D/17 N85-16954

VALIDATION OF THE COMMUNICATIONS LINK ANALYSIS AND SIMULATION SYSTEM (CLASS)†

Walter R. Braun*
Teresa M. McKenzie

LinCom Corporation
P.O. Box 15897
Los Angeles, CA 90015
(213) 381-3701

ABSTRACT

CLASS (Communications Link Analysis and Simulation System) is a software package developed for NASA to predict the communication and tracking performance of the Tracking and Data Relay Satellite System (TDRSS) services. This paper describes the methods used to verify CLASS.

1. INTRODUCTION

The Communications Link Analysis and Simulation System (CLASS) presently under development for NASA Goddard Space Flight Center is an integrated set of FORTRAN programs capable of predicting the compatibility and performance of the communication and tracking links for all services and signal formats supported by the Tracking and Data Relay Satellite System (TDRSS).

The capabilities and structure of CLASS are presented in another paper in these Proceedings, "Communications Link Analysis and Simulation System" by Robert Godfrey. Models of major components of CLASS are described in a second paper in the Proceedings, "Modeling Techniques in the Communications Link Analysis and Simulation System (CLASS)" by the same authors as the current paper.

The usefulness of a software tool such as CLASS depends strongly on the reliability and accuracy of the results it produces. For this reason, considerable attention was paid to validation throughout the CLASS development. The purpose of this paper is to describe those efforts. The models mentioned in this paper were discussed in the second paper cited in the above paragraph.

Verification has been and continues to be done by making four types of comparisons: comparisons with analysis (Section 2), with Monte Carlo-type simulations (Section 3), with measurements (Section 4), and with TDRSS test data (Section 5). The prediction of bit error rate (BER) on links both with and without radio-frequency interference (RFI) has been verified in the first three ways. The prediction of pseudo-noise (PN) code acquisition has been checked by comparison with analysis. Finally, in the next couple of years the entire CLASS will be validated on both subsystem and system levels by TDRSS test data.

2. COMPARISON WITH ANALYSIS

One approach taken to verify CLASS is to compare its predicted results with those obtained by analyses, both in-house and published. In this section we describe such efforts for single-parameter sensitivities of BER, the Viterbi decoder performance, BER for a link with RFI, and PN-code acquisition time.

The BER sensitivity to each user constraint (member of a set of distortion parameters that characterize the TDRSS user's transmitter [1]) was evaluated with CLASS using an otherwise perfect signal and a linear, wideband channel. The results were then compared to analytical single-parameter sensitivity results. Typical results are shown in Figure 1. The slight discrepancy in Figure 1c is due to the fact that the sampled signal model does not allow the modeling of instantaneous phase transitions. It can be seen that agreement is excellent.

Comparison of CLASS with purely analytical models of non-ideal channels is not practical because of the limitations the latter place on the channel that can be treated. Figure 2 shows that a typical channel model for analysis does not include filtering effects on the transmitted signal, in distinction from even a minimal model for simulation.

The R_0 approximation method for computing the BER for a convolutionally encoded Gaussian channel from E_b/N_0 (ratio of bit energy to noise one-sided power spectral density) was checked by comparing it

†This work was supported by NASA Goddard Space Flight Center, Greenbelt, MD, under contracts NAS5-27240, NAS5-25681, and NAS5-23591.

*W. Braun is currently with Brown, Boveri, & Co., Limited, Baden, Switzerland.

with two other models: a Linkabit Corporation software model probably based on the union bound and an in-house Monte Carlo-type simulation. Figure 3 shows that the R_0 approximation matches the simulation for BER's above about 10^{-5} and is upper-bounded by the Linkabit model for all BER's, as it should be. The validation of the R_0 approximation for non-Gaussian, RFI links is discussed in Section 3.

The analytical model for BER on an RFI link was partially validated by showing that the two sub-models, one for high bit rates and one for low, give similar results in the range of bit rates near the bit rate which is the cross-over point between the sub-models, even though the sub-models themselves are quite different. Figure 4 shows the good agreement for a typical link. The vertical scale on the plot is omitted for national security reasons.

Finaly, the model for PN code acquisition performance, applicable to both variable and fixed dwell-time systems, was verified by showing excellent agreement between its predictions and exact results for the fixed dwell-time algorithm, as described in [2].

3. COMPARISON WITH MONTE CARLO-TYPE SIMULATIONS

A variety of BER predictions made by Monte Carlo-type simulations were compared to those made by CLASS. The CLASS link was configured as near as possible to the link used in the Monte Carlo simulations. Three simulation programs of no-RFI links and one of an RFI link were used.

The first comparison for a no-RFI link was with Champ, a simulation program of Comsat Corp. for the evaluation of BER and synchronization (tracking) (see, e.g., [3]). BER results for a TDMA link agreed within 0.5 dB.

The second such comparison was with Link, a program of TRW, Inc., which is usually run without uplink noise (see, e.g., [4]). Such published results were duplicated by CLASS.

The third comparison for a no-RFI link was with an in-house program that modeled the BPSK link shown in Figure 2a. Here, the pulse shaping filter is modeled as a half-Nyquist filter with a roll-off parameter $\alpha = .1$. The satellite input and output filters are of the Chebyshev type with a bandwidth equal to three times the data rate and a ripple of .1 dB. The receiver low-pass filter is matched to the pulse-shaping filter. The high-power amplifier is linear while the satellite TWTA characteristic is given by Figure 5. For the Monte Carlo simulation the same 63-bit signal used in CLASS was combined with 32 different uplink noise waveforms to find the uplink waveform contribution to the detector input. The downlink noise effect was modeled analytically. No effort was made to smooth the resulting performance curves in order to demonstrate the slow convergence of the results. Typical results are shown in Figure 6 for two different operating points of the TWTA. Note that the Monte Carlo curves follow the CLASS results quite well, but with some wild variations, despite the large number of bits simulated.

The predictions of the analytical program for BER on an RFI link have been compared with those from an in-house Monte Carlo-type program for coded links without interleaver. The two data rates used in the comparison were low enough that the analytical model also included no interleaver. The BPSK link had uplink noise, a non-linearity, and no downlink noise or receiver losses. The RFI was severe. The BER's were identical within 10%. This finding confirms not only the approach taken in the analytical program to model the matched filter output in RFI but also the applicability of the R_0 approach for coded BER computation on a channel which is not nearly Gaussian.

4. COMPARISON WITH MEASUREMENTS

Probably the most convincing validation of results obtained with software is close agreement with hardware results. Both no-RFI and RFI link predictions were checked this way.

One comparison of CLASS with hardware was with Harris, Corp., breadboard measurements made in 1978 for a TDMA satellite communication system. The link was nonlinear and included uplink and downlink thermal noise and adjacent channel interference. Agreement was within 1 dB.

The RFI BER model was verified with Harris Corp. breadboard measurements using TDRSS hardware and an RFI test generator. Four RFI scenarios were used. Two distributions of RFI power and pulse arrival rate were used, a benign environment and a severe environment. On each environment were based two scenarios, one with only noise-type pulses and one with the pulses divided between noise-type and continuous wave (CW)-type. The results in Table 1 demonstrate that the predictions were accurate in most cases and that they were in all cases pessimistic. The model was designed not to underestimate the RFI effect.

5. COMPARISON WITH TDRSS TEST DATA

Currently an effort is under way to develop a comprehensive CLASS validation plan using the first TDRS in orbit and the TDRSS ground station. Baseline hardware losses of TDRSS subsystems will be measured. Then the sensitivity of all the performance measures predicted by CLASS to all the sources of signal distortion and interference will be verified. A great effort has been made to reduce the number of tests to the minimum necessary for a complete validation.

REFERENCES

1. "Tracking and Data Relay Satellite System (TDRSS) Users' Guide, Revision 4," STDN No. 101.2, NASA Goddard Space Flight Center, January 1980.

2. Braun, W. R., "Performance Analysis for the Expanding Search PN Acquisition Algorthm," IEEE Trans. on Comm., Vol. COM-30, No. 3, March 1982.

3. Palmer, L. C., and Lebowitz, S., "Including Synchronization in Time-Domain Channel Simulations," Comsat Technical Review, Vol. 7, No. 2, Fall 1977.

4. Poza, H. B., and Berger, H. L., "Performance Characterization of Advanced Wideband Data Links," International Conference on Communications, 1975.

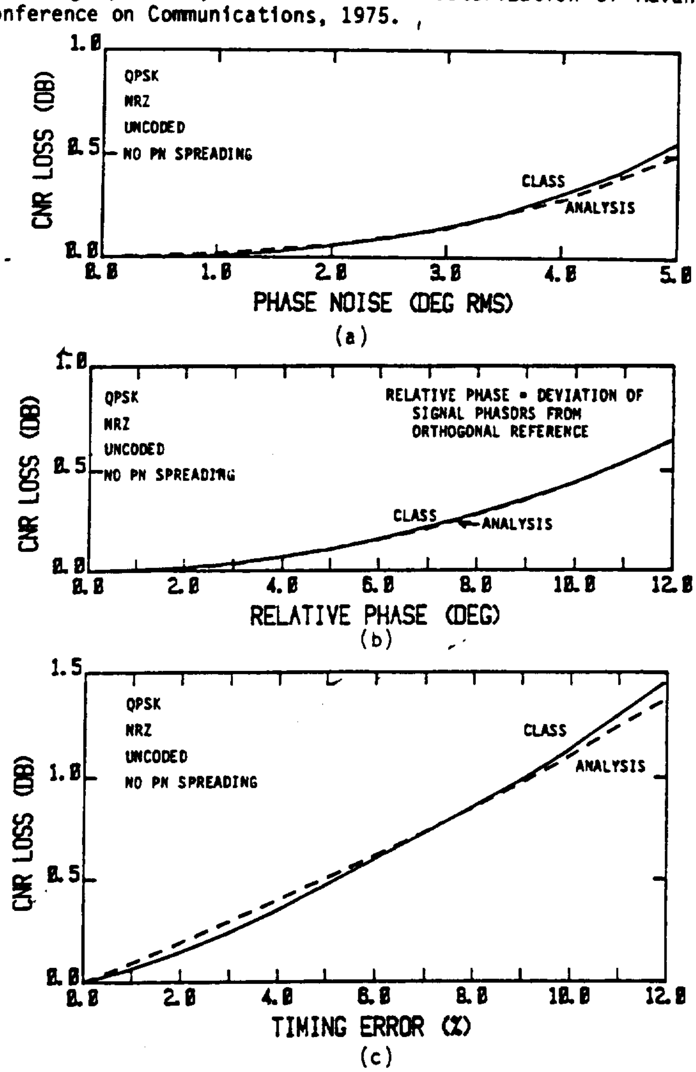

Figure 1. COMPARISON OF ANALYTICAL AND SIMULATED SINGLE PARAMETER SENSITIVITIES. (A) UNTRACKED PHASE NOISE, (B) MODULATOR PHASE ERROR, (C) RECOVERED CLOCK PHASE ERROR.

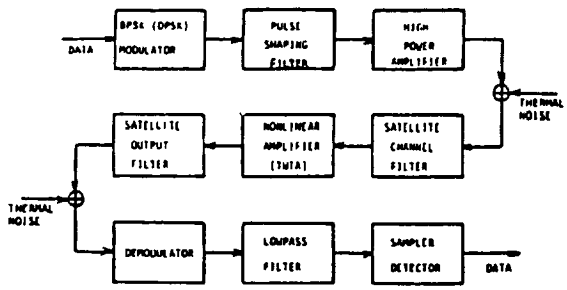

Figure 2a. MINIMAL CHANNEL MODEL FOR SIMULATION.

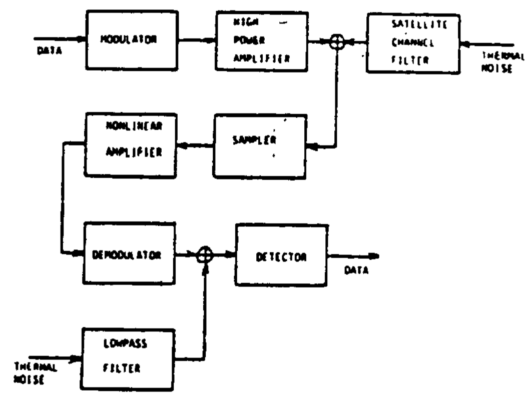

Figure 2b. TYPICAL CHANNEL MODEL FOR ANALYSIS.

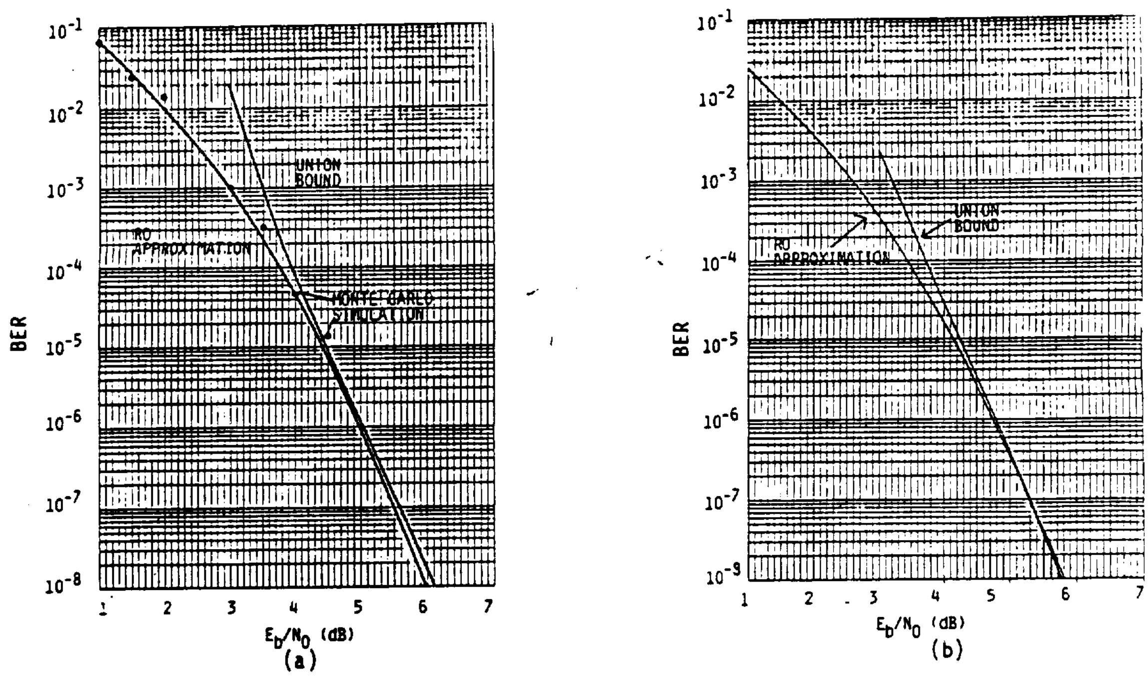

Figure 3. COMPARISON OF PERFORMANCE MODELS FOR (A) RATE-1/2 CODE, (B) RATE-1/3 CODE.

ORIGINAL PAGE IS
OF POOR QUALITY

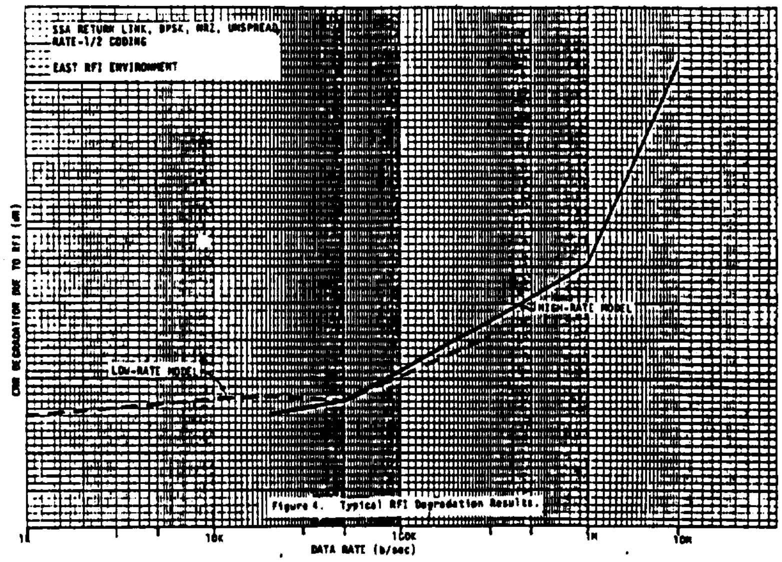

Figure 4. TYPICAL RFI DEGRADATION RESULTS.

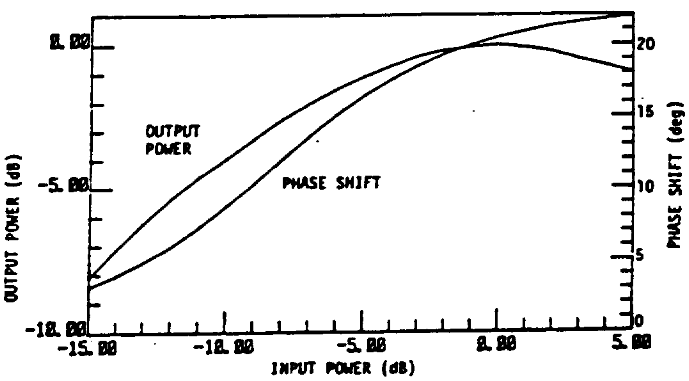

Figure 5. TYPICAL TWT CHARACTERISTIC.

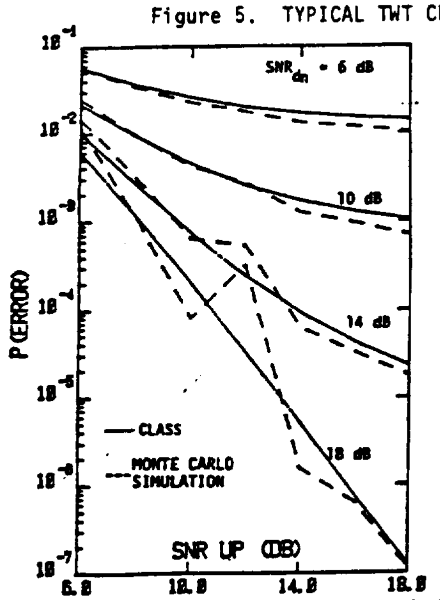

Figure 6a. BER PERFORMANCE FOR TWTA WITH 3 dB INPUT BACKOFF.

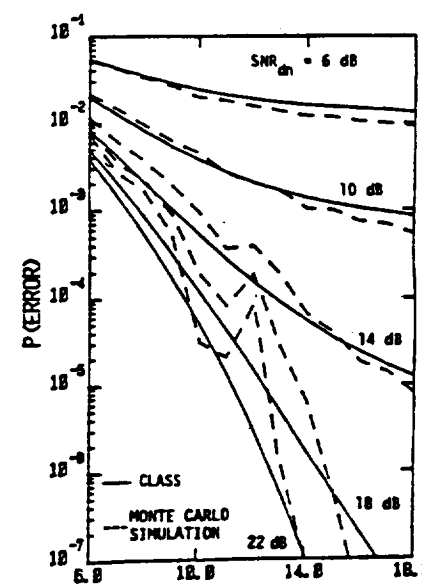

Figure 6b. BER PERFORMANCE FOR STATURATED TWTA.

Table 1. VERIFICATION OF RFI MODEL: BER DEGRADATION.

RFI PULSES	NOISE-ONLY		NOISE+CW	
ENVIRONMENT	BENIGN ENVIRONMENT		BENIGN ENVIRONMENT	
DATA RATE	200 Kbps	6 Mbps	200 Kbps	6 Mbps
MEASUREMENT	.9 dB	1.5 dB	.6 dB	1.3 dB (1.9)[1]
CLASS PREDICTION	1.46	3.02	1.19	2.84

RFI PULSES	NOISE-ONLY		NOISE+CW	
ENVIRONMENT	SEVERE ENVIRONMENT		SEVERE ENVIRONMENT	
DATA RATE	200 Kbps	6 Mbps	200 Kbps	6 Mbps
MEASUREMENT	4.0 dB	8.0 dB	2.1 dB (3.6)	6.0 dB (9.8)
CLASS PREDICTION	5.32	11.51	5.22	11.67

[1] Numbers in parentheses come from "RFI Test Study Second Interim Report" by Harris Corp., 26 February 1980. Others come from "RFI Test Study Final Report," by Harris Corp., 24 April 1980.