DSS Tests of Sequential Decoding Performance

J. W. Layland
Communications Systems Research Section

This article describes the results to date of a series of one-way tests of the DSN sequential decoding capability, which have been performed at DSS 71. The tests utilize the Data Decoder Assembly as configured for the Helios formats and data rates, and are aimed principally at establishing the telemetry threshold for the Helios requirement of 10^{-4} deletions probability.

I. Introduction

Convolutional encoding with sequential decoding is a very powerful technique for communicating at low-error probability with deep space probes. It has been used successfully with several Pioneer spacecraft, and is planned for use on Helios, the German solar probe. Performance predictions for decoding on the spacecraft to DSN links have been developed by modeling (Ref. 1), and by nonreal-time tests (Ref. 2). Since midsummer of 1973, one-way real-time tests of sequential decoding, as configured for Helios data format, have been under way at DSS 71. These tests represent the cooperative efforts of numerous members of JPL's Office of Technical Divisions and Tracking and Data Acquisition Office, the crew of DSS 71, and the use of many hundreds of hours of test time in DSS 71. The results obtained to date with this test program are described in this article.

The tests have had two principal goals: to improve confidence and reduce tolerances in performance threshold predictions provided to Helios Project for their formats, data rates, and chosen modulation indices of 42 deg and 55 deg; and to obtain experimentally the dependence of performance upon modulation index. Tests at lower data rates were accelerated by time scaling of loop bandwidth and data rates of 8 bits/s to 2048 bits/s, but the planned pattern of tests at multiple modulation indices has been completed only at the four highest data rates. The tests have shown a 0.5- to 1.3-dB poorer performance than expected.

II. Test Configuration, Procedure, and Problems

The test configuration for sequential decoding testing is shown in Fig. 1. The output from the test is a magnetic tape Original Data Record (ODR) containing, for each data frame processed by the Data Decoder Assembly (DDA), the number of decoding computations that were used in processing it. These ODR tapes are later analyzed off-line to determine the cumulative distribution of computations, which is then used to evaluate system performance. In the DSN station, the tests require the use of the Simulation Conversion Assembly (SCA), the test transmitter, the Antenna Microwave Assembly, the Y-Factor Assembly, a receiver, the Subcarrier Demodulator Assembly (SDA), two telemetry/command processors (TCPs) with Symbol Synchronizer Assemblies (SSAs), and one DDA. The TCP-DDA-SSA string operates under control of nonstandard DSS software, the DDA Stand-Alone TCP Verification Program, and provides the ODR end-product of the tests. The second TCP-SSA string operates with the MM'71 Test Program No. DOI-5087-TP, and acts as a monitor for the telemetry channel to verify station set-up accuracy, and to identify drifts in parameters.

The SCA provides a pseudorandom data sequence for the test transmitter. The subcarrier frequency used is 32993 Hz, and data rates of interest range from 16 to 4096 symbols/s. The biphase modulated subcarrier, in turn, phase modulates the carrier at the test transmitter with a modulation index that may vary from 35 deg to 75 deg depending upon data rate, and other factors. This simulated telemetry signal is then processed by the station receiving equipment much like the signal from a spacecraft. The "received" signal strength is set as required using the Y-factor measurement technique (Ref. 4) prior to the start of a test. The modulation indices are set by precision attenuators. Extreme care is required in this setup because of the sensitivity of decoding performance; the decoding erasure rate can vary by an order of magnitude with a 0.5-dB change in signal strength. After setup, the Test Program 5087 output monitors channel statistics, and when stable operation of the receiver and SDA is observed, the TCP/DDA Program is activated to develop the ODR of decoder performance.

The signal strength was set to a value slightly above that which had previously been predicted would provide a 10^{-4} deletion probability. This signal strength was specified as a desired signal power times symbol duration-to-noise spectral density ratio (ST_{sym}/N_0) at a 45-deg modulation angle, and all Y-factor setup and calibration was derived from that point. The modulation index for the actual run was subsequently established through precision attenuators. For some of the tests, this was specifically the Helios modulation angles of 42 deg or 55 deg. For the four highest data rates this also included a four-point pattern of three modulation indices and two signal strengths intended to bracket the performance at the optimum modulation index. The primary data point was selected to achieve a 10^{-4} deletion probability at the approximately optimum modulation index. The secondary data points were set at that signal strength but at approximately 7-deg above and below optimum modulation index, and at the approximately optimum modulation index with 0.5 dB lower signal strength to achieve an estimated 10^{-3} deletion probability. The test parameter selections were based upon the previous modeling effort (Ref. 1).

The ODR tapes from tests in November and December have been transferred to a single master tape for final processing. Table 1 is an overall catalog of these tests, organized by data rate. Each file of the master tape is derived from one of the ODR tapes. A number of problems were encountered in reviewing these data. In a few cases, station parameter drifts of up to several tenths of a dB occurred during a test run. Such drifts were most evident in reviewing the decoder statistics, but could also be seen in the signal-to-noise ratio (SNR) estimates from the monitoring TCP. As a result of this drift, later parts of some of the longer data runs have been rejected. The second major problem is that "glitches", in the form of bursts of adjacent frames with large numbers of computations per frame, appeared in many of the data records. These bursts ranged in length up to several hundred frames and are definitely *not* an artifact of sequential decoding. Some of these bursts were traced to an intermittent problem in the SCA encoder. The bursts, and sections of the apparently normal data before and after them, were rejected, and in all cases, the remaining data from these tests displayed statistics that agreed reasonably well with expectations. It is almost certain, however, that some of the isolated single erasures that remain in the data were also caused by the problem that caused the bursts, and hence that the measured performance is somewhat poorer than would occur in flight operation. There was no trace of this problem in the SNR estimates from the monitoring TCP. The third problem encountered was that test results are consistently poorer than had been predicted, by 0.5 to 1.3 dB. No explanation for this seems to exist, except possibly for the undocumented information that DSS 71 is consistently at the low-performance end of known station-to-station variation.

III. Test Results

A summary of the principal test result appears in Table 2. Threshold tolerances in this table correspond to the 2-sigma confidence interval based upon sample size, and do not include the tolerance for test parameter setup. The accepted setup tolerances for the tests are a maximum of 0.4 dB for Y-factor setup, and a maximum of 0.3 dB for setting of the modulation index. Most of the test setups should be in fact much better than this maximum budgeted tolerance of 0.7 dB. Figure 2 shows the estimate threshold signal strength needed to achieve a 10^{-4} deletion probability as a function of data Rate R. The signal strength is given in terms of $P_t/N_0 \times 1/R$: the total power-to-noise spectral density ratio, normalized by data rate. The secondary comparison curves on Fig. 2 show two types of prior predictions of Helios telemetry threshold. One set of curves is for the predictions based upon the medium-rate model (Ref. 1). The second set is a heuristic composite prediction of the Helios telemetry threshold based upon nonreal-time tests (Ref. 2) and the medium-rate model. As can be seen, the current test data from DSS 71 exhibit noticeably poorer performance than the prior predictions. While this may be entirely due to station-to-station variations in performance, conducting part of these tests at other DSSs is necessary to ascertain that fact. The minimum of additional tests at DSS 71 needed to complete Fig. 2 consists of the points at 42-deg modulation index (MI), 128 bits/s and 64 bits/s, and a refinement of the point at 55 deg, 128 bits/s. These points are important because they define the crossover in performance between the two Helios modulation indices.

Figures 3(a) through 3(d) show computation distribution curves for the multimodulation-index subset of the tests for data rates of 2048 bits/s to 256 bits/s. The separation between computation distribution curves for runs with similar or identical parameters, while it is significant, is still within the experimental tolerances ascribed to the test setup. Figure 4(a) through 4(d) show the deletion probability as a function of modulation index as estimated via the medium-rate model (Ref.1). Principal data points from the multimodulation-index test subset are shown on this figure for comparison. The differences between model and experiment are in all cases within the experimental tolerances of the test.

Figures 5(a) through 5(e) show the computation distribution curves for data rates of 128 bits/s to 8 bits/s, and include comparison of scaled-time and normal configuration tests where available. There is excellent agreement between scaled and nonscaled tests at 32 bits/s – the sharp separation at low probability is believed to be a remnant of the burst-erasure problem mentioned earlier. At 8 bits/s, the agreement is far less perfect in the high-probability segment of the distribution, where there appears to be more than 0.5 dB separation in the additive *white* noise component. The parallel SNR monitoring TCP also indicated approximately 0.7 dB more degradation in the 8 bits/s run than in the time-scaled 128 bits/s run, which in turn showed more degradation than expected. Despite this, the tail of the computation distributions shows acceptable agreement. Since it is this tail that determines erasure probability, and since the distribution tail is dominated by the correlated carrier reference noise instead of the additive white noise, it has been tentatively determined to accept the scaled 8 bits/s test results, subject to change by further testing. The scaled test at 16 bits/s is also considered conditionally acceptable since it is bracketed by one clearly good test and one conditionally acceptable test. The scaled test at 128 bits/s was adjudged bad data, but prior tests at CTA 21 had shown agreement (Ref. 3). Hence the scaled test at 64 bits/s is believed valid, being bracketed by two successful comparisons. One additional weak point in these tests is evident from Fig. 5: because of the poorer than predicted performance at DSS 71, several tests had deletion probabilities above 10^{-3}, and while the extrapolation to 10^{-4} deletion probability is reasonably straightforward, it could introduce biases on the order of several tenths of a dB.

IV. Commentary and Future Work

The principal results of tests conducted to date appear in Fig. 2, and Figs. 3(a) through 3(d). The tests are complete as planned at the four highest data rates. With respect to determining Helios telemetry threshold, the main requirements are to fill in three weak points at midrange data rates, to perform some tests at 8 and 16 bit/s that achieve a 10^{-4} deletion probability, and to determine if the performance difference between current tests and prior predictions is due to station-to-station variations, or some other causes. The tolerance due to sample size in the current tests is generally below the tolerance ascribed to setup parameters. This tolerance is also below the performance difference between the current test and predictions. Hence the most fruitful area for future testing appears to be in evaluating and (hopefully) reducing setup tolerances, and in evaluating station-to-station variation.

References

1. Layland, J. W., "A Sequential Decoding Medium Rate Performance Model" in *The Deep Space Network Progress Report*, Technical Report 32-1526, Vol. XVIII, Jet Propulsion Laboratory, Pasadena, Calif., Dec. 15, 1973.
2. Lumb, D., NASA Ames Research Center, Moffett Field, Calif. Private communication at Helios Working Group Splinter Session, Sept. 27, 1973.
3. Butman, S., et al., "A Scaled Time Telemetry Test Capability for Sequential Decoding" in *The Deep Space Network Progress Report*, Technical Report 32-1526, Vol. XIX, Jet Propulsion Laboratory, Pasadena, Calif., Feb. 15, 1974.
4. DSIF Program Library, *Documentation for Y-Factor Computer Program*, DOI-5343-SP-B. Jet Propulsion Laboratory, Pasadena, Calif., Sept. 29, 1972.

Table 1. Catalog of Phase 2 tests

Symbol rate, symbols/s	Day of year	File number	Receiver PLL	ST_{sym}/N_0, dB	MI, deg
4096	324	11	DSN(12)	0.0	67.5
	320	12		0.5	75
	319	15		0.5[a]	60
	319	15		0.5[a]	67.5
	360	21		0.5	55
	360	22		0.5	60
2048	325	1	DSN	0.7	67
	325	7		0.7	60
	330	13		0.2	60
	324	14		0.7	53
	361	20		0.7	55
1024	330	2	DSN	1.0	48
	332	3		1.0	53
	332	3		1.0	62
	331	4		1.0	48
	331	4		1.0	53
	333	5		1.0	62
	333	5		0.5	55
512	333	16	DSN	0.8[b]	52
	345	23		1.6	55
	340	24		1.3	62
	337–338	26		1.3	42
	338–339	26		1.3	52
256	352	25	DSN	2.3	55
128	312	6	DSN	3.1[c]	45
	313	8		3.1[a,c]	40
	317	9		3.1[c]	50
	318	10		3.1[a,c]	55
64	344	18	DSN	3.4	67
	351	19		3.7	42
32	No Data				
16	353	30	DSN	5.3	42
4096	351	27	192 Hz	2.3[c]	55
2048	351	28	192 Hz	3.0	55
1024	344	18	192 Hz	3.4	45
	344	18		3.4[c]	67
	348	28		3.7	42
	348	28		3.7[b]	55
	362	29		4.2	42
512	345	23	192 Hz	4.5	42
256	346	17	192 Hz	5.3	42

[a]Master-tape label says 99.0 dB.
[b]Parameter drifts.
[c]Bad data.

Table 2. Test Result Summary

Bit rate R, bits/s	Sample size, frames	Optimum MI, deg	Telemetry threshold at $P_d = 10^{-4}$ $P_t/N_0 \times 1/R$, dB	
			55 deg	42 deg
2048	7×10^4	65	7.0 ± 0.2	–
1024	6×10^4	62	7.2 ± 0.2	–
512	5×10^4	60	7.4 ± 0.2	–
256	4×10^4	57	7.7 ± 0.2	8.3 ± 0.5
128	10^3	–	8.8 ± 0.8	–
64	10^4 (scaled)	–	9.7 ± 0.4	–
32	9×10^2 and 2×10^4 (scaled)	–	–	10.0 ± 0.3
16	8×10^3 (scaled)	–	–	11.0 ± 0.4
8	9×10^2 and 10^4 (scaled)	–	–	12.0 ± 0.4

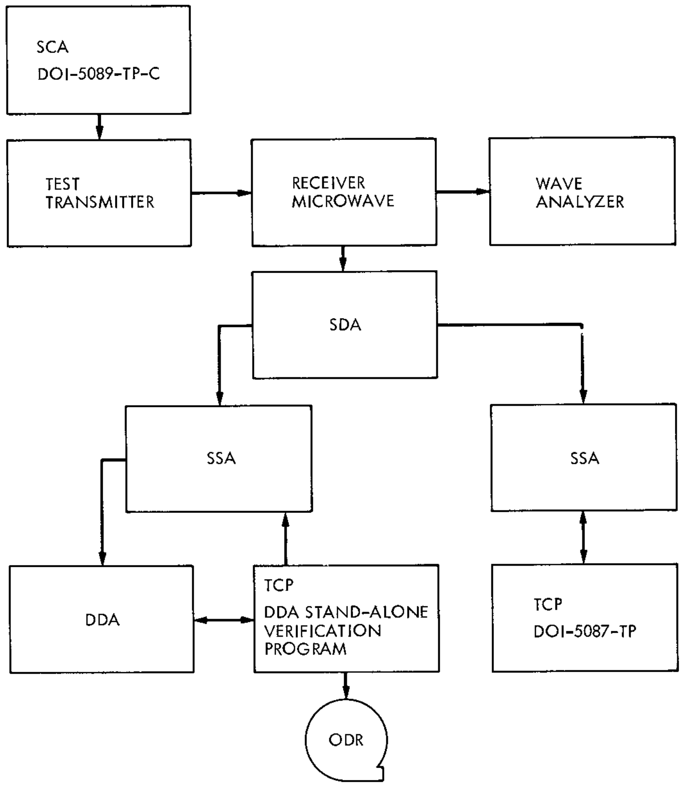

Fig. 1. Telemetry test configuration

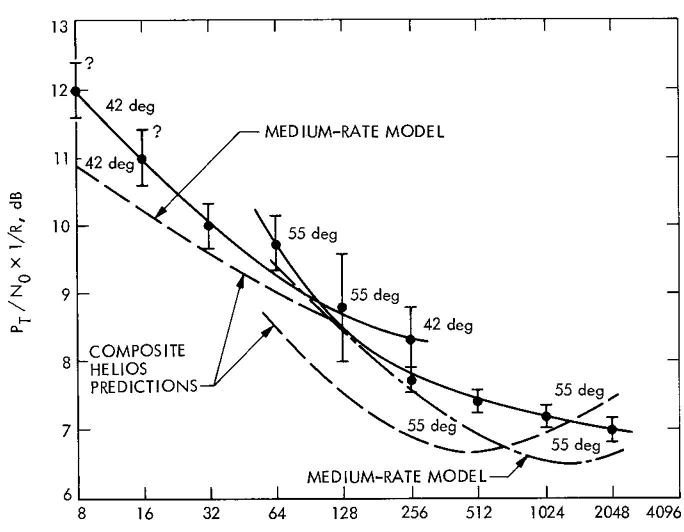

Fig. 2. Telemetry thresholds of 10^{-4} Pd comparison of DSS-71 tests and prior predictions

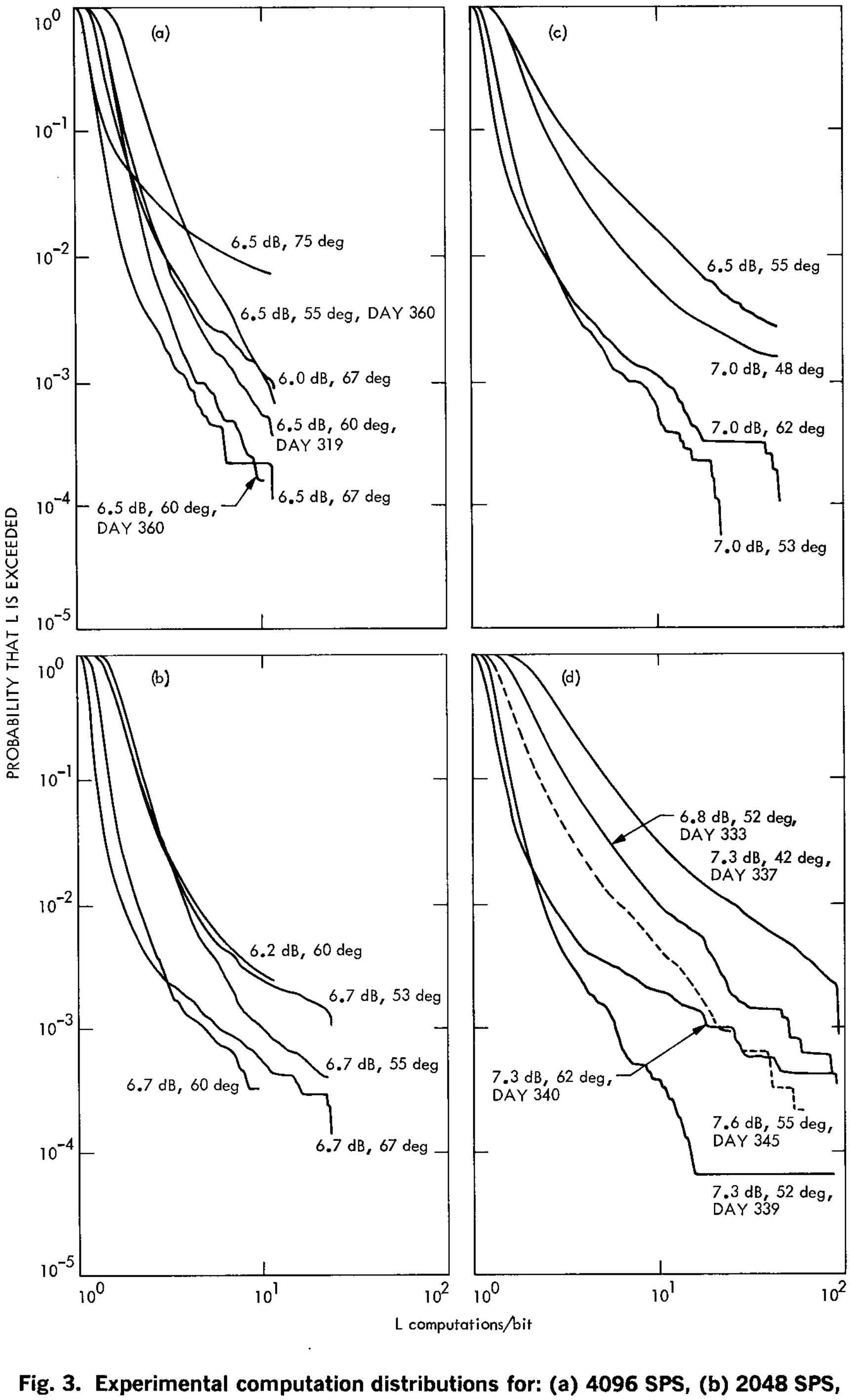

Fig. 3. Experimental computation distributions for: (a) 4096 SPS, (b) 2048 SPS, (c) 1024 SPS, (d) 512 SPS

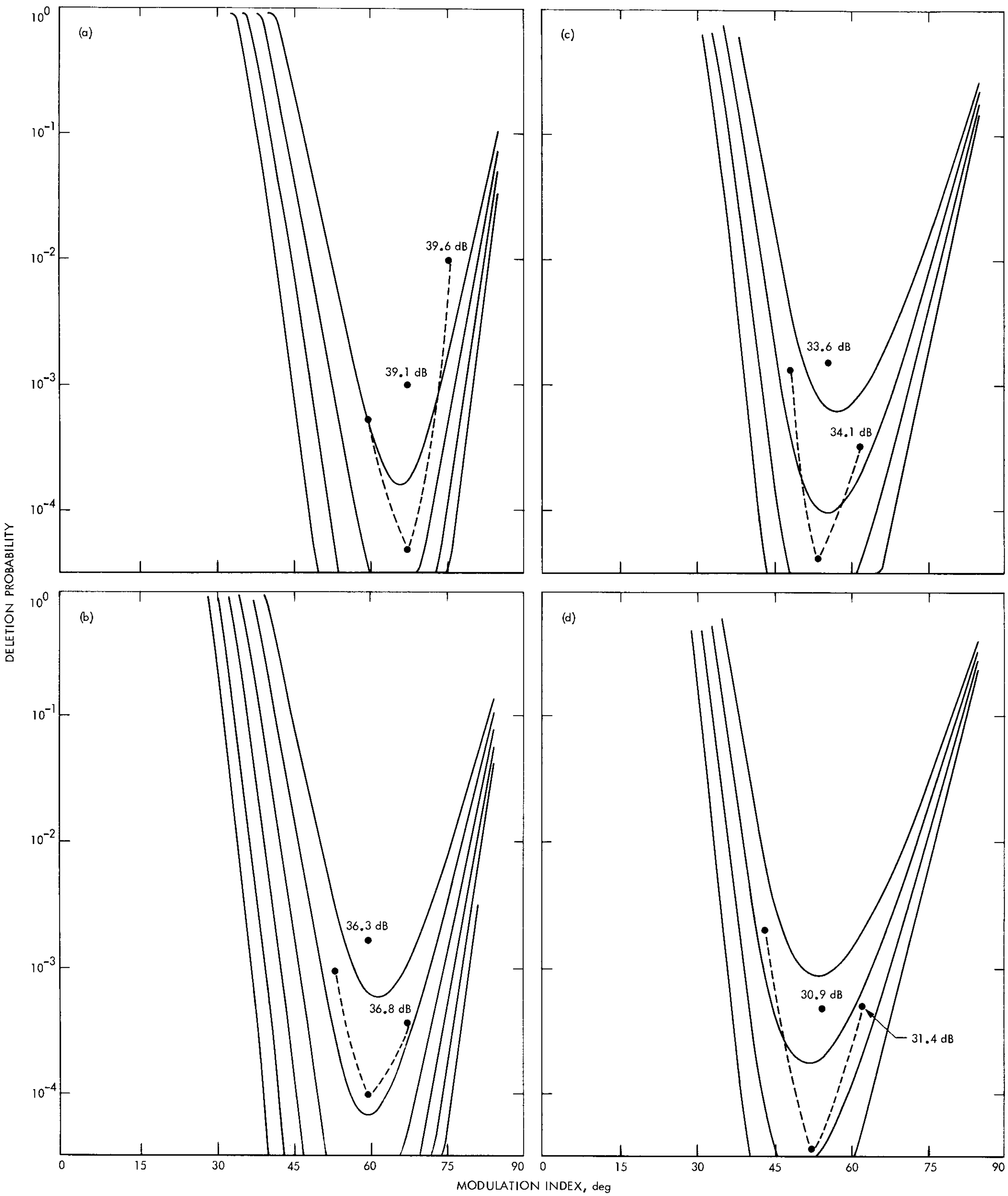

Fig. 4. Deletion probability as a function of modulation index: comparison of test and model for: (a) 4096 SPS, P_t/N_0 = 39, 39.5, 40, 40.5; (b) 2048 SPS, P_t/N_0 = 36, 36.5, 38, 38.5; (c) 1024 SPS, P_t/N_0 = 33.5, 34, 34.5, 35; (d) 512 SPS, P_t/N_0 = 31, 31.5, 32, 32.5

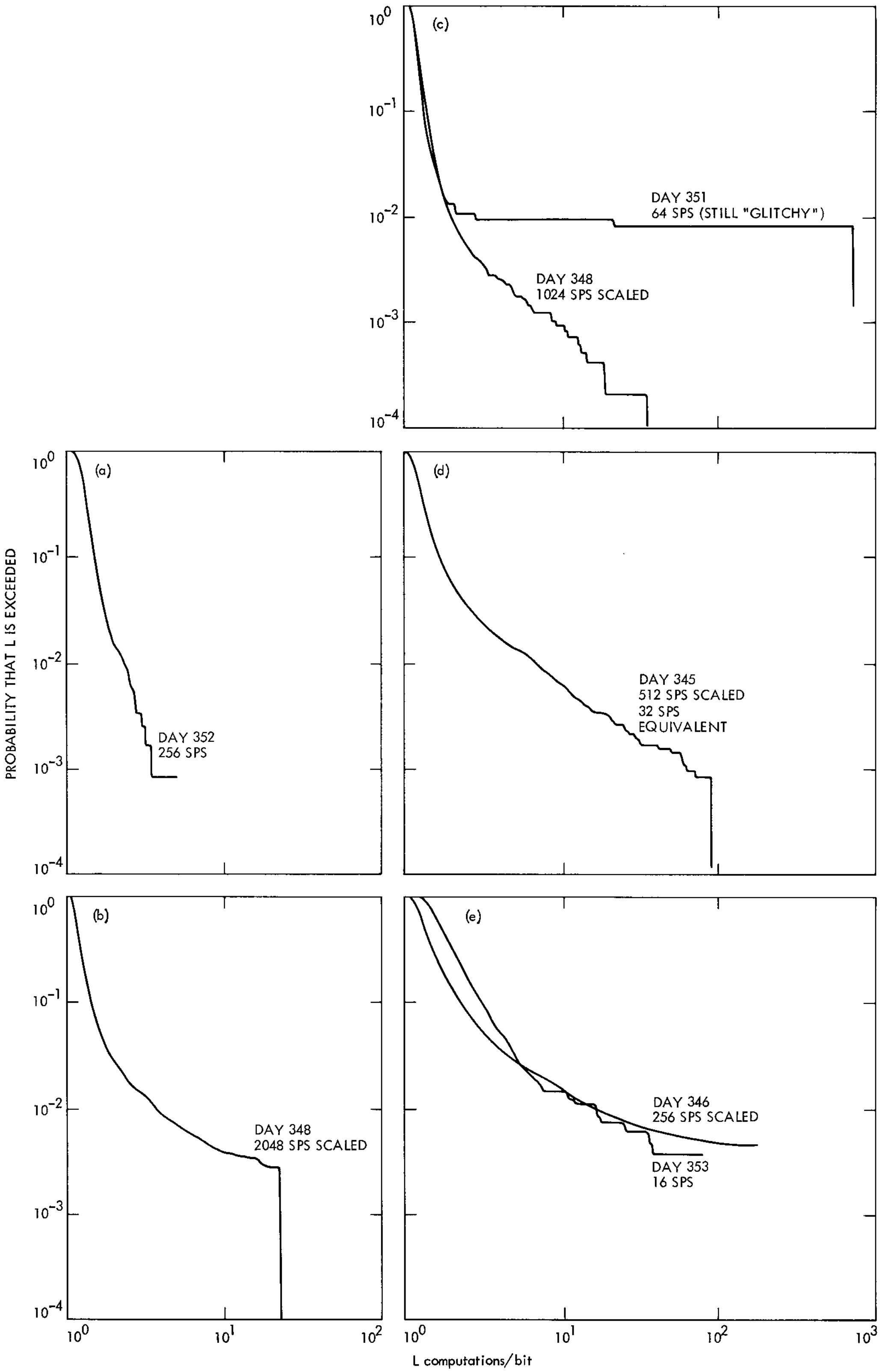

Fig. 5. Experimental computation distributions for: (a) 256 SPS, $P_t/N_0 \times 1/R = 8.3$ dB, MI = 55 deg; (b) 128 SPS, $P_t/N_0 \times 1/R = 9.0$ dB, MI = 55 deg; (c) 64 SPS, $P_t/N_0 \times 1/R = 9.7$ dB, MI = 42 deg; (d) 32 SPS, $P_t/N_0 \times 1/R = 10.5$ dB, MI = 42 deg; (e) 16 SPS, $P_t/N_0 \times 1/R = 11.3$ dB, MI = 42 deg