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# EFFECTS OF SPACECRAFT INTERFERENCE ON A 136 MHz PCM TELEMETRY DATA LINK


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# EFFECTS OF SPACECRAFT INTERFERENCE ON A 136 MHz PCM TELEMETRY DATA LINK

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November 1969

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# EFFECTS OF SPACECRAFT INTERFERENCE ON A 136 MHz PCM TELEMETRY DATA LINK

## I. INTRODUCTION

The quantity and quality of the data retrieved from a spacecraft-to-earth 136 MHz telemetry link are at times affected by either co-channel or adjacent-channel types of radio-frequency interference (RFI) from similar spacecraft operating within the same frequency band. There are presently about 45 spacecraft, supported by the National Aeronautics and Space Administrations (NASA), Space Tracking and Data Acquisition Network (STADAN), each transmitting in the 136-138 MHz space research band.

The STADAN-supported spacecraft employ both pulse-code modulation (PCM) and pulse-frequency modulation (PFM); reference 1 analyzes the effects of spacecraft-type RFI on the Interplanetary Monitoring Platform (IMP-F) spacecraft 136 MHz PFM system.

This report analyzes typical PCM/PM (phase modulated) data samples, obtained while tracking the Orbiting Solar Observatory OSO-5(F) spacecraft, that were processed by the Information Processing Division (IPD). A total of 14 analog-recorded tapes, covering a 7-day randomly selected interval, were examined for suspected spacecraft-type RFI. These 14 analog tapes were either reported by the STADAN stations (RFI Reports) as having spacecraft-type RFI or predicted by the Advanced Development Division (ADD) using the RFI Prediction Model (Reference 2).

The IPD processed tape samples have been correlated with the STADAN reported and ADD predicted spacecraft RFI; there is good agreement between each of the three areas. Each of these aspects are discussed separately.

A significant amount of spacecraft-type RFI was observed and verified to be in the tapes and is described herein.

## II. SPACECRAFT RFI PREDICTION MODEL

Based upon known orbital elements (Reference 3), 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:

$$S = \frac{P_{to} G_{to} G_{ro} \lambda_0^2}{(4 \pi R_0)^2} \tag{1}$$

$P_{to}$ = Spacecraft antenna input power, watts

$G_{to}$ = Spacecraft antenna gain, above isotropic

$G_{ro}$ = Station receiving antenna gain, above isotropic

$\lambda_0$ = Operating wavelength

$R_0$ = Spacecraft-to-station range (same units as $\lambda_0$).

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

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

The computer flow diagram, for the RFI 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 I/S ratios, values of I and S, are simultaneously printed and identified, for each spacecraft for each time reading.

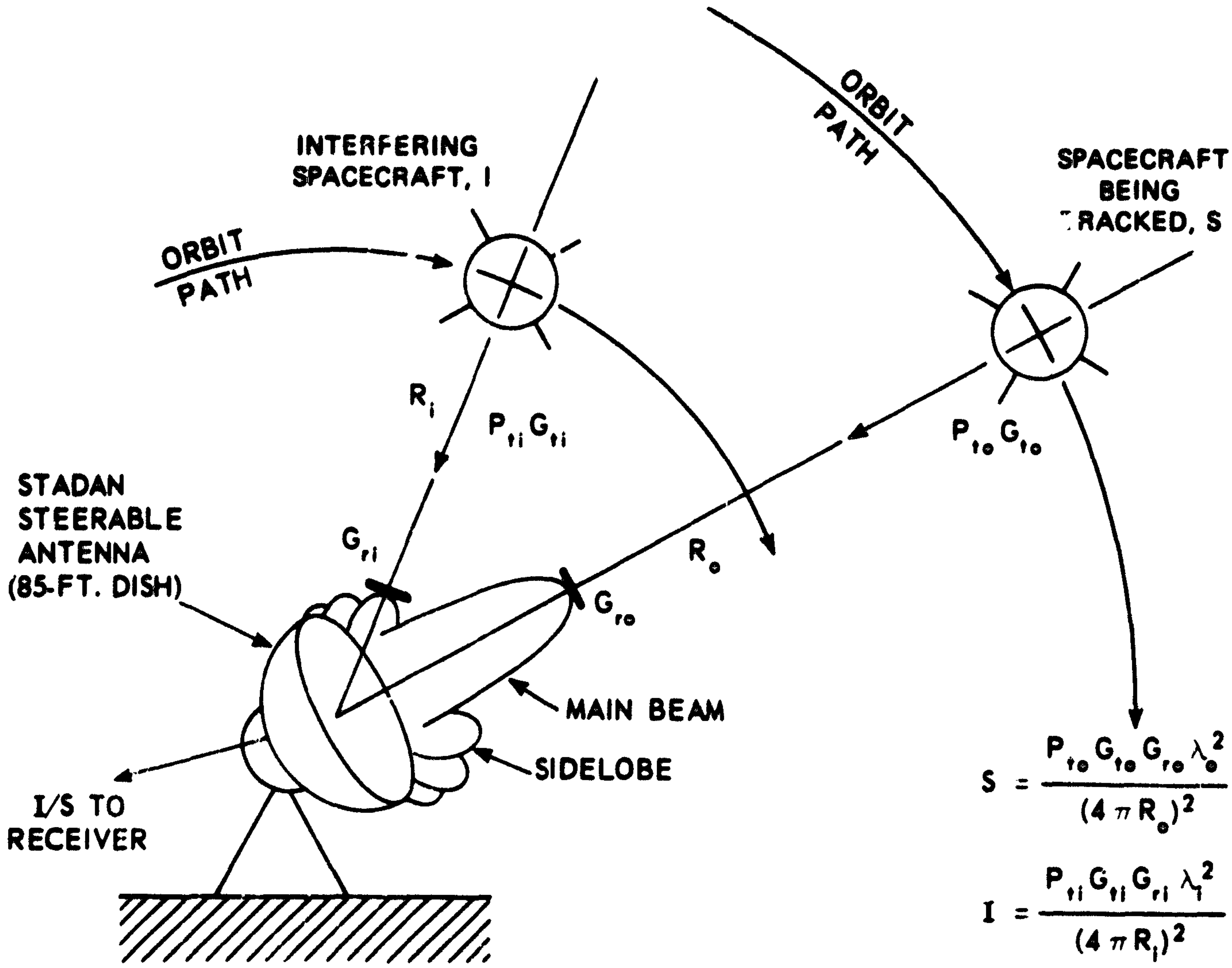



Figure 1. Radio Link Parameters for RFI Prediction Program

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

When

$$|f_o - f_i| \leq \frac{B_o}{2} + \frac{B_i}{2}, \tag{2}$$

RFI is present if

$$\frac{I}{S} \geq -20\,\text{db}.$$

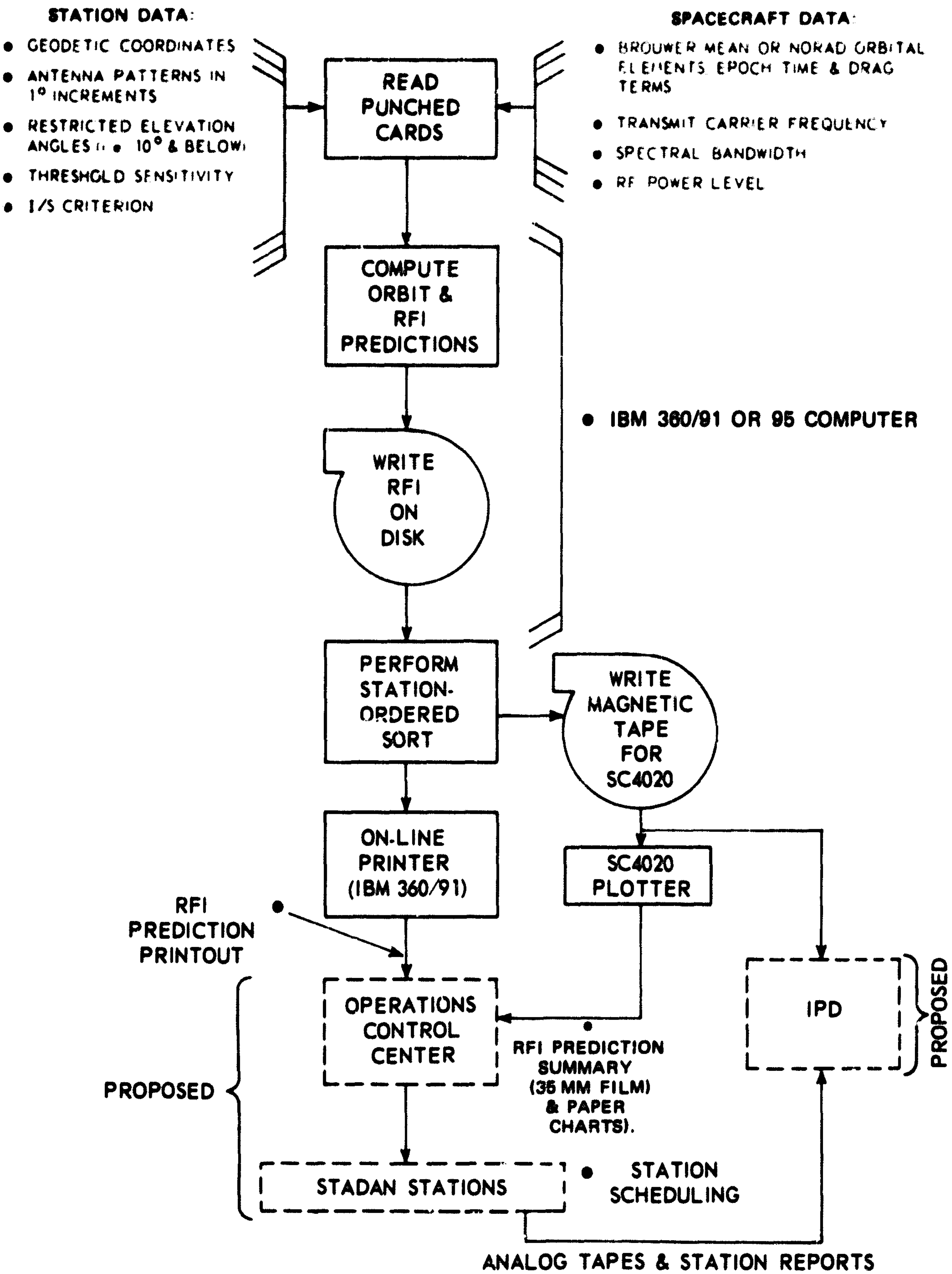



Figure 2. Flow Diagram, Spacecraft Interference Prediction Computer Program

The bandwidths, $B_0$ and $B_i$, are the emitted spectral bandwidths of the respective tracking and interfering spacecraft; whereas $f_0$ and $f_i$ are the respective carrier center frequencies. An ideal, uniformly flat, emitted spectral bandwidth is assumed in order 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.

The predicted I/S ratios were computed at 2-minute intervals; I/S ratios then were plotted on the IPD tape evaluation strip charts along with STADAN-station recordings of receiver automatic gain control (AGC). The averaged PCM frame sync correlator output was used to detect the presence of RFI in the OSO-5(F) tape samples. Certain additional ancilliary-type data processing equipment, including a spectrum analyzer, was also used to identify spacecraft RFI.

## III. EVALUATION OF SPACECRAFT RFI

### A. Description of IPD Data Evaluation System

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 processable from the orbit groups. 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 4).

For a more detailed study of signal anomalies, a strip chart analysis is often performed such as shown on Figure 3 for PCM data (Reference 5). This analysis gives a visual indication of any burst-type noise which appears in a pass. A spacecraft RFI unique noise-strip-chart characteristic can be identified. Strip charts were obtained, using the IPD's E-5 tape evaluation line, with the addition of a PCM Performance Monitor, recently developed by the Processor Development Branch, which provides strip chart and quality analyses of various recorded analog signals. The strip chart contains information such as: (1) the receiver AGC recordings, (2) the PCM tape evaluation processor search-to-lock indicator (indication of IPD's data recovery), (3) an average frame sync error rate indicator (indication of IPD's data quality), (4) the bit synchronizer 1/2 bit slippage indicator (indication of jitter), (5) STADAN and IPD's combined ground tape recorder reproduce wow/flutter and drift characteristics, (6) the serial decimal time code, and (7) an indication of the signal plus noise (S + N) amplitude level variations of the "raw" PCM signal.

The performance monitor counts the relative number of frame sync words, recovered with zero bit errors, when the PCM system is in the "lock" mode. The ratio of the number of frames with zero errors in the frame sync word to the number of recovered frames (FOE) is defined as:

$$\text{FOE} = \frac{\text{Number of recovered frame sync words with zero errors}}{\text{Number of recovered frames}} \leq 1 \quad (3)$$

Also,

$$\text{FOE} \approx (1 - n\,\text{Pe}) \quad (4)$$

where

$n$ = number of bits in each frame sync word
Pe = average bit error probability $\leq 1/10$

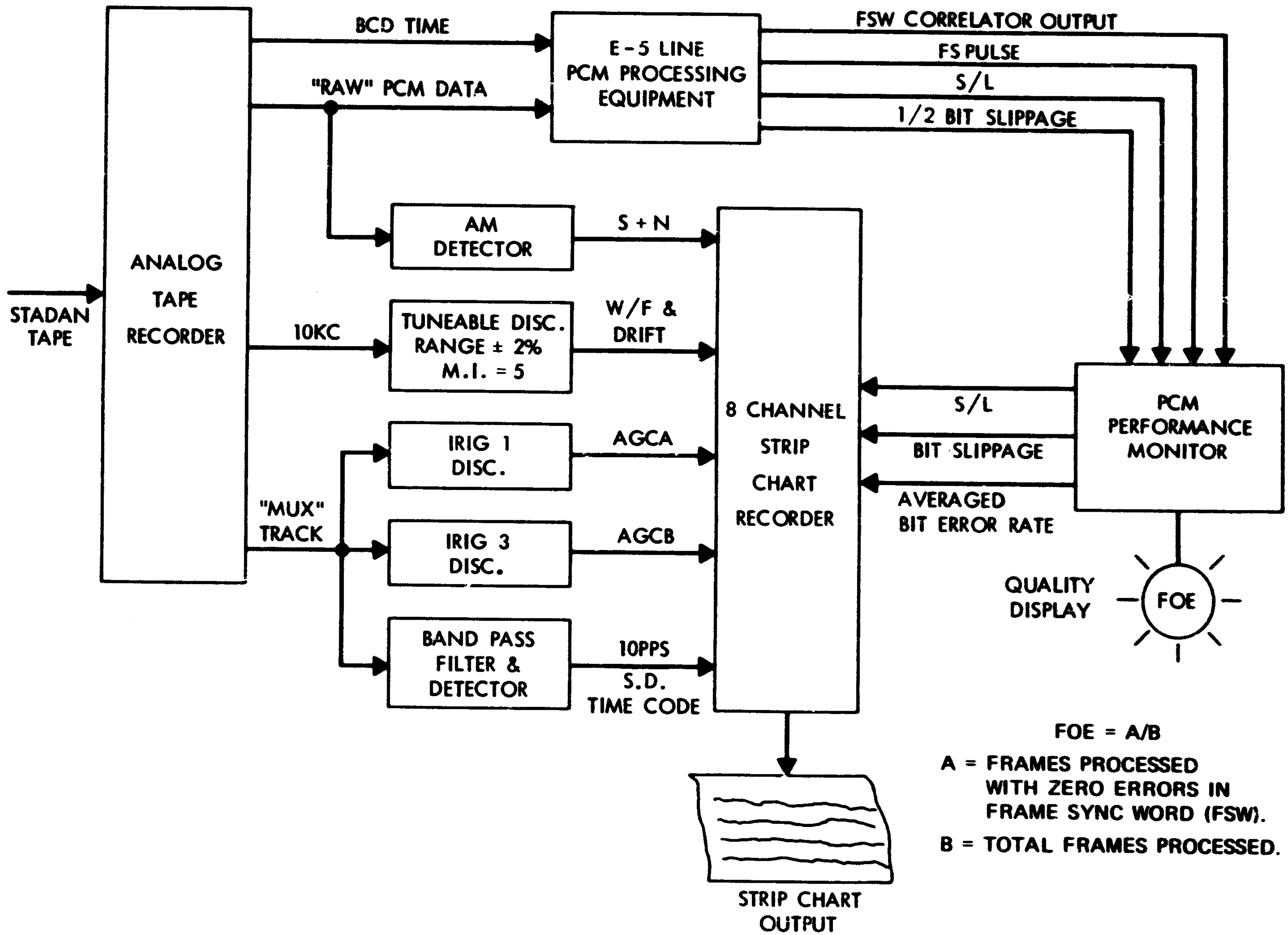



Figure 3. The IPD PCM Tape Evaluation System

In practice, the acronym, FOE, is a figure-of-merit quality factor; the FOE parameter, obtained from the first expression, being used in the second expression to compute the PCM bit-error probability, Pe. It is assumed that the bit errors are independent, and that the process is stationary.

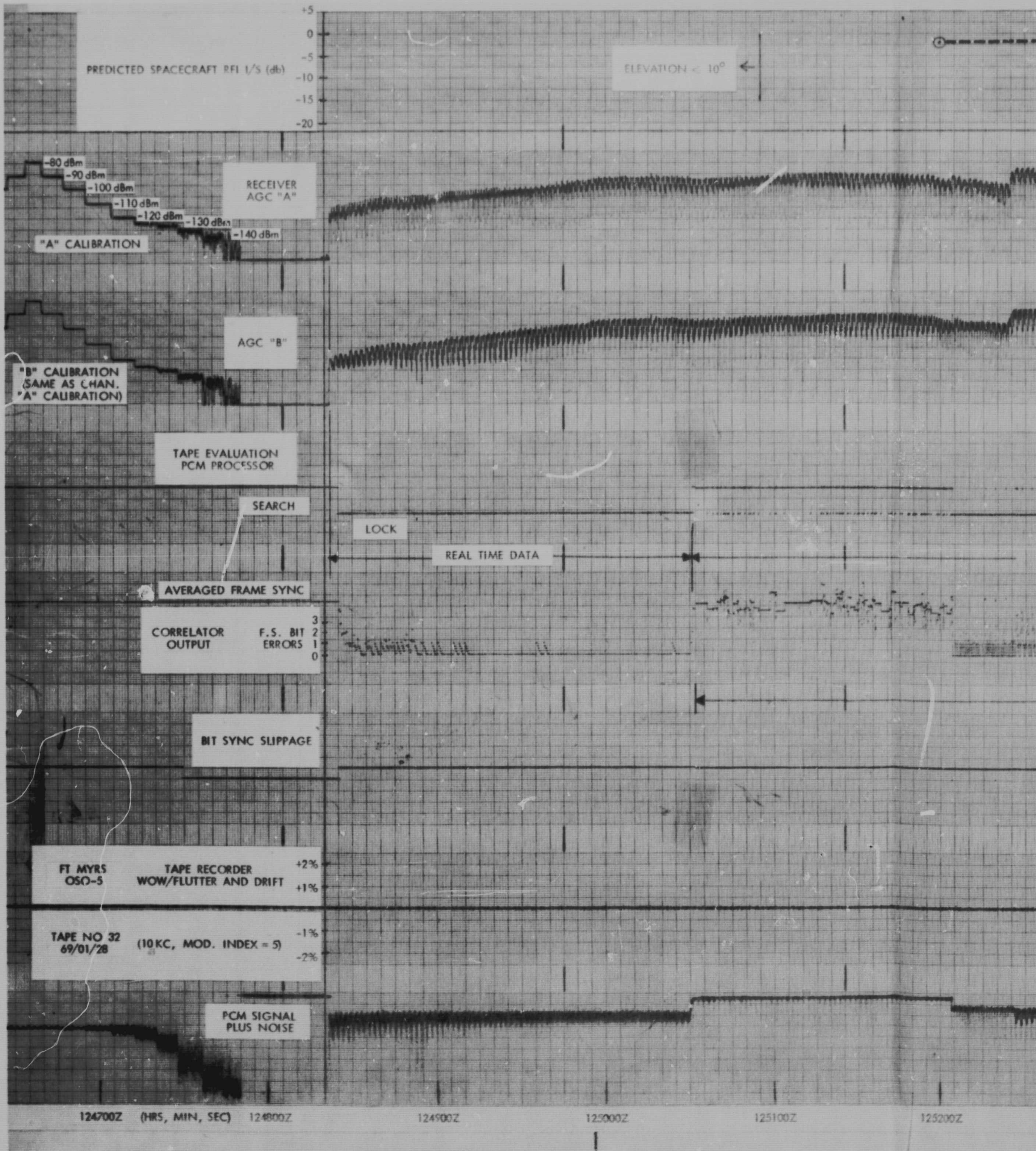
B. OSO-5(F) Tape Sample Analysis

A 7-day period (randomly selected) of OSO-5(F) spacecraft PCM telemetry tapes covering January 26 through February 1, 1969 was examined for spacecraft type RFI. A total of 14 analog tapes (reported by the STADAN stations or predicted by the ADD) were verified by the IPD evaluation system as having various amounts of spacecraft-type RFI.

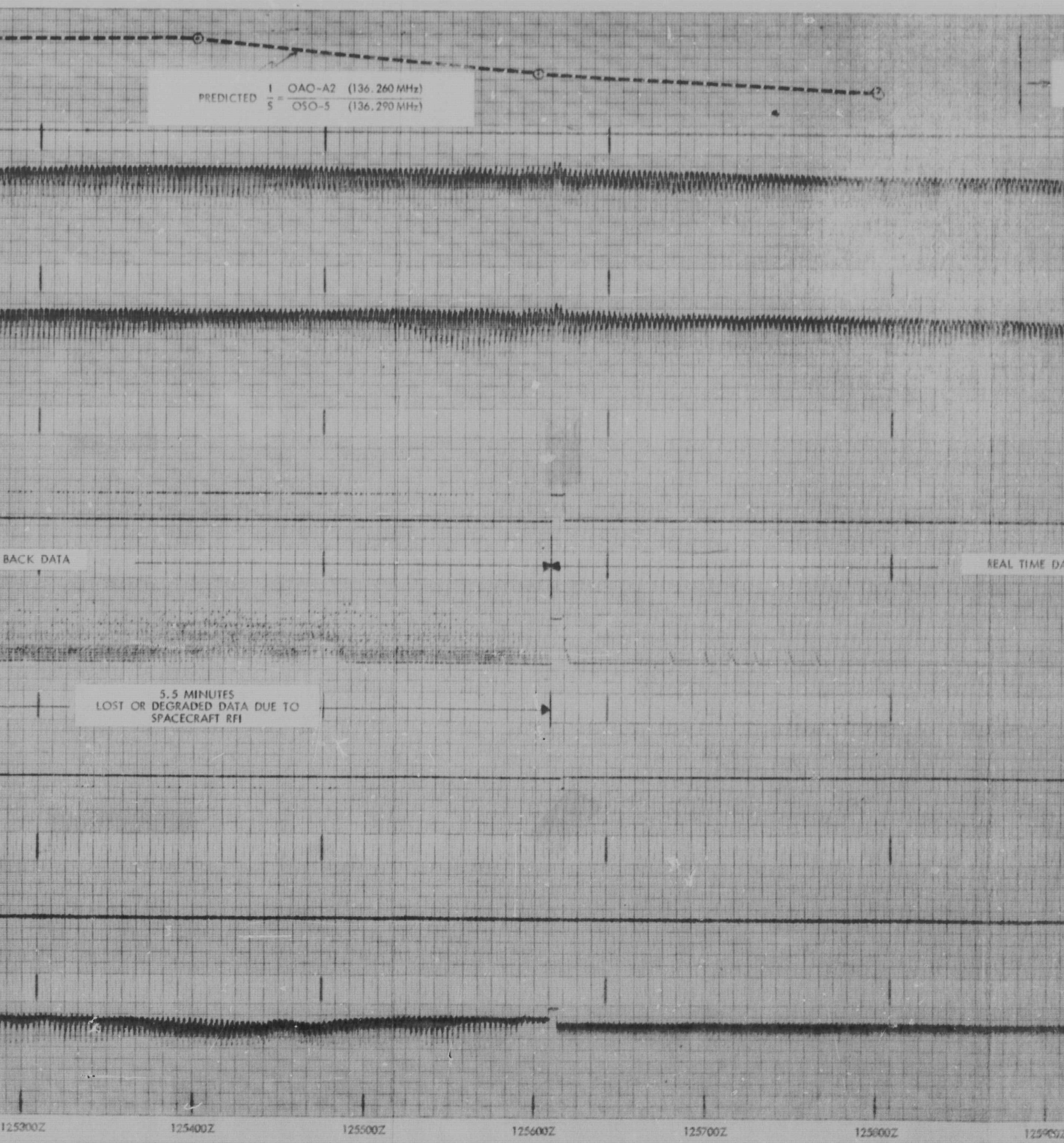
Four of the 14 OSO-5(F) analog strip-charts were selected for discussion in this report and are shown in Figures 4 through 7, inclusive. Figure 4, corresponding to the Fort Myer's tape No. 32, reveals that a significant portion of a spacecraft pass can be lost, or seriously degraded, 5.5 minutes (42%) of the 13-minute pass being thus affected as observed by the frame sync correlator output channel during the "playback" data mode. It should be noted that the "playback" data was almost completely obliterated in this particular pass. On the other hand, the narrow band "real-time" data mode was affected less than the wide band "playback" data since the "playback" data radio-frequency spectrum is much wider (14.4 kilobit/sec) compared to the "real-time" spectrum with a bit rate of 800 bits/sec. The "playback" mode is therefore more susceptible to adjacent channel RFI than the "real-time" mode. The predicted I/S ratio (top channel, Figure 4) indicates that interference from the OAO-A2 spacecraft, operating on a 136.260 MHz carrier frequency, was sufficiently high (I/S $\geq$ -20 db) to interfere with the OSO-5(F) channel, operating on an assigned carrier frequency of 136.290 MHz during the wide band "playback" transmission.

Figure 5, corresponding to the OSO-5 Santiago tape No. 28, shows that the interference appearing in the averaged Frame Sync Correlator Output channel is highly correlated with the predicted interference-to-signal (I/S) ratio.

The receiver channel "B" AGC recording, in Figure 5, shows that the "B" channel was inadvertently phase locked to the interfering OAO-A2 signal, on 136.260 MHz, appearing near the end of the pass; whereas, receiver channel "A" was locked to OSO-5 on 136.290 MHz properly. The IPD clearly identified the interfering OAO-A2 baseband bit rate by analyzing the resulting data beat frequency from the OSO-5 magnetic tape recording. Furthermore, both receiver channels "A" and "B" were inadvertently phased locked to the interfering 136.260 MHz OAO-A2 signal at the beginning of the pass.




FOLDOUT FRAME #1



PREDICTED 1/5 = OAO-A2 (136.260 MHz) / OSO-5 (136.290 MHz)
BACK DATA
REAL TIME DA
5.5 MINUTES
LOST OR DEGRADED DATA DUE TO
SPACECRAFT RFI
125300Z
125400Z
125500Z
125600Z
125700Z
125800Z

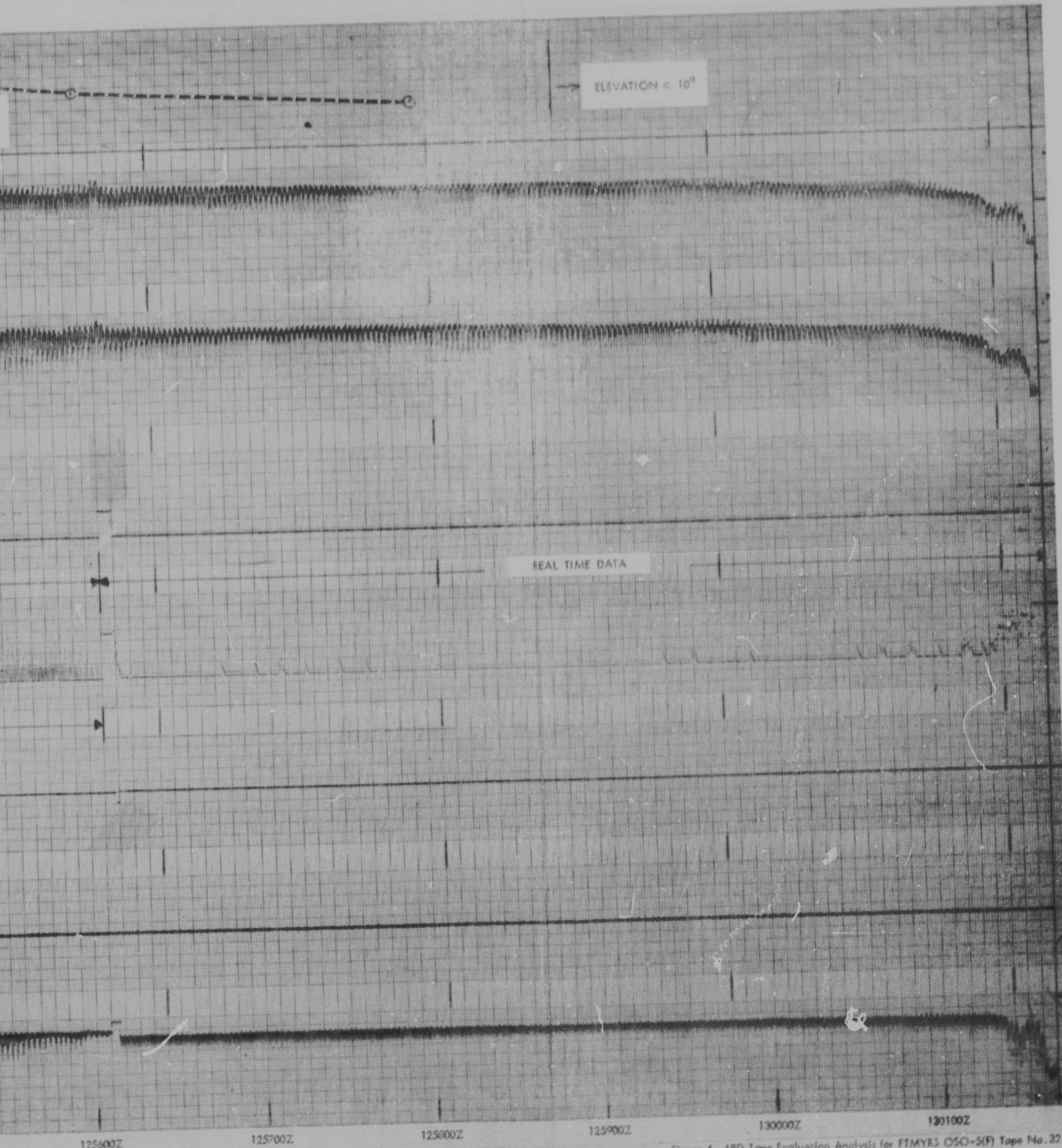
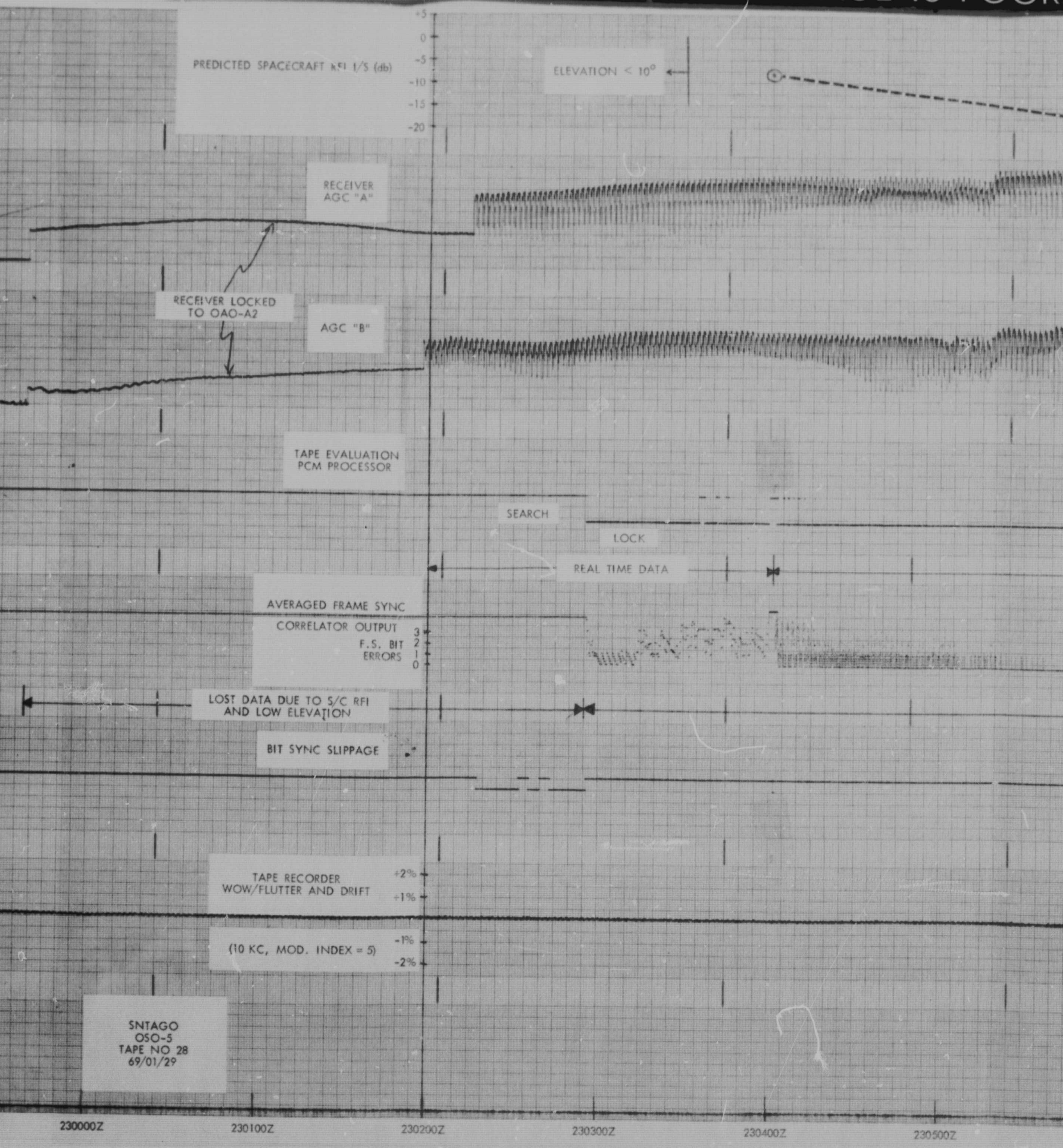


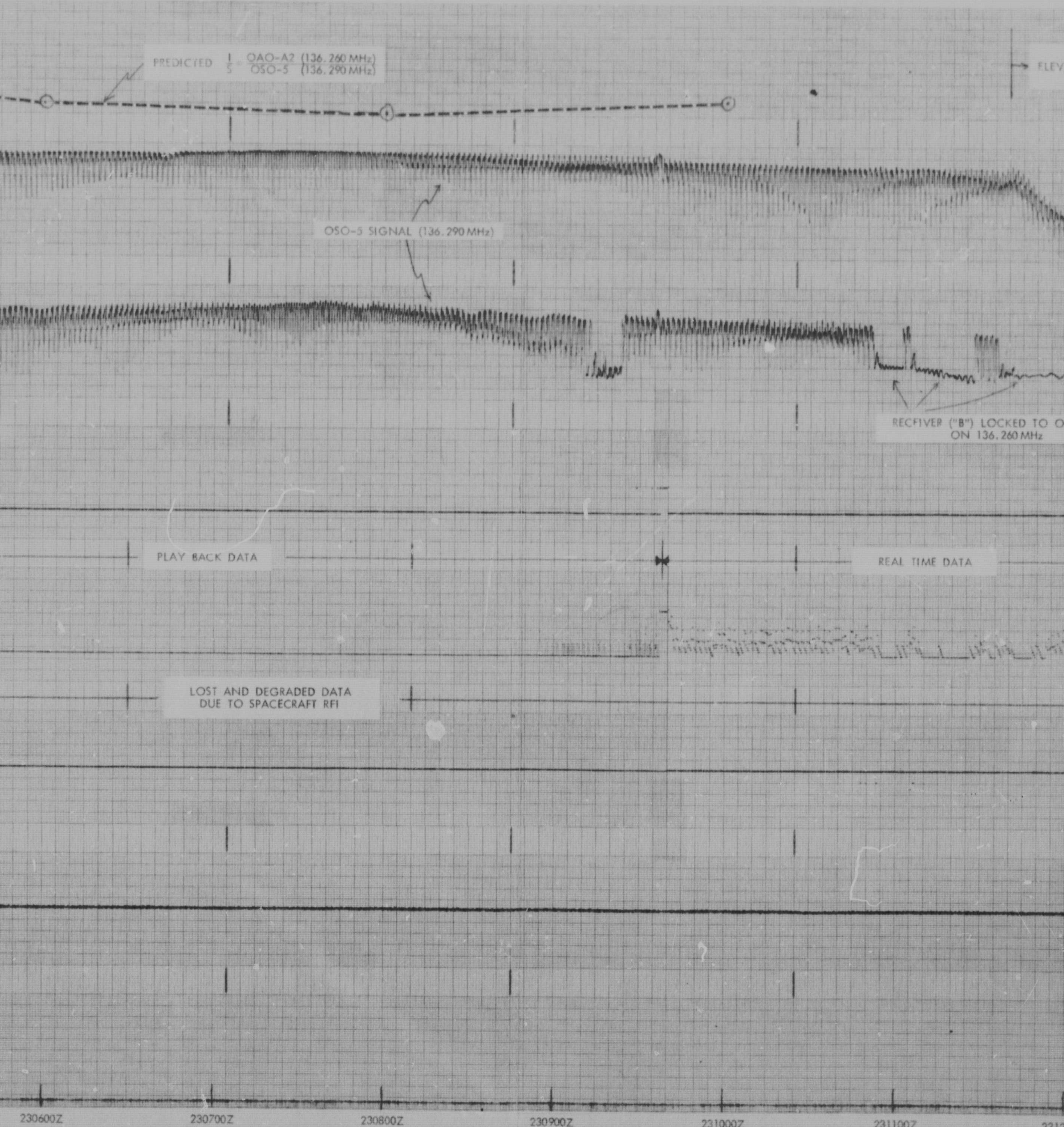

Figure 4. IPD Tape Evaluation Analysis for FTMYRS OSO-5(F) Tape No. 32



FOLDOUT FRAME #3




FOLDOUT FRAME #1




FOLDOUT FRAME #2

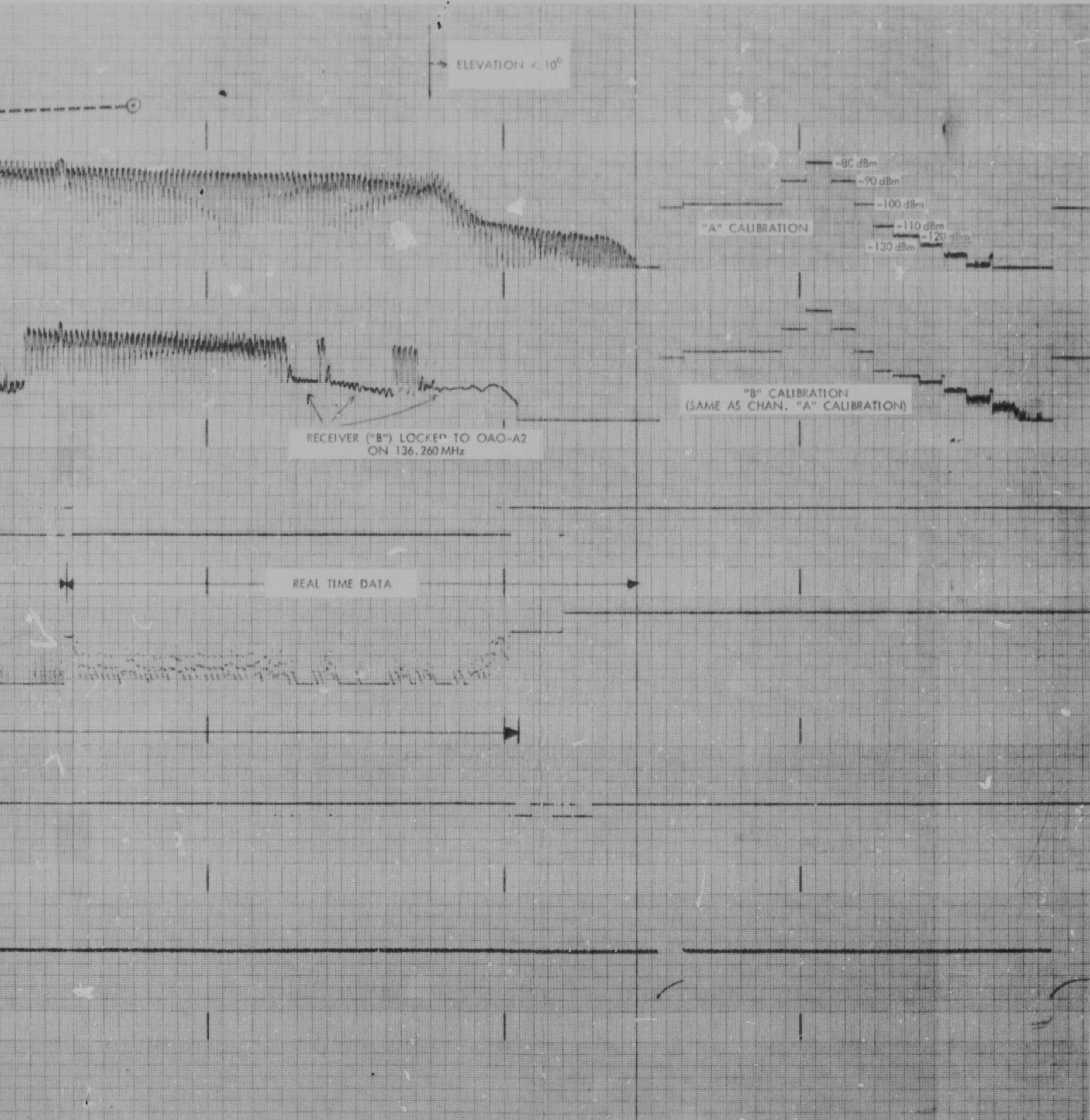
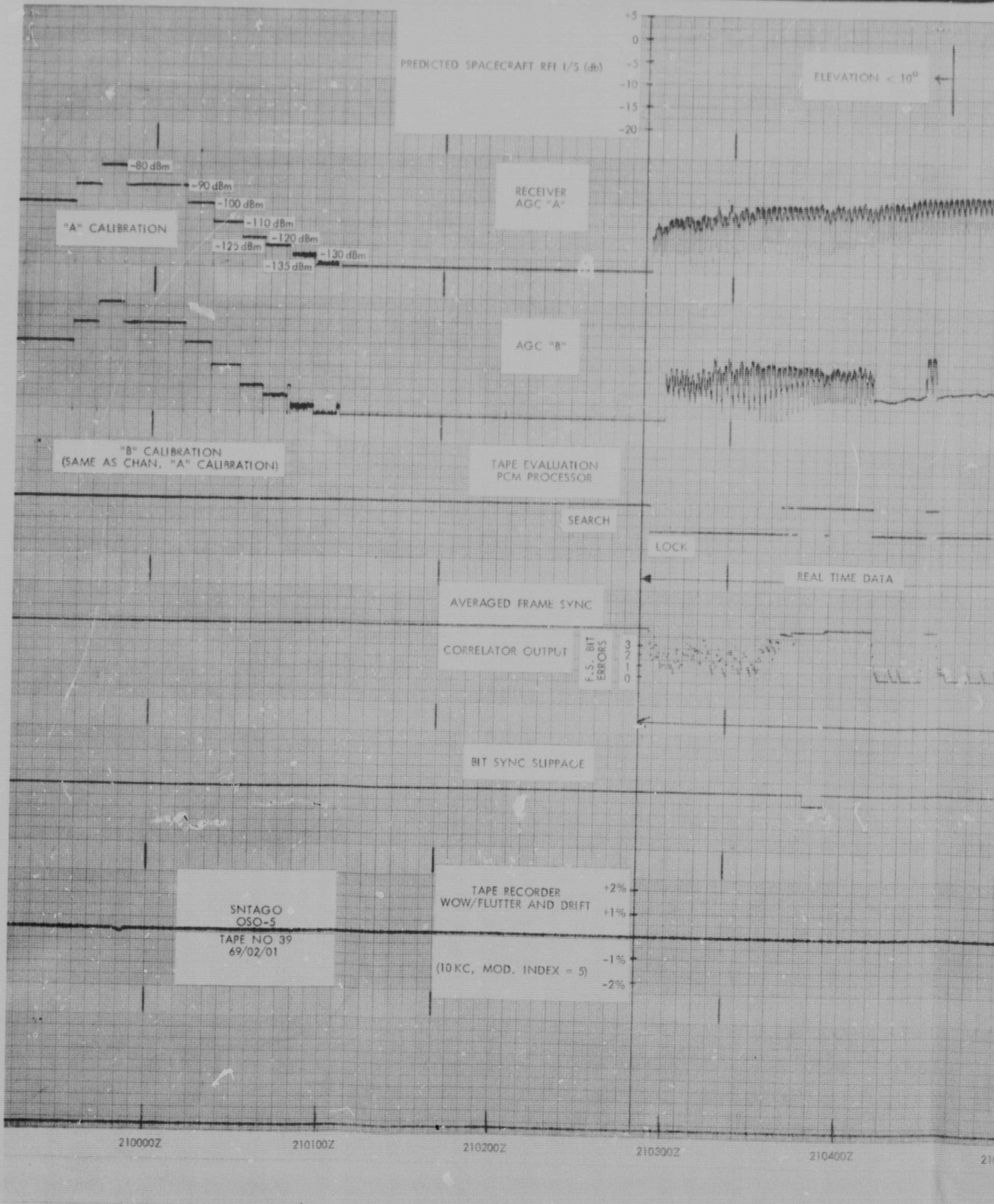


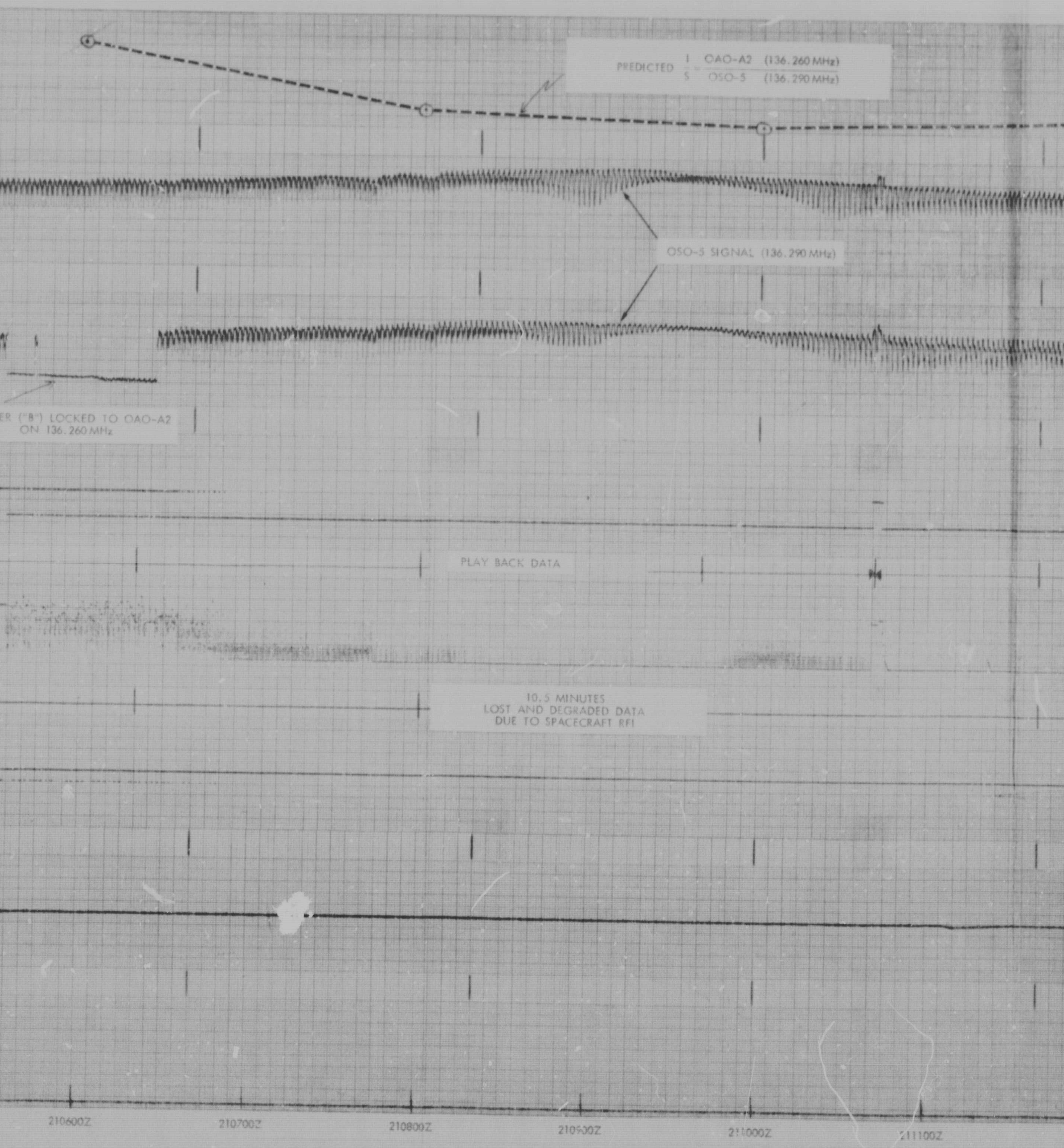

Figure 5. IPD Tape Evaluation Analysis for SNTAGO OSO-5(F) Tape No. 28



FOLDOUT FRAME #3




FOLDOUT FRAME #1




FOLDOUT FRAME #2

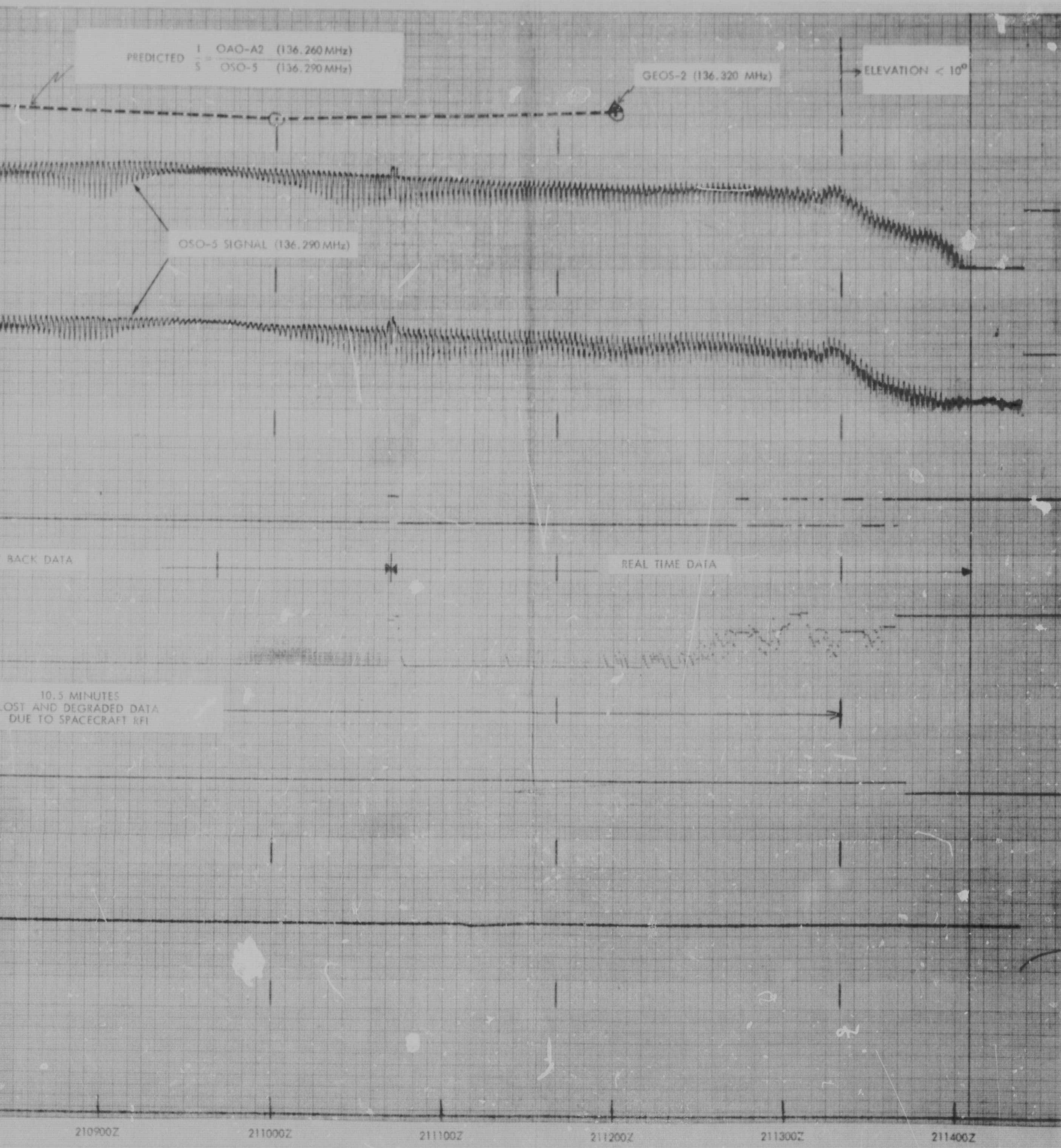
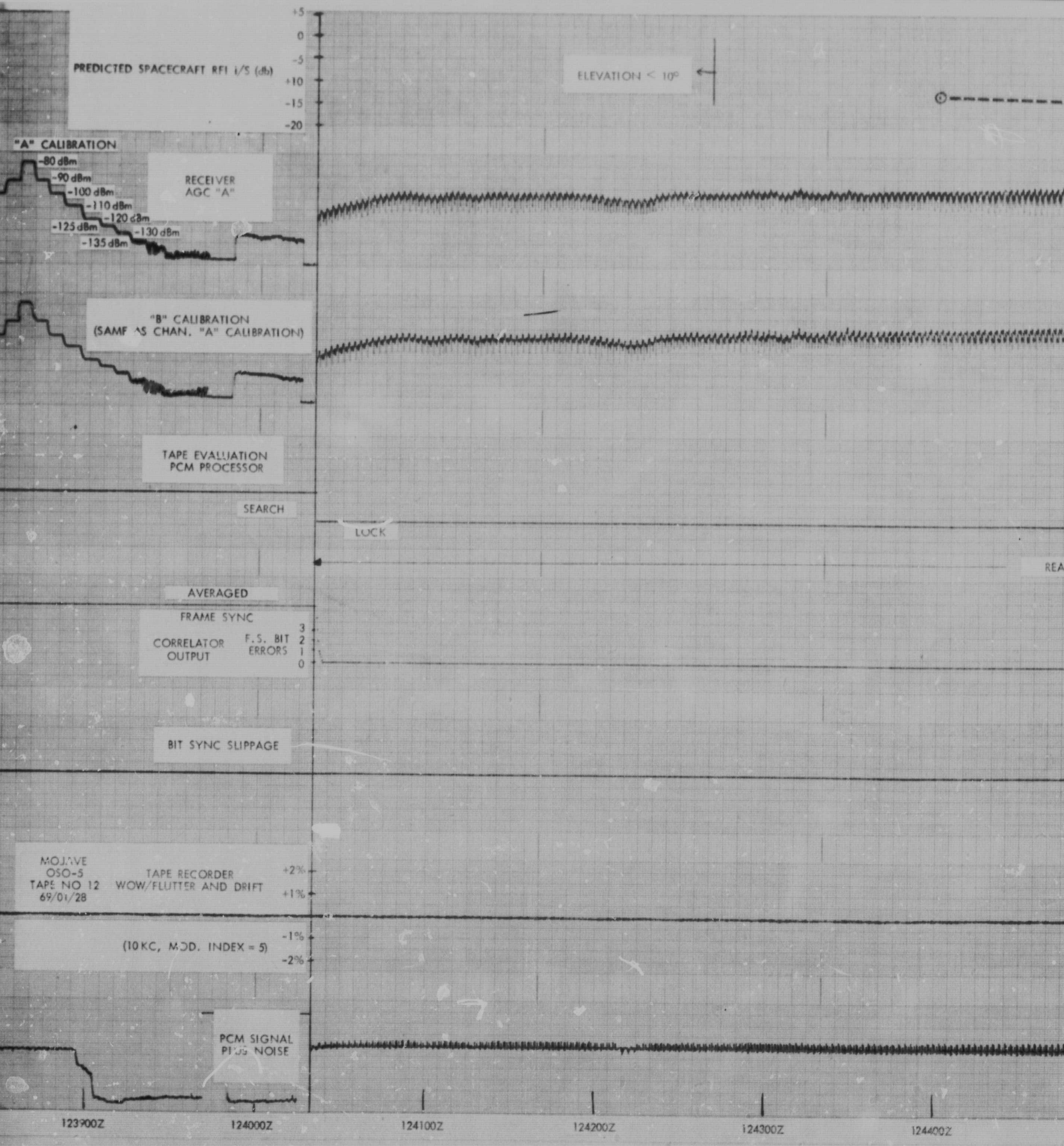



Figure 6. IPD Tape Evaluation Analysis for SNTAGO OSO-5(F) Tape No. 39

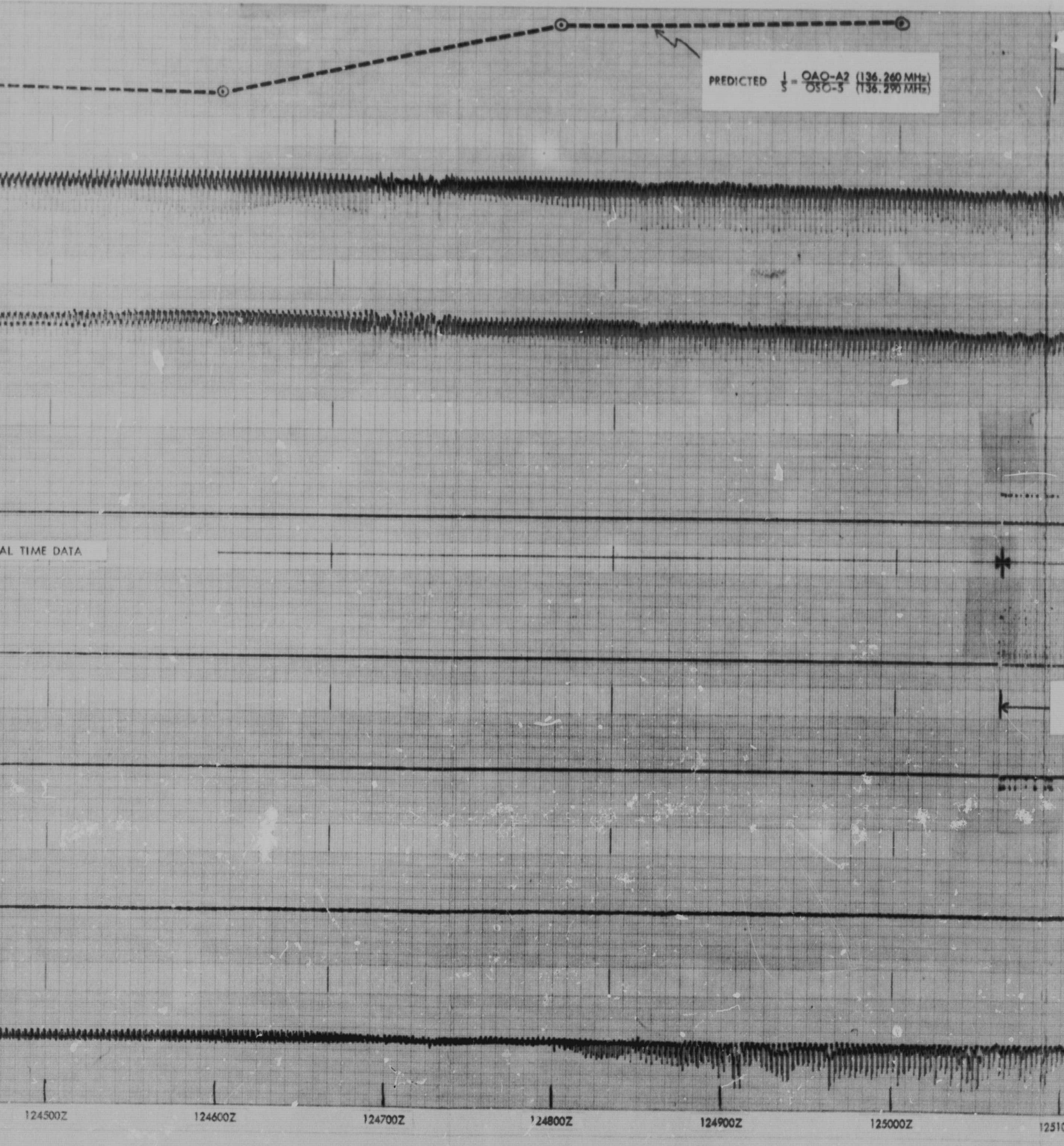


FOLDOUT FRAME #2

FOLDOUT FRAME # 3




FOLDOUT FRAME #1



PREDICTED 1/5 = OAO-A2 (136.260 MHz) / OSO-5 (136.290 MHz)
AL TIME DATA
124500Z
124600Z
124700Z
124800Z
124900Z
125000Z

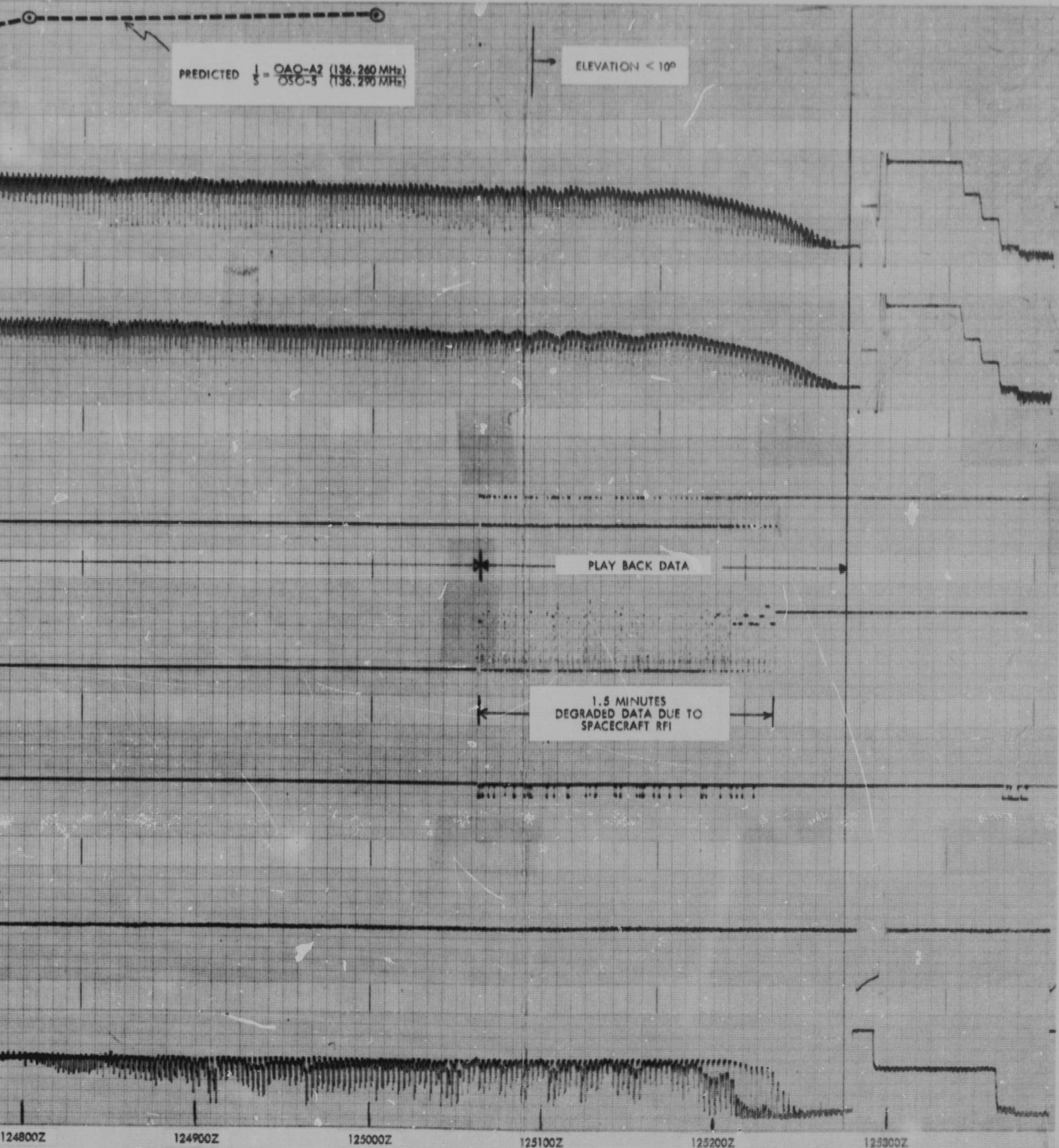



Figure 7. IPD Tape Evaluation Analysis for Mojave OSC-5(F) Tape No. 12



FOLDOUT FRAME # 2

FOLDOUT FRAME # 3

A similiar incident also occurred for one minute, at the end of the 9-minute long OSO-5 tape No. 40 from the Orroral station, when both receiver channels "A" and "B" were inadvertently phase locked to the interfering OAO-A2 signal. At one time, a 30 kHz signal appeared on the data track (observed by spectrum analyzer) which is the difference frequency between the OSO-5 and OAO-A2 carrier frequencies.

Figure 6, corresponding to the OSO-5 Santiago tape No. 39, reveals a similar situation wherein the telemetry receiver "B" channel was inadvertently phase locked to the OAO-A2 signal; whereas, channel "A" was locked to the OSO-5 signal being tracked. Both the "real-time" and "playback" OSO-5 data were lost at this time, for about a 2.5 minute interval, at the beginning of the pass; a total of 10.5 minutes of data was either lost, or degraded, due to spacecraft RFI, during this 11-minute pass.

The predicted OAO-A2 interference level reduced to a value close to the I/S = -20 db threshold, at about 210900Z, with a corresponding reduction in interference measured by the Frame Sync Correlator output. GEOS-2, on an adjacent-channel 136.320 MHz carrier frequency, was predicted to cause interference with OSO-5 at 211200Z; there was a corresponding increase in the OSO-5 Frame Sync Correlator output channel at that time.

Mojave OSO-5 tape No. 12 (Figure 7) is interesting from two standpoints. First, even though the predicted interference-to-signal ratio was high above the -20 db interference threshold level, the OAO-A2 transmission did not interfere with the OSO-5 "real-time" data transmission. However, the moment the OSO-5 wide band "playback" data began transmitting at 125037Z, there was a corresponding step increase in interference as simultaneously monitored by the IPD tape evaluation processor averaged frame sync correlator and bit-sync slippage channels (Figure 7). Consequently, 1.5 minutes of a 2-minute "playback" dump were significantly degraded, or lost, at the end of the pass.

C. STADAN Station RFI Report Analysis

The STADAN ground stations, while taking spacecraft telemetry data, and observing interferometer-type minitrack meridian crossings, also monitor the received spacecraft signal level as well as RFI that may be present during the pass. A separate teletype message, of each RFI event, has been reported by the stations; the weekly summary reports (Reference 6), generated from the daily teletype-messages, were received, and only spacecraft-type RFI events, described as such in the summary reports, were counted.

The station RFI reports were analyzed from two aspects: first, the total number of 136 MHz spacecraft RFI events occurring within a 7-month period, were graphed versus carrier frequency to reveal interference loading within the band; second, the average percentage of spacecraft RFI was computed, in terms of the total minutes of recorded data, for a given period of time. The total number of minutes of telemetry data, recorded by the STADAN stations, was obtained from the Reference 7 Weekly Reports.

The station RFI reports were graphed into two groups; the first group covering the 136.0 MHz to 136.5 MHz region, and the second covering the 136.5 MHz to 138.0 MHz portion of the band. The total number of reported spacecraft RFI events, in both Figures 8 and 9, contain only RFI identified by the stations as being either confirmed interference from another spacecraft, or interference "highly suspected" by station personnel as originating from another spacecraft. For example, slightly over 300 such interference events were reported for the AIMP-E operations (136.11 MHz) for a 7-month period (Figure 8).

Figure 8 shows that the lower 0.5 MHz portion (136.0-136.5 MHz) of the space research band is more heavily populated with spacecraft-type RFI than the upper 1.5 MHz (136.5-138.0 MHz) portion of the band. For instance, 60.5% of the spacecraft RFI events occurred within the one-half megahertz 136.0-136.5 MHz region; whereas Figure 9 shows that only 39.5% of the spacecraft RFI events occurred within the 136.5-138.0 MHz region—a bandwidth, 3 times as wide. The data in Figures 8 and 9 includes station reports for both telemetry and minitrack operations.

To compute the average percentage spacecraft RFI, a detailed analysis was made of four typical spacecraft—(AIMP-E, IMP-5, OSO-5, and ERS-28)—to determine the average level of spacecraft RFI observed in STADAN operations for these spacecraft. The detailed analysis is given in Tables I through IV, inclusive; a tabulated summary of the results is given in Table V.

The AIMP-E spacecraft (No. 7, Figure 8) had the largest number of reported spacecraft RFI events, for the 66 frequencies in the 136 MHz band, yet AIMP-E shows less than 1% spacecraft RFI when normalized to the total minutes of telemetry data recorded for that spacecraft. On the other hand, spacecraft including IMP-5, (No. 5, Figure 8) and OSO-5 (No. 20, Figure 8), show over 2% spacecraft RFI for correspondingly fewer RFI events. Furthermore, ERS-28 (No. 56, Figure 9) shows only 0.24% spacecraft RFI for the 136.84 MHz telemetry data channel, but over 6% reported spacecraft interference for Minitrack Operations.

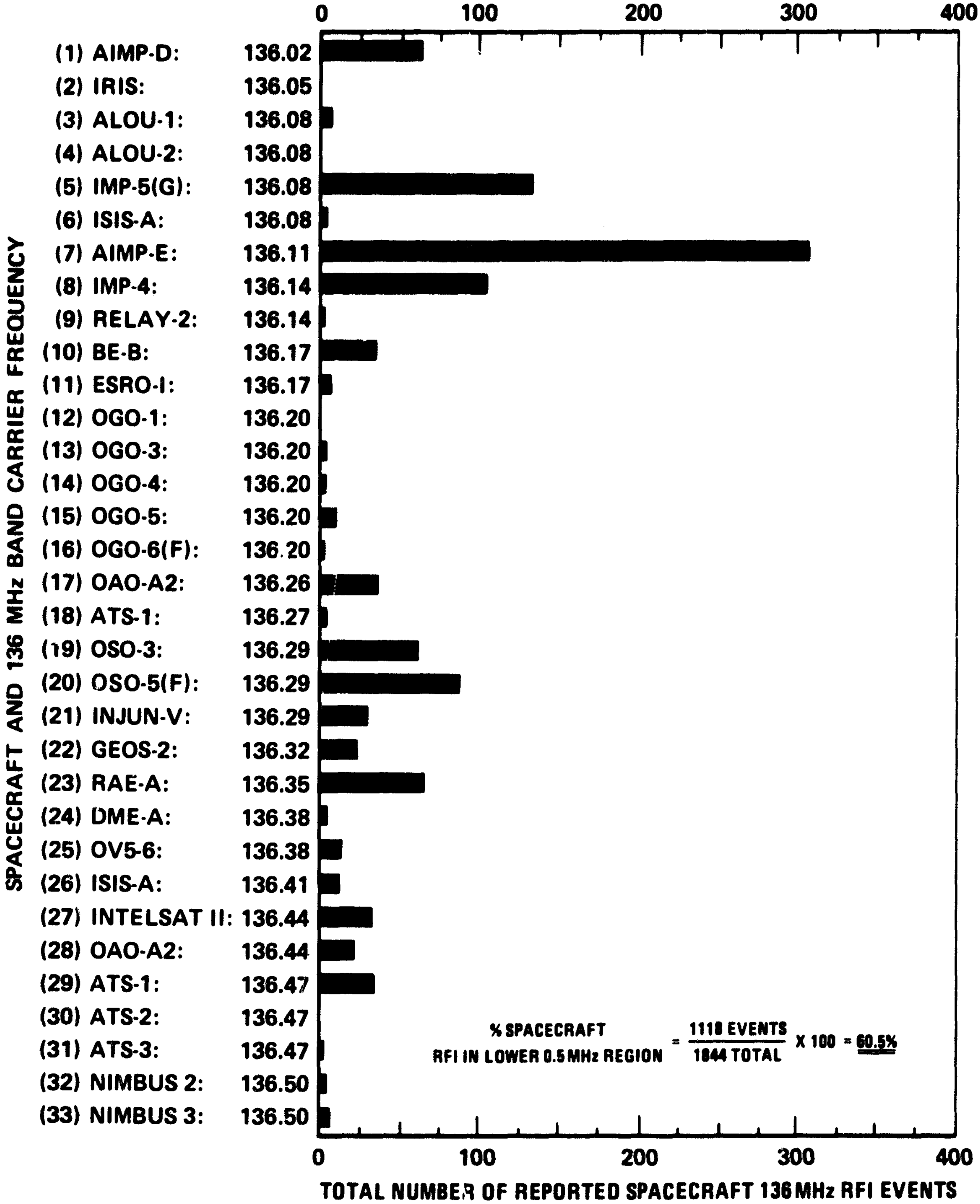



Figure 8. STADAN-Reported Spacecraft RFI Events in 136.0-136.5 MHz Region for January-July 1969 (7 Months)

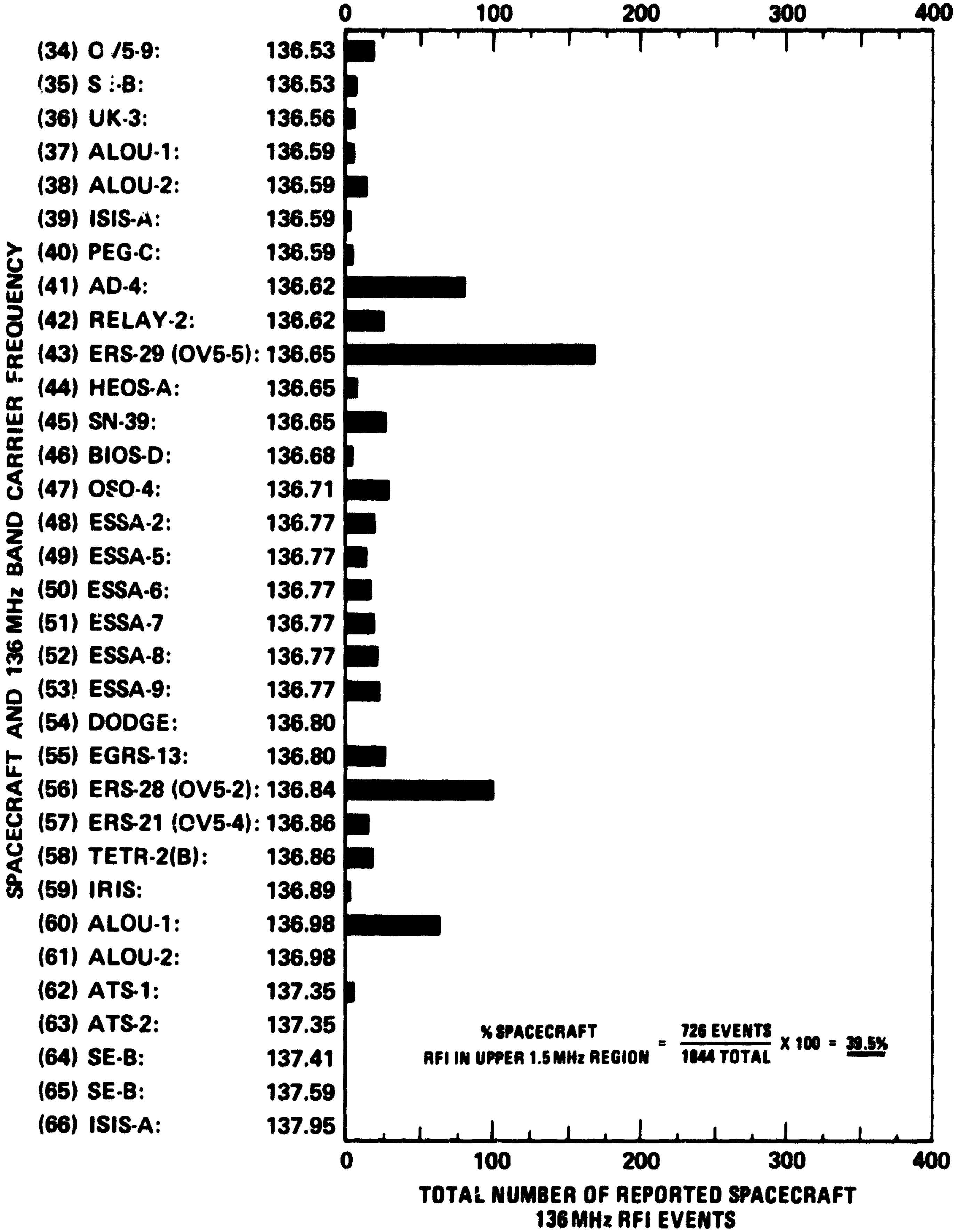



Figure 9. STADAN-Reported Spacecraft RFI Events in 136.50-138.00 MHz Region for January-July 1969 (7 Months)

Table I
STADAN Station-Reported Spacecraft RFI for AIMP-E
(3-Week Period)

| Date | | STADAN Station | Station-Reported RFI Start-Stop Time (HH MM SS) | Spacecraft RFI Event Duration (MM SS) 136 MHz Telemetry (TLM) |
|---|---|---|---|---|
| (1) 1-1-69 | 1st Week in Jan. '69 | JOBURG | 184014Z-194100Z | 6046 |
| (2) 1-1-69 | | SNTAGO | - | † |
| (3) 1-5-69 | | ALASKA | 151600Z-151725Z | 0125 |
| (4) 2-1-69 | 1st Week in Feb. '69 | ALASKA | 112240Z-112420Z | 0140 |
| (5) 2-1-69 | | FT MYRS | 011455Z-011600Z | 0105 |
| (6) 2-1-69 | | FT MYRS | 230300Z-230500Z | 0200 |
| (7) 2-2-69 | | ALASKA | 093330Z-094245Z | 0915 |
| (8) 2-2-69 | | JOBURG | 203830Z-204900Z | 1030 |
| (9) 2-3-69 | | ALASKA | 115220Z-115500Z | 0240 |
| (10) 2-3-69 | | ALASKA | -141240Z | † |
| (11) 2-3-69 | | JOBURG | 201200Z-202145Z | 0945 |
| (12) 2-3-69 | | FT MYRS | 025000Z-025955Z | 0955 |
| (13) 2-3-69 | | FT MYRS | 081000Z-081900Z | 0900 |
| (14) 2-5-69 | | JOBURG | 222500Z-222600Z | 0100 |
| (15) 2-6-69 | | SNTAGO | 090810Z-091400Z | 0550 |
| (16) 2-7-69 | | SNTAGO | 072600Z-073200Z | 0600 |
| (17) 3-1-69 | 1st Week in Mar. '69 | ALASKA | 055830Z-060300Z | 0430 |
| (18) 3-1-69 | | ALASKA | 135910Z-140330Z | 0420 |
| (19) 3-2-69 | | ALASKA | 101700Z-101900Z | 0200 |
| (20) 3-2-69 | | JOBURG | 182800Z-185000Z | 2200 |
| (21) 3-2-69 | | JOBURG | 203600Z-204000Z | 0400 |
| (22) 3-3-69 | | ALASKA | 082800Z-083230Z | 0430 |
| (23) 3-3-69 | | JOBURG | 014340Z-014430Z | 0050 |
| (24) 3-4-69 | | FT MYRS | 044800Z-045500Z | 0700 |
| (25) 3-4-69 | | MADGAR | 170720Z-170920Z | 0200 |
| (26) 3-5-69 | | FT MYRS | 045800Z-050800Z | 1000 |
| (27) 3-7-69 | | ORORAL | 134940Z-135347Z | 0407 |
| (28) 3-7-69 | | ORORAL | 211900Z-213500Z | 1600 |
| Total Observed Spacecraft RFI - | | | | 212.1 minutes |
| Average AIMP-E RFI Duration - 8.2 mins/RFI event | | | | |

Average % Spacecraft RFI observed in AIMP-E Operations $= \frac{\text{(8.2 mins/RFI event) (28 RFI events)}}{\text{29,643 mins TLM data taken}} \times 100 = 0.77\%$

†RFI event occurred; duration not reported.

Table II
STADAN Station-Reported Spacecraft RFI for IMP-5 (1-Week Period)

| Date | | STADAN Station | Station-Reported RFI Start-Stop Time (HH MM SS) | Spacecraft RFI Event Duration (MM SS) 136 MHz Telemetry (TLM) |
|---|---|---|---|---|
| (1) 6-24-69 | 1st | JOBURG | 113000Z-114800Z | 1800 |
| (2) 6-24-69 | Day | SNTAGO | 154900Z-155130Z | 0230 |
| (3) 6-25-69 | | ALASKA | 212000Z-213100Z | 1100 |
| (4) 6-25-69 | 2nd | JOBURG | 071400Z-071555Z | 0155 |
| (5) 6-25-69 | Day | JOBURG | 095250Z-095310Z | 0020 |
| (6) 6-25-69 | | JOBURG | 110505Z-111400Z | 0855 |
| (7) 6-26-69 | 3rd | ORORAL | 013106Z-014024Z | 0918 |
| (8) 6-26-69 | Day | JOBURG | 103600Z-104500Z | 0900 |
| (9) 6-27-69 | | ALASKA | 135125Z-140515Z | 1450 |
| (10) 6-27-69 | | ROSMAN | 145700Z-150800Z | 1100 |
| (11) 6-27-69 | | ROSMAN | 151700Z-152500Z | 0800 |
| (12) 6-27-69 | 4th | ROSMAN | 160400Z-161200Z | 0800 |
| (13) 6-27-69 | Day | ROSMAN | 164900Z-165200Z | 0300 |
| (14) 6-27-69 | | ROSMAN | 180000Z-180600Z | 0600 |
| (15) 6-27-69 | | ROSMAN | 154740Z-155650Z | 0910 |
| (16) 6-27-69 | | ROSMAN | 161900Z-162700Z | 0800 |
| (17) 6-27-69 | | JOBURG | 083000Z-084156Z | 1156 |
| (18) 6-28-69 | 5th | JOBURG | 084410Z-085520Z | 1110 |
| (19) 6-28-69 | Day | MADGAR | 134510Z-141200Z | 2750 |
| (20) 6-29-69 | 6th | JOBURG | 085700Z-090900Z | 1200 |
| (21) 6-29-69 | Day | MADGAR | 073710Z-074400Z | 0650 |
| (22) 6-30-69 | | JOBURG | 082200Z-082600Z | 0400 |
| (23) 6-30-69 | | QUITOE | 141000Z-141040Z | 0040 |
| (24) 6-30-69 | 7th | SNTAGO | 161300Z-161750Z | 0450 |
| (25) 6-30-69 | Day | SNTAGO | 162440Z-163015Z | 0535 |
| (26) 6-30-69 | | MADGAR | 073710Z-074400Z | 0650 |
| (27) 6-30-69 | | MADGAR | 124500Z-124800Z | 0300 |
| Total Observed Spacecraft RFI - 223.7 minutes | | | | |
| Average IMP-5 RFI Duration - 8.3 mins/RFI event | | | | |
| Average % Spacecraft RFI observed in IMP-5 Operations - 2.05%* | | | | |

*$\dfrac{(8.3 \text{ mins./RFI event}) \ (27 \text{ RFI events})}{10{,}913 \text{ mins. TLM data recorded}} \times 100 = 2.05\%$

Table III

STADAN Station-Reported Spacecraft RFI for OSO-5 (3-Week Period)

| Date | | STADAN Station | Station-Reported RFI Start-Stop Time (HH MM SS) | Spacecraft RFI Event Duration (MM SS) 136 MHz Telemetry (TLM) |
|---|---|---|---|---|
| (1) 1-22-69 | 1st Week | JOBURG | 171900Z-172400Z | 0500 |
| (2) 1-22-69 | | JOBURG | 205240Z- | † |
| (3) 1-25-69 | | JOBURG | At 152000Z | † |
| (4) 1-26-69 | | MOJAVE | At 162000Z | † |
| (5) 1-27-69 | | SNTAGO | - | † |
| (6) 1-28-69 | 2nd Week | ORORAL | 102840Z-103000Z | 0120 |
| (7) 1-28-69 | | ORORAL | 121100Z-121830Z | 0730 |
| (8) 1-28-69 | | FT MYRS | 124900Z-130100Z | 1200 |
| (9) 1-29-69 | | SNTAGO | 230100Z-231250Z | 1150 |
| (10) 1-31-69 | | ORORAL | - | † |
| (11) 1-31-69 | | FT MYRS | 105000Z-105400Z | 0400 |
| (12) 2-1-69 | | SNTAGO | 210251Z-211400Z | 1109 |
| (13) 2-3-69 | | ORORAL | - | † |
| (14) 2-3-69 | | FT MYRS | 070900Z-072200Z | 1300 |
| (15) 2-4-69 | 3rd Week | SNTAGO | 172253Z-173400Z | 1107 |
| (16) 2-6-69 | | ORORAL | - | † |
| (17) 2-8-69 | | ORORAL | - | † |
| (18) 2-9-69 | | ORORAL | - | † |

Total Observed Spacecraft RFI - 76.9 minutes

Average OSO-5(F) RFI Duration - 8.6 mins/RFI event

Average % Spacecraft RFI observed in OSO-5(F) Operations - 2.27%*

$$^{*}\frac{(8.6 \text{ mins./RFI event})\ (18 \text{ RFI events})}{6{,}819 \text{ mins. TLM data recorded}} \times 100 = 2.27\%$$

† RFI event occurred; duration not reported.

Table IV

STADAN Station-Reported Spacecraft RFI for ERS-28 (3-Week Period)

| Date | | STADAN Station | Station-Reported RFI Start-Stop Time (HHMMSS) | Spacecraft RFI Event Duration (MMSS) | |
|---|---|---|---|---|---|
| | | | | 136 MHz Telemetry (TLM) | Minitrack (M/T) |
| (1) 1-1-69 | 1st Week in Jan. '69 | SNTAGO | 141122Z-142000Z | 0838 | |
| (2) 1-1-69 | | SNTAGO | 155600Z-160300Z | 0700 | |
| (3) 1-3-69 | | JOBURG | 080200Z-081100Z | | 0900 |
| (4) 1-4-69 | | SNTAGO | 124400Z-130400Z | | 2000 |
| (5) 1-5-69 | | QUITOE | 010800Z-014000Z | | 3200 |
| (6) 1-6-69 | | MADGAR | - - | | † |
| (7) 2-1-69 | 1st Week in Feb. '69 | SNTAGO | 113500Z-115700Z | | 2200 |
| (8) 2-1-69 | | MADGAR | 025000Z-032000Z | | 3000 |
| (9) 2-3-69 | | FT MYRS | 134400Z-135200Z | 0800 | |
| (10) 2-3-69 | | FT MYRS | 140800Z-141200Z | 0400 | |
| (11) 2-7-69 | | JOBURG | - - | | † |
| (12) 3-3-69 | 1st Week in Mar. '69 | MADGAR | - - | | † |
| (13) 3-4-69 | | QUITOE | - - | | † |
| (14) 3-5-69 | | MADGAR | 170530Z-171800Z | | 1230 |
| (15) 3-6-69 | | LIMA PU | - - | | † |
| Total Observed Spacecraft RFI - | | | | 27.5 minutes | 125.5 minutes |
| Average ERS-28 RFI Duration - | | | | 6.9 mins/RFI event | 20.9 mins/RFI event |
| Average % Spacecraft RFI observed in ERS-28 Operations - | | | | 0.24%* | 6.09%** |

$$^{*}\frac{(6.3 \text{ mins./RFI event})(4 \text{ RFI events})}{11{,}429 \text{ mins. TLM data recorded}} \times 100 = 0.24\% \text{ for Telemetry.}$$

$$^{**}\frac{(20.9 \text{ mins./RFI event})(11 \text{ RFI events})}{(16.8 \text{ mins. per M/T pass})(225 \text{ passes})} \times 100 = 6.09\% \text{ for Minitrack.}$$

†RFI event occurred; duration not reported.

Table V
Summary of Typical Station-Reported Spacecraft Interference in 136 MHz Band

| Spacecraft | Observation Period (Weeks) | Total Number of Spacecraft RFI Events Reported | Total Observed RFI (Minutes) | Average Spacecraft RFI Event Duration (Minutes/Event) | Minutes of 136 MHz Data Recorded | | Average Percentage 136 MHz Spacecraft RFI |
|---|---|---|---|---|---|---|---|
| | | | | | Telemetry | Minitrack | |
| AIMP-E | 3 | 28 | 212.1 | 8.2 | 29,643 | — | 0.77% |
| IMP-5 | 1 | 27 | 223.7 | 8.3 | 10,913 | — | 2.05% |
| OSO-5 | 3 | 13 | 76.9* | 8.6 | 6,819 | — | 2.27% |
| ERS-28 | 3 | 4 | 27.5 | 6.9 | 11,429 | — | 0.24% |
| ERS-28 | 3 | 11 | 125.5 | 20.9 | — | 3,780 | 6.09% |

*Playback and Real-time included

## IV. CORRELATION OF PREDICTED, REPORTED, AND TAPE-OBSERVED SPACECRAFT RFI

All fourteen (14) OSO-5(F) analog tapes, examined by the IPD contained interference that was either CLEARLY IDENTIFIED as spacecraft-type RFI, or placed in the category of "suspected" spacecraft RFI. Table VI is a summary of the STADAN-station reported, the ADD-predicted, and the corresponding IPD-observed interference for the fourteen (14) OSO-5(F) sample tapes; there is excellent agreement between all three categories.

Eight of the strip-chart analog tapes, corresponding to station magnetic tape Nos. 17. 18, 27, 32, 28, 40, 45, and 39, listed in Table VII, show good time correlation between the predicted, the reported and the analog-tape observed start/stop times for the spacecraft-type RFI. For instance, Table VII shows that the start/stop times for the predicted (and observed values) agree within 0 to 4 minutes that corresponds to an accuracy commensurate with the accuracy of the Brouwer orbital elements utilized in the IBM 360 program, in turn used to predict spacecraft RFI.

The remaining six (6) strip-chart tapes, corresponding to station magnetic tape Nos. 07, 08, 30, 26, 12, and 38, listed in Table VI, show four (4) predicted and IPD-observed RFI events for OSO-5(F) that were "not reported" by the STADAN stations, and two (2) spacecraft type RFI events in the "not predicted" category.

The "not predicted" RFI events are explained as follows: first, one IPD-observed RFI event, existing for only one (1) minute, on tape No. 07, could have been missed by the computer since the prediction printout times are at 2-minute intervals; second, the IPD-observed spacecraft-type RFI event, on tape No. 26, occurred at an elevation angle, of less than 10°, that is, below the minimum cutoff elevation angle used in the prediction computer program.

There is evidence in the Table VI listing that the STADAN stations have become fairly adept at identifying spacecraft-type RFI; for instance, the station correctly identified eight (8) out of twelve (12) interfering spacecraft that were predicted to cause interference with OSO-5(F). Furthermore, the station reported interference start/stop times (see Table VII listing) are also in reasonable agreement with the ADD-predicted and the IPD-observed start/stop times.

The predictions in the Table VI listing show that the OAO-A2, INJUN-5, and GEOS-2 spacecrafts were involved in interference events with OSO-5(F) at various times, as observed by the IPD, in the fourteen OSO-5(F) sample tapes. Table VIII lists the spacecraft, and corresponding transmitter parameters, inputted in the OSO-5(F) prediction program.

## Table VI
## Comparison of STADAN Reported, ADD Predicted, and IPD Observed OSO-5 Spacecraft RFI Start/Stop Times

| STADAN Station | Tape No. | STADAN Reported (Daily Report) | | | | | ADD Predicted | | | | | | IPD Observed | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Date | Start (HH MM) | Stop (HH MM) | Suspected S/C | Max. AGC Level (-dbm) | Start (HH MM) | Stop (HH MM) | Interfering S/C | Worst I/S (db) | Time (HH MM) | AGC (-dbm) | Start (HH MM) | Stop (HH MM) |
| (1)MOJAVE | 07 | 1/26/69 | 1620Z | – | OAO-A2 GEOS-2 | 88 | | | Not Predicted* | | | | 1623Z | 1624Z |
| (2)SNTAGO | 17 | 1/27/69 | 0059Z | – | OAO-A2 | NR | 0102Z | – | OAO-A2 | -18.1 | 0102Z | 92.2 | 0102Z | 0103Z |
| (3)SNTAGO | 18 | 1/27/69 | 0240Z | – | OAO-A2 | 84 | 0244Z | 0250Z | OAO-A2 | -13.1 | 0244Z | 91.4 | 0243Z | 0251Z |
| (4)MOJAVE | 08 | 1/27/69 | Not Reported | | | 87 | 1252Z | – | Injun-5 | -17.6 | 1252Z | 85.9 | 1252Z | 1257Z |
| (5)FT MYRS | 30 | 1/28/69 | Not Reported | | | 88 | 0934Z | – | GEOS-2 | -9.9 | 0934Z | 88.8 | 0931Z | 0932Z |
| (6)ORORAL | 26 | 1/28/69 | 1029Z | 1030Z | OAO-A2 | NR | | | Not Predicted** | | | | 1029Z | 1031Z |
| (7)ORORAL | 27 | 1/28/69 | 1211Z | 1218Z | OAO-A2 | NR | 1214Z | 1216Z | OAO-A2 | -14.1 | 1214Z | 92.4 | 1214Z | 1216Z |
| (8)MOJAVE | 12 | 1/28/69 | Not Reported | | | 85 | 1244Z | 1250Z | OAO-A2 | +1.2 | 1248Z | 87.2 | 1250Z | 1252Z |
| (9)FT MYRS | 32 | 1/28/63 | 1249Z | 1301Z | OAO-A2 | 90 | 1252Z | 1258Z | OAO-A2 | -1.4 | 1254Z | 86.9 | 1250Z | 1258Z |
| (10)SNTAGO | 28 | 1/29/69 | 2301Z | 2313Z | OAO-A2 | NR | 2304Z | 2310Z | OAO-A2 | -8.4 | 2304Z | 91.1 | 2300Z | 2312Z |
| (11)ORORAL | 40 | 1/31/69 | 1011Z | EOP | OAO-A2 | NR | 1014Z | 1018Z | OAO-A2 | -11.4 | 1014Z | 92.6 | 1018Z | 1020Z |
| (12)FT MYRS | 45 | 1/31/69 | 1050Z | 1054Z | OAO-A2 GEOS-2 Injun-5 OSO-3 | 92 | 1054Z | 1100Z | OAO-A2 | -15.1 | 1054Z | 89.6 | 1052Z | 1059Z |
| (13)SNTAGO | 38 | 1/31/69 | Not Reported | | | 83 | 1924Z | – | OAO-A2 | -14.6 | 1924Z | 91.6 | 1924Z | 1930Z |
| (14)SNTAGO | 39 | 2/01/69 | 2103Z | 2114Z | OAO-A2 | 83 | 2106Z | 2112Z | OAO-A2 GEOS-2 | 17.5 17.2 | 2112Z | 90.7 | 2103Z | 2113Z |

*RFI lasted for less than 2 minutes.

**OSO-5 elevation angle < 10°

NR = Not Reported

Table VII

Correlation of Predicted, Observed, and STADAN-Reported Start/Stop Times for Spacecraft-Type RFI

| OSO-5 Magnetic Tape No. | STADAN Station | Time Spacecraft-Type RFI Is Present | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Start Times | | | | Stop Times | | | |
| | | ADD Predicted (HH MM) | IPD Observed (HH MM) | Start Time Difference, $\|\Delta t\|$* Start (minutes) | STADAN Reported (HH MM) | ADD Predicted (HH MM) | IPD Observed (HH MM) | $\|\Delta t\|$* Stop (minutes) | STADAN Reported (HH MM) |
| 17 | SNTAGO | 0102Z | 0102Z | 00 | 0059Z | — | 0103Z | — | — |
| 18 | SNTAGO | 0244Z | 0243Z | 01 | 0240Z | 0250Z | 0251Z | 01 | — |
| 27 | ORORAL | 1214Z | 1214Z | 00 | 1211Z | 1216Z | 1216Z | 00 | 1218Z |
| 32 | FT MYRS | 1252Z | 1250Z | 02 | 1249Z | 1258Z | 1258Z | 00 | 1301Z |
| 28 | SNTAGO | 2304Z | 2300Z | 04 | 2301Z | 2310Z | 2312Z | 02 | 2313Z |
| 40 | ORORAL | 1014Z | 1018Z | 04 | 1011Z | 1018Z | 1020Z | 02 | EOP |
| 45 | FT MYRS | 1054Z | 1052Z | 02 | 1050Z | 1100Z | 1059Z | 01 | 1054Z |
| 39 | SNTAGO | 2106Z | 2103Z | 03 | 2103Z | 2112Z | 2113Z | 01 | 2114Z |

*$|\Delta t|$ = |Predicted Time (HH MM) - Observed Time (HH MM)| minutes.

EOP = End of Pass

Table VIII
Spacecraft Parameters Inputted to OSO-5(F) Spacecraft
RFI Prediction Program

| Tracking Spacecraft | Interfering Spacecraft | Spacecraft Transmitter Characteristics* used in the RFI Prediction Program | | | |
|---|---|---|---|---|---|
| | | RF Power (watts) | Carrier Frequency (MHz) | Bandwidth (kHz) Real-Time Mode | Bandwidth (kHz) Playback Mode |
| OSO-5(F) | — | 0.57 | 136.290 | 10 | 40 |
| — | OAO-A2 | 1.60 | 136.260 | 40 | — |
| — | INJUN-5 | 0.25 | 136.290 | 30 | — |
| — | GEOS-2 | 0.40 | 136.320 | 20 | — |
| — | OSO-3 | 0.57 | 136.290 | 10 | 40** |

*Assumes an Isotropic-type spacecraft antenna

**OSO-3 wideband "playback" mode (7.2 K b/s bit rate) was inoperative; only 400 b/s "real-time" mode operated

The STADAN antenna used during the recorded pass was used in the prediction program for determining the I/S ratios.

## V. OSO-5(F) 136 MHz TELEMETRY DATA LOST OR DEGRADED

The Information Processing Division carefully examined the fourteen (14) selected OSO-5(F) station magnetic tape recordings, and resulting analog strip charts and evaluation results to determine the amount of lost and degraded data. The resulting lost and degraded data expressed in minutes, was then identified with both the "real-time" and "playback" modes. These modes were then further identified with spacecraft-type RFI, and interference from other sources, including atmospheric disturbances, etc. The following criteria were utilized to make this identification:

- Averaged frame sync bit errors counted at correlator output to determine average PCM bit error probability
- Length of time interference was present determined from analog strip charts reproduced from station magnetic tapes
- Spacecraft-type RFI detected in "raw" magnetic tape data using 1) spectrum analyzer, to identify bit rates; 2) using AGC's and S+N variations to observed interference and varying S/N ratios; and 3) using oscilloscope and viscorder to identify interference-intermodulation waveforms.
- Interference-to-Signal threshold of $I/S \geq -20$ db used to determine if spacecraft-type interference was predicted.

The minutes of lost and degraded data, resulting only from spacecraft-type RFI, for both "real-time" and "playback" modes, was then tabulated (Table IX) versus the actual recorded telemetry data (in minutes) for the whole pass. The subsequent "lost" and "degraded" data percentages were then expressed for both "real-time" and "playback" modes (also see Figure 10).

Considering only the effects of spacecraft-type RFI, the percentages of lost and degraded OSO-5(F) "real-time" and "playback" data per spacecraft RFI averaged out as shown in Tables IX and X.

It is thus seen that the OSO-5(F) "playback" data is more seriously affected, by interference from other spacecraft, than the "real-time" data.

The average bit error probability, Pe, for the fourteen (14) OSO-5(F) spacecraft RFI tapes, was then determined from the percentage of recovered frame sync words (FOE), with zero errors, and the expressions:

$$FOE \approx (1 - n\,Pe)$$

where n = number of bits in each frame sync word, 16 for OSO spacecraft.

## Table IX
## IPD Analysis of OSO-5(F) Magnetic Tapes Containing Lost or Degraded Data

| STADAN Station | Tape No. | Actual Recording Interval | | Lost/Degraded Data Due to Interference from Other Spacecraft | | | | | | | | Average Bit Error * Probability | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Mins Lost | | Mins Degraded | | % Lost | | % Degraded | | | |
| | | RT (mins) | PB (mins) | RT | PB | RT | PB | RT | PB | RT | PB | RT* | PB* |
| (1)MOJAVE | 07 | 11.0 | 2.0 | 0.3 | 1.0 | 1.0 | 1.0 | 2.7 | 50.0 | 9.1 | 50.0 | $10^{-3}$ | $10^{-2}$ |
| (2)SNTAGO | 17 | 6.5 | 5.5 | 0 | 0 | 0 | 1.0 | 0 | 0 | 0 | 18.2 | $10^{-2}$ | $10^{-3}$ |
| (3)SNTAGO | 18 | 5.5 | 5.5 | 0.2 | 2.5 | 3.5 | 3.0 | 3.6 | 45.0 | 63.6 | 54.5 | $10^{-2}$ | $10^{-2}$ |
| (4)MOJAVE | 08 | 10.5 | 2.0 | 0 | 0 | 0 | 1.0 | 0 | 0 | 0 | 50.0 | $10^{-5}$ | $10^{-2}$ |
| (5)FT MYRS | 30 | 8.0 | 5.5 | 0 | 0 | 0 | 0.5 | 0 | 0 | 0 | 9.1 | $10^{-5}$ | $10^{-4}$ |
| (6)ORORAL | 26 | 12.0 | 0 | 1.0 | — | 1.0 | — | 8.3 | — | 8.3 | — | $10^{-2}$ | — |
| (7)ORORAL | 27 | 8.0 | 0 | 0 | — | 2.0 | — | — | — | 25.0 | — | $10^{-3}$ | — |
| (8)MOJAVE | 12 | 10.0 | 2.0 | 0 | 1.0 | 0 | 1.0 | 0 | 50.0 | 10.0 | 50.0 | $10^{-5}$ | $10^{-1}$ |
| (9)FT MYRS | 3[illegible] | 8.5 | 5.5 | 0 | 2.0 | 2.0 | 3.5 | 0 | 36.3 | 23.4 | 63.8 | $10^{-2}$ | $10^{-1}$ |
| (10)SNTAGO | 28 | 7.5 | 5.5 | 3.5 | 0.1 | 4.0 | 5.4 | 46.8 | 1.8 | 53.3 | 98.0 | $10^{-1}$ | $10^{-2}$ |
| (11)ORORAL | 40 | 9.0 | 0 | 2.0 | — | 1.0 | — | 22.2 | — | 11.1 | — | $10^{-3}$ | — |
| (12)FT MYRS | 45 | 6.5 | 6.5 | 0 | 0.5 | 1.0 | 6.0 | 0 | 7.8 | 15.4 | 92.3 | $10^{-2}$ | $10^{-2}$ |
| (13)SNTAGO | 38 | 5.5 | 6.0 | 0 | 0 | 0 | 2.0 | 0 | 0 | 0 | 33.3 | $10^{-4}$ | $10^{-4}$ |
| (14)SNTAGO | 39 | 5.5 | 5.5 | 1.0 | 2.0 | 4.0 | 3.5 | 18.2 | 36.4 | 72.8 | 63.7 | $10^{-2}$ | $10^{-1}$ |
| Total Minutes | | 114.0 | 51.5 | 8.0 | 9.1 | 19.5 | 27.9 | 7.0% Average | 17.7% Average | 17.1% Average | 54.2% Average | $1 \times 10^{-2}$ Average | $3 \times 10^{-2}$ Average |

*"Real-Time" average bit error probability includes degrading influences from all sources, i.e., other spacecraft, atmospheric disturbances, fading signal levels at low elevation angles, etc. "Playback" average bit error probability includes only effects of interference from "other spacecraft." RT = Real-Time; PB = Playback.

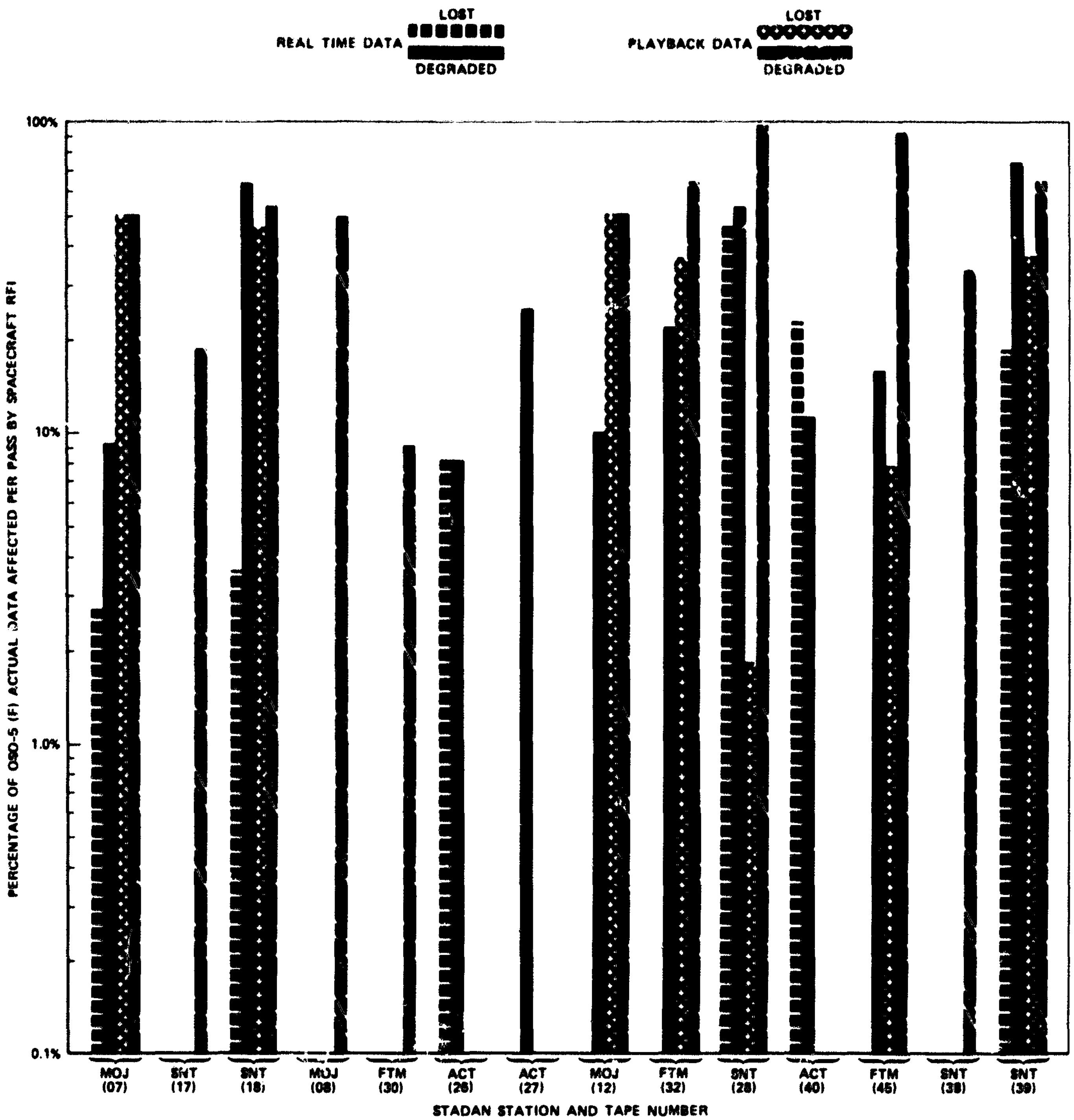



Figure 10. Percentage Real-Time and Playback Data Affected By Spacecraft RFI in Fourteen (14) OSO-5(F) Passes

Tabie X
OSO-5(F) Real-Time/Playback Lost/Degraded Data Due to Spacecraft RFI, in 14 Tapes

| | Real-Time | Playback |
|---|---|---|
| Average Lost Data | 7.0% | 17.7% |
| Average Degraded Data | 17.1% | 54.2% |

The standard theoretical bit error probability curve for gaussian noise distribution and "matched" filter detection was then used to relate Pe and normalized signal-to-noise ratios (db).

The resulting "real-time" average bit error probability includes degrading influence from ALL SOURCES, i.e., other spacecraft, atmospheric disturbances, fading signals at low elevation angles, etc., whereas the "playback" average bit error probability includes ONLY effects of interference from "other spacecraft."

The "playback" average PCM bit error probability was significantly degraded, due to spacecraft RFI, in a number of the fourteen OSO-5(F) tapes (see right-hand column, Table IX). For instance, the average "playback" bit error probability for all tapes with "playback" data, is $3 \times 10^{-2}$. This represents a degradation of over three orders of magnitude, or a corresponding signal-to-noise ratio change of 7db in the data bandwidth, compared to the "quiet," interference-free, average "fidelity" reference level of $2.5 \times 10^{-5}$ found in reference 8.

The "real-time" PCM bit error probability, for all fourteen (14) OSO-5(F) magnetic tapes, averaged $1 \times 10^{-2}$ due to degrading influences from all sources. Separation of spacecraft RFI effects from all other noise sources for the "real-time" bit error probability is practically impossible for the tapes analyzed.

Table XI tabulates the lost and degraded minutes of data in the fourteen spacecraft RFI tapes found in the one week sample for OSO-5(F) along with the scheduled pass(s) durations for the week.

Averaged over the total number of 173 data tapes for the one week sample, 0.53% of the "real-time" data are lost due to spacecraft interference and 1.29% of the data are degraded. In addition, 1.3% of the "play-back" data are lost due to spacecraft interference; 3.99% of the data are degraded due to spacecraft interference.

Table XI

Summary of OSO-5(F)* Lost and Degraded Data Due to Spacecraft RFI for One Week Sample of 173 Tapes

| Data Type | No. of Passes Per Day | Average Duration of Pass (minutes) | Total Scheduled Per Week (minutes) | Total Spacecraft RFI Per Sample Week | | Average Effect of S/C RFI on OSO-5(F) | |
|---|---|---|---|---|---|---|---|
| | | | | Lost (mins) | Degraded (mins) | Lost (%) | Degraded (%) |
| Real-Time | 27 | 8 | 1512 | 8.0 | 19.5 | 0.53% | 1.29% |
| Playback | 20 | 5 | 700 | 9.1 | 27.9 | 1.30% | 3.99% |

*OAO-A2 is the main interfering source for the OSO-5(F) spacecraft.

## VI. CONCLUSIONS

For the Orbiting Solar Observatory OSO-5(F) 136 MHz pulse-code modulation telemetry channel, it has been shown that a good correlation exists between the Advanced Development Division's spacecraft radio frequency interference (RFI) prediction program, the Information Processing Division's data processing analysis, and the STADAN station reports for spacecraft-type interference.

The ensuing spacecraft interference statistics, resulting from a thorough analysis of fourteen (14) typical OSO-5(F) station-recorded magnetic tapes, over a one week interval, and station interference reports, are summarized as follows:

- OSO-5(F) "playback" mode, utilizing a 14.4 kilobit/sec PCM bit rate, is more susceptible to adjacent-channel spacecraft-type interference than the 800 bit/sec "real-time" transmission mode.

- Considering only the degrading effects of spacecraft-type radio frequency interference in the one week sample, the average percentage of completely lost OSO-5(F) "real-time" data was 0.53%; whereas on the average, 1.29% of the data was seriously degraded normalized to a total of 173 data tape for the 1-week sample.

- PCM average bit error probability ($3 \times 10^{-2}$), for the OSO-5(F) 136 MHz telemetry "playback" mode, degraded over three orders of magnitude from a "quiet" average quality reference of $2.5 \times 10^{-5}$. This represents a 7 db average signal-to-noise ratio degradation for 3.99% of the pass data recorded in 173 tapes for the sample week. The corresponding lost "playback" data due to spacecraft RFI is 1.3%.

- OAO-A2 was the main interfering source for the OSO-5(F) spacecraft during this seven-day sample.

- The average percentage of spacecraft-type interference, computed from STADAN stations reports, agrees with percentages derived from the processing of station data magnetic tapes. For instance, station-reported telemetry data statistics, for four typical STADAN-supported spacecraft, reveal an interference level, from other spacecraft, on the order of 1% or 2%; whereas the processed OSO-5(F) magnetic tape samples show that spacecraft-type interference level is the same order of magnitude for the "real-time" mode.

- STADAN-station interference reports for 66 telemetry channels, representing 48 spacecrafts, reveal that about 60% of the spacecraft-type interference occurs within the one-half megahertz bandwidth from 136.0-136.5 MHz, and 40% within the 1.5 MHz region from 136.5-138.0 MHz.

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