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NOVEL APPLICATIONS OF THE NASA/GSFC VITERBI DECODER HARDWARE SIMULATOR

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ABSTRACT

NASA/GSFC has had developed an all digital, real time, programmable Viterbi decoder simulator operating at rates up to 6 Msps. With this simulator, the BER performance of convolutionally encoded/Viterbi decoded Shuttle-TDRSS return link channels under pulsed RFI conditions has been predicted. The principles of the simulator are described with special emphasis on the channel simulator and the essential interaction between CLASS software and the simulator. The sensitivity of coded BER as function of several illustrative RFI parameters is discussed for two typical Shuttle-TDRSS return link configurations.

1. INTRODUCTION

The Shuttle - TDRSS return links, S-band and K-band mode 1, channel 3, employ convolutional encoding /Viterbi decoding. During certain periods the TDRSS ground receiver may have to contend with high level pulsed RFI. These pulses may affect many consecutive information symbols depending on the symbol rate and RFI pulse duration.

An analytical software package of CLASS (Communication Link Analysis and Simulation System), [1,6], has the capability to predict the performance of the decoders under RFI conditions when the channel can be modeled as a memoryless channel. To evaluate the performance when the decoder has to contend with a series of consecutive pulses affected by RFI (i.e. a non-memoryless channel), NASA GSFC engaged Linkabit Corporation to develop an all digital convolutional encoder/Viterbi decoder simulator This simulator can be programmed to simulate a large variety of time-varying channels, including pulsed RFI, and operates at symbol rates up to 6 Msps. It has been used at NASA GSFC to predict the impact of RFI on the return link performance of TDRSS users such as Space Telescope and Shuttle.

This paper describes the major features of this simulator and its interfaces with CLASS. It presents the results of tests measuring the impact of illustrative RFI on some Shuttle - TDRSS return links.

2. OVERVIEW OF THE SIMULATOR

The present configuration of the simulator is shown in Figure 1 [2]. The simulator is configured and controlled via the desk top calculator, which provides the capability of automated testing. In addition, the configuration data generated with CLASS can be downloaded to the calculator. The error rate tester is controlled via the desk top calculator or via front panel controls. A PN sequence, which simulates the data source, is generated in the error rate tester and looped back to the tester for BER measurement after being processed by the encoder, transition probability generator and decoder. Interleaving and deinterleaving is optional. The error rate tester also generates the symbol rate clock, which allows symbol rates up to 6 Msps. The encoder and decoder are either rate 1/2 or rate 1/3, with constraint length 7. The deinterleaver is integrated with the decoder and the decoder metric growth is monitored to establish interleaver/deinterleaver synchronization.

The transition probability generator models the discrete channel formed by the modulator, channel characteristics and noise, and the quantized output of the demodulator/detector. The TPG maps each symbol into one of the possible 8 soft decision levels at the input of the deinterleaver/decoder, based on a probabilistic process for which the data is generated with CLASS.

CHANNEL MODELING

With the TPG the channel is modeled as follows: The time varying channel is divided into as many as 32 different channel conditions or states. Each of these channel conditions is time-invariant and is modeled as a discrete, binary input to 8-ary output, memoryless channel. The time variation is then achieved by selecting one of the available channel conditions for each transmitted symbol. The transitions between channel conditions are modeled as a zero or first order Markov process with up to 32 states. In addition, it is possible to specify the number of symbols the TPG is to stay (or hold) in a channel condition, once entered. This is particularly useful when modeling pulsed RFI as the hold time is equal to the number of channel symbols the RFI pulse overlaps. For the application described here the transitions between channel conditions are modeled as a zero order Markov process i.e. the probability of entering a channel condition is independent of the previous channel condition. For a pulsed RFI environment the channel condition transitions are then determined from the

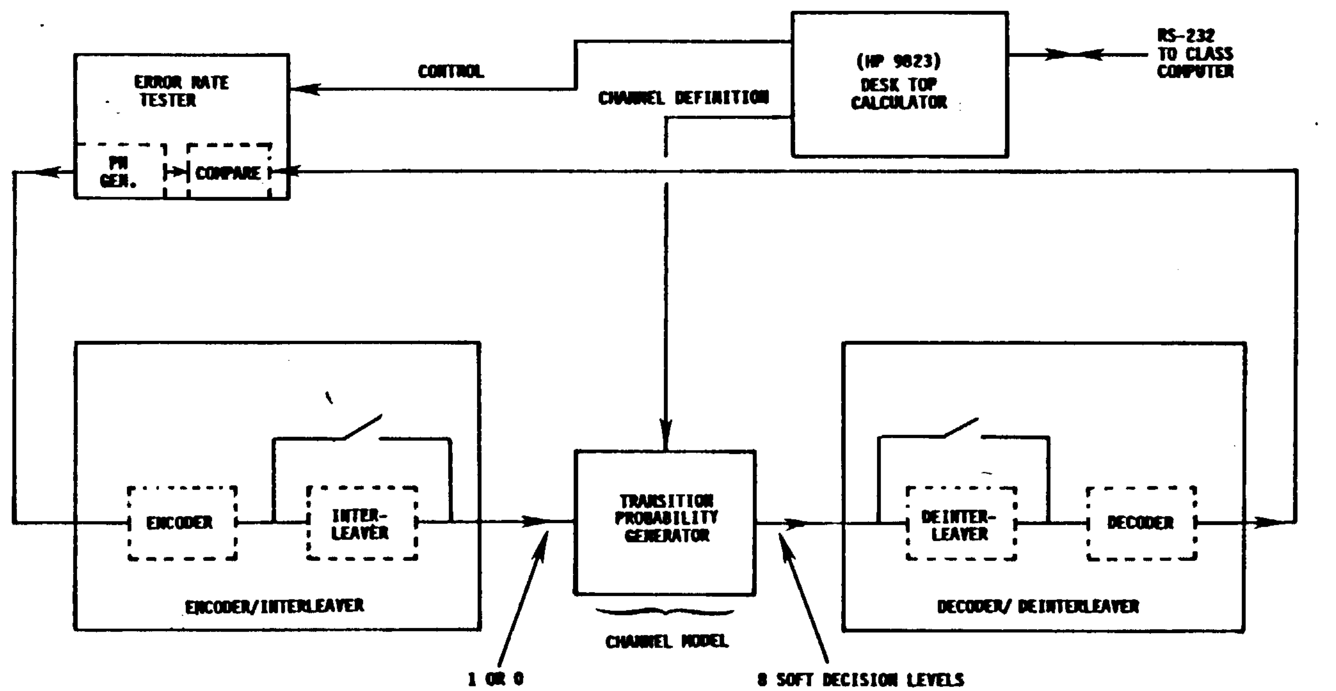


FIGURE 1: BLOCK DIAGRAM OF ALL DIGITAL, REAL-TIME SIMULATOR

duty cycle, T_j, and pulse duration, M_j, of each associated RFI condition. When the phenomenon of erlapping RFI pulses is neglected, which is a good approximation for low duty cycles, the probability of entering a channel condition is easily found to be:

$$Pr_j = \frac{T_j}{M_j}\left(\sum_{i=1}^{N_e} \frac{T_i}{M_i} \right)^{-1} \quad (1)$$

with:

Pr_j - the probability of entering channel condition j.

T_j - the duty cycle of the RFI associated with the j-th channel condition.

M_j - the pulse duration of the RFI associated with the j-th channel condition.

N_e - total number of different channel conditions.

Figure 2 shows a functional diagram of the TPG and a typical list of channel conditions. The two rightmost columns show the duty cycle and pulse duration from which CLASS software calculates the transition probabilities via (1). These probabilities are downloaded into the desk top calculator. Most channels are modeled with the pulse duration of the NO-RFI channel condition, approximately an AWGN channel condition, equal to 1 as shown in the table of Figure 1. This implies that the TPG is not forced to stay in the non-RFI condition and that the RFI channel conditions may be selected after any number of channel symbols which are not affected by RFI.

For each channel condition the discrete binary to 8-ary memoryless channel is fully characterized by calculating the 8-level soft decision statistics, assuming that a "1" is transmitted, as the TPG models each channel condition as a symmetric channel. These soft decision statistics are calculated by CLASS. For full details on the methods followed in these computations see [1]. In addition to the RFI parameters listed in Figure 2, the following parameters must be specified in order for CLASS to compute the soft decision statistics:

Shuttle: EIRP, Data rate

TDRSS : Return/down link noise, AM/AM, AM/PM, clipping level

The next section describes some results on decoder performance and shows typical soft-decision statistics.

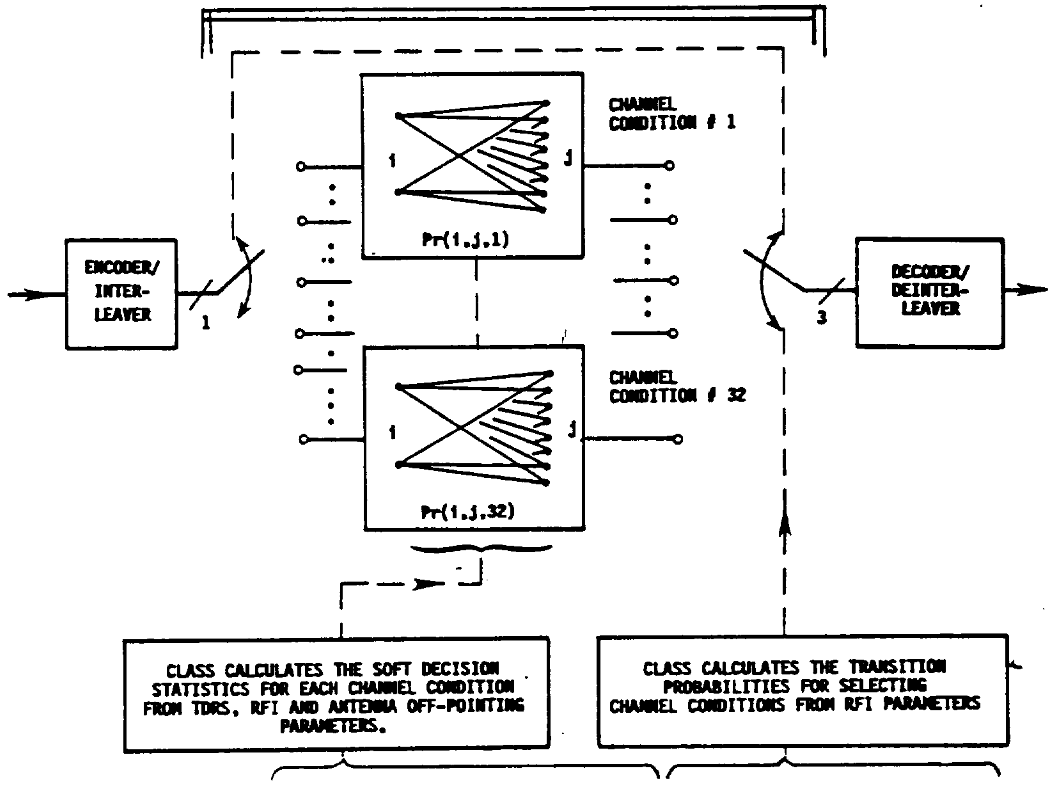
3. SIMULATION RESULTS

The simulation results presented in this paper illustrate the capability of the simulator to assess the impact of several RFI parameters on the performance of the Viterbi algorithm decoder. As examples, the impact of illustrative RFI on the Shuttle - TDRSS K- and S-band has been simulated.

SHUTTLE-TDRSS K-BAND

For the simulation described here the configuration data for the TPG are computed with the following signal and channel parameters, [3],:

- Shuttle channel 3, up to 50 Mbps, characterized as BPSK with 47.3 dbW EIRP, rate 1/2 coding.
- Pulsed RFI
  - Duty cycle: < 1%
  - For each test a choice of:
    - -- In-band or out-of-band CW
    - -- Two illustrative RFI power levels
    - -- 1, 10 or 20 consecutive information symbols overlapped by a single RFI pulse
- TDRSS KSA return link transponder
  - 250 MHz noise bandwidth
  - 44 dBW thermal noise level
  - ALC with 10 dB clipper and 1.2 degrees per dB AM/PM



CHANNEL CONDITION	RFI TYPE	IN-BAND OUT-OF-BAND	RFI POWER	DUTY CYCLE	PULSE DURATION (IN SYMBOLS)
1	NO RFI	N.A.	N.A.	T_1	1
2	NOISE	N.A.	P_2	T_2	N_2
3	CW	IN	P_3	T_3	N_3
4	CW	OUT	P_4	T_4	N_4
⋮	⋮	⋮	⋮	⋮	⋮

FIGURE 2: TRANSITION PROBABILITY GENERATOR

The BPSK signal characterization is an approximation to the actual QDSB signal structure and is reasonable due to the 6 dB dominance of the channel 3 signal relative to the composite of the channel 1 and 2 signals.

The TDRS transponder characteristics indicated reflect the actual KSA return link transponder. The thermal noise level of 44 dBW refers to the fact that the thermal noise power within the 250 MHz bandwidth may be equivalently obtained by having the TDRS point directly at a 44 dBW thermal noise source on the surface of the earth that is radiating via an omnidirectional antenna.

The duty cycle of less than 1% is purely illustrative, as is the number of consecutive symbols overlapped by RFI. The in-band RFI, modeled in CLASS with a RFI frequency which precisely coincides with the carrier, leads to worst case performance for a given RFI power level. Six combinations of the RFI parameters are evaluated. These are listed in Table 1. As a companion to Table 1, Table 2 summarizes the soft decision statistics that apply to each RFI presence. The NO RFI channel condition is the same for each scenario and is also listed in this table.

Table 3 shows the BER obtained through simulation, as well as the channel symbol error rate for each scenario. As seen, and expected, performance degradation is much more severe under in-band RFI conditions.

Also to be observed from Table 3 is the expected increasing degradation that occurs as the RFI EIRP and the number of symbols overlapped increases. Especially interesting is the approach of the decoded BER to the channel error rate for the particularly severe scenarios. This phenomenon reflects that for those scenarios virtual each RFI pulse is sufficiently severe and long to cause a burst of decoding errors. Note that the degradation of the channel during the out-of-band RFI pulses is not sufficiently severe to consistently cause a burst of decoding errors.

SHUTTLE-TDRSS S-BAND

For the simulation described here the configuration data for the TPG are computed with the following signal and channel parameters:

- Shuttle S-band return link, BPSK with typical EIRP and 96 or 192 Kbps, rate 1/3 coding.
- Illustrative pulsed RFI
  - Severe RFI with a duty cycle < 2%
  - 1, 2, 3 or 4 consecutive information symbols overlapped by RFI
- TDRSS SSA return link transponder
  - 20 MHz noise bandwidth
  - 29 dBW thermal noise level
  - ALC with 10 dB clipper and 1.2 degrees per dB AM/PM

The design of the rate 1/3 decoder of the Shuttle unique receiver of the TDRSS ground equipment is slightly different from the decoder used in the simulator. The major difference is the path memory length which is 64 decoded bits instead of the 32 decoded bits in the simulator. In addition, the metric assignment for the different decoder input quantization levels are probably different. The exact assignments are proprietary. As part of the evaluation of the impact of RFI on the Shuttle decoder, it was shown that degradation of performance for both decoders is very comparable. This was shown by configuring the software decoder simulator "CODES", which is part of CLASS, either as the Shuttle decoder or as the all digital, real time simulator and comparing the results.

Figure 3 shows the BER degradation due to RFI as function of the number of consecutive symbols affected by RFI, for a variety of margins of the Shuttle EIRP. We see that for the same margin the 192 kbps is degraded more severely than the 96 kbps. This is due to the higher duty cycle of the in-band RFI, which is a result of the wider receive filter. When we compare the A-margin curves with the B-margin curves, we see that the degradation due to consecutive symbols affected by RFI, is more severe when the margin is higher.

It is interesting, as well, to compare the simulation speed of the software package CODES, which allows detailed specification of different convolutional codes and hardware constraints, with the simulation speed of the hardware simulator. A ten million bit simulation takes 5 to 10 hours with CODES on the CLASS computer. With the hardare simulator such a simulation takes less than 20 minutes, which includes inputting the data into CLASS and operating the hardware simulator.

TABLE 1

RFI SCENARIOS CONSIDERED IN SECTION 3

Desired signal EIRP = 47.3 dBW

SCENARIO NO.	RFI DUTYCYCLE	RFI CLASS	RFI EIRP	NO. OF CONSECUTIVE SYMBOLS OVERLAPPED BY RFI PULSE
1	< 1%	IN-BAND	E_1*	20
2	< 1%	IN-BAND	E_2*	10
3	< 1%	IN-BAND	E_2	20
4	< 1%	OUT-OF-BAND	E_1	20
5	< 1%	OUT-OF-BAND	E_2	10
6	< 1%	OUT-OF-BAND	E_2	20

* $E_2 > E_1$

TABLE 2

CONDITIONAL SOFT DECISION PROBABILITY DISTRIBUTIONS FOR RFI SCENARIOS OF TABLE 1

QUANTIZATION LEVEL*	NO RFI	IN-BAND, E_1	IN-BAND, E_2	OUT-OF-BAND, E_1	OUT-OF-BAND, E_2
1	1.6×10^{-5}	.052	.270	.015	.086
2	10^{-4}	.044	.034	.013	.029
3	6.5×10^{-4}	.057	.031	.021	.035
4	3.1×10^{-3}	.064	.029	.033	.042
5	.011	.063	.027	.047	.048
6	.033	.058	.026	.063	.054
7	.074	.052	.026	.079	.059
8	.878	.610	.559	.729	.645

* Assumes transmission of a + symbol polarity. The channel is assumed to be symmetric.

TABLE 3

MEASURED ERROR RATES FOR RFI SCENARIOS OF TABLE 1

SCENARIO	DECODED BER	CHANNEL SYMBOL ERROR RATE
1	1.4×10^{-4}	4.7×10^{-3}
2	1.1×10^{-3}	5.3×10^{-3}
3	1.3×10^{-3}	5.3×10^{-3}
4	8.4×10^{-7}	4.2×10^{-3}
5	6.0×10^{-5}	4.6×10^{-3}
6	1.6×10^{-4}	4.6×10^{-3}

- HAD INTERLEAVING/DEINTERLEAVING BEEN EMPLOYED DECODED BER WOULD BE $\ll 10^{-6}$ IN ALL CASES.

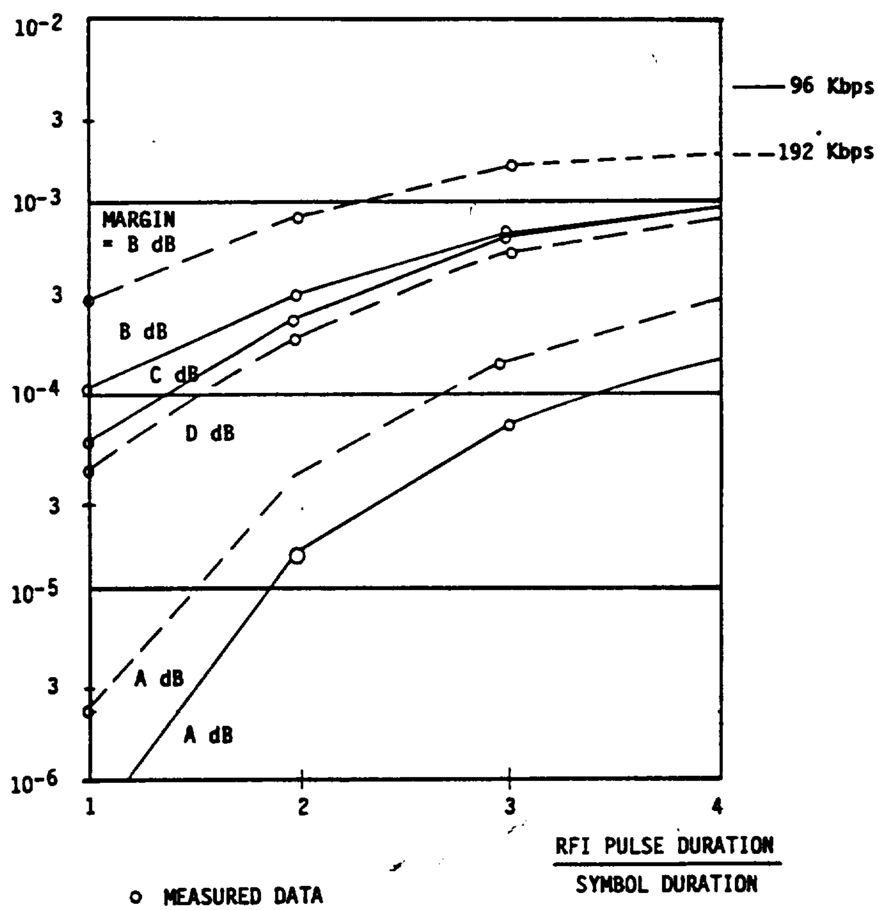


FIGURE 3: ILLUSTRATIVE IMPACT OF RFI PULSE DURATION ON SHUTTLE-TDRSS S-BAND RETURN LINK. ($A \geq D \geq C \geq B$)

4. SUMMARY

The NASA/GSFC Viterbi decoder hardware simulator extends the capability of CLASS to include non-interleaved channels when the impact of pulsed RFI on the coded BER of the TDRSS return link is assessed. The discrete, bursty channel is simulated by computing a set of soft decision probability distributions with CLASS. The simulator chooses one soft decision probability distribution for each channel symbol.

The simulation results show the sensitivity of coded BER to a variety of illustrative RFI parameters. The sensitivity of coded BER to the RFI pulse duration can be easily assessed as is shown with the Shuttle-TDRSS S-band simulations. As an example of the impact of the RFI power levels, pulse duration and of the RFI being on-band/out-of-band, the coded BER of the Shuttle-TDRSS K-band is evaluated for some illustrative RFI parameters.

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