 1, pp. 26-29, March 1968.

3. Huelsman, L. P., and S. P. Johnson, An Annotated Bibliography for Distributed RC Networks, University of Arizona, Engineering Experiment Station Report, Prepared under Grant NGL 03-002-136, 11 pages, September 1968.

4. Huelsman, L. P., and S. P. Johnson, The Modeling of Distributed RC Networks, University of Arizona, Engineering Experiment Station Report, Prepared under GRANT NGL 03-002-136, No. 18, 25 pages, September 1968.

5. Huelsman, L. P., GOSPEL - A General Optimization Software Package for Electrical Network Design, University of Arizona, Engineering Experiment Station Report, Prepared under Grant NGL 03-002-136, 94 pages, September 1968.

6. Huelsman, L. P., DLANET - A Digital Computer Program for the Analysis of Distributed-Lumped-Active Networks, University of Arizona, Engineering Experiment Station Report, Prepared under Grant NGL 03-002-136, 46 pages, November 1968.

7. Huelsman, L. P., Synthesis of Distributed-Lumped-Active Networks by Complex Optimization, Proceedings of the Second Hawaii International Conference on System Sciences, pp. 167-171, January 22-24, 1969.

8. Huelsman, L. P., and M. L. Gentry, Modification of the Digital Computer Program DLANET to include the Effects of Differential Input Voltage-Controlled Voltage Sources, University of Arizona, Engineering Experiment Station Report, Prepared under Grant NGL 03-002-136, 13 pages, March 1969.

9. Huelsman, L. P., and G. R. Allgaier, A Grid Search Optimization Subroutine for use with the GOSPEL Optimization Software Package, University of Arizona, Engineering Experiment Station Report, Prepared under Grant NGL 03-002-136, 19 pages, June 1969.

10. Huelsman, L. P. and F. L. Watson, Automated Generation of Distributed-Lumped-Active Network Design Charts by Digital Computer Root-Locus Techniques, University of Arizona, Engineering Experiment Station Report, Prepared under Grant NGL 03-002-136, 43 pages, July 1969.

11. Huelsman, L. P., The Values of the Parameters of a Distributed RC Null Network, IEEE Transactions on Circuit Theory, vol. CT-16, no. 3, p. 376, August 1969.

12. Huelsman, L. P., The Distributed-Lumped-Active Network, IEEE Spectrum, vol. 8, pp. 51-58, August 1969.

13. Huelsman, L. P., and T. A. Liebert, A Comparison of Numerical Techniques for Determining the Parameters of Distributed RC Network, University of Arizona, Engineering Experiment Station Report, Prepared under Grant NGL 03-002-136, 29 pages, August 1969.

B. Items Published During Preceding Six Months

14. Robinson, D. E., and L. P. Huelsman, Lumped Element Modeling of Two Dimensional Distributed RC Networks, University of Arizona, Engineering Experiment Station Report prepared under NASA Grant NGL-03-002-136, 24 pages, January, 1970.

15. Huelsman, L. P., Constrained Complex Optimization and its Application to Distributed-Lumped-Active Network Design, Proceedings of the Third Hawaii International Conference on System Sciences, Part I, pp. 45-58, 1970.

16. Huelsman, L. P., ANLYZ - A Digital Computer Program for the Complex Analysis of Distributed-Lumped-Active Networks, University of Arizona, Engineering Experiment Station Report prepared under NASA Grant NGL-03-002-136, 33 pages, October, 1969.

17. Johnson, S. P., and L. P. Huelsman, A High Q Distributed-Lumped-Active Network Configuration with Zero Real Part Pole Sensitivity, Proceedings of the IEE to appear.