FINAL REPORT
NASA GRANT NGR 18-002-026

DEVELOPMENT OF COMMUNICATIONS ANALYSIS TECHNIQUES

Submitted to
The National Aeronautics
and Space Administration

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1. Introduction

NASA Grant NGR 18-002-026 "Development of Communications Systems Analysis Techniques", was awarded to the University of Louisville on February 15, 1971. The grant was for one year and was funded with $29,750 from NASA and $8,362 of cost sharing by the school. The Principal Investigator was Dr. R. D. Shelton, Associate Professor of Electrical Engineering and Computer Science.

The personnel who were paid with grant funds are listed in Table 1. All worked on the grant part time, usually one-fourth to one-half time. In addition, Mr. Paul Watkins aided the effort by developing a computer program and writing a report on it.

The major publications resulting from the grant are listed in Table 2. A semiannual report and monthly progress reports were submitted to the Manned Spacecraft Center. A special report comparing circuit analysis programs was also provided. In keeping with the NASA policy of reporting grant results in the open literature, the details contained in these publications will not be repeated here. Instead their contents will be briefly reviewed to summarize the grant accomplishments.

Table 1. Grant Personnel

NAME	TITLE	DEGREE RECEIVED
Dr. R. D. Shelton	Principal Investigator	
Mr. Alan F. Neel	Graduate Assistant	M. Eng.
Mr. P. Gerstle	Research Assistant	M. Eng.
Mr. S. L. Gruebbel	Research Assistant	B.E.E.
Mr. D. L. Neal	Research Assistant	B.E.E.
Miss A. Reed	Clerical Assistant	
Mr. W. May	Clerical Assistant	

Table 2. Publications

	TITLE	AUTHORS	PRESENTED
1.	FASP User's Manual	R. D. Shelton, A. F. Neel, and H. Stiegler	University of Louisville Technical Report
2.	FASP Systems Manual	R. D. Shelton, A. F. Neel, and H. Stiegler	University of Louisville Technical Report
3.	Development of Large Scale Computer Programs as a Student Project	R. D. Shelton, and A. F. Neel	Proceedings of the Purdue Symposium on Application of Computers to Electrical Engineering Education
4.	FASP - A Student Developed Program	R. D. Shelton, and A. F. Neel	IEEE Transactions on Education
5.	Computer Simulation of Voice Frequency Telephone Cables	A. F. Neel	M. Eng. Report to University of Louisville
6.	Optimum Filters for Frequency Modulation	P. Gerstle	M. Eng Report to University of Louisville
7.	A Computer Program to Calculate the Distortion of an FM Filter	P. Watkins	M. Eng. Report to University of Louisville
8.	Optimum Filters for Narrow-Band FM	R. D. Shelton	Proceedings of the IEEE

2. Major Results

a. Completion of FASP

FASP stands for Frequency Analysis of Systems Program. It consists of about 4000 FORTRAN statements chosen so that the program will run on most computers with little or no modification. The program is intended for analysis or design of linear dynamic systems such as control systems, but can be used for solution of any problem that can be described by a system of linear time-invariant differential equations. The user supplies a description of the system to be analyzed in a problem-oriented format. The program will then supply a wide variety of information about the system, including transfer functions, frequency plots in several formats, and plots showing how the system performance changes as design parameters are adjusted.

The development of FASP was begun under a previous NASA grant and completed under NGR 18-002-026. This involved a replacement of the root finding subroutines with others that were more compact and gave greater accuracy under most conditions. Also as FASP was delivered to a number of organizations a number of minor but time-consuming problems developed. It seems that the slight differences between FORTRAN compilers on different computers make a truly universal program of this scope impossible. The program could be running on four or five different types of computers and still not work when placed on a new one until some debugging was done. When it is necessary to

overlay the program the problem is greatly compounded. Generally speaking an extensive continuing effort is needed on a program of this scope to adapt it to user needs and arrange for correction and documentation of the inevitable bugs that the users encounter. More time was devoted to this effort than had originally been anticipated, at the expense of some new activities that were planned.

The publication Nos. 1 - 4 in Table 1 describe the details of the FASP program and its development. The M. Eng. report No. 5 was undertaken primarily to conduct an extensive test of FASP on an application (involving high order systems) where experimental evidence was available for validation.

During the summer of 1972 some valuable additions were made to FASP under National Science Foundation sponsorship The additions enable the program to provide time domain outputs such as impulse and step responses of systems. The new version of FASP incorporating these additions will be called FASP II. The system and user's manuals are being modified now and a paper is being prepared for submittal to Electronics Letters. When these are completed, the material will be supplied to NASA. Also underway are some comparisons of the performance of FASP II with those of a continuous system simulator(CSMP) on an IBM 360/65. It is expected that FASP II will be more efficient for linear problems.

The old version of FASP was useful enough for ten different organizations to get it and put it on eight different types

of computers. With the addition of time response capability, FASP II should be even more popular.

b. Analytical and Experimental Results on FM Distortion

The problem of determining the distortion produced when a frequency modulated signal is passed through a realistic bandpass filter has long occupied the attention of communications researchers. The problem is important because such performance data are necessary for the design of increasingly popular angle modulation systems. And the problem is difficult--what results that are available are in complex form that are difficult to apply in realistic cases and whose accuracy is controversial.

Under a previous NASA grant the principal investigator began a study of FM distortion using a new series expansion method developed by Bedrosian and Rice. This effort resulted in bandwidth-distortion trade off curves for a number of widely used types of filters. The results were validated by a direct digital computer simulation of an FM system, and the results were presented in papers in the IEEE Transactions on Communications and the Proceedings of the National Electronics Conference.

In the course of this work it became apparent that the method would permit a complete optimization to be carried out. That is, the optimum bandpass filter for FM could be determined. Under the present grant, NGR 18-002-026, this optimization was successfully completed and documented in the Proceedings of the IEEE. These are believed to be the first quantitative

results on optimum bandpass filters for FM. They generally show that linear phase filters such as the Bessel filter are near the optimum, but the results vary slightly with modulation index.

These results were obtained in the summer of 1971 by an extensive series of computer runs which amounted to a trial and error search for the optimum filter. In order to make this feasible, the program was converted from CSMP to FORTRAN and modified to run on an obsolete minicomputer which was available free.

At the same time a FM system simulator was being constructed from discrete electronic components. It was not completed and validated against previous experimental work until the Spring of 1972 - after publication of the computer results. It was with great interest and some trepidation that the experiments were run duplicating the computer optimization. They came out beautifully. The agreement was more than satisfactory. The experimental results were documented in the M. Eng. report No. 6.

This work is continuing on an unsponsored basis. An M. Eng. student is adding to the hardware to verify the third order case and some other constraints. When these results are completed, a paper will be submitted to the IEEE Transactions on Communications and copies will be provided to NASA.

All these results are limited to the narrowband FM case due to convergence limitations of the series used. The M. Eng.

report No. 7. represents a program based on a different series by Medford which seems to work better for wideband FM. While the program was completed, unfortunately the time ran out on this task before the extensive series of optimization runs could be made. It may be possible to do some of this during the present year.

3. Conclusion

The two major accomplishments of the grant have been summarized. Both the FASP program and the FM distortion study represent efforts that will continue. They have been greatly aided by the support provided by this grant. It is hoped and expected that NASA and the technical public will get its money's worth by utilization of these results.