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FIDELITY OF THE PCM TELEMETRY DATA INFORMATION SYSTEM FOR OGO-B-D-E-F, RAE-A, ISIS-A, AND OSO-D-E-F SATELLITES

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ABSTRACT

A fidelity measure has been defined and used to evaluate the present PCM Information System from the Spacecraft through the Central Processing Facility. This fidelity measure removes a majority of existing "biased-errors" thereby yielding a potentially obtainable quality measure of the experimenters data. Analysis of the bit error probability for all processed satellite passes yields the overall quality of data shipped to the experimenters. The overall average quality of experimenters data for several PCM data satellites was found to have a bit error probability between 1×10^{-3} and 1×10^{-5}. The average fidelity for these same spacecrafts was found to have a bit error probability between 1×10^{-4} and 1×10^{-6}. The average fidelity and its standard deviation for most satellite data analyzed are approximately one-half order of magnitude better than the overall average quality and its standard deviation. The present Information System performance is not commensurate with the available and predicted spacecraft power; many factors contributing to the system degradation are prevalent in the actual quality and must be taken into consideration for predicting and improving the present and future Information System Performance.

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I. Introduction

Pulse Code Modulation (PCM) telemetry data from Scientific Satellites along with ground time are presently being recorded on analog magnetic tape by the Space Tracking and Data Acquisition Networks (STADAN); the analog tapes are mailed to the Information Processing Division (IPD) at the Goddard Space Flight Center. The IPD data processing facilities perform bit, word, and frame synchronization on the "raw" PCM data and formats each decoded data frame along with a time reading (related to a bit position of the frame sync word) on a digital tape. This digital tape is processed on the IPD computers which perform editing, quality checking, time verification, and orbit merging for preparation of the experimenter decommutation tapes.

Figure 1 represents the overall data flow of the present Telemetry Data Information System containing two analog tape recorders (STADAN record and IPD reproduce systems). Analog signals, other than PCM data and time codes, are recorded on the analog tapes at the STADAN but will not be treated in this report since they are not used directly in the PCM Data Processing at the IPD.

This report is concerned primarily with conveying to the reader the past and present performance of the PCM Telemetry Data Information System for several scientific satellites being processed at the IPD facilities. Average performance measures of satellite data for all prime stations over a selected number of PCM satellites are presented.

The performance must be determined for the present system to provide the system designers, operational personnel, and management with information as to the actual system behavior and characteristics of spacecraft data quality not only to improve the existing system but to provide information for specifying desirable performance characteristics of future systems.

A performance measure is defined by the author which enables one to remove (for statistical analysis purposes) the majority of "noise" sources such as S/C RFI, multipath, propagation disturbances, low elevation noise, etc. which cause the telemetry receiver or PCM processor to drop lock thereby adding non-random biased-noise errors to performance measurements. This performance measure yields a measure of the "fidelity" of the Information System. Fidelity will be used in conjunction with other statistical parameters and performance measures presently available at the IPD.

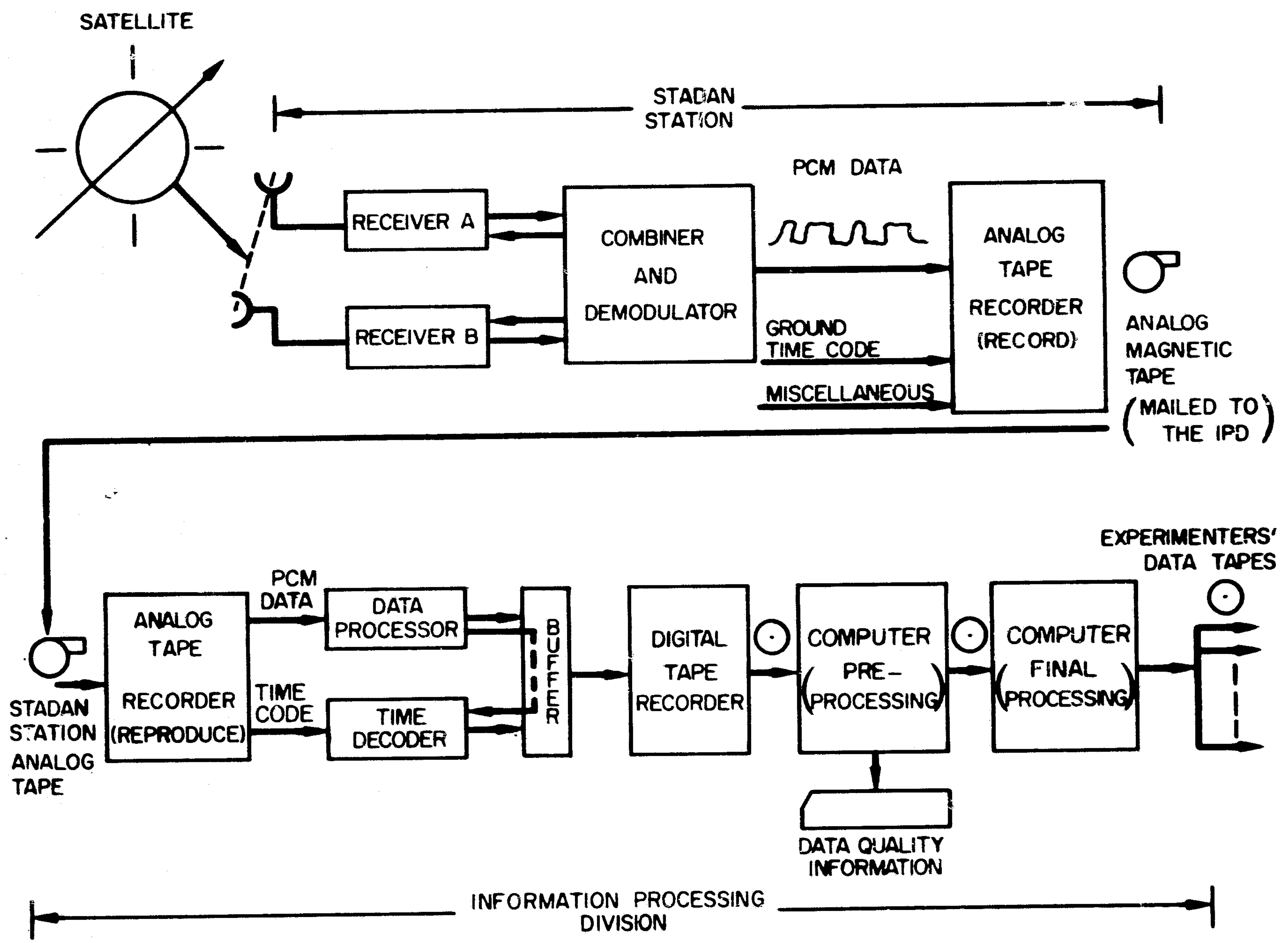

Figure 1–Overall Data Flow of the PCM Telemetry Data Information System

II. Fidelity Measurements

Fidelity as defined by Wester's Dictionary is the degree to which an electrical device, such as a radio receiving set, accurately reproduces its effect. "Fidelity" as applied to the Information System being discussed is the degree to which the STADAN/IPD system accurately reproduces its quality output. Fidelity is a measure of the potentially available quality of the Information System and is not a measure of the actual quality of the data being shipped to the experimenters.

The Fidelity measure is based only on the quality of the processed data for those recorded satellite passes which, when processed on the IPD PCM lines, once having acquired "lock" on the PCM data will remain in lock, and when "drop-lock" occurs, the PCM line would never re-acquire lock. By analyzing these selected satellite passes, one can remove the majority of bias-errors caused by S/C RFI, propagation disturbances, multipath, low elevation noise etc. and one can then obtain a truer fidelity measure of the STADAN/IPD performance on satellite data.

The major difference between "fidelity" and quality as used here is that the quality of the experimenters' data is generally computed over all recoverable data while the fidelity is computed over only those satellite passes which yield a data recovery (D.R.) of 100%:

$$\text{where D.R.} = \frac{\text{(Frames Recovered) (Bits/Frame)} \times 100\%}{\text{(Final LOS Time - Inital AOS Time)} \ (10^{-3}\,\text{sec}) \ \text{(Bits/sec)}}$$

where LOS and AOS are the IPD's final and inital loss-and-acquisition times of data respectively in milliseconds.

Fidelity is defined as the bit error probability (quality) of the recovered frames of data when the D.R. = 100%. Therefore Fidelity $\cong P_e \Big|_{\text{D.R.} = 100\%}$.

The overall average quality (bit error probability) of the experimenters data is always worse than the average fidelity. However, the fidelity yields a near-optimum obtainable quality of the information system or a performance measure which could be achieved if the majority of present system noise "bias" errors could be removed as shown in Figure 2c.

An advantage of working with fidelity is that it allows one to have more confidence that he is dealing with a near-gaussian process when analyzing and evaluating the repeatability of the system performance. This fidelity measure will be used in conjunction with other quality measures to monitor the Information system.

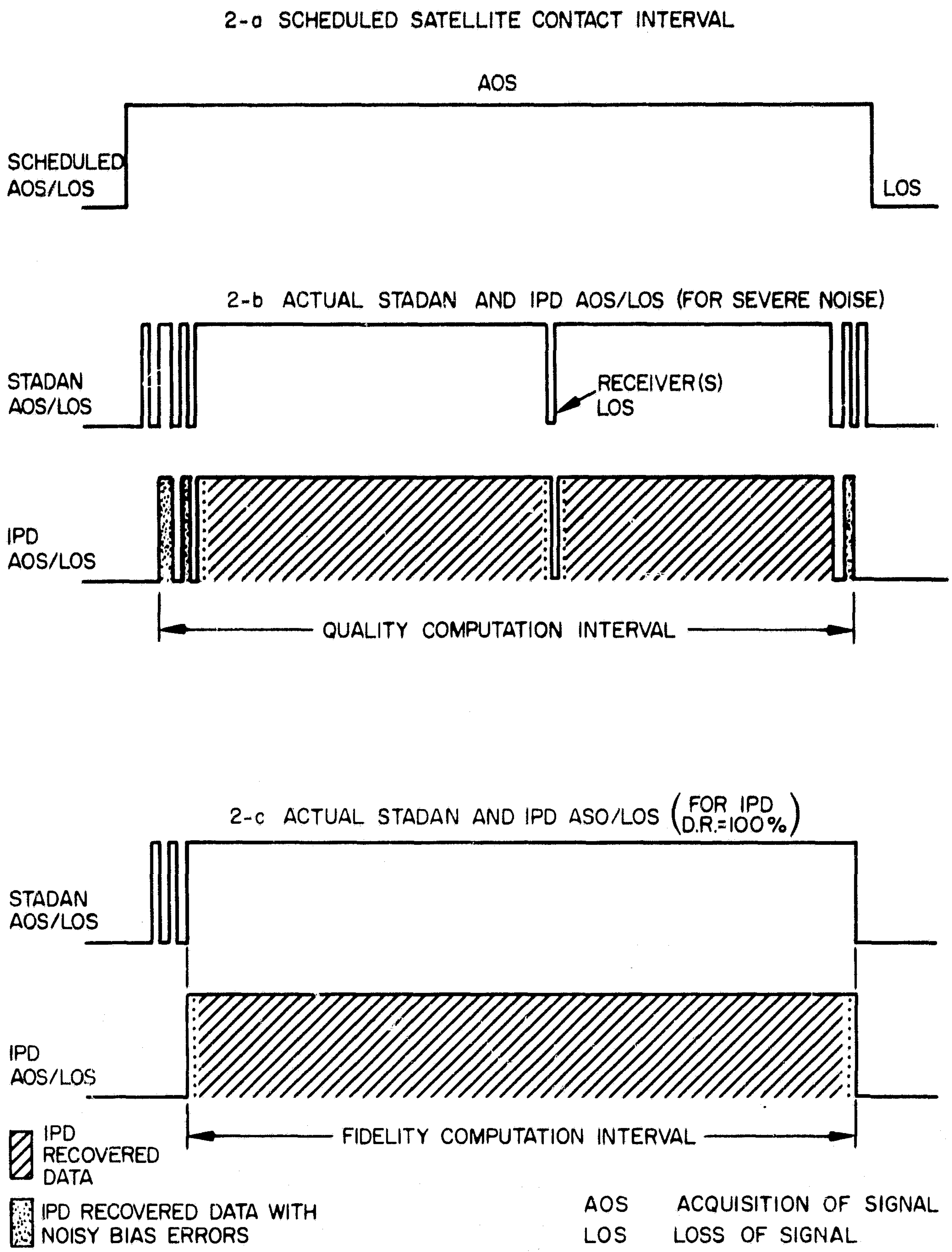

Figure 2—Comparison of Quality and Fidelity Measurement Intervals

III. Acquisition Problems in the Present Information System

Tracking data is used by the Computations Division in computing the operations predictions which contain information such as Greenwich Mean Time, STADAN station, satellite range, antenna elevation and azimuth tracking angles, etc. The STADAN stations are scheduled by the Project Operations Support Division for acquisition of the spacecraft signal and for analog tape recorder turn-on/turn-off interval for acquiring telemetry data. In addition, each satellite project has different requirements and procedures for acquisition of the telementry data. Also, the IPD has a requirement for STADAN recording of all analog tapes in that at least 30 seconds of time be recorded prior to the PCM data recording to allow the IPD reproduce tape recorders to obtain proper speed and to allow the time decoder to decode time properly prior to processing of the PCM data. In the situation where multiple over-lapping analog tapes are required to support a satellite pass, then a sufficient tape leader is required since time and data are simultaneously recorded on an overlap tape; the tape leader allows time for IPD's tape recorder to acquire proper speed.

In the present schedule criteria for data acquisition no special emphasis is placed on the quality of the recovered data during acquisition times. The following are factors which could and do contribute to degraded data quality in the present Information System:

1. Incorrect Predictions
2. Incorrect Scheduling Criteria
3. Incorrect Acquisition Procedures
4. Varying Signal-to-Noise Ratios at acquisition time (multipath, low elevation noise sources, etc.)
5. Faulty or degraded ground equipment (STADAN Stations and IPD)
6. Faulty or unstable spacecraft
7. Improper data recording and reproduction procedures (STADAN Stations and IPD)
8. Operator differences and errors (STADAN Stations and IPD)
9. S/C RFI and other noise sources
10. Non-optimum Data Processing Operations

All of these factors are contributors to the degradation of the data quality. These noise sources (biases) introduce many errors in a recorded pass; so much that in most satellites, they completely "mask-out" the theoretical expected change in data quality as a function of spacecraft range!

Figure 3 represents theoretical and typical hypothetical density functions for the quality of satellite passes (with gaussian noise distribution assumed). Example shown is for the case where the actual quality is worse than the predicted quality. Curve A is the theoretical curve with the predicted average quality shown; for simplicity, only one STADAN antenna type is assumed. Curves B and C represent hypothetical typical density functions for the quality of satellite passes processed in the IPD data processing facilities. Curve B represents all passes processed with the average quality as indicated. Curve C represents all passes whose data recovery is 100%; the average fidelity is shown and is better than the overall average quality. Note the change in shape of curves B and C from curve A due to those files in the actual situation having severe non-random bias errors such as those previously mentioned. The fidelity removes the majority of the bias errors and enables one to observe the effect of their removal.

Figure 4 is a comparison of the theoretical and typical hypothetical Information System performance curves for several spacecraft. The "best actual curve" assumes that all bias errors are removed except those introduced by the ground analog and digital tape recorders (the minimum P_e shown to be between 1×10^{-7} to 1×10^{-8}). The actual operating region is shown and each spacecraft performance curve would be a function of the data acquisition, recording, and processing procedures along with any spacecraft anomalies.

The actual bit error probability remains virtually constant at high S/N ratio's. The effect of this "saturation" of the Information System performance curve for changes in satellite range (S/N) is shown on figure 5 for hypothetical situations. Three satellite range variations (orbits) are shown and "mapped-on" the bit error probability curve. The resultant output quality-time curves show that little correlation in data quality is observed for orbits A and B due to the saturated performance curve. Hence it becomes obvious that in the present Information System at high S/N ratio's the output data quality is invariant for satellite range change or station-to-station performance due to the "masking-out" of the variations with "biased-errors".

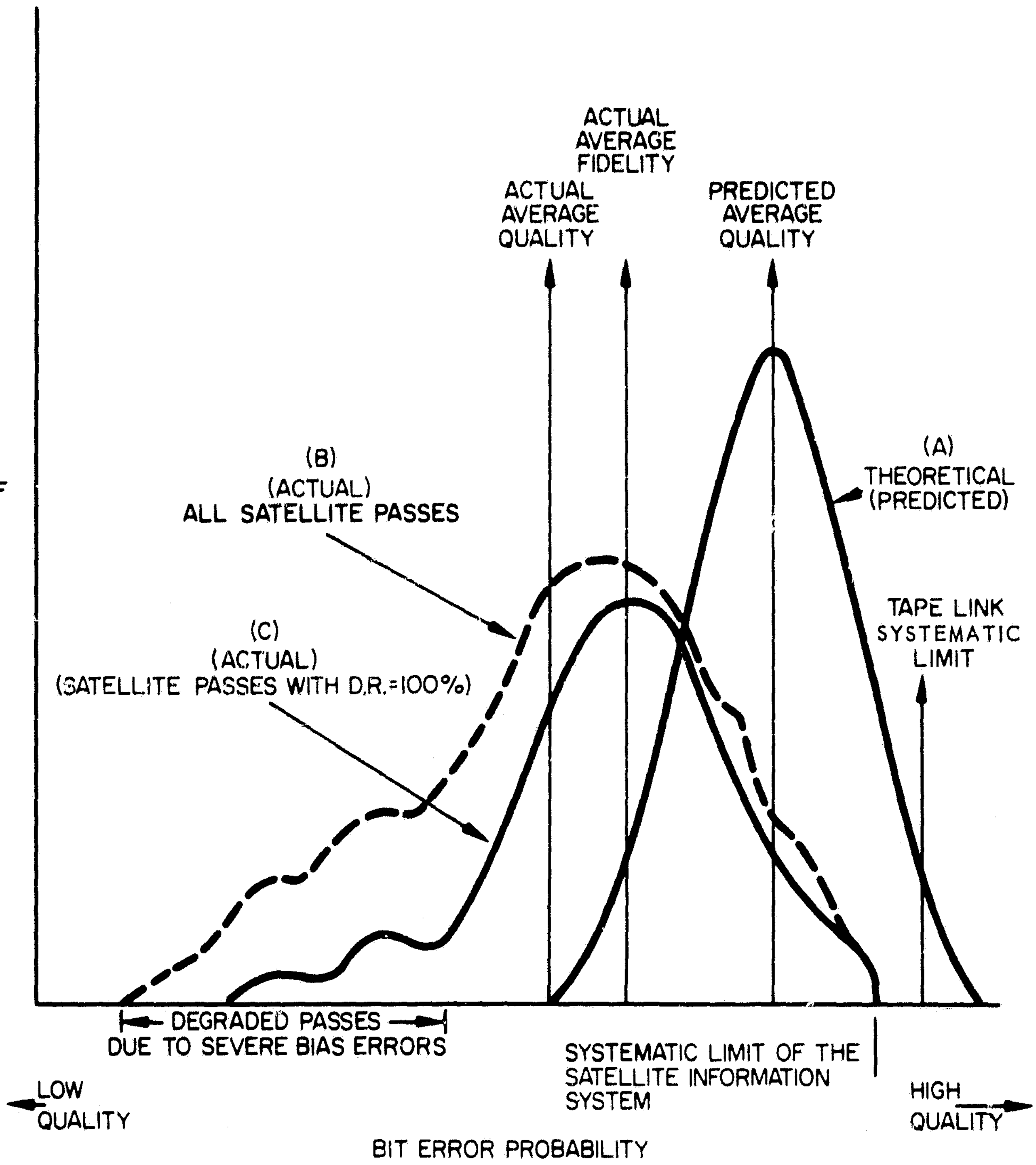

Figure 3–Theoretical and Typical Hypothetical Density Functions of the Quality of Satellite Passes for Gaussian Noise

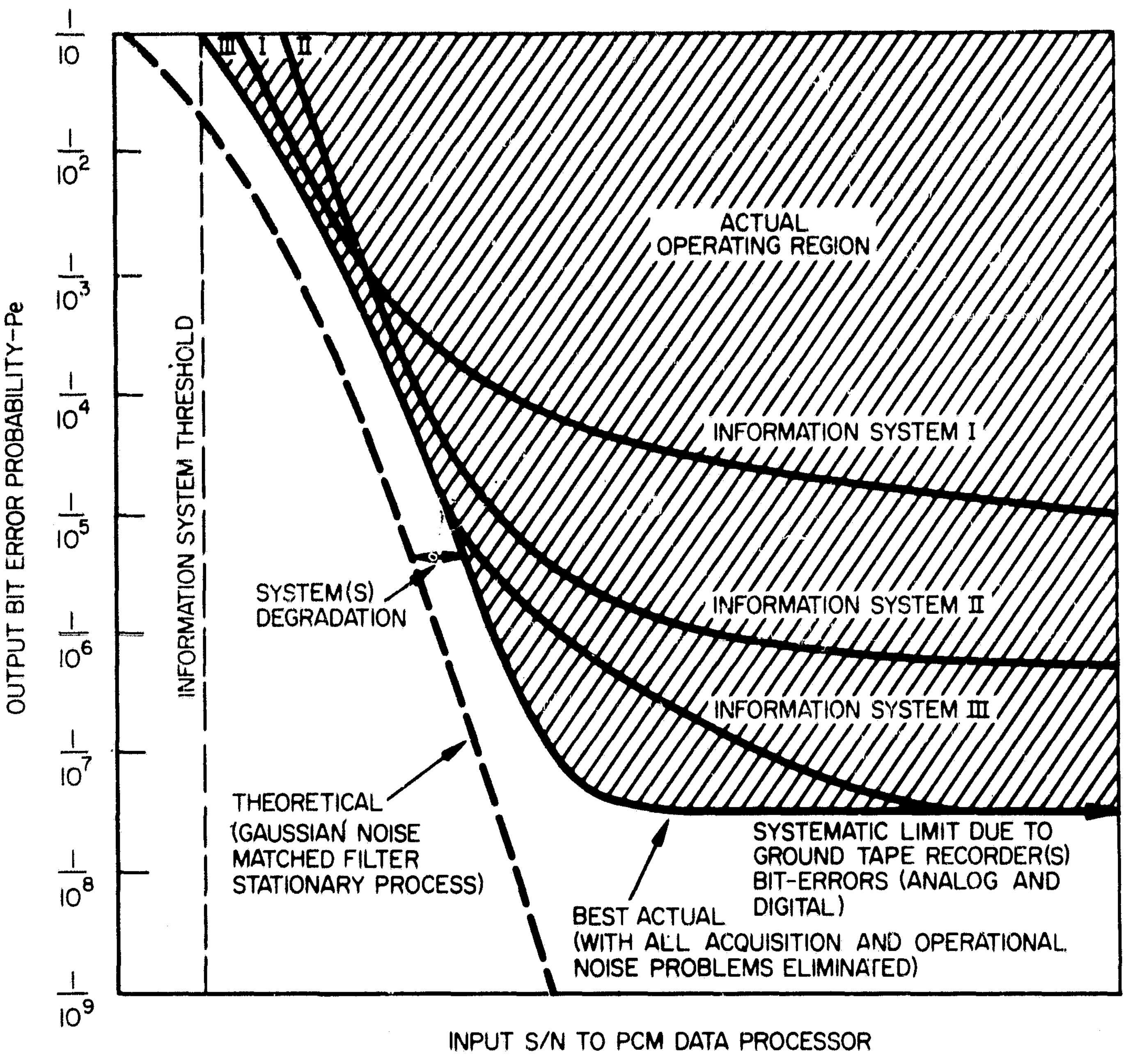

Figure 4–Comparison of Theoretical to Hypothetical Information System(s) Performance Curves Including all Operational and Acquisition Noise Sources

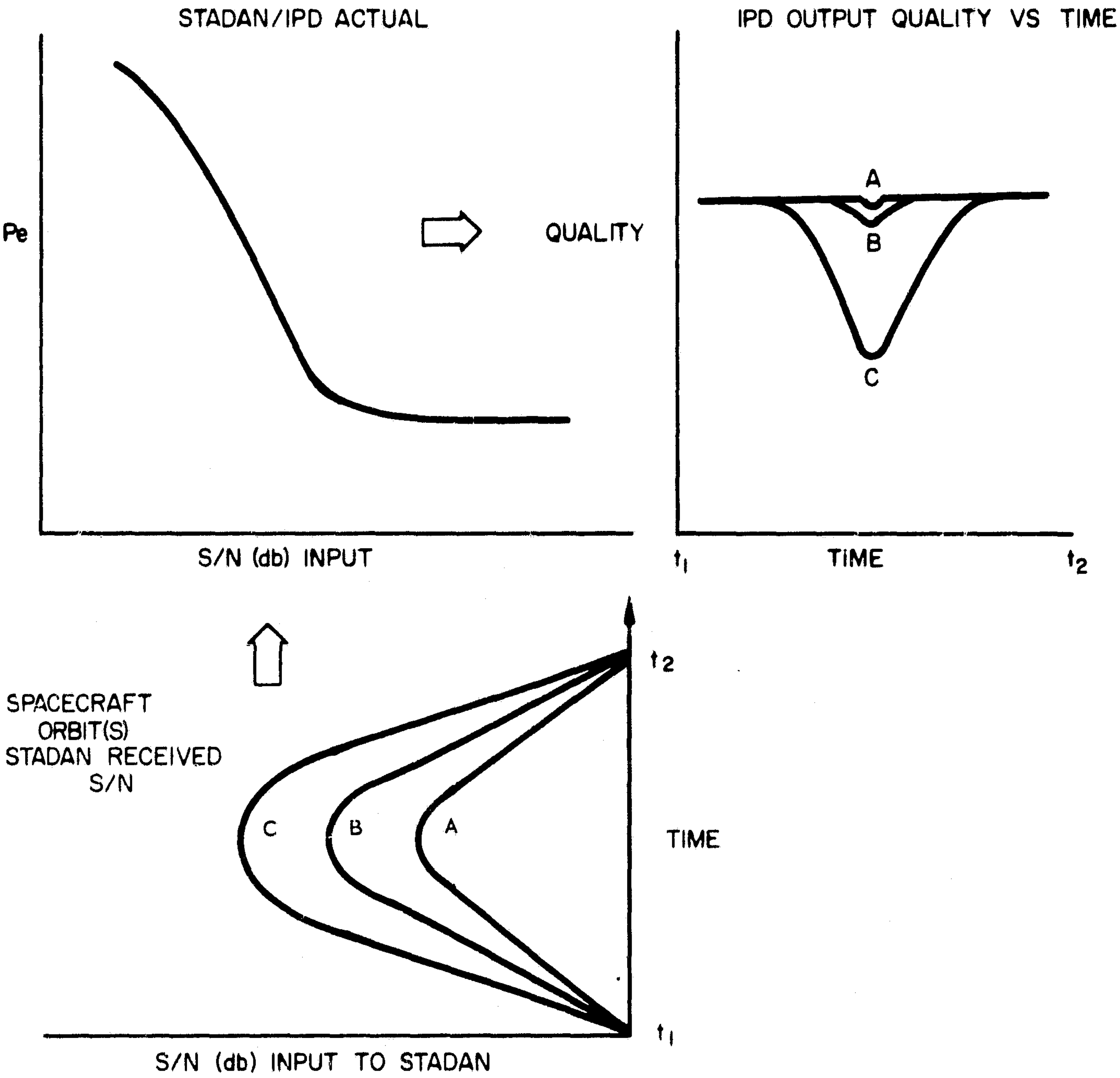

Figure 5–Hypothetical Orbit-to-System Performance-to-Quality Transfer Characteristics as a Function of Time

IV. Comparison of Fidelity and Quality Measures of Actual Spacecraft Data

A Quality Control Monitoring System (QCMS) is under development (Reference 1) which can now be readily used to obtain the quality and fidelity measures for those satellites being processed at the IPD. The QCMS consists of a CRT for visual display with controls and a memory for manipulation of the displayed data. The system operates as an adjunct to a CDC 3200 computer through which the data are entered into the system (See Figure 6). The data inputs are either quality cards or tape resulting from the A/D and pre-edit processes shown on Figure 1. A function keyboard or typewriter input is used to select any satellite-data type and STADAN stations for analysis purposes. A plot of the time history of data quality and data recovery is presented on the CRT along with selected statistics of the satellite passes.

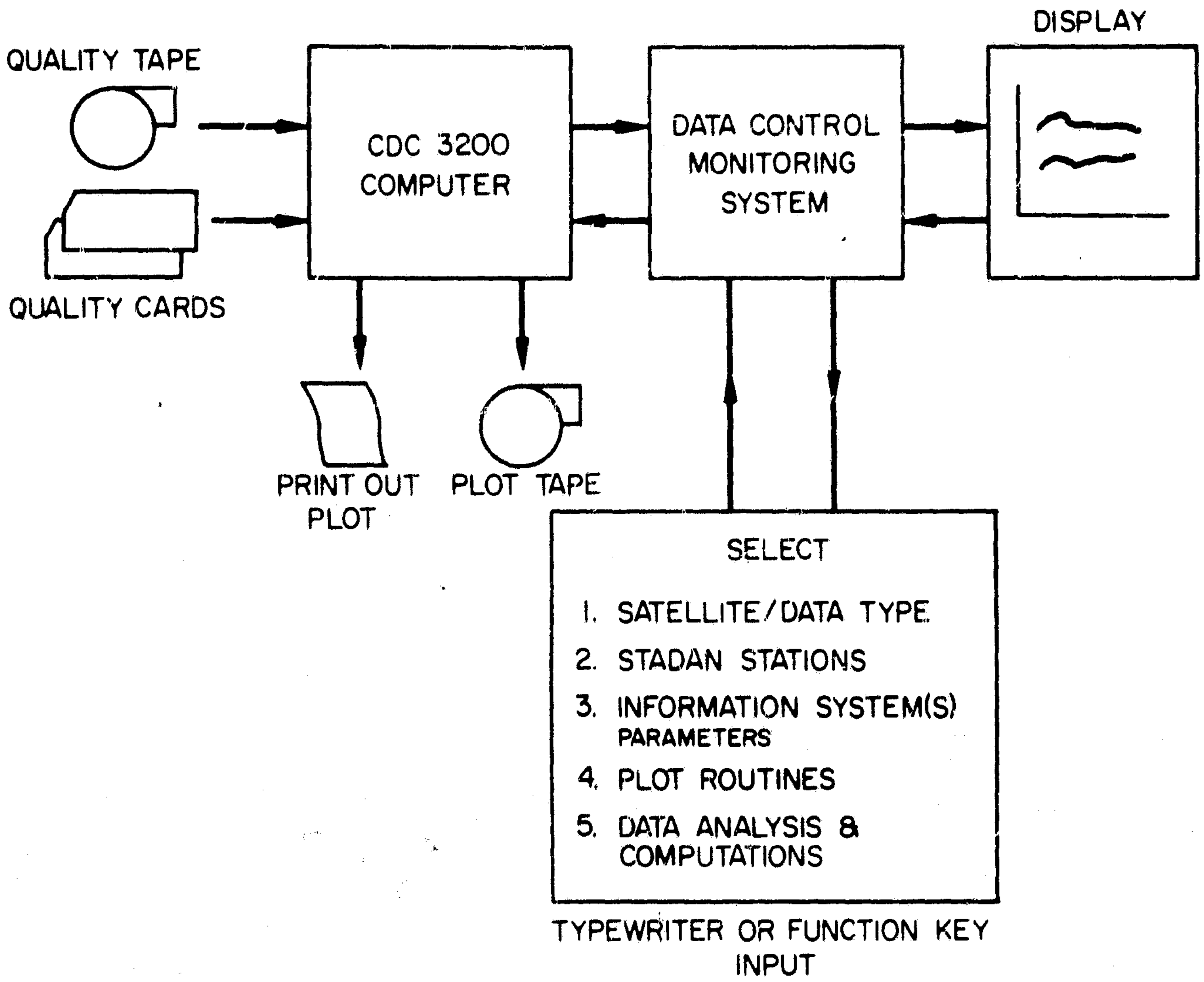

Figure 6–A Quality Control Monitoring System

Table I contains the results made on the QCMS for data quality cards available as of September, 1969 for each satellite indicated. The statistics represent unweighted average quality and fidelity measures for all stations combined per satellite data type. Note that in all cases the fidelity is better than the overall quality.

Figure 7 was used to relate the percentage of detected frame sync words with zero bit errors (FOE) to P_e and S/N for different frame sync word lengths.

For example, OGO - B at 1 Kc bit rate and 27 bits in frame sync word a FOE quality of 98.05% was measured, the bit error probability is computed by $P_e = \frac{1 - .9805}{27} = \frac{.0195}{27} = 7 \times 10^{-4}$.

A P_e of 7×10^{-4} corresponds to a S/N of approximately 6.9 db on figure 7.

It should be noted that the quality measures computed from the output information of the A/D conversion lines (i.e. FOE and P_e) were used to infer what the input S/N (to the IPD) would have been using the theoretical curve of figure 7 with zero system degradation assumed and a stationary-gaussian process. In the actual situation, the S/N (input to STADAN stations) would be higher than that tabulated on table I due to the degradation of information systems performance (i.e., receivers, demodulators, tape link, and A/D Lines, etc.) which are not known at this time. The fidelity measure experiences a truer stationary-gaussian process than the overall quality measure.

The Fidelity results show that in most cases the playback (higher bit rate) commanded transmitted data has better quality than other spacecraft data types. This contradicts the theory of higher bit rate satellites with on-board tape recorders generally yielding lower quality. This phenomenon further reinforces the authors concept of system(s) "biased-errors" "masking-out" the theoretical expectations. The playback data are generally commanded above the horizon whereas other data types are acquired near the horizon thereby yielding poorer quality data (Reference 2). Other factors such as poor low-frequency response characteristics of analog type recorder could degrade low frequency real time (non commanded) satellite data.

Figure 8 represents a bar graph of the average quality and fidelity measure found on Table I. Note that OGO-E 64 Kc real-time data has the best average fidelity (2×10^{-6}) while OGO-F 16 Kc real-time data has the best quality (6×10^{-6}).

TABLE I

Tabulation of Quality and Fidelity Measurements for Several PCM Satellites

Satellite Name	Date Launched	No. of Bits in FS Word	Bit Rate (kc)	Quality Measure					Fidelity Measure					
				Average Quality		Standard Deviation σ FOE (%)	Average Bit Error Probability Pe	No. of Files	Average Fidelity		Standard Deviation σ FOE (%)	Average Bit Error Probability Pe	No. of Files	% of Total Files
				FOE (%)	S/N (db)				FOE (%)	S/N (db)				
(1) OGO - B(3)	7 Jun 66	27	1,0	98,05	+6,9	3,68	7.0×10^{-4}	1850	98,33	+7,2	3,16	6.0×10^{-4}	1567	84,8
Eccentric Orbit		27	8,0	98,34	+7,2	6,34	6.0×10^{-4}	3012	99,36	+7,7	2,13	2.7×10^{-4}	1721	57,3
Apogee = 116 kkm		27	64,0	97,18	+6,6	8,48	1.2×10^{-3}	4839	98,18	+7,1	6,62	6.5×10^{-4}	2293	47,6
Perigee = 6,5 kkm		27	64,0*	98,84	+7,4	4,06	4.0×10^{-4}	697	99,33	+7,7	2,28	2.7×10^{-4}	125	17,3
(2) OGO - D(4)	28 Jun 67	27	4,0	99,83	+8,5	0,16	7.0×10^{-4}	39	99,84	+8,6	0,16	6.8×10^{-4}	30	76,8
Polar Orbit		27	16,0	99,82	+8,5	0,53	7.0×10^{-4}	1351	99,86	+8,6	0,43	6.8×10^{-4}	812	60,0
Apogee 780 km		27	64,0	99,34	+7,7	3,07	2.7×10^{-4}	3591	99,62	+8,0	3,49	1.7×10^{-4}	1691	47,1
Perigee 400 km		27	128,0*	99,60	+8,0	1,94	1.7×10^{-4}	6055	99,69	+8,5	0,61	1.5×10^{-4}	2323	38,4
(3) OGO - E(5)	4 Mar 68	27	1,0	99,91	+8,8	0,56	3.8×10^{-5}	1306	99,99	+9,9	0,03	4.0×10^{-6}	938	71,7
Eccentric Orbit		27	8,0	99,44	+7,7	2,69	2.7×10^{-4}	2290	99,98	+9,7	0,08	6.0×10^{-6}	623	27,2
Apogee = 151 kkm		27	64,0	99,68	+8,5	2,14	1.5×10^{-4}	1186	99,96	+9,2	0,15	2.0×10^{-6}	85	7,2
Perigee = 8,8 kkm		27	64,0*	99,61	+8,5	2,23	1.5×10^{-4}	327	99,76	+8,3	0,89	1.2×10^{-4}	80	24,5
(4) OGO - F(6)	9 Aug 69	27	8,0	-	-	-	-	-	-	-	-	-	-	-
Polar Orbit		27	16,0	99,98	+9,7	0,04	6.0×10^{-6}	20	99,99	+9,9	0,03	4.0×10^{-6}	10	50,0
Apogee = 1,1 kkm			64,0	99,94	+9,0	0,23	3.0×10^{-5}	42	99,98	+9,7	0,05	6.0×10^{-6}	16	38,1
Perigee = 400 km		27	128,0*	99,70	+8,4	1,19	1.3×10^{-4}	32	-	-	-	-	0	00,0
(5) RAE-A	8 Jul 68	28	0,4	97,46	+6,7	6,29	1.0×10^{-3}	744	99,10	+7,5	1,54	3.5×10^{-4}	230	31,0
Circular Orbit		28	10,0*	98,61	+7,3	3,04	5.0×10^{-4}	6832	99,25	+7,6	1,16	3.0×10^{-4}	4818	70,6
Range = 5,8 kkm														
(6) ISIS-A	30 Jan 69	24	11,52	99,62	+8,0	3,71	1.7×10^{-4}	1670	99,93	+8,9	0,20	3.5×10^{-5}	1097	65,7
Eliptical Orbit														
Apogee = 3,5 kkm														
Perigee = 580 km														
(7) OSO - D(4)	3 Feb 65	16	0,4	98,41	+6,8	2,83	8.0×10^{-4}	2946	98,79	+6,9	1,53	7.0×10^{-4}	2450	83,2
Circular Orbit		16	7,2*	99,56	+7,9	2,12	2.5×10^{-4}	2971**	99,69	+8,0	0,96	1.6×10^{-4}	157	52,8
Apogee = 617 km														
Perigee = 536 km														
(8) OSO - E(3)	8 Mar 67	16	0,4	98,22	+6,6	3,74	1.0×10^{-3}	1692	98,71	+6,9	1,65	7.0×10^{-4}	1439	84,8
Circular Orbit			7,2*	99,65	+7,9	2,81	1.8×10^{-4}	7363**	99,90	+8,6	0,28	6.5×10^{-5}	247	33,4
Apogee = 551 km														
Perigee = 525 km														
(9) OSO - F(5)	22 Jan 69	16	0,8	-	-	-	-	-	-	-	-	-	-	-
Circular Orbit			14,4*	99,81	+8,2	1,22	1.3×10^{-4}	767	99,96	+9,1	0,38	2.5×10^{-5}	610	79,5
Apogee = 556 km														
Perigee = 532 km														

NOTE

(1) S/N (db) was determined from the theoretical P_e curve, in reality the S/N to the IPD would be higher by the amount of the IPD system degradation (generally ranges from 1 db to 3 db).

(2) * Playback data

(3) ** Includes real time and playback data after on-board tape recorder failure

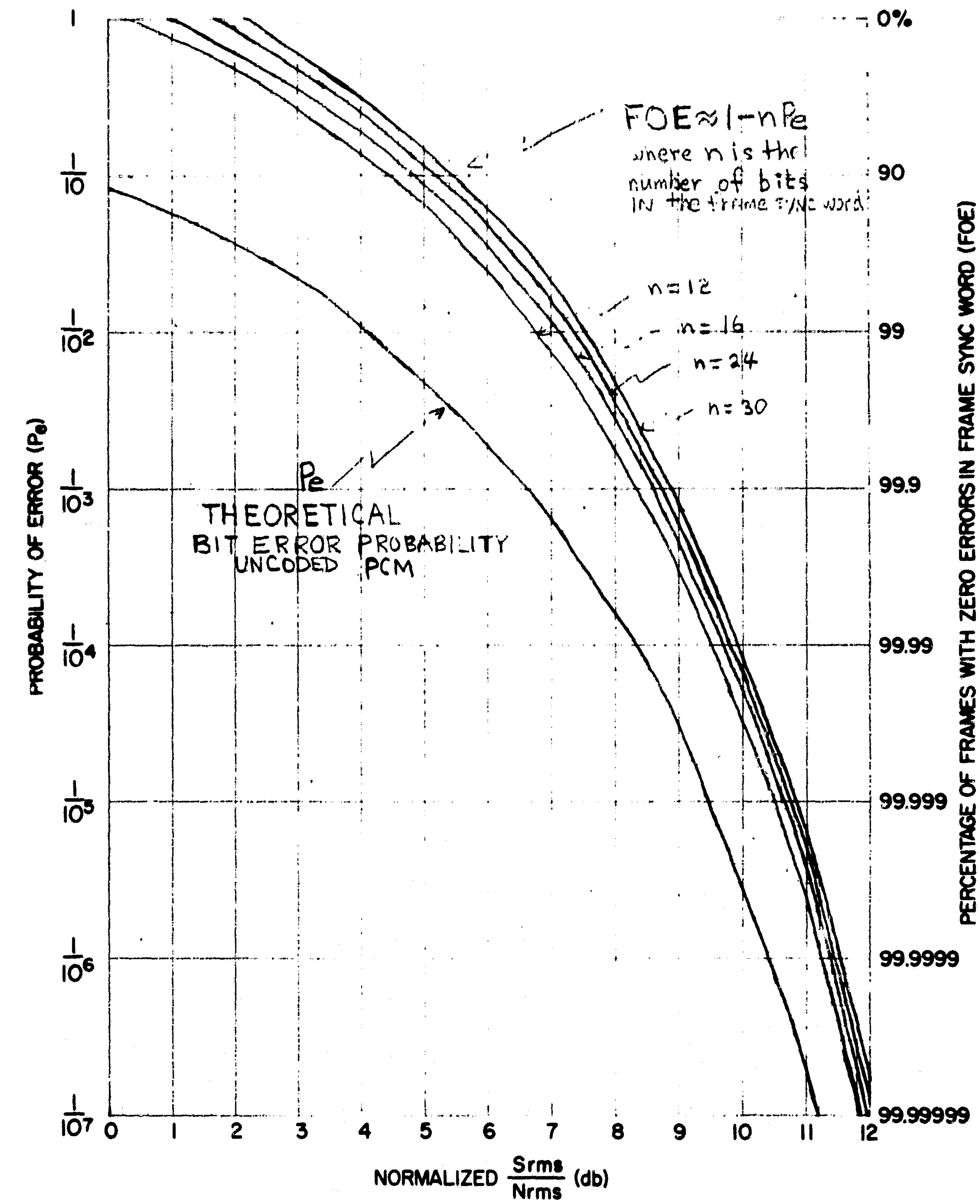

Figure 7–Relationship between the P_e and FOE Theoretical Outputs of a PCM Data Processor as a Function of S/N

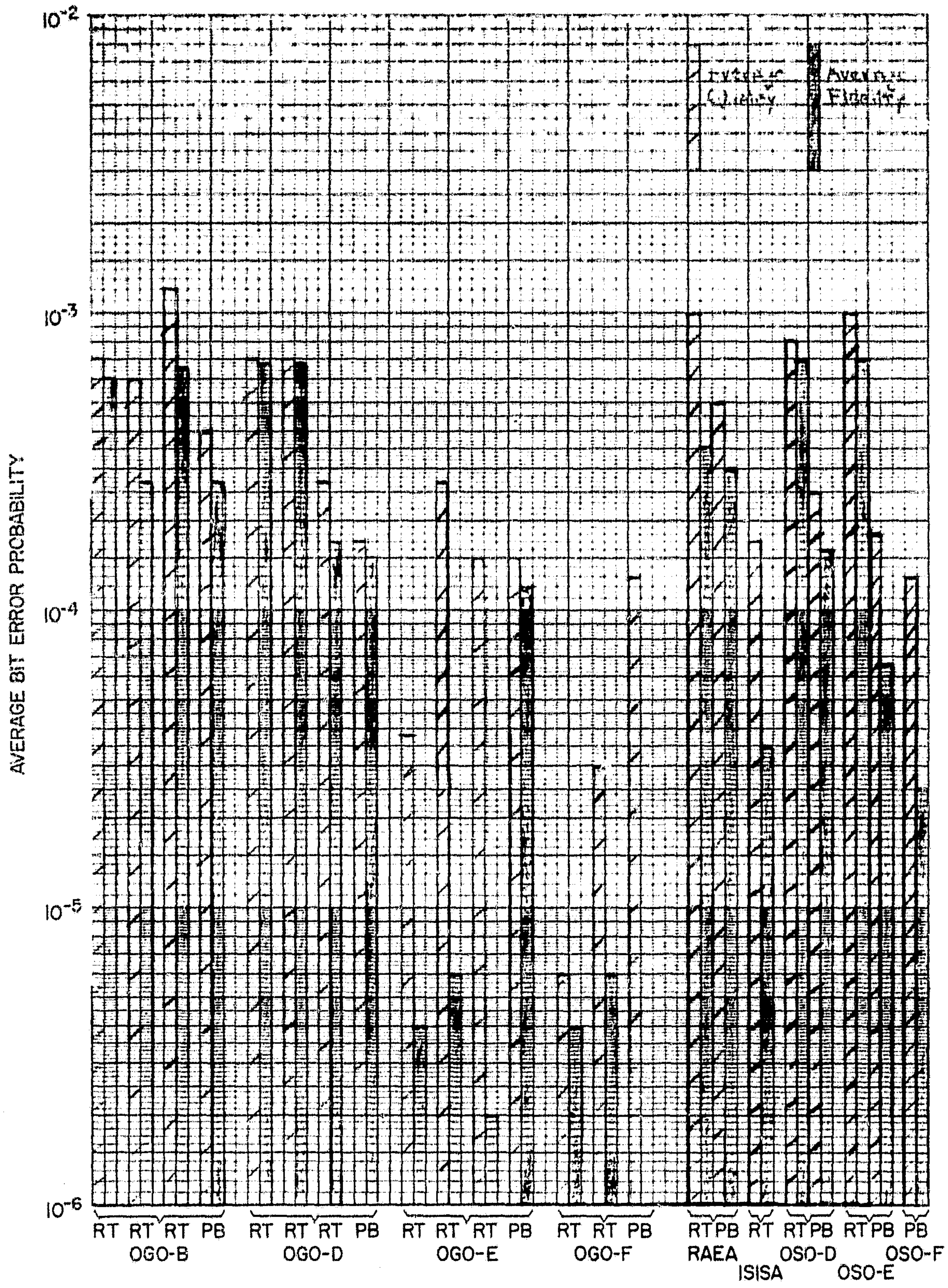

Figure 8—Comparison of Average Quality and Fidelity Measures

V. Summary and Recommendations

The fidelity measure defined by the author in this report enables one to evaluate and determine a measure of the potentially available quality of the Information System by removing a majority of the existing "biased-errors." This Fidelity can be used to compare station-to-station and Information System Performance. Only those files which exhibit the properties required for computations of the fidelity are used; the quality computed over all processed files yields the quality of the experimenters data.

The "link" calculations indicate enough received power that the worst case predicted bit error probability is better than 1×10^{-6}. Due to many factors not taken into consideration throughout the Information System, the actual average fidelity for the PCM satellite data analyzed in this report is between 1×10^{-4} and 1×10^{-6} and is not what it has been predicted to be. The author theorizes that existing "biased-errors" are completely "masking-out" the theoretical expectations in the present Information System.

A coordinated effort between various groups involved with the Information System should review the present acquisition problems and actual system performance to better understand and improve the data quality and system fidelity. A periodic link simulation and evaluation should be made to isolate and determine the magnitude of each existing non-random bias-errors along with system(s) degradation's to obtain more realistic link evaluation and performance measurements.

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