THE COMMUNICATIONS LINK ANALYSIS AND SIMULATION SYSTEM (CLASS)

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ABSTRACT

The Communications Link Analysis and Simulation System (CLASS) is a comprehensive, computerized communications and tracking system analysis tool under development by the Networks Directorate of the NASA/GSFC. The primary use of this system is to provide the capability to predict the performance of the Tracking and Data Relay Satellite System (TDRSS) User Communications and Tracking links through the TDRSS. This paper describes, in brief form, the general capabilities and operational philosophy of the current and final versions of the CLASS along with some examples of analyses which have been performed utilizing the capabilities of this system.

1. INTRODUCTION

The CLASS is a computerized analysis system for evaluating the performance of communications and tracking links with respect to all performance parameters. The system has been developed specifically to permit the performance evaluations of the forward (command) and return (telemetry) link communications through the TDRSS. The system modeling is, however, designed to permit other systems to be analyzed as will be done when the CLASS is used as a design tool to support future NASA Networks development programs such as TDAS. The initial versions of the system are currently in operational use providing performance analysis of the TDRSS User/TDRSS interface to insure compatibility between the TDRSS Users communications system and TDRSS requirements. The system is also currently in use providing TDRSS user design analysis in an effort to help these users optimize their communications link performance when transmitting through the TDRSS.

The CLASS models all elements of the communications link from the point at which the data is generated to the point at which the data is utilized. A diagram of the modeled TDRSS and TDRSS User systems is shown in Figure 1. The communications channel environment models and data bases are also shown in this figure. A diagram of the TDRSS system as modeled is shown in Figure 2. The performance of the system modeled can be evaluated by analytical or simulation techniques or by a combination of the techniques as appropriate. A pictorial representation of the capabilities of the CLASS system is shown in Figure 3.

The CLASS system has been under development since 1976 and is scheduled for completion in mid 1985. The final system, which is coded in Fortran, is expected to exceed 500,000 lines of code. The initial versions of the system are operational on a dedicated Perkin Elmer 3244 computer and accessed by remote terminals. This computer facility is also utilized in the development of the system. The system is being developed through the efforts of contractors (primarily the LinCom Corporation and Stanford Telecommunications Incorporated) and inhouse NASA/GSFC elements. The development and operation of the system is controlled by NASA/GSFC.

A brief description of the modeling techniques used within the CLASS and the techniques that have, and will, be used to validate the CLASS is contained in the papers by Walter R. Braun and Teresa McKenzie of the LinCom Corporation which are contained in these proceedings. The first paper is titled "Modeling Techniques Used in the Communications Link Analysis and Simulation System (CLASS)" and the second is titled "Validation of the Communications Link Analysis and Simulation System (CLASS)".

2. SYSTEM PHILOSOPHY

The CLASS system is designed to permit reliable and accurate operation by a diverse group of CLASS system users. This operation is attained through the use of authority levels where, at the lowest level (General User Level), it is configured to provide a basic end-to-end system bit error rate analysis capability where only TDRSS User communications system parameters can be varied. The inputs and outputs at this level are heavily protected to insure accurate properly documented analysis. All communications with the system at this level are conversational and self prompting since the user is not required or expected to have a detailed knowledge of the CLASS or of the TDRSS.

The next higher level is the Network Systems Engineer Level and is designed for use by personnel with a good knowledge of the TDRSS and TDRSS User systems but with little or no knowledge of the CLASS. This level provides the capability to analyze all communications link parameters on an end-to-end basis. Here again, only TDRSS User parameters can be modified for the analysis.

The highest level provides the capability to analyse the system on an end-to-end, system by system or subsystem basis. At this level any communications system parameter, TDRSS User, TDRSS or environment, can be varied or modified for the analysis. The user at this level is required to have a detailed knowledge of the CLASS, the TDRSS and the TDRSS User systems.

At all levels, the CLASS system is configured to provide conversational, self prompting inputs and outputs in an effort to simplify the operation of a very complex analysis system and to insure that the results derived at each level are correct and reliable. The system itself is currently being validated and will be fully validated when complete to insure the accuracy of the analysis techniques and models. The system is operated under a central control system which links the appropriate analysis/simulation modules to provide the required analysis. At the General User and Network Systems Engineer levels, the control system selects all analysis and system modules (except for user system data) and fully controls all execution. At the highest level, the CLASS user can override the control system as desired to perform other non-standard types of analysis.

The currently operational analysis capabilities of the CLASS system (the initial system is called Interim CLASS) are shown in Figure 4 by authority level for the General User and NSE levels. These lists represent a subset of the capabilities that will be available when the system is completed.

3. CLASS ANALYSIS CAPABILITIES

The TDRSS, which will be the primary spaceflight communications and tracking support element of the NASA Networks, is a threshold communications system where normal operating margins are expected, and in some cases encouraged, to be small. This results in a communications or tracking link where maximum efficiency must be used, where signal distortions must be minimized, where all channel environment parameters must be considered, and where accurate, thorough and rapid analysis of all appropriate performance parameters must be conducted. The classical communications system analysis techniques in use cannot provide the analysis capabilities and accuracies required, they cannot consider simultaneously all of the significant parameters and cannot consider the non-gaussian communications channel environment of the TDRSS. These classic techniques also can not provide the rapid analysis capability needed by the Networks to ensure performance and compatibility of the TDRSS User/TDRSS interface in a dynamic analysis environment.

The solution to this problem is the development of the CLASS system which can provide all necessary analyses in the required time frame and to the required accuracy. The CLASS also permits many of the analyses to be performed by personnel who are not experts in the area of communications system analysis thereby reducing the demand on this limited resource. This user can for example, by inputting a description of the TDRSS user data system, transmitter and antenna systems, perform an analysis to determine the bit error rate of the data at the output of the TDRSS this analysis can consider simultaneously the users specific link parameters, all signal distortion parameters, antenna characteristics, user vehicle dynamics, the impact of RFI, multipath, atmospherics and TDRSS hardware and software characteristics. This analysis can be performed for all TDRSS compatible signal configurations, both forward (command) and return (telemetry), as well as certain classes of signal structures which are not totally compatible with TDRSS interface requirements.

The primary performance parameters which can be analyzed by the CLASS are data/symbol bit error rate, data/symbol slippage statistics, cycle slippage statistics, signal/data acquisition statistics, loss of lock probabilities, tracking data accuracies, false lock statistics, system interference, and autotrack system performance. These parameters can be analyzed on an end-to-end system basis or on a system-by-system basis. They can be performed as a single point analysis for a single value of each variable, on a sensitivity basis where the performance parameter is computed against the variation of one or more variables or the evaluation can be on a time line basis where the performance parameters are evaluated against a mission time line. Any or all elements of the communications channel can be included in the performance analysis. In general the current operating CLASS system evaluates these performance parameters on an individual basis whereas the final system will provide for the simultaneous evaluation of all applicable performance parameters. These parameters can be used to evaluate the performance capabilities of the TDRSS User link or to evaluate the performance of the TDRSS system or any component of the system.

The CLASS also provides a group of ancillary, or secondary, capabilities which complement or supplement those previously described. These provide the capability to plot or compute statistics relative to TDRSS communications coverage of user spacecraft, prediction of forward and return link flux density restrictions as they affect support capabilities for the user, subprograms to provide formatted data for Interface Control Documents, and other TDRSS/user interface efforts, as well as the ability to evaluate total signal compatibility when any end-to-end evaluation is performed. Also, since the CLASS inherently contains a current description of the interface capabilities of the TDRSS system, this information is provided to the system user, at his request, on a subject by subject basis.

4. CURRENTLY OPERTIONAL ANALYSIS TYPES

The current CLASS system (the Interim CLASS) is capable of performing a variety of analyses based upon the capabilities discussed in Section 3. Some of the more frequently used types are discussed below to provide examples of the CLASS capabilities.

Evaluation of the effect of signal distortions on bit error rate: This evaluation is performed to determine the User Constraint Loss parameter for use in link performance predictions as shown in Figure 5. It can also be utilized to evaluate the sensitivity of the TDRSS in response to variations in one or more link or channel parameters as shown in Figure 6.

Evaluation of TDRSS User bit error rate performance margins: This type of analysis is utilized to evaluate the BER performance of a given set of user parameters on a single point or time line basis. The result is usually expressed as a user EIRP margin relative to achieving a 1 in 10^5 BER. The primary purpose of the CLASS is to provide the User Constraint Loss, RFI Loss, Dynamics Loss, Atmospheric Loss, Antenna Switching Loss, and Multipath Loss data as shown in the example in Figure 7. When operated in this mode, the system also provides a full compatibility evaluation and a link diagram showing all models included in the analysis along with the values of the TDRSS variables involved. An example of this link diagram is shown in Figure 8.

Link acquisition time analysis: This analysis determines the acquisition time statistics for the user link including all elements (total link) or for just one element (e.g., PN acquisition). A total link acquisition time analysis is shown in Figure 9 for a forward link.

The effect of antenna switching of system performance: This type of analysis is conducted to evaluate the effect of antenna switching on user communications channel BER performance, loss of lock statistics and acquisition times. An example is shown in Figure 10. This capability provides both a performance evaluation and an aid in user design activities.

Self interference analysis: A system capability which is executed to monitor the interference caused by the other users of the TDRSS system when support is being provided to a specific user. The results of this continuing analysis are utilized in NASA network planning and user mission design and planning. An example of this type of analysis is shown in Figure 11.

TDRSS user time line performance: A capability to provide a mission time line analysis of any performance parameter while considering all channel and TDRSS elements. An example of a Centaur return link BER performance margin analysis for a planetary insertion trajectory time line is shown in Figure 12. This example analysis includes the effect of Centaur dynamics, antenna switching, plume attenuation and signal characteristics.

TDRSS system performance evaluations: These analyses are conducted to evaluate the performance of the TDRSS system, in total or on a subsystem-by-subsystem basis, relative to specification requirements or to characterize the system performance for the purpose of providing the TDRSS users with current accurate performance predictions. Examples of these analyses are shown in Figure 13 and 14.

5. SYSTEM AVAILABILITY AND USE

Access to the CLASS analysis is currently available through the Network Systems Engineers who are a part of the Networks Mission Support Team. The Network System Engineer will either perform the analysis or refer the request to a CLASS analyst. CLASS system analyses are automatically performed by the NSE as a part of the ICD development efforts. The use of the CLASS for mission design or mission optimization type efforts will normally be executed through the CLASS development contractors. More information on this subject can be provided by contacting the CLASS Development Manager.

For certain TDRSS users, direct access to the CLASS system will be available at the General User authority level. The capabilities available at this level are designed to permit TDRSS user communications system sizing and planning types of analysis. Access at this level may be limited due to computer loading considerations.

ACKNOWLEDGEMENT

I would link to acknowledge the contributions of the LinCom Corportion, expecially Dr. William Lindsey, Dr. Walter Braun and Terese McKenzie, for their invaluable aid in the development of the CLASS concept and the development of many of the components of the CLASS system.

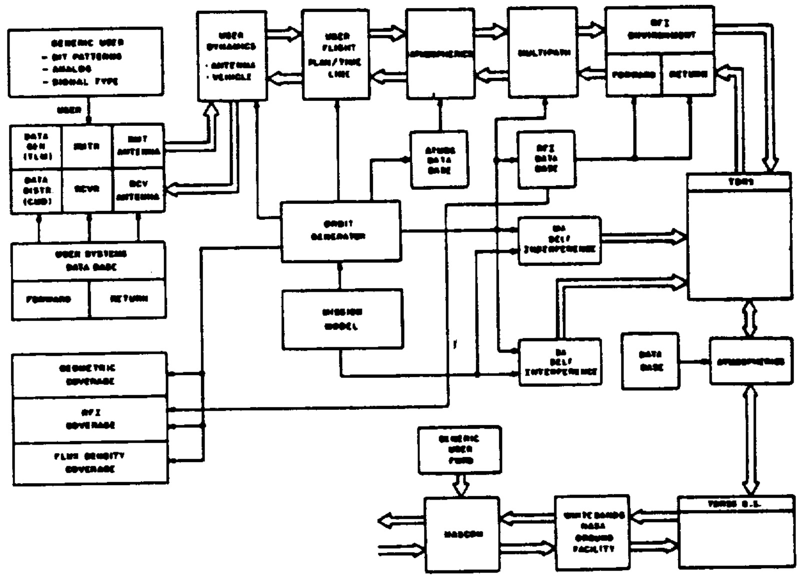

FIGURE 1: CLASS MODEL DIAGRAM

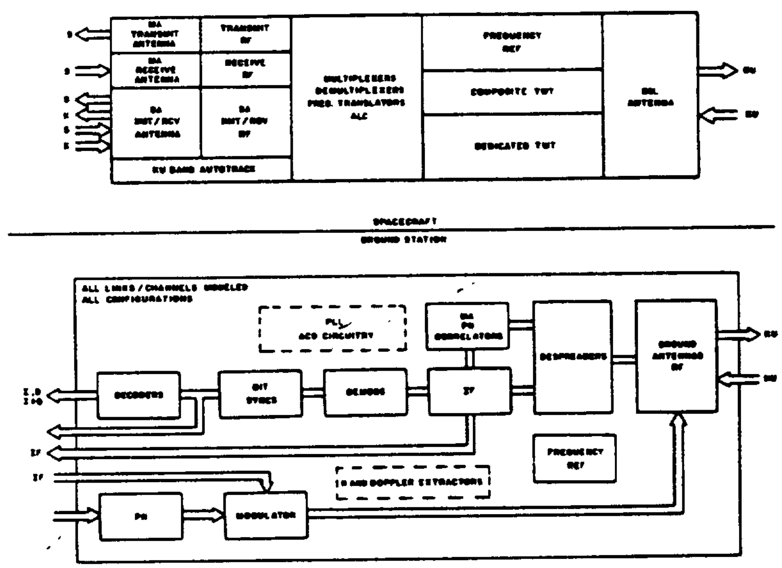

FIGURE 2: CLASS TDRSS COMPONENT COMPONENT MODEL

INTERIM CLASS CAPABILITIES

BY AUTHORITY LEVEL

General User Level

1. TDRSS Capabilities Description - Return Link
2. TDRSS Capabilities Description - Forward Link
3. User/TDRSS Link Signal Margin Calculation - Forward Link and Return Link (Reduced)

Network Support Engineer Level

1. TDRSS Capabilities Description - Return Link
2. TDRSS Capabilities Description - Forward Link
3. User/TDRSS Link Signal Margin Calculation - Forward and Return Link (Full)
4. User/TDRSS Link BER Evaluation - Forward and Return Link
5. User/TDRSS Link Signal Performance Time Line - Forward and Return Link EIRP Margin or BER
6. User Constraint Analysis - Sensitivity
7. Total Link Acquisition Time
8. TDRSS Coverage
9. TDRSS/User Coverage Statistics
10. User Data Base
11. Forward Link Flux Density Analysis
12. Return Link Flux Density Analysis

FIGURE 4

COMMUNICATIONS LINK ANALYSIS AND SIMULATION SYSTEM

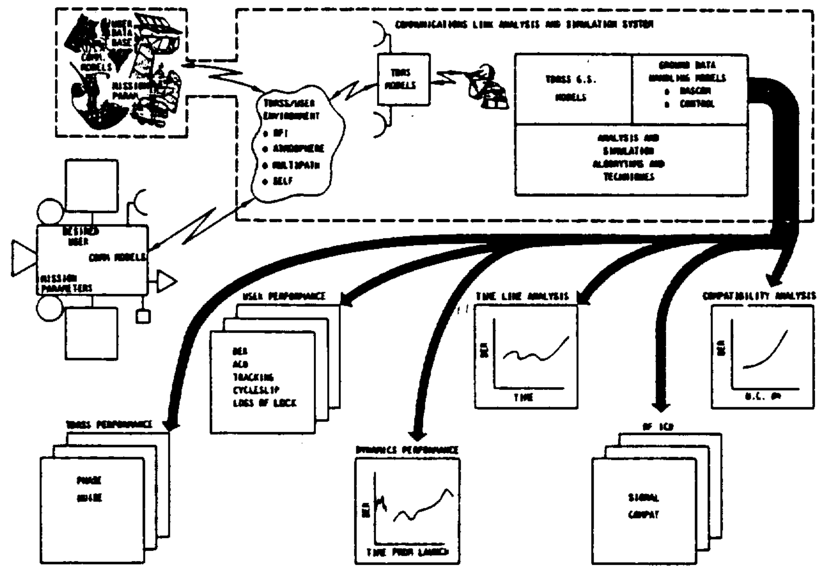

FIGURE 3: CLASS SYSTEM CAPABILITIES

LINK PERFORMANCE DEGRADATION DUE TO EXCEEDING USER CONSTRAINT LIMITS

SHUTTLE S-BAND LINK

S-BAND SIGNAL DESCRIPTION
- DATA RATE 192 kbps
- DG 2, MODE 1, NRZ, CODED, BPSK, TWT TRANSMITTER REPRESENTATION

CONSTRAINT PARAMETER	STDN 101.2 LIMIT	SHUTTLE* VALUE	INDIVIDUAL DEGRADATION (dB)
PHASE NOISE/COHERENT	<1° rms	<10° rms	.3
PHASE NOISE/NON-COHERENT	<1° rms	<10° rms	.3
MODULATOR PHASE IMBLANCE(BPSK)	± 3° peak	± 11° peak	.1
DATA ASYMMETRY (PEAK)	± 3%	± 3.8%	.1
AM/PM	≤ 12 deg/dB	≤ 14 deg/dB	.2
GAIN FLATNESS (PEAK)	± .3 dB	± .4 dB	0
		COMBINED TOTAL	≤0.8

*AS PER REFERENCED LETTER

#ROUNDED TO NEAREST .1 dB

FIGURE 5: SHUTTLE USER CONSTRAINT DEGRADATION ANALYSIS

-PRINT OUT THE RESULTS:
-ENTER 1 FOR BER PERFORMANCE, 2 FOR SENSITIVITY
3 FOR BOTH, 4 FOR PRINT-PORT
-3

VALUE OF PARAMETER 12 : 0.00 DESIGN VALUE: 0.00

CASE	UP-CNR VAR.	BIT ERROR RATE I CHANL	BIT ERROR RATE Q CHANL	RMS PH. ERR.(DEG) I CHANL	RMS PH. ERR.(DEG) Q CHANL	IDEAL BER I CHANL	IDEAL BER Q CHANL
1	-6.00	1.49E-04	1.49E-04	3.72E+00	3.72E+00	2.40E-06	2.40E-06
2	-4.00	3.86E-06	3.86E-06	3.67E+00	3.67E+00	3.11E-09	3.11E-09
3	-2.00	3.50E-08	3.50E-08	3.64E+00	3.64E+00	9.13E-14	9.13E-14
4	0.00	1.26E-10	1.26E-10	3.61E+00	3.61E+00	7.28E-21	7.28E-21
5	2.00	3.27E-13	3.27E-13	3.60E+00	3.60E+00	5.94E-32	5.94E-32

VALUE OF PARAMETER 12 : 3.00 DESIGN VALUE: 0.00

CASE	UP-CNR VAR.	BIT ERROR RATE I CHANL	BIT ERROR RATE Q CHANL	RMS PH. ERR.(DEG) I CHANL	RMS PH. ERR.(DEG) Q CHANL	IDEAL BER I CHANL	IDEAL BER Q CHANL
1	-6.00	1.76E-04	1.76E-04	3.72E+00	3.72E+00	2.40E-06	2.40E-06
2	-4.00	5.38E-06	5.38E-06	3.67E+00	3.67E+00	3.11E-09	3.11E-09
3	-2.00	6.16E-08	6.16E-08	3.64E+00	3.64E+00	9.13E-14	9.13E-14
4	0.00	3.16E-10	3.16E-10	3.61E+00	3.61E+00	7.28E-21	7.28E-21
5	2.00	1.22E-12	1.22E-12	3.60E+00	3.60E+00	5.94E-32	5.94E-32

VALUE OF PARAMETER 12 : 6.00 DESIGN VALUE: 0.00

CASE	UP-CNR VAR.	BIT ERROR RATE I CHANL	BIT ERROR RATE Q CHANL	RMS PH. ERR.(DEG) I CHANL	RMS PH. ERR.(DEG) Q CHANL	IDEAL BER I CHANL	IDEAL BER Q CHANL
1	-6.00	2.37E-04	2.37E-04	3.72E+00	3.72E+00	2.40E-06	2.40E-06
2	-4.00	8.94E-06	8.94E-06	3.67E+00	3.67E+00	3.11E-09	3.11E-09
3	-2.00	1.45E-07	1.45E-07	3.64E+00	3.64E+00	9.13E-14	9.13E-14
4	0.00	1.22E-09	1.22E-09	3.61E+00	3.61E+00	7.28E-21	7.28E-21
5	2.00	8.51E-12	8.51E-12	3.60E+00	3.60E+00	5.94E-32	5.94E-32

FIGURE 6: TYPICAL TABULATED PERFORMANCE RESULTS

SPACE TELESCOPE

RETURN LINK PERFORMANCE MARGIN

LINK NO. 1

MA SERVICE, DATA GROUP = 1, MODE = 2, 2287.5 MHz, LCP
RANGE = 44276.0 Km

I-CHANNEL

DATA RATE = 4.0 KBPS
MOD 2 ADDED TO PN
DATA TYPE = NRZ-L
RATE 1/2 CODED

Q-CHANNEL

DATA RATE = 32.0 KBPS
MOD 2 ADDED TO PN
DATA TYPE = NRZ-L
RATE 1/2 CODED

PARAMETER	LINK DATA I-CHANNEL	LINK DATA Q-CHANNEL	TOLERANCE I-CHANNEL	TOLERANCE Q-CHANNEL	REMARKS
1. USER TRANSMITTER POWER - dBW	6.3	6.3	.5	.5	NOTE A
2. USER PASSIVE LOSS - dB	4.2	4.2	0	0	NOTE A
3. USER ANTENNA GAIN - dBi	28.4	28.4	0	0	NOTE A
4. USER POINTING LOSS - dB	.3	.3	0	0	NOTE A
5. POLARIZATION LOSS - dB	.3	.3	0	0	NOTE A
6. USER DATA/TOTAL POWER RATIO - dB	-1.0	-1.0			NOTE A
7. FREE SPACE LOSS - dB	192.4	192.4			NOTE A
8. TDRSS RECEIVED POWER - UNITY GAIN dBW	-160.5	-160.5			SUM 1 THRU 7
9. USER CONSTRAINT LOSS - dB	.5	.5	0	0	NOTE B
10. OTHER LOSSES - dB	0	0	0	0	NOTE C
11. RFI LOSS - dB	.5	.5	0	0	NOTE D
12. DEGRADED EFFECTIVE POWER - UNITY dBW	-170.1	-170.1			SUM 8 THRU 11
13. REQUIRED EFFECTIVE POWER - UNITY dBW	-180.6	-171.2			STDN 101.2
14. EFFECTIVE USER CHANNEL MARGIN - dB	10.3	1.2	+.5 SUM -.5 RSS	+.5 SUM -.5 RSS	12 MINUS 13
15. EFFECTIVE COMBINED MARGIN - dB	*	X			NOTE B

NOTE A - FROM REFERENCE-SUBJECT TO CHANGE BY USER
NOTE B - FROM CLASS ANALYSIS
NOTE C - FROM CLASS ANALYSIS IF COMPUTED
CONTAINS - ANTENNA SWITCHING LOSS - dB - *
DYNAMICS LOSS - dB - *
ATMOSPHERICS LOSS - dB - .02 dB
MULTIPATH LOSS - dB - *

NOTE D - FROM CLASS ANALYSIS
0 DEG OFF POINTING
REQUIREMENTS AND ANALYSIS GROUP
NSC - CLASS
5/20/83

*NOT APPLICABLE OR NOT COMPUTED

LINK COMPATIBILITY EVALUATION
- LINK IS ESSENTIALLY COMPATIBLE -
1. MARGIN IS EXCESSIVE FOR SERVICE
- ALL OTHER CHECKED ITEMS ARE COMPATIBLE -

FIGURE 7: SAMPLE RETURN LINK PERFORMANCE EVALUATION

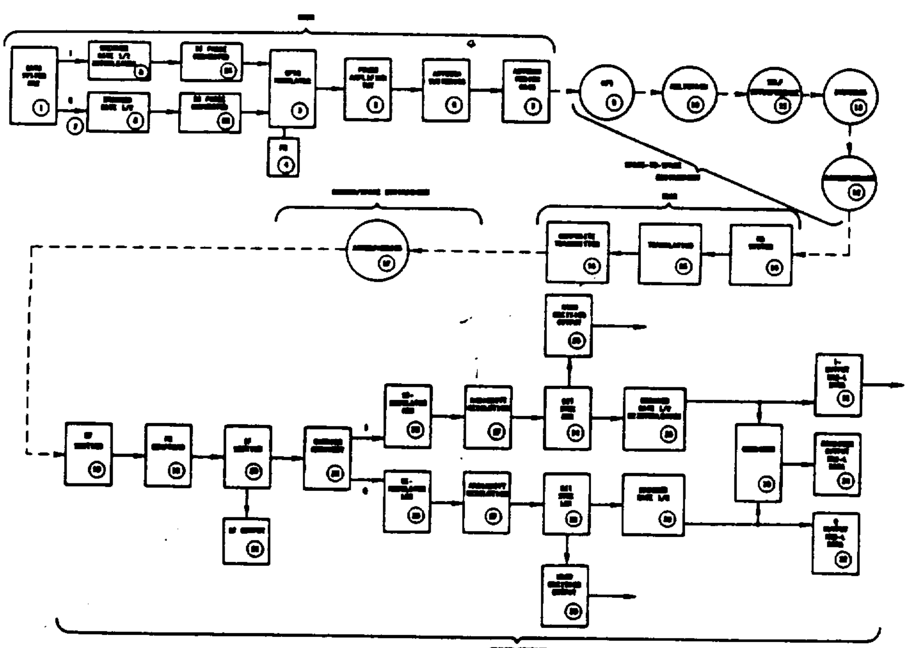

FIGURE 8: RETURN LINK - EXAMPLE

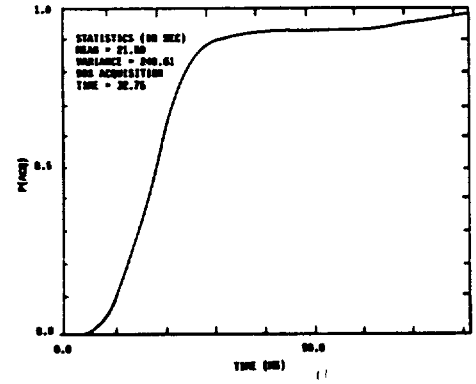

FIGURE 9: EXAMPLE OF CUMULATIVE PDF PLOT FOR FORWARD LINK USER

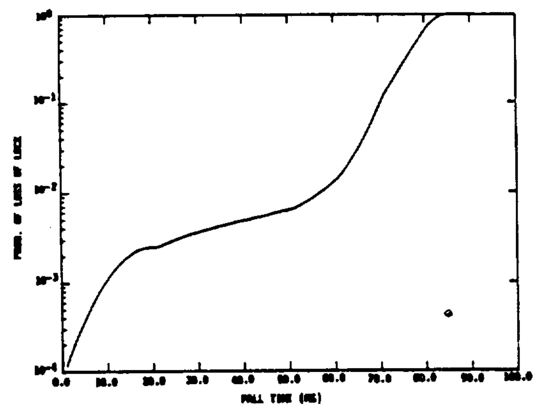

FIGURE 10: PROBABILITY OF LOSS OF LOCK AS A FUNCTION OF TIME RELATIVE TO THE BEGINNING OF PAGE. ANTENNA SWITCHING ANALYSIS

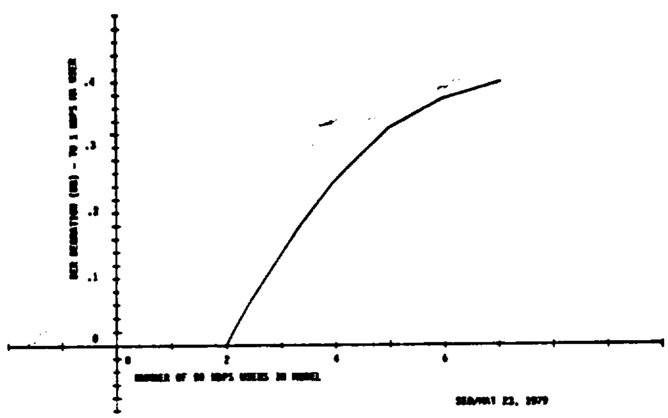

FIGURE 11: MA SELF INTERFERENCE ANALYSIS TOTAL NUMBER OF USERS-30

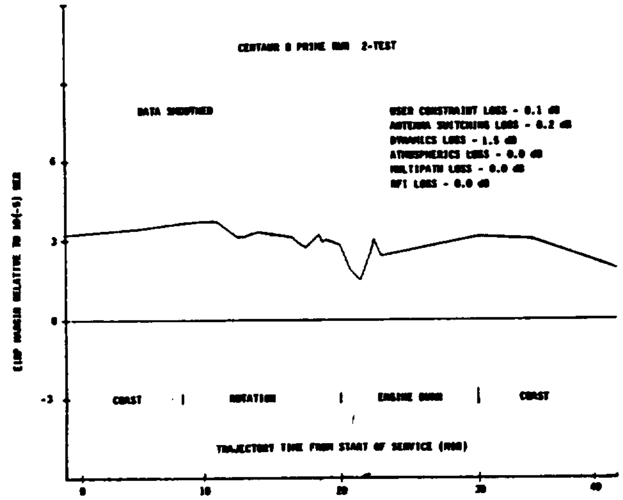

FIGURE 12: CENTAUR TEST TIMELINE

SEARCH SCHEME \ USER EIRP (DBW)	4	5	6	7	8	9	10
Expanding Window Search	115.5	70.3	47.0	37.6	36.5	36.0	35.0
Abbreviated Expanding Window Search	121.4	73.7	45.5	30.4	21.1	18.9	18.4
Extended Search	122.2	74.5	46.7	31.6	22.4	18.0	12.6
Alternate Expanding Window Search	115.1	66.8	45.4	34.2	28.5	21.7	16.5

*Applies to symbol rates < 3 ksps and 8 kHz predetection filter.

FIGURE 13: MODE 1 ACQUISITION TIME (SEC) VS USER EIRP FOR 90% ACQUISITION PROBABILITY*

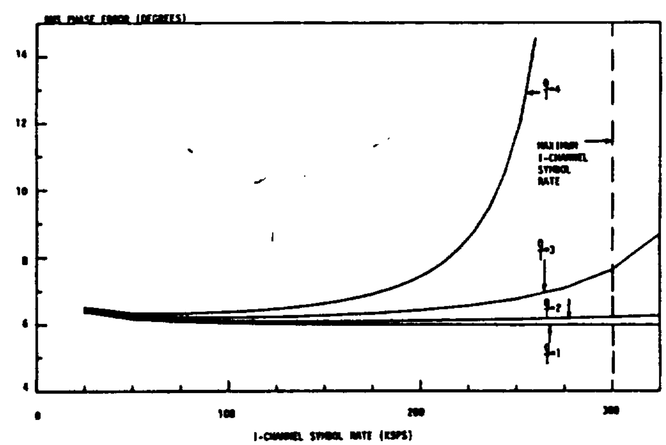

FIGURE 14: MODE 3 TRACKING RMS PHASE ERROR PERFORMANCE — CODED MHZ; 50 Hz LOOP BANDWIDTH