SEMI-ANNUAL PROGRESS REPORT

NASA GRANT NGR 44-011-026

Submitted by

R. D. Shelton

Electrical Engineering Department

Texas Tech University

to

Office of Scientific and Technical Information

National Aeronautics and Space Administration

ABSTRACT

This report outlines the progress made on NASA Grant NGR 44-011-026 from September 1968 to June 1970. It supplements and organizes the material presented in the six dissertations and master's reports, the eight technical papers, seven major grantee reports, and the monthly progress reports sent to the Manned Spacecraft Center.

June 30, 1970

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I. INTRODUCTION

The National Aeronautics and Space Administration awarded NASA Grant NGR 44-011-026 entitled "Performance Improvement Analysis for the Apollo Unified S-Band System" to Texas Tech University on September 1, 1968. NASA provided the amount of $27,021, while Tech was to provide cost sharing in the amount of $4,697. The principal investigator was Dr. R. D. Shelton. On October 1, 1969 a supplement to the grant was received. NASA funds for the supplement were to be $22,954, and Tech was to provide $8,036 of cost sharing funds.

The objective of the grant was to develop communications system analysis techniques to be used by the Communications Systems Analysis Branch at the NASA Manned Spacecraft Center. In order to provide close coordination, monthly progress reports were requested. In addition four MS reports, two Ph.D. dissertations, seven technical papers (including two published in refereed journals), and seven major grantee reports have been produced to date. The principal purpose of this report is to show how each of these documents has contributed to the grant objective.

II. REVIEW OF PROGRESS

Tables I, II, and III summarize the various publications by type. In the text however they will be discussed by subject:

1. Techniques for Computer Simulation of Communications Systems
2. Development of Computer Aided Analysis Techniques
3. Methods of Phase Lock Loop Performance Improvement
4. Angle Modulation Distortion Analysis Techniques
5. New Methods of Signal Parameter Estimation

TABLE I

M.S. REPORTS AND PH.D. DISSERTATIONS

	Title	Author	Date	Level	Pages
1.	Digital Simulations of Filters and Phase Lock Loop Demodulators	J. L. Mathis	May 1969	M.S.	67
2.	Digital Simulations of Optimum Filters and Predictors	R. A. Newkirk	May 1969	M.S.	90
3.	Computer Modeling of Linear Integrated Circuit Operational Amplifiers	M. J. Ryan	December 1969	M.S.	98
4.	Digital Simulation of Phase Modulation Distortion	J. M. Hall	May 1970	M.S.	44
5.	An Investigation of High Order Phase Lock Systems	A. F. Adkins	May 1970	Ph.D.	118
6.	Signal Parameter Estimation by the Method of Moments	F. S. Yeatts	June 1970	Ph.D.	85

TABLE II

TECHNICAL PAPERS

	Title	Authors	Date	Presented to
1.	A Computer Aided Design System for the Design of Filters	A. F. Adkins, R. D. Shelton, and C. T. Dawson	December 1969	Asilomar Conference on Circuits and Systems
2.	Phase Lock Loop Performance Improvement	T. J. Jones, and R. D. Shelton	April 1970	National Telemetering Conference
3.	Computer Aided Design of Phase Lock Loops	A. F. Adkins, R. D. Shelton, and C. T. Dawson	April 1970	Houston Conference on Circuits, Systems, and Computers
4.	Error Rate Minimization for Improved Phase-Locked Loop Damping Characteristics	T. J. Jones	April 1970	Southwestern IEEE Conference
5.	Change of Error Criterion in Mean Square Optimization	R. D. Shelton, and T. J. Jones	April 1970	Electronics Letters (Journal)
6.	Noise Bandwidth of Common Filters	R. D. Shelton, and A. F. Adkins	To be published in Fall 1970	IEEE Transactions on Communications Technology (Journal)
7.	Signal Parameter Estimation by the Method of Moments	R. D. Shelton, and F. S. Yeatts	December 1970	National Electronics Conference
8.	Effect of IF Filter Characteristics on Angle Modulation Distortion	R. D. Shelton, O. E. Williams, and J. M. Hall	December 1970	National Electronics Conference

TABLE III

OTHER REPORTS

	Title	Author	Date	Pages
1.	CPSD-1 Phaselock Loop Analysis Prototype	A. F. Adkins	April 1969	37
2.	Renewal Proposal NGR 44-011-026	R. D. Shelton	June 1969	23
3.	CPSD-2 Electrical Filter Synthesis Prototype	A. F. Adkins	July 1969	35
4.	FASP Users Manual	R. D. Shelton, and D. M. Green	July 1970	20
5.	FASP Systems Manual	R. D. Shelton, and H. Stiegler	July 1970	240
6.	CPSD-3 Electrical Filter Synthesis	A. F. Adkins, and D. M. Green	July 1970	40
7.	Semi Annual Progress Report NGR 44-011-026	R. D. Shelton	July 1970	14
8.	An FM/FM Distortion Problem Due to Insufficient Predetection Bandwidth	O. E. Williams, and R. D. Shelton	August 1969	15

1. Techniques for Computer Simulation of Communications Systems

Digital computer simulation is a technique which can save a great deal of time and expense in design and analysis of communication systems. The simulation languages like CSMP, used on the larger IBM 360 computers, are particularly convenient. However, FORTRAN provides even greater flexibility at the expense of slightly greater program design time.

The M. S. report, "Digital Simulations of Filters and Phase Lock Loop Demodulators," demonstrates the procedures by which CSMP may be used to test the performance of the most critical portion of a communication system - the demodulators. Baseband simulations were shown to provide test data for demodulators in a very reasonable computer run time. While they were not included in the report, carrier simulations requiring much greater run times were used to validate the baseband simulations. The greatly increased run time requirements for carrier models was found to be a general characteristic. It results from the requirement to have step increments that are small compared to the (very short) carrier period and run times that are long compared to the (very long) modulation signal period. This characteristic was found to severely limit the size of the communication system that can be simulated with a carrier model. The M. S. report, "Digital Simulations of Optimum Filters and Predictors," carries this development of communication simulation techniques further by analyzing the ultimate limits of signal to noise ratio that can be obtained by realizable devices. The technical paper, "Effect of IF Filter Characteristics on Angle Modulation Distortion" includes simulations done with both CSMP and FORTRAN to demonstrate how each technique may be used. Listings of the FORTRAN program were sent to the Manned Spacecraft Center to be used in in-house distortion calculations. Upon request from NASA, a special study of a system under design at MSC was made and reported in "An FM/FM Distortion Problem Due to Insufficient Predetection Bandwidth."

2. Development of Computer Aided Analysis Techniques

The Communications Systems Analysis Branch of the Manned Spacecraft Center has developed a Computer Aided Analysis system primarily for calculation of overall communications performance of the space communication system for Apollo and other advanced missions. However, the existence of this large set of hardware and software permits the development of additional user-oriented computer aided analysis programs with a very nominal amount of effort. In contrast to the main CAA programs, these programs can be used to design and analyze a single block of a system and greatly extend the versatility of the CAA system.

Texas Tech has designed two programs on a flow chart level and sent the designs to the Manned Spacecraft Center in two computer program specifications documents: CPSD-1 "Phaselock Loop Analysis Prototype" and CPSD-2 "Electrical Filter Synthesis Prototype." The programs were then coded and integrated into the CAA system by Lockheed programmers at NASA.* Results of test of these computer aided analysis programs were presented to the technical public in the papers, "A Computer Aided Design System for the Design of Filters" and "Computer Aided Design of Phase Lock Loops". A third specification document, CPSD-3 "Electrical Filter Synthesis," to be delivered in July, will add hardware design capability to the filter program previously implemented. This network synthesis program employs the latest techniques of active network synthesis using integrated circuit operational amplifiers in low sensitivity configurations. As a preliminary to this design an investigation was made into the effect of frequency limitations of these operational amplifiers on the characteristics of the finished filters. This investigation resulted in the M. S. report, "Computer

*Computer Program Documentation, "Phaselock Loop Analysis Prototype Program," (Program M038) by E. N. Hess, Lockheed Electronics Company.

Modeling of Linear Integrated Circuit Operational Amplifiers" which develops rules-of-thumb for the selection of operational amplifiers so that their internal reactances do not interfere with network response for the synthesised filters.

The production of these computer aided analysis programs resulted in the development of some useful techniques for frequency analysis of systems on the block diagram level. Since the programs in their original form were closely tied to the CAA system, it was decided to convert them into a form that would be more widely available to other NASA centers and to the technical public. The result is a user-oriented program called FASP (Frequency Analysis of Systems Program.) FASP was designed to be as machine independent as possible by the use of American National Standards Institute FORTRAN and avoidance of certain statements that are machine dependent. Also the size of the FASP system can easily be scaled to match the memory of any particular computer. The FASP input language is comparable to those of other user-oriented programs like ECAP or CSMP in that it does not require the user to be familiar with computer programming in order to use FASP. Basically FASP allows a system to be easily specified on a block diagram or signal flow graph level and will then provide between any two requested points in the system: 1) the transfer function; 2) Bode, Nyquist, and Nichols plots; 3) root locus plots as any system parameter is varied; and 4) impulse, step, and ramp time responses. In its present form (FASP-Zero) the system has all the output capabilities listed except the time responses and is being tested on an IBM 360/50 and a CDC 1604 at Tech and on a Univac 1108 at NASA. Draft versions of the FASP Users Manual and FASP Systems Manual are also being checked. In the fall it is planned to make an improved version, FASP-I, available to the technical public through the NASA Technology Utilization Program.

3. Methods of Phase Lock Loop Performance Improvement

Phase lock loops are non-linear feedback circuits that are widely used in space communications systems for demodulation and carrier tracking. While they are relatively difficult to design and analyze, they are almost invariably used in modern high performance systems because they allow the systems to operate over greater distances than conventional components. Most of the phase lock loops previously used are second order, that is the differential equation describing their dynamics is second order. For critical applications, such as tracking of an acceleration input, higher order systems are known to yield superior performance. However these loops are usually avoided as they are very difficult to design for stable operation.

The computer aided analysis program described in CPSD-1 "Phase Lock Loop Analysis Prototype" and "Computer Aided Design of Phase Lock Loops" makes it possible to design these higher order loops in a much more convenient manner. Only a very short time is required to specify a loop design and obtain its performance data. Iterations of this procedure can produce a design in a few minutes that would take many hours without the computer system. With this as motivation, a study was made of some of the precise advantages that third, fourth, and higher order loops have over second order loops. These results and design procedures leading to stable loops are presented in the Ph.D. dissertation "An Investigation of High Order Phase Lock Systems."

A second investigation into techniques for improvement of phase lock loop performance dealt with mean square optimization by use of different error criteria than are commonly used. Previous studies have used minimization of the phase error in the loop as the main criterion of optimality. For phase lock loops used as frequency demodulators it is interesting to consider minimization of both phase and frequency errors. The results of this study were presented in the papers "Error Rate Minimization for Improved Phase-Locked Loop Damping

Characteristics" where error rate minimization was considered, and "Phase Lock Loop Performance Improvement" where the sum of error and error rate was minimized as the criterion of optimality. These studies led to some general theorems dealing with the changes that occur in the optimum system when the error criterion and test inputs are changed. These results were published in the technical paper "Change of Error Criterion in Mean Square Optimization."

4. Angle Modulation Distortion Analysis Techniques

The problem of determining the distortion produced when an angle modulated signal is passed through a non-ideal filter (such as a receiver IF filter) has long occupied the attention of some of the most distinguished researchers in electrical engineering. The interest comes because the problem is both important and difficult. It is important to be able to predict the distortion produced in a filtered phase or frequency modulated signal because the bandwidth of receiver filters must be minimized in order to minimize the noise output. However, reducing the bandwidth of filters inevitably means that the filter characteristics appear less like those of an ideal filter in the signal bandwidth. Thus there is a delicate compromise to be made in selection of filter type and bandwidth. The difficulty of the problem has prevented development of the theoretical tools necessary to allow the compromise to be efficiently made. The existing theory presents the distortion in an infinite series form which converges only for relatively small modulation indexes, and worse, the series is so difficult to evaluate that optimization studies of the effect of filter type, order, and bandwidth are unfeasible.

Recently Bedrosian and Rice have developed a new series expansion which converges more satisfactorily, is valid for larger modulation indexes, and is simple enough to permit optimization studies in reasonable computer run times. The paper, "Effect of IF Filter Characteristics on Angle Modulation Distortion," presents the results of such a study. Curves in the paper permit quantitative trade-offs between bandwidth and distortion to be made for a number of practical filters. In addition comparisons between filter types demonstrate quantitatively that linear phase (exemplified by the Bessel filter) is far more important in reduction of distortion than amplitude flatness (as exemplified by the Butterworth filter.) Interestingly, the easily-implemented synchronously-tuned filter turns out to be an attractive compromise. The M.S. report, "Digital Simulation of Phase Modulation Distortion" includes a simulation approach to distortion calculation which was used to validate the Bedrosian-Rice expansion results. Another aspect of the problem is that a small change in IF filter bandwidth can cause a large change in output distortion. Thus in comparing different filters, it is important that the bandwidths be equivalent. The most equitable measure of bandwidth for IF filters is the equivalent noise bandwidth since this determines the total noise passed by the filter and thus determines the range at which threshold occurs. Equivalent noise bandwidths for many of the filters studied were not available so that a fairly general study was made and published in the paper, "Noise Bandwidths of Common Filters."

5. New Methods of Signal Parameter Estimation

Measurement of such signal parameters as amplitude, phase, and frequency can be based on the statistical theory of parameter estimation. This procedure has the advantage that new measurement techniques can be based on well known statistical methods, and their performance can be compared to known optimum bounds. The method of maximum likelihood is known to produce optimum estimates in the sense of minimum variance of the estimates. While this method is often difficult or impossible to apply, it is usually possible to evaluate the performance bound or the variance of the estimates.

A second general procedure, the method of moments, is much simpler to apply. Thus a general study of this method was made, resulting in the Ph.D. dissertation, "Signal Parameter Estimation by the Method of Moments." The general results show that in many cases method of moments estimators can easily be implemented that have performances near the optimum at least for the interesting low signal-to-noise ratio case. The results were also presented to the technical public in a paper by the same title.

III. DISTRIBUTION OF EFFORT

Tables IV and V summarize the effort of the personnel working on the grant. The most noteworthy point is the unusually large effort that was supported by by non-NASA funds. Four of the professional level investigators were U.S. Air Force officers attending graduate school under the Air Force Institute of Technology (AFIT) Program. Two other graduate students were mainly supported by fellowships. The only expense to NASA for the substantial results of these men was the cost of producing their reports. Also the school contribution of faculty supervision was unusually large. The undergraduate assistants, most of whom were helping with the programming of FASP, were supported by NASA funds.

Because of the contribution of senior level personnel time by the Air Force (which is not included in the cost sharing figures) and by Tech, the accomplishments of grant personnel are more voluminous than the relatively modest NASA grant funds would indicate.

TABLE IV

PROFESSIONAL SALARY AND WAGES DISTRIBUTION*

Name	Period	Fraction of Time Supported by: Texas Tech	Air Force (AFIT)	NASA
Prof. R. D. Shelton, Ph.D.	Fall 68 - Spring 69	1/4		
	Summer 69			1
	Fall 69 - Spring 70	1/4		
	Summer 70			1
Prof T. J. Jones, Sc.D.	Summer 69			1
	Fall 69 - Summer 70	1/4		
Prof. A. F. Adkins, Ph.D.	Spring 69			1/2
	Summer 69			1**
	Fall 69	1/4		
	Spring 70			1/2
Maj. O. E. Williams Jr., M.S.	Spring 69 - Summer 70		1/4	
Maj. F. S. Yeatts, Ph.D.	Fall 68 - Spring 70		1/4	
Capt. J. L. Mathis, M.S.	Fall 68		1/4	
Lt. M. J. Ryan, M.S.	Spring 69 - Fall 69		1/4	
Mr. J. M. Hall, M.S.	Fall 68 - Spring 69	1/2		
	Summer 69			1/2
Mr. R. A. Newkirk, M.S.	Summer 68 - Fall 68	1/4		

*Degrees and rank shown as of July 1970.

**Summer job at Manned Spacecraft Center.

TABLE V

STUDENT ASSISTANT FRACTION OF TIME

Name	Period	Fraction of Time Worked
A. Neel	Spring 70	1/2
D. Hefner	Spring 70	1/2
H. Stiegler	Spring 70 - Summer 70	1/2
P. Welch	Spring 70	1/2
C. Benson	Fall 68 - Spring 70	1
B. Brock	Spring 69 - Spring 70	1/4
D. Krause	Spring 70	1/4
B. Schwede	Spring 70 - Summer 70	1
R. Nuss	Spring 70	1/4
B. Abbott	Spring 70	1/4
D. Stotts	Summer 70	1