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PREPRINT

PREDICTED AND ACTUAL SPACECRAFT RADIO FREQUENCY INTERFERENCE FOR PFM TELEMETRY

THOMAS J. KARRAS
RALPH E. TAYLOR

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GSFC
GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

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ABSTRACT

This report describes the results of a first attempt to correlate, on a quantitative and qualitative basis, the Advanced Development Division's spacecraft (S/C) radio frequency interference (RFI) predict's, the STADAN observed-and-reported S/C RFI, and the Information Processing Division's actual data recovery and data quality results due to S/C RFI. Correlations were obtained for a pulse frequency modulation (PFM) telemetry system operating in the 136 MHz band.

A three day interval, covering November 8, 9, and 10 in 1968 and chosen at random for the IMP-F(4) spacecraft, was used for S/C RFI correlations. A total of ten analog tapes, recorded at the STADAN network, were examined for S/C RFI. These tapes were reported by the STADAN or observed at the IPD as having S/C RFI interferences; the tapes were processed and analyzed to observe the effects of the RFI. A S/C RFI prediction program was used to determine the interference and tracking signal levels as a function of time. A high degree of correlation was found; S/C RFI being verified in eight out of ten analog tapes.

An analysis of the three day sample indicates that 3% of the telemetry data for IMP-F is significantly degraded by S/C RFI. Of the 3% affected data, 0.8% was completely lost and 2.2% was degraded 3 db, on the average, corresponding to an average bit error rate increase from 10^{-5} to 10^{-2}.

In terms of station-observed S/C RFI, the earth-orbiting IMP-F S/C received next-to-the-largest amount of S/C RFI (76 events) for the 1st quarter of 1969; the lunar-orbiting AIMP-E experienced 151 S/C RFI events for the same period. Approximately 1.3% of all STADAN passes showed reported S/C RFI.

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PREDICTED AND ACTUAL SPACECRAFT RADIO FREQUENCY INTERFERENCE FOR PFM TELEMETRY

I. INTRODUCTION

The 136 MHz space research band has become overcrowded such that satellite-to-satellite radio frequency interference (RFI) has been observed while tracking a given spacecraft (S/C) in the Space Tracking and Data Acquisition Network (STADAN). There are presently about 40 earth-orbiting S/C actively supported by the National Aeronautics and Space Administration (NASA), other government agencies, and international projects; a number expected to double in the next decade. Satellite-to-satellite type RFI, hereafter referred to as S/C RFI, is expected to increase as the number of S/C increase.

The quantity and quality of the data retrieved from a satellite-to-earth telemetry link is affected by various radio link parameters including carrier frequency, channel spacing, emitted spectrum width and satellite range. Using these parameters as inputs, an RFI prediction model, automated on the IBM 360/91 or /95 digital computer in Fortran IV language by the Advanced Development Division (ADD), predicts the station-received signal levels for both the tracking S/C and the interfering spacecrafts and the link parameters including station antenna radiation patterns segmented in one degree increments.

This report examines typical samples of S/C RFI observed in the IMP-F spacecraft PFM/PM type telemetry data recorded by STADAN and processed by the Information Processing Division (IPD). A three day interval, selected at random, was examined in detail for correlation of the STADAN reported RFI, predicted RFI, and the IPD observed degradation in the processed data during cited time intervals. A total of ten analog recorded tapes were examined for S/C type RFI. The IPD tape evaluation strip charts of the "raw" PFM data and receiver AGC levels were obtained and the actual processed data quality indices along with the predicted S/C RFI were plotted on the PFM strip charts as a function of time.

The ADD S/C RFI prediction model and the IPD data processing results are briefly discussed. A tabulation of STADAN reported, ADD predicted, and the IPD observed S/C RFI results is presented.

II. DESCRIPTION OF THE RFI PREDICTION MODEL

Based upon known orbital elements (Reference 1), a given spacecraft's orbit can be predicted several weeks ahead in time with reasonable accuracy; these predictions normally include range and aspect angle referenced to a given earth station. A computer program (Reference 2) was consequently developed that predicts station-received signal power levels, based on predicted range and known link parameters, according to Frii's propagation equation:

$$S = \frac{P_{to} G_{to} G_{ro} \lambda_o^2}{(4\pi R_o)^2} \qquad (1)$$

P_{to} = S/C antenna input power

G_{to} = S/C antenna gain, above isotropic

G_{ro} = Station antenna gain, above isotropic

λ_o = operating wavelength

R_o = S/C-to-station range

STADAN stations at times experience RFI due to the simultaneous appearance of multiple S/C having overlapping 136 MHz emission spectrums. RFI can result from two or more S/C simultaneously within the main lobe, or from an interfering S/C transversing a station's antenna side lobe while the S/C being tracked is positioned within the main lobe (see Figure 1).

For a steerable antenna (e.g. 85 foot diameter dish), the S/C being tracked is assumed positioned perfectly within the main lobe at the maximum gain point; whereas, an interfering S/C can appear at any point in the radiation pattern. Both the main lobe and side lobes are inputted to the computer in fine one degree increments: the received tracking S/C power level, S, and interference power level, I, being simultaneously determined at any given two-minute time interval. Interference-to-signal ratios, I/S, are then computed from Equation (1) for all S/C. The magnitude of the predicted I/S ratio determines if S/C RFI is present; an interference condition is defined as existing when the interference power level, I, is 20 db, or less, below the tracking signal level, S.

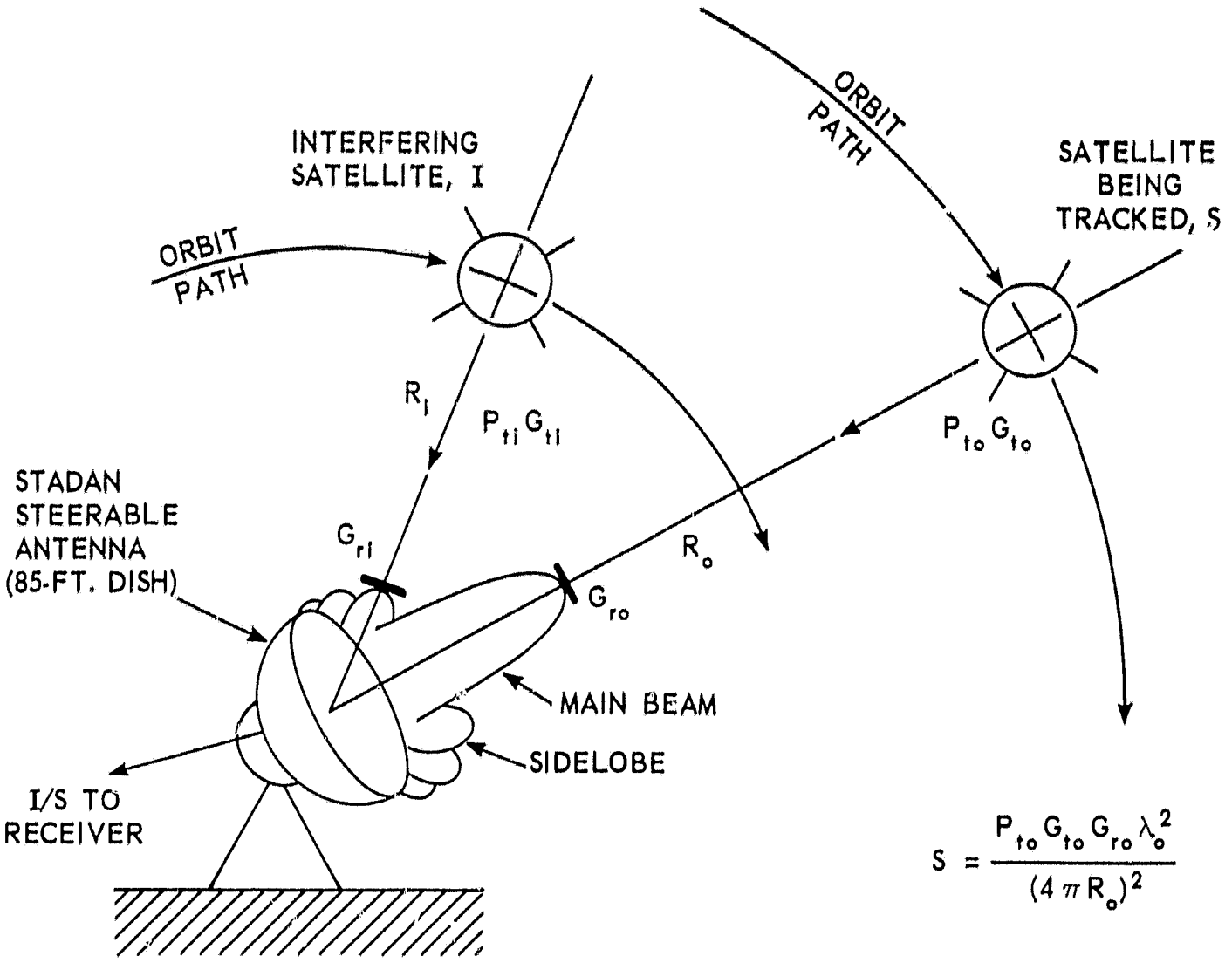


Figure 1. Radio Link Parameters for RFI Prediction Program

The computer flow diagram, for the S/C prediction model, is shown in Figure 2. Also shown is a proposed interfacing of the RFI model into an operational system within the T&DS Directorate. The RFI prediction printout time points occur at two minute intervals. The I/S ratios, values of I and S, are simultaneously printed and identified, for each S/C, for each time reading.

Prior to computing the I/S ratio, a S/C visibility search sub-routine eliminates S/C below a minimum restricted elevation angle (i.e. 10 degrees and below), and a frequency search is made based on the criterion:

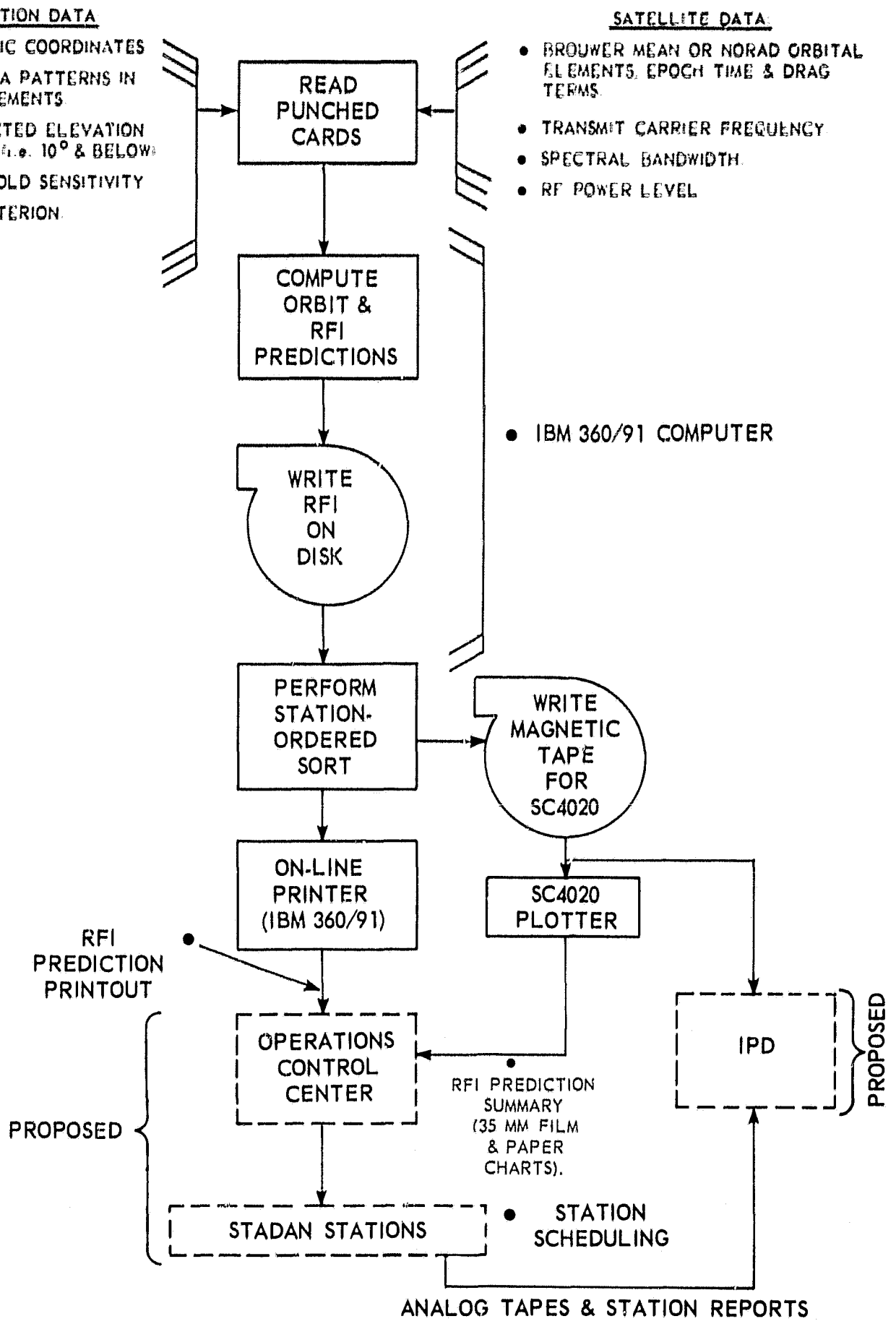


Figure 2. Flow Diagram, Satellite Interference Prediction Computer Program

$$|f_c - f_i| \leq \frac{B_o}{2} + \frac{B_i}{2} \qquad (2)$$

The bandwidths, B_o and B_i, are the emitted spectral bandwidths of the respective tracking and interfering S/C; whereas, f_o and f_i are the respective carrier center frequencies. An ideal, uniformly flat, emitted spectral bandwidth is assumed to simplify computations; the spectrum is assumed symmetrically centered about the carrier frequency.

The computed signal levels are compared to the station's receiver threshold sensitivity to eliminate weak signals, below threshold, from the printout.

III. STADAN REPORTING OF RFI

The Project Operation Support Division (POSD) schedules the STADAN recording of satellite passes, regardless of possible S/C RFI, with the intent of providing all available data to the satellite projects. The stations, while recording the telemetry data, simultaneously monitor the received power level and recorded data and submit daily reports of any S/C RFI or atmospheric disturbance observed during the pass. The S/C type RFI is identified wherever possible and confirmed with the control centers. This information is forwarded to various groups within Goddard.

Daily and weekly reports are prepared on all types of STADAN interference; these reports being prepared from the individual STADAN-station teletype messages. Figure 3 summarizes by spacecraft and for the months of January, February, and March of 1969, all S/C RFI reported by STADAN. There are approximately 20,000 satellite passes scheduled per month with approximately 250 passes/month showing reported S/C RFI; hence, approximately 1.3% of the passes were affected by S/C RFI. Of the reported S/C RFI events from Figure 3, 48% of the events were reported for only four out of the forty-two spacecrafts. They are: AIMP-E, ERS-28, IMP-4, and OSO-5.

A total of 751 S/C RFI events were reported for the 3 month period; each S/C RFI event lasting from 2 minutes to 1 hour depending upon the type spacecraft and a given pass. Of the S/C RFI events which were greater than 10 minutes, the average interfering time was 19 minutes; of those which were less than 10 minutes, the average interfering time was 4.6 minutes. The high-orbit spacecraft, due to increased viewing time, account for a larger percentage of S/C RFI compared to near-earth satellites with shorter viewing times.

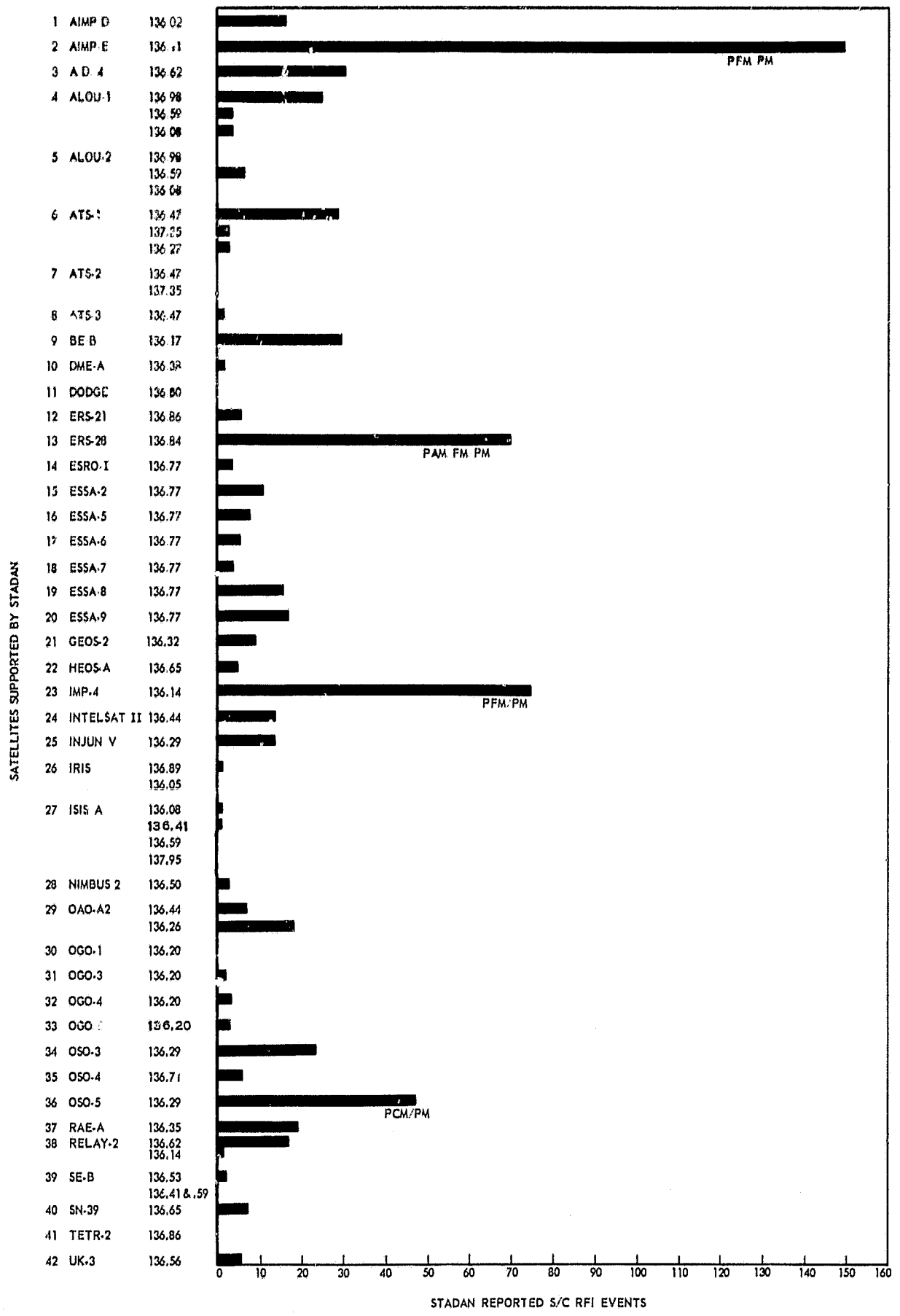


Figure 3. STADAN Reported S/C RFI Events for the First Quarter of CY-1969 in the 136 MHz Band (751 S/C RFI Events Reported)

IV. IPD EVALUATION OF RFI

The analog tapes recorded by STADAN are mailed to the IPD and generally processed by orbit groups in a chronological order. Those passes which fail to meet established criteria are investigated for anomalies such as those reported by STADAN in the analog tape logs, pass summaries, and daily station reports. In some cases when the degraded data are unaccountable, the analog tapes are reprocessed. The IPD determines what data are useable from the orbit groups to meet the project needs. The ADD is presently developing a system for flagging and identifying potential RFI passes for possible IPD correlation with data quality and data recovery results (Reference 3).

For a more detailed analysis of signal anomalies, strip chart analysis is often performed such as shown on Figure 4 for PFM data. This analysis gives a visual indication of any burst-type noise which could appear in a degraded pass. A S/C RFI unique noise-strip-chart characteristic can be identified.

Each reported and observed S/C RFI event was strip charted and presented in Section V. Also, each analog tape was processed on the IMP-F analog-digital (A/D) processing line using a special program to examine each recovered data point. The data processor contains a bank of correlators, and matched filters, whose peak output voltage is measured and stored at the end of each PFM frequency burst. At the end of each sequence of data, approximately 20.5 seconds or 496 data points, the mean and standard deviation of the detected correlation output(s) were computed and plotted as a function of time during the S/C RFI intervals alongside the PFM strip charts. The ratio of the mean to the standard deviation per sequence (which is the output signal-to-noise (S/N) power ratio) is proportional to the input S/N power ratio. The performance characteristic curve, generated with gaussian additive band-limited white noise, for the IMP-F line of probability of word error versus S/N input, was used to generate the calibration curve shown on Figure 5 used in the analysis.

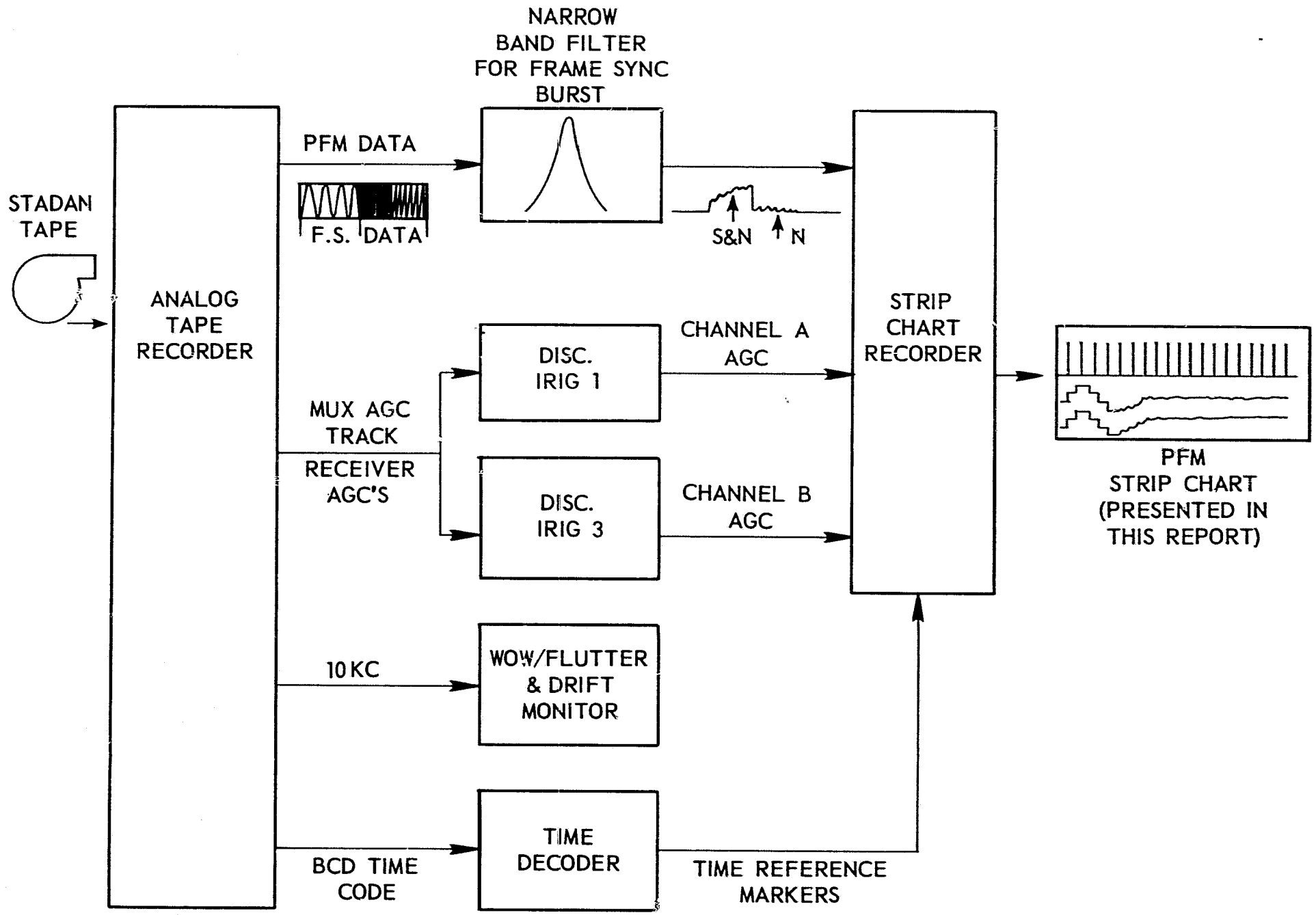


Figure 4. The IPD Tape Evaluation PFM Strip Chart Analysis

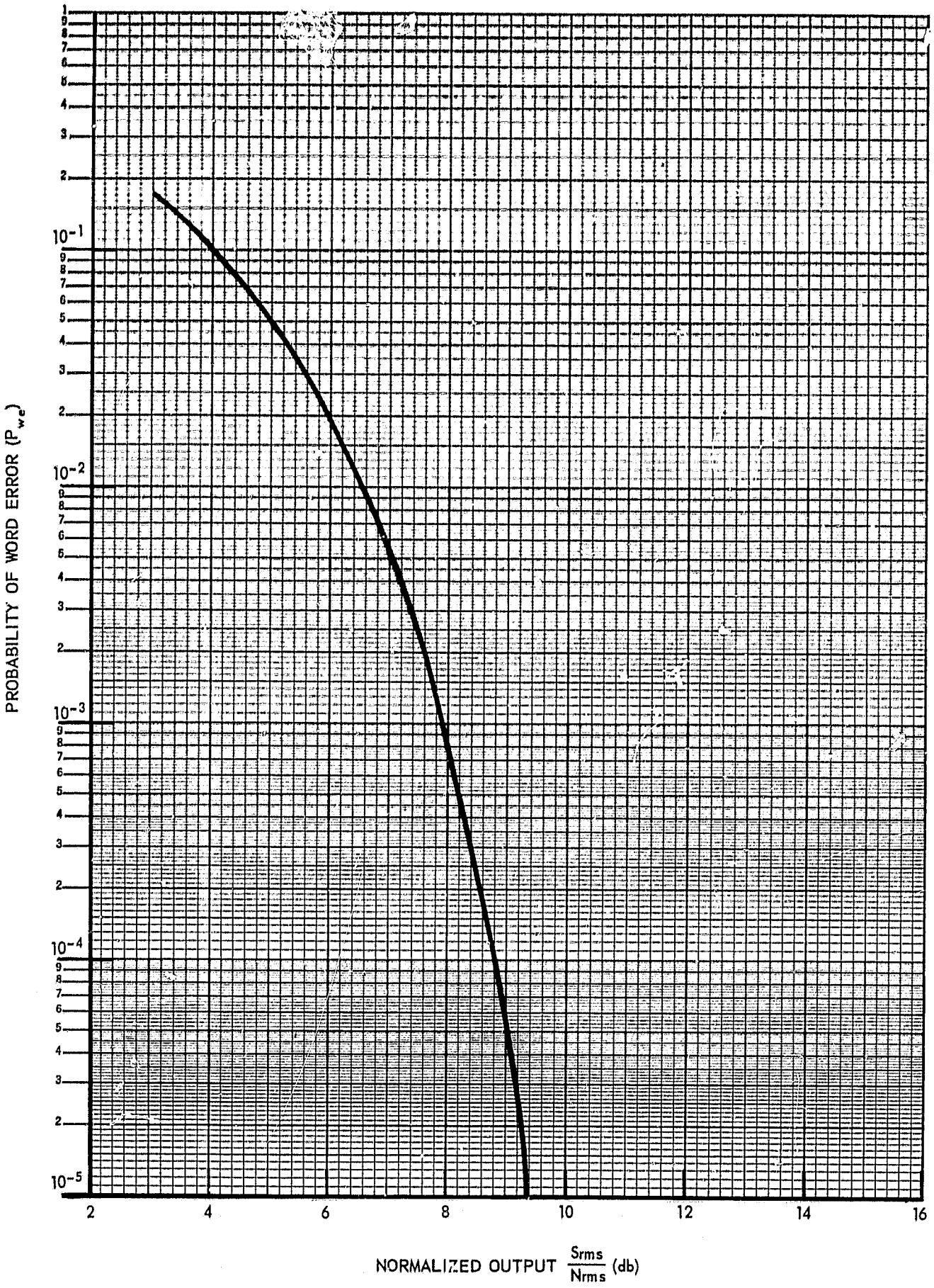


Figure 5. Calibration Curve for IMP-F PFM Data Quality

V. CORRELATION OF PREDICTED, REPORTED, AND ACTUAL RFI

A three day period of IMP-F(4) spacecraft PFM telemetry data was randomly selected covering November 8, 9, and 10, 1968. The station reports were examined for possible S/C RFI in conjunction with the IPD processed files which were below the data processing criteria. A total of ten analog tapes, out of the 3-day period, were found in the IPD to have S/C RFI unique noise characteristics. These observed time intervals, along with the STADAN reported time intervals, were used in the RFI program. The S/C RFI interference-to-signal (I/S) ratios were computed and plotted with the IPD results. The ten tapes were reprocessed through the IMP-F data processing line and a distribution plot of the data quality indices per sequence was determined (see Appendix A). Also, a strip chart analysis was made for each tape in the IPD tape evaluation facility. The reported, predicted, and actual S/C RFI time intervals were then selected, consolidated, and presented on Figures 6 through 15.

The first S/C RFI tape sample is shown on Figure 6. The top curve represents the ADD predicted S/C RFI interval and the I/S ratios. Immediately below the predicted S/C RFI is the actual data quality indices of the recovered S/C RFI data. Those regions where the data quality points are not available is indicative of either no data available from the demodulator at the station or severe S/N due to S/C RFI; this results in complete loss of data. The dashed horizontal line represents the mean output data quality throughout the remainder of the analog tape excluding the S/C RFI interval. Note on Figure 6 that the S/C RFI prediction started approximately four minutes after the actual S/C RFI; the predicted curve probably being truncated by the 10° elevation angle cutoff criteria. However, the interference level was sufficiently high, during the 4-minute interval, to cause data loss.

The bottom half of Figure 6 contains a strip chart analysis of the compressed frame sync pulse along with the noise passing through the frame sync filter. Also shown are the two channels of the STADAN receiver AGC recordings.

The tape evaluation label contains information pertaining to the station pass taken from the magnetic tape log. The maximum AGC readings, both station reported and ADD predicted, are shown on the label. In most of the ten analog tapes, the predicted received signal strength was within four decibels of the STADAN measured value; closer agreement should result when the spacecraft antenna radiation pattern model is included in the ADD prediction program.

The remaining figures (7 through 15) contain the other nine S/C RFI samples analyzed in this report.

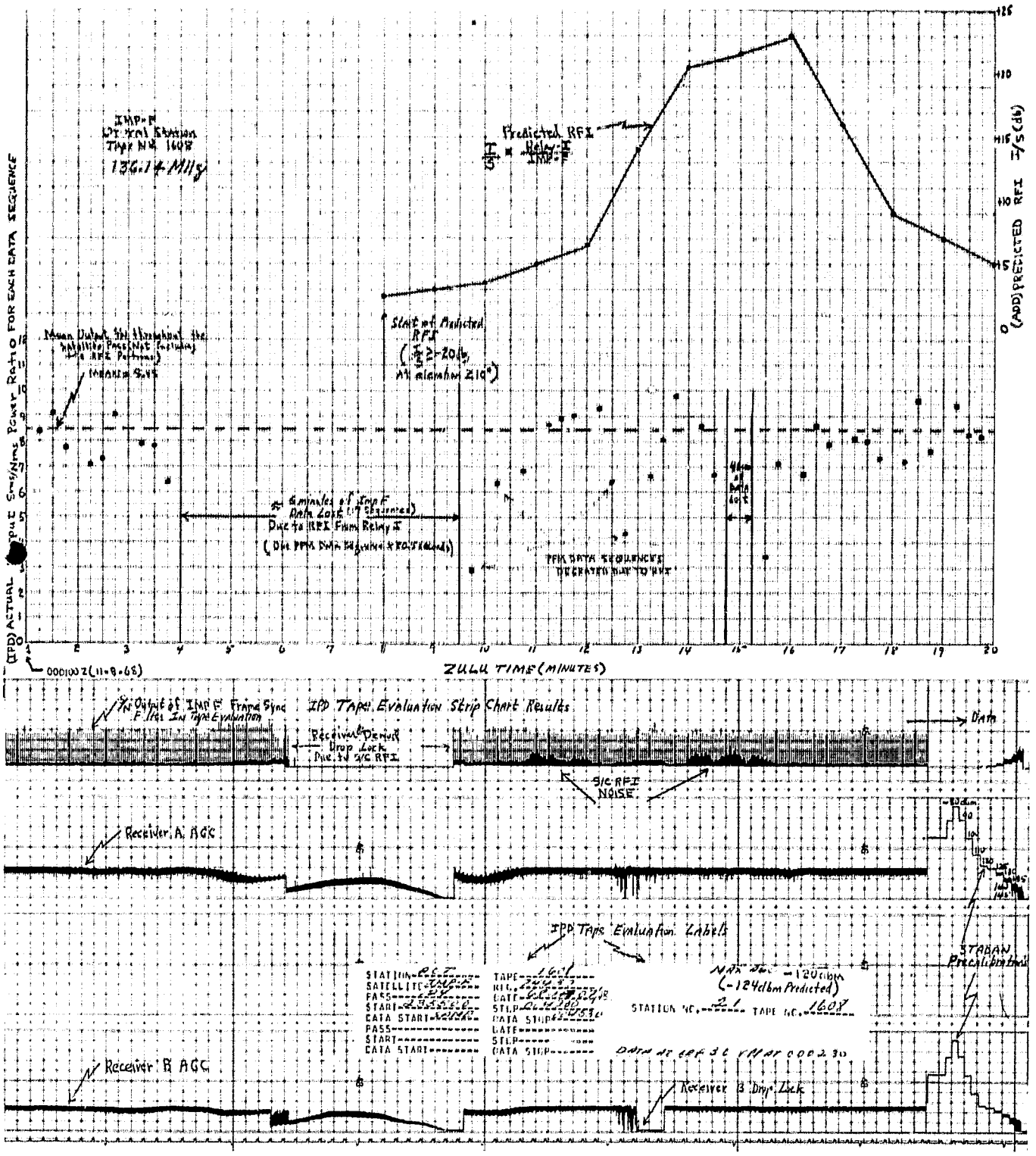
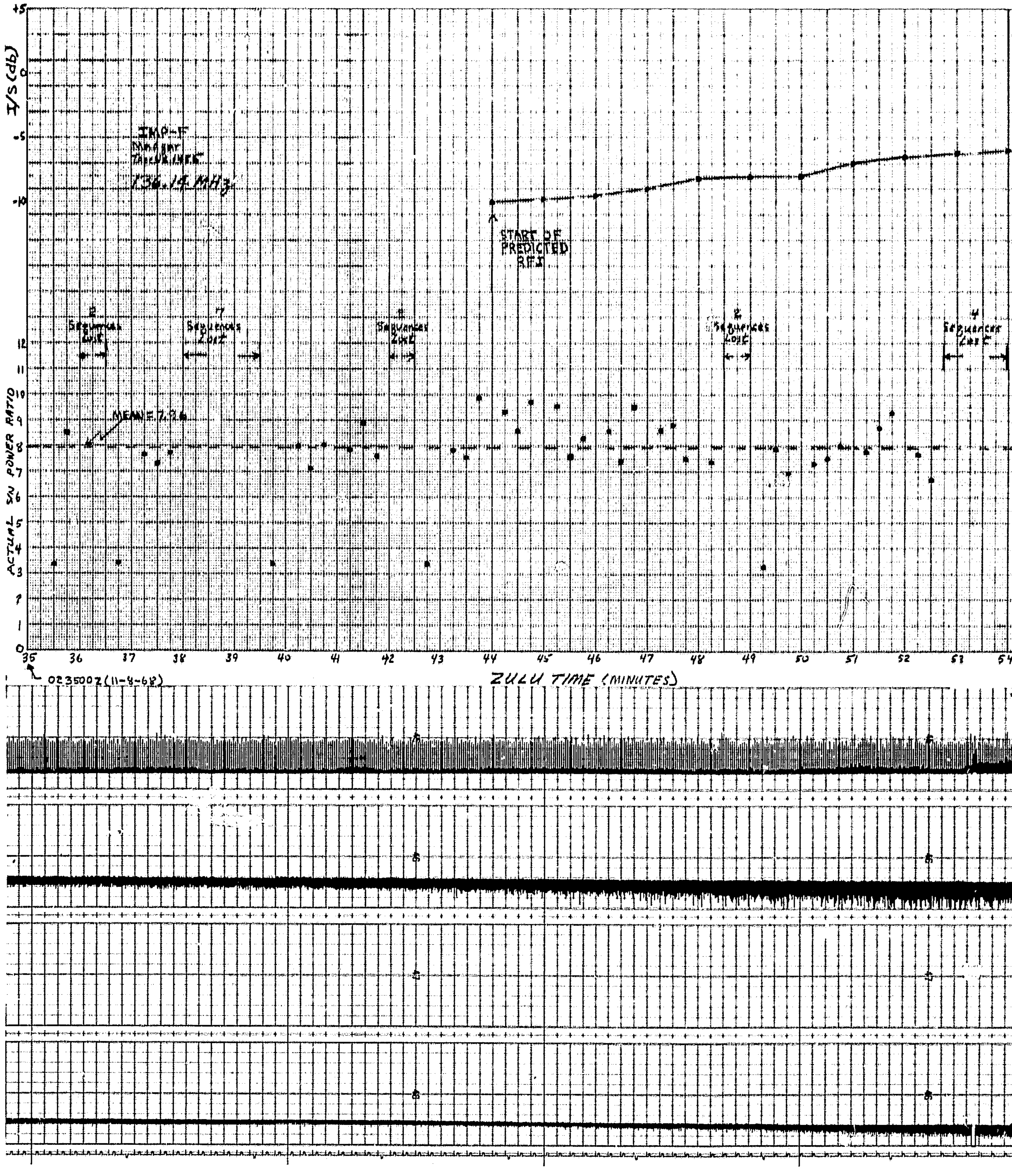


Figure 6. ADD Predicted RFI & IPD Actual Output S/N and Tape Evaluation Results (IMPF, Ororal, Tape No. 1608)



I/S (db)
IMP-F
136.14 MHz
START OF PREDICTED RFI
2 Sequences Lost
7 Sequences Lost
Sequences Lost
2 Sequences Lost
4 Sequences Lost
MEAN = 7.96
ACTUAL S/N POWER RATIO
023500Z (11-8-68)
ZULU TIME (MINUTES)

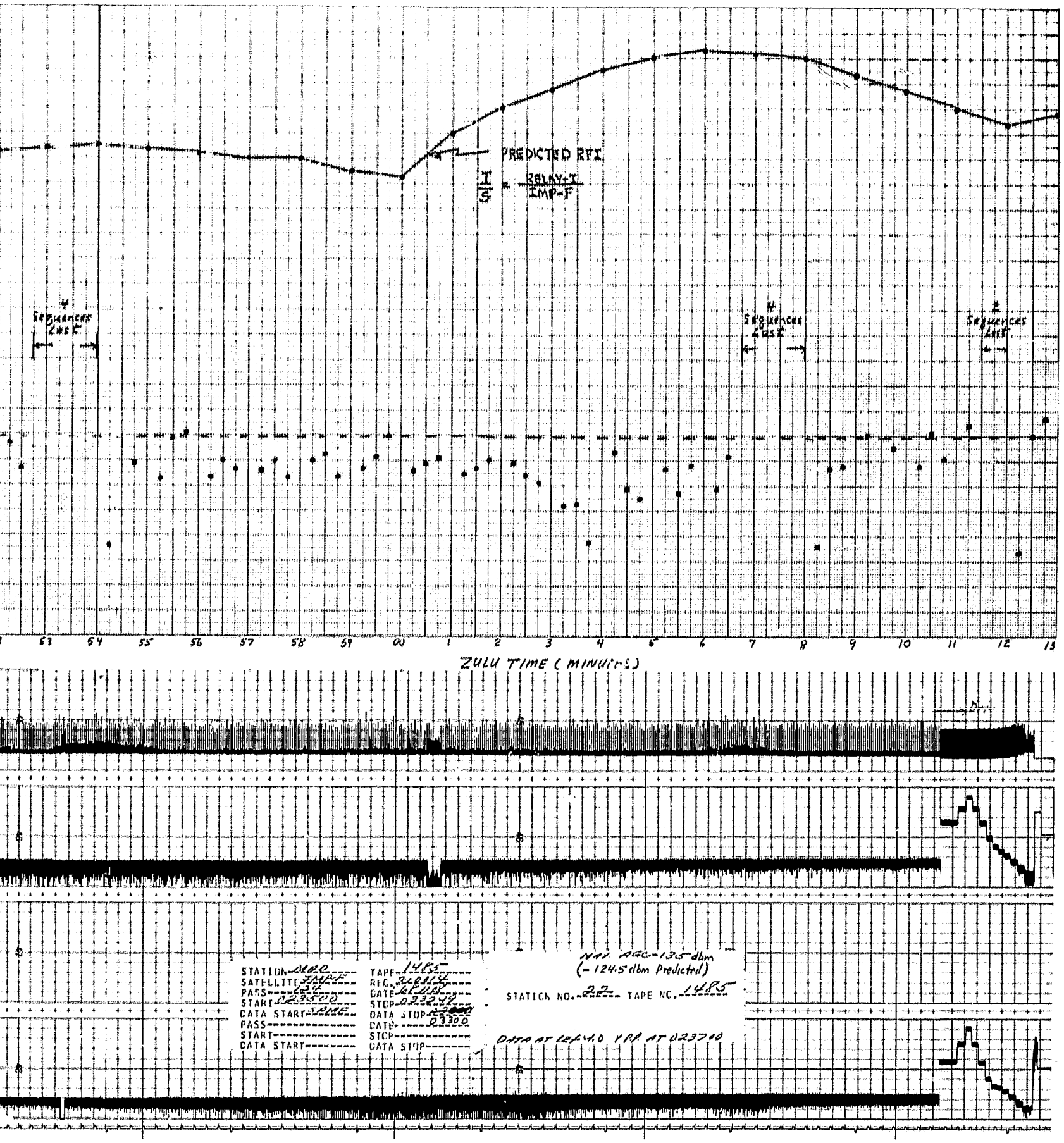


Figure 7. ADD Predicted RFI & IPD Actual Output S/N and Tape Evaluation Results
(IMP F, Madgar, Tape No. 1485)

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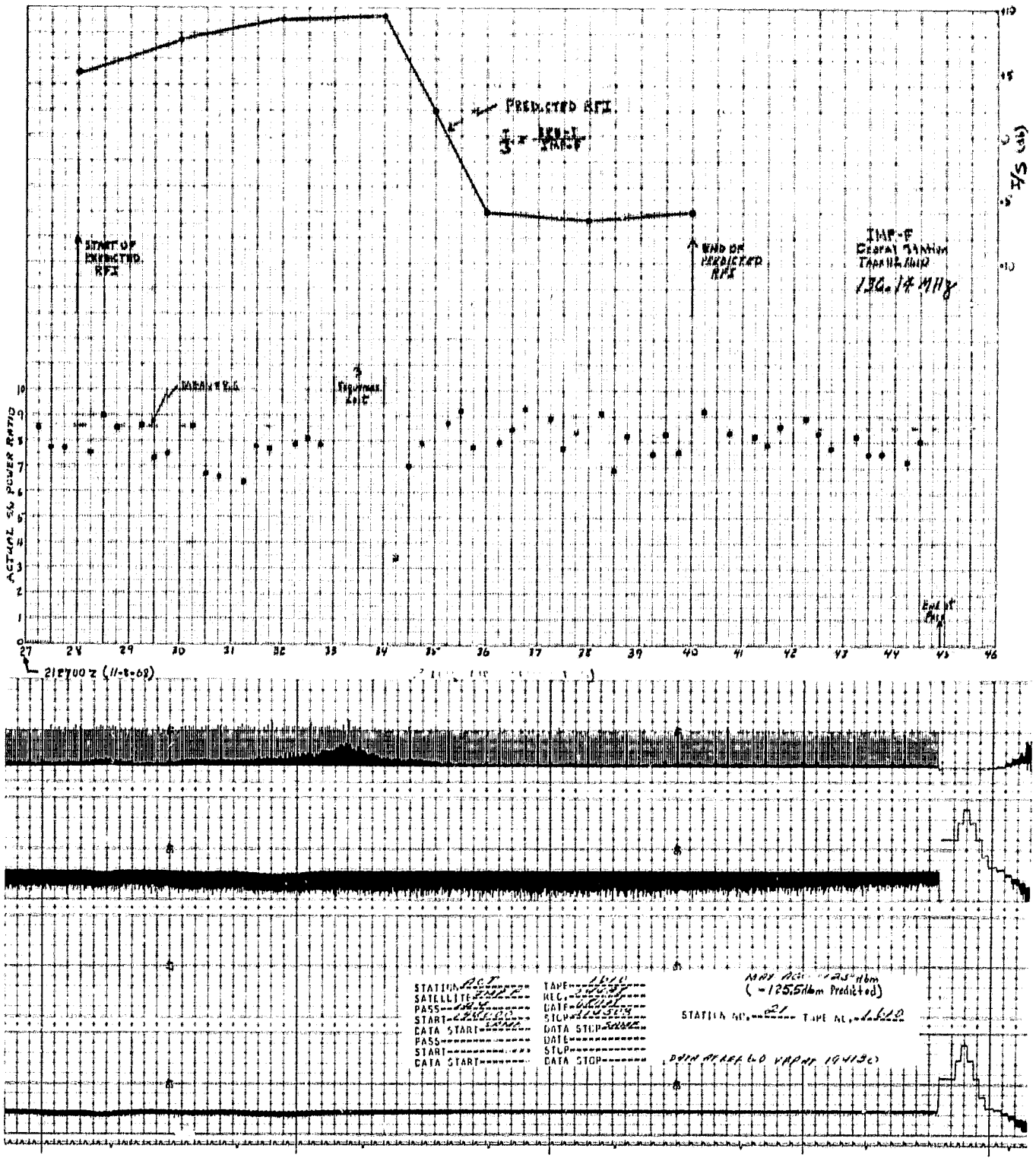


Figure 8. ADD Predicted RFI & IPD Actual Output S/N and Tape Evaluation Results (IMP F, Ororal, Tape No. 1610)

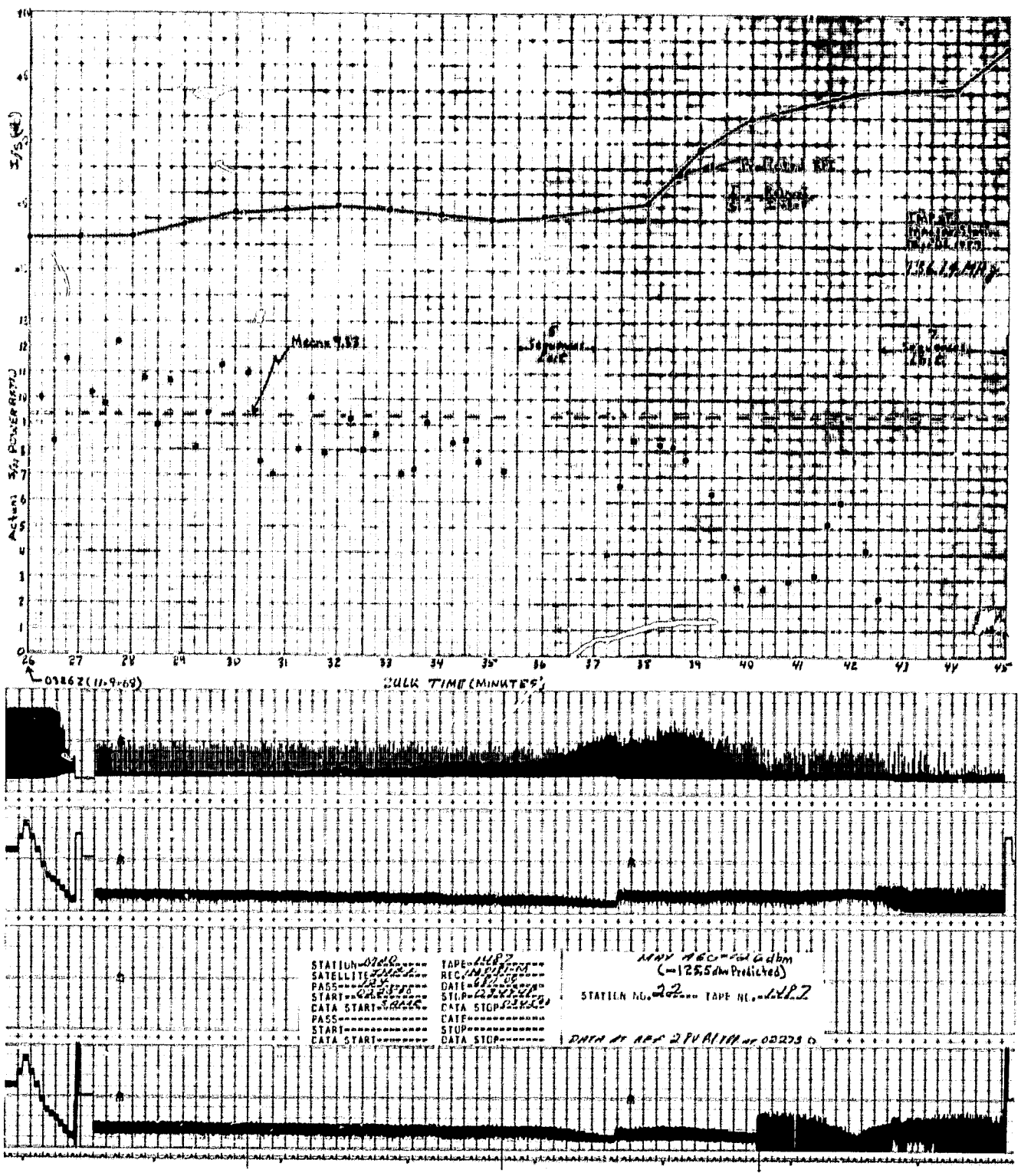


Figure 9. ADD Predicted RFI & IPD Actual Output S/N and Tape Evaluation Results
(IMP F Madgar, Tape No. 1487)

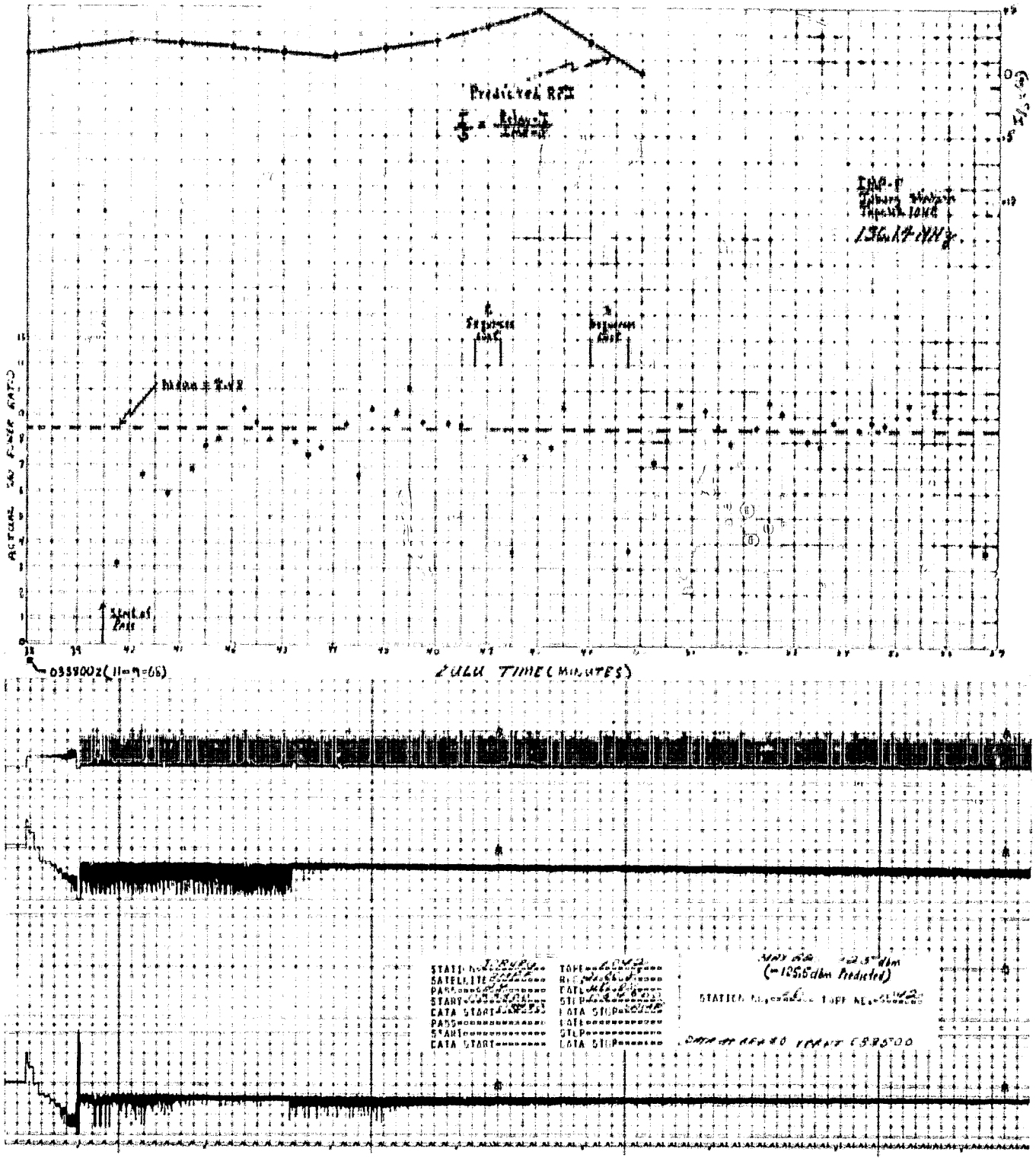


Figure 10. ADD Predicted RFI & IPD Actual Output S/N and Tape Evaluation Results (IMP F, Joburg, Tape No. 1042)

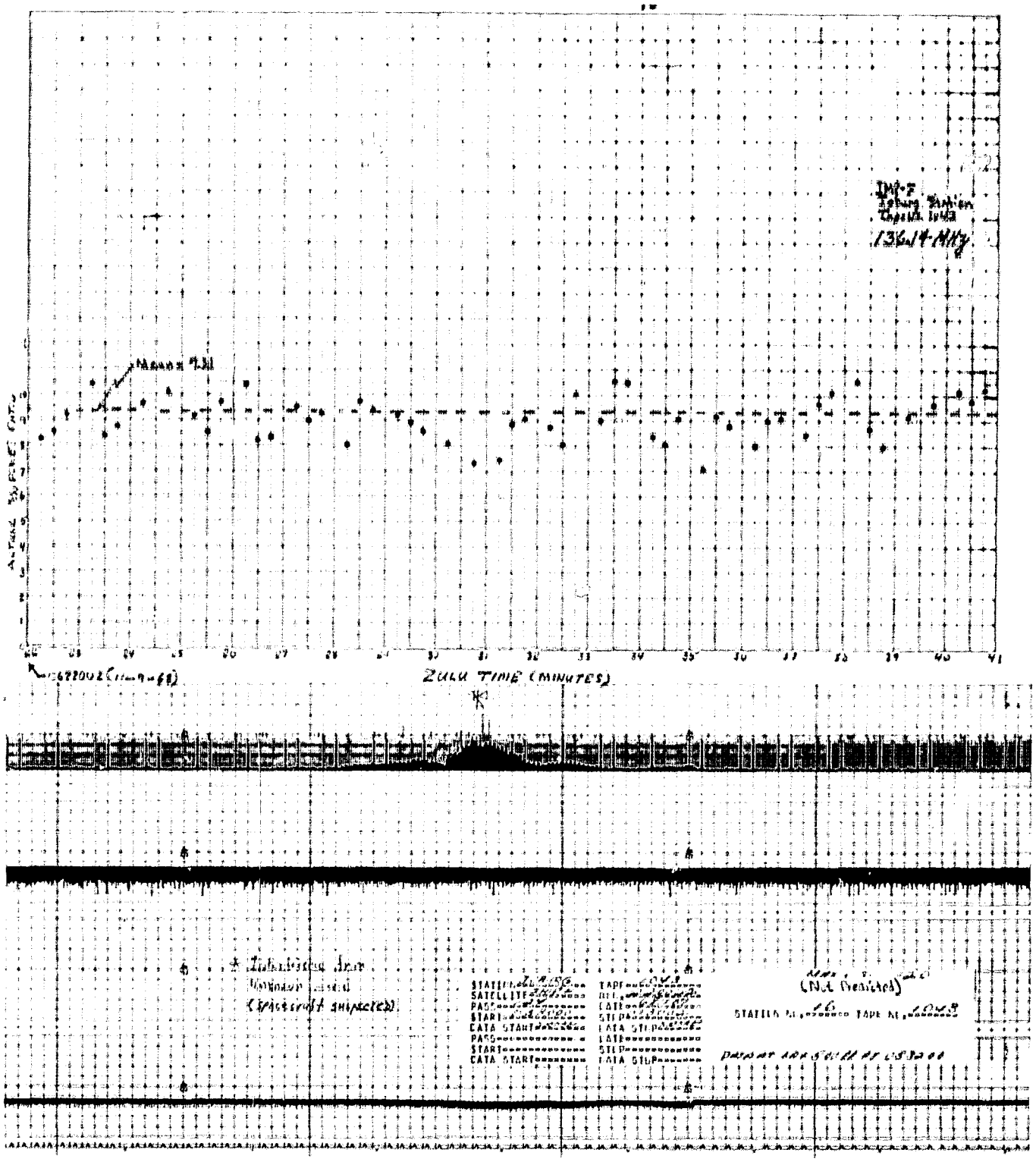


Figure 11. ADD Predicted RFI & IPD Actual Output S/N and Tape Evaluation Results (IMP F, Joburg, Tape No. 1043)

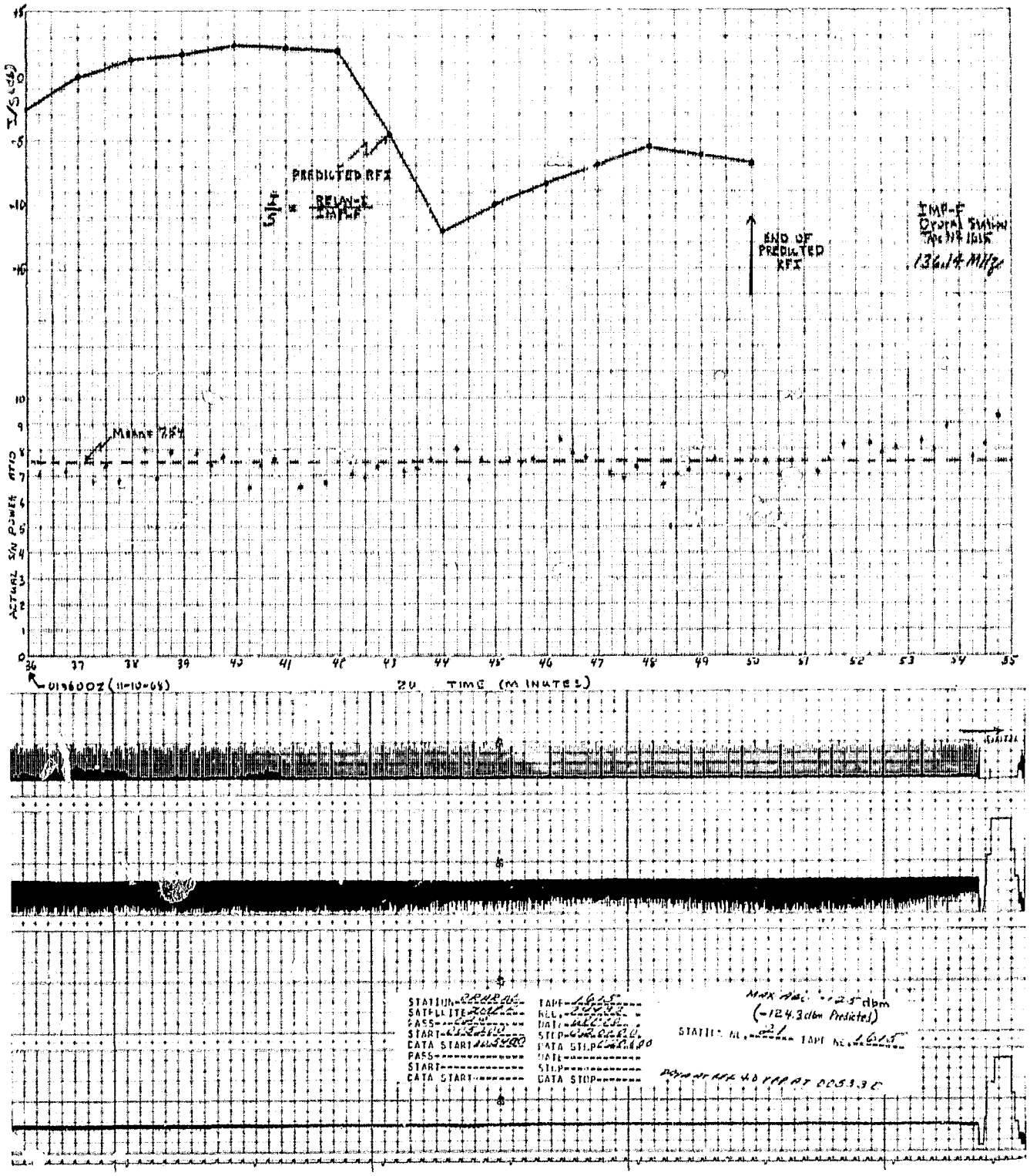
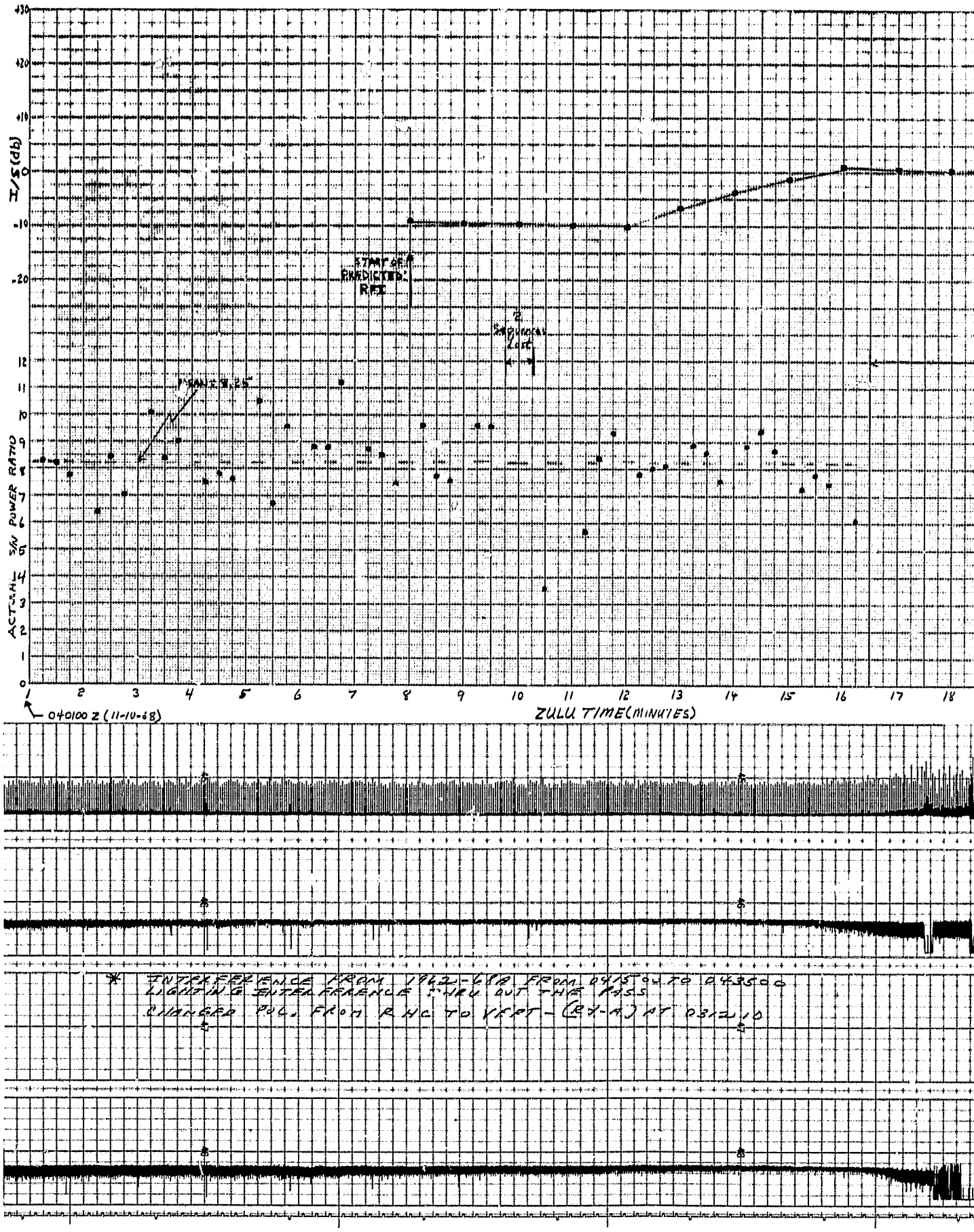


Figure 12. ADD Predicted RFI & IPD Actual Output S/N and Tape Evaluation Results (IMP F, Ororal, Tape No. 1615)


I/S (db)
+30
+20
+10
0
-10
-20
S/N POWER RATIO
ACTUAL
12
11
10
9
8
7
6
5
4
3
2
1
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
ZULU TIME (MINUTES)
040100 Z (11-10-68)
PREDICTED RFI
INTERFERENCE FROM 1982-6PB FROM 0415 TO 0435
LIGHTNING INTERFERENCE THRU OUT THIS PASS
CHANGED POL. FROM RHC TO VERT-(RX-A) AT 0312.10

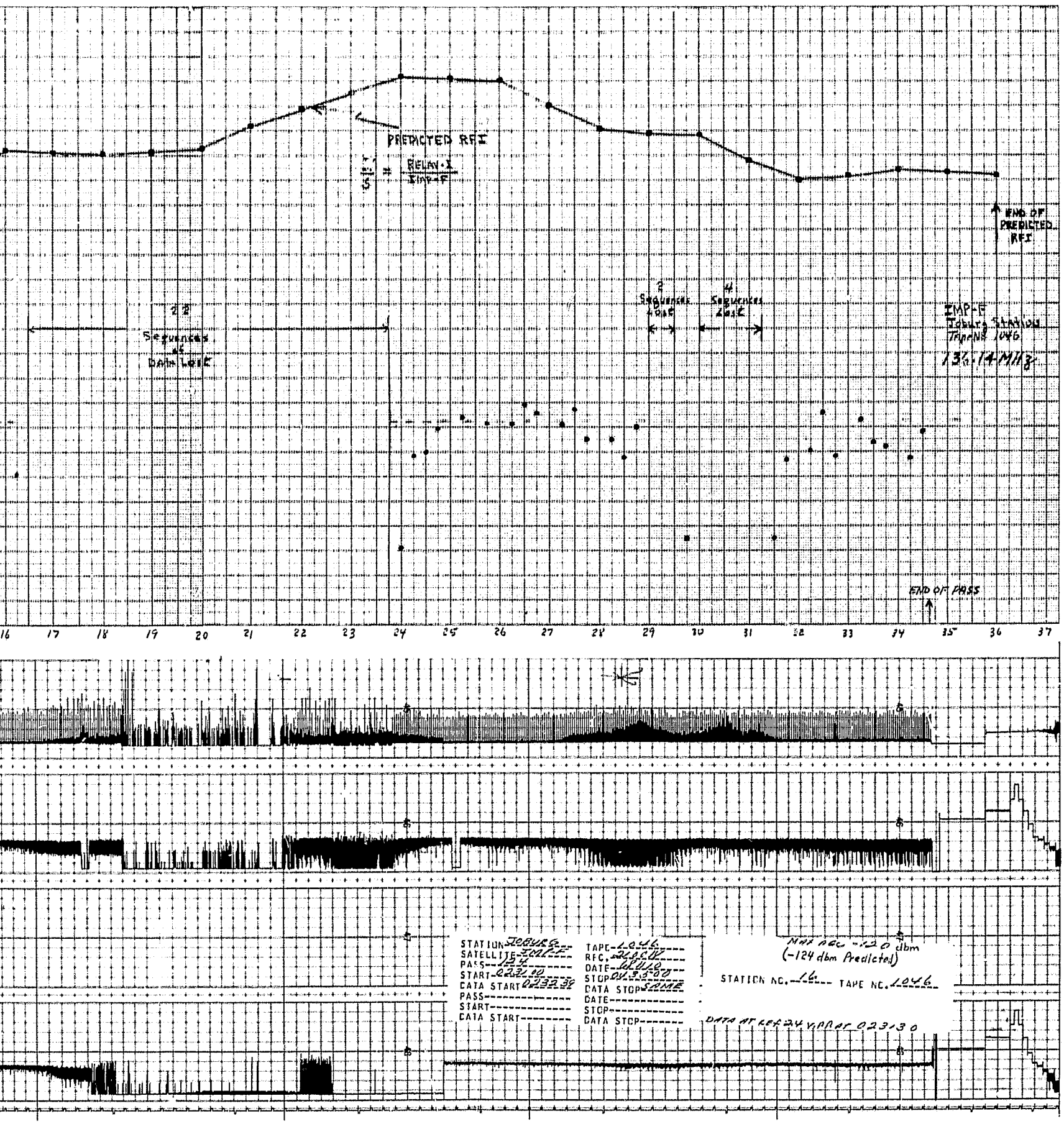
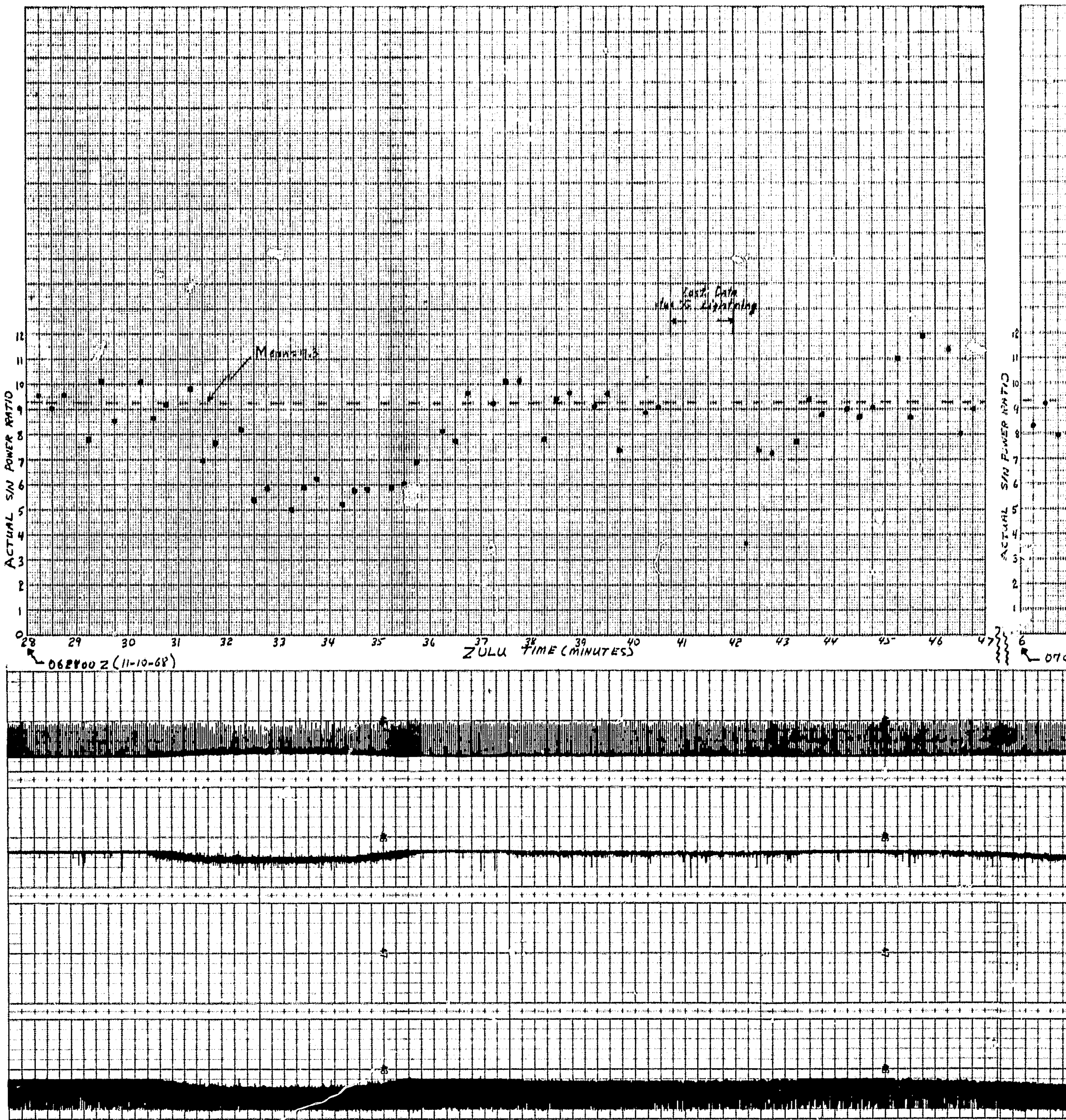


Figure 13. ADD Predicted RFI & IPD Actual Output S/N and Tape Evaluation Results (IMP F, Joburg, Tape No. 1046)


ACTUAL S/N POWER RATIO
0
1
2
3
4
5
6
7
8
9
10
11
12
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
ZULU TIME (MINUTES)
062800 Z (11-10-68)

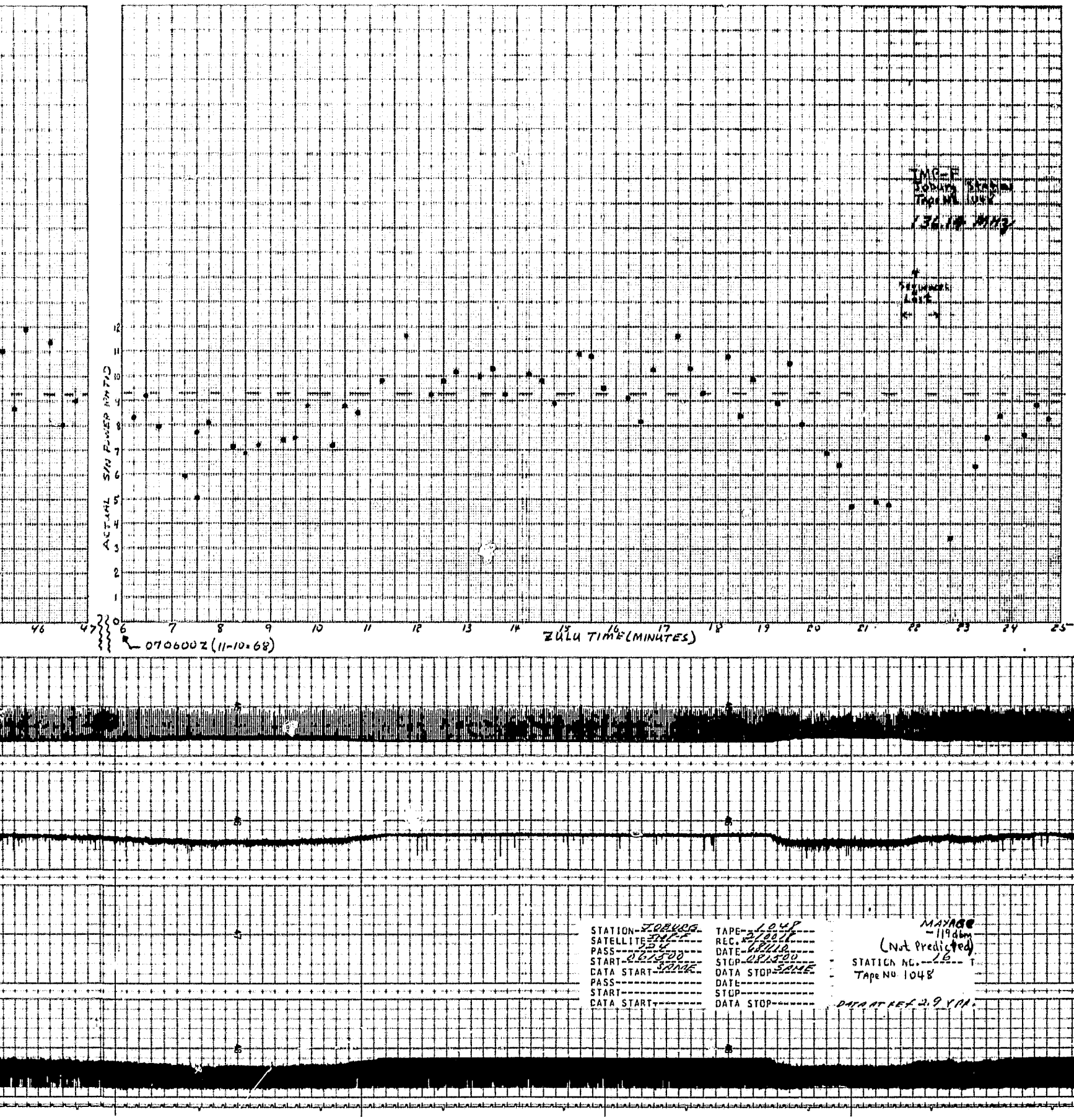


Figure 14. ADD Predicted RFI & IPD Actual Output S/N and Tape Evaluation Results (IMP F, Joburg, Tape No. 1048)

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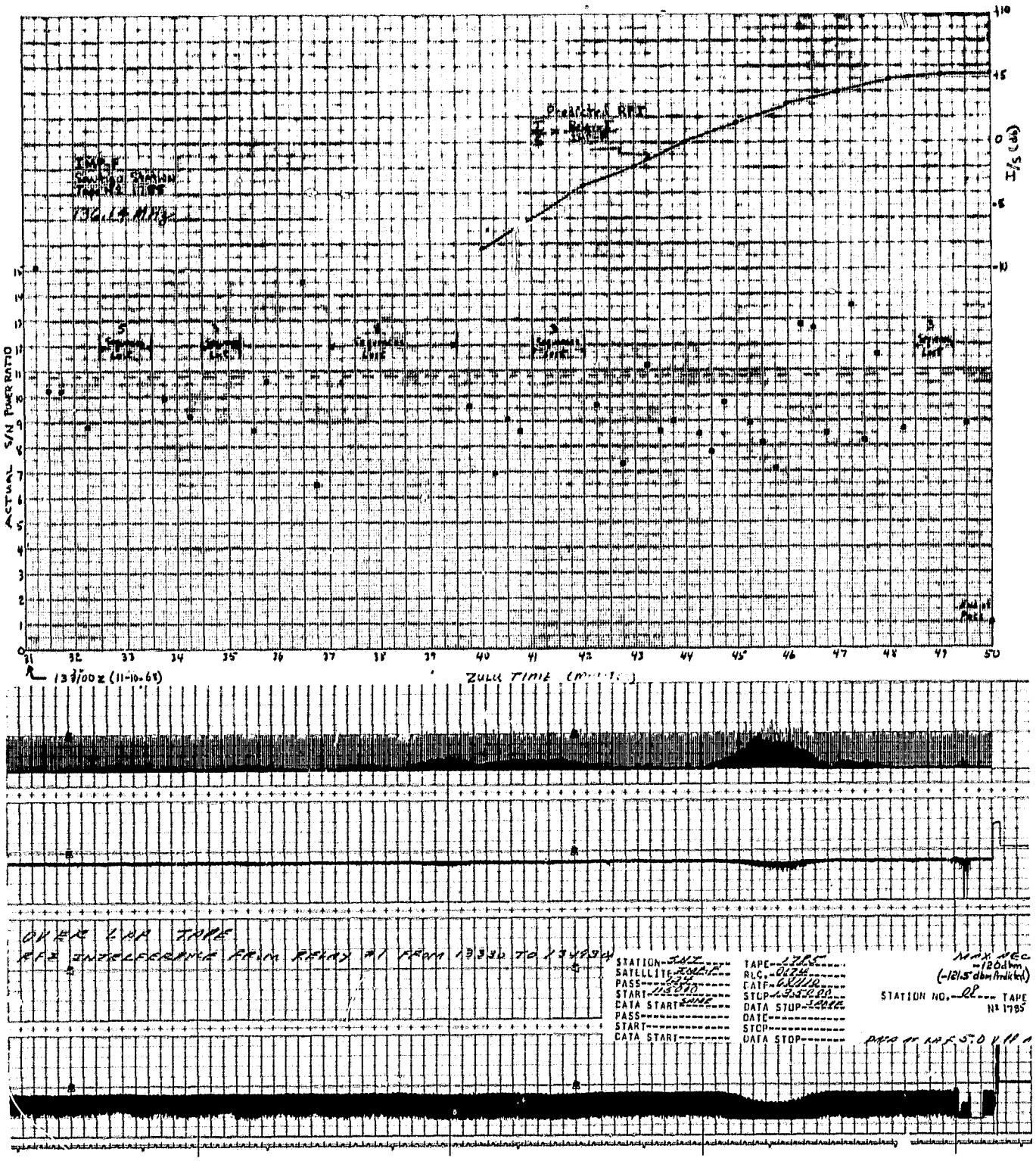

Figure 15. ADD Predicted RFI & IPD Actual Output S/N and Tape Evaluation Results
(IMP F, Santigo, Tape No. 1785)

VI. SUMMARY

Table 1 summarizes the ADD predicted, STADAN reported, and the IPD actual S/C RFI for the ten analog station tapes investigated for the IMP-F spacecraft.

The STADAN stations' RFI suspected spacecraft and RFI observed intervals, extracted from the STADAN daily reports, are shown under the column labeled STADAN. The asterisk next to the suspected spacecraft indicates that this S/C RFI event was also reported on the magnetic tape log. For the ten analog tapes (containing 13 S/C RFI events observed by the IPD), nine events were reported in the STADAN daily reports and only five were reported on the magnetic tape logs. Two of the S/C RFI events reported by STADAN were indicated as "unknown"; nine out of the ten analog tapes were reported as having S/C RFI.

The columns labeled IPD Observed contain the observed start/stop S/C RFI intervals.

The columns labeled ADD Predicted indicate the predicted start/stop S/C RFI interference interval, the interfering S/C; the worst case I/S ratio and the time of occurrence is also presented. Note that nine out of the 13 IPD-observed S/C RFI events (eight out of ten analog tapes or passes), were predicted with good accuracy.

The authors believe that the S/C RFI not predicted (but observed) in this report, for the two Joburg analog tapes, could have been caused by the AIMP-E spacecraft which is not in the present S/C RFI prediction program.

No attempt was made to compute the correlation coefficients of this evaluation since non-discrete samples exist along with discontinuous samples due to areas of complete data drop outs.

Table 2 summarizes the actual RFI results examined in the three day interval for the IMP-F satellite. The pass duration was determined from the tape log start/stop times and verified with the actual start/stop times from the IMP-F processing line. Each tape was run using a special program which examines the average data quality indices per sequence and the distribution of the S/N output plotted in Appendix A. The mean S/N output of each tape (not including the "wild" readings which were mainly caused by the RFI) was calibrated and the error rate determined and indicated in Table 2. The mean from the distribution plots yields the average data quality throughout the tape and establishes a reference by which an average data quality degradation indicator for the RFI recovered data can be

Table 1

The ADD Predicted, STADAN Reported, and the IPD Actual S/C RFI from 11/8/68 to 11/10/68 Inclusive for the IMP-F Spacecraft

STADAN Reported (Daily Station Reports)					IPD Observed		ADD Predicted				
STADAN Station	Date	Start	Stop	Suspected S/C	Start	Stop	Start	Stop	Interfering S/C	Worst I/S(db)	Time
1. Ororal	11/8/68	0004Z	0021Z	Relay-1*	0004Z	0016Z	0008Z	0028Z	Relay-1	+23.1	0016Z
2. Madgar	11/8/68	— Not Reported —			0250Z	0315Z	0244Z	0313Z	Relay-1	+ 1.8	0306Z
3. Ororal	11/8/68	2123Z	2134Z	Relay-1	2128Z	2135Z	2128Z	2140Z	BE-B	+ 9.7	2134Z
4. Madgar	11/9/68	0315Z	0345Z	Unknown*	0317Z	0326Z	0306Z	0314Z	Alou-1	+11.9	0314Z
					0331Z	0345Z	0324Z	0400Z	Relay-1	+11.0	0348Z
5. Joburg	11/9/68	0340Z	0350Z	Relay-1	0339Z	0350Z	0332Z	0350Z	Relay-1	+ 4.7	0344Z
6. Joburg	11/9/68	0631Z	0636Z	Unknown*	0628Z	0635Z	— Not Predicted —				
7. Ororal	11/10/68	0124Z	0137Z	Relay 1, 2 AIMP-E, BE-B ESRO I	0136Z	0141Z	0134Z	0150Z	Relay-1	+ 2.2	0140Z
8. Joburg	11/10/68	0415Z	0435Z	Relay-1*	0416Z	0435Z	0408Z	0436Z	Relay-1	+15.9	0424Z
9. Joburg	11/10/68	0629Z	0634Z	Relay 1 & 2	0630Z	0636Z	— Not Predicted —				
				AIMP-E, BE-B	0706Z	0712Z	— Not Predicted —				
				ESRO I	0719Z	0724Z	— Not Predicted —				
10. Sntigo	11/10/68	1332Z	1349Z	Relay-1*	1331Z	1350Z	1340Z	1402Z	Relay-1	+ 5.7	1350Z

*S/C RFI Event Reported on Magnetic Tape Logs

Table 2

Tabulation of the IPD RFI Results for the IMRF Satellite from 11/8/68 to 11/10/68

IMP-F Tape Examined			Average Data Quality of the Pass*		Total RFI Observed				Average Degradation in Data Quality of the Recovered RFI Data			
Station Name	Tape Number	Pass Duration (Minutes)	db	P_{WE}	Total Time (Minutes)	Sequences Lost	Time Lost	% Data Lost Per Pass	db	P_{WE}	Time Duration (Minutes)	% Time Per Pass
Ororal	1608	50.5	9.1	4×10^{-5}	12.0	19	6.3	12.5	3.6	3×10^{-2}	5.7	11.3
Madgar	1485	57.8	9.0	6×10^{-5}	29.0	12	4.0	6.9	3.5	3.2×10^{-2}	25.0	43.2
Ororal	1610	125	9.3	1×10^{-5}	7.0	3	1.0	0.8	3.8	3.0×10^{-2}	6.0	4.8
Madgar	1487	80.0	9.6	1×10^{-6}	23.0	12	4.0	5.0	5.0	1×10^{-2}	19.0	23.7
Joburg	1042	120.5	9.1	4×10^{-5}	11.0	5	1.7	1.41	3.7	3.5×10^{-2}	10.3	8.32
Joburg	1043	120.0	9.7	1×10^{-6}	7.0	0	0	0	3.2	1×10^{-3}	2.0	0.166
Ororal	1615	61.8	8.7	1.3×10^{-4}	5.0	0	0	0	3.0	1.3×10^{-4}	0	0
Joburg	1046	62.3	9.1	4×10^{-5}	19.0	28	9.3	14.7	3.7	3.5×10^{-2}	9.7	15.6
Joburg	1048	120.0	9.6	1×10^{-6}	17.0	4	1.3	1.08	2.6	1×10^{-3}	15.7	13.1
Santigo	1785	120.0	10.8	1×10^{-7}	19.0	22	7.3	6.1	2.0	1×10^{-5}	11.7	9.77
					Total = 149 min		Total = 34.9 min				Total = 95.4 min	

*Not including RFI

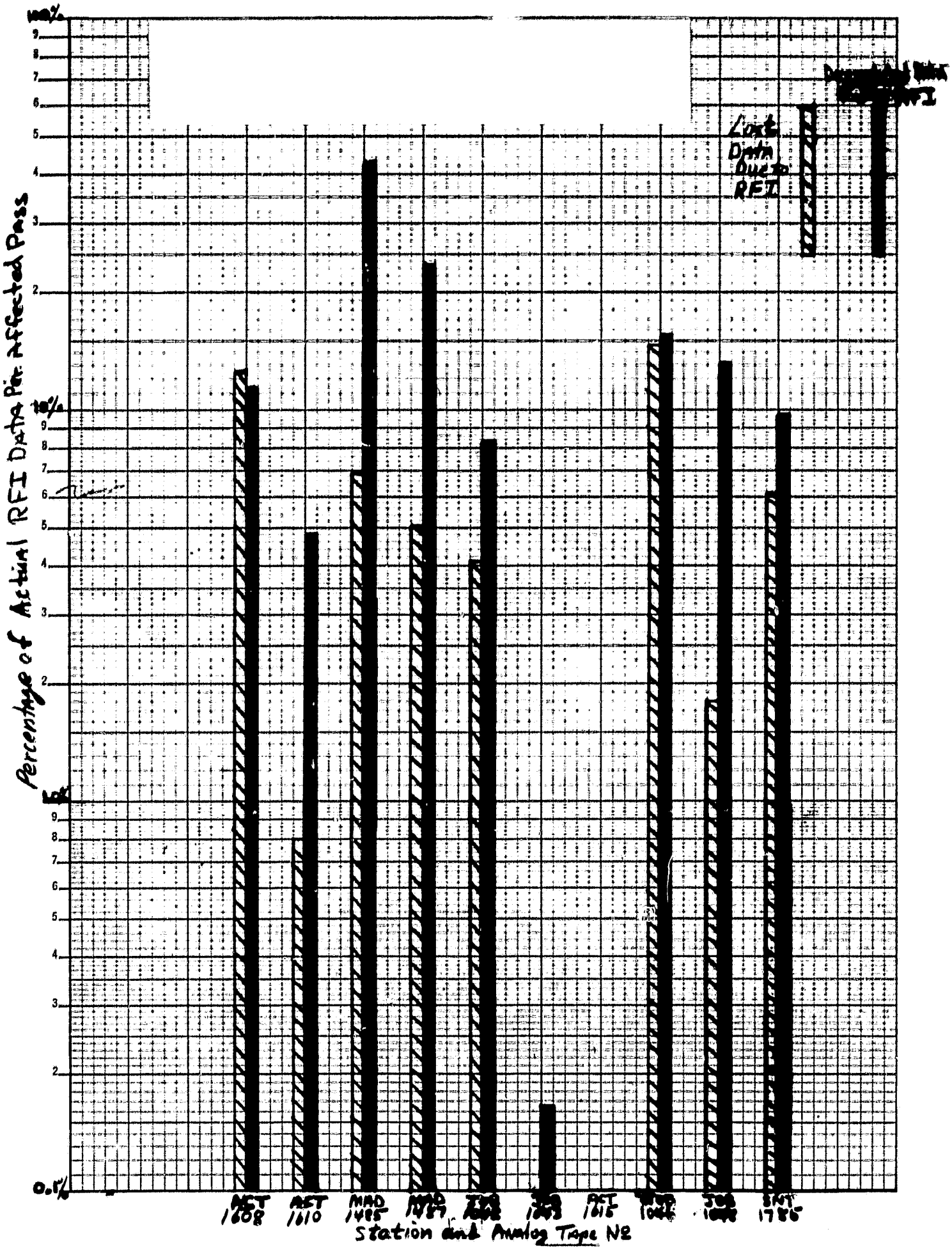

Figure 16. RFI Passes Observed by the IPD for the IMP-F Satellite from 11/8/68(0000Z) to 11/10/68(2400Z)

determined. This is also noted in Table 2. The mean degraded RFI region was computed using the distribution figures in Appendix A.

Figure 16 plots the percentage of loss data and degraded data during the RFI intervals within each of the processed analog tapes. Since the damples were taken over a three day period (4320 minutes), the percentage of RFI observed by IPD was 3.44%. However, 0.8% of the data was lost and 2.2% of the recovered RFI data was degraded on the average of approximately 3 db; 0.44% of the observed RFI data did not undergo any noticeable degradation.

The average duration of the actual S/C RFI for IMP-F is approximately 13 minutes. The average lost data interval is 3.5 minutes and the degraded interval is 9.5 minutes for the affected S/C RFI analog tapes.

The stations record approximately 1000 analog tapes for IMP-4 per three months; for the 76 reported S/C RFI, this results in 7.5% of the data tapes containing RFI. The three day sample in this report indicates that 10 analog tapes (out of a total of 40 tapes recorded) or 25% of the passes had S/C RFI. This is approximately 3 times higher than the 7.5% reported for the first quarter of 1969.

VII. CONCLUSIONS

A good correlation exists between the Advanced Development Division's satellite-to-satellite predicted radio frequency interference (S/C RFI), the STADAN-reported S/C RFI, and the Information Processing Division's actual data processing results. The IMP-F has been reported as being highly susceptible to S/C RFI. The results of this report indicate that at least 3% of the time the PFM telemetry data is affected by S/C RFI. The Relay I spacecraft appears to be the main interfering spacecraft for IMP-F.

The RFI prediction model could be a useful tool for the IPD in correlating low quality and low quantity of processed data. If the S/C RFI continues to increase in the future, consolidating the RFI model with station scheduling procedures could improve on the data recovery and data quality of the experimenters' data. If several alternate passes are available, the pass containing the least amount of S/C RFI is preferred.

The following statistics can be concluded from the results of this report:

- Station-reported S/C RFI is exceeding 1% for 40 STADAN-supported S/C (i.e., over 200 S/C RFI events/month out of 20,000 passes/month)

- 10% (i.e., 4 out of 40 supported S/C) receive 48% of S/C RFI during January, February, and March 1969. These are: AIMP-E (21%), IMP-4 (11%), ERS-28 (10%), and OSO-5 (6%), where approximate values are indicated.

- S/C RFI Data for IMP-4

  a. 0.8% of processed data are completely lost in digitization process.

  b. 2.2% of the processed data are degraded, on the average, by 3 db (i.e., bit error rate increases from 10^{-5} to 10^{-2}).

A near future task will be undertaken by the authors to perform a similar S/C RFI correlation using the OSO-5(F) spacecraft for pulse code modulation (PCM/PM).

ACKNOWLEDGEMENTS

The authors acknowledge the encouragement given by Mr. Robert Fitzgerald to have this RFI correlation study pursued. Mr. Lloyd Rhodes is recognized for his contribution in digitizing the analog tapes with a special analysis program to obtain the data quality indices. Mr. Wilfred Hillstrom is recognized for plotting the I/S ratios versus time in Appendix A; Mr. P. Ashcraft, University of Cincinnati coop student, is recognized for summarizing the STADAN RFI reports; Mr. M. L. Kaiser, Wolf Research and Development Corporation, provided Computer Programming and S/C RFI prediction printout tabulations on the ADD contract NAS 5-9756.

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2. Taylor, R. E., "Radio Frequency Interference Prediction Program for Earth-Orbiting Satellites," GSFC X-523-67-508, October, 1967.

3. Karras, T. J. and Lee, R. C., "On Satellite Telemetry Data Recovery and Data Quality," GSFC X-563-69-81, February, 1969.

APPENDIX A

DISTRIBUTION OF S/N OUTPUT PLOTS FOR THE RFI ANALOG TAPES

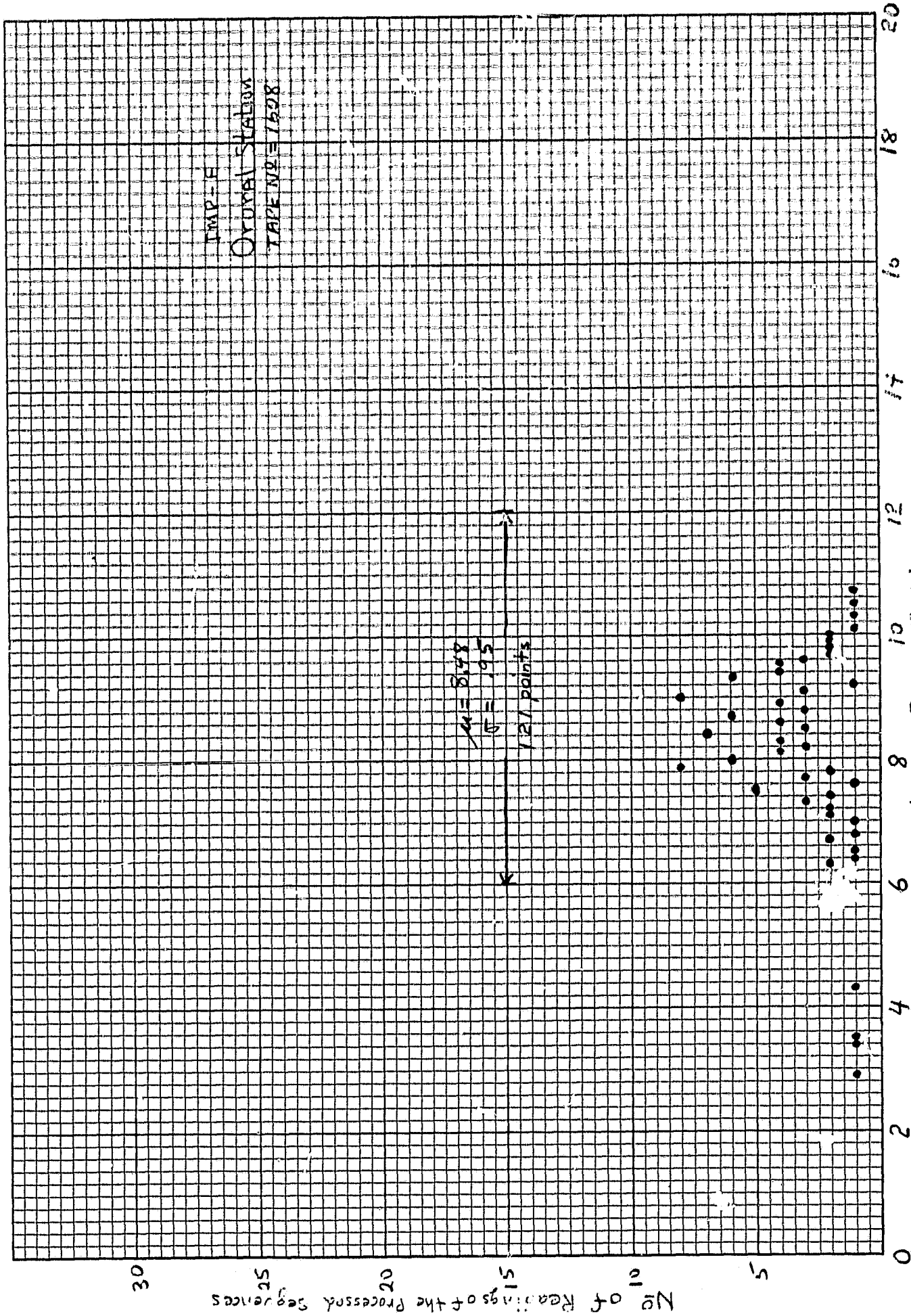

Figure A-1. IPD Output S/N Power Ratio Distribution Plot of a Processed Pass (IMP F, Ororal, Tape No. 1608)

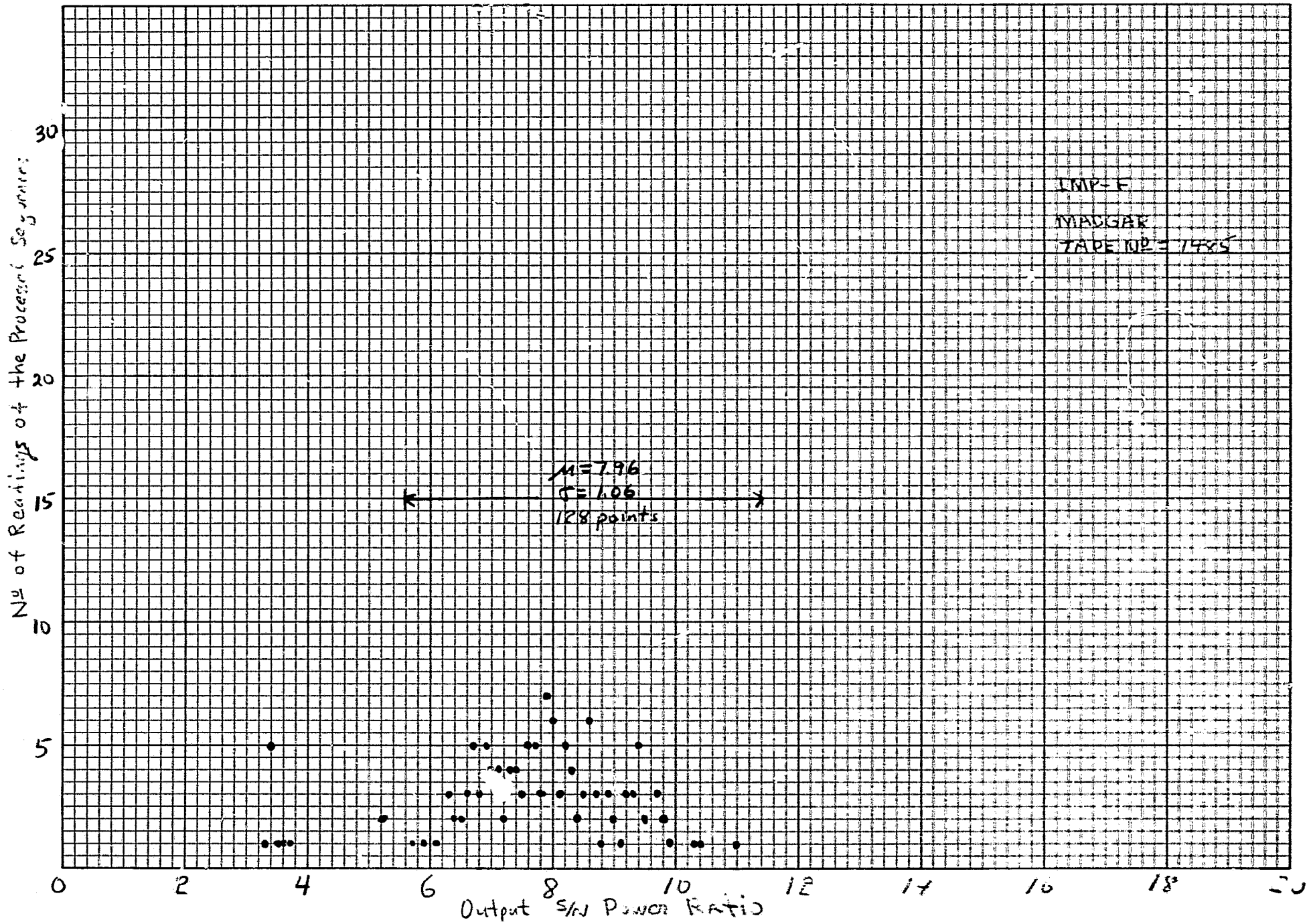

Figure A-2. IPD Output S/N Power Ratio Distribution Plot of a Processed Pass (IMP F, Madgar, Tape No. 1485)

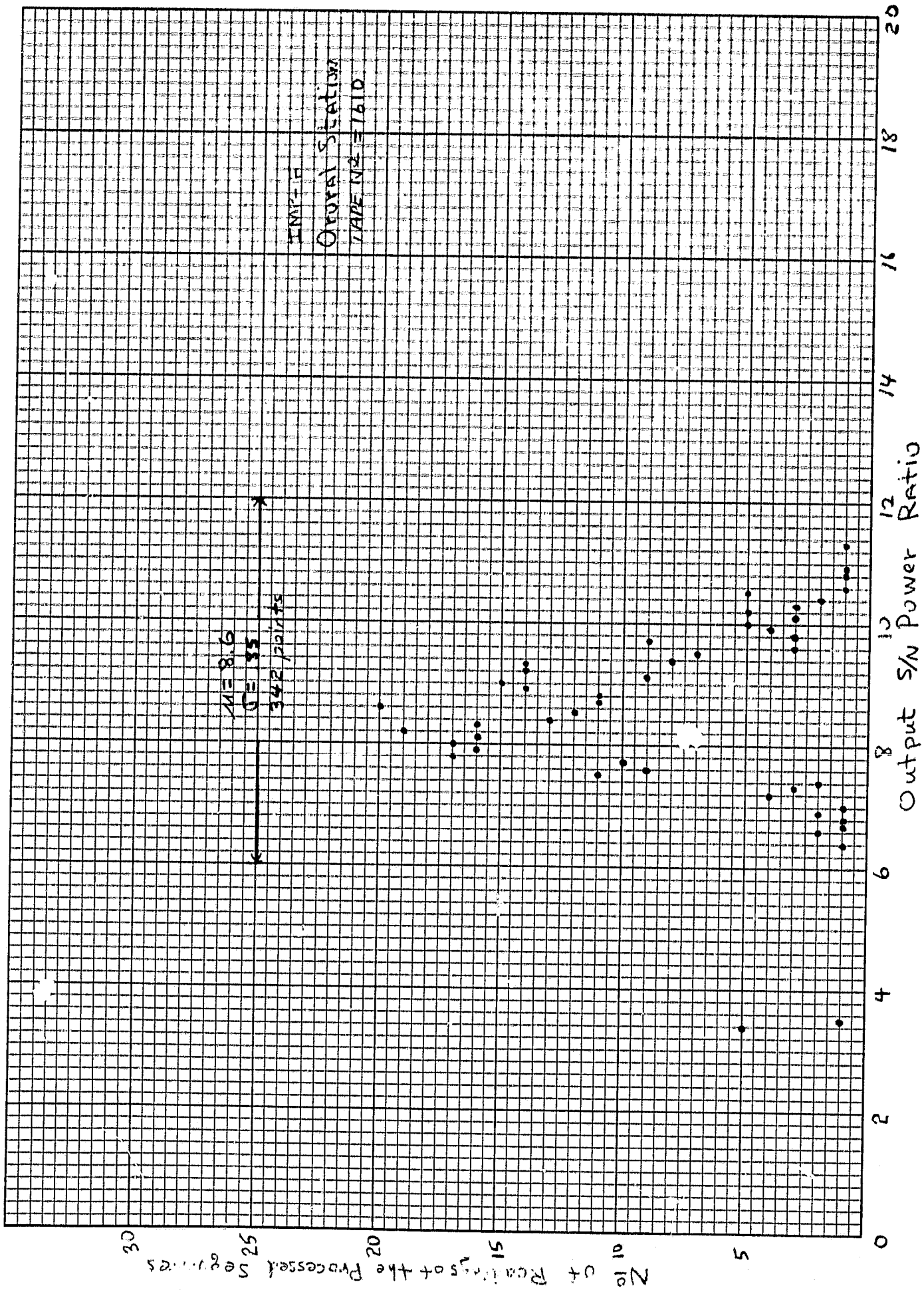

Figure A-3. IPD Output S/N Power Ratio Distribution Plot of a Processed Pass (IMP F, Ororal, Tape No. 1610)

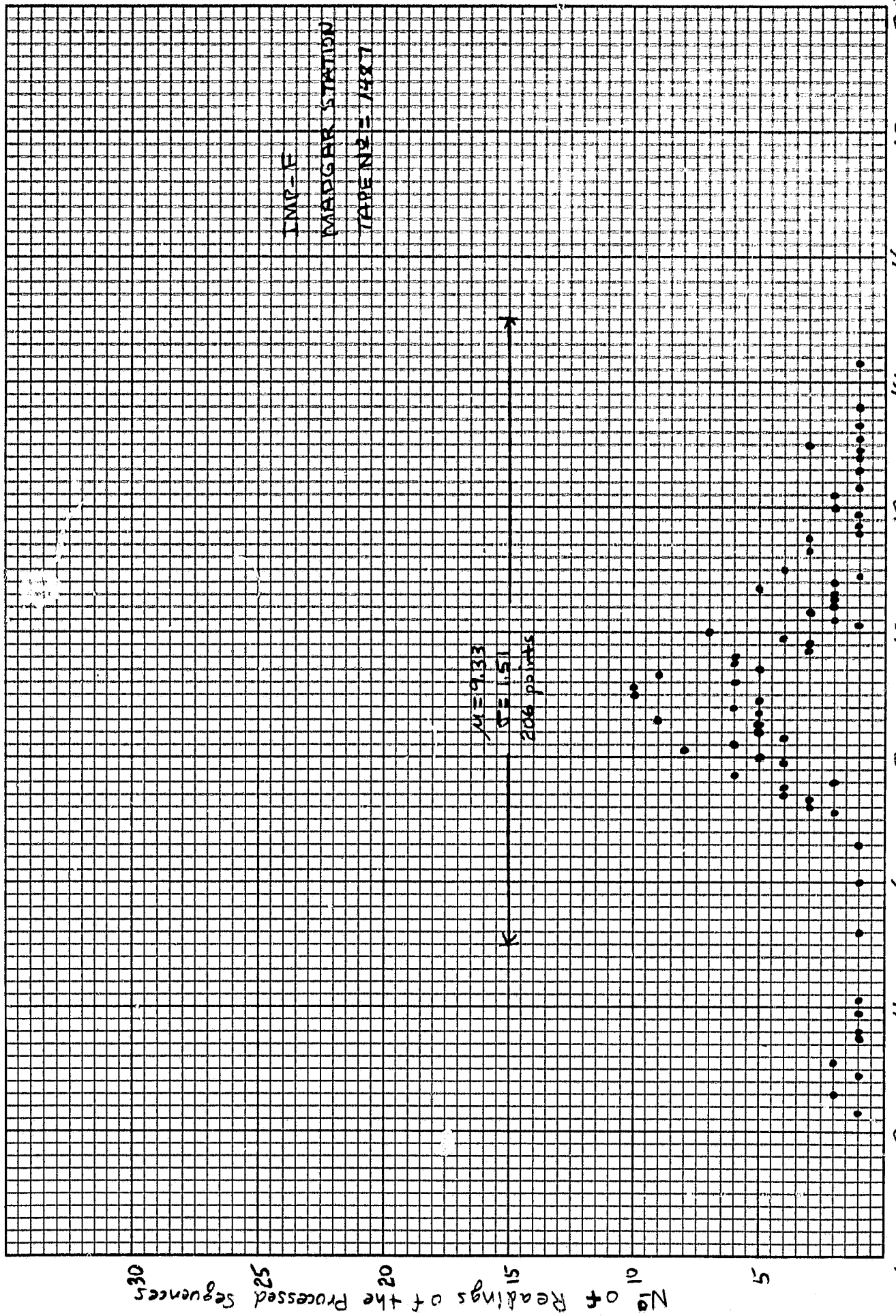

Figure A-4. IPD Output S/N Power Ratio Distribution Plot of a Processed Pass (IMP F, Madgar, Tape No. 1487)

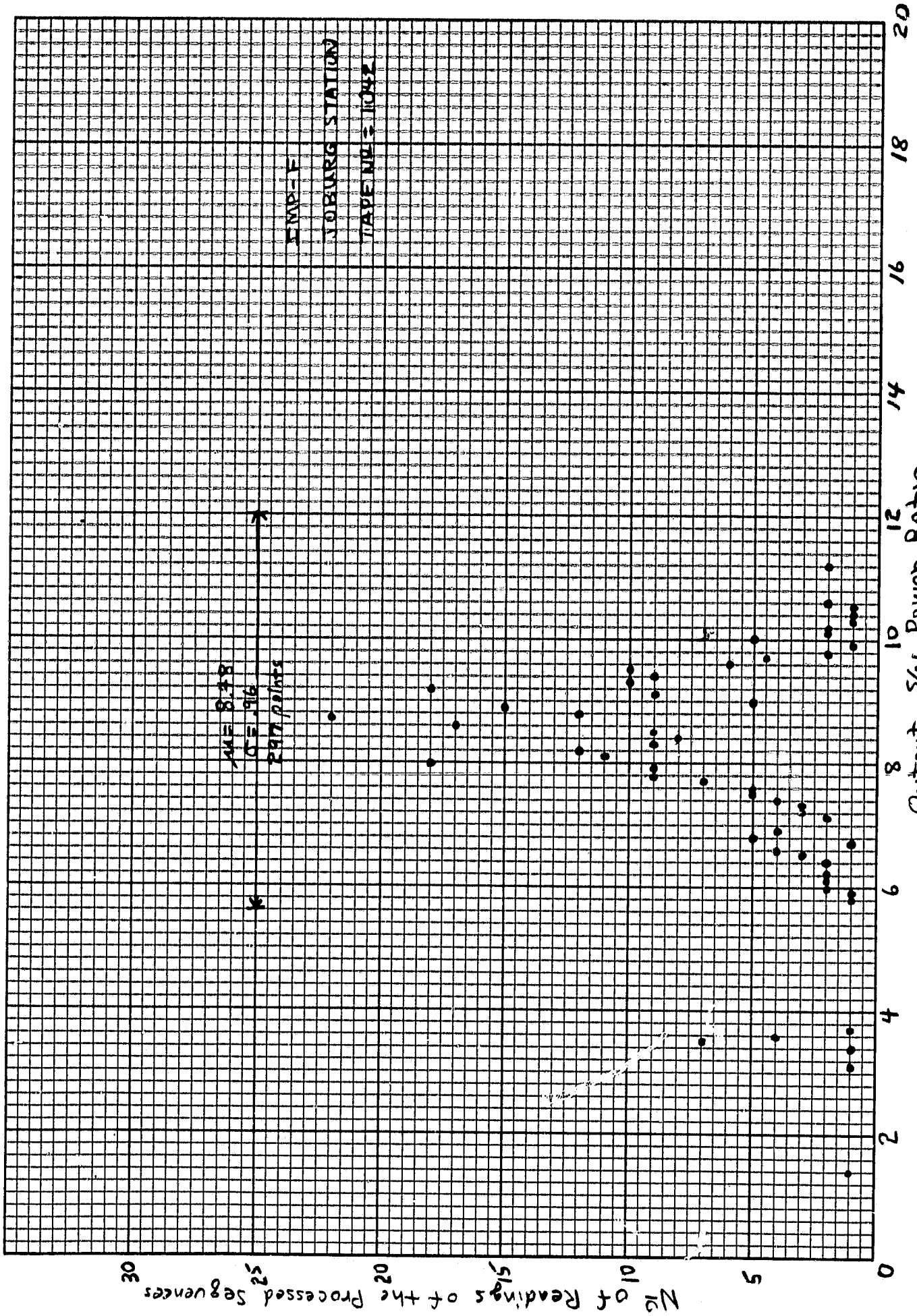

Figure A-5. IPD Output S/N Power Ratio Distribution Plot of a Processed Pass (IMP F, Joburg, Tape No. 1042)

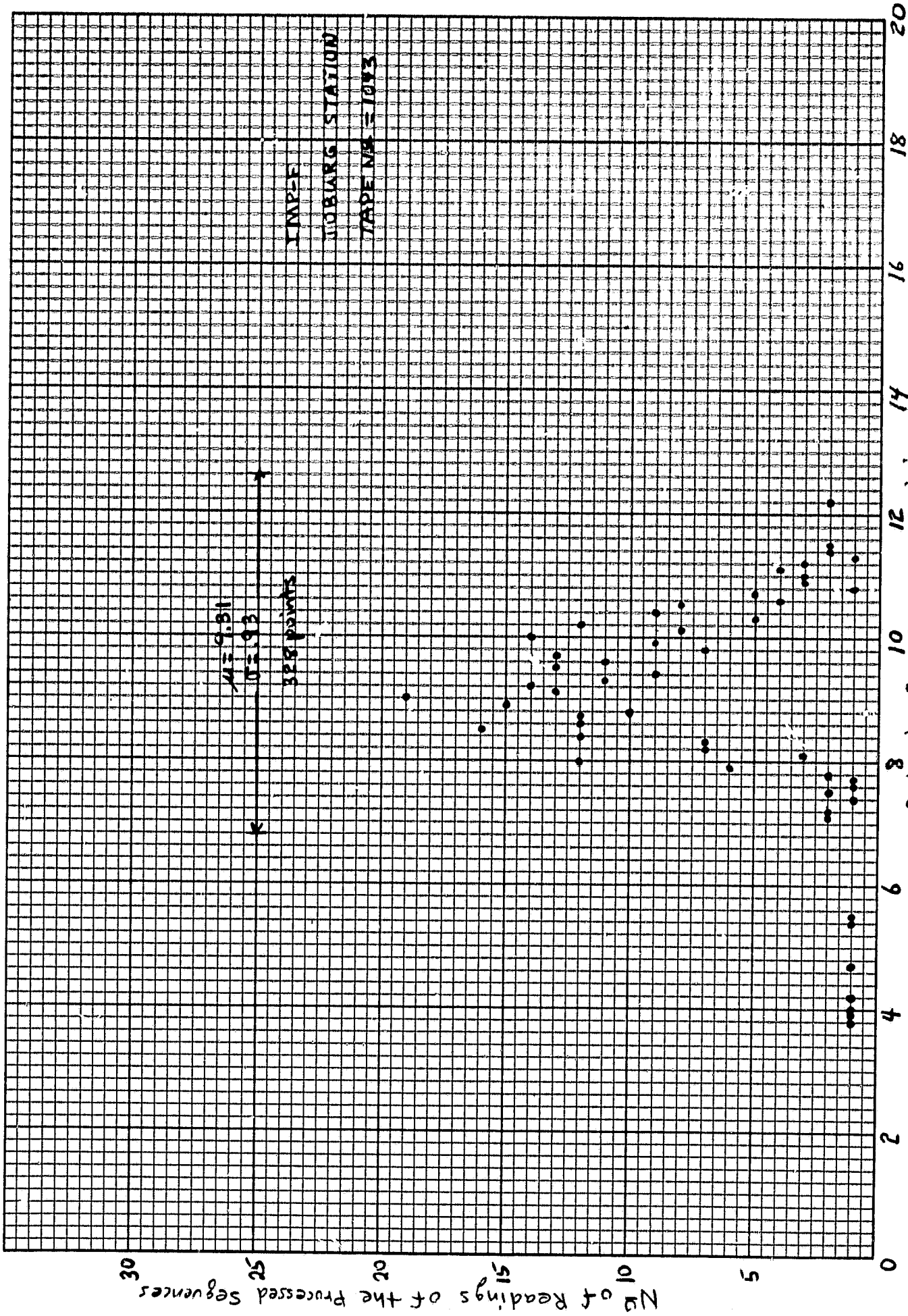

Figure A-6. IPD Output S/N Power Ratio Distribution Plot of a Processed Pass (IMP F, Joburg, Tape No. 1043)

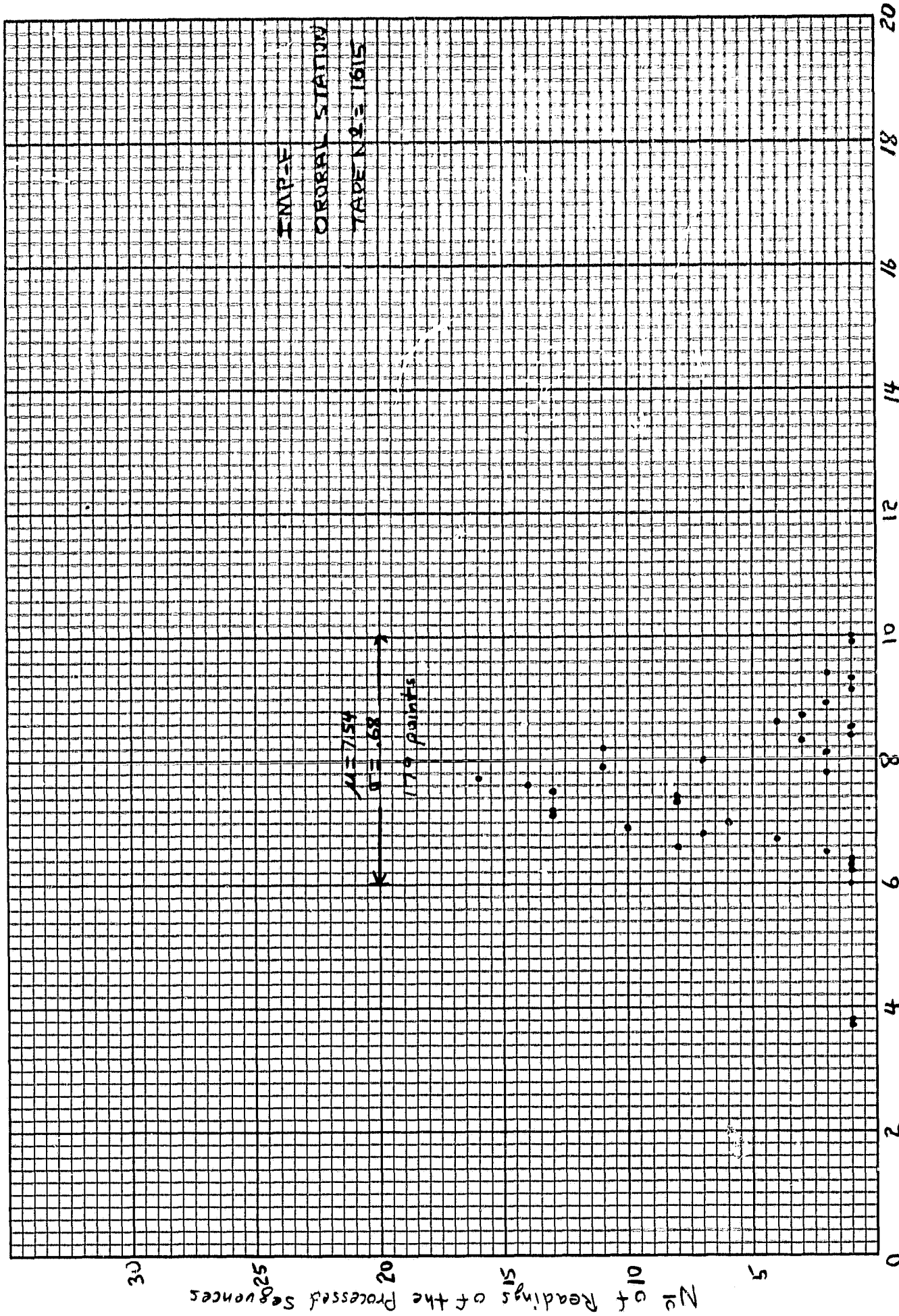

Figure A-7. IPD Output S/N Power Ratio Distribution Plot of a Processed Pass (IMP F, Ororal, Tape No. 1615)

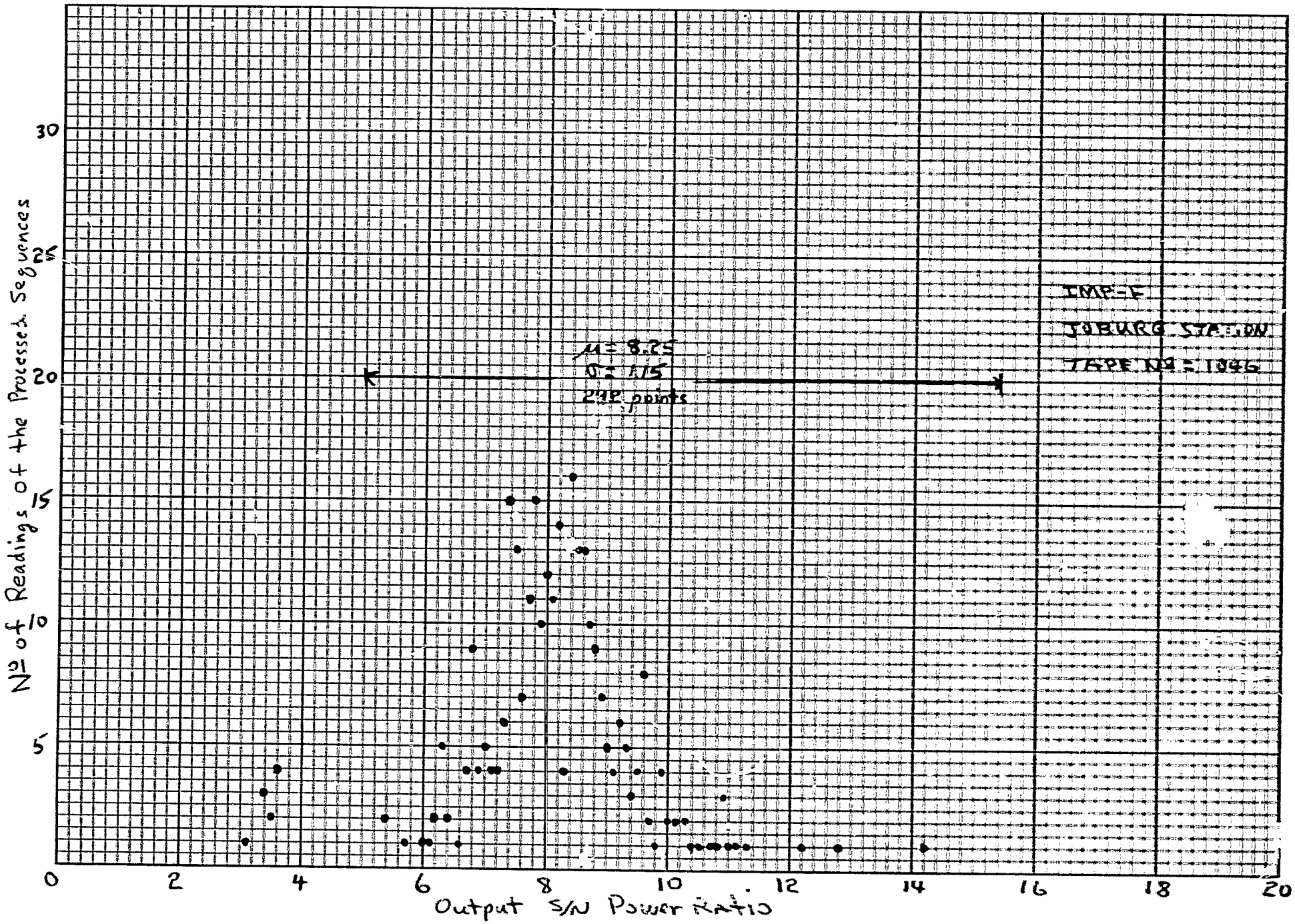

Figure A-8. IPD Output S/N Power Ratio Distribution Plot of a Processed Pass (IMP F, Joburg, Tape No. 1046)

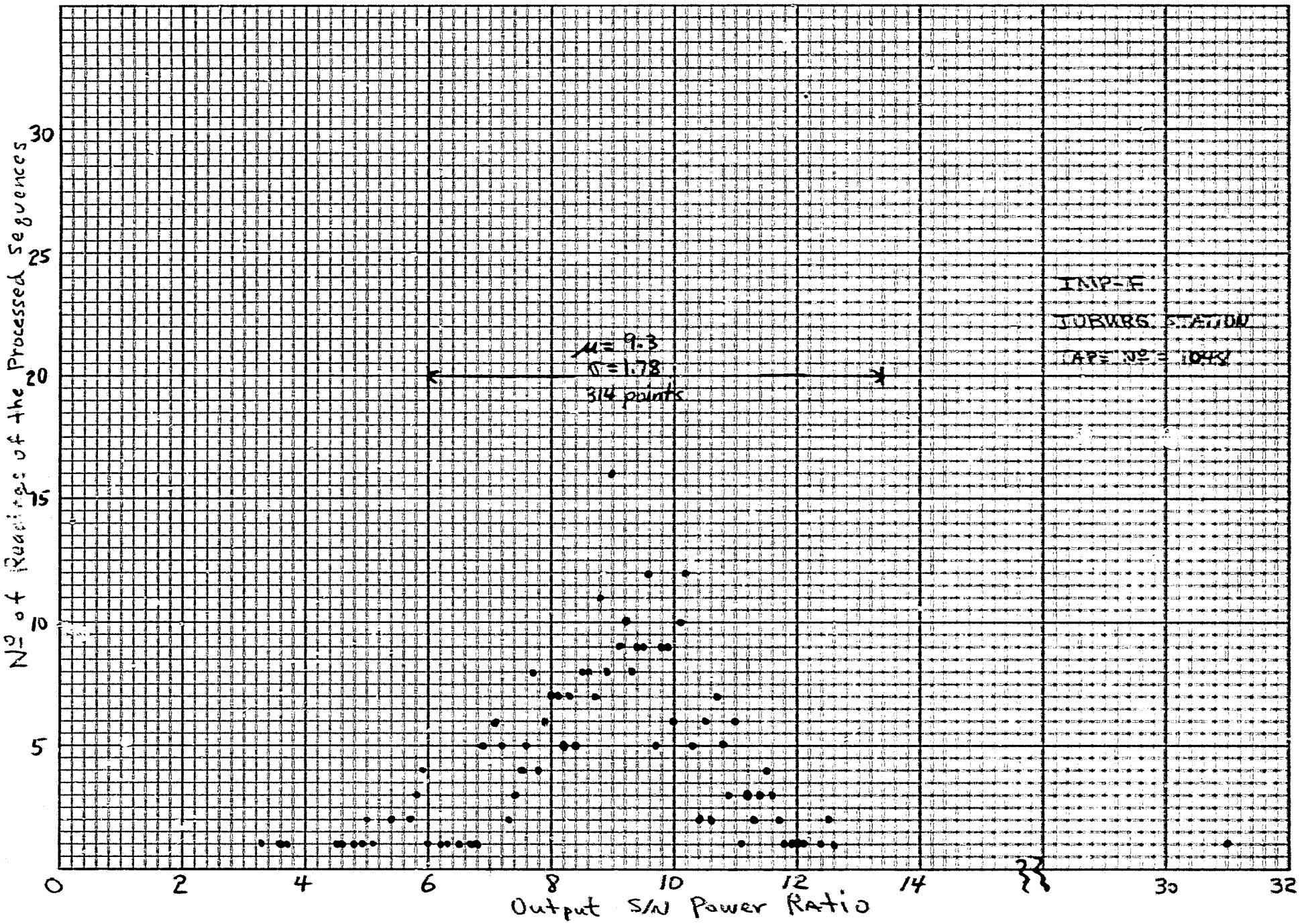

Figure A-9. IPD Output S/N Power Ratio Distribution Plot of a Processed Pass (IMP F, Joburg, Tape No. 1048)

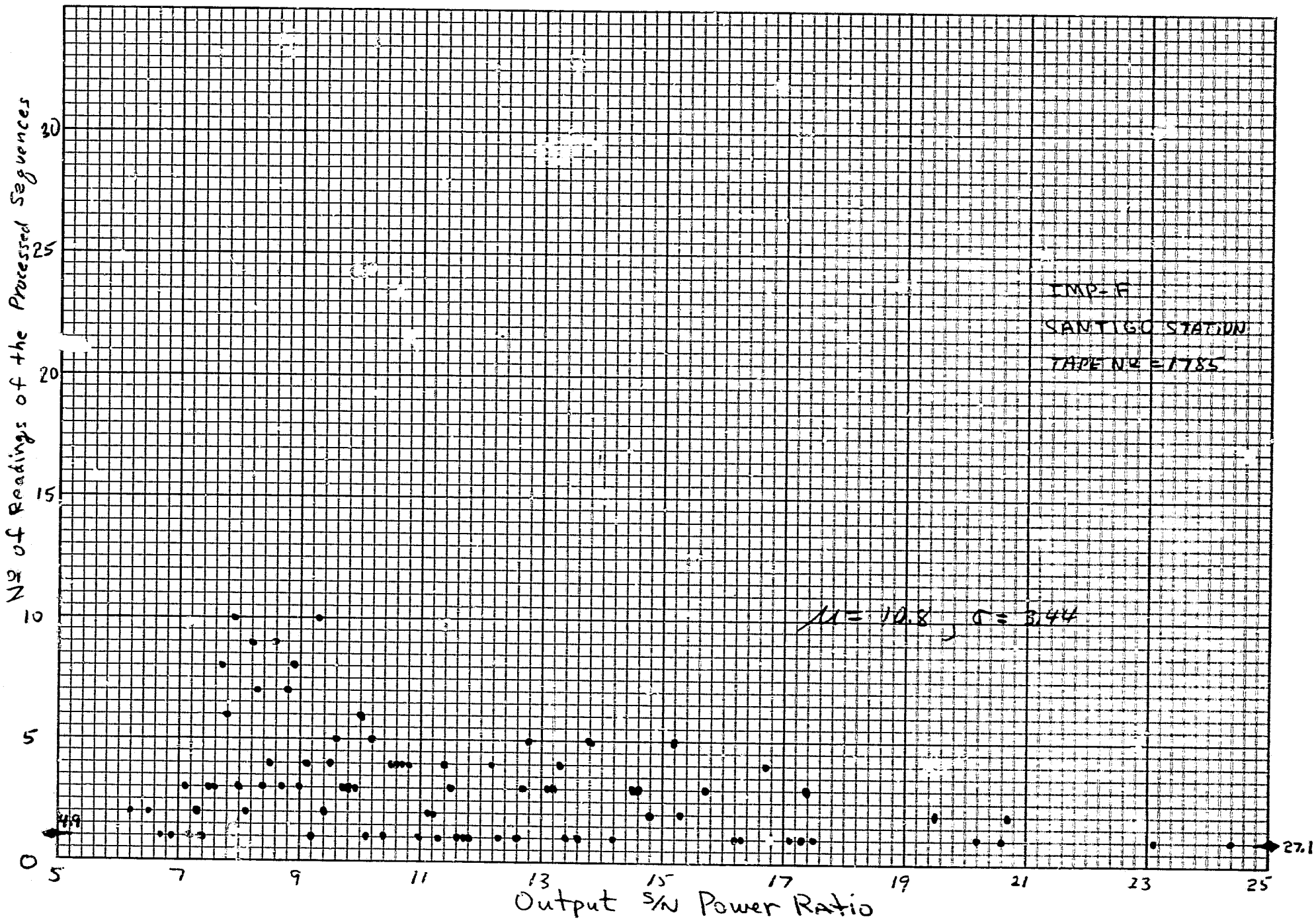

Figure A-10. IPD Output S/N Power Ratio Distribution Plot of a Processed Pass (IMP F, Santigo, Tape No. 1785)